UNIVERSITY OF
KWAZULU-NATAL

DESIGN, MODELLING AND OPTIMISATION OF AN ISOLATED SMALL HYDROPOWER PLANT USING PUMPED STORAGE HYDROPOWER AND CONTROL TECHNIQUES

by

SAMUEL AYANROHUNMU OLUSEGUN ILUPEJU

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SUPERVISOR: DR FREDDIE INAMBAO

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Dr Freddie Inambao

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DETAILS OF THE CONTRIBUTION TO PUBLICATIONS that form part/or include research presented in this thesis (include publications in preparation, submitted, in press and published and give details of the contributions of each author to the experimental work and writing of each publication).

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ABSTRACT

Pumped Storage Hydropower (PSH) has proved to be a reliable power generation technology, especially in cases of emergency peak power demand. It is best utilised in areas where the availability of water is a challenge because it allows water retention and reuse using the pump back mechanism instead of the water being discharged to continue its course. A pumped storage hydropower system consists of two reservoirs, one higher in elevation than the other lower, the turbine house (power station) and pumping plant between the two reservoirs. During off-peak periods, excess electricity which is cheap pumps water from the lower to the upper reservoir because power demand is low. The stored energy is released to run back into the lower reservoir through the turbines to generate electricity in peak demand period, converting the stored potential energy into electricity at a higher economic value.

South Africa is among the highest emitters of carbon dioxide in the world, with more than 75% of primary energy requirement from fossil fuels. Specifically South Africa is ranked 12th in the world in terms of top emitters of carbon dioxide, exposing its citizens to risks associated with this emission [1]. Therefore there is an urgent need to protect lives by technically reducing release of the poisonous gases through reducing fossil fuel dependency. Renewable Energy (RE), which is abundant and sustainable, can be quickly implemented, offer many work opportunities and have a much lower impact on the environment. With over 8 000 potential small Hydropower sites identified in Eastern Cape and KwaZulu Natal (KZN) Provinces, generation can improve.

The system proposed is the design, optimisation and integration of a control system to a standalone micro hydropower hybrid. The conventional hydropower plant, which is a primary electricity source, allocates power to pump from the lower reservoir to the upper at off-peak periods when consumption and price of electricity is low at regulated flow. Various calculations were derived to compute the primary design parameters (flow, head and system efficiencies) with the other inputs. Matlab Simulink was engaged to describe the interaction between these variables and to vary parameters for optimum output, especially in reducing pumping mode power input for maximum pumped storage hydropower plant generation. Different categories of small hydropower plant sizes can be determined and analysed using this model which will give suitable results. Though the value of generation output from the PSH is small compared to input pump power it is able to compensate for peak load demand. The control system is introduced using Flowcode software to automate every technical process to ensure optimum system performance.

The automation considers, time of the day, the volume of the upper reservoir and the available pumping power to efficiently manage the hydropower plant model.

With the introduction of this generation technique, the results have shown that generation of more electricity at peak time when the price of selling the electricity is very high can be easily accomplished. The control effectively minimises electricity losses, breakdown of equipment, and ensures availability of resource at the exact time of demand. With this design, existing hydro plants may be upgraded for optimum generation without posing any negative effect on the environment in the way that coal fired plants do. Other renewable energy sources may be exploited in pumping activities to reduce the effect of pumping to the upper reservoir on the conventional hydropower plant.

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NOMENCLATURE

Roman Symbols

A	Surface area of the pipe [m^2]
D	Inside diameter of the penstock [m]
D_d	Inside diameter of the delivery pipe [m]
D_s	Inside diameter of the suction pipe [m]
g	Acceleration due to gravity [m/s^2]
H_g	Rated generating head at the PSH [m]
H_{geo}	Geodetic flow head [m]
H_n	Available net head for the turbine [m]
H_p	Rated pumping head to reservoir III [m]
H_v	Pressure drops [m]
h_L	Total sum of the losses along the flow path [m]
h_R	Specific energy head transferred to the runner [m]
L	Length of pipe [m]
L_s	Length of suction pipe [m]
L_d	Length of delivery pipe [m]
m	Mass flow rate [kg/s]
P	Flow pressure [Pa]
P_R	Power transfer from the fluid to the turbine runner [kW]
P_n	Total available power of a plant [kW]
P_g	Rated generating power at PSH [kW]
P_p	Pumping power [kW]
Q	Flow rate [m^3/s]
Q_g	Rated generating flow at the PSH [m^3/s]
Q_p	Pumping flow rate [m^3/s]
s	Time [s]
t	Wall thickness of penstock (m)
V	Velocity of water in the a pipe [m/s]
V_s	Velocity of water in the suction pipe [m/s]
V_d	Velocity of water in the delivery pipe [m/s]
V	Volume [m^3]

Greek Symbols

ε	Roughness coefficient [mm]
υ	Kinematic viscosity [m^2/s]
μ	Dynamic viscosity [kg/ms]
σ_t	Admissible stress of steel (N/m^2)
ρ_w	Density of water [kg/m^3]
ρ	Density [kg/m^3]

Dimensionless symbols

f	Friction factor
f_s	Friction factor of the suction pipe
f_d	Friction factor of the delivery pipe
f_T	Friction factor of valve
k	Losses constant
k_d	Losses constant in the delivery pipe
k_s	Losses constant in the suction pipe
k_{en}	Loss constant at the entrance
k_{ex}	Loss constant at the exit
Re_d	Reynolds number of the delivery pipe
Re_s	Reynolds number of the suction pipe
π	pi
√	Square root
α	Proportional to
Ɛ	Relative roughness ε/D
Σ	Sum of
η_h	Hydraulic efficiency
η_t	Turbine efficiency
η_p	Pump efficiency

Subscripts

max	*Maximum*
s	*Suction*
d	*Delivery*
T	*Total*
ex	*Exit*
en	*Entrance*
w	*Water*
n	*Net*
h	*Head*
geo	*Geodetic*

ACRONYMS AND ABBREVIATIONS

BEP: Best efficiency

CAES: Compressed Air Energy Storage

EU: European Union

GHG: Green House Gases

GW: Giga Watt

HP: Hydropower

HPP: Hydropower Plant

Hr: Hour

kW: Kilo Watt

LCA: Life Cycle Assessment

MW: Mega Watt

MWh: Mega Watt-hour

PV: Photovoltaic

PSH: Pumped Storage Hydropower

RE: Renewable Energy

RES: Renewable Energy Sources:

SHP: Small Hydropower

US: United States

CHAPTER 1 : INTRODUCTION

1.0 Background

Distribution and transmission of green and adequate power in the form of electricity has been a great issue in both developed and developing countries all around the globe. Inability to secure adequate generation of electricity from a particular source or resource has expanded the scope of searching generation options especially among renewable sources. The most sustainable of the renewable energy sources is hydropower generation technology. The two categories of hydropower are large and small hydropower. A large hydropower system can be installed as a conventional plant where water is allowed to fall from a suitable height to run turbines for power conversion and pumped storage hydroelectric plant in which unused power is used to lift water to a certain height, to be released when the need arises. Hydropower generation is not the primary generation option in South Africa, but used to supply and maintain peak load stability. One of the reasons for this could be as a result of water being scarcely distributed in the South Africa, requiring sound management strategies. Power generation in South Africa is managed by Eskom, the utility company that generates electricity in South Africa by government mandate. The Drakensberg and the Palmiet pumped storage hydropower plants are large scale generation systems installed to maximise efficient use of water for peak time generation. These pumped storage schemes are collectively owned by the South African Department of Water and Environmental Affairs and Eskom. They operate reversible pump/turbines to generate about 1 400 MW
of hydroelectric power in total.

1.1 Overview Power Generation in South Africa

Electricity is a scarce resource; the first step in controlling the effects of its inadequate generation on the society is prudent utilisation, thereby minimising pollution and environmental degradation attached to conventional generation of power.

Generation of power in South Africa is handled by Eskom, a state owned utility company which generates about two-third of Africa‘s electricity. It is said to supply about 95% of electricity in South Africa. Eskom also imports and exports power; it buys from the Cahora-Bassa hydro project in Mozambique. Current power generation capacity is approximately 40 000 MW, of which 90% is achieved using coal, the remaining percentage is through nuclear and hydro-pumped storage.

South Africa, a leading emitters of greenhouse gases (GHG) globally because over three-quarters of energy input in the country is converted from coal. As a result, South Africa is rated among the top 12 emitters of poisonous carbon dioxide in the world, exposing people to a high hazard level associated with this emission [1].

The need is urgent to devise more ways to make sure poisonous emission release is minimised by technically engaging some of the suggested procedures [1] below:

i. Minimise dependency on fossil fuel powered plants.
ii. Minimise carbon footprint.
iii. Extend energy mix options and distribution.
iv. Renewable energy (RE) options, which are abundant available, sustainable, easy to implemented, provide job opportunities and having reduced environmental impact are to be implemented.
v. Put in place electricity generation technology with zero emissions.

In hydroplant technology, energy of water is converted into mechanical energy when it is conveyed in a penstock into water turbines at a certain height in a typical schematic hydroelectric power station [2]. Water whirls the turbine runner as it flows through the turbine shaft; this then engages the generator (usually a synchronous generator) to convert mechanical energy at the turbine output to electricity. This feeds into the main transmission grid while used water is released to continue its course in the river or into a dam [3].

The application of water in the conversion of energy in the form of electricity depends primarily on its availability [4]. Hydropower generation is bound to thrive where water resources are easily available. Hydroelectric power stations can run to provide uninterrupted base load power [5]. [6] reported that electricity through hydro-generation technology is cheaper compared to generation through coal-fired technology in terms of the costs of operation. The fact that during generation of power using coal the input is consumed, which is not the case during generation of power using water, gives hydropower an edge in terms of cheaper running costs [7]. Because of its ability to start up very quickly pumped storage hydropower is able to react quickly to demand as a result of a sharp rise in peak load can be used to salvage peak demand requirements [8], [9]. Pumped storage plant can generate power and achieve its maximum capacity in less than three minutes. From a cold start a coal-plant would require many hours to begin supply of generation to consumers. The possibility of a pump storage plant being operated using remote control makes it less cumbersome to manage. An example of this is the remote controlled Germiston hydroelectric power stations operated by Eskom on the Orange River [6].

1.1.1 Pumped Storage Hydropower Principle

In areas where availability of water is a challenge, pumped storage hydropower schemes integration will offer one of the best alternatives to conventional hydroelectric power stations to provide the power needed during peak periods through allowing water retention and reuse instead discharge.

A pumped storage hydropower system consists of two reservoirs at different elevations with the turbine house and pumping plant between the two reservoirs [10]. During off-peak periods, water is lifted from the lower reservoir to the upper reservoir while power demand is low, but the same is released at peak demand time to run the turbines and convert hydraulic energy into mechanical energy and then into electricity by means of a generator attached to the turbines [9]. Though it is more expensive to operate when compared to conventional hydropower plants as result of the cost of pumping, but the benefit is significant because the response is quick during demand and brings about main grid stability [6].

1.1.2 Eskom’s Pumped Storage Schemes and Inter-Catchment Water Transfer

According to [6], electricity is generated at the Drakensberg pumped storage plant at peak time only, when consumption per day is at its maximum. The average generation capacity of the plant is about 1000 MW. The hydropower plant also serves other water transfer schemes, including the Thukela-Vaal basin. At the same time, the Palmiet PSH plant generates about 400 MW at peak period also and as Drakensberg to Steenbras Dam.

1.2 Water Requirement Factor

The National Water Act (1998) and the National Water Policy (1997) were promulgated by the government with the goal of transforming society for citizens to be able to live a healthy life and to engage in viable economic activities [11]. Access to water is fundamental to human worth, health, social and economic advancement [11]. From a priority point of view, water is essential for drinking, health, agriculture and sanitation before water use is extended to industrial consumption, power generation, tourism and mining operations [12].

South Africa is categorised as a dry country. Although the rainfall pattern is uneven, with some parts having wider variation than others, the country‘s average rainfall is about 450 mm per annum compared to 860 mm per year which is the world average. Thus, the reality is that many factors limit the quantity of water available for electricity generation, namely: climate change, pollution, social and environmental activities as well as global obligations [13]. The estimated mean annual run-off value South Africa‘s water is 43 500 million m^3 yearly. By the year 2000, water use value was 12 871 million m^3 a year [13]. The need to develop surface water resources is paramount as a way of meeting growing water demand in South Africa. This will extend supply to major urban and industrial communities, power generation, irrigation and fishing activities. Over 569 dams are constructed and managed with reserve capacity up to 32 400 million m^3 balancing about 19 water management areas across the nation [13].

1.3 Pumped Storage Hydropower Plant (PSH) operations

Hydropower technologies are grouped according to capacity; large, medium and small installed power plants. A small hydro is described as a system with generating capacity between 0.5 MW to 10 MW, though this varies from country to country. Systems that have an installed capacity of between 500 kW to 2 MW are categorised as mini-hydro while a micro-hydropower plant is classified with a generating capacity between 5 kW to 500 kW [14]. This research is related to the micro hydropower category. [15] classified hydropower plants into four:

i. Ordinary flow plants.
ii. Pumped storage hydropower.
iii. Plant with reserve.
iv. Flowing run-of-river.

In the run-off-river type of small hydropower plants, load-frequency control contribution to electric power option is minimum [16] because of the implementation of water level control cycle in the place of power-frequency control cycle. It is suggested that availability of PSH will:

i. Stabilise generation of reliable electric power systems the will ensure provision of energy reserve for capacity regulation.
ii. Provide off-peak capacity which integrates other renewable energy (RE) sources.

PSH was considered for this study because it is believed to be a mature RE system, capable of supplying both few kilowatts (kW) and thousands of megawatts (MW) in a flexible approach [17], [18]. A statement by the National Hydropower Association (NHA) [19] and the Hydro Research Foundation in 2010 revealed that the US PSH capacity at that time stood at 21 000 MW, about 2.5% of total generating capacity [16]. Many nations now generate more than what the US produces – 5% of European Union (EU) total energy portion is now supplied by PSH [19]. The summit also announced that worldwide, with global an annual growth rate of 10% coupled with the fact that some PSH are being constructed, total generation should exceed 203 000 MW by the year 2014 [20]. Table 1.1 shows the list of some pumped storage hydropower plants in the world, including the Drakensberg power plant.

Table 1.1: Pumped storage power plants [127].

Location	Plant Name	On-Line Date	Hydraulic Head (m)	Max Total Rating (MW)	Hours of Discharge	Plant Cost
Australia	Tumut 3	1973		1690		
China	Tianhuangping	2001	590	1800		$1080 M
	Guangzhu	2000	554	2400		
France	Grand Maison	1987	955	1800		
Germany	Markersbach	1981		1050		
	Goldisthal	2002		1060		$ 700 M
Iran	Siah Bisheh	1996		1140		
Italy	Piastra Edolo	1982	1260	1020		
	Chiotas	1981	1070	1184		
	Presenzano	1992		1000		
	Lago Delio	1971		1040		
Japan	Imaichi	1991	524	1050	7.2	
	Okuyoshino	1978	505	1240		
	Kazunogowa	2001	714	1600	8.2	$3200 M
	Matanogawa	1999	489	1200		
	Ohkawachi	1995	411	1280	6	
	Okukiyotsu	1982	470	1040		
	Okumino	1995	485	1036		
	Okutataragi	1998	387	1240		
	Shimogo	1991	387	1040		
	Shin Takesagawa	1981	229	1280	7	
	Shin Toyne	1973	203	1150		
	Tamahara	1986	518	1200	13	
Luxembourg	Vianden	1964	287	1096		
Russia	Zagorsk	1994	539	1200		
	Kaishador	1993		1600		
	Dneister	1996		2268		
South Africa	Drakensbergs	1983	473	1200		
Taiwan	Minghu	1985	310	1008		$ 866 M
	Mingtan	1994	380	1620		$ 1338 M
U.K./Wales	Dinorwig	1984	545	1890	5	$ 310 M
USA / CA	Castaic	1978	350	1566	10	
USA / CA	Helms	1984	520	1212	153	$ 416 M
USA / MA	Northfield Mt	1973	240	1080	10	$ 685 M
USA / MI	Ludington	1973	110	1980	9	$ 327 M
USA / NY	Blenheim-Gilboa	1973	340	1200	12	$ 212 M
USA / NY	Lewiston (Niagara)	1961	33	2880	20	
USA / SC	Bad Creek	1991	370	1065	24	$ 652 M
USA / TN	Racoon Mt	1979	310	1900	21	$ 288 M
USA / VA	Bath County	1985	380	2700	11	$1650 M

1.4 Problems Associated with Pumped Storage Hydropower

i. Capital investment: Installation of hydropower plants requires a huge capital investment.

ii. Pump back: Generation is a function of the available water energy in the upper reservoir, which is equally as a result of available power to pump to the upper reservoir.

iii. Specific period of operating: It can only produce energy for a limited time based on available volume.

iv. Operational costs: In PSH, due to pump back cost, cost of running plants are higher and are therefore a more expensive to construct when compared to a conventional hydropower plant.

1.5 Advantages of Pumped Storage Hydropower

i. The main advantage of small hydropower plants is that they can be installed either as stand-alone or as a hybrid plant with other RE sources.
ii. Small PSH is more environmentally and ecologically acceptable.
iii. Pumped storage, rather than coal-fired, power stations are preferred as it supplies power at peak when needed within minutes, whereas a coal-fired power station requires several hours.

1.6 Research Aim

The main aim of the research work was to develop a model of a continuous flow micro-pumped storage hydro-power plant for electric power generation to be utilized in a typical South African community.

The objectives were as follows:

i. To design a hybrid power generation technology that generates, according to demand.
ii. Investigate the implementation of the design in the commercial generation of power.
iii. Improve on the efficiency of the pumped storage hydropower system operations.
iv. Test and integrate the continuous generation of energy through the introduction of a pump back mechanism.
v. To generate results based on experimental outcomes and recommend implementation of the design.
vi. To design a control system to enhance plant performance.

1.7 Challenges of Pumped Storage Hydropower Plants

Storing energy is a major challenge as energy generated in commercial quantity which is not used is wasted [21]-[22]. It is of great advantage to understand that energy should be generated when needed and electricity demand changes with the time of the day as well as on a seasonal basis [23]. As expected, daytime requires peak demand and night time, low demand. For a reliable system, power generation is achieved with real-time demand [24]. PSH is the only commercially proven technology available for grid-scale energy storage. The pumped storage plant is the only way of large-scale energy storage [25]-[26].

It was reported that about 6 000 to 8 000 suitable potential sites for small hydropower generation are available in KwaZulu-Natal and the Eastern Cape provinces [27]. The Drakensberg 1 000 MW PSH plant is the largest hydropower plant in South Africa while the second-largest plant, Palmiet is sited in Cape Town. The quantity of energy converted basically depends on the value of the flow rate as well as the available head. [28] stated that pumped storage hydropower activities depend on site selection, reservoir size, shape and operational regime.

[29] listed two main factors responsible for efficient and continuous generation of energy: *flow rate*, which is the volume of water discharged at a given time, measured in cubic metres per second (m^3/s) and *head*, this is the vertical height in metres from the level of entry into the penstock to the point water exits at the power plant.

In an attempt of reducing the cost of transferring water to fill the upper dam [29] suggests linkage to wind turbines so as to be able to take advantage of the surplus power produced by local wind farms.

1.8 Layout of Thesis

Chapter 2 of this research work reviews various renewable energy sources available in South Africa. Chapter 3 reviews the potentials of hydropower both large and small scale globally, in Africa as a continent and also in South Africa. In Chapter 4, an overview of pumped storage hydropower is discussed. Hydroelectricity techniques and components form the content of Chapter 5 while in Chapter 6, three scenarios or designs for proposed hybrid hydropower plants are presented. Chapter 7 is where details of the proposed hybrid plant design were computed. Results and discussions follow in Chapter 8. In Chapter 9, a control system was introduced to manage the plant while Chapter 10 presents conclusions and recommendations.

CHAPTER 2 : RENEWABLE ENERGY SOURCES AND SMALL HYDROPOWER PLANTS

2.0 Introduction

One of the major responsibilities of a government is the establishment of a national energy policy that ensures adequate harnessing of national energy resources for the needs of the nation. From a constitutional rights point of view, the generation, transmission, distribution and consumption of power in the form of electricity is expected it to be sustainable in quantity and also improve the standard of living of the people as legislated in South Africa (Act No. 108 of 1996) [30]. Greenhouse Gases (GHGs) are gases in the earth's lower atmosphere that constitute environmental pollution and at the same time increasing the temperature of the earth and leading to global warming [30].

Wind energy in South Africa is evident, and it is distributed in various proportions all across the continent. As a continent divided by the equator, solar resource is also abundantly available (see Figure 1 in publication 1). South Africa‘s biomass and hydro energy resources are restricted due to limited water [1].

Renewable energy source is a very wide energy option distributed differently in volume all across the globe. These sources are called renewable because they are of cyclical natural phenomena and non depleting. This sources include the sun, wind, hydro, ocean current waves geothermal tides and so on. Renewable technology is the conversion technology from primary renewable energy source to the desired form of energy [30].

2.1 Overview of Renewable Energy Resources in South Africa

In South Africa electricity from coal has dominated the energy generation sector, the main reason being that it is availability in large quantities. However, there are other renewable energy options available to give a substantial electricity input into the nation‘s grid [31].

2.1.1 Wind Energy

Wind energy is one of the most employed renewable energy sources (RES) globally. It is generated by conversion of wind into electricity using wind turbines [10]. Wind turbines have many advantages for both grid and off-grid applications even in sub-urban and farm locations [32]. Wind energy opportunities are sometimes combined with hydropower or solar to make a hybrid system [33]. Roscoe Wind Farm in Texas, has 627 wind turbines located within 400 km^2, generating 781.5 MW of electricity, making it the largest wind farm globally [31]. The province of Western Cape and Eastern Cape in South Africa experience the largest potentials of wind energy [33].

2.1.2 Hydropower

Apart from the conventional option of generation, other options include pumped storage, run-of-river and tidal power [34]. Hydropower potentials in South Africa is second in volume to coal, supplying about 12% of the national demand [31]. The two primary river systems in South Africa are the Orange and the Limpopo [35]. The Orange River flows in a westerly direction into the Atlantic Ocean across the Namibia border. The Vaal River and the Caledon River are tributaries to the Orange. The Limpopo system flows into the Indian Ocean through other smaller rivers [35]. Total hydropower potential in South Africa is estimated to be five times bigger than the present installed hydropower capacity [35].

2.1.3 Solar Energy

Solar energy is a renewable energy as a result of radiation from the sun. It may be engaged in the form of solar water heating and solar photovoltaic. It is a leading energy resource in many developed countries [31]. The two energy forms captured from the Sun are:

i. ***Solar photovoltaic:*** In a photovoltaic cell or sometimes called ‗PV' cell instantly converts radiations from the sun into direct current electricity as seen in Figure 2.1.

ii. ***Solar water heating:*** In solar water heating, heat energy from the sun is directly utilised to heat water through the use of collectors.

Figure 2.1: Solar PV installations [36]

2.1.4 Biomass Energy

Biomass is a renewable energy resource that is most common in sub-urban settlements. It supplies basic heat for daily domestic heating activities. It is obtainable from direct or by-product of biological materials which include saw dust, bamboo, sugarcane and industrial waste [31].

2.1.5 Landfill Gas

Landfill gas (LFG) is the gas obtained from a decomposing garbage site, also called a refuse dump. Decomposing landfill generates a harmful gas, which many considered to be a pollutant. When refuse decomposes at landfill site, gas is released mostly methane, which is a greenhouse gas. As a high energy burning gas, it is highly desirable for electricity generation. The first landfill gas to electricity project was undertaken by eThekwini Municipality in Kwa-Zulu Natal of South Africa with a total capacity of 7.5 MW [31].

2.1.6 Ocean Current and Ocean Wave Energy

Another RES with huge potential for generation of electricity is from ocean currents and ocean waves. This is because a large number of ocean currents flow at a suitable speed to produce power through turbines or other equipment [34]. The Agulhas Current is estimated to have the potential for power generation of up to 40 GW. Though the potential is high the challenges associated to harnessing this energy, which includes sea conditions and transportation from the generation point to onshore are yet to be taken care off [31]. Wave energy is another RES derivable by implementation of proper technology to convert to useful energy. An example of a wave energy farm which has a capacity of 2.25 MW is situated off Portugal‘s coast [31]. Western Cape Province has the highest potential of wave energy in South Africa [37].

2.2 Publication 1: Hydropower Potentials in Africa: Integration of Stand-Alone and Mini-Grid to Power System.

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Hydropower Potentials in Africa: Integration of Stand-Alone and Mini Grid to Power System

Samuel A.O. Ilupeju and Freddie L. Inambao

University of Kwa-Zulu Natal, Durban, South Africa

Corresponding emails: ilurohun@yahoo.com; inambaof@ukzn.ac.za

ABSTRACT

Power generation is becoming an issue of concern in developing world, especially in Africa. There is tremendous population growth in addition to a progressive rise in the use of electronic devices which has contributed to a greater energy consumption and need. The three focuses of the strategic electricity plan, namely, supply option, demand management option and the demand forecasting option are being frustrated with load shedding management options. Energy is available and enormous, but the challenge of converting from its existing form to useful form in the form of electricity has to be addressed if power for all is going to be a reality.
Hydropower (HP) is clean, available, reliable, adequate and renewable. It is established that about 70% of the earth's surface is covered by water. Engaging small hydropower (SHP) schemes will go a long way solving the menace. Many developed countries have installed stand-alone and mini grid system with great success. With the enormous untapped potentials in Africa, it is time we localise installation of SHP, which is cheaper and requires little technical know-how or skilled labour instead of depending on large scale HP which takes years to install and also capital intensive even for nations to handle.

KEYWORDS: Renewable energy, small hydropower, standalone, electric power generation, mini grid, sustainable energy.

1. INTRODUCTION

In many countries, especially in Africa, sufficient power generation is being an issue of concern. A lot of practice is engaged to balance the distribution of this inadequate, but highly significant commodity such as energy efficiency option, domestic renewable such as solar panels and sometimes load shedding which may result in total blackout for days. There is tremendous population growth in addition to a progressive rise in the use of electronic devices like smart phones, televisions and household comfort gadgets such as refrigerators, blenders and microwave ovens, which have contributed to higher energy consumption and need. A greater number of households without these common devices show great aspiration of having them in the nearest future. The three focuses of the strategic electricity plan, namely, demand management option, supply option, and the demand forecasting option are being frustrated with load shedding management options [1]. The law of conservation of energy establishes the fact that at every particular time, there is enough energy for human consumption, but the challenges of converting from its existing form to a useful form of electricity has to be addressed if power for all is going to be a reality. [2] gave an illustration on energy distribution that each m^2 of the earth's inhabitable surface is crossed by or accessible to an average energy flux of about 500 W available from solar and other renewable energy (RE) sources. Assume that only 4 % is harnessed, it can supply about 2 kW per 10 by 10 m area. Now let us assume an estimated population density of 500 people per km^2 in the suburban towns, consuming 2 kW per person, there will be total energy demand of 1000 kW/km^2. This volume is achievable by using just 5 % of the land for energy generation. With the availability of sufficient RE resources for system integration to meet a major share of energy demands, it may then be concluded that with proper harnessing methods at maximum efficiency, renewable energy will provide adequate and continuous quantity of energy for standard living. To meet its growing demand, Africa has an urgent need to raise the level of investment in its power sector. There is a great need to seek other available energy sources for sustainable economic and social growth. The majority of people in Africans lives in rural areas using traditional biomass for cooking and live below US $1. This confirms the fact that Africa represents about 14 % of the world's population, whereas contributes only 4 % of the global energy [3].
A prominent characteristic of renewable energy sources is being environmentally regulated. Common sources include; solar, fuel cells, wind, hydro etc. depend on geographical location which is subject to climatic situation of the environment. Climate is beyond human control, its unpredictability makes renewable energy sources sometimes unreliable depending on method of harnessing engaged. As a result of this, the volume of energy from renewable sources differs from one location to another and how much of it available rest on how much of the source can be exploited.
Conversion technique is also a function of the available resource. Each resource may be too little to satisfy energy need for immediate environment resulting in harnessing more resources to supply adequate energy to meet every activity. Energy conversion definitely gives us an idea of how much energy is available in a particular environment and for what purpose can the harnessed energy be implemented. Both factors will also put in place an economic platform to make the facility available to other users at an affordable price taking into consideration plant maintenance pay back.

To achieve the maximum provision of adequate power system for economic growth, it is vital to efficiently manage stages of energy conversion process by the use of applicable technology. It is a fact that the world population increases and material consumption depletes including fossil used in most conventional power generation plants, bringing about increased cost of energy generation [4]. There is great need to start maximising harnessing renewable energy sources available by combining two or more sources. One of the challenges of combining renewable sources is synchronisation of technologies that result due to reduction in availability per time. This also is a major challenge integration RE into the main grid system.

One of the main sources of pollution in the world is the massive use of fossil resources in energy production, both at domestic and industrial use categories. Greenhouse gases (GHG) emissions are generated from major natural processes [17]. Energy related activities alone emits about 60 % world total and about 80 % of CO_2 quantity.

Due to the fact that large quantity energy storage is almost impossible, the electrical system needs to constantly balance production and consumption [31]. As consumption varies constantly everyday as a result of different energy use like air conditioning in heat period and heating in cold season over the year, therefore renewable energy is climate controlled generation and consumption is climate controlled [17]. In urban centres where energy consumption is on the high side, base load is provided by more efficient power plants. In rural settings, with small overall consumption and few cottage industries, base load can be met with electricity supply from renewable sources [24].

1.1 Electrical Loads

Before going further into exploiting sustainable, renewable sources, there is need to know the specific load requirement to be met so as to project efficiently electricity generation. Load in a power system varies with time daily, having a certain period of maximum power demand [5]. Electrical power generated absolutely depends on the demand side of power. In electric power use, two load cases are significant; base load and peak load. There is more demand for electricity in the day and generating plants are expected to work at full load [6]. The uniform load available for use at the power plant to satisfy the enormous amount of need is called the base load which is also the daily electricity requirement calculated by adding hourly energy requirements (Eh) for a complete day [7]. The generating sources for the base load should be environmentally friendly, economical and capable of generating mass quantity of energy [8]. The peak demands of the load over and above the base load of the power plant for the time of high power demand giving a flexible power in a sufficient amount to cope with the big load fluctuation is called peak load. It is also the maximum power requirement at any point of the day i.e. the highest load value at any hour. In meeting power need technically, the two loads must be significantly considered. Large hydro power, nuclear power, fossil fuel plants are some of the technologies for sustainable base load. For the peak load power consideration, gas thermal, hydropower, pumped storage systems and other various generation technologies are mostly involved [5]. Considering the harmful emissions from the electricity plants, pumped storage hydropower system are most suitable clean and green peak load generators [9]. When renewable sources are linked to a grid back- up capacity and for a stand –alone system energy storage is a vital issue [5]. The pumped storage system is the best solution to the challenges of power generation for locations where there are storage lakes, also in a place where there is varying synchronization between generation and consumption, and where there is water shortage [10] [5]. It is also a balance in safe operation in the electricity grid by ensuring energy demand and supply is controlled [1].

1.2. Energy Consumption Efficiency

The purpose of an electrical power system is to deliver energy in a reliable way from the production points to the consumers [11]. This will provide insight to both grid operators, as a strategic tool to plan grid investment and end users for sustainable energy efficiency. Energy planning can be reviewed as a threefold structure consisting of the energy system, the system efficiency and the system management [2].

The complete energy system may be too difficult to analyse in the urban setting. Energy use should be considered as a function of the generation method. Some energy sources are not matched to end users than the other, whereas in the grid supply, all sources are fed into the grid which is then used for particular activities leading to increased energy losses as a result of diversion into non-economic operations. The Sun primarily gives energy in two forms; heat and light [12]. Domestic need of hot water does not need energy from fuel with an efficiency of about 30 % converted to mechanical energy while about 60 % is lost to the environment as heat. Now, using part of the 30 % from fuel to heat water as an example is economically inefficient [2]. This is one of the reasons why energy use should determine the energy conversion method so as to minimise losses in achieving better system efficiency. This leads to the second aspect of energy planning.

Efficiency is calculated as the ratio of useful energy output to the total energy input in a particular production process. Sources of energy, conversion technology as well as end use all contribute significantly to energy efficiency [2].

Energy management is embarked on to ensure that there is improved overall efficiency and reduced financial losses in energy consumption. It is obvious that renewable energy conversion technologies are usually more expensive, therefore energy waste should be reduced to the minimal [2] [13].

One may not be able to quench coal from supplying at low demand, and energy generated which is not used is wasted except diverted to service other aspects like Pumped Storage system [10]. For a fuel power plant, once energy is not needed, remaining fuel is preserved. Renewable energy is highly efficient in energy management, most especially when operated in hybrid technology [14].
The question now is how to meet peak load in a situation as the one described above? Ideally, power plants are to operate at the average power consumption and should buffer energy demand when the need arises. Even though electricity storage, either as finished product (batteries) or as potential energy (pumped storage scheme) has always been technically difficult, inefficient and expensive but the highest demand is satisfied through additional generators [15]. PSH is not always engaged in micro hydro generation system, work is going on in the design of complete renewable driven micro pumped storage plant for community use [9].

2. RENEWABLE SOURCES

Simple RE technology adoption for electricity generation in a particular geographic location will thrive on availability of abundant resources. In major part of the continent Africa, three major renewable options are solar PV, Wind and hydropower resources. Hydropower generation is not totally dependable; it is exposed to a major climatic challenge of drought season. Hybrid power plant of predominant renewable sources has proven to serve effectively in rural electrification either as standalone or grid connected [16]. With the increased integration of these resources and complementing technologies, there is a good future for improved system efficiency and higher sustainable renewable energy RE generation. Smart grid is described as a solution to integrating different RE effectively [17]. Due to the necessity of smart grid, the University of KwaZulu Natal in collaboration with the largest producer of power in Africa ESKOM have established a centre for related studies. There is a wide room for new energy plant installation, especially in rural areas where there is little or no electricity supply. The existing energy infrastructures, markets and other institutional arrangements may need adapting, but there are few, if any, technical limits of the planned system integration of RE technologies across the very broad range of present energy supply systems worldwide, though other barriers may exist [18]. Because of the unpredictable and intermittent nature of solar PV and wind resources, the two will be supporting hydro generation. Now, there is need to unfold the abundance of each resource in Africa and other regional locations within the continent to know which to integrate for the proposed power generating structures.

Table 1. Renewable energy sources with distribution in South Africa [19].

Technology	**MW allocation in Determination**	**MW capacity in the First Phase**	**MW capacity in the Second Phase**	**MW capacity in future Phases**
Onshore wind	1 850.0 MW	634.0 MW	562.5 MW	653.5 MW
Solar photovoltaic	1 450.0 MW	631.5 MW	417.1 MW	401.1 MW
Concentrated solar power	200.0 MW	150.0 MW	50.0 MW	0.0 MW
Small hydro (≤ 10MW)	75.0 MW	0.0 MW	14.3 MW	60.7 MW
Landfill gas	25.0 MW	0.0 MW	0.0 MW	25.0 MW
Biomass	12.5 MW	0.0 MW	0.0 MW	12.5 MW
Biogas	12.5 MW	0.0 MW	0.0 MW	12.5 MW
Total	**3 625.0 MW**	**1 415.5 MW**	**1 043.9 MW**	**1 165.6 MW**

2.1. Solar Photovoltaic Resource

Solar photovoltaic (SPV) system converts solar energy directly into electrical energy using semi-conductor base materials also called modules [17]. A lot of work has been done on this technology bringing about tremendous improvement because of distinct benefits, especially when there is the need to satisfy remote power demand. These benefits include; easy upgrade because of the modular panels, require no fuel, emission is zero, it can be used in isolation and can equally be connected to the grid and also produce no noise when working [20]. Photovoltaic (PV) modular capacity ranges from small PV system of 50 W to large grid connected Solar PV power plant of up to 50 MW.
Many power plants are rated by the capacity ratio, which is the ratio of actual energy generated during a period relative to the maximum possible if the generator produced its rated output at all-time [10].

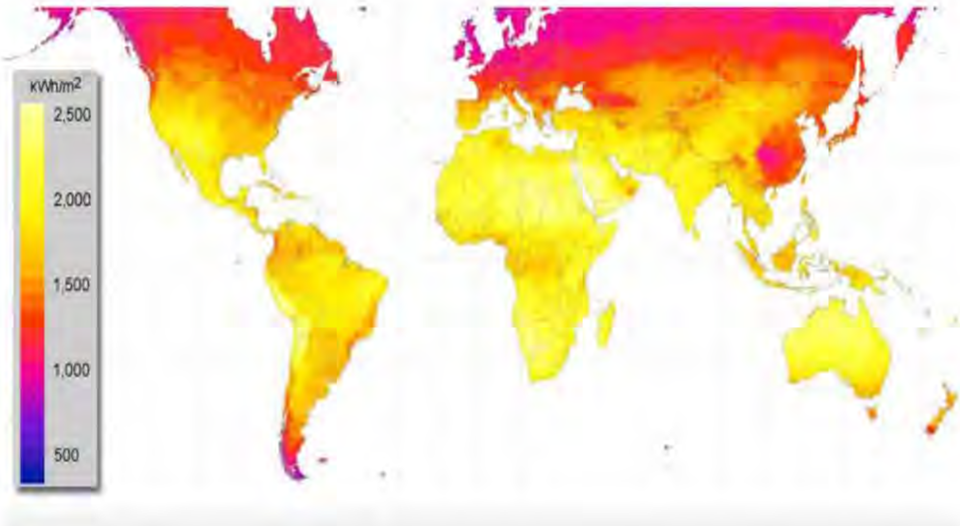

Fig. 1 World solar resource showing yearly sum of global irradiance [21].

Fig. 1 reveals world solar resource, [12] gave an average of 7.0 – 8.5 kWh/m^2/day solar radiation availability in Africa. Major concerns about renewables still point to the challenge of sustainability. A major impairment to continuous use of SPV is the weather, time and climate [22]. Inability to have solar power all through the day or year makes it impossible to be used as the only power source, though the degree of unavailability is low. In a research where 30 years weather data of European annual demand curves were analysed on a 15-minute interval [23]. It was revealed from the analysis that 90% of the power supplied could come from renewable energy sources and that there is only a 0.4% chance that high demand correlates with low solar and wind generation. This disadvantage is to some extent curbed by the introduction of power storage equipment. Inability to have large, power storage devices also pose a huge technical challenge to the world of unlimited exploit of solar energy. At the same time it has been proved to be a sustainable, low technical skill and a pollution free technology for rural power supply [11]. SPV system is being supported by wind and hydropower plant in location where there is adequate resources to develop a hybrid power plant [7].

2.2. Wind Power Resource

Wind power system has been in practice for centuries especially for on and off farm activities. Where resource is abundant, hundreds of MW can be exploited through wind turbines. A small wind turbine configured with SPV will supply power to a village or district mini grid. A lot of wind turbine improvement has been done to enhance efficiency of the turbine through blade design. Tubular tower designs minimise vibrations which will also reduce maintenance cost. Wind turbines offer a very advantageous cost-competitive solution for off- grid applications in rural areas. Wind generation costs have been decreasing over the years and this trend is forecast to continue. The price of conventional energy sources, especially fossil fuels, is constantly rising, whereas the costs of small wind are showing a gradual decline, emphasising the attractiveness of these technologies. Reports by [24] proved costs will reduce by about 20 % by 2015 [20].

Small wind can also be combined easily in hybrid systems with hydropower, solar or diesel, creating even more possibilities [25]. Wind – SPV hybrid will increase system reliability, this allows each energy source to supplement each other and it is an attractive arrangement for small loads especially on off grid and mini grid configuration [20]. It can be configured as AC mini grid with DC coupled component suitable for rural power supply. The second configuration is a modular AC system integrating SPV power input and battery for storage. This arrangement accommodates larger loads and an average life span of 20 years with a capacity factor of 30 %. The figure below reveals the distribution of world wind resource with abundance in Africa.

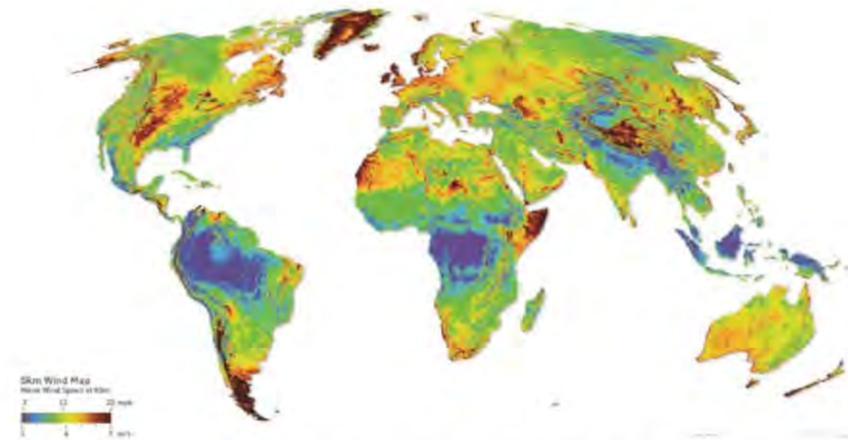

Fig. 2 World wind resource showing Africa [12].

2.3. Hydropower Resource

More emphasis will be on hydropower as our main power source. HP contributes enormously to achieving base load in several countries worldwide, either as Large HP or Small HP. Small hydro-power projects most time function on 'run off river' schemes that divert water through civil structures into turbine converting energy in flowing water into mechanical power which is then converted to electricity [26]. Most small hydropower systems are run off river, especially pico and micro plants.

Plant size is a function of many factors ranging from topology, design height, flow, river-size, availability of storage structures, environmental impacts, other water use, available design structures, end-users, appropriate technology and many others [26]. All this listed conditions also describe the design components (turbine type, generator size, and head) which will invariably determine plant cost. Most micro and mini hydro plant projects supply power between 100 kW to 1 MW, enough for stand-alone, especially when the location is far from the main grid or possibly supply the main grid.

Hydropower (HP) is clean, available, reliable, adequate and renewable. It is established that about 70% of the earth's surface is covered by water. Engaging small hydropower (SHP) schemes will go a long way solving the menace [27]. Many countries have installed standalone and mini grid system with great success [3]. With the enormous untapped potentials in Africa [28], it is time of SHP installation is adapted fully in Africa on standalone basis which is cheaper and requires little technical know-how or skilled labour instead of depending on large scale HP which takes years to install and also capital intensive even for nations to invest in. Mini hydro is described as an important option as it is suitable for decentralize and private sector investment. Uganda and Rwanda have programmes in place to specifically foster private sector participation in this field [3]. This paper will consider the requirement for types of standalone SHP and the economic importance of engaging them in rural and suburban settlements.

2.3.1. Africa Hydropower Overview

The West Africa region has installed capacity of about 25% of total African capacity, Nigeria and Ghana are the biggest LHP contributors [10]. Small hydro potential for Nigeria has been assessed at 824 MW, over 278 unexploited sites have been identified of which only 4% has been exploited [29] [10]. [28] conducted a survey in five East African countries to estimate SHP potentials in the region. The countries are Kenya, Uganda, Tanzania, Rwanda and Burundi. The report shows there is enormous potential in the region. Uganda is among the countries in Sub-Saharan Africa with the lowest electricity distribution rates with only 6 % of the total population have access to electric power. Power sources depend on fuel generating sets, car batteries and solar PV systems to achieve a minimum level of electricity supply and six pico hydro power sites have been developed in Uganda [30]. In Burundi, 99% of the country's utility comes from HP. There is still more room for further development, especially in micro, mini and small hydropower capacity [28]. Potentials in North African countries is great with much development from the region but [31] still reported more potentials are still untapped. Southern African countries are not left out in hydro potentials; there are over 8000 potential sites for SHP in Kwa-Zulu Natal and Eastern Cape provinces of South Africa alone [10]. With great potentials in Zambia, installed SHP capacity is 62 MW [31]. Mozambique has the largest LHP installed capacity of 2500 MW but very little SHP installed capacity (0.1MW) [10]. Central Africa is

another region with tremendous hydro-potentials. HP potential is about 419 000 MW with installed capacity of around 3 816 MW for large HP and the Democratic Republic of Congo contributes the greatest. Only 1% of its potential capacity is exploited and SHP is poorly developed in the Central Region just like the other four regions [31].
South Africa alone produces about 390 TWh of electricity with amounts to about 70 % of total generation in the sub- Sahara Africa. In 2007, the average generation capacity of sub-Sahara Africa was only about 110 MW per million inhabitants. Seychelles was about 1,110 MW, South Africa follows with 880 MW, while in Guinea and Togo, the per million inhabitants MW was about 15 [32]. Comparing the figures to what is obtainable in developed countries; one will be convinced of the need for energy increase in Africa. The generation capacity in the European Union is about 1,650 MW per million inhabitants, and in the U.S. it is 3,320.

2.3.2 Small Hydropower Components

[23] identified three basic challenges to HP especially at large scale capacity. Firstly, large dams are in many cases environmentally not sustainable. They are also most times located far away from existing grids. Thirdly, large HP is very capital intensive project and has very long lead times. For this work, more emphasis will be on small HP systems.
A typical micro hydroelectric power project consists of civil and electromechanical components. The civil aspect takes care of structures from intake down to penstock [10] [20]. The turbine aspect of the plant converts energy in water to mechanical energy at the shaft of the turbine is the mechanical conversion while conversion of energy at the shaft constitutes the electrical aspect. Electrical energy output is transmitted through cable and wires to the end-users [33]. The height between the source and power house, discharge, direction of flow, all have a part in turbine selection [34]. Turbines are classified as impulse or reaction turbines. Impulse turbines are Pelton, Crossflow, Turgo etc. characterised for high head and low flow. Reaction turbines perform well with low head and high flow and these include Francis, Kaplan, Bulb etc. [13]. Though there is no clear demarcation between high head and low head as what is categorised as high for a micro plant with Pelton turbine could be low head for a mini plant with Francis turbine. A pico scheme is easy to install because may not need penstock, which makes it very cheap to construct [26] [34]. Plant efficiency depends on many factors including loading, site conditions and precipitation. Variation in equipment costs of micro and pico hydro scheme is very little [20].
Most mini hydroelectric power plants also work 'run-off river' with some work going in maximising small hydro power generation by water reuse through pumped storage system [34]. With cheap plant construction, environmental friendly configuration, possibility of independence and continuous power supply advantage. A mini power project has a capacity ratio of 45 %, an average plant cost if $1 800/kW and is commonly adopted by private investors [20].
Considering the challenge of climate in renewable energy generation, it is of great importance to closely consider the possibility of erratic climate change as a result of the global warming so as to avoid putting the sustainability of hydropower generation at risk. In an attempt to ensure the base load is met at all times, the author is working on introducing the possibility of integrating a micro pumped storage facility [5]. This will serve as a non-polluting storage facility to produce electricity as demanded.

4. SMART GRID AS SOLUTION

4.1. Energy Losses

Generated electric power is transported through the main grid from the generator to the customer as high voltage through a long distance transmission and the delivered to distribution networks as low voltage.
Electricity topology flows from generation, transmission, distribution and this is not complete without good knowledge of consumption demand by the end users [20]. Transmission and distribution of electricity through grid needs to meet certain requirements in achieving this in a renewable energy environment. Some of these requirements are generator size, annual output, cost of transmission and the cost of distribution [35].
Losses account for about 9 % of electricity produced worldwide as a result of transmission and distribution, cutting down supply in ordinary electrical grids [11]. The effect is considerably significant in long transmission line. A report estimated the amount of power that would be lost during the delivery of 2000 MW from Cahora Bassa in Mozambique through the 1500-km line to South Africa as nearly equal to the entire consumption capacity of the host generating country.
In a report by [11, 32] about 585 million people in sub-Saharan Africa (about 70 % of the population) had no access to electricity. In Nicaragua, more than 58 % of the rural population lack access to electric power [32]. By 2030, the figure for sub-Saharan Africa is expected to rise significantly to about 652 million people with over 80 % of this group living in rural areas [32]. Research showed that losses due to distribution account for over 2/3 of the total delivery losses. The high losses in distribution is attributed to resistance losses in conductors are proportional to the square of the electric current [20]. Lower voltage translates distribution to higher current flow, making distribution system less efficient. For this reason, for rural energy production, consumption should be done within the region to avoid unnecessary waste of power.

4.2. Aspect of Distribution Interconnection

The issue of 'grid' either 'smart', 'mini', 'micro', or 'just' is basically for transmission and distribution of electric power from the producer to the consumers. There are many options involved in grid technology. [36] described various options a mini grid. The operator can connect its plant either as a small power producer SPPs or as a small power distributor SPDs. When an operator generates and supplies the main grid, SPP. If on the other hand buys from the grid and resell it to consumers using the existing distribution network, becoming a SPD. Also the operator can become both an SPP and an SPD.
Mini grids minimise the cost of interconnection and avoids the acquisition of huge technical materials like transformers, lines, switchgears, towers etc. [36].
For a typical HP plant, the frequency of a generator depends on the speed of rotation at the shaft achieved by balancing the pressure and flow rate of water running the turbine and the electrical load quantity. In an isolated mini grid of renewable energy sources, plant generator must maintain frequency control and this is achieved by engaging two methods [36]. The first one uses a mechanical controller that widens supply valve as soon as the system detects a drop in frequency, while it closes the valve when excessive frequency is detected. The other method is engaging ELC to control generator load [13]. It is a common technology used in micro grid HP system where frequency is controlled by adding progressively higher loads called design load to slow down the shaft speed until exact load is obtained for proper AC frequency. In order to maintain this design load, ELC typically diverts excess load to restive heating element [13].

4.3. Grid and Smart Grid Technology

Among the renewable energy sources, the wind and solar are variable sources that are only partially predictable, while hydropower are controllable sources [18]. Renewable electricity production could comprise power plants from mentioned sources geographically located in a specific area connected or not connected to the transmission grid for the purpose of distributing needed quantity of load per time. The intermittent and unpredictable nature of renewable sources makes it difficult to actually balance energy generation and distribution as required for grid stability because change in rotational frequency [36]. To now integrate sources of unstable power generation technologies into a reliable network, smart electrical grid is inevitable [37].
This work identifies the functionality and reliability of a grid that arise from the integration of renewable energy sources for sub-urban community or a typical farm area. Small-hydro systems are simple, reasonably reliable, low cost, provide cheap electricity, scalable, standalone and continuous power without the need for environmental safeguards. Communities consume electricity, basically for domestic purposes like lighting, media, heating and cooking while for few commercial uses such as food processing, preservation (refrigeration), handling and other operations.
To avert severe environmental failure, energy policies must look into the massive integration of renewable resources and improvement of the electric system [37]. A Smart Grid is an electricity grid that allows the massive integration of unpredictable and intermittent renewable sources, and distributes power highly efficiently to end users [37]. It is an electricity network that uses distributed energy resources and advanced communication and control technologies to deliver electricity more cost effectively, with lower greenhouse intensity and with active involvement of the customers [11]. Smart grid has more intelligence than the initial existing grid, which allows a balance of power from various unpredictable generators from non- constant renewable sources resulting in continuous variable load [17]. A smart grid also gives an exclusive opportunity for electrification of suburban and rural settlements out of reach of main grid that requires electrification for daily living and other economic activities most especially in the sub-Sahara regions [38].
Investors in Cambodia used mini grid distribution system to supply diesel generator produced sometime with wiring tied to trees before being connected to their customers [36]. With the expansion of main grid across rural areas, there was fear of being out of business. A Regulatory body in Cambodia resolved this problem by setting technical standards to connect to the main grid by the introduction of bulk purchase tariffs and retail purchase tariffs. A different scenario in Sagar Island in India, where 11 solar generating stations with combined capacity of 500 kW, supplied power to business and domestic purpose with an average of 1400 households [36]. Standalone plants can be significantly manned when proper billing is put in place, even at the district levels.
This situation is clearly reflected in the current map of sub-Saharan Africa's grid either not well interconnected or non-existing in some areas. [38] reported that while some authors suggested introduction of 'Just Grid' others proposed implementation of 'Smart Grid'. 'Just Grid' will help guarantee access to modern energy services without marginalizing the poor while Smart Grids will help provide an efficient mechanism to address the massive electricity infrastructure building requirements. The two are to provide distribution of power systems to contribute towards equitable and inclusive global, economic and social development [38]. The average lifetime of a grid is considered to be around 20-30 years based on depreciation calculations, but can be stand more 50 years if properly maintained. For this reason, a good thumb rule is that

operation and maintenance cost of power distribution facilities should be between 1/8 and 1/30 of capital on annual basis [20].

4. CONCLUSIONS

HP has been identified as a major source for providing adequate electricity to meet base load in developing countries either through conventional or pumped storage technology. From the data provided, a large percentage of SHP potential is untapped, which is a loss to society. Wind and solar can deliver quite an appreciable amount of electricity likewise. The resources are enormous enough to provide needed electrical power to make life better, especially for people living in poor urban or rural areas in Africa. When the resources are explored, it will result in economy boost in communities. There is a ready market for generated power, as policies are on ground to encourage investors to explore hydro projects. There is a need to involve private investors to participate in the development of the resources. These renewable energy sources are clean and available, environmentally, widespread and substantial.
Smart grid is the answer to rural and standalone electricity distribution and should be embraced in Africa.

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2.3 Small Hydropower Plant (SHP)

In many parts of the globe, increasing energy need is becoming an unending challenge for RES as most rural communities in developing countries settle for other primary energy sources [38]. Most of the time they engage fossil fuel powered generators and sometimes thermal power plants as sources of power [39]. Harnessing renewable energy potentials especially hydropower requires putting in place sound policy, incentives and greater financial commitments [40]. Small hydropower plants (SHPs) are very appropriate in areas that are far from the grid, rural communities where hydro facilities are available [41], where equipment can be easily transported for generation and distribution of electricity and also it is ultimately characterised with low power consumption or demand [42]. More work needs to be conducted in the area of installation of small hydropower plant with low head. Table 2.1 gives the capacity and potential for all hydropower sites in South Africa [43].

SHP are considered as high head, low head and contemporary to other use [42]. Basically the high head and the low head types are compared in terms of discharge capacity, power mean annual production, civil engineering aspect, turbine choice, generator costs keeping in mind a design that is reliable at minimum cost [44]. [42] reports gave the electricity unit cost irrespective of the source at the same price within a particular location even when the components in each technique differ in price. The electrical components of a typical hydropower plant cost are about 25% - 30% of the total plant cost [45]. The civil engineering aspect for a high head plant consumes about 60%, while turbine costs almost 15% of total plant cost [46]. In the case of low head plants, the turbine cost is about 25% while the civil engineering takes about 47%. This indicates that low head turbines cost more than high head. The high cost of the civil engineering aspect of high head plant is attributed to the cost of the penstock which consumes up to 46.8%. This portion can be reduced to ensure that the cost of plant installation is minimised drastically [47]. Also we need to understand that about 26% cost of the civil engineering aspect of a low head hydropower plant total cost is being reduced by the integration of an inflatable threshold device. Realisticly, investment in small hydropower plants is not to make ‗surplus profit quickly' but to ensure ‗sustainable money' [42].

The future of SHP development is very dependent on its integration with other renewable energy sources and on favourable environmental policies which enable such technology [48]. The potential of hydropower in the EU is approximately 11.8% of the total renewable energy potentials available in the region. About 36.1% of the total renewable energy harnessed in 1995 comes from hydropower out of which small hydro took about 3%. This is because large hydropower plants are the most exploited for electricity purpose [42].

Table 2.1: Total capacity and potential for all hydropower classes [35]

Hydropower Category and Size (MW, Kw)	Hydropower Type	Installed Capacity (MW)	Potential for Development	
			Firmly Established (MW)	Additional Long-Term (MW)
Pico (up to 20 kW)	Conventional	0,02	0,1	0,2
	Unconventional	-	-	60,0
Micro (20 kW to 100 kW)	Conventional	0,1	0,4	0,5
	Unconventional	-	-	3,3
Mini (100 kW to 1 MW)	Conventional	8,1	5,5	3
	Unconventional	-	-	2
Small (1 MW to 10 MW)	Conventional	25,7	27	20
	Transfers	-	25	5
	Refurbishment	-	11	-
Subtotal for small/mini/micro and pico hydropower in South Africa		33,92	69	94
Conventional macro hydropower (> 10 MW)	Diversion fed	-	3 700	1 500
	Storage regulated head	653	1 271	250
	Run-of-river	-	120	150
Subtotal for renewable hydropower in SA		687	5 160	1 994
Macro (large) (> 10 MW)	Pumped storage	1 580	7 000	3 200
Total for macro and small hydropower in SA		2 267	12 160	5 194
Macro (large) (> 10 MW)	Imported hydro	800	1 400	35 000 (+)
GRAND TOTAL FOR ALL HYDROPOWER		3 067	13 560	-

Table 2.2: Capital cost and maintenance of selected power generation techniques [35]

Power plant	Plant capacity (kW)	Overnight cost ($/kW)	Operation and Maintenance cost ($/kW)
Onshore wind	100,000	$2,438	$28.07
Offshore wind	400,000	$5,975	$53.33
Small PV	7,000	$6,050	$26.04
Large PV	150,000	$4,755	$16.7
Pumped storage	250,000	$5,595	$13.03

This research intended to engage the use of photovoltaic (PV) in lifting water from the lower reservoir straight into the upper reservoir during pumping mode due to the abundance of sunlight during the day when energy need is at its peak. However, this did not occur because of the unpredictability of the climate and the high installation and post-installation costs [49]. Integration of wind driven pump mode was also considered but, like PV [50], is dependent on climate and has high installation costs which will also affect the sustainability of the system. In order to avoid short term future challenges as a result of the hybrid generation system, this design considers the use of combined conventional and PSH system. Table 2.2 compares three types of renewable sources in terms of capacity and running cost which shows that the operating cost of pumped storage plant is minimal while Figure 2.2 is a picture of a typical hydroplant power house.

Figure 2.2: Small hydropower plant picture showing turbine and generator [36].

2.3.1 Types of Small Hydropower Plant (SHP)

SHP can be categorised in terms of capacity (see BIE publication), in terms of head and scheme as shown in Table 2.3 [51].

Table 2.3: Classification of SHP in terms of head

PLANT TYPE	HEAD
High head	>100 m
Medium head	30 m – 100 m
Low head	2 m - 30 m

In terms of scheme, we have;

i. River run-of schemes.

ii. Plant site base, powerhouse location scheme.

iii. Community water supply pipe connected scheme [51].

In SHP civil works account for about half the total cost of plant [46]. This means in plant design considerations should be given to this aspect for minimum cost. The generation cost of SHP is given in the Figure 2.3. This shows that the cost of electricity generation by means of hydropower is relatively low compared to other sources of electricity.

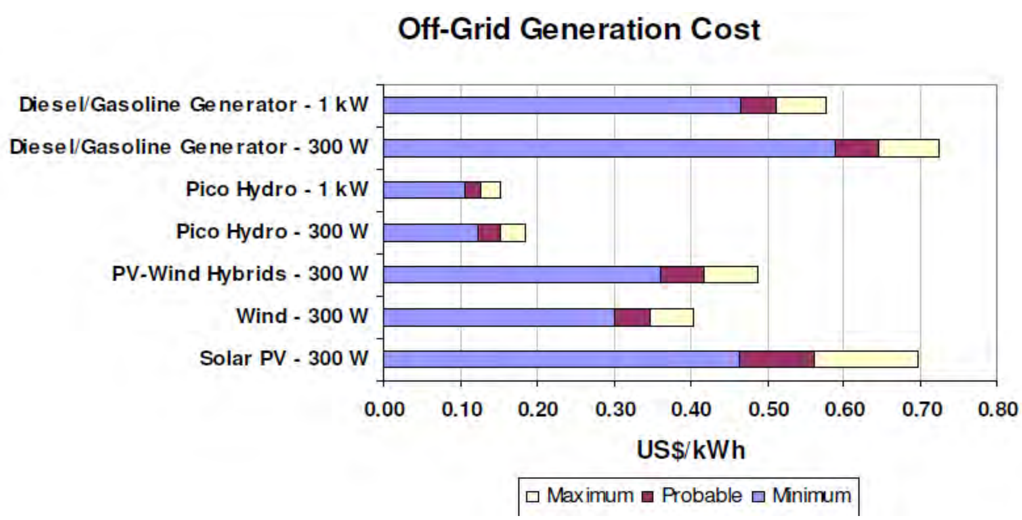

Figure 2.3: The Capital costs for renewable energy systems [52]

2.3.2 Advantages of Small Hydropower Plant (SHP)

This work is premised on the major benefits associated with exploitation of hydropower energy. These include:

i. Small hydropower potential is available almost everywhere across the globe, therefore bringing the possibility of electricity consumption to all.

ii. Small hydropower potential does not generate heat, making it of less impact to the society.
iii. It does not contribute to environmental pollution.
iv. Construction time is shorter compared to large scale plant and the requirements and policies guiding installation are light. It can be easily upgraded.
v. Small hydropower potential is necessary in water resource management procedures as an element of multipurpose water use.
vi. Simple machinery, construction and management know-how.
vii. Minimise losses due to transmission and distribution of electricity.

Other advantages are available in the publications attached.

2.4 Publication 2: Potentials of Small Hydro Power in South Africa: The Current Status and Investment Opportunities

POTENTIALS OF SMALL HYDRO POWER IN SOUTH AFRICA: THE CURRENT STATUS AND INVESTMENT OPPORTUNITIES

Samuel A.O. Ilupeju and Freddie L. Inambao
University of Kwa-Zulu Natal, Durban, South Africa

ABSTRACT

The economy of any country is highly dependent on the development of stable and adequate power generation. The need for power in Africa is increasing and the potential for power generation is substantial. Hydropower (HP), both large and small contributes about one-fifth of world electrical power. A survey output puts the number of small hydro power (SHP) potential sites in Kwa-Zulu Natal and Eastern Cape provinces at about 8 000. In South Africa HP generation is negligible as coal contributes about 90% of total energy generated while other sources contribute the remaining 10%. South Africa is ranked 12th in the world in terms of the top emitters of carbon dioxide, exposing dwellers to risks associated with this emission as a result of coal fired plants. It was predicted that the global demand for electrical energy will gradually rise and the growth for HP production is projected at 2.4% - 3.6% from 1990 to 2020. SHP is considered to be one of the most cost effective and environmental friendly energy generation technologies available. With the availability, reliability and simplicity of SHP technology coupled with associated advantages, this paper is to set us on a new bearing toward its employment.

1. INTRODUCTION

Electricity is generated in various ways, but the prominent ones are biomass, fuel, and gas, coal, geothermal, nuclear and hydro-power. The economy of a society is highly influenced by the availability and reliability of energy. The law of conservation of energy states that energy is neither created nor destroyed but can be converted from one form to the other. It is the conversion process that makes it available to end users and the reliability depends on the quantity provided which is a function of the energy source employed in the generation combined with available infrastructures supported by friendly policies.

Renewable energy sources are the primary energy sources in human history and they pose zero or little threat to human lives by avoiding the severe environmental impacts which fossil fuels generated energy contribute to the environment. Some of the renewable technologies draw power from the water and wind power, sun; which radiates energy in the form of light and heat, etc. The technology of utilizing energy in falling water through a definite height has been recognised as a source of power a long time. It is generally accepted as one of the oldest renewable energy techniques known for mechanical energy conversion which then yields electricity generation for domestic or commercial purposes [1]. The last two decades have witnessed a renewed interest in the development of small hydro power (SHP) projects mainly due to its benefits, particularly concerning environment and the ability to produce power in remote stand-alone areas. There are lots of advantages of integrating SHPs into power generation scheme and these will be identified in this report, beginning with being economically viable and the gestation period is relatively short. [1] reported that a fresh interest in SHP technology has resulted in China building over 85,000 small-scale electricity producing hydropower plants.

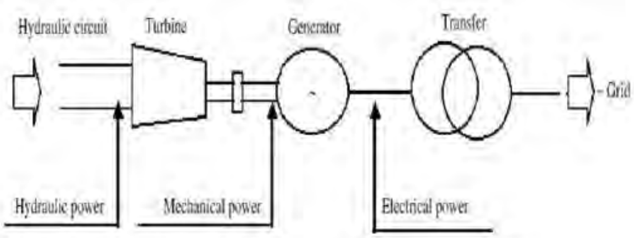

Figure 1. A sketch of the power conversion process [2].

1.1 WHY HYDRO POWER?

The human race has depended on electricity to the extent that every aspect of life depends on it. Every economic activity including; manufacturing, domestic, industrial, communication and major effective services all rest on the pillar of energy to function [3]. Electricity as a source of power is less stressful to use; it can be easily controlled, neat and instant compared to other energy sources that are predominant in various parts of Africa including fuel and biomass.

It is important to remind ourselves that the entire world is going green, thereby working towards generation of clean, adequate and reliable power. South Africa is among the highest emitters of carbon dioxide in the world, with more than 75% of the primary energy requirement from fossil fuels. Specifically South Africa is ranked 12th in the world in terms of the top emitters of carbon dioxide, exposing dwellers to risks associated with this emission [4]. Among these green sources, hydropower is a major player. HP contributes about 20% of world electricity generation with countries like, China, USA, Canada, Brazil, leading in the aspect [5]. It is estimated that out of HP capacity, at least 728,500 MW installed capacity provide power to over 55 counties [5]. It is also regarded as the largest and most mature renewable energy source (RES). HP represents 90% of RES in the EU and supplies 14% of electricity demand [6]. It is available in large scale and small scale, proportion depending on the availability of water, which is the major player in the generation process. HP equipment are expensive, making the initial cost of constructing an HP plant high, but the equipment are sturdy and reliable with a lasting life span of many decades [6]. The availability of raw materials puts HP at advantage of cheaper production cost over other energy sources. There are different scales used to classify categories of HP based on the country policies. [6] puts large hydropower (LHP) at quantity above 30 MW while generally capacities less than 30 MW fall under the categories of small hydropower (SHP) sizes. SHP is further divided into categories as shown in the fig. below [7].

Table 1. Showing SHP categories by capacity [7].

Size	Capacity
Small-scale HP	2.5 MW- 25 MW
Mini HP	500 KW- 2 MW
Micro HP	5 KW- 500 KW
Pico HP	<5 KW

2. NEED FOR SMALL HYDRO POWER PLANTS

[8] predicts that the global demand for electrical energy will gradually rise and the growth for HP production is projected at 2.4% - 3.6% from 1990 to 2020. Small scale hydro-power (SHP) is considered to be one of the most cost effective and environmentally friendly energy generation technologies available [9], in most cases just water running through a river without storage, or surface dam or at a given head. It is the most ideal small scale energy technology for isolated and/or rural community electrification in developing countries. Though there are criticisms of LHP development in terms of impact on the environment and fishing activities, SHP offers a perfect solution as there is almost zero carbon emission and negligible other environmental impacts. Many countries in the developing world have embraced generation of electricity through exploitation of SHP potentials. [6] reported that DOE identified about 500,000 viable SHP sites capable of generating 100,000MW in her search for potential HP development site. This represents about 10% of the US electricity generation capacity as well as about 80%of US renewable generation capacity. SHP installed capacity in the EU is projected from 11% to 30% by 2015. This overall significance replaces energy from fossil fuel based on minimal environmental impact.

Many African countries' electricity policies are being tailored after renewable energy generation which has wider advantages over other conventional sources of energy. The main focus centred on increasing the quantity of power through RES in which hydropower plays the greatest role [10]. It is as well necessary to know that energy is to be generated when needed or else energy not consumed is wasted since there is no storage device to store a huge quantity of electricity. There should be a balance between demand and supply of power taking also into consideration future demand plan. There is a need for flexibility in electricity generation and that is why SHP is the best technology that can handle quick response, energy generation when needed in order to meet needs [10], [11]. SHP can also be merged with other schemes that are available among RES to make a complete reliable stand-alone power plant.

There is an urgent need to tap into the available resources considering carefully the institutional feasibilities and technical potentials integrating PV, fuel cells etc. [10].

In small- scale hydropower systems useful power is extracted from energy in the flowing water. SHP is a clean, sustainable, efficient and available renewable energy source with huge and yet largely untapped potential. These advantages will enable it to make a significant contribution to future energy needs, thereby offering a very good alternative to other conventional sources of electricity [12]. The good thing about SHP is that it combines the advantages of hydropower and other power generation sources without the disadvantages of large-scale installations.

It is important to note that SHP potential depends greatly on the availability of suitable water flow quantity to generate clean and reliable quantity of power, mostly electricity. Most SHP runs in rivers, therefore without the need for a reservoir.

Table 2. Continent contribution to world Installed SHP capacity. [12]

Region	% Installed SHP capacity
Africa	0.5 %
Asia	68 %
Europe	22.3 %
North America	6.1 %
South America	2.7 %
Australia/Oceania	0.4 %

2.1 SMALL HYDRO POWER POTENTIALS IN SOUTH AFRICA

In South Africa HP generation is negligible as coal contributes about 90% of total energy generated while other sources contribute 10% [4]. South Africa has both LHP and SHP potentials. Drakensberg, Palmiet, Lima and Ingula are some of the LHP capacities with Drakensberg and Palmiet in active generation. The future of electricity through hydropower generation in South Africa will increase tremendously if the potentials are fully explored [7]. HP, apart from the generation of electricity can serve the purposes of recreation, dam control, water exchange, fishing activities etc. With the significances of LHP, SHP distribution in South Africa is also quite enormous. A survey output puts the number of SHP potential sites in Kwa-Zulu Natal and Eastern Cape provinces at about 8 000 which are suitable for small hydro-utilization below 100 megawatts [13]. Timely utilization of the potentials will go a long way saving the overburdened power generation sector. It is good to know that SHP can be utilized both conventionally and as pumped storage hydropower (PSH).

3. TECHNOLOGIES IN SMALL HYDRO POWER.

Though SHP's efficiency and reliability are high, new technologies are being developed to improve the system operations. These innovations include the new designs includes, the use of new composite materials for low head turbines, high-speed generators, operation of variable speed pumps, submersible technologies, new types of computer-based digital controllers for remote diagnostic and automatic monitoring, and web cameras to allow regular checks on the remote - control basis.

Leading in the market sector of SHP is Europe, which has resulted in the saturation of the sector in various part of the continent with viable technology. The cost of production of SHP equipment has reduced drastically as a result of new optimal turbine design and technical developments due to standardisation. This step will further lower the price, therefore eradicating the fear of high investment cost, bringing about increased plant installation [14].

SHP offers good employment opportunity. [14] reports manufacturers of turbines at 60-70 with over 8000 workers apart from consultants and contractors.

One of the critical challenges in SHP is the actual size of a small scale hydropower plant. This is because it determines the obtainable power plant performance as a function of maximum exploitation of the water hydraulic potential which affects the overall profitability of the index if the plant as an investment.

In many countries today, small hydropower is one of the most valuable sources of rural electricity, supplying power for various domestic and agricultural processing activities which improve quality living. [15] reports that one can take the advantage of multiple propose projects for drinking water and irrigation systems to install small hydro schemes.
HP is an old and developed technology with competitive outputs from various equipment where turbines and generators plays prominent roles [15]. SHP construction is a multi- disciplinary engineering in operation, but basically installation of electromechanical equipment and few civil works involving, hydrology, hydraulics, structures, electrical, mechanical, geologic and environmental experts [10]. The civil works aspects include construction of different intakes and diversion structure 'weir'. A weir is a man-made structure constructed across the river flow so as to give a continuous steady flow. Desilting tank; slows down flow steadily for foreign and suspended material accompanying flow to settle down before falling into the turbine. This process is particularly low-head plant, but in case of medium and high head plant, flow is directed through forebay [10], [15]. Forebay; a simple structure at the end of a weir for meeting immediate water need, penstock; conveying water through forebay or weir as the case may be into the turbine. The flow is usually regulated through a valve at the top of the penstock. A small building is needed to house the generating and control equipment. From the turbine discharge point, tailrace channels the flow into a river or dam depending on the structure of the environment.

Considering the electromechanical components, these are turbines, generators and control equipment [15].

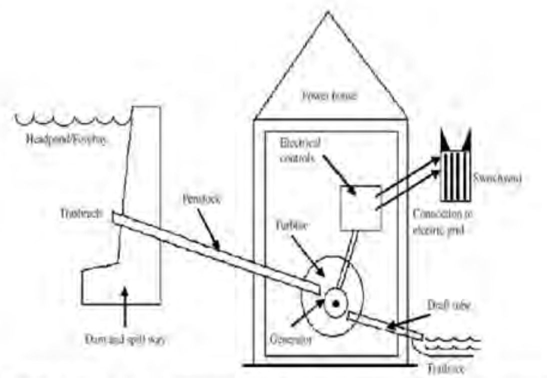

Figure 2. Schematic description of components in a small hydro system [2].

Turbine designs have experienced tremendous improvement. The suitability and relevance of each design is a function of the geographical nature of potential site.
[6] worked on a research in determining the cost effectiveness of developing SHP site. Electrical energy is generated in SHP as hydro turbines convert water power into mechanical power which are engaged in driving an electric generator through the shaft of a motor. Mathematically, rated generating power Pg is expressed as:

$$P_g = \rho_w . g . Q_g . H_g . \eta \text{--------------------} (1).$$

P_g, rated generating power, (kW),
η, efficiency,
ρ_w, density of water (kg/m^3),
g, gravitation constant (m/s^2),
Q_g, rated generating flow (m^3/s),
H_g, rated generating head (m).

Engaging renewable energy resources, power generation process causes little or no pollution to immediate or surrounding environment. Planning and development is an important step in reducing power outages or shedding due to immediate increase or projected future. SHP is an approved method to achieving this growing need [15]. Increased energy yield means increased development. SHP is a sustainable energy generation system with wide application and optimal efficiency. The installation of this system plays a significant role in the development of small scale manufacturing and industries because it is cheap source due to its availability [15].

Apart from power generation SHP can also serve as water distribution scheme, supply potable water to the surrounding communities. Secondly, it can serve as an irrigation scheme as well as flood control purpose. SHP plays a huge role in environmental protection purposes, non-polluting and preservation of aquatic habitat. Efficient, low head turbines, fish friendly turbines that enables fish to pass through the turbine without being hurt are part of new innovation to improve SHP employment [16]. Another improvement in turbine is the development in terms of improved efficiency and dynamic characteristics. This has led to efficiency of small turbines has increased from around 88 to 93 percent and the efficiency curve has been considerably improved [16].

4. PROSPECTS OF SMALL HYDRO POWER.

SHP potential capacity was estimated between 150-200 GW with economic potentials of about 7300TWh/yr. As at 2005, 32% of the resources is being utilized out of which only 5% are from SHP. In North America and Europe, a large percentage of the technology potentials have been utilized. Presently, greatest potentials of new SHP installations are in developing countries (in which African countries are). In remote settlements where energy use activities are low, small to micro HP installation can be a good solution to generate electricity, which can be distributed through the local grids or consumed in isolation.

Table 3. Shows the potentials technical SHP capacity distribution [5].

Continent	Percentage exploitation	Capacity
Asia	15 %	60-80 GW
South America	7 %	40-50 GW
Pacific and Africa	< 5%	

[5] identified three key phases of administering HP. These are new installations, renovation of the existing and expansion of the existing plants.

RES development is necessary in reducing carbon dioxide emissions [4] [5]. Apart from high efficiency and low cost of installation benefits of SHP, low head, use of variable speed generators, reduced cost of equipment and environmental friendly technologies are part of the factors attracting expansion of SHP. The EU had up to 17400 SHP plants distributed around the region as at 1999 with capacity up to 12.5 GW supplying about 50 TWhr/yr. This production is about 10% of HP total production. From 1995 to 2010, SHP production increased by 18TWhr in EU countries leading to 4.7% rise in global RE production. Development of RE will reduce the rate of depending on importation of energy and help in handling better climate change [5]. In EU, the contribution of RE increases from 5.4 % to 6 % between 1997 and 2001. To further target of reducing emission below 8%, EU set to achieve 22.1% RES generation by 2010 [5].

Two major factors responsible for SHP potential are the quantity of water flow; a function of average annual precipitation and the head; which depends on the topography of the potential site. The head can be artificially designed either when too high or too low or vice versa.

SHP design falls into three categories as a result of the topography and the head [5];

a. High head HP plant

b. Low head HP plant

c. Supplemental HP system- this system main operation could be irrigation, drinking, waste disposal systems.

[17] presented a method for assessing small hydropower projects that are subject to uncertain electricity prices. Design and construction of SHP plants must be precise according to the function for optimal size. Conducting a proper and genuine feasibility study is important for the team to know the exact potential design criteria before construction of the plant is embarked on [10]. When a plant is erected wrongly, there may not be alternative use and the process is absolutely irreversible. Expanding the plant is another capital gulping activity. Therefore, correct investment decisions in terms of size, time and location are of great priority.

Major SHP plants are designed as "run off" the river types which pose a threat in season of drought as a result of no water storage procedure. Power generation depends majorly on flow of water [10]. A larger plant can generate at maximum with a great inflow of water, but in a period of less flow, the efficiency will be reduced, incurring higher investment and running cost. To achieve optimal capacity, both inflow consistency and size factor has to be looked into critically [18].

It is as well important to construct SHP plant that will generate needed energy at the lowest possible cost by considering two important variables [16] [14].

i. Using the technical advantage larger pipes over small pipes in terms of friction, the friction depends on pipe characteristics (surface friction and diameter) and whether the fluid flow is laminar or turbulent.
ii. The higher the flow to the turbine, the greater the generated power [14].

5. CONCLUSION

The use of petroleum products, especially diesel and petrol in most rural communities substitute installation of SHP.
SHP growth is estimated to be between 1% - 6% per year over the next 20 years with significant growth in sub-Africa region.

While fresh installations will flood developing countries, refurbishing and expansion were expected in already developed areas.
SHP is a proven technology that generates at low operation cost and longest equipment life span.
It is also characterized with the highest energy conversion process, up to 95% water, energy conversion to electricity, whereas best fuel plant conversion is about 60%.
Contribution of HP to RE is mature and prominent with such a huge potentials enough to result in a significant contribution to future energy need.

There is high potential for PSH in Africa. This is of great importance as the economy of the continent is dependent on the development of stable power generation. A good number of organizations are looking into identifying various potentials in Africa as encouragement to African economic advancement. Some countries in Africa have been identified as potential SHP providers, namely, Kenya, Uganda, South Africa, Nigeria, Mozambique, Zambia and Rwanda [19].

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CHAPTER 3 : HYDROPOWER POTENTIALS

3.0 Introduction

Before going deeper into the research work, determining the potential of hydropower, i.e. quantity, is necessary. This will be reviewed globally then regionally in terms of Africa then specifically in terms of South Africa. This is necessary to evaluate the benefits of the research outputs implementation.

3.1 Global Potentials

The global contribution from hydropower has increased over time and the growth is expected to contine due to the fact that the potentials are great [53]. A review of renewable energy sources in global power generation will not be complete without knowing details of the vital role hydropower plays. The latest stage in energy demand globally has placed such an enormous burden on the shoulders of various government institutions to provide electricity to their people. Energy sector development is one of the paramount aspects of government responsibilities either directly or indirectly and this involves enacting relevant policies to enable smooth operations [54].

In the global context, hydropower has the largest potential amongst renewable power resources with generation already occurring in over 150 countries with total power harnessed using hydropower technologies amounting to over 3 329 TWh in 2009 [55]. This represents about 85% of the global renewable energy generation and about 16.5% of total electricity [56]. Apart from pumped storage hydropower input, about 956 GW capacity of hydropower was installed globally between 2009 and 2010 [55]. Estimated value of installed pumped storage hydropower capacity is about 150 GW [57] with an increase of 30 GW in hydropower capacity in 2010 alone [58]. Global increase of hydropower is about 5% per annum (this value varies from one country to another). Many countries electricity generation are close to 100% hydropower. For example, hydropower capacity in Norway is almost 100%; in 2009 it was 97% and in 2010 increased to 99%. Brazil‘s generation capacity is estimated to be about 84%, Venezuela 74% and South and Central America in general about 64%. Many African countries also operate power generation at 100% [55].

China‘s installed capacity has increased tremendously standing at about 210 GW in 2010. Overall, Asia has the largest percentage [57]. Total installed capacity in the US in 2010 was 78 GW excluding 20.5 GW from PSH capacities. China‘s 1.1 GW Nam Theun HP plant in Laos, 2.4 GW in Jin‘anqiao plant, 0.9 GW Foz do Chapeco plant in Brazil, 0.5 GW and 0.3 GW in Ethiopia are some of the largest hydropower projects to be concluded in 2010 [59]. Installed PSH in on the increase especially in countries where other RE sources are abundantly available to store energy for reuse on demand [55]. Most of these are in Europe, US, and Japan [55]. The year 2010 recorded a new installed global capacity of about 4 GW of PSH. As a result of the need for more generation through hydropower [57] gave 98 GW in 2005 to 136 GW in 2010.

Globally, 61 GW of SHP is installed [60]. This has been identified as a vital component in the future energy mix. Apart from generation of electricity, hydropower is a significant carbon emissions reduction technology. SHP installations are spread across many developed countries. Over 100 000 small micro hydro projects have been installed in China and Vietnam also recorded over 130 000 pico hydro projects [61]. The generated SHP energy is widely used for various activities which include rural residential and community lighting, media access, small scale enterprises, agricultural activities and grid base power supply. [61] reported that more than 50 million houses are being served through mini grids fed from small hydropower plants. Over 60 000 micro businesses are equally served by mini grids in which more than 48 000 MW is generated through SHP installations, geothermal, wind and bio-gas. In Lao‘s Peoplo Democratic Republic with over 26.5GW hydropower potential [47], over 100 000 small hydropower plant units have been installed [62], and all these form just about 2% of the country‘s potential [47].

Pico hydropower plants have been explored with impressive results in many countries especially of Southern Asia. The potential for pico hydro power technology in African nations is untapped, introduction of which can boost the economic strength of the country and at the same time enhance rural living patterns [63].

3.2 Regional Potentials

As at 2007 [3], an estimated 1.5 billion of the world‘s population do not have access to electricity. Distribution of electricity varies from one geographical location to another. In Africa, access to electricity is as low as 5% and not more than 20%, except Egypt and South Africa which exceed that. Hydropower accounted for about 32% of installed capacity in Africa in 2011. This accounts for about 7% of the continent's potential [55]. Growth of hydropower capacity can occur throgh installation of new generation plants, improvement in the efficiency of existing facilities, adding hydroelectricity capacity to existing water dams with suitable geographical locations, and building more PSH capacity.

The current installed capacity in Africa is about 147 GW [64]. Apart from South Africa, the average per capital consumption of electricity in sub-Sahara Africa is 153 kWh per annum. This figure amounts to one-quarter of that of India, and 6% of the world average rate. Reports show that about 600 million of Africa's population does not have access to electricity while many countries still regularly experience blackouts of various degrees, which is why [64] recommends an increase in power sector investment. The same report recommended an average of 250 GW capacity for Africa to meet demand by 2030 meaning increase of an average of 7 GW per annum [65]. Hydropower is rated the least costly of the renewable energy solutions today [35], [64]. This is followed by wind, biomass, geothermal and solar, which is the most expensive. Hydropower in Ethiopia and other East Africa countries has large potential. West Africa and Central Africa are reported to have potential for both large and small hydropower plants. Mini hydropower generation technologies are significantly able to supply rural electricity demand [66]. The portion of renewable energy would increase from 20% to 62% if adequate investment is in place.

[48] has developed a renewable energy power sector planning tool for regions in Africa, System Planning Test (SPLAT), which models the integration of every energy source within a region for maximum generation [66].

[54] investigated SHP for rural development in East African countries. The result of the investigation reveals that Burundi has about 15 sites suitable for SHP installations to generate about 3 MW in addition to the existing SHP sites. More than 56 new sites were discovered in Tanzania that can deliver up to 200 MW. Ethiopia has about 300 hydropower sites within eleven river basins. Abbay river basin, which is the largest in terms of hydropower potential, can generate up to 79 000 GWh annually which amounts to over 49% of the country's potential. In Uganda, 23 more sites able to deliver 54 MW when harnessed were discovered in the year 2005, most located along the Nile. 25 MW of this capacity is already installed [54]. In Rwanda, 51 small hydropower sites able to generate 3.4 MW are located between two river basins namely River Congo and River Nile. Table 3.1 lists potentials of hydropower in some other African countries.

Table 3.1: Hydropower overview in Southern Africa countries [67]

Country	Hydropower Installed capacity (MW)	Development Potential Available (MW)
Angola	291	12 000
DR-Congo	2 442	60 000
Lesotho	76	450
Malawi	245	600
Mozambique	2 184	12 500
Namibia	240	120
South Africa	2 267	17 667
Swaziland	62	200
Tanzania	396	3 000
Zambia	1 670	6 000
Zimbabwe	670	1 500
Total	10 642	113 890

3.3 Potentials in Southern Africa

Overviewing the potential of hydropower in some Southern African countries, the first on the list, Lesotho accounts for about 76 MW. The Muela large hydroelectric plant generates 72 MW [67] while the remaining capacity is supplied by a few SHP. [68] recently reported a potential of approximately 20 MW from 22 sites. Hydropwer contributes to about 99.7% of installed 2.308 GW electricity capacity in Mozambique. The rate of electricity distribution is about 14%; 26% is estimated to serve urban dwellers, while only 5% of the sub-urban population has access to electricity. SHP potential is about is 190 MW [67].

Over 80% of available electric power in Swaziland is supplied by South Africa while the other 20% is generated locally from hydropower technology. In total, the rate of electrification is only 27%; 4% in the rural area and about 40% in the urban centres. The average exploitable hydropower potential is estimated to be 110 MW and 8 MW could be available from small hydropower of any scale quantity [69]. About 57% of national electricity capacity is delivered by hydropower in Zimbabwe with an average of 40% distribution access to electricity nationwide although rural population access is about 19%.

Coal-fired power stations contribute up to 90% of South Africa‘s total electricity generation capacity [7]. Only 5% power is supplied by hydropower, including conventional and pumped storage schemes. The overall electrification rate is about 81% of which 63% serves the rural communities [67]. Seventy percent of the total electricity generated in sub-Sahara Africa comes from South Africa alone, which is why South Africa is the only country within the region to provide more that 50% of its population with electricity [55].

3.4 Publication 3: Smart Electricity Distribution for Sustainable Development in Southern Africa Sub-urban Settlements

SMART ELECTRICITY DISTRIBUTION FOR SUSTAINABLE DEVELOPMENT IN SOUTHERN AFRICA SUB-URBAN SETTLEMENTS

Samuel A.O. Ilupeju and Freddie L. Inambao
University of Kwa-Zulu Natal, Durban, South Africa

ABSTRACT

Energy availability is enormous, but the challenge of converting from its existing form to useful form in the form of electricity has to be addressed if power for all is going to be a reality. Majority of people in Africans live in rural areas using traditional biomass for cooking and live below 1 USD. Hydropower, wind power and solar power resources are adequately obtainable. An efficient harnessing technologies needs to be put in place to make electricity for all in Africa obtainable by having mini installations to serve local communities to overcome a number of socio-economic challenges posed by inadequate and or no power supply.

Generation of electricity from some RE sources such as wind and sunlight fluctuates as a result of the variability in resource volume available per time. The ability of the existing grid to support high levels of variable renewable generation is uncertain. This makes it difficult to maintain turbine frequency therefore destabilising electricity generation volume. A grid that will overcome the challenges of integrating more RE sources by ensuring reliability, safety, security, profitability and small private enterprises participation is needed. Intermittent nature and partially predictable availability of some renewable sources (wind, sun) pose a great challenge to balance energy production and consumption in real time, as required for grid stability. Smart grid is proposed as a tool to provide insight to policies maker, grid operators and end users for sustainable energy efficiency.

1. INTRODUCTION

Due to explosive world population growth rate, energy need has also skyrocketed, and being the backbone of every development, dependable and available quantity is required. In recent times, most homes now have electronics ranging from TV, radio, computer, tablets and phones in addition to necessary domestic power consumption which includes cooking, lighting, refrigeration, preservation and so on. Industrial and agricultural processes efficiencies are enhanced through the use of electricity. These activities require consumption of power. The current electricity situation in Africa calls for a serious attention. There is a great need to seek other available energy sources for sustainable economic and social growth. Majority of people in Africans live in rural areas using traditional biomass for cooking and live below 1 USD. One of the available solutions is maximum utilization of renewable energy sources. It requires an urgent need to raise the level of investment in its power sector through introducing favourable policies. Africa represents about 14% of the world's population whereas contributes only 4% of the global energy [1].

Conventional generation of power has much impact on the society, causing physical and environmental degradation, pollution (in many aspects). United Nations Framework Convention on Climate Change (UNFCCC) identified need for countries to undergo CO_2 mitigation strategies as part of efforts to address the climate change issues [1]. Two CO_2 emission reduction levels were imposed by Nigeria energy system which will reduce to 20% by 2030. There were introduction of technology options for the mitigation of CO_2 and these are demand-side management, increased gas-use, supply-side management, and increased use of renewable energy technologies [1]. To combat the menaces listed above, more emphasis has been placed on engaging green energy solutions in power generation. Renewable energy sources have proven record of reducing greenhouse emissions. Renewable energy sources are the primary energy sources in human history and they pose little or zero threat to human lives by avoiding the severe environmental impacts which fossil fuel energy contributes to the environment. Some of the renewable technologies draw power from the water, wind power and the Sun etc. These sources are abundantly distributed across the continent Africa (fig. 1 and fig.2), especially the Southern region and the three mentioned will the discussion of energy distribution in this paper. The most abundant, reliable and controllable source of all green sources is hydropower. The use of mini and micro-hydro power plants was injected into the Nigeria energy system as a positive step in achieving the vision 20% by 2030. A major natural impairment to renewable energy (RE) generation is climate, making it of great importance to closely consider the possibility of erratic climate change as a result of the global warming so as to avoid putting the sustainability of hydropower generation in question.

Why exploring RE? [2] gave an illustration on energy distribution that each m^2 of the earth's inhabitable surface is crossed by or accessible to an average energy flux of about 500 W available from solar and other RE sources. Assume that only 4 % is harnessed, it can supply about 2 kW per 10 by 10 m area. With an estimated population density of 500 people per km^2 in the suburban towns, consuming 2 kW per person, there will be total energy demand of 1000 kW/km^2. This volume is achievable by using just 5 % of the land for energy generation. It is then concluded that with proper harnessing methods at maximum efficiency, renewable energy will provide adequate and continuous quantity of energy for standard living.

Some of the reasons for renewable energy plant installation as identified by [3] include; firstly most sources from oil which is common in many parts of Africa as source of electricity are expensive bringing cost of power generation on the high side. Secondly, there is high carbon emission and lastly, fuel shortage also causes power interruption.

In an attempt to ensure base load is met at all times, hydropower, wind and solar photovoltaic (SPV) commonly available in all parts of Southern Africa are combined for either a standalone or a main grid feeding hybrid power system. This combination is to avoid the effect of the main natural impairment to renewable energy generation; climate, making it of great importance to closely consider the possibility of erratic climate change as a result of the global warming so as to avoid putting the sustainability of RE generation in jeopardy.

Voltage and frequency are the major parameters controlling power distribution in a network [4]. Most RE sources experience intermittency, bring about uncontrollable variability, unpredictability and location dependent output. Generation of electricity from some RE sources such as wind and sunlight fluctuates as a result of the variability in resource volume available per time. The ability of the existing grid to support high levels of variable renewable generation is uncertain. This makes it difficult to maintain turbine frequency therefore destabilising electricity generation volume. A grid that will overcome the challenges of integrating more RE sources by ensuring reliability, safety, security and profitability is needed.

Large dams are in many cases are environmentally unsustainable as it pose threats of environmental havoc, power site being located far away from existing grids, large HP's high cost intensity and long period of construction are some of the factors that prevent implementation of HP for rural power supply. Small scale plants have proved to be solutions to the disadvantages of large scale plants and greenhouse emissions. Most mini hydroelectric power plants work run-off river [3]. The author is presently working on maximising small hydro power generation by water reuse through pumped storage system. With cheap plant construction, environmental friendly configuration, possibility of independent and continuous power supply advantage. Mini power project has capacity ratio of 45 %, with an average plant cost if $1 800/kW making it most commonly adopted by private investors. Variation in equipment costs of micro and pico hydro scheme is very little [3]. Renewable electricity generating technologies typically have higher first costs and lower operating costs than fossil-fuelled generating technologies [5]. Since, hydropower, wind power and solar power are adequately obtainable, efficient harnessing technologies need to be put in place to make electricity for all in Africa a reality.

2. RENEWABLE SOURCES

2.1 RENEWABLE HYBRID SYSTEM

Combining two or more RE sources for either a standalone or grid feeding power generation is not a new technology. [6] designed pumping station for a pumped-storage wind-hydro power plant for optimum sizing and design of a pumping station unit in a hybrid wind-hydro plant. The design consists of a number of identical pumps operating in parallel with two other, using one variable-speed pumps or an additional set of smaller jockey pumps. The design is aimed at reducing the amount of the wind generated energy that cannot be transformed to hydraulic energy due to power operation limits of the pumps and the resulting step-wise operation of the pumping station. A simulated detailed economic analysis of the plant using dynamic algorithm evaluation was carried out on plant operation for a period of one year. Design variable included in the study includes, the number of the wind generators in the wind farm, the number and the size (nominal flow rate) of the pumps in the pumping station, and the turbine power. The basic concept used in the study was to explore rejected wind energy by hydro turbines of the system to produce the desired guaranteed electricity during the peak hours when the marginal production cost of the conventional power station is very high.

[7] also investigated the introduction of pumped storage systems in isolated power production systems for Crete and Rhodes isolated systems with high thermoelectric production and wind energy rejection. Investigations were conducted on four possibilities of power generation system for the study area from pumped storage upper and lower reservoirs possible alternatives. Two major considerations in introducing pumped storage system are for the maximisation of the wind energy penetration and the minimisation of the energy production cost. With the introduction of hydropower system, Crete yields to almost 10% annual electricity production cost reduction including overcoming annual wind energy rejection whereas in Rhodes, annual electricity production cost reduction reduced by 1.85%.

[8] designed a home energy management system that integrates the power resources from the traditional grid and renewable energy sources. The proposed system provides and manages a smart home energy requirement by installing renewable energy; and scheduling and arranging the power flow during peak and off-peak period. To optimize the energy flow and the consumption efficiency between the utility provider and the home owner, a two-way communication protocol was developed. The system was tested and the results showed that the integration of RES managed better smart home power consumption. Integrating the renewable energy source saved about 33% of the home energy bill [8].

2.2 RENEWABLE SOURCES INTEGRATION IN A SMART GRID.

As stated above that 5 % of the earth surface can generate enough energy for the whole world [2], it can be concluded that the challenge for low power generation is energy conversion related. Table 1 gives list of exploitable RE potentials in South Africa [9] described smart grid technology as the key to an efficient distribution and use of energy resources putting in mind the state of climate change the whole world is currently facing. Therefore, to efficiently integrate these power sources in a smart grid, there is need to explore the available quantity of these resources within the region.

Table 1: Renewable energy exploitable potentials in South Africa [10].

Technology	MW Distribution	MW 1st Phase	MW 2nd Phase	MW Last Phase
Onshore wind	1850.0 MW	634.0 MW	562.5 MW	653.5 MW
Solar photovoltaic	1450.0 MW	631.5 MW	417.1 MW	401.1 MW
Concentrated solar power	200.0 MW	150.0 MW	50.0 MW	0.0 MW
Small hydro (≤ 10MW)	75.0 MW	0.0 MW	14.3 MW	60.7 MW
Landfill gas	25.0 MW	0.0 MW	0.0 MW	25.0 MW
Biomass	12.5 MW	0.0 MW	0.0 MW	12.5 MW
Biogas	12.5 MW	0.0 MW	0.0 MW	12.5 MW
Total	**3625.0 MW**	**1415.5 MW**	**1043.9 MW**	**1165.6 MW**

RES majorly from hydropower, wind and solar photovoltaic have recorded great success over the years [11], this is because RE only, account for over 20 % world electricity production, 83 % of which attributed to hydropower [11] [12] [9]. Due to the necessity of smart grid, the University of KwaZulu Natal in collaboration with the largest producer of power in Africa ESKOM have established a centre for related studies. There is a wide room for new energy plant installation, especially in rural areas where there is little or no electricity supply.

2.3 SOLAR PHOTOVOLTAIC RESOURCE

Solar photovoltaic (SPV) system converts solar energy directly into electrical energy using semi-conductor base materials also called modules [9]. A lot of work has been done on this technology bringing about tremendous improvement because of distinct benefits, especially when there is the need to satisfy remote power demand. These benefits include; easy upgrade because of the modular panels, require no fuel, emission is zero, it can be used in isolation and can equally be connected to the grid and also produce no noise when working [3]. Photovoltaic (PV) modular capacity ranges from small PV system of 50 W to large grid connected Solar PV power plant of up to 50 MW. SPVs have high capacity ratio, which is the ratio of actual energy generated during a period relative to the maximum possible if the generator produced its rated output at all-time [10].

Fig. 1 reveals world solar resource, [13] gave an average of 7.0 – 8.5 kWh/m^2/day solar radiation availability in Africa.

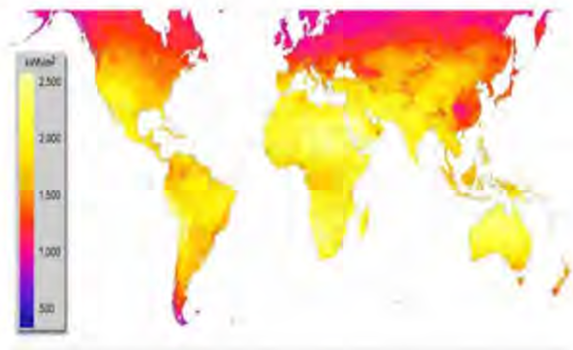

Figure. 1: Showing world solar radiation distribution [14].

Inability to have solar power all through the day or year makes it impossible to be used as the only power source, though the degree of unavailability is low. In a research where 30 years weather data of European annual demand curves were analysed on a 15-minute interval [15]. It was revealed from the analysis that 90% of the power supplied could come from renewable energy sources and that there is only a 0.4% chance that high demand correlates with low solar and wind generation. This disadvantage is to some extent curbed by the introduction of power storage equipment. SPV at the same time has been proved to be a sustainable, low technical skill and a pollution free technology for rural power supply [16]. When supported by wind and hydropower resources in locations where they are adequately available, a stable hybrid power plant is developed [17].

2.4 Wind Power Resource

Wind power emerged as one of the fastest growing energy source [18]. Where resource is abundant, hundreds of MW can be exploited through wind turbines. A small wind turbine configured with SPV will supply power to a village or district mini grid. Efficient blade design is one of the improvements to enhancing wind turbine reliability. Tubular tower designs minimise vibrations which will also reduce maintenance cost. Wind turbines offer a very advantageous cost-competitive solution for off- grid applications in rural areas. The cost of wind generated power is decreasing over the years and this trend is forecast to continue. The price of conventional energy sources, especially fossil fuels, is constantly rising, whereas the costs of small wind are showing a gradual decline, emphasising the attractiveness of these technologies. Reports by [19] proved costs will still reduce by about 20 % by 2015 [3].

Small wind can also be combined easily in hybrid systems with hydropower, solar or diesel, creating even more possibilities [20]. Wind – SPV hybrid will increase system reliability, this allows each energy source to supplement each other and it is an attractive arrangement for small loads especially on off grid and mini grid configuration [3]. It can be configured as AC mini grid with DC coupled component suitable for rural power supply. The second configuration is a modular AC system integrating SPV power input and battery for storage. This arrangement accommodates larger loads and an average life span of 20 years with a capacity factor of 30 %. The figure below reveals the distribution of world wind resource with abundance in Africa.

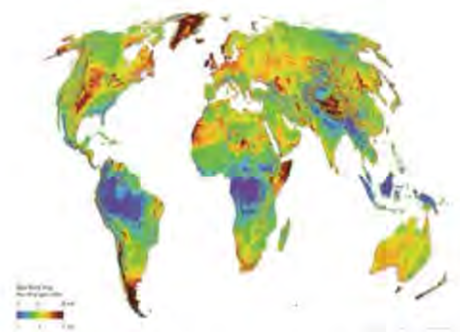

Figure 2: Showing world wind resource distribution [10].

2.5 SMALL HYDROPOWER RESOURCE OVERVIEW

Southern Africa countries are not left out in small hydro potentials; there are over 8000 potential sites for SHP in Kwa-Zulu Natal and Eastern Cape provinces of South Africa alone [12]. With great potentials in Zambia, installed SHP capacity is 62 MW [21]. Mozambique has the largest LHP installed capacity of 2500 MW but very little SHP installed capacity (0.1MW) [12]. In conventional hydropower system, water is released after running the turbines, which serves as a loss and gives no room for reuse. In a pumped storage technology, this scarce resource can be secured in the lower reservoir and later pumped into the upper reservoir. Many have worked on the application of pumped storage systems in maximizing power production to national grids through water transfer mechanism and efficient installation hydro power plant turbine. Below is the overview of hydropower potentials of some countries in Southern Africa, which more emphasis on small hydropower potentials.

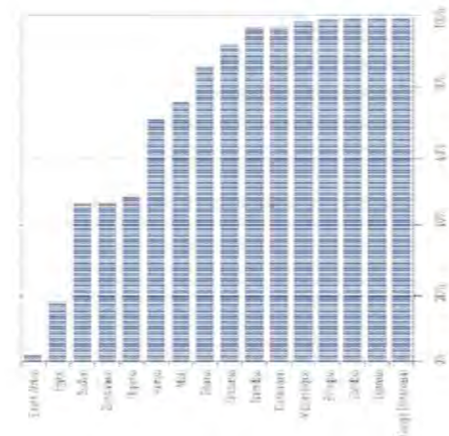

Figure. 3. Showing % contribution of HP to national electricity output in selected African countries.

Lesotho

Hydropower accounts for about 76 MW in Lesotho. LHP from Muela hydro plant generates 72 MW [22] while the remaining is supplied by a few SHP. [23] recently reported a potential of approximately 20 MW from 22 site [22].

Mozambique

HP contributes to about 99.7 % installed 2.308 GW electricity capacity in Mozambique. The electrification rate is only 14%, with an estimated 26% urban, while only 5 % of rural population has access to electricity. SHP potential is about is 190 MW [22].

South Africa

South Africa alone produces about 390 TWh of electricity with amounts to about 70 % of total generation in the sub-Sahara Africa [24]. About 90% of South Africa's electricity is generated in coal-fired power stations [25]. Only 5 % power is supplied by both hydroelectric and pumped storage schemes. The national electrification rate stands at 81 %, with rural areas covered for 63 % [22].

Swaziland

South Africa supplies 80% of Swaziland's electricity while the remaining 20% of the country electricity requirement is delivered by hydropower. Overall electrification rate is estimated at 27%, with 40 % urban and 4% rural areas. The country has an exploitable HP potential estimate of 110 MW and 8 MW of small hydropower from mini to micro scale [26].

Zimbabwe

In Zimbabwe, 57 % of national electricity capacity is delivered by hydropower. About 40 % have access to electricity nationwide while rural population is only 19 %.

3. MAJOR TECHNOLOGIES USED IN ENERGY GENERATION

To achieve maximum provision of economic and adequate power system, it is vital to efficiently manage the stage of energy conversion process by the use of applicable technology. It is a fact that the world population increases and material consumption depletes including fossil used in most conventional power generation plants bringing about increased cost of energy generation. There is great need to start maximising harnessing renewable energy sources available by combining two or more sources. One of the challenges of combining renewable sources is synchronisation of technologies that result due to reduction in availability per time. This also is a major challenge integration RE into main grid system. Most renewable energy sources availability is intermittent in nature resulting in frequency and voltage instability. Because of this, it is important for every power system to maintain frequency and voltage stability in generation due to renewable sources variability. In situation where many induction generators are involved in renewable energy especially wind and small hydro scheme, this instability is aggravated. Listed below are some of the generator types engaged in electricity generation mode.

Synchronous Generators
Power generation from the turbine normally produces mechanical energy through a rotating shaft which drives a generator that converts energy from mechanical to electrical form. The generator is usually a synchronous machine, rotating at constant speed to deliver an alternative current and voltage at a given standard frequency which depends on the country value.

Induction Generators
For relatively small power installations especially renewable energy sources like wind and small hydropower generators, asynchronous or induction generators are considered for production of energy from rotating machine. Induction generators have different characteristics from the synchronous generators…..when dealing with frequency and voltage control. One of the advantages of these generators is that they are considered more rugged, more reliable and cheaper than the equivalent synchronous machines.

Rotating DC Generators
DC generators are used for very low power in the range of a few dozen or hundred Watts. It is not considered for medium and large scale generation.

Photovoltaic generators
Photovoltaic (PV) generators are used in direct conversion of solar energy into electricity using solar panels. The actual voltage and current delivered by such panels depends factors including, the surface of the panel, its orientation, the incident solar radiation and also on the load. The output of such panels generates direct current (DC).

4. SMART GRID INTEGRATION CONFIGURATION

Electrical power system is to deliver energy in a reliable way from the production points to the end users [16]. Losses account for about 9 % of electricity produced worldwide as a result of transmission and distribution, cutting down supply in ordinary electrical grids [16]. Several researches show that losses due to distribution account for over 2/3 of the total delivery losses. The high losses in distribution is attributed to resistance losses in conductors are proportional to the square of the electric current [3]. Lower voltage translates distribution to higher current flow, making distribution system less efficient. For this reason, for rural energy production, consumption should be done within the region to avoid unnecessary waste of scarce energy. Smart grid ideas help reduce electricity generated global greenhouse gas emissions that account for 38 % of global energy sector emissions through the integration of renewable resources, substitution of electric for fossil energy in transportation, and increased end-use efficiency [27].
Utilization of renewable energy resources in smart grid system has been increasing [9]. This is accompanied with a significant number of programs and organs to establish its full implementation in various countries. RE is available and enormous either for domestic or industrial activities. Smart Grid integrates conventional electrical grid with the recent development of information and telecommunications technologies to improve the efficiency of power generations, transmissions, distributions and consumptions systems [28]. A unique feature of the smart grid is the integration of renewable and storage energy resources at the consumption end. The concept of smart grid has been implemented in electric power systems for successful transmission and distribution of electricity [9], indicating promising potentials useful for developers of renewable energy sources and policies making.
The issue of 'grid' either 'smart', 'mini', 'micro', or 'just' is basically for transmission and distribution of electric power from the producer to the consumers. There are many options involved in grid technology. [29] described various options a mini grid. The operator can connect its plant either as a small power producer SPPs or as a small power distributor SPDs. When an operator generates and supplies the main grid, SPP. If on the other hand buys from the grid and resell it to consumers using the existing distribution network, becoming a SPD. Also the operator can become both an SPP and an SPD. To avoids the acquisition of huge technical materials like transformers, lines, switchgears, towers etc. and minimise the cost of interconnection mini smart grids is the answer [29].
System management is enhanced, beginning from power generation whether large or small scale networked to transmission infrastructure, distribution of power to

consumers ranging from commercial to residential consumption purposes, and down into the equipment and systems that use electricity in these facilities.

Table 2. Compares summarily between Traditional Grid and Smart Grid [30].

TRADITIONAL GRID	SMART GRID
Centralized Generation	Distributed Generation
Electromechanical	Digital
Failures and Blackouts	Adaptive and Islanding
Lack of real time monitoring	Extensive real time monitoring
Slow Reaction time	Extremely quick reaction time
Manual Restoration	Self-healing
One way Communication	Two-way communication
No energy Storage	Energy Storage
Total control by Utility	Increased customer participation

5. RE EFFICIENCY IN LOAD BALANCING

Energy planning can be reviewed as a threefold structure consisting of the energy system, the system efficiency and the system management [2]. The complete energy system may be too difficult to analyse in the urban setting. Energy use should be considered as a function of the generation method. Some energy sources are not matched to end users than the other whereas in the grid supply, all sources are fed into the grid which is then used for particular activities leading to increased energy losses as a result of diversion into non-economic operations. The Sun gives primarily energy in two forms; heat and light. Domestic need of hot water does not need energy from fuel with efficiency of about 30 % converted to mechanical energy while about 60 % is lost to the environment as heat. Now, using part of the 30 % from fuel to heat water as an example is economically inefficient. This is one of the reasons why energy use should determine energy conversion method so as to minimise losses in achieving better system efficiency. This leads to the second aspect of energy planning. Efficiency is calculated as the ratio of useful energy output to the total energy input in a particular production process. Sources of energy, conversion technology as well as end use all contribute significantly to energy efficiency.

Energy management is embarked on to ensure that there is improved overall efficiency and reduced financial losses in energy consumption. It is obvious that renewable energy conversion technologies are usually more expensive, therefore energy waste should be reduced to the minimal. Energy management will then thrive well when the dynamics of energy supply and consumption is understood. Most time energy dynamics depends on the end user, whereas energy is now supplied to meet environment need. Average power demand is at peak in the morning and also in the evening, while at night it is minimal. This will help the supplier to plan how to manage supply situation at peak, which is the crucial part of the dynamics and is subject to energy source. One may not be able to quench coal from supplying at low demand, and energy generated which is not used is wasted except diverted to service other aspects like Pumped Storage system. Renewable energy is highly efficient in energy management, most especially when operated in hybrid technology.

As been established earlier, prominent characteristic of renewable energy sources is been environmentally regulated. Climate is beyond human control, it is unpredictable making renewable energy sources most time unreliable depending on method of harnessing engaged. Therefore as a result of this, the volume of energy from renewable sources differ from one location to another and how much of it available rest on how much of the source can be exploited. Conversion technique is also a function of the available resource. Each resource may be too little to satisfy energy need for immediate environment resulting in harnessing more resources to supply adequate energy to meet every activity. Energy conversion definitely gives us an idea of how much energy is available in a particular environment and for what purpose can the harnessed energy be implemented. Both factors will also put in place an economic platform to make the facility available to other users at an affordable price taking into consideration plant maintenance pay back.

6. CONCLUSIONS

RE resources are enough to provide needed electrical power to make life better, especially for people living in poor urban or rural areas in Southern Africa. When the resources are explored, it will result in economy boost in communities.

Renewable technologies can play increasingly important roles in providing reliable, affordable, low-cost power in Southern Africa.

Even though the initial investment costs for introducing renewable technologies into the power system are higher than that of fossil or nuclear; however, with smart grid managed RE, the no input material with the reduction in transmission and distribution investments far exceed the additional investment costs [31]. There is a ready market for the generated power. Right and enticing policies should be put in place for private investors to participate in the development of the projects. Above all these renewable energy sources are clean and available, environmentally, widespread and substantial. Therefore, smart grid is the answer to rural and standalone electricity distribution and should be embraced in Africa.

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8. AUTHORS

Principal Author:

Mr Samuel A.O. Ilupeju is a registered PhD student in Mechanical Engineering with the University of Kwa-Zulu Natal. He graduated from the University of Ibadan and the University of Ilorin both in Nigeria for his M.Sc. and B.Eng. degrees respectively. He is a member of Green Energy Solution group, working on the design of a continuous micro pumped storage hydropower plant for a small South African community.

ilurohun@yahoo.com

Co- Author: Dr Freddie Inambao holds a PhD in Technical Sciences from Volgograd State Technical University. He has worked for University of Zambia, University of Botswana, University of Durban Westville, and now at the University of KwaZulu-Natal as a Senior Lecturer following the merger. He has authored and co-authored over 50 technical papers, publications and presentations covering Alternative Energy Systems, Energy Management, Internal Combustion Engines, Fuels, Pumps and Thermodynamics.

inambaof@ukzn.ac.za

Presenter: The paper is presented by Mr Samuel.

3.5 Publication 4: A Review of Renewable Energy in Africa: The Relevance of Small Hydro-Power

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A Review of Renewable Energy in Africa: The Relevance of Small Hydro-Power

Freddie L. Inambao and Samuel A.O. Ilupeju
University of Kwa-Zulu Natal, Durban, South Africa
Email: inambaof@ukzn.ac.za ; ilurohun@yahoo.com .

Abstract
Africa is blessed with various resources to make it a giant continent but due to inadequate energy generation, exploring all the resources is not possible leading to inability to meet up to her full status. Hydropower is one the energy sources that is available, renewable and sustainable but has been neglected. Many researchers have reported the abundance of potential sites in Africa suitable for small hydro-utilization below 100 megawatts which can serve as isolated systems or supply national grids. Small hydro-power (SHP) generates clean and renewable electrical energy and is one of the most cost effective and environmental friendly energy generation technologies available. This paper reviews the distribution of hydro-power in Africa, its advantages, and some of the technologies involved in bringing power through SHP to all including rural dwellers.

Keywords
Renewable energy, hydro-power, small hydro-power, energy generation.

1. Introduction

The power sector is the backbone of every economy. Most national development schemes and plans are actualized on the platform of consistent, reliable, available and adequate power supply. Several methods can be utilised for generation of power including nuclear, fossil, wind, photo-voltaic, hydro, chemical, compressed air energy storage and many others. One or more methods can be combined to make a complete (isolated) power plant. For example, wind energy can be used to power a hydro-power generation plant. Power generated at a time needs to be consumed at the same time unless there is a way of storing it. Pumped Storage Hydro-power has become a major player in the power generation market because of its large quantity energy storage with wide spread facilities and robust technology. It has cogent advantages over other power generation methods in which renewability of the resource is most important.

The need for power in Africa is increasing and the potential for power generation is substantial, but much work needs to be done in order to fully explore and develop suitable methodologies.

1.1 Energy Need

Coal is the major supply input to many power generating stations in South Africa but depletion of coal stocks, poor coal quality, high maintenance levels, plant failure and inadequate reserve margin are some of the factors affecting power generation. Therefore, there is a need to explore other viable and available modes of power generation.

The South African government's Free Basic Electricity (FBE) policy was announced in 2000 but eventually kicked off in September 2004, to provide free basic electricity services to the poor. The policy provides about 50 kWh/m of electricity for lighting, water heating, ironing and media access (radio and television). This provision can not meet the listed need but small hydro-power (SHP) would go a long way in providing a continuous supply of adequate quantity of energy since there are over 8000 potential sites for SHP in Kwa-Zulu Natal and Eastern Cape provinces alone. A government commitment toward universal access to electricity by 2012 was made in 2004 by former President Thabo Mbeki. This would ensure that every household would have access to electricity by 2012 amounting to electrification of a minimum of 1.2 million household per year. In the year 2007, 575 000 households per year was the target with about R5 billion to R6 billion funding to achieve this.

[14] reported that in 2009 about 12 648 GWh was being exported to Southern Africa Development Countries (SADC) out of which Mozambique received 8243 GWh. In the same year 12 189 GWh was purchased by ESKOM. As part of government efforts to ensure adequate and continuous supply of electrical energy to every household, the Private Sector Participation (PSP) policy was introduced in 1998 which recommended that 30% of new generation capacity be developed by Independent Power Producers (IPPs). IPP's mandate is to increase generation of power from renewable energy sources, e.g. bio-gas, wind, solar and hydro [14]. However, renewable energy project is yet to be embraced with both hands by private investors. With such a rapid growth in social and economic development leading to increased power consumption, developing renewable energy technologies should be fast tracked. To account for power production, [14] reported that South Africa introduced a tariff system "Renewable Energy feed-in-Tariff" (REFIT). Guidelines have been provided for several renewable energy sources. Solar power with a storage capacity of six hours has a tariff allocation of R2.10/kWh. Wind is R1.25/kWh, small hydro is R0.94/kWh and land fill gas is R0.90/kWh.

Hydro-power (HP) generates clean and renewable electrical energy. Many countries have set targets to engage in more hydro-power generation. Spain committed a lot of measures to increase energy from renewable sources to 12% of total production by 2010 [12], [11] so as to combat the environmental menace imposed by carbon gas emissions. Spain instituted several organs to obtain greater power efficiency and alternative power generation sources, such as CIEMAT and IDAE. Between 1986 and 2001, Spain experienced rapid evolution in hydro-power with total accumulated power amounting to 1 607.3 MW, an average growth of 53 MW each year [11].

Hydro-power has come to stay in electrical power generation in the world as a renewable energy source. According to [12], in 2002 hydro-power both large and small contributed up to 19% of world electrical power. [10] predicts that the global demand for electrical energy will gradually rise and the growth for HP production is projected at 2.4% - 3.6% from 1990 to 2020. Small scale hydro-power (SHP) is considered to be one of the most cost effective and environmental friendly energy generation technologies available [12], in most cases just water running through a river without storage, or surface dam or at a given head. It is the most ideal small scale energy technology for isolated and/or rural community electrification in developing countries. SHP "run of river" schemes have minimal environmental impacts.

Small HP size definition varies from country to county so there is no standard upper or lower limit division. [12] proposed the following size definitions: Small HP 2.5 - 25 MW; Mini HP 500kW - 2 MW; Micro HP < 500kW; Pico HP < 5kW.

2. Status

According to [14] the abundance of coal resources in South Africa has been the main justification for engaging in coal fired power generation. Climate change, decline in coal quantity and the high cost of developing new coal mines are threats to the future availability of this resource. There have been several efforts to reduce the country's carbon emission. During the Copenhagen climate change talks in December 2009 South Africa announced that they would aim to reduce the country's carbon emission by at least 34% by 2020. Apart from carbon emission, another environmental hazard is increase in acid mine drainage cause by coal mining activities.

[14] reported a cost comparison of different energy sources in South Africa from present to future, specifically 2030. The overall cost will increase from R0.51/KWh - R1.66/KWh, with nuclear energy rising from R0.72/KWh - R1.76/KWh and open-cycle gas turbine (OCGT) will rising from R2.51/KWh - R4.23/KWh. The same research conducted on renewable energy sources shows that energy cost will reduce from R1.25/KWh - R0.89/KWh in that time period. Another advantage of renewable energy is the possibility of job creation which is greater than any other major method.

[12] stated that exploited HP potential was 2 650 TW/yr. Other renewable combined generated less

than 2% of global power need. North America and Europe are leading in terms of exploited hydro-potentials compared to other continents. About 40 GW of global consumption is generated by small hydro with China contributing 15 GW which is believed to reach 100 GW if fully exploited. About 18 GW is estimated to be generated from SHP. In Europe, HP provides 17% of electricity [12] with a target of 4.2 GW increase by 2010, being generated from over 120 HP sites and able to provide 100 MW capacity, spread over the continent.

2.1 Hydro-Technology

Energy in moving water is converted to electrical energy using a turbine and motor. The turbine converts hydraulic energy to mechanical energy through its rotating shaft while the motor converts mechanical energy to electrical energy. No matter the type of technology involved – either water from the river or stored in a reservoir with a suitable pressure head to provide adequate hydraulic energy – rushing water power is used to rotate the turbine based on the specifications of the turbine. For a conventional HP, water is conducted from the river through a weir. A weir is a human-made barrier [12] which maintains a continuous flow of water into the forebay which slows down the flow to filter out particles that can cause damage to turbines such as stones, litter and wood. Penstock, a sort of pressure pipe, is now used in leading filtered water from forebay to the turbine.

Power plant equipment selection is basically a function of the nature of the particular site characteristics. The head and the flow rate are the major factors while other factors include desired running speed of the generator and the ability of the turbine to generate power under reduced flow situations [12]. Turbine efficiency depends largely on speed, head and flow rate.

Turbines are classified as high heads, medium heads or low heads. Differentiating between various classifications of turbines can be difficult because head is commensurate to size of the turbine. A low head for a large turbine could be a high head for a small turbine. Another reason is turbine type also affects head, [12] e.g. a Pelton turbine for a 10 kW plant system may require a head of 50 m, whereas a 1 MW plant system requires a minimum head of 150 m.

Mathematically, turbine speed is inversely proportional to the square root of the head. About 1 500rpm of speed is required by the turbine shaft to generate electricity and minimize speed change in the turbine-generator system arrangement [12]. Therefore, faster turbines are required when a low head is needed. Turbines are further classified based on mode of operation as impulse or reaction type [12], [8]. In impulse turbines, water enters into the runners at atmospheric pressure. The jets of water drive the runners which operate in air. Reaction turbines in contrast have a rotor which is enclosed in a pressure casing fully immersed in water. The pressure difference across runner blades cause the runners to rotate. Pelton turbines are the major types of impulse turbine [8]. Turgo and Crossflow are also Impulse turbines [12]. Pelton turbines operate as a wheel with split buckets set around the rim and water hitting the wheel tangentially. Turgo turbines are similar to Pelton turbines in design but the water jets strike the plane of the runner at an angle of 20^o. Unlike Pelton turbines, interference of the incoming jet and the discharge fluid do not affect flow rate and also, with equivalent power, Turgo turbines can have a smaller runner diameter than Pelton turbines [12].

One of the main differences in reaction and impulse turbines is that the runners operate in a completely water filled casing. Reaction turbines have a diffuser, also called a 'draft tube', placed under the runner for water discharge. Before discharge, the draft tube slows the discharged water and in the process reduces static pressure below the runner bringing about more effective head. Kaplan and Francis are the major types of reaction turbines. [12] as well as Bulb [8].

The design of Reaction turbines is more sophisticated compared to Impulse turbines, especially in terms of profiled casing and blade arrangement, making them less viable in SH and MH projects [12]. Despite this disadvantage, reaction turbines work well under low pressure and that is why they are installed closer to where power is needed. They are less difficult to install and less time consuming to implement. The ability of a turbine system to retain efficiency at reduced flow plays a vital role in turbine selection. [12] reported that Pelton, Crossflow and Kaplan turbines maintain relatively high efficiency when operating below design flow while Francis turbines fail below half their design flow. Propeller turbines also perform poorly below 80% full flow.

The reliability of SH systems was greatly improved with the introduction of the Electronic Load Controller (ELC). The ELC is a system device that regulates system speed to ensure that voltage and frequency is balanced as electrical load varies all through. Power supply to national grids have load variation kept at a regulated frequency, normally between 50 – 60 Hz. Small hydro stations in many isolated locations in developing countries may not be connected to national grids leading to fluctuation in electrical loads of generated power resulting in equipment breakdown. An ELC helps to achieve regulated power in turbines when operating at design power by adjusting electrical output instead of water power input [12].

Researchers have established that high head hydro systems are most cost effective. [12] stated that the higher the load, the less water is needed for a particular power quantity, therefore smaller and cheaper equipment is suitable. High head hydro systems are low cost and can take advantage of small streams in mountainous environments which make them suitable for sparsely populated areas, although the produced power needs to be consumed within the environment as transmission over a long distance would require extra investment which would negate the low cost advantages of remote high head systems. However, low head hydro systems are most common for SH due to availability of suitable sites. [12] put the cost of a mini SH costs between $2500- $3000/kW.

2.2 Global Overview of Hydropower

HP projects throughout the world provide about 19% of world installed capacity. About 118 GW was under construction. This figure has revealed the HP is one of the most important RES for power generation. The SHP which range between 5 kW - 25 MW but up to 50 MW in China and Indian are said to have contributed about 47 GW to the global electricity generation, 25 GW of it generated in developing countries. China is leading with the deployment of SHP, followed by countries like India, Brazil, Peru, Malaysia and Pakistan. HP generation globally by 2008 was about 3 170.9 TWh with China generating 585.2 TW/h which is about 18.5% of world production. Other countries of significant contribution to HP are Canada, Brazil, US and Russia [14]. [14] reported that ESKOM has a total net maximum capacity of 40 503 MW. Globally, [10] reports ongoing hydropower development projects at about 100 000 MW with 84 000 MW coming from Asia. South America contributes 14 800 MW, Africa 2 403 MW, Europe 2211 MW, North & Central America 1 236 MW [3]. [2] put globally installed capacity of SHP around 50 000 MW against the estimated potential of 180 000 MW. Small hydro is attracting worldwide attention as a result of its short period of construction, reduced financial commitment and simplicity of the technology. It is indeed a feasible solution to the growing demand for rural electrification programmes in Africa.

Deployment of SHP is spread across many developed countries with a number of mini, micro and pico projects that supply electrical power for domestic and essential purposes to thousands of households. Over 100 000 small micro hydro projects have been installed in China [16]. Vietnam also recorded over 130 000 pico hydro projects. The generated SHP energy is widely used for various activities which include rural residential and community lighting, media access, small scale enterprises, agricultural activities and grid base power supply. [16] reported that more than 50 million households are served by small hydro scale mini grids. Up to 60 000 small scale business enterprises are served by small hydro mini grids and over 48 000 MW is generated from mostly SHP, geothermal, wind and bio-gas.

Pico hydro power technology allows a small river or stream to generate electricity of up to 5 kW. This system has been explored successfully in countries of South-Eastern Asia. Many African countries have many untapped geographical potential for pico hydro power technology which can boost the economic strength of the country and improve living standards of rural dwellers [15].

[15] reported that Uganda is among the countries in Sub-Saharan Africa with the lowest electrification rates. Only 6 % of the total population have access to electricity, and depend on fuel generating sets, car batteries and solar PV systems to achieve a minimum level of electricity supply. About six pico hydro power sites have been developed in Uganda, Gwere (500 W) which serves 72 homesteads, Okabi (450 - 750 W depending on the river flow) which serves 98 homesteads and Menyar (500 W), is an

entirely community-based project serving serving 94 homesteads, and Manafwa, a household-based project.

2.3 Africa Overview of Hydropower

There is high potential for SHP in Africa. This is of great importance as the economy of the continent is dependent on development of stable power generation. A good number of organizations are looking into identifying various potentials in Africa as encouragement to African economic advancement. Some countries in Africa have been identified as potential SHP providers, namely, Kenya, Uganda, South Africa, Nigeria, Mozambique, Zambia and Rwanda [16].

[4] conducted a survey in five East African countries to estimate SHP potentials in the region. The countries are Kenya, Uganda, Tanzania, Rwanda and Burundi. Kenya has a few existing installed SHP plants managed by KenGen producing about 60 MW and 7 private tea factories run SHP with a total estimated capacity of about 1.6 MW. Uganda has hydrological resources potentially able to produce electricity power of over 2 500 MW. While large hydropower sites mainly concentrated along the Nile River can generate 2 000 MW, small hydro scattered in many parts of the country of the 0.5 - 5.0 MW generation range can make up the 500 MW balance [4]. In Tanzania, it is estimated that there exists about 300 MW of small scale hydro power potential in total scattered around the country. The remote isolated population depends greatly on expensive imported diesel to meet up with power requirements. Investment in SHP in the area is great and open to private investors [4]. Rwanda has identified and quantified more than 259 sites that can be restored or equipped for SHP. In Burundi, 99% of the country's utility comes from HP. There is still more room for further development especially in micro, mini and small hydropower capacity [4]. Preliminary estimates measure the Nile River's hydroelectric potential at 8 000 MW, and Uganda's hydroelectric potential along the Victoria Nile River at nearly 2 000 MW.

2.3.1 North Africa

Most of the potential in North Africa (Algeria, Egypt, Libya, Morocco and Tunisia) has already been tapped and the majority of the installed capacity is along the Nile River.

In terms of large hydropower development, Algeria, Libya and Tunisia are poorly developed. Egypt is reported to have installed capacities of 2 810 MW while Morocco has installed capacity of 1 205 MW [10].

2.3.2 Southern Africa

This region (Botswana, Lesotho, Madagascar, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe) has so far exploited about 60% of its HP potential. Mozambique has the largest LHP installed capacity of 2500 MW but very little SHP installed capacity (0.1MW). Zambia is second to Mozambique in terms of hydro potentials due to the Zambezi and Kariba Rivers and has developed 30% of it. With all the potential in Zambia, installed SHP capacity is 62 MW [10]. SHP potential is yet to be explored fully in South Africa as most of the hydro system plants are LHP, both conventional and pumped storage type. The first pumped storage hydropower plant in South Africa is the Drakensberg Pumped Storage Scheme commissioned in 1982 with a generating capability of about 1 200 MW. The Palmiet Pumped Storage Scheme is the second and can generate 400 MW during peak demand periods and began commercial operation in 1988. The ongoing Ingula Pumped Storage Scheme can generate 1 332 MW which is scheduled for completion in 2014. The Ingula scheme is located 23km north-east of Van Reenen, within the little Drakensberg mountain range. The machine hall houses four pump-turbines which will generate at a rated head of 441 m. The Lima Pumped Storage Scheme is located near Roossenekal in the Limpopo province with 1500 MW capacity and a head of 636 m earmarked for completion in 2014 [6].

2.3.3 East Africa

This region has the second largest potential in Africa, having about 20% of its capacity developed. Countries in the region include Burundi, Kenya, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Somalia, Sudan, Tanzania and Uganda. In order to respond to the energy challenges, the region created the Eastern Africa Power Pool in 2005 to exploit the existing potential [10]. Ethiopia has developed about 80 MW of SHP installed. Uganda has a population of about 25 million. [16] reported that the country has great potential for developing hydro resources for power generation. With 320 MW hydro plants installed, the SHP ratio is about 16.7 MW. [16] also revealed that added to the initial identified potential sites in Uganda, 71 more rivers were also discovered that can serve mini HP able to deliver up to 200 MW. All these potentials are non-Nile sites within the country. Uganda has a vast hydropower potential of over 3000 MW with less than 10% already exploited [1]. There is need for private investors to explore the potentials as power market in Uganda has been open for private sector participation. [16] reported two plants of 5.1 MW and 1.5 MW were built and operational which is been handled by private investors. Only 9% of the population had access to electricity in 2009 but as at 2011 about 3% of rural people and 42% of urban people have access to electricity. Almost 95% of population use traditional solid fuels in residential sector for heating, light and cooking [1].

2.3.4 West Africa

The West Africa region has installed capacity of about 25% of total African capacity, with Nigeria and Ghana being the biggest LHP contributors. Although there is high potential in countries such as Nigeria and Ghana SHP contribution to power development is relatively small in the whole of West Africa. [10] attributed the low HP developmental status in the region to reasons such as high initial cost, unavailability of hydrological data, insufficient knowledge in SHP development, inadequate support from government policies, awareness of environmental concerns [10].

[5], [7] reported that SHP potential sites exist in virtually all parts of Nigeria, where 278 unexploited sites have been identified with total potentials of 740 MW and the potential overall is estimated to reach 3 500 MW. Eight small hydropower stations with aggregate capacity of 37.0 MW have been installed in Nigeria by private companies and the government [17]. These are distributed around Jos Plateau, where there is a 2 MW Station at Kwall falls on N'Gell river (river Kaduna) and an 8 MW station at Kurra falls which was developed by a private company (NESCO) more than 75 years ago.

Small hydro potential for Nigeria has been assessed at 824 MW, of which only 4% has been exploited. About 40% of the population have access to electricity, 82% of which are urban dwellers while 10% are in rural areas [13].

2.3.5 Central Africa

The countries of this region are Angola, Cameroun, Central African Republic, Chad, Congo, Democratic Republic of Congo, Gabon, Equatorial Guinea and Sao Tome & Principe. The region has the greatest hydropower potential in Africa, most of which is concentrated around the Congo basin. HP potential is about 419 000 MW with installed capacity at around 3 816 MW for large HP and the Democratic Republic of Congo contributes the greatest. Only 1% of its potential capacity is exploited and SHP is poorly developed in the Central Region just like the other four regions [10].

2.4 Challenges associated with Hydropower installation in Africa

Installation of HP plants is by far under-developed in Africa compared to available potentials. Some of the reasons contributing to this social menace are listed below as reported by [10].

(1) Lack of infrastructure in the design and manufacture of turbines, installation and operation.
(2) Lack of access to appropriate technologies pico, micro, mini and small hydropower. This can be overcome by networking, sharing of best practices and information dissemination through forums and conferences.
(3) Lack of local capacity (local skills and know how) in developing SHP projects. There is the need for technical assistance in the planning, development and implementation.
(4) Lack of information about potential sites (hydrological data).
(5) Lack of SHP awareness, incentives and motivation.
(6) Lack of private sector participation in SHP development.
(7) Lack of joint venture (public and private sector partnership).

3. Tables

Table. 1 Economic Hydropower Potential by Continent and % Exploitation [9].

Region	Economic Hydro Potential	% Exploitation
Africa	12%	8
Asia	45%	25
Europe	10%	75
North & Central America	13%	75
South America	20%	30

Table 2: Some Small Hydro Potential sites in Surveyed States in Nigeria [17].

S/N	State	River Basin	Total Sites	Potential Capacity (MW)
1.	Sokoto	Sokoto-Rima	22	30.6
2.	Katsina	Sokoto-Rima	11	8.0
3.	Niger	Niger	30	117.6
4.	Kaduna	Niger	19	59.2
5.	Kwara	Niger	12	38.8
6.	Kano	Hadeja-Jama'are	28	46.2
7.	Borno	Chad	29	20.8
8.	Bauchi	Upper-Benue	20	42.6
9.	Gongola	Upper-Benue	38	162.7
10	Plateau	Lower-Benue	32	110.4
11	Benue	Lower-Benue	19	69.2
12	Cross River	Cross River	18	28.1

4. Conclusion

With the saturation of the market for HP facilities in developed countries, HP vendors have a great market in Africa.

1. Small HP has been identified as a major source for providing adequate electricity in developing countries either through conventional or pumped storage technology.

2. A large percentage of SHP potential is untapped, which is a loss to society.

3. There is a need to involve private investors to participate in the development of the resources.

4. The resources are enormous enough to provide needed electrical power to make life better especially for people living in poor urban or rural areas in Africa.

5. There will be an economy boost in developing these resources.

6. There is a ready market for generated power, as policies are on ground to encourage investors to explore hydro projects.

7. Hydro power is a renewable energy source which is clean and available. Water is not consumed in the process of power generation.

8. It is an environmentally friendly means of power generation, widespread and substantial.

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CHAPTER 4 : PUMPED STORAGE HYDROPWER (PSH) PLANT REVIEW

4.0 Introduction

Pumped storage systems takes advantage of hydraulic technologies requiring two reservoirs of different height in converting energy stored in water into needed energy, mostly electricity [70]. The upper reservoir is used to store water in periods of low consumption which is released to convert the potential energy into electricity using a hydro turbine (Figure 4.1). This review will analyse some aspects of the technology necessary in this research work.

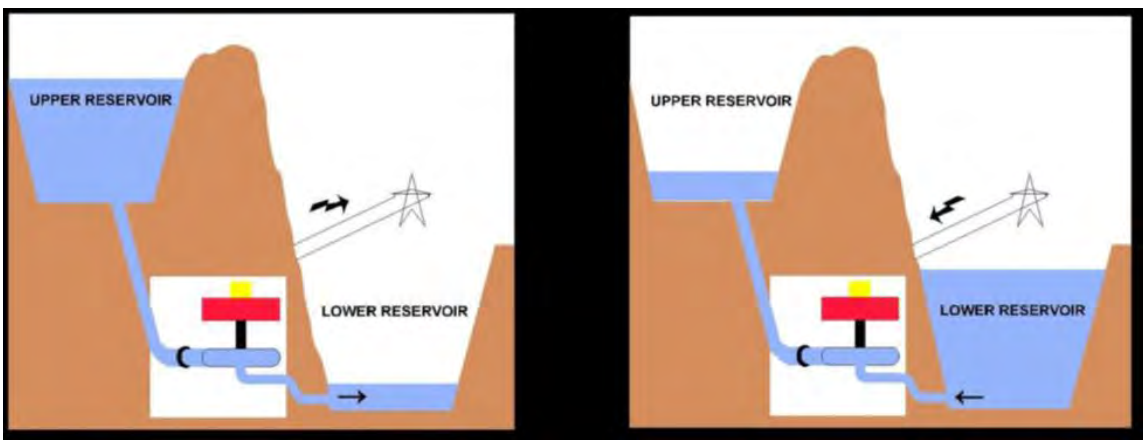

Figure 4.1: Schematic diagram of a typical pumped storage hydropower plant

4.1 Overview of Pumped Storage Hydropower Plants

The first Pumped Storage Hydropower (PSH) plant in South Africa is the *Drakensberg* pumped storage scheme commissioned in 1982 with a generating capability of about 1 200 MW. *Palmiet* Pumped Storage Scheme is the second and can generate 400 MW during peak demand periods and began commercial operation in 1988. The ongoing *Ingula* Pumped Storage Scheme can generate 1 332 MW, which is scheduled for completion in 2014. The *Ingula* hydropower plant scheme is 23 km north-east of Van Reenen, not far from Drakensberg range. The plant houses four pump-turbines which will generate at a rated head of 441 m. The *Lima* scheme is located near Roossenekal in the Limpopo province with 1 500 MW capacity and a head of 636 m earmarked for completion in 2014 [6].

The majority of pumped storage plant schemes are installed in Europe with Germany top the list of PSH operators with over 23 plants with capacity varying from 62.5 MW to over 1 000 MW [15]. In terms of installed capacity, Germany is second to Spain with 14 PSH plants with sizes ranging from 65 MW to 745 MW. About five major PSH plants are operational in Portugal all having a mean generation capacity of 160 MW. Pump-back type is the prevailing PSH operating method engaged in Portugal and Spain which plays a vital role in irrigation and flood control. The ‗Dinorwig' with capacity of 1 782 MW was largest PSH the largest PSH plant in Europe and achieves full load from spinning in less than 20 s [15]. In 1987, EDF plant was commissioned with a capacity of 1 800 MW in the French Alps.

It is reported that, more pumped storage plants have been installed in the USA and Japan [15]. The same report gave the number of installed PSH, each operating between 8 MW to 2 000 MW installed capacities in the United States as 39. Helms' 543 m head, 1 050 MW pumped storage hydropower works is the highest head plant in the States. Another plant is situated on the Tennessee River with 1 530 MW capacity, which is the largest managed by Tennessee Valley Authority [15].

[15] reported that out of the major pumped storage plants in the USA whose installed capacity is greater than 100 MW, 17 plants are purely pumped storage facilities, operating daily. There are other 12 plants which have facilities for big energy storage capacity to pump back on weekly and seasonal rounds. The overall average of PSH in the USA is 520 MW. [71] reported that there are hundreds of PHS stations operating with total capacity of 127 GW worldwide out of which Japan currently has the largest pumped storage hydropower capacity in the world. Japan capacity is on the rise, 34 PSH majors plants generate up to 24 575 MW [15] originally to back-up nuclear power plants. These pumped storage plants operate daily with large MW return for up to 5 to 10 hours operational time. PSH installations in Japan are between 200 MW to 1 932 MW, it equally takes a bigger ratio in total input to Japan electricity generation than the input of USA to total national production. [8].

4.2 Hybrid Pumped Storage Hydropower Systems

[72] released a briefing paper on the status of renewable energy in Europe which confirms hydropower as the main renewable energy source in the continent. Countries are accepting the technology because of its

abilities to efficiently work as a reversible turbine, that is serves as a pump when in pumping mode and at the same time serve as turbine during generation mode. This is though not the case for all sites, as some use full turbine and pump separately. This can easily release electricity within a few minutes as energy demand rises. The briefing categorically stated that without involving hydropower; conventionally and also PSH, meeting 35% of RES-electricity by 2020 will be impossible in the EU.

[73] worked on theoretical settings involved in hybrid plant of photovoltaic (PV) and hydropower energy system useful for reliable and sustainable energy supply. The duo discovered that intermittent nature of generation from PV is a great challenge in maintaining continuous energy use because availability varies with time of the day and climatic conditions, therefore is not able to provide continuous generation. They combined a PV with pumped storage source to give a more sustainable hybrid plant to continuously ensure generation of power. In their research, PV was regarded as the main source of power while PSH generates at controlled rate at a time of no PV. This application widely fits in various physical, climatic and hydrological conditions, therefore makes its application rewarding.

A computer program that can be used to locate PSH most appropriate potential sites and location benefits was developed [74]. The developed program was then used in evaluating a distance of 20 km to 40 km area. To analyse site challenges, the developed model ‗triangulated irregular network' was used. It was discovered that the developed programme was able to identify pumped storage potential sites. Within the area of its application, five suitable locations were found within 800 km^2 of research field in Ireland, with 710 MW to 979 MW approximated electricity capacity with a storage value of 8 634 MWh. The conclusion of research is that the program is able to identify new PHS sites.

The renewable generation goal in many countries has extended to increase electricity generation and reducing GHG emissions. PSH plants are capable of providing the required flexibility. [75] proposed an output planning model which describes an efficient technology arrangement that provides massive storage facility with capacity to deliver peak load demand and at the same time prompt in nature with pollution in the form of GHG emissions in mind. The technology; pumped storage system is best proposed. The European Union [76], specifically marked out a definite goal to increase the portion of domestic electricity consumption using renewable energy options by 20% before 2020. In the US, about 29 States have come up with policies to increase renewable energy portion. Pumped storage hydropower has a record of over 300 sites with global installed capacity of over 95 GW [77]. Addition of pumps and more turbines to existing hydropower plants can be implemented to significantly increase generation capacity due to limited availability of new potentials [74, 78]. Also, the option of compressed air energy storage was given attention for the purpose of alternative energy contribution. [79] came out with the fact that in the United States, the average efficiency of recent PHS plants is 0.74. Transmission losses in BES system is much lower, the efficiency value of compressed air energy storage and that of PHS fall in the same range, but PHS has the lowest emissions content value.

4.3 Isolated Hybrid Hydropower Plants

Basically in a hybrid power generation scenario, excess energy from the primary energy source is used to store water at a suitable height to be used by hydro turbines to produce according to demand, extra electricity during peak hours. This stored power is released when the cost of power generation is highest. In situations where the unused energy from wind is enough or higher that the capacity of the pump, when the upper reservoir is filled to capacity, the excess wind energy is diverted to execute low priority loads [29]. On the other hand, it is possible to have low water levels in the upper reservoir, thereby being unable to generate expected local grid energy delivery requirement If this happens, the PHS system absorbs "cheap" energy from the grid which is used when consumption is low. [29] analysed the diversion of unused wind energy to enhance generation by pumping water in a reservoir for PSH generation during peak demand time in addition to the generating capacity of the existing stations. [22] applying the developed energy model was able to increase RES contribution by 15%, thereby enhancing the energy requirement on the island by 25%.

[80] conducted a research in which a pumped storage system powered by wind was designed and proposed for an isolated islands of Karpathos and Kasos, situated in the Greek peninsula. It is aimed to maximise wind energy input which will also minimise importation of petroleum fuel for electricity generation. It consists of hybrid plant of wind powered PSH to guarantee electricity generation for certain hours per day. They thoroughly examined three different sites suitable for the pumped storage system installation before the optimum is selected based on topographical features of the area and the available space invariably reducing construction work and cost. Penstock connects the upper reservoir with the existing sea used as the lower reservoir as the system was designed to utilise seawater for operation. With the design, annual electricity consumption will exceed 23% in the Island by 2014. Careful location siting of the system results in efficient set-up cost, environmental benefits, and capacity enhancement.

[80] faced the task of siting a pumped storage plant in Kasos island in a way to balance and improve power production in the two islands for system stability. Seawater was used because the needed water quantity requirement for system operations could not be met. Apart from siting the location of the proposed point, physical visit is of high relevance in choosing the most suitable. The team that investigated siting of the Island of Kasos plant consists of geologists, hydro-geologists, mechanical, civil engineers and other relevant disciplines because of the multifaceted nature of the construction and the interconnectivity of various fields of expertise. The evaluation of the proposed sites was based on the site features and design parameters [80] such as:

i. Topographic and soil conditions.
ii. The head available.
iii. Penstock length between the two reservoirs.
iv. Space available for construction.
v. Access road or path.

4.4 Optimisation

The optimisation system is of high importance because of the interaction between parameters. Hydropower operation of any hydro unit basically produces nominal output power values at the expense of the possibility of maximum working performance. Hydropower working variables; the head and the flow rate usually vary with specific operation. Another variable that needs to be optimized in hydro unit operation is systems efficiency (turbine, pump and generator). Optimisation depends on what the operation aims to optimise. This can be in terms of optimising for low cost, high power demands, reservoir capacity and management. Figure 4.2 shows an optimised conventional large hydropower plant.

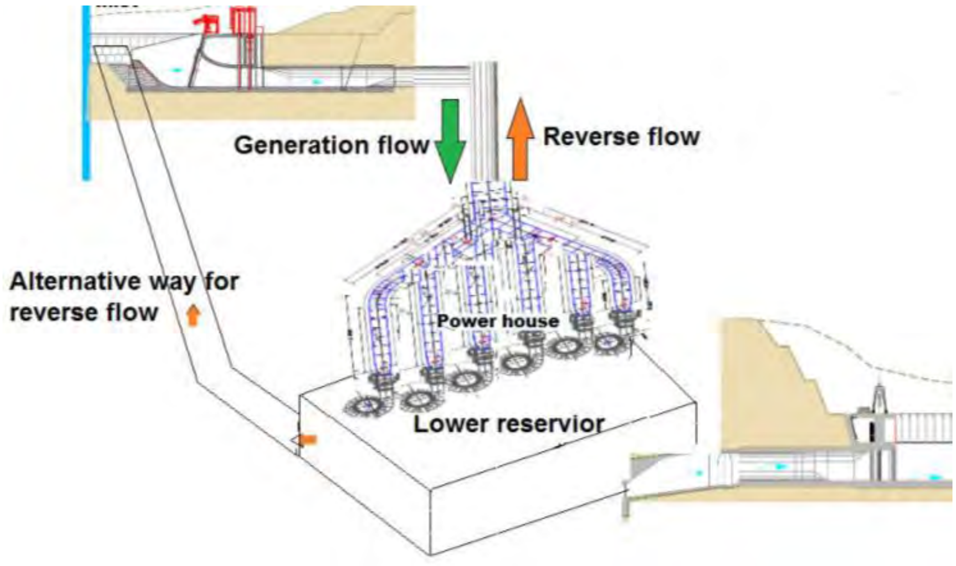

Figure 4.2: Optimization of a Pumped Storage Hydro- Power (PSH) plant [81]

Optimisation in hydropower begins with determining the required size at which pumped storage hydropower reservoir work. Plant planners need to decide system capacity in terms of technical components dimensions. Most PSH designs are identified based on hydrological and environmental topography. Existing hydropower plants or dams may be upgraded into a PSH; likewise both reservoirs may be human made. Categories of PSH depend on whether the proposed plant is a mixed, pumped storage hydropower plant in which the system is made of one natural flow or pure pumped storage hydropower plants which does not include a natural flow. Operation of the two types basically depends on installed capacity in pumping mode and in turbining mode as well as the storage capacity of both lower and upper reservoir structures which will give us the exact period of operation at full capacity.

PSH plants are originally designed to provide adequate electricity at the time of high electricity demand. It balances the grid for demand driven fluctuations as well as generation-driven fluctuations by providing a wide range of grid-stabilising services. This system operates on daily and weekly cycles as water is released from the upper reservoir through the turbines for electricity generation. Generation duration depends on the capacity of the reservoir as well as the length of peak demand time. PSH can be used to optimise the operation of the conventional hydropower plant because it is pumped during periods of low cost while generation is done when the demand is high which also results in a high financial value of electricity. A distinguishing characteristic of PSH is that there is no natural inflow into the upper reservoir. The nominal size of the PSH plant depends absolutely on the amount of energy needed to be produced in order to stabilize the supply of electricity.

In every energy storage system, it is observed that there is a need to consider plant storage in MWh and the Power rating in MW. It is quite important to also consider the financial viability, transmission line capacity, base load and the peak load in designing a particular plant. For the pump storage to be feasible (deciding the capacity of reservoirs) you should have at least 400 m head difference.

The need for power in Africa is increasing and the potential for power generation is substantial. Solar and wind sources are not adequately engaged in Africa, though the duo cannot be relied upon as they are highly unpredictable, but for a sustainable energy policy, having an energy storage system is a role to resolve urgently and adequately. PSH has been identified as the only reliable solution. Designing a PSH plant is a function of site selection.

[81] listed seven factors needed in siting a PSH site:

i. Potential capacity.
ii. Location from main demand and generating centres.
iii. Water availability.
iv. Head condition.
v. Accessibility.
vi. Costs.
vii. Multi-purpose potential.

CHAPTER 5 : HYDRO-ELECTRICITY TECHNIQUES AND COMPONENTS

5.0 Introduction

One of the advantages of research is improvement of hydro system efficiency, production output, electricity availability and improvement of health quality through reduction of environmental pollution and degradation. In the next 30 years world water use is likely to increase by 50% [82]. Water quality is directly linked with preservation of lives. Good water vitalizes the human body and does not damage hydropower equipment which is advantageous to Life Cycle Assessment (LCA). This is a call to maximize water use at all cost. Most of the time efficiency is enhanced by the choice of appropriate technology and plant components.

5.1 Small Hydro-Power System Generation Component Overview

[46] worked on standardising every aspect of civil works in the development of a typical high-head SHP. [46] indicates that there are more than 17 400 SHP installed in Europe and the number of such plants in Switzerland is about 1 100, with total installed capacity of about 750 MW. [46] worked on standardising every aspect of civil works in the development of a typical high-head SHP. An optimization tool ‗POPHEYE' was developed in the course of the research which allows a step by step design and optimization for evaluation of different alternatives for SHPs according to the layout, head and discharge. Through this research [46] was able to select an optimum design discharge for the project by means of these economic parameters.

The function of design discharge of the SHP was finally used to get a result of the economic analysis of the plant in terms of the production cost, net benefit and economic efficiency.

5.2 Water Intake and Sand Trapping

SHP intake location depends on several factors which are geographic in nature. Some of these are identified by [46] as submergence, geotechnical conditions, environmental considerations, sediment exclusion and ice formation where necessary. It should be placed strategically to ensure an adequate quantity of water is captured into the plant. Structures which will help in the performance of the intake include trash-rack and position of intake. [46] described three methods of sand trapping, namely; Bieri flushing, Dufour sand trap and Buchi flushing systems. The Bieri type of desander flushes sediments which settle in a settling basin. In the Bieri flushing method, volume of sand deposit, number of flushing intervals, slide opening, and duration of flushing time can be regulated through a control system. The operation of the Dufour sediment trap is described as a continuous sluicing of the sediment deposits by means of openings in the chamber bottom through which the sediment together with a certain amount of water enters a channel with a flushing gate at its downstream end [46]. For Buchi type, the flushing channel is not apart as it is in the Bieri system, therefore flushing of sediment can be achieved by periodic draw down from the chamber. Any of these structures can be put in place to enhance intake into the penstock. This research will not go into water diversion engineering details from the river source but from the intake of the penstock, therefore these geographical factors will not be considered in the design of the plant system.

5.3 Penstock Material

The choice of penstock material depends on the operational pressure, the nature of the environment and financial buoyancy. A suitable pipe diameter is recommended to prevent losses and pressure drop in the pipe system. A small diameter result in increased losses in the pipe as water flows [83]. Steel is the most used pipe material because of the material strength and minimum flow losses. The pipe thickness is selected to withstand flow pressure. The equation is given below [46].

$$t = \frac{D \,.\, P_{max}}{2 \,.\, \sigma_t} \qquad (5.1)$$

σ_t = admissible stress of steel (235 *10^6 N/m^2)
t = wall thickness of penstock (m)

The pipe could be surface lay or buried, but in SHP, due to factors around the plant system, buried is most times a good option though the choice comes with extra construction and financial commitment. Buried type serves as support to the pipe.

5.4 Design Criteria for Headrace

Another component of a hydropower system is the headrace. It conveys water from the settling basin and feeds into the penstock with or without a forebay. The headrace may be an open canal, buried canal or buried pipe with free or pressurised flow. Materials used in construction could be concrete as used in Figure 5.1 or PVC, bearing in mind that headrace systems should perform their functions efficiently with minimum maintenance, ease of operation and minimum head losses.

Figure 5.1: Example of open headrace canal [20]

In the design of a headrace, it is important to adapt it to the natural configuration of the slopes and the topographic conditions. From the research conducted and discharges studied by [46], canal slopes between 0.1% and 0.4% are considered optimal. The optimum hydraulic section for a rectangular canal is obtained when the width is about two times the water depth. Therefore, it is appropriate for headrace to have a rectangular cross section which will also encourage easy construction and maintenance. Flow in headrace is recommended not to exceed 2.0 m/s to 2.5 m/s while a minimum velocity of about 0.6 m/s has to be considered in order to avoid sediment settling in the headrace canal [46], [84]. Table 5.1 listed some of the main components parameters of a typical hydropower plant.

Table 5.1: Main characteristics of installed turbine and generator [3]

Description	Characteristic values
Powerhouse location	On ground surface
Number of units	4 units(equal capacity)
Turbine type	Vertical Francis
Turbine rated speed	600 rpm
Net head of the turbine	297 m
Maximum turbine discharge	15 m^3/s
Generator type	3-phase synchronous
Generator related speed	600 rpm
Generator Installed capacity	153 MW
Annual firm energy production	434 GWH
Annual average energy production	543 GWH

5.5 Flow in a Pump

The three important characteristics of a pump system that need to be considered in the design are pressure, friction and flow. Pressure is expressed as the force responsible for the flow of the fluid measured in Pascal. Friction also is the force that resists the smooth flow of fluid in a vessel [85]. Flow is the quantity of a fluid displaced per unit time. As a result of friction, losses are experienced in the system which is described as a decrease in pressure in the system as a result of friction.

Pressure, head, friction and velocity are the four forms of energy in pump systems. Head, pressure and velocity pressures interact with each other in liquids [86]. Pressure energy is the energy generated when particles in a liquid or gas particles interact as they move close to one another.

Head energy is the energy available to a liquid as a result of been placed at a certain height, making it an important parameter to be considered in electricity production as far as a hydro-turbine is concerned [86].

Friction energy describes the energy that is lost in a system as a result of forces against movement of a liquid through pipes and system fittings. Friction occurs in a fluid as it moves through a pipe in two ways. Firtsly, friction is generated between fluid layers in a pipe as they travel with different velocities. Secondly, friction is caused by the interaction of the pipe wall with the fluid [85]. The degree of roughness of the wall of the container determines the friction value. For instance the higher the wall roughness, the higher the friction value; according to this, it is expected that fluid velocity is higher at the centre than at the walls [86].

Friction depends on parameters whose increase results in increased friction value, such as the viscosity of the fluid, which is also the resistance to flow of a fluid in a pipe or container, and the pipe surface roughness and the speed of flow in the pipe. It should be noted that friction will increase with a positive change in the identified factors [86].

To achieve delivery at the required flow rate, a pump is designed to supply the needed quantity of energy to overcome total losses in the system attributed to friction. When the value of frictional losses is too high, there is a need to review pipe diameter size – an increase in diameter size may normalise the friction value. In a system like this, the friction value should remain minimal [85]. Apart from losses in the pipes, which is the main aspect, other fittings like elbows, joints (expansion and contraction), valves, inlets and outlets all form point of losses. Most of the time, losses at the fittings are not significant except in cases of multiple fittings.

Velocity energy is the energy in moving objects or fluid. It is important to note that a certain number of variables determine how you define a system [85]. In this model a number of parameters are involved in defining the state of the system and these include head, site location, flow, materials in design, velocity and so on. A hydropower plant design is flexible and the precise requirement needed to specify the nature of a particular hydro-plant depends on the size, location, generation sources and distribution pattern to be established [85]. Conclusively:

Pump energy = Friction energy + Head energy

5.6 Losses

High levels of technical and non-technical losses have been identified at the level of electricity consumption. Some generation sources do not efficiently handle energy conversion techniques. We need a secure and reliable supply of power at all times so as not to give room to interruption which is a common phenomenon in developing nations especially in sub-Sahara Africa. There is a need for energy efficiency both in generation and consumption. This definitely has a lot to do with identifying power sources and also usage. One of the generation options that balances this need is hydropower.

Some sources of losses in a hydropower plant are due to [81]:

i. Efficiency of the generator.
ii. Efficiency of the turbine.
iii. Flow in the pipes.
iv. Change in climate; high evaporation due hot weather.
v. Leakage in the pipe system.
vi. Other river use purposes.

5.7 Temperature Effect on Flow

Mass flow m = $\rho \cdot Q$

where

ρ: Density

m: Mass flow rate

Q: Volumetric flow rate.

The mass flow of water decreases as density decreases. Water density and viscosity decrease as the temperature increases. So for a given mass flow rate, the following are true:

i. The volumetric flow rate and average velocity will increase as temperature increases.
ii. The head loss/ frictional pressure drop will decrease.

This can be established because water is most dense at 4ºC [87]; the value of change in volume per degree change in temperature is insignificant. Hot water flowing down a pipe to a cooler end at a steady temperature will experience a variation in density, but the density of the fluid at any point will be constant. This makes the volumetric flow rates independent of density at any point of flow because whatever volume that enters a pipe leaves the exit except when there is a leak in the pipe.

This is explained by examining the chemical dynamics of water. There is an adequate internal energy that resists crystallization in flowing water because the collision of molecules of water against the container wall, river-bed and against one another keeps them above freezing temperatures per time. Water is a unique substance, also because of the super-cooling effect which makes it remain liquid even at extreme temperatures. Another possible reason for low temperature not affecting flow is that there are three types of energy at work in flowing water. Firstly, the kinetic energy in the system due to vibration of water molecules held together by hydrogen bonding. The kinetic energy in the moving water molecules is still great enough to overcome the lockdown of hydrogen bonding, and therefore it still exists as a liquid because freezing point, in temperature, decreases with increasing kinetic energy. Secondly, the chemical potential energy stored in the bonds is decreased by dipole interactions, and lastly the potential energy from its position relative to the earth. When water falls down a hill, the initial potential energy before the fall will decrease while increasing the kinetic energy.

The working temperature of the operating fluid in this research is within the range of environmental temperature, which is believed not to have a tangible effect on the volumetric flow rate. This is supported by the fact that even at a temperature of 0ºC, rivers still flow in winter.

5.8 Density Effect on Pumps

The useful mechanical energy exerted on a liquid, for example water being pumped, can be described in terms the required head which is totally dependent on the weight of the liquid to be pumped as in this case water from the lower reservoir to the upper one [88]. Pumping activity is carried out to the head required irrespective of the flow, which makes it independent of the density. Density is a vital parameter in determining pump power consumption. The required head of the pump is a function of the rate of flow of the system [89].

In cases where the suction pipe length is short, experience has revealed that pipes with similar cross-sectional area can be used for both suction and delivery pipes provided the velocity of fluid is suitable [88]. For suction lines that are long with valves and bends, it is technically appropriate to use a suction pipe that is a size larger than the delivery pipe so as to minimise pressure drop in the system [88], [90].

5.8.0 Introduction to Pumps

A pump is a mechanical devicefor the displacement of fluid from one point to another. Categories of pumps are many depending on which author is consulted and on the applications. [91] categorised types of pumps as positive displacement pumps, rotodynamic (Centrifugal) pumps and miscellaneous pumps.There are numerous types of pumps used today for many activities and it is the responsibility of the plant design engineer to carefully consider selection of the most appropriate pump to fit a clear design purpose. The applications of pumps cut across several uses such as medical (artificial heart), water cooling industries and water pumping activities. In the selection of hydro pump for a particular technical operation, some factors need to be put into proper consideration. These factors include, amongst others [92]:

i. Speed of the pump.
ii. Working pressure of the system.
iii. Characteristics of the fluid to be pumped.
iv. The size and price of the pump.
v. Operation temperature.
vi. Pump life expectancy.

In the selection of a hydro pump for particular technical operation, some factors need to be be carefully considered [92]. These factors include:

i. Speed of the pump.
ii. Working pressure of the system.
iii. Characteristics of the fluid to be pumped; operation temperature, size and prices of the pump, life cycle assessment and so on.

For example, the speed of a pump is directly proportional to the displacement [93]. Also, the volume of the fluid displaced per time is largely dependent on the number of revolutions per time period. Let us have these two scenarios, a small pump with a high number of revolutions and a large pump operating at a low number of revolutions per time period. The delivery after a specific period may be close. The cost of a pump is usually a function of the size [92]. Having a small pump operating at a high revolution will drastically reduce the cost of the pump [18]. It can be said that the more the revolutions per time period, the smaller the size and invariably the less the cost of the pump. The fundamental principle is that because of inertia and centrifugal force, as one increases the pump size, the speed of revolution reduces.

Two side effects of operating a pump at the highest acceleration are cavitation and abnormal drop in pressure [92]. Cavitation will eventually minimise the design life expectancy by of the pump [94]. Pumping highly viscous fluid may result in cavitation due to the increased pressure required to move the fluid as it is charging through the pipe.

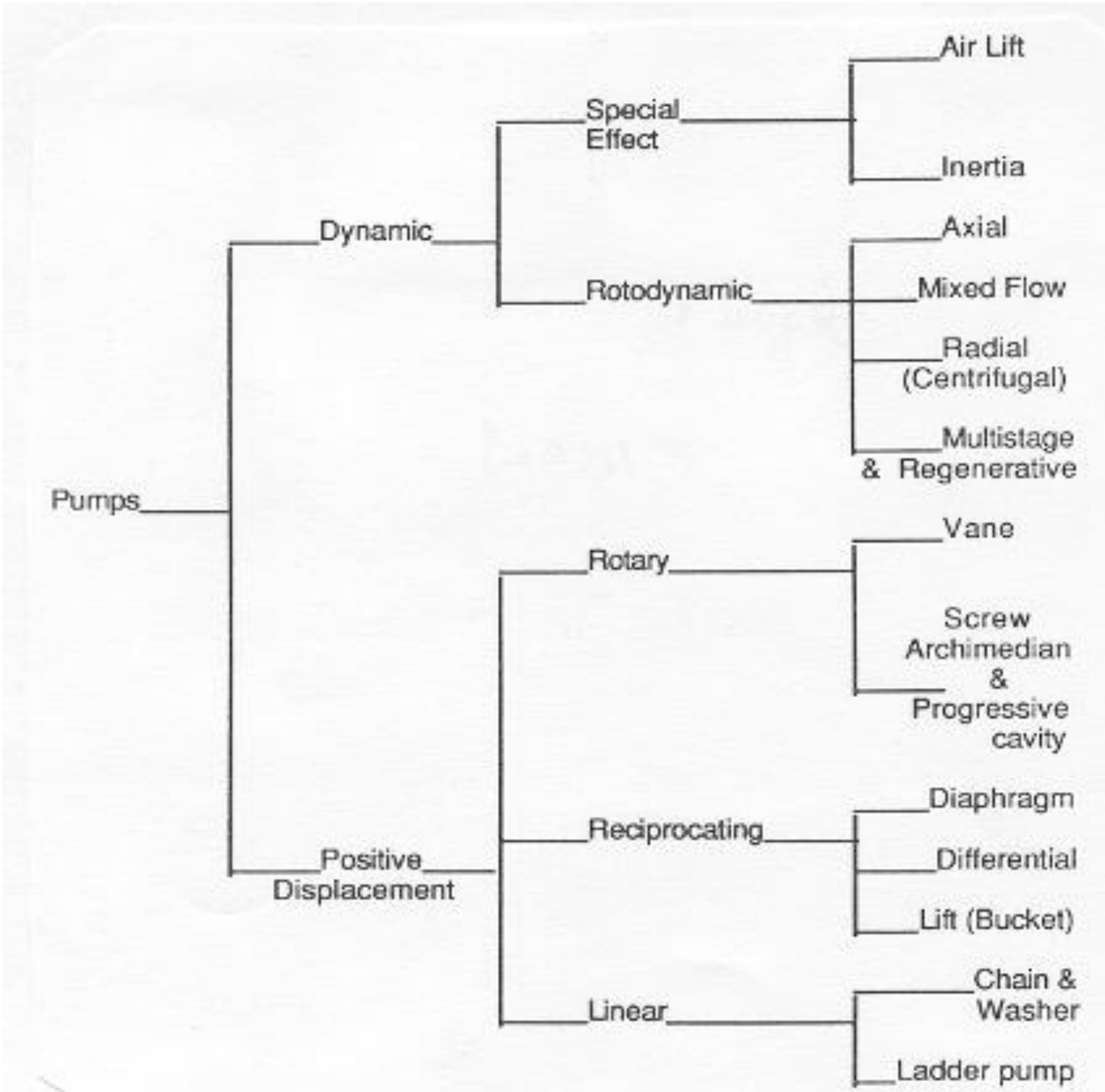

Figure 5.2: Types of pumps [95]

5.8.1 Pumps for Pumped Storage Hydro-Power Plants

[95] classifies pumps as kinetic pumps and positive displacement pumps. Kinetic pumps can be grouped as radial flow types, axial flow types and the mixed flow types. This type of pump operates by allowing fluid to be lifted into the pump via the impeller and released by the vanes after converting the kinetic energy with the use of the rotating impeller to a more useful static pressure. Centrifugal pumps, which is our focus in this work, falls under radial flow pumps [96]. A centrifugal pump also operates at high flow

rate and a low increase in pressure. In addition to the rate of flow and the required head, pump operation power is used in the selection processes [83], [97]. The least limit head needed in the suction pipe or line to ensure cavitation [95]; [91] eradicated in the pumping system is called the net positive suction head required ($NPSH_R$).

This study will be designed based on three basic pump design parameters, namely:

i. Heads;
ii. Discharge;
iii. Design Power.

Likewise pump selection review is accomplished by considering to details of these three [98]. Flow rate, head, viscosity, pressure and density are classified as primary parameters in pump selection [93]. Viscosity of a fluid is the property that explains the resistance to flow through a medium. The higher the viscosity the more difficult it is to move the fluid. Viscous liquids tend to increase pump power, increase pipe friction value, reduce efficiency, reduce capacity and also the head.

Pump capacity is determined by the discharge [18], [99]-[100]. The head is a function of the density and the viscosity of the working fluid. These conditions now contribute to consideration of material and energy balance in the flow rate determination [93].

5.8.2 Net Positive Suction Head (NPSH)

NPSH forms a significant parameter in the determination of the capacity of a pump and can be considered as available ($NPSH_A$) or as required ($NPSH_R$). All the potential head losses occurring in the pump between intake and the impeller to ensure that the fluid does not drop to less than its vapour pressure count in computing ($NPSH_R$) value. $NPSH_R$ is usually less than $NPSH_A$ by adjusting the static head and friction losses [93] through:

i. Raising the elevation of the source point;
ii. Lowering the elevation of the pump inlet;
iii. Raising the level of fluid in the suction vessel;
iv. Increasing the diameter of the pump suction and delivery pipes;
v. Reducing the length of the suction and deliver pipes.

$NPSH_R$ value can be reduced by engaging some of the following options [93]:

i. Using a larger and slower-speed pump.
ii. Mounting a double-suction impeller.
iii. Using a larger impeller inlet (eye) area.
iv. Installation of an inducer and an oversized pump.

5.8.3 Running pumps in Series or Parallel

A series or parallel pump system pattern is normally introduced in cases of a high-head or high-flow pump operations. A series pump pattern is when the heads are summated and the resulting combined capacity is equal to that of the pump having the least capacity [101]. In a parallel pump system, the capacity of each pump in the system is added, also where flows recombine, the pump head will be equal [93]. Pumps in parallel are implemented often in fluid handling due to reduced cost of operation because the similar head advantage prevents operational challenges [102]. To compensate for the varying capacity factor or existing plant size increase, installation of two smaller pumps may cost less than installing a larger one [99].

5.8.4 Pump Operation and Control

High and low level switches are engaged in controlling pumping operation when the level of the water in the reservoir is either low or high [93]. When the volume is high in the reservoir, pumping operation starts while at low level it stops. This is installed to prevent damage to the pump as a result of continuous switching on and off [103]. A variable-speed pump is sometimes used to control operation speed so as to achieve varying pump capacity determined by system curve analysis. This totally avoids problems as a result of pumps working below required minimum criteria. A continuous flow is employed in small pumps to relieve pressure gain from the pump while a controlled flow is generally introduced in high capacity systems in which using a continuous flow would result in higher operating costs or the selection of a larger pump [93].

Some hints by [7] are listed which are of great relevance to maximising application of a parallel pump arrangement system. Continuous usage of a parallel pumping system in multiple pump operation most times results in substantial energy savings [18]. This was illustrated by comparing two pumps frequently operated together to a single pump. Though parallel pump placement increases flow rate, increased friction losses can lead to a higher discharge pressure, and reduced flow rate and efficiency because more energy is needed to lift a given fluid volume.

A greater flow rate is obtainable by a parallel pump arrangement combined to a static head arrangement. Parallel pumps are arranged so as to operate efficiently the number of pumps required to meet variable flow rate operations [104]. A proposed design practice is to implement parallel pumps from the level of Best Efficiency Point (BEP) at minimum flow rate to the maximum flow rate left of BEP. The idea is to allow the pumps to have the highest achievable operating efficiency of the overall flow rate when matched with the time profile. [104] noted that dissimilar pumps may be installed in parallel as long as the pumps have similar shutoff head characteristics and/or are not operated together continuously unless provision is made to prevent shutdown of the system.

The BEP is the point where highest efficiency value in a pump sysem is obtained [105]. The most stable point in a pump system is near to or at the BEP [93].

5.8.5 Applications of Pumps

In conclusion, the flexibility of parallel pumps is preferred when operating in static head-dominated systems rather than in friction-dominated systems which is why prospective pump system engineers are encouraged to use a single pump with capacity to meet system requirements rather than operating two pumps in parallel [94]. The choice still depends on quantity of energy consumed which is applicable to certain periods of the day or demand charges [96]. There is a need to check quantity of energy consumed by multiple pumps compared to the amount consumed by a single pump with adjustable speed drive control. It is of great advantage to choose multiple pumps with head-versus-capacity performance curves that rise at a constant rate when these pumps approach no-flow or shutoff head. There are high performance centrifugal pumps designed for high-head/low-capacity, used in process industries that have ―drooping” pump performance curves [106]-[107]. They are capable of supplying peak pressure at a certain flow rate, and the pumping head decreases in approaching no-flow conditions.

[108] worked on design considerations for Hydronic Pump System. Hydronic Pumps are water pumps for fresh/raw water supply, process heat exchangers/boilers, cooling and chilled water systems, heating and steam systems, wastewater treatment and drainage. Basically, they transfer water from the source to the

required destination. A good example and one that is similar to the work is filling a high level reservoir. Adequate pressure is required to make the liquid flow at the expected rate, which must overcome head ‗losses‘ in the system to achieve purpose. Losses can be static or friction head, but most systems combine both static and friction head. Centrifugal pumps are the most common of many types of pumps available and are in different categories according to function. There are single or double suction, in line or base mounted, close or flexible coupled and vertical turbine pumps. Though in many applications more than one pump design could be engaged, the listed criteria will help in making the right choices [108]:

Heads are classified according to their application. A few of those relevant to this design are the following:

i. Static Head: Static head is simply the difference in elevations of the outlet and the inlet point of the system or the height of the supply and destination reservoirs. The static head is known as the potential energy of the system and is independent of flow and pipe diameter.
ii. Friction Head. This is the energy loss due to resistance to fluid movement and is proportional to the square of the flow rate, pipe diameter and viscosity.
iii. Discharge Head. This is the vertical distance that the liquid is able to be pumped.
iv. Dynamic Head. This includes the dynamic discharge head plus dynamic suction lift or minus dynamic suction head into one computation.
v. Total Head. The difference between the head at the discharge and the head at the inlet of the pump. It is sum of discharge head, suction lift and friction loss. The Total Head produced by a pump is independent of the nature of the liquid (i.e. specific gravity or density) as is the head in any part of the system.
vi. Velocity Head. The head needed to accelerate the liquid. Knowing the velocity of the liquid, the velocity head loss can be calculated by a simple formula: Head = $V^2/2\ g$ in which g is acceleration due to gravity. The velocity head difference is proportional to the difference in kinetic energy between the inlet and outlet of the system.

5.8.7 Consequences of Improper Pump Selection

Selecting a pump that is either too large or too small can reduce system performance [96]. Using a smaller size pump may result in inadequate flow because it fails to meet system requirements [109]. On the other hand, oversized pumps, while providing sufficient flow, can incur higher purchase costs for pump and motor assembly and also higher energy costs [98], because oversized pumps operate less efficiently and definitely increase maintenance requirements due to operating further from their BEP resulting in greater stress [94].

5.8.8 Performance Curve

A performance curve relates total head with flow rate for a specific impeller diameter on a graph beginning from zero flow. The head at this point corresponds to the ―shut-off head" of the pump [93]. The curve then decreases to a point where the flow is maximum and the head minimum [97]. This point is sometimes called the ―run-out point". Beyond this, the pump cannot operate. The pump's range of operation is from shut off head point to run out point. In general [93]:

- High Head = Lower Flow
- Low Head = High Flow
- Low Flow = Lower output power
- High Flow = High output power

5.8.9 Multiple Pump Configurations

Parallel pump configuration is always employed to handle wide variations in flow when considering multiple pumps [83]. This arrangement allows pumps to be energised and de-energised to meet system needs. One way to arrange pumps in parallel is to use two or more pumps of the same type [18]. Alternatively, pumps with different flow rates can be installed in parallel and configured such that the small pump – often referred to as the ‗pony pump' – operates during normal conditions while the larger pump operates during periods of high demand [101].

As a generality, the larger the pump the higher the efficiency [18]. While it is true that large pumps offer higher efficiency, don't be misguided by this generic statement. It will almost always be true that a smaller pump matched to the system will operate at lower cost-even though its efficiency as a pump is lower. Magnetically driven pumps may also need to be treated differently because a change of impeller diameter affects only the hydraulic power. Mechanical power loss in the drive is independent of diameter and so if the speed is unchanged the magnetic losses will not change.

5.9 Turbine for Pumped Storage Hydro-Power Plants

5.9.1 Introduction to Turbines

[110] describes a typical hydraulic turbines as being a machine which converts hydraulic energy in water into mechanical energy at the turbine shaft as water is released from a specific height to drive the blades of the turbine.

5.9.2 Evolution of Turbines Types

The use of turbines in hydropower is not a new thing, even though development in the area is blooming daily. History has revealed that implementing water wheels to do work began with China and Egypt which who used Undershot wheels. Power is generated as a function of the speed of water that flows beneath the wheel buckets [111]. Undershot was overthrown by a new development called Overshots, in which water drives the wheel bucket through the top channel. The third development was Breast wheels where the driving water and the buckets run at the same height level.

As energy generation requirements increased , turbine technology came in. Engineer Fourneyron developed the first turbine in 1827 which generates as water flows into the turbine runner radially. Another English engineer, Francis, invented the Francis turbine as an improvement on the Fourneyron. In the Francis turbine, water enters and flows through the runner radially but exits axially [111]. Pelton, an American engineer, designed another turbine type which till today requires the highest hydraulic heads of all turbines. Water jets out through a nozzle to the runner under atmospheric situation. In 1913, Kaplan developed a propeller turbine with blades rigidly attached to the runner which operates perfectly at minimum heads [111]. Further developments on important component are birthing turbines with better economic operations and efficiencies [112].

5.9.3 Classification of Turbines

The approach of conversion of energy by the turbine differentiates the two categories of hydro turbine available today [111]. These two categories are discussed below.

5.9.3.1 Characteristics of Impulse Turbines

The conversion of energy process in impulse turbines operates based on impulses generated in the system. When a force is applied on an object (say water) for a period of time, impulses are generated which increases the speed of the water as it moves in the direction of the applied force. The impulse forces generated due to movement of water channelled through the buckets converts water energy to useful mechanical energy. The principle is simple; water is injected from the turbine nozzle at a very high pressure, flows through the runner from the nozzle to the rotor blade at atmospheric pressure and finally exits the blade with the same pressure. Another name for impulse turbines is partial turbines and the commonest type of impulse turbine is the Pelton turbine [111].

5.9.3.2 Characteristics of Reaction Turbines

Reaction turbines draw mechanical energy from potential energy and the kinetic energy from water which is available through transfer from the runner blades to the turbine shaft [113]. Two major aspects are necessary in energy conversion by turbines of useful mechanical energy from falling water. These are the impulse aspect and the reaction aspect. Pressure drops as water flows through into the runner exit due to the runners being full of water. The impulse force aspect transfers impulse forces through canals between blades of the runner thereby bringing a change to vector velocity due to the difference in pressure between the jet pressure and the atmospheric pressure. Francis, Bulb and Kaplan are examples of turbines in the reaction categories and are also known to be full turbines [111].

5.9.4 Types of Turbines

The choice of turbine for specific site allocation is highly dependent on their hydrodynamic properties and by the ability to accomplish the expected purpose of installation. Figure 5.2 identifies different types of turbines and their application for specific plant size.

5.9.4.1 Pelton

Pelton turbine design is majorly determined by flow rate, head and rotational speed [111]. Pelton turbines are usually arranged in a horizontal or a vertical shaft. Horizontal Pelton turbines are common in small and medium turbine sizes with one or two jets. Vertical shaft arrangement is primarily for large Pelton turbines with many jets symmetrically distributed around the runner [111]. The runner design may be monocast in which disc and buckets are cast in one piece, but more common in modern power plants of higher power and bigger sizes is disc and bucket cast in separate pieces. Materials used in runner and buckets are considered based on the head factor, stresses and sand portion in water, while cast iron, cast steel or weldable steel alloy are some of the material used in manufacturing the components. In addition to the listed factors, for systems with large head, cavitation, sand erosion and fatigue as a result of continuous generation activity are considered in design [111].

5.9.4.2 Francis

There are two types of Francis turbines arrangements which are the horizontal shaft and the vertical shaft [111]. Horizontal shafts arrangements are used in Francis turbines with small capacity and dimension. Water flows from the supply penstock in an axial direction through the scroll casing into the tail race canal. In vertical shaft Francis turbines water enters into the turbine through the gate valve into the runner and out through the tail race tunnel. It is used in large turbine arrangements where units are built up in an underground cavern directing water into the vertical chamber of the turbine. The main components include Guide vane cascade, Shaft seal, Draft tube and others. The runner in most cases is made of stainless steel [111].

5.9.4.3 Kaplan

Kaplan turbines are employed for low heads and large discharges for the following reasons:

i. Small dimensions.
ii. High speed of rotation.
iii. Average progressively increasing efficiency curve.
iv. Suitable for maximum loading ability.

Water flows axially through the runners made of only a few blades radially positioned on the hub. The slight curvature in the runner blades reduces losses by creating a high flow velocity resulting in better efficiency. The small runner diameter makes its rotational speed more than two times higher than that of the Francis turbine of corresponding head and discharge. Some of the main components are; runner vanes, crown, guide vane cascade, guide vanes, scroll casing, axial-thrust bearing, turbine shaft, generator shaft and so on [111].

5.9.4.4 Bulb

Bulb turbines are used for the lowest possible head designs. The major parts of a bulb turbine are stay cone and rotating parts [111]. Bulb is so named due to the type of arrangement in the system, in which all turbine components are in a bulb-like structure [114]. It is a type of Kaplan turbine (reaction turbine) with components of the turbine housed in a bulb

5.9.4.5 Axial Turbines

Axial turbines are suitable for low head plants with head ranging between 2 m and 40 m. These turbines operate with a runner composed of blades as a modified Kaplan turbine [46].

5.9.4.6 Propeller Turbines

In a propeller turbine mostly with three to six blades, water strikes all of the blades with the same intensity. The blades pitch are fixed or adjustable. Main components of propeller turbines are a scroll case, wicket gates, and a draft tube. They can reach very high rotation speeds in a short time which makes them very effective for low heads. Propeller turbines are suitable for run-of-river power stations and there are several different types of propeller turbines [115].

5.9.4.7 Cross-Flow Turbines

Another name for this turbine is Banki-Michell turbine. It is a form of impulse turbine for a wide range of application covering that of Pelton, Kaplan and Francis characteristics. Suitable head of operation is between 5 m and 200 m. It relevant in SHP because of suitable height and high efficiency at reduced flow. It is relatively cheap, easily maintainable, therefore highly relevant in SHP [46].

5.9.4.8 Turgo Turbines

Turgo Turbines are impulse turbines similar to a Pelton turbine in operation, but capable of handling higher flow rates. Turgo turbines operate in a head that ranges between the overlap of Francis and Pelton turbines. It is a bit less efficient compared to a Pelton turbine, but highly efficient in small hydro plant installations because it can be connected directly to a generator. Its choice is not unconnected to the fact that the runner is cheaper compared to Pelton‘s. There is no need for air tight housing, unlike Francis‘ and at the same time it has higher specific speed capable of handling greater flow than the same diameter wheel of a Pelton turbine. These advantages contribute to reduced installation cost [115].

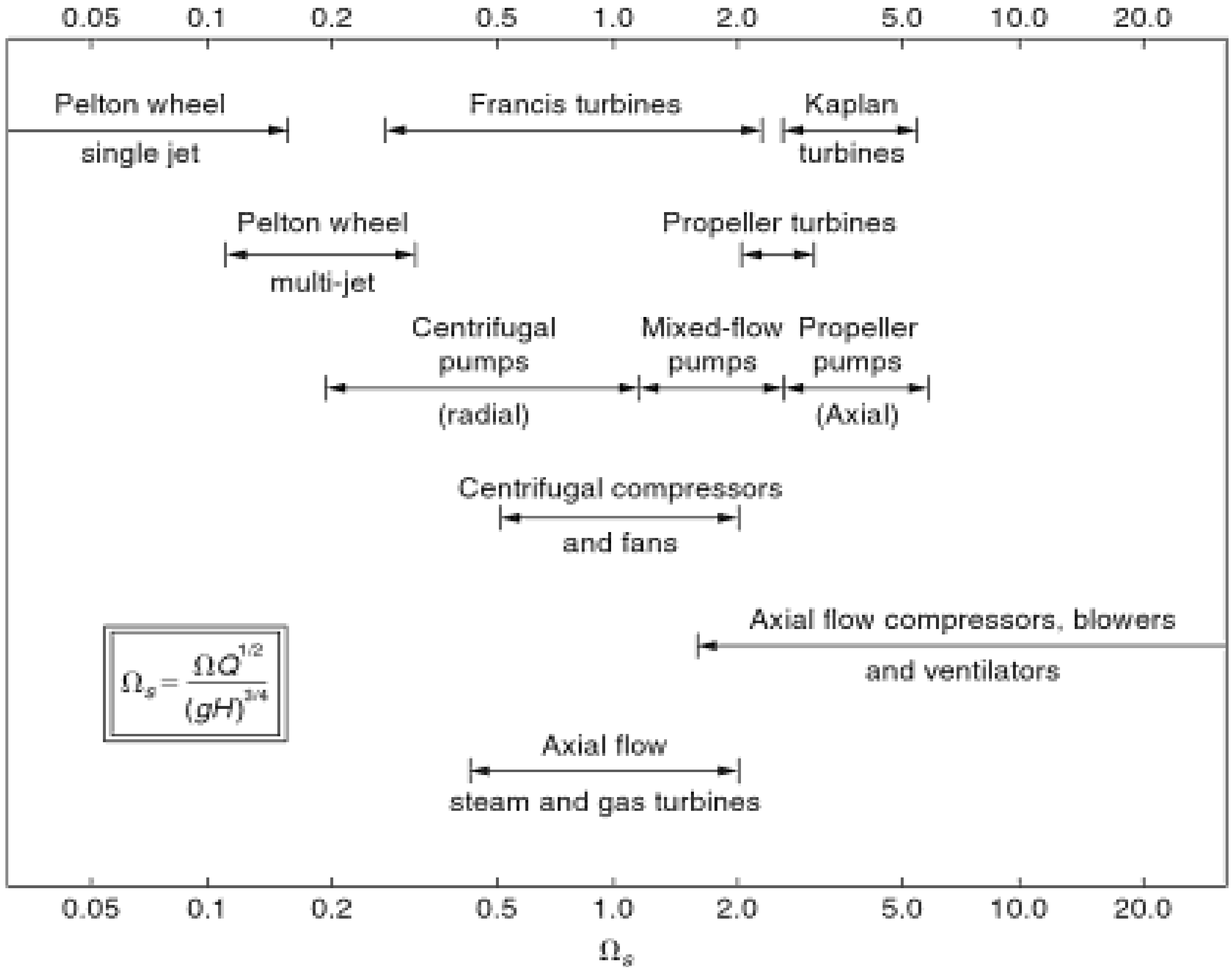

Figure 5.3: Impulse turbines operate at lower specific speeds compared to reaction turbines [14]

5.9.5 Turbine Efficiency

As energy is being converted from one form to another, certain losses will occur. For the pumped storage scheme, about 40% loss of efficiency is expected – about 20% in pumping and 20% in generating. [116]. The efficiencies in Crossflow turbine varies between 49% and 82% during conversion. For Francis turbines, efficiency could be as low as 2% and up to 91%. [117]. Two fundamental factors – design points and flow rates – are responsible for turbine efficiencies [118].

Equation 5.6 describes the hydraulic efficiency η_h of a turbine:

$$\eta_h = \frac{P_R}{P_n} \qquad (5.6)$$

where:

P_R: Power transfer from the fluid to the turbine runner and,

P_n: Total available power of a plant [111].

5.9.6 The Equations Governing Operation of a Turbine

Energy is lost as a result of flow in the turbines especially in flow friction and change of directions. In reaction turbines losses are recorded as:

1. Energy losses in the guide vane cascade;
2. Energy that is lost in the runner;
3. Energy that is lost in the draft tube; and
4. Impact losses can occur at the inlet of the runner. This loss occurs when the relative velocity vector of the flow enters the runner with another direction than the inlet direction of the blade.

Specific energy head transferred to the runner is given by:

$$h_R = H_n - h_L, \ldots \qquad (5.5)$$

$$P_n = \rho Q g H_n \ldots \qquad (5.6)$$

where:

h_L: Total sum of the losses along the flow path is and

H_n: Available net head for the turbine [111].

P_n: Generated power.

The net head H_n is defined at the inlet of the turbine referred to the level of the tail water of reaction turbines or the outlet of the nozzle of a jet turbine.

5.9.7 Choice of Turbine Used in Pumped Storage Hydropower Plant

The available head between the upper and the lower reservoir primarily determine the type of equipment in PSH. Kaplan turbine is most suitable for low heads; Francis and Pelton turbines are considered in larger heads. The Kaplan turbine rotor is propeller shaped, designed for high efficiency hydro conversion systems. Its efficiency reduces as the design velocity water drops and is not efficient for upward pumping while the electric generator is easily made reversible to serve as generator or as motor [119]. In Francis turbines, water is led into the runner (rotating blades) by a set of fixed guiding blades placed at optimum incident angle. In a multistage version (a pump containing two or more impellers), heads above 1000 m can be achieved with completely reversible and modest losses.

This research work will not consider particular turbine characteristics for the design. Turbine type, sizes and design are primarily determined by [51]:

i. Net head.
ii. Variation of flow discharge through the turbine.
iii. Rotational speed.
iv. Cavitation problems (quality of water available from penstock).
v. Cost.

Turbine efficiency (%) depends on the required head of the turbine as well as the turbine flowrate value [110]. In Kaplan turbines, blade angle arrangement significantly affects turbine response as water rushes by controlling water flowrate as water passes through the turbine [114]. This type of turbine can achieve an efficiency of up to 0.95 at design but about 0.8 for existing Francis turbine plants for one-stage pumping water to upper reservoir and regenerating electric energy at downward release into the turbine. Practically, the efficiency of multistage Francis turbines is 0.7 for hydropower plants of hydraulic head between 1000 m and 1500 m [119]. Pelton turbine efficiency is about 0.9; its tandem arrangement of separate turbine and pump allows a rapid shift between pumping mode and generation mode or vice versa.

Every aspect of design parameters able to accommodate small hydropower plant installation needs to be identifed, therefore having a good understanding of applicable turbine is very important to. [117] based their study on discharge and design head to determine the turbine to be selected. Crossflow, Francis and semi-Kaplan turbines were investigated to determine the most suitable for the design. Crossflow and Francis turbines were considered because of the variable nature of the flow [120].

[50] developed and introduced a model capable of sizing both technical components and the economic cosiderations in developing a pumped storage hydropower plant system powered by wind on an island in Spain. The plant has a hydraulic height between the two reservoirs of 650 m. Each of the reservoirs has a volume capacity of 200 000 m^3 with three installed Pelton turbines which generate 750 kW at a flow rate of 495 m^3/h. The same plant can equally produce 1 500 kW with flow rate of 978 m^3/h, or when flowing at 2 226 m^3/h it can produce up to 3 300 kW.

5.9.8 Technology Developments

The variable speed pump-turbine is one of the innovations introduced in PSH systems to bring about improvements to system performance and has been observed at work in various PSH plants [121]. A major advantage is that the quantity of energy consumed is moderated into the pumping activity with the use of asynchronous motor-generators allowing adjustment of the pump/turbine rotation speed [118]. Another advantage is that a variable speed pump-turbine system operates at efficiency value that is near maximum value by facilitating storage of energy when the system detects extra power. This technology reduces the number of times the plant is powered and halted thereby regulating the system frequency [122]. Through research, it was discovered that there would be over $1000/kW increase in the component cost value of installing a variable speed hydropower plant in this work instead of an ordinary pumped storage hydropower plant.

Another aspect of engineering advancement is the development of a turbine pump runner with multiple blade which has proven to deliver up to 4% rise in pump efficiency [121].

5.10 Managing Electrical Loads

The integration of pumped storage systems is definitely an extra huge cost which many could avoid in a system design, but it is of great additional power impact when system sustainability is considered. Many renewable options are available worldwide today, but the question is what is their sustainability? It is of no economic importance if power plants projects are designed but not able to sustain even a base load not to mention the ability to handle peak time demand. As mentioned, electric power production is to meet two major loads which are; base load and peak load. These two loads are demand based.

Base load is to meet the basic large amount of energy needed. Technologies capable of generating mass power such as hydropower, nuclear power, and coal fired plants are engaged to deliver this. Peak load is the energy required to satisfy extra load demands while at maximum demand. In meeting this load requirement, CAES, pumped storage systems, gas, thermal, advanced Batteries, PV cells, fuel cells and generation methods are used. Considering technologies that produce mass energy amount, hydropower is the cleanest because it will not contribute to the increase of pollution emissions.

With this review it can be summarised that having two or more renewable sources combined together, the sustainability of the system is enhanced so that both base load and peak load can be met. Whether a system is stand-alone or feeds the grid, it is important to design an attached storage technology so as to be able to handle periods of peak demand and low production as a result overhauling and or expansion. Pumped storage has a major role to play in enhancing the reliability and flexibility of electricity and mitigating the adverse effects of generating systems.

CHAPTER 6 : RESEARCH METHODOLOGY

6.0 Introduction

The aim of this research is look into the design, modelling and simulation of a hybrid pumped storage hydropower plant. A lot of details have been provided on PSH plant design, but for the consideration of the actual design type, review of PSH will be emphasised. A conventional pumped storage hydropower plant follows the pattern where water is released from a height to run a turbine to generate mechanical power at the turbine shaft. Conversion of power from mechanical to electrical power is accoplished by a generator.

[81] listed the following types of PSH:

i. Pure pumped storage.
ii. Pumped-back pumped storage.
iii. Seasonal pumped storage.
iv. According to mode of operation.
v. According to design.

Different scenarios were identified as possible plant designs based on the fact that a PSH plant is a consumer of energy; there is a need to have a source of power to pump water to the upper reservoir. The power consumed during the pumping mode is given as pump power (P_p) which is more than the power released during generation mode, power generated (P_g). The question is how we get enough power to accomplish lifting to the upper reservoir. The initial design was to combine two or three renewable energy options to serve as input power. This was reached based on the findings about South African climate parameters. South Africa has enough sunlight that can provide adequate pumping power. Another option is engaging wind power to power the pumps. However, these two renewable sources are not sustainable enough as they are too dependent on climatic factors per time.

Photovoltaic (PV) is efficient, but the limiting factor being time of the day makes it unsuitable but not that integrating it with PSH will be a failure. The peak period is the time when sun emits energy and the time we need to pump is the time when sunlight is unavailable. This makes it an unsuitable option for efficient plant performance. If it is employed, then the basic concept is to exploit the rejected photovoltaic energy amounts to drive hydro turbines of the system to produce desired guaranteed electricity during the peak hours when the marginal production cost of the conventional power station is very high and use the excess electricity produced from the PV modules to pump water to the upper reservoir and store it in the form of hydrodynamic energy.

6.1 The Scenarios

Many plant design configurations and ideas were conceived snd suggested before considering the main design in Chapter 7. This design may not work efficiently in all situations as the specific design is done according to the physical details of each location, but the simulation can be used for any situation of both conventional and or pumped storage plant facilities ‗PSH'.

An energy equation is developed that models interdependence between the two systems which make up the hybrid hydro plant. MATLAB Simulink is the tool used to describe the interaction between contributing plant parameters in the simulation. Firstly, analytical method is used step by step in computing values in the energy equation. This is followed by cross checking with MATLAB Simulink. The results obtained from both are compared. Three different design approaches are suggested in this chapter. The reason for is to ensure that the most efficient design in terms of output power, construction inputs, space, maintenance cost, environmental impact is embraced. The three scenarios work on the same principles: height, material dimension, turbine, generator, pump and technology. The main differences and outputs distinguishing these plant designs will be discussed further in this chapter.

6.2 Mathematical Modelling and Simulation

Mathematical representation (energy equations) of the design which describe the behaviour and function of the following are developed and implemented to related parameters identified in the proposed design. The flow, and also the losses in pipes, turbines and pumps, elbows, valves, entrances and exits are modelled in the equation. The modelling will keenly look into:

i. The distance between the reservoir and the turbine/pump;
ii. The lower reservoir;
iii. The pump, which lifts water into the upper reservoir; and
iv. The upper reservoir.

v. This will be followed by modelling the flow and also model losses from the top to the bottom, which are losses in pipes, turbines and pumps and minor losses at the elbows, valves and entrances.

6.3 Plant Capacity Design

The model considered design of plant components such as pump, flow, head and losses. Plant site selection and turbine selection are not included in the section. The selection was carried out mathematically involving interaction of relevant parameters.

6.3.1 Scenario 1: Sustainable Energy Generation from Pumped Hydropower

Publication 5:

Sustainable Energy Generation From Pumped Hydropower

Samuel A.O. Ilupeju, Freddie L. Inambao, Ntumba M. Mutombo, and Taha Selim Ustun

Abstract – For any society energy is identified as a pillar of social and economic development. During the production of sustainable electricity there is degradation and pollution of the immediate environment. Hydro-power (HP) is one available source that is clean and renewable and which can be used to manage power supply/demand options. A pumped storage hydropower (PSH) system allows water re-use while eliminating environmental pollution. Apart from PSH being used as a huge battery, storing energy in the water of an upper reservoir until its release for instant power generation on demand, it may also be also engaged in reducing greenhouse gas emissions - a major threat to humanity. To fully explore the world of PSH this paper sought to identify potential distribution, possible capacity and current technologies involved in Africa's five regions. This approach is common for large hydropower plants, but for this study, PSH was used with a small hydropower unit to model a hybrid power plant using a reversible turbine. Flowcode V5 and Proteus were used to design the study's control aspect. Two floaters were installed in a PHS upper reservoir, one at its lowest level to halt generation, another at the top of the reservoir to avoid spill during pumping activity. Results obtained in this study established technically the concept of pumped storage for small hydropower project could be used to meet peak demand for a rural or farm community.

Key words: *Pumped storage system, small hydropower, renewable energy, power generation, peak demand.*

1. INTRODUCTION

This paper underlines the potential of a small hydropower hybrid unit, primarily to help minimise major power related challenge - achieving peak electricity demand, increase electricity generation, reducing effects of global warming and fresh water scarcity, alleviation of poverty and enhancing sustenance.[1]

S. A. O Ilupeju[1]; F. L. Inambao[2] and N. M. Mutombo[3]
[1, 2, 3]Green Energy Solution Research Group, Mechanical Engineering Department, University of KwaZulu-Natal, South Africa
(ilurohun@yahoo.com[1], inambaof@ukzn.ac.za[2], marentumba@yahoo.fr[3]).
T.S. Ustun, Carnegie Mellon University, Pittsburgh, PA, USA (ustun@cmu.edu).

Conventional and pumped storage hydropower technologies were combined to build a hybrid small hydropower plant.

A pumped storage hydropower plant design consists of two reservoirs, each separated by a suitable hydraulic head necessary to drive a design turbine at maximum output resulting in power generation to drive essential equipment. During off-peak periods (low demand), water was pumped from the lower to the upper reservoir. The first mode is named the pumping mode (PM). The water is then released back into the lower reservoir through turbines to generate electricity for peak demand periods. There is high financial return from by converting the stored potential energy into electricity, known as the generation mode (GM). It is a worthwhile instalment as it makes available considerable electric power during low consumption periods. The technology converts unused energy at off-peak into potential energy - stored in the upper reservoir. It is more expensive to manage compared to conventional hydroelectric power stations because of pumping costs, but the quick time response to meet power needs makes it a major player in maintaining the stability of national grids [1]. In conventional HP, water is not expected to flow back after generation as it flows through the hydraulic turbines' driving generator into a dam, river or reservoir. PSH normally requires construction of two reservoirs, but depending on topography at least one needs to be constructed for every project [2], making the system totally dependent on environmental conditions.This study's main aim was to provide adequate electricity to meet domestic needs. For example, in Ireland, 32% of final electricity was consumed in the residential sector in 2009. This was the second largest electricity consuming sector in the economy, exceeded only by the industrial sector [3]. In South Africa, 22.5% of final electricity was consumed by the residential sector in 2013 [4].

1.1.Need for Pumped Storage Hydropower system

Employment of water for hydroelectric power is a function of availability of the resource. Where a water resource is richly available, hydroelectric power stations can run continuously to provide 24-hour base load electricity. [1] reported electricity generated by a hydro-electric power station was cheaper than that produced by a coal-fired power station as running costs were lower. Another advantage of water over coal in power generation was coal was consumed in the process of power generation, whereas water was not, but merely utilised its energy. In addition, a pumped storage hydro-system offered fast reaction time to sudden changes in consumer demand and emergencies because of ability to start-up quickly, so could frequently be used to meet peak demand. It could reach peak generation of power within three minutes [5], whereas a coal-fired power station required several hours from a cold start before generating power. Therefore, energy capacity planning was necessary to ensure anticipated future power demand was met strategically. This plan was vital in maintaining regular electricity by focusing fully on supply options, demand management, and demand forecasting options. A technical advantage offered by a pumped storage plant was power was usually generated when needed, making it simple for engineers to produce electricity on demand - thereby ensuring control [1].

In areas where availability of water presented a challenge, pumped storage schemes were suitable option against a conventional hydroelectric power station to provide power needed during peak periods. It allowed water retention and reuse instead of water discharge. A pumped storage system could be compared to a huge battery storing potential energy (water) in its upper reservoir when electricity consumption was low, until released for instant power generation on demand. A major disadvantage was that a pumped storage plant was actually a net consumer of energy. It returned about 3 kilowatt-hours (kWh) of electricity for each 4 kWh for pumping activities carried out at off –peak [6]. Additional advantages were continuous operation by the most efficient plants in the entire system. Also, the attractiveness of such small hydropower plants was they could be stand-alone or be employed in a hybrid combination with other renewable energy sources and were more environmentally and ecologically acceptable. Finally, there were profitable financial implications, since energy generated during peak periods had a higher monetary value than energy expended during off-peak pumping [6].

Storing energy was a major challenge in power generation as unused energy generated in commercial quantity was wasted. It was of great advantage to understand energy be generated when needed - demand changes, time of day and seasonal requirement; as expected, daytime required peak demand; night time, low demand. For a reliable system, power generation was achieved with real-time demand. Pumped storage hydropower was the only commercially proven technology available for grid-scale energy storage to fill the gap; the only economic route to large-scale energy storage [7].

1.2. Africa Overview of Hydropower

Hydropower potential was high in regions of sub-Saharan Africa. [8]reported development of such potential was of great value to economic buoyancy within each region. Countries identified with substantial hydro potential included DRC, Kenya, Uganda, South Africa, Nigeria, Mozambique, Zambia and Rwanda. With the present contribution of HP being about 20% in global electricity generation [9]; [10] and [2], intensive harnessing would definitely result in improved economic and domestic values. In South Africa, in spite of HP potential, coal still contributed up to 90% of total energy generated; other sources, including HP, contributed 10% [4]. One of many surveys on HP potential carried out by [11]in five East African countries disclosed that in Uganda 2 500 MW could be harnessed to hydrological resources. In Tanzania, estimated small scale hydropower (SHP) potential in total scattered around the country could supply up to 300 MW. Rwanda has identified and quantified more than 259 sites which might be restored or equipped for SHP, while about 99% of Burundi's utility came from HP with room for development, especially in micro, mini and small hydropower capacities[11]. The River Nile's hydroelectric potential was valued at 8 000 MW. Egypt was reported to have installed up to 2 810 MW of HP capacity. The southern African region has exploited about 60 % of its HP potential [6]. Three pumped storage HP plants already generate electricity – Drakensberg, Palmiet, Ingula. Another PSH scheme, known as Lima, since renamed Tubatse, was fully planned and construction was imminent[12]. The Drakensberg PSH, commissioned 32 years ago, has a generating capacity about 1 200 MW.
The Palmiet PSH generates 400 MW; Ingula offers 1 332 MW

Table 1: Hydropower technical potential for key African countries [13]

Countries	Technical	Cumulative	
	(TWh/yr)	(TWh/yr)	(%)
DR Congo	774	774	41,8
Ethiopia	260	1034	55,8
Madagascar	180	1214	65,6
Cameroon	115	1329	71,8
Gabon	76	1405	75,9
Angola	65	1470	79,4
Egypt	50	1520	82,1
Mozambique	38	1558	84,1
Tanzania	40	1598	86,3
Nigeria	32	1630	88,0
Zambia	30	1660	89,6
Sudan	19	1679	90,7
Guinea	19	1698	91,7
Zimbabwe	18	1716	92,7

West Africa, [14] records 25 % installed capacity of HP with highest potential in Nigeria and Ghana. [15] and [16] in Nigeria more than 278 unexploited sites have been

identified with total potential of 740 MW spread countrywide; HP potential was estimated at 3 500 MW.
The Central African region had the highest HP potential in Africa [14]. HP potential was about 419 000 MW in the Democratic Republic of Congo while installed capacity was up to 3 816 MW for large HP. Only about 1% of its potential capacity has been exploited, making it the least developed region for SHP installation [14].

1.3. Pumped storage system: Peakdemand solution

[17] recommended the use of wind-based pumped hydro-storage schemes (wind-hydro) technology on a smaller scale, such as wind-based pumped hydro as an appropriate solution to increase up-to-now limited wind power penetration non-interconnected regions. [17] worked on insufficient generation problems on the basis of several black-outs especially during summer, when tourism increased that was faced by the many scattered Greek islands. Electricity generation was based mostly on thermal power plants, diesel engines and gas turbines which emitted considerable amounts of pollutants and operated at high production cost. The application of the energy model developed increased RES contribution by 9%, reaching 19% of the island's energy balance. [18] investigated the introduction of pumped storage systems in isolated power production systems for Crete and Rhodes - isolated systems with high thermoelectric production and wind energy rejection. Two major considerations in introducing a pumped storage system are for maximisation of wind energy penetration and minimisation of costs. Energy was stored whenever wind energy was rejected and thermal generators burning cheap heavy fuel oil did not operate at nominal powers. Before the introduction of PSH, the existing power production system in isolated areas includes three thermal power plants, diesel engines, gas turbines and a combined cycle. With the introduction of a pumped storage system, Crete yielded almost 10% annual electricity production cost reduction, including overcoming annual wind energy rejection, whereas in Rhodes, annual electricity production cost was reduced by 1.85%.

2. METHOD AND CALCULATIONS

Proposed plant design was a hybrid picohydropower plant that combined conventional SHP and pumped storage technologies in a single generating system. The idea was to achieve maximum utilisation of water resources in a location to generate peak power in time of need. As shown in Figure 1, on average, there were daily two peak periods and two off-peak periods.

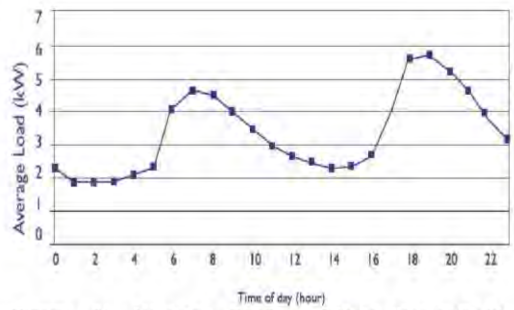

Figure 1: Average South African household daily electricity consumption pattern [19]

The primary source of generation was the run-of -river tagged I. From the tailrace of I water was directed into a lower reservoir II as shown in Figure 2.

Excess electricity during off -peak periods was used to lift water from II to an upper reservoir III. This operated a second system - the pumped storage system.

Water from the pumped storage plant was stored for reuse in II, or be allowed to continue to flow along the river for other purposes.

The proposed system was expected to be a stand alone plant or to supply the main grid, depending on generation guidelines. Flowcode,a graphical programming tool which designed complex electronic systems and Proteus, a programming software that integrated perfectly microprocessor models and animated components which helped combine microcontroller related designs' simulations were used to develop control of the proposed plant. Methods to workout this technique are presented.

Parameters used in the work were obtained from ICUE publication [20]. MatLab-Simulink was used to simulate the parameters and results were obtained. The parameters of the working site are listed.

The output power at the hydro turbine of 80 % efficiency = 3.924 kW
Flow = $0.05 m^3/s$
Head = 10m

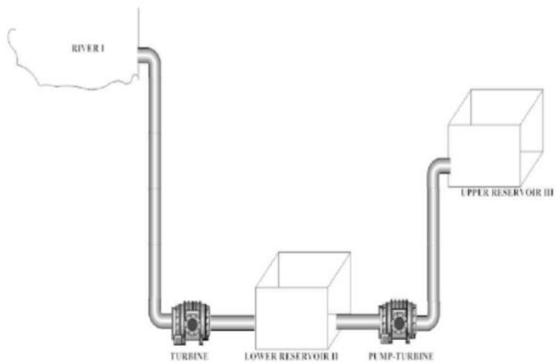

Figure 2: .Proposed PSH and hydropower hybrid plant

The proposed design used a reversible turbine to power its PSH section, the pump-turbine efficiency was given as 75%; choice of turbine was not specifically selected for this work. A generic model was investigated in this paper to give an idea of possibility of installing a hybrid plant of similar configuration.

Mathematical Representation of the Design:

$$P_g = \rho_w . g . Q_g . H_g . \eta_t \qquad (1)$$

$$P_p = \frac{\rho_w . g . Q_p . H_p}{\eta_p} \qquad (2)$$

From equation 2,

$$Q_p = P_p . \eta_p / \rho_w . g . H_p \qquad (3)$$

P_g = rated generating power at PSH,
η_t = turbine efficiency,
ρ_w = density of water in kg/m^3
g= gravitational constant in m/s^2
Q_g = rated generating flow in m^3/s at the PSH
H_g = rated generating head in m at the PSH = 5m
P_p = pumping power,
Q_p = pumping flow in m^3/s
η_p = pump efficiency,
H_p = rated pumping head in m to III = 5m
H_L = losses in the line pumping line to III in m.

Firstly, one needed to design parameters l such as diameter of the suction and delivery pipes. Calculating the flow was the first approach. From Figure.1, the first peak is about one-third of the primary generation,
Using test plant data in Equation 3,

$$Q_p = \frac{1308 * 0.75}{1000 * 9.8 * 5} = 0.016\ m^3/s$$

second peak is about two-third of the primary generation, Q_p = 0.016 m^3/s while at 2.616 kW, Q_p = 0.04 m^3/s.

Considering losses in the pipe, an average flow of 0.03 m3/s was achieved for the lifting of water from the lower to the upper reservoir.
In 8hr pumping operation,
Volume to be lifted = 0.03*3600*8 = 864m^3
A pipe diameter to account for losses, not more that 10% hydraulic, was selected; 0.2m for suction line and 0.15m for delivery line.

Surface area of suction pipe

$A_s = \frac{(0.2^2) * \pi}{4} = 0.03142 m^2$

Surface area of delivery pipe

$A_d = \frac{(0.15^2) * \pi}{4} = 0.0177 m^2$

But $V = {}^{Q}/_{A}$ (4)

From Equation 4,

Therefore $V_s = \frac{Q}{A_s} = \frac{0.03}{0.03142} = 0.955 m/s$

And also, $V_d = \frac{Q}{A_d} = \frac{0.03}{0.0177} = 1.7 m/s$

Figure 3 is used to generate losses in the pumping mode, there is need to find the friction factor f using the values of Reynolds number Re and relative roughness ${}^{\varepsilon}/_{D}$. The value of ε for a steel pipe = 0.045*10^{-3}

${}^{\varepsilon}/_{D} = \frac{0.000045}{0.2} = 0.225e^{-3}$ (5)

Now calculating the Reynolds Re,
$Re_s = V_s * D_s / \vartheta$
ϑ, kinematic viscosity of water at 20°C = $1.004e^{-6}$
$Re_s = 0.955 * 0.2/1.004e^{-6} = 1.95e^5$
$Re_d = 1.7 * 0.15/1.004e^{-6} = 2.54e^5$
Using Moody's diagram,
$f_s = 0.015$
$f_d = 0.017$

Losses were calculated at the entrance, elbows, valve, pump, pipes (suction and delivery) and at the exit. Details of this were not presented in this manuscript, but the values will be used in relevant calculations [21].

Major head losses h_{major}

$f * \frac{l}{D} * \frac{V^2}{2g}(K_{suction} + K_{delivery})$ (6)

$f_s * \frac{l_s}{D_s} * \frac{Vs^2}{2g} + f_d * \frac{l_d}{D_d} * \frac{Vd^2}{2g}$

l_s and l_d are suction and delivery lengths respectively

$0.015 * \frac{3}{0.2} * \frac{0.955^2}{2g} + 0.017 * \frac{5}{0.15} * \frac{1.7^2}{2g}$

0.006975 + 0.0833

Minor head losses, h_{minor},

$$= \frac{V^2}{2g} * (K_{entrance} + K_{valve} + 2K_{bend} + K_{exit}) \quad (7)$$

Using Equation 7,

$$= \frac{V^2}{2g} * [(0.5 + f * \frac{Le_v}{D_v} + 2 * f * \frac{Le_b}{D_b} + 1)]$$

For a gate valve, $f * \frac{Le_v}{D_v} = 0.019 * 8$

For the two elbows, $2 * f * \frac{Le_b}{D_b} = 2 * 0.019 * 30$

Total minor losses = 0.0232+0.0446+0.0838+0.0147

These values were entered into the MatLab Simulink model (Figure 4) to achieve optimum results.

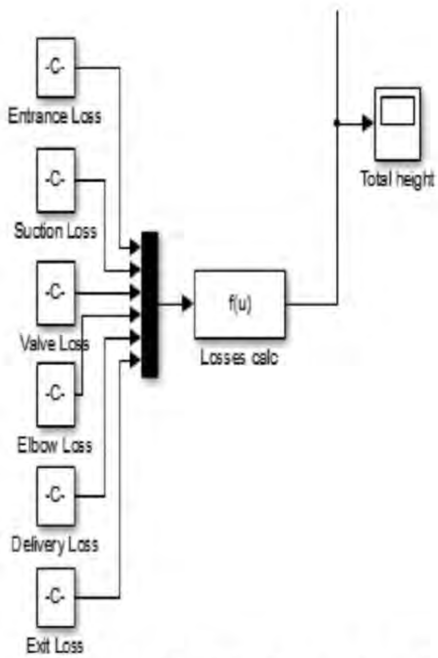

Figure 3: A Simulink diagram to calculate total pumping height losses

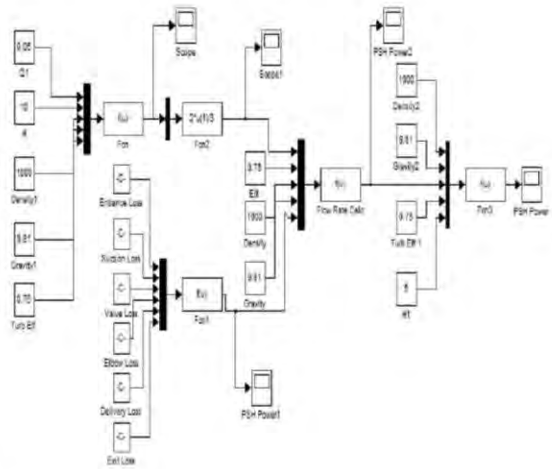

Figure 4: Amalgamated Simulink for entire hybrid plant

Three parameters were used for controls' design.- time, volume of water available and power available to pump water during pumping mode. Figure 5 is a flowchart designed using Flowcode V5 to model time allocation in the operation of the plant, equally generating codes based on allocated time of plant operation.

Proteus ISIS was used to design controls, based on available volume in both reservoir II and III. For example, it might be the pumping time from reservoir II to III based on the flow code programme as seen in Figure 6, where power available for pumping was low;

Proteus over-rode Flowcode. If reservoir III was full, a sensor attached to the top floater as seen in Figures 7 and 8 would also override the decision to avoid overflow in III.

The two floaters controlled water volume in reservoir III, received from II and also generated extra power at peak time. If the volume in reservoir III was low at PSH generation, Proteus would also override the Flowcode decision with the aid of a sensor attached to a bottom floater. This software modelled the plant's entire control system.

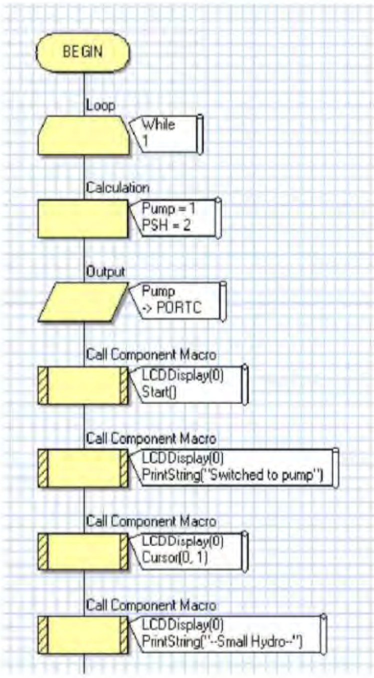

Figure 5: Flowcode V5 flow control chart.

3. RESULTS AND DISCUSSION

3.1 Plant Design

Output power from the plant was computed by Simulink at 3.924kW from a fixed height of 10m; electricity was used between 12pm and 5am for pumping activities from II to III at an average volumetric flow rate of 0.03m^3/s.This flow led to design of pipe size for both maximum and minimum flow.

Total head of 5.3889m was achieved using a diameter 0.2m for suction pipe and 0.15m. When diameters of pipes were decreased to 0.15m and 0.1m for suction and delivery pipes respectively, losses increased, reducing the output power of the hybrid plant.

At minimum consumption, 2.616kW of electricity was available to pump water to II; at a height of 5m from III, 1.366kW of power was recoverable from the PSH, deliverable at peak time when consumption was high, at a better economic value. Without a storage plant, the unused electricity would have been wasted. As water levels in III reduced during generation mode, the leas power - about 0.55kW would be available to add to the primary supply as shown in Figure 10.

A need for power in Africa was increasing, but potential for power generation was substantial.
Solar and wind sources were not adequately engaged in Africa, although the duo could not be relied upon being highly unpredictable. But for a sustainable energy policy with an suitable energy storage PSH has been identified as the answer.

Designing a PSH plant is a function of site. [22] categorised types of PSH include pure pumped storage, pumped-back pumped storage, seasonal pumped storage, according to mode of operation and according to design types.

3.2 Plant Control

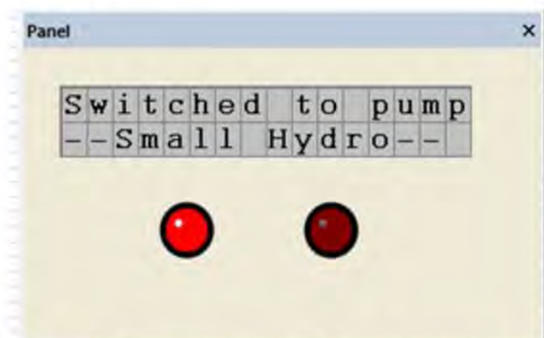

Figure 6: Plant operation indicator at pumping and pumped storage modes

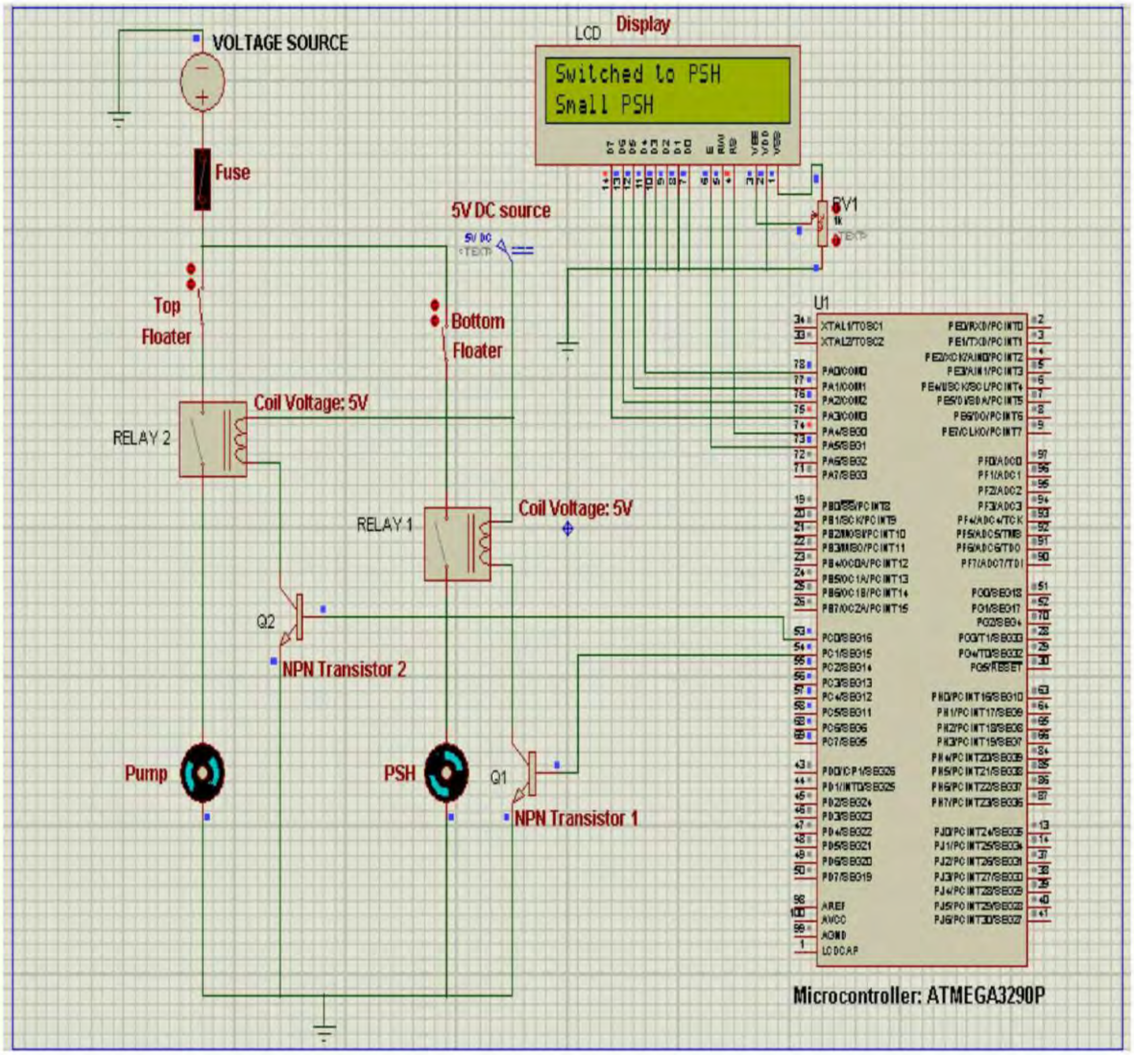

Figure 7: Proteus plant operation indicator model for volume control showing the two floaters on

The floaters provided an accurate result for balanced operation of a hybrid plant. The governing control strategy worked for the proposed plant with quick response at any given time providing excess power was available from the primary hydropower plant. Flowcode and Proteus proved to be relevant in the management of the plant's control. The display aspect provided ease of identifying which plant systems were or were not working at a given time. It also disclosed any reason for unexpected ted malfunction especially with floater control.

4. CONCLUSIONS

The results proved a hybrid of a conventional and pumped storage hydro plant was feasible and able to meet peak time demand for electricity.

Hydro-power was a renewable energy source which was clean and available. Water was not consumed during power generation, allowing for reuse. A large percentage of SHP potential remained untapped - to society's loss.

There was need to encourage private investor participation in the development as resources sere substantial enough to provide electrical power to increase quality of life, of especially those in poor urban or rural areas of Africa. Development of this recourse could spark an economy boom.

The control technology interface was user-friendly and capable of handling more complex hydro-power activity when there was need for plant expansion; Flowcode would be upgraded as it was effective for plant management.

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Principal Author:

Mr Samuel A.O. Ilupeju is a registered PhD student in Mechanical Engineering with the University of Kwa-Zulu Natal. He graduated from the University of Ibadan and the University of Ilorin both in Nigeria for his M.Sc. and B.Eng. degrees respectively. He is a member of Green Energy Solution group, working on the design of a continuous micro pumped storage hydropower plant for a small South African community.
ilurohun@yahoo.com

Co- Author:

Dr Freddie Inambao holds a PhD in Technical Sciences from Volgograd State Technical University. He has worked for University of Zambia, University of Botswana, University of Durban Westville, and now at the University of KwaZulu-Natal as a Senior Lecturer following the merger. He has authored and co-authored over 70 technical papers, publications and presentations covering Alternative Energy Systems, Energy Management, Internal Combustion Engines, Fuels, Pumps and Thermodynamics.
inambaof@ukzn.ac.za

Co- Author:

Ntumba M. Mutombo received a Master degree in Mechanical Engineering from the University of KwaZulu Natal. He is resently completing a PhD in Renewable Energy at the same University.

Co- Author:

Taha Selim Ustun received B.E degree in Electrical and Electronic Engineering from the Middle East Technical University Turkey in 2007 and Master of Engineering Science degree from University of Malaysia, Malaysia in 2009. He has received PhD in Electrical Engineering from Victoria University, Melbourne, Australia. Currently, he is an Assistant Professor in Electrical Engineering, School of Electrical and Computer Engineering Carnegie Mellon University, Pittsburgh, PA, USA. His research interests are Power System Protection, Communication in Power Networks, Distributed Generation, Microgrids and Smartgrids.

Presenter: Paper presented by Samuel Ilupeju.

6.3.2 Scenario 2: Hydropower Generation: A hybrid technology approach for optimum electricity supply in Africa

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Hydropower Generation: A hybrid technology approach for optimum electricity supply in Africa.

Samuel A.O. Ilupeju[1], Freddie L. Inambao[1], Luke Philogene[1] and Taha Selim Ustun[2]

[1] GES Research Group, Mechanical Engineering Department, University of KwaZulu-Natal, Durban, South Africa.
[2] Carnegie Mellon University, Pittsburgh, PA, USA

Abstract

Renewable energy source availability is enormous in Africa. The quantity of each is adequate to generate the required power for the day to day activities. These energy sources can serve as stand-alone or even supply power to national grids, but the truth is these sources are underutilised, thereby hindering technological, economic and social growth resulting in poor infrastructural development in many areas within the continent. This paper reviewed hydro-power potentials with more emphasis on small hydro-power potentials. Small conventional power generation method has been combined with a pumped storage system to generate power. Advantages and disadvantages of engaging pumped storage hydro-power (PSH) system, the possibility of solving power demand and management forecast through its use for power storage and generation purposes, availability in Africa and global distribution are also reviewed. There are great potentials in small hydropower generation for sustainable development in Africa. Favourable policies are also needed to achieve this.

Keywords

Pumped storage technology, Hydropower generation, Renewable Energy, Small hydropower plant.

1. Introduction

Hydropower (HP) generates clean and renewable electricity resulting in many countries to have set targets to engage in more hydro-power generation. Spain for example committed a lot of measures to increase energy from renewable sources to 12% of total production by 2010 (1), (2) so as to combat the environmental menaces imposed by carbon gas emissions. Spain instituted several organs to obtain greater power efficiency and alternative power generation sources, such as CIEMAT and IDAE. Between 1986 and 2001, Spain experienced a rapid evolution in hydropower with total accumulated power amounting to 1 607.3 MW, an average growth of 53 MW each year (2). Through the declaration in 2012 as the ―International Year for Sustainable Energy for All" (SE4ALL), the International Renewable Energy Agency (IRENA) launched a global renewable energy roadmap for doubling the share of renewables in the global energy mix by 2030 from the present 20% to about 40%. It is aimed to transform power generation sector of developed countries to exploiting and absorbing more renewables sources, upgrades and modernise old grid systems, introduce new and innovative solutions. This approach is believed to help meet rising electricity demand, give room to new investment opportunities (3).

Hydro-power has gained recognition rapidly in electrical power generation in the world as a renewable energy source. Hydro-power contributes up to 20% of world electrical power (1);(4). (5) predicts that the global demand for electrical energy will gradually rise and the growth for HP production is projected at 2.4% - 3.6% from 1990 to 2020. Small scale hydropower (SHP) is referred to as one of the most cost effective and environmentally friendly energy generation technologies available (1), designed for water to run through a river without storage, or surface dam or at a given head. It is described as the most ideal small scale energy technology for isolated and/or rural community electrification in developing countries. SHP ―run of river" schemes have minimal environmental impacts (6);(7).

2.1. Pumped Storage Power Stations

A major requirement for hydroelectric power generation is availability of water. Water resource is richly available and at the same time location dependent. Hydroelectric power stations can be run continuously to provide 24 hour base load electricity, applicable in many countries of Africa, for example Rwanda, DRC, Uganda and Burundi (8);(9). Hydropower can be engaged conventionally or as Pumped storage system. Both methods are efficient and effective but depend on the location and method to be engaged in harnessing the resource. Electricity generated by hydro-electric power stations is cheaper over time than that produced by coal-fired power stations because of much lower running cost (10);(11). HP has advantages over coal in power generation in that coal is consumed in the process of power generation whereas water is not consumed, but its energy is utilised efficiently in power generation. With over 71 % of the earth been covered by water, water the most available substance on earth and energy available from it enormous and that is why (12) puts world hydro power potential amount at 20 billion Mega Watt hours per year and only 30% of this is developed so far.

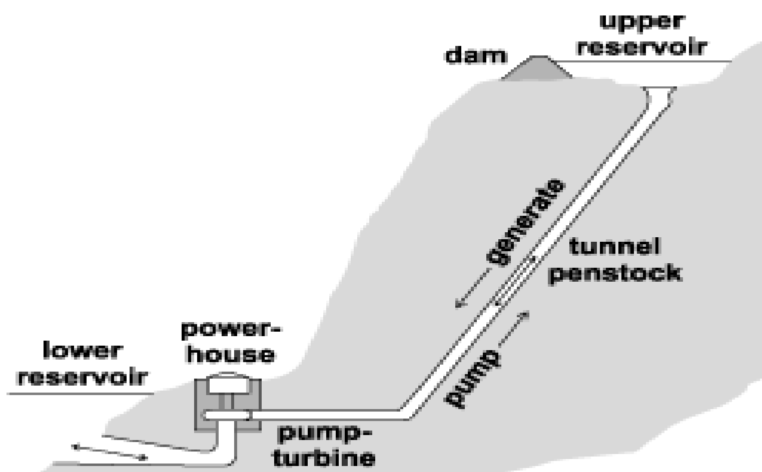

Figure 1. A typical Pumped Storage Hydropower Plant System sketch.

Pumped Storage Hydro system has a quick reaction time which enables it to respond swiftly to sudden changes in consumer demand and emergencies because of the ability able to start up very quickly and thus frequently used to salvage peak demand situation (10). It reaches peak generation of power in as little as three minutes, whereas a coal-fired power station requires several hours from cold start before it can start generating power. Energy capacity planning is necessary in ensuring anticipated future power demands is strategically met. This strategic power plan is vital to maintain regular electricity by focusing fully on three major factors, namely:

i. Supply options.

ii. Demand management option.

iii. Demand forecasting option.

Another advantage of hydropower, especially PSH, is that power is usually generated when it is needed which makes it simple for engineers to produce electricity on demand thereby ensuring control. The possibility of being completely automated in its operation makes it less cumbersome in managing. An example is the hydroelectric power stations on the Orange River being operated by remote control from Eskom‘s National Control Centre in Germiston.

2.2. Hydro-power Technology Review

Hydro-power, being an environmental friendly technology, is reported that of all known generation system hydro-power has the highest operating efficiency (12). It allows water retention and reuse instead of the water being discharged when optimised with a pumped storage hydro plant. (11) likened a pumped storage system to a huge battery that stores energy of water in the upper reservoir until it is released for instantaneous power generation when there is a demand for electricity. Though pumped storage plant is actually a net consumer of energy, it makes the stored power available when needed at a higher price. It returns approximately 3 kilowatt-hours (kWh) of electricity for each 4 kilowatt-hours required for pumping which makes pumping activities carried out at off peak when energy consumption is low and generation is at peak times (11). PSH technology permits continuous operation of the highest efficiency plants in the total system. Pumped storage generation, by its use of large quantities of off-peak power for the pumping process allowing other power option to operate under much more stable loading conditions.

Energy use in the daytime is at peak demand and at night time, low demand. For a reliable system, power generation is achieved with real-time demand. Storing energy for the peak time is a major challenge as energy generated in commercial quantity which is not used is wasted. Solar energy source could have been engaged in pump activity but the period of its availability is within the period of peak energy consumption. Solar energy is unreliable because it availability is highly dependent on climatic factors. Pumped Storage Hydropower is one of the commercially proven technologies available for grid-scale energy storage. The pumped storage plant is the only way of large-scale energy storage (13);(14).

2.3. Plant rating

Hydropower plants are rated by the amount of electricity they generate. Large hydropower facilities have capacities greater than 30 megawatts and supply many consumers while small HP capacities are less than 30 MW. Small HP plants also can be sub divided into various groups namely; Small HP 2.5 - 25 MW; Mini HP 500kW - 2 MW; Micro HP < 500kW; Pico HP < 5kW (15). A micro or small hydroelectric power system can generate enough electricity to provide power to a home, farm, ranch, or village (16).

2.4. Combined Renewable Power Systems

Experts believed that pumped storage hydropower still remains the most established technology for large-scale electricity storage, with plants consisting of two water reservoirs in different altitudes connected by a penstock (17);(18). During off- peak periods, pumps are used to lift water to the upper basin to be able to release it to the lower basin during peak times, driving turbines in the same way as in conventional hydro plants. Considering more pumped storage plants are inevitable with increasing intermittent nature of other renewable energy sources. (19) analysed the recent development and evaluates the revenue potential as well as possible barriers to increasing the prospect of new pumped-hydro storage plants even though profitability remains a major challenge. Characterized by high investment costs, this makes profitability a struggle in market situations, though a significant investment opportunity exists for the installation of an energy storage system in this wind farm. (19).

(20) evaluated the techno-economic viability of a system that incorporates the simultaneous operation of existing and new wind farms (WFs) with pumped storage and hydro turbines in non-interconnected Greek islands. It is to provide the electrical grid of the remote island with guaranteed energy amounts during the peak load demand hours on a daily basis to prevent problem of power shortage as a result of restriction of wind power due to electrical grid limitations. The performance of the system was simulated during a selected time period for various system configurations and an attempt was made to localize the optimum solution by calculating various financial indices. Three main variables with a payback period less than 10 years were considered, which are, produced energy selling price, the percentage of state subsidization and the price of the wind energy surplus bought from the already existing WFs. They came out with outstanding result that derived 24 MW for WFs, 15 MW water pumping system and 13.5 MW hydro-turbines. This made the contribution of renewable energy to the gross energy increase by almost 15%, about 25% of the island‘s energy consumption pattern. They concluded that proposed analysis may be equally well applied to every remote island possessing remarkable wind potential and appropriate topography. (21) proposed a potential supporting schemes for new pumped hydro storage (PHS) facilities operated with wind-originated power in Croatia to guarantee investment cost recovery, feed-in tariffs, as a reward for an integrated renewable energy sources (RESs) analysed. They mathematically set market share required for the efficient operation of a PHS facility and the levels of feed-in tariff (FIT). Though the most widespread storage in power systems is the pumped/reversible hydro storage. The electricity market does not adequately reward all services that PHS provide to the electricity system due to the result of the research which puts the level of FIT for an applied project in Croatia in the range 42–265 €/MW h for an average load factor of 20%. The price for charging the storage and the number of pumps and penstocks, could lower the capital cost.

A numerical methodology for optimum sizing of the various components of a reversible hydraulic system designed to recover the electric energy that is rejected from wind farms due to imposed grid limitations using hybrid wind–hydro power generation was analysed by (18). They considered various commercial and standardized components (pumps, small water turbines, penstock/discharge pipe diameter, electric motors and generators), and performed a detailed calculation of the various energy losses in the pipeline, the pumps, the turbine and the electrical equipment. The economic analysis was based on dynamic evaluation methods: the Net Present Value (NPV) and the internal rate of return (IRR) are used as criteria of the economic viability of the investment. The results showed that a well optimized design may be crucial for the technical and economic viability of the examined system (18).

(22) conducted a research on overview of the setbacks that inhibit the smooth operation of small hydropower plants in Lesotho. It was reported that Lesotho‘s energy balance is largely dominated by combustible renewable resources whereas the country is well endowed with hydropower resources for the development of both large and small-scale hydropower projects. Several challenges that inhibit achieving this developmental status were in order to reap the full benefits of this resource. High capital investment costs on projects of this nature and heavy siltation of small reservoirs due to extensive soil erosion are major ones. Various studies have identified up to 22 sites, with a combined potential of more than 20 MW to be suitable for small hydropower development. Of these sites, four have been developed to operational from mid-1980 to early 1990‘s. The plants were designed as hybrid systems with diesel generator sets. Three of those plants operate on a river run-off system running on diesel for most periods of the year, increasing overhead cost and at the same time contributing to atmospheric pollution generation. As at the period of this publication, two of the plants are mothballed as a result of the costs and other frequently encountered operational problems.

(23) evaluated the contribution of hydropower in meeting electric energy needs in Turkey. It compared production of electricity and hydroelectricity in the world to that of Turkey and examined Turkey‘s water resources and its potential, hydropower potential. Current status of hydropower in Turkey is investigated in detail and hydroelectricity was compared to thermal

electricity. It also examined the contributions of hydroelectricity to the total and renewable electricity generation, and the usage status of hydro potential. Finally, this report concluded that hydropower is the second largest contributor in meeting Turkey‘s electric energy needs after thermal, mainly natural gas. It is also estimated that the contribution of hydropower will continue because a vast amount of its economically feasible hydro potential (about 64%) is undeveloped.

A theoretical study of the economic advantages of large-scale energy storage use to complement a wind farm in a base-load dominated electricity grid was conducted in Australia. A computer model was developed which simulates the operation of several energy storage systems when used with the 190 MW Portland Wind Farm (PWF) located in Portland, Victoria, Australia (24). A variety of operating strategies were compared using a dynamic programming model which finds the maximum possible revenue which a given system can generate for a set of input conditions. Three energy storage systems were modelled and cost analysis carried out.These are Pumped Seawater Hydro Storage (PSHS), Compressed Air Energy Storage (CAES), and Thermal Energy Storage (TES).

(25) worked on economic evaluation of wind-powered pumped storage system. As the world is turning to exploration of green energy, wind power has become another primary renewable resource of great value in economic utility and industrialization development, like hydraulic power at the time when comes with the pressure from energy crisis and environmental protection. (25) considered a wind-powered pumped storage system based on an 8 MW wind farm, calculated the effect of pumped storage power station to wind power regulation and developed a model on economic evaluation. It was discovered that there is significant smoothing of the produced power that is enough to power the system with extra economic benefits. The basic concept is to exploit the rejected wind energy amounts in order the hydro turbines of the system to produce the desired guaranteed electricity during the peak hours when the marginal production cost of the conventional power station is very high.

From the above research, (25) developed the following scheme:

i. The excess electricity production from the wind turbines is used for pumping water to the upper reservoir storing it in the form of hydrodynamic energy.

ii. If the rejected wind energy amounts are higher than the pumps' capacity or the upper reservoir is full, the residual wind energy (i.e. the energy that cannot be stored), is forwarded to low priority loads.

iii. If the water stored in the upper reservoir is inadequate to fulfill the condition of guaranteed energy delivered to the local grid during the next day, the PHS system absorbs ‗cheap" energy from the local grid during low consumption periods (e.g. nights).

iv. The energy stored in the upper reservoir is released to be consumed via the existing hydro turbines during the prearranged hours of the guaranteed energy production.

Based on the major shortcomings of Pumped Storage Hydro-Power, (26) designed a system that uses derived energy from sources like nuclear, fossil, wind to pump water to the upper reservoir storing energy and ensuring continuous generation of electric power to cover urgently needed energy demand. (27) reported that from the design, there are over 130 GW of pumped storage in operation around the world balancing unplanned power outages, which makes about 3% of instantaneous global generating capacity.

(7) conducted a survey on pumped hydroelectric storage (PHS). The research handled issues like PHS technology, the pros and cons, history, and the prospect and came out with the fact that PHS is the most established technology for utility-scale electricity storage and has been commercially deployed since the 1890s. For over a decade now many have shown interest in reviving development of PHS facilities worldwide. This is because most other low-carbon electricity resources such as, wind, solar, and nuclear cannot flexibly adjust their output to match fluctuating power demands, leaving us with an urgent need for an increasing bulk electricity storage. It further described the two main types of PHS as:

i. Pure or off-stream PHS, which rely entirely on water that were previously pumped into an upper reservoir as the source of energy and

ii. Combined or pump-back PHS, which use both pumped water and natural stream flow water to generate power. Off-stream PHS (closed-loop systems), is also described as entirely isolated from natural ecosystems.

3. Methods

The motivation for this work was conceived from the last point above. With the aim being to guarantee energy supply during the peak load demand hours on a daily basis and also to prevent problem of power shortage, the possibility of running both conventional hydropower and PSH technologies in an SHP considered. Figure 2 describes the plant arrangement, showing the turbines, pump, reservoirs and the river I.

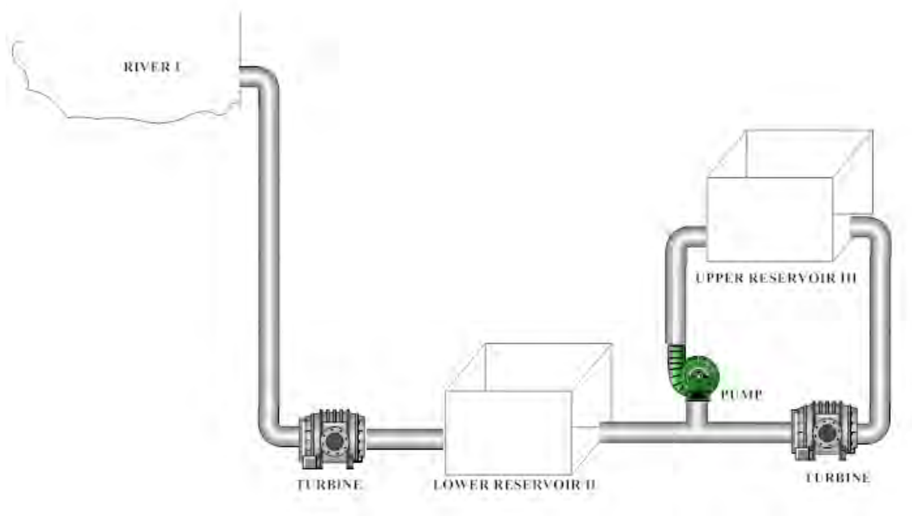

Figure 2. A sketch of the proposed PSH and hydropower hybrid power plant.

The primary source of power is the river run-off plant I. This plant is designed to work at all time.. During off-peak periods, excess electricity is to pump water from the lower reservoir II to the upper reservoir III as shown in Figure 2 because power demand is low, but released to run back into the lower reservoir through the turbines to generate electricity in peak demand period by converting the stored potential energy into electricity. Consumption patterns of South Africa as shown in Figure 3 are used. As shown , there are basically two peak periods and two off-peak periods per day. This proposed system may be installed as a standalone plant and at the same time may serve the main grid.

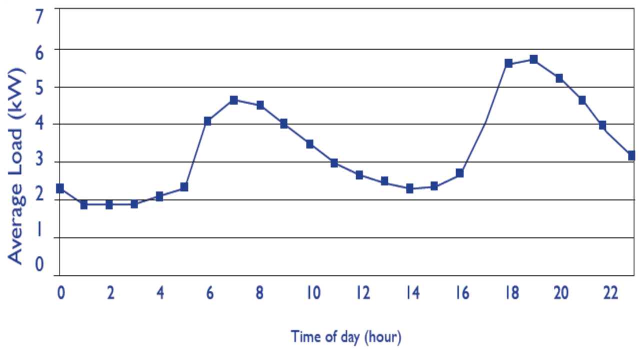

Figure 3. Average South African household daily electricity consumption pattern (28).

PSH eliminates most adverse and environmental effects associated with large energy development projects (29). The amount of energy that can be captured depends on the amount of water flowing per second (the flow rate) and the height from which the water falls (the head). Two main factors responsible for efficient and continuous generation of energy are:

i. Flow rate, which is the quantity of water discharged or flowing past a point at a given time, measured in cubic metres per second (m^3/s),

ii. Head, this is the vertical height in metres (m) from the level where the water enters the penstock to the level where the water leaves the turbine section

The controlling factor will be the number of working turbine per time. This is because, large quantity power cannot be stored and the main storage system is PSH. The task is now, how to compensate consumed power during pumping and have it delivered back during generation mode.

The following facts should be mentioned about the system;

i. This system is to model power generation using PSH.

ii. The design is a Pico PSH.

iii. It is controlled and ensurescontinuous generation.

iv. The system is fully hydro generation i.e, a combination of conventional and PSH generation methods.

v. The PSH system is powered by the hydro system to avoid the menaces of climatic impairments.

Therefore, the following will be put into consideration;

i. A flowing river of any discharge capacity since discharge can be increased.

ii. Generation during peak hours will be the combination of both systems.

iii. For this research the conventional method will be identified as ‗hydro plant' while the other is PSH.

iv. PSH is the controlling plant; it will release required energy to match demand as we know this system is to reduce energy waste during generation mode.

v. PSH is chosen because of the advantage of quick response to energy need.

vi. Generation at off peak will be hydro and certain addition from PSH.

Plant I will power pumping mode at off peak, especially at night when demand is lowest which will be released at peak time. The design does not at this stage take into consideration some exact values of necessary parameters such as; the number of units, turbine type, and turbine rated speed, losses and net head. Other ones not specified in the calculations include, maximum turbine discharge, generator type, generator related speed and generator capacity. This is because PSH is not normally implemented at SHP level, this is a kind of a generic model to investigate the possibility of running a PSH of small capacity. Flowcode, a graphical programming tool developed to design complex electronic system as shown in Figure 4 and Proteus, a programming software that integrates perfectly microprocessor models and animated components which help in combine simulation of whole microcontroller related designs are used to develop control for the proposed plant.

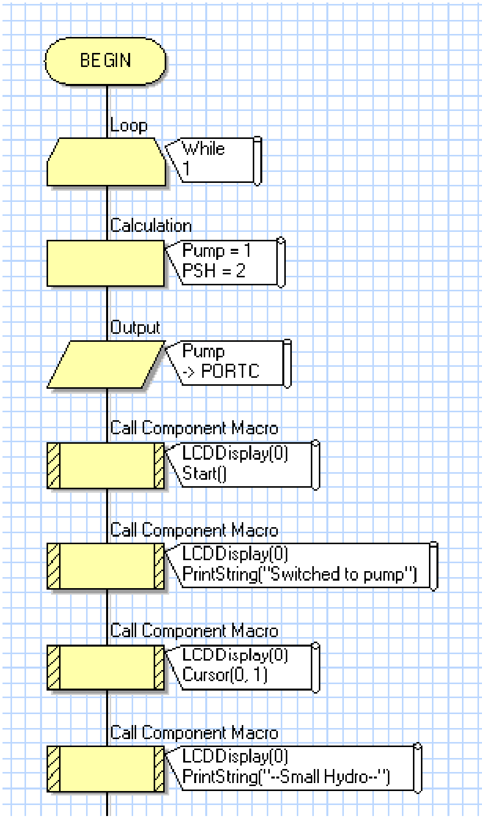

Figure 4. Flowcode V5 flow control chart.

Parameters used in the work were obtained from ICUE publication (30). Matlab-Simulink is used to simulate the parameters and results were obtained.

The output power at the hydro turbine of 80 % efficiency = 3.924 kW,low = 0.05m3/s, head = 10m.

The proposed design uses a non-reversible turbine of 80 % efficiency to generate power its PSH part and a separate pump efficiency is given as 85%;Mathematical Representation of the Design is given in (1) and (2) below.

$$P_g = \rho_w . g . Q_g . H_g . \eta \qquad (1)$$

$$P_p = \frac{\rho_w . g . Q_p . H_p}{\eta_t} \qquad (2)$$

From equation 2, the below can be written.

$$Q_p = P_p.\eta / \rho_w.g.H_p \qquad (3)$$

where

P_g = rated generating power at PSH,

η_t = turbine efficiency,

ρ_w = density of water in kg/m^3

G = gravitational constant in m/s^2

Q_g = rated generating flow in m^3/s at the PSH

H_g = rated generating head in m at the PSH = 5m

P_p = pumping power,

Q_p = pumping flow in m^3/s

η_p = pump efficiency,

H_p = rated pumping head in m to III = 5m

H_L = losses in the line pumping line to III in m.

Firstly, there is need to design parameters like the diameter of the suction and the delivery pipes. Calculating the flow is the first approach. From Figure 1, the first peak is about one-third of the primary generation,

Using test plant data,

From Equation 3,

$Q_p = \frac{1308*0.85}{1000*9.8*5} = 0.022 \ m^3/s$ second peak is about two-third of the primary generation,

Q_p = 0.022 m^3/s while at 2.616 kW, Q_p = 0.045 m^3/s.

Considering losses in the pipe, an average flow of 0.03 m^3/s is achieved for the lifting of water from the lower reservoir to the upper reservoir.

In 8hr pumping operation,

Volume to be lifted = 0.03*3600*8 = 864m^3

A pipe diameter that will account for losses not more that 10% hydraulic is selected,

0.2m for suction line and 0.15m for delivery line.

Surface area of suction pipe

$A_s = \frac{(0.2^2)*\pi}{4} = 0.03142m^2$ (4)

Surface area of delivery pipe

$A_s = \frac{(0.15^2)*\pi}{4} = 0.0177m^2$ (5)

But $V = \frac{Q}{A}$

Therefore $V_s = \frac{Q}{A_s} = \frac{0.03}{0.03142} = 0.955m/s$ (6)

And also, $V_d = \frac{Q}{A_d} = \frac{0.03}{0.0177} = 1.7m/s$

To generate losses in the pumping mode, there is need to find the friction factor *f* using the values of Reynolds number Re and relative roughness $\varepsilon/_D$. The value of ε for a steel pipe = 0.045*10^{-3}

$$\varepsilon/_D = \frac{0.000045}{0.2} = 0.225e^{-3}$$

Now calculating the Reynolds Re,

$Re_s = V_s * D_{s/}\vartheta$

ϑ, kinematic viscosity of water at 20°C = $1.004e^{-6}$

$Re_s = 0.955 * 0.2/1.004e^{-6} = 1.95e^5$

$Re_d = 1.7 * 0.15/1.004e^{-6} = 2.54e^5$

Using Moody's diagram and confirming with Simulink as shown in Figure 4,

$f_s = 0.015$

$f_d = 0.017$

Losses are calculated at the entrance, elbows, valve, pump, pipes (both suction and delivery) and at the exit. Details of this are not presented in this manuscript, but the values will be used in relevant calculations (31).

Major head losses h_{major}

$f * \frac{l}{D} * \frac{V^2}{2g}(K_{suction} + K_{delivery})$

$f_s * \frac{l_s}{D_S} * \frac{Vs^2}{2g} + f_d * \frac{l_d}{D_d} * \frac{Vd^2}{2g}$

$0.015 * \frac{3}{0.2} * \frac{0.955^2}{2g} + 0.017 * \frac{3}{0.15} * \frac{1.7^2}{2g}$

0.006975 + 0.0833

Minor head losses, $h_{minor,}$

$= \frac{V^2}{2g} * (K_{entrance} + K_{valve} + 2K_{bend} + K_{exit})$

$= \frac{V^2}{2g} * [(0.5 + f * \frac{Le_v}{D_v} + 2 * f * \frac{Le_b}{D_b} + 1)]$

For a gate valve, $f * \frac{Le_v}{D_v} = 0.019 * 8$

For the two elbows, $2 * f * \frac{Le_b}{D_b} = 2 * 0.019 * 30$

Total minor losses = 0.0232+0.0446+0.0838+0.0147

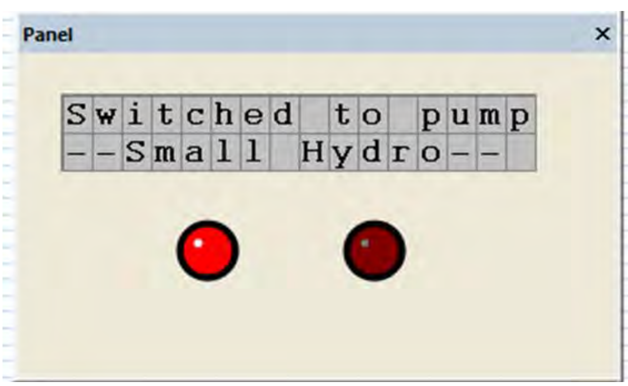

Figure 5. Plant operation indicator at pumping mode.

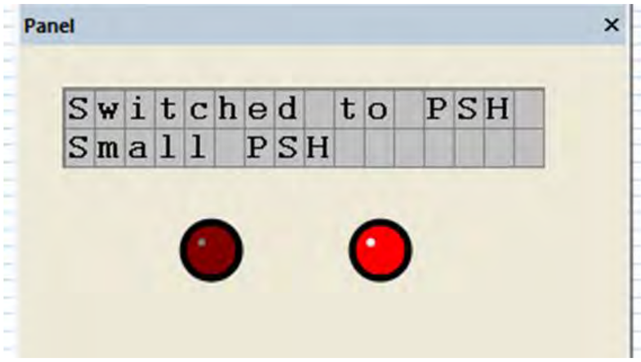

Figure 6. Plant operation indicator during PSH generation.

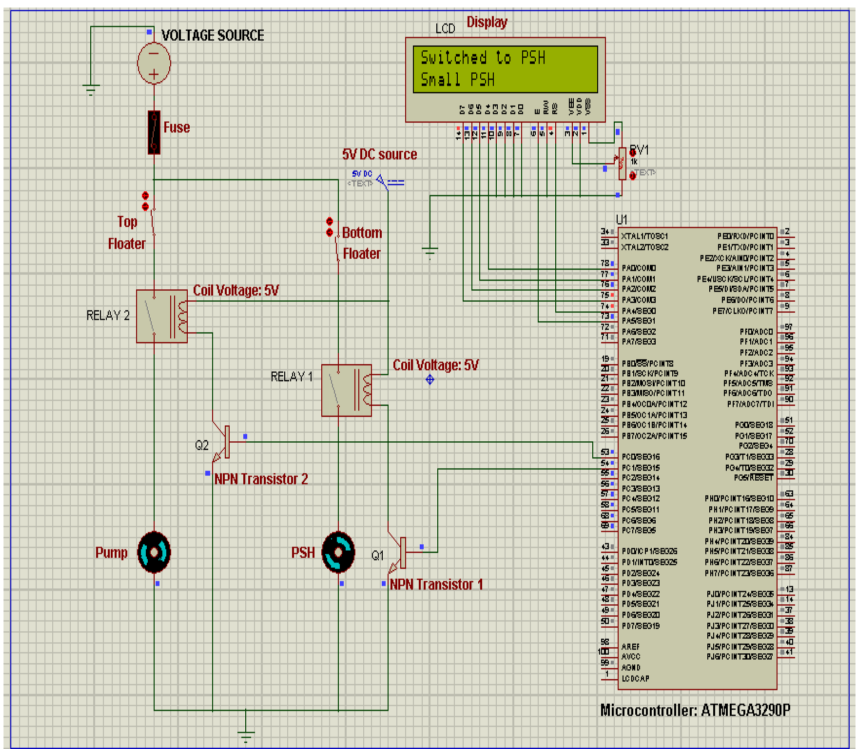

Figure 7. Proteus plant operation indicator model for volume control showing the two floaters on.

4. Results and Discussion

Considering Figure 3, unused electricity between the hours of 23:00 to 05:00 and 12 noon to 16:00 is used to pump water from II to III at a flow rate of 0.03 m^3/s for a minimum of 8 hours to allow adequate potential energy be stored in the upper reservoir III. With achieved total head of 5.3889 m, pumping mode will be able reserve 864 m^3 of water in III for generation between the hours of 06:00 to11:00 and also between 17:00 to 21:00. This can be sold at a higher price to compensate for the electricity loss during pumping activities.

Between 23:00 to 05:00, an average electricity of 2.616 kW is used in lifting water to III, but between 12 noon to 16:00 about 1.308 kW of electricity is available for pump to lift water to III. At the peak period with full upper reservoir III, out of the 2.6 kW used, 1.6 kW is recovered, all within the isolated system. There is need to note that as the water level in III reduces during generation mode. Generated power also reduces until it reaches a height of 2 m with a generation of 0.66 kW. With no storage in place, generated power from plant I will be wasted, but the integration of PSH made it possible to recover the energy when needed at a higher economic value. Figures 5-7 shows Flowcode V5 and Proteus indicators showing the operation of the system in the design. This will help the operator to know the working system per time and also easily prevent breakdown of the entire system.

5. Conclusion

PHS is a well-established technology for large-scale storage of electricity, its slow development has been due to a lack of topographically suitable locations and profitability. It has been identified as a major source for providing adequate electricity in developing countries either through conventional or pumped storage technology with topographically suitable locations, reducing investment cost thereby boosting long term profitability. A large percentage of SHP potential is untapped, which is a loss to society, most especially in Sub-Sahara Africa developing countries. The resources are enormous enough to provide needed electrical power to make life better, especially for people living in poor urban or rural areas in Africa. There will be an economy boost in developing these resources, therefore, need to involve private investors to participate in the development of the resources is vital.

There is also a ready market for generated power, as policies are on ground to encourage investors to explore hydro projects. Other renewable energy sources can be integrated to upgrade the generation and consumption into a smart grid system. With the introduction of PV, upper reservoir size may not be as wide as it was PSH only because PV will still supply power during the day, which is also the peak period while at night which is off peak PSH can be introduced for the required power need. This mitigates the intermittent nature of renewable energy generation. Availability of solar radiation in Africa is enormous and PHS is a well-established technology for large-scale storage of electricity. Its development in Africa means its domestic potential is yet to be exhausted.

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6.3.3 Scenario 3: Small hydropower and pumped storage Hybrid Plant C.

Publication 7:

Prospects for small pumped storage hydropower in South Africa

Samuel A.O. Ilupeju and Freddie L. Inambao.

GES Research Group, Mechanical Engineering Department, University of KwaZulu-Natal, Durban, South Africa.
Email: 213567986@stu.ukzn.ac.za, inambaof@ukzn.ac.za.
Phone: +27312608530, +27785405751

Abstract

Maximising power generation resources is an aspect that needs more development to achieve electricity for all the nearest future. It is obvious that small hydropower technology has needed potentials to ease increasing electricity demand, especially in the developing countries of the world. Small hydropower plant is combined with a pumped storage scheme to achieve peak electricity generation to be consumed within generation community. This will enhance viable economic activities within this community that has not benefitted from electricity consumption due to the grid scheme being far from them. Excess power from the river run-off hydropower plant at off-peak is used to store energy in the form of water in the upper reservoir. This is released at peak period when demand and cost is on the increase. Matlab Simulink is used to describe the relationship of different parameters involved. Though pumped storage is a consumer of power, the output power generated from the hybrid is absolutely worthwhile. This is best implemented in standalone hydropower sites.

Keyword

Pumped- storage, hydropower, small hydropower, renewable energy, power generation.

1. Introduction

Energy in the form of electricity is one of the most critical drives for socio- economic developments in any society. This, couple with the recent increase in electric power consumption require urgent attention to avoid preventable regular blackout and low shedding of the utility.

With the rapid depletion of materials used in conventional power generation, for example, coal and gas, there is an urgent and serious need to approach this high energy demand situation for societal development which will definitely enhance national power drive and ensuring timely, adequate, and clean, sustainable and environment friendly power delivery through establishment of renewable power generation methods (Klunne, 2013). This depletion in conventional power generation resources has resulted in energy institutions in search of other sources that can deliver such high power demand. Apart from the fluctuating generation processes, affordability and high capital commitment of government institutions are major challenges to list a few in ensuring electricity sustainability is maintained.

The whole world is reaching peak energy consumption level. The issue of power generation has become a huge burden on countries' power utility institutions, even in developing countries where a number of automobile companies have rolled out electricity powered vehicles. This has not left developing nations unconcerned as various African leaders are investing a lot of monetary commitment in power related projects to make available an affordable, reliable and sustainable quantity of electricity to all at all time. These qualities of electricity all play vital roles in its availability because it is geographically controlled based on the generating resource(s) available. Some of these resources include renewable energy sources (RES), natural gas, fossil, biomass, nuclear, to mention a few. Of the RES, wind, solar, hydro sources are known to be most available, but are distributed in different proportion because of its dependency on climate (Klunne, 2013). Arid land may be deficient of water, but be rich of high quantity of solar radiation and wind. Water availability is also distributed in different amount and resource should be employed based on availability to give room to maximum use.

RES are available, relatively cheap and are not consumed, unlike coal and gas, but the fundamental challenge of high initial cost has been a huge limitation to its implementation resulting in low RES employment for electricity generation. There are arguments on the sustainability of RES in electricity generation base on the need to meet the base load and possibly meet the peak load demand as well. RES difficulty in meeting the demands is basically due to resource fluctuation because most are climatically allocated or available. Though wind power and hydropower are really making waves in generation of reasonable quantity of power. In Southern Africa countries, wind, solar and hydro potentials are enormous to generate power in the form electricity for all. This does not just flow on its own; it has to undergo conversion processes for efficient harnessing of available quantity.

In this work, HP mode of generation will be involved in electricity supply through one of its conversion methods. As we know that HP systems are approached in two major technologies which are identical to one another in generation but with the inclusion of pumping mode for storage consideration which will be utilised at peak period to ensure base load demand is adequately met. Many researches have integrated many RES to form a hybrid system; some make a smart grid system either at the generation stage or at consumption stage. This work will not go into details of that now at this stage though forms part of the broad objectives. We limit this work to developing a strictly hydropower hybrid system, combining the conventional hydro system with pumped storage hydro system on a small river for a Pico HP hybrid plant with the main objective of maximising peak period power generation in the hybrid system. Other objectives include ensuring water reuse to overcome the drought effect in the season of low river flow.

A basic fact is that expected continuous development in developing countries may not be realistic because energy consumption is on the increase without a commensurate generation increase. This in some case as developed to increase in electricity price and blackouts. There is need to also understand that to commercialise distribution of substantially adequate electricity, there must be a balance in energy generation and management policies.

Hydropower as a renewable energy source

Advantages of hydropower implementation were categorised into three by (IHA., 2003), and given below as;

Operational Advantages of HP

These include, minimum cost of operation and maintenance, long life span (between 50 to 100 years and more), load flexibly, proven technology, creation of employment opportunities, highest energy efficiency rate, high level of working reliability, optimises power supply of other generating options when hybrid.

Social Advantages

In relation to its effect to humanity, hydropower utilisation is incomparable. Water is made available for other uses, efficient in flood control, enhances recreational facilities, and creates opportunities for involvement of local manpower both in construction and operation. Other ones are standard of living conditions is enhanced as livelihoods are sustained.

Environmental Aspects

A major challenge to health is pollution. A polluted environment is dangerous in the sense that once pollutants are released, every life within the range is exposed to the risk attached to its inhalation. Hydropower at small scale level does not release any contaminant either to the atmosphere or to water. Also, non-renewable fuel resources such as coal, gas, oil and biomass depletion is prevented. It also improves quality of hydrological activities, while ultimately does not deplete the water as it uses for electricity generation purposes.

2. Pumped storage overview in Africa

Hydropower implementation combines benefits across environmentally suitable technical inputs with moderate financial implications. From the look of things, especially in developing nations without gainsay, renewable energy resources is the future of efficient development of sustainable energy capacity. In fact, it provides the majority of supply in 55 countries. For several countries, hydropower is the only domestic energy resource (Yuksel, 2010).

About 24.4% of renewable resources are involved in electricity generation globally. 52.3% are consumed by residential industrial and public sectors. With hydropower supplying up to 87% of total renewable electricity worldwide, our focus is on optimising the resource (Mahmood et al., 2014).

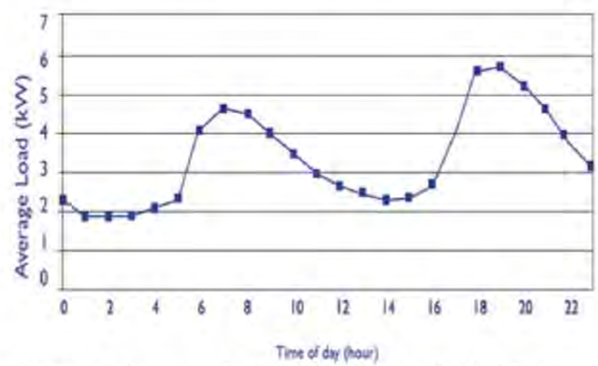

Figure 1. Average South African household daily electricity consumption pattern [11].

The electrical load is at peak in the daytime and low at night, this is an established fact as shown in figure 1. The design combines conventional hydropower tagged 'CHP' and the pumped storage hydropower plant in a small scale dimension, i.e. both plants are categorised under SHP for the purpose of this work . While CHP supplies electricity for the community at full capacity at all times, PSH supplies at a controlled rate to maintain demand load at all times. This is done by considering active turbine according to demand and if demand is at maximum, all turbine work, but if low redundant turbine(s) is/are shut. Good knowledge of environmental power consumption pattern is necessary to have an optimum efficient plant.

The design of the pumped storage hydropower is with a non-reversible turbine to address maximum generation at peak period based on the load demand so that required quantity of power is achieved within the operation time.

Energy stored in the upper reservoir is released into the penstock as needed per time, according to th consumption pattern in figure 1. The needed electric power demand will be met by engaging a number of turbines to deliver the expected quantity. This will serve as a control to power generation. It is the power needed that is produced.

The features involved in the small pumped storage hydropower system are as listed by (Hawaii, 2004) which this research will consider as a guide.

1. A penstock pipe to convey the water to the power house
2. A water turbine that converts the energy of flowing or falling water into mechanical energy that drives a generator, which generates electrical power – this is the heart of a hydropower generation system.
3. A control mechanism to provide stable electrical power.
4. Electrical transmission lines to deliver the power to its destination.
5. A tailrace through which the water is released back to the river or lower reservoir.
6. Low and high elevated reservoirs.
7. Pumps that transfer from low reservoir to high reservoir.

2.1 Hydro-Technology

Hydropower storage development should focus in finding pairs of reservoirs with high head differences and large storage volumes within a small distance. Based on this criterion, a GIS based mapping of the potential pump storage sites in Norway was created by (Zinke and Arnesen, 2013) to find the most promising pump storage hydropower plant locations within the whole country (Tilahun, 2009)

Power plant equipment selection is basically a function of the nature of the particular site characteristics. The head and the flow rate are the major factors while other factors include desired running speed of the generator and the ability of the turbine to generate power under reduced flow situations (Paish, 2002). Turbine efficiency depends largely on speed, head and flow rate. Turbines are classified as high heads, medium heads or low heads. Differentiating between the various classifications of turbines can be difficult because head is commensurate to size of the turbine. A low head for a large turbine could be a high head for a small turbine. Another reason is turbine type also affects the head, (Paish, 2002) e.g. a Pelton turbine for a 10 kW plant system may require a head of 50 m, whereas a 1 MW plant system requires a minimum head of 150 m. Mathematically, turbine speed is inversely proportional to the square root of the head. About 1 500rpm of speed is required by the turbine shaft to generate electricity and minimize speed change in the turbine-generator system arrangement (Paish, 2002). Therefore, faster turbines are required when a low head is needed. Turbines are further classified based on mode of operation as impulse or reaction type (Paish, 2002), (Kjølle, 2001). In impulse turbines, water enters into the runners at atmospheric pressure. The jets of water drive the runners which operate in air. Reaction turbines in contrast, have a rotor which is enclosed in a pressure casing fully immersed in water. The pressure difference across runner blades causes the runners to rotate. Pelton turbines are the major types of impulse turbine (Kjølle, 2001). Turgo and Crossflow are also Impulse turbines (Paish, 2002). Pelton turbines operate as a wheel with split buckets set around the rim and water hitting the wheel tangentially. Turgo turbines are similar to Pelton turbines in design, but the water jets strike the plane of the runner at an angle of 20°. Unlike Pelton turbines, interference of the incoming jet and the discharge fluid do not affect the flow rate and also, with equivalent power, Turgo turbines can have a smaller runner diameter than Pelton turbines (Paish, 2002). The choice of turbine and pump will not be explained in this work.

3. Proposed Design

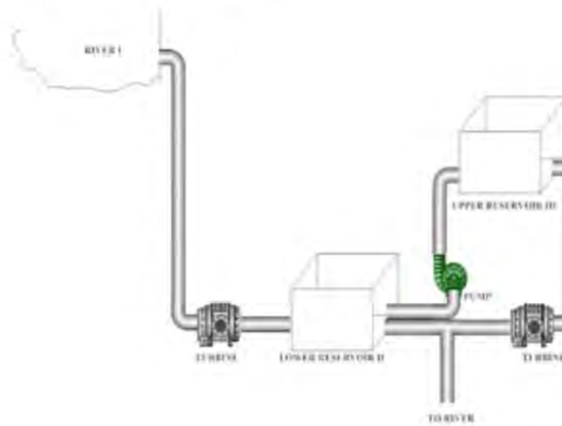

Figure 2. Proposed CHP and SHP hybrid plant

3. Method and Calculations

As described before, the hybrid combines both conventional hydropower with pumped storage hydropower technologies. As revealed in figure 2, river I powers the entire system as generation of electricity is achieved. Water is released from the tailrace into the lower reservoir II. At off-peak, water in reservoir II is lifted by the pump into the upper reservoir III and be kept as potential energy to be released at a most peak period of the day when the economic value is higher. The design gives room for water reuse and at the same time for water to be released to the river to continue its course for other activities. Calculations to determine plant characteristics were carried out in order to achieve best plant design and at the same time Matlab Simulin was used to simulate parameters for optimum plant efficiency.

Data used in the course of this research were collected at the Centre for Research in Energy and Energy Conservation (CREEC), of the Makerere University in Uganda on the river run-off Pico hydropower plant constructed and operated for research purpose by the Centre. Some of the data are presented below.
The output power at the hydro turbine of 80 % efficiency = 3.924 kW
Flow = 0.05m3/s
Head = 10m
For this work;
Turbine efficiency of 80% will be used.
Pump efficiency of 85 % will be used.

First, using equations for hydropower generation mode and pumping mode.
Mathematically,

$$P_g = \rho_w . g. Q_g . H_g . \eta \quad (1)$$

$$P_p = \frac{\rho_w . g. Q_p . H_p}{\eta_t} \quad (2)$$

From equation 2,

$$Q_p = P_p . \eta / \rho_w . g. H_p \quad (3)$$

P_g = rated generating power at PSH,
η_t = turbine efficiency,
ρ_w = density of water in kg/m^3
G = gravitational constant in m/s^2
Q_g = rated generating flow in m^3/s at the PSH
H_g = rated generating head in m at the PSH = 5m
P_p = pumping power,
Q_p = pumping flow in m^3/s
η_p = pump efficiency,
H_p = rated pumping head in m to III = 5m
H_L = losses in the line pumping line to III in m.

Because of the two peak and two off-peak periods per day as revealed in figure 1, pump flow will be designed based on the pipe size which is calculated as a function of available power for pumping. Firstly, the diameter of the suction and the delivery pipes is designed. If the first peak is about one-third of the primary generation,
Using test plant data,

$$Q_p = \frac{1308*0.85}{1000*9.8*5} = 0.022 \frac{m^3}{s},$$

second peak is about two-third of the primary generation,

Q_p = 0.022 m^3/s while at 2.616 kW, Q_p = 0.045 m^3/s.

To consider for losses in the pipe, an average flow of 0.03 m^3/s is designed for the lifting of water from the lower reservoir to the upper reservoir.
In 8hr pumping operation,
Volume to be lifted = 0.03*3600*8 = 864m^3
This could be divided per average time of pumping activity.
A pipe diameter that will account for losses not more that 10% hydraulic is selected,
0.2m for suction line and 0.15m for delivery line.
Surface area of suction pipe

$A_s = \frac{(0.2^2)*\pi}{4} = 0.03142m^2$

Surface area of delivery pipe

$A_s = \frac{(0.15^2)*\pi}{4} = 0.0177m^2$

But $V = \frac{Q}{A}$

Therefore $V_s = \frac{Q}{A_s} = \frac{0.03}{0.03142} = 0.955m/s$

And also, $V_d = \frac{Q}{A_d} = \frac{0.03}{0.0177} = 1.7m/s$

To generate losses in the pumping mode, there is need to find the friction factor f using the values of Reynolds number Re and relative roughness $\varepsilon/_D$.
The value of ε for a steel pipe = 0.045*10^{-3}

$$\varepsilon/_D = \frac{0.000045}{0.2} = 0.225e^{-3}$$

Now calculating the Reynolds Re,
$Re_s = V_s * D_s/\vartheta$
ϑ, kinematic viscosity of water at 20°C = $1.004e^{-6}$
$Re_s = 0.955 * 0.2/1.004e^{-6} = 1.95e^5$
$Re_d = 1.7 * 0.15/1.004e^{-6} = 2.54e^5$
Using Moody's diagram and confirming with Simulink as shown in figure 4,
$f_s = 0.015$
$f_d = 0.017$

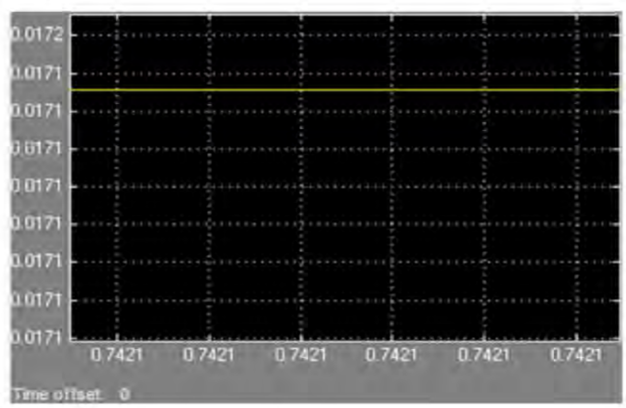

Figure 3. Simulink output for f_s

Losses are calculated at the entrance, elbows, valve, pump, pipes (both suction and delivery) and at the exit. Details of this are not presented in this manuscript, but the values will be used in relevant calculations.

Major head losses h_{major}

$$f * \frac{l}{D} * \frac{V^2}{2g}(K_{suction} + K_{delivery})$$

$$f_s * \frac{l}{D_S} * \frac{Vs^2}{2g} + f_d * \frac{l}{D_d} * \frac{Vd^2}{2g}$$

$$0.015 * \frac{2}{0.2} * \frac{0.955^2}{2g} + 0.017 * \frac{3}{0.15} * \frac{1.7^2}{2g}$$

$$0.006975 + 0.0833$$

Minor head losses, h_{minor},

$$= \frac{V^2}{2g} * (K_{entrance} + K_{valve} + 2K_{bend} + K_{exit})$$

$$= \frac{V^2}{2g} * [(0.5 + f * \frac{Le_v}{D_v} + 2 * f * \frac{Le_b}{D_b} + 1)]$$

For a gate valve, $f * \frac{Le_v}{D_v} = 0.019 * 8$

For the two elbows, $2 * f * \frac{Le_b}{D_b} = 2 * 0.019 * 30$

Total minor losses = 0.0232+0.0446+0.0838+0.0147

4. Results and Discussion

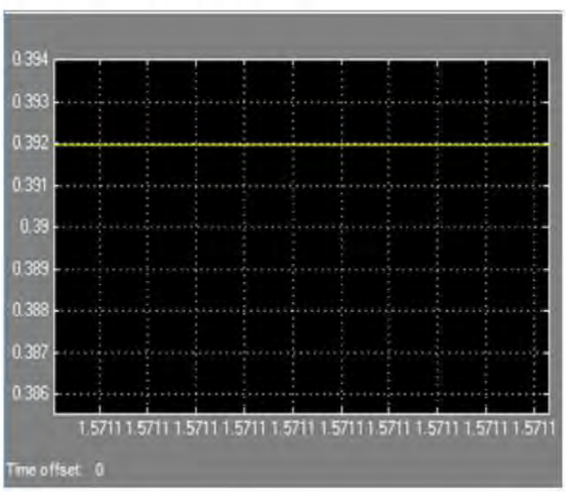

Figure 4. Shows a Simulink diagram to calculate total pumping losses.

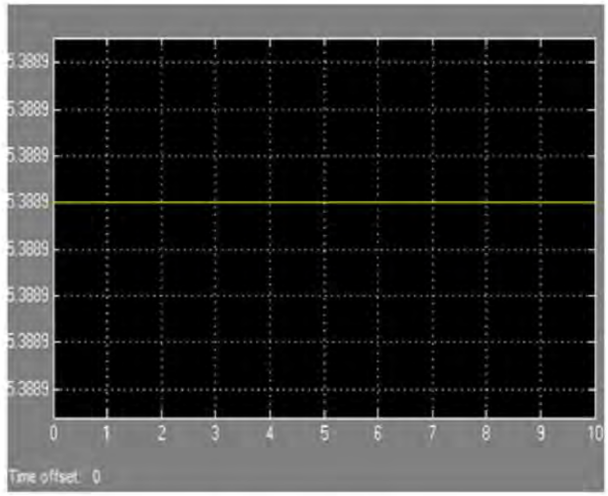

Figure 5. Shows total head with losses

Figure 6 shows that at a total head of 5.39m, the primary power source generation is 3.924kW. With off-peak excess between 23:00 to 05:00 hours an average of 2.6kW will lift up to 864m^3. At both off-peak times, an average of two-third and one-third of generated power is available for pump operations, this is shown in figure 7 and figure 8 respectively.

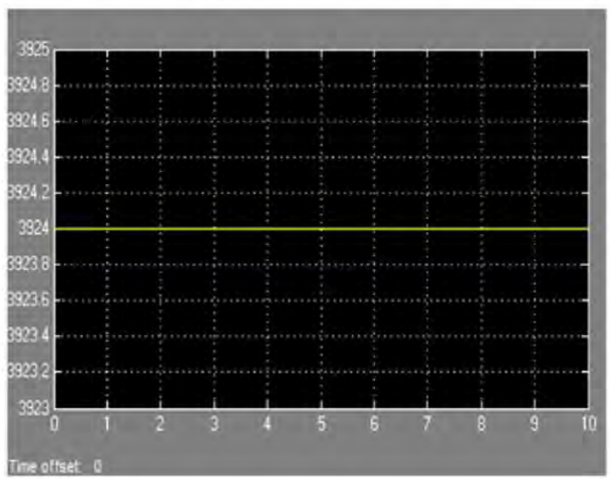

Figure 6. Output power from the run-off hydro plant

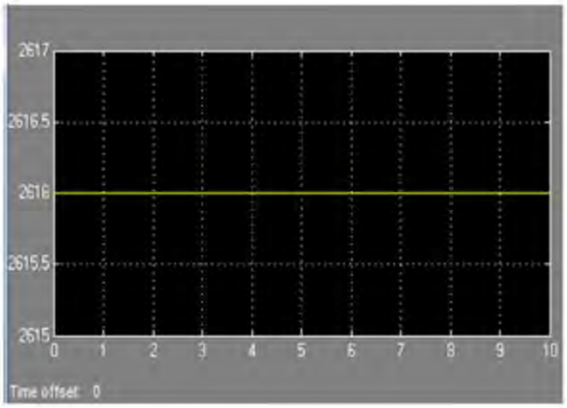

Figure 7. Shows pump input power at 2/3 generation

Figure 9 revealed the recovered power at maximum reservoir III capacity. 1.6kW is available to enhance distribution of 3.9kW from the primary HP source at peak period. Though the generation at the PSH decreases with decrease in water level at III, figure 10 shows 0.66kW is still achievable.

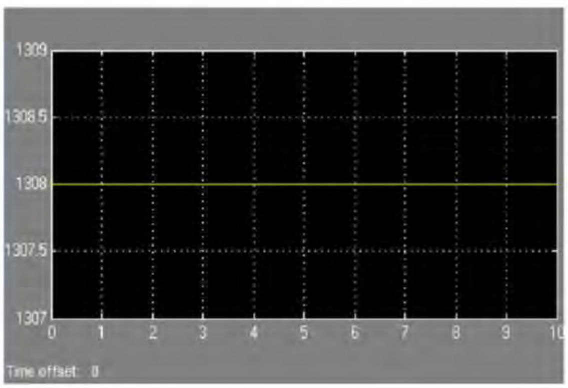

Figure 8. Shows pump input power at 1/3 generation

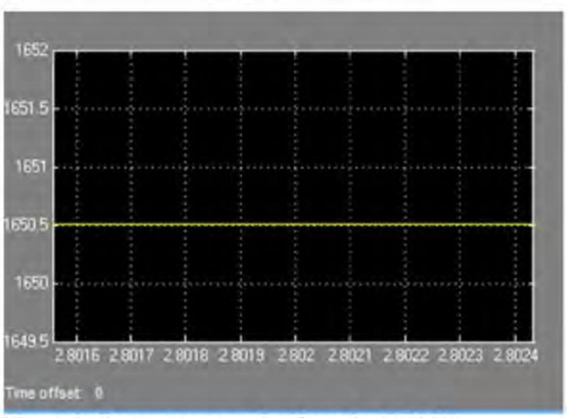

Figure 9. Output power at 5m from the PSH III

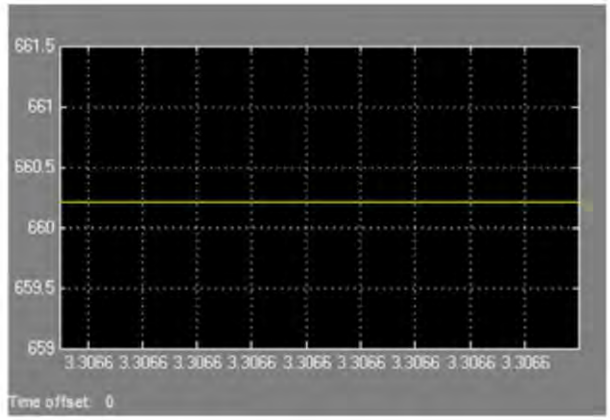

Figure 10. Output power at 2m from the PSH III

5. Conclusions

Even though policy guiding electricity in South Africa is a centralised one, where all generations feed the national grid. Isolated generation and consumption that will eradicate the challenges of long distance transmission losses and non-spread of the main grid to remote communities will be solved. Distribution and transmission of power through the main grid has been identified to contributed up to 9% losses in generated power (ITU, 2012). Another important contribution of maximum exploitation of water resource is flood control. In some parts of the globe, floods have resulted in unquantifiable magnitude of losses both to life and properties. Other geographical locations suffers drought of several degrees due to uneven distribution based on season and location factors. This should give us a picture that water resource as a topic is necessary for proper planning if humanity. But it is obvious from experience and knowledge that one of the technical ways to maximise water use is reservoir operation either as man-made or natural dams.

With the results obtained from the simulation, it is obvious that integrating PSH to existing small hydropower facilities will boost electricity generation in Africa, especially in South Africa, where potentials of SHP is high.

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CHAPTER 7 : RESEARCH MODEL DESIGN

7.0 Introduction

The research is divided into four basic parts and these parts are working together to achieve a design most suitable for every geographical location. The aspects of the research are:

- ***Design***: this involves the arrangement scheme of how the plant will look like.
- ***Modelling***: mathematical representation of the design.
- ***Simulation***: observe behaviour of the system by altering some of the parameters in a process of optimising.
- ***Control***: operation of the plant using electromechanical devices and sensors to ensure the desired output performance is achieved without the need of human inputs.

The results obtained will be discussed in Chapter 8 and will form the output of the work. This design is a continuous working system. The controlling factor will be the number of working turbine per time. This is because, large quantity power cannot be stored and the main storage system is PSH. The task now is, how to compensate consumed power during pumping and have it delivered back during generation mode.

7.1 Energy Demand Pattern

Energy consumption rates differ with seasons and with time of the day. By season, the energy rate change is provided in the Table 7.1. Summer is the low demand time while winter is the high demand time. The daily electricity consumption pattern is portrayed in Figure 7.1.

Table 7.1: South African energy consumption rate by season and time of demand [123]

Cost	Minimum Demand Season (summer)	Maximum Demand Season (winter)
Peak c/kWh	65.86	174.87
Off-peak c/kWh	43.89	55.10

Figure 7.1 depicts how an average South African household consumes electricity on a daily basis. Let the values on the figure be divided into four segments. The primary hydro is expected to supply 300 kW of

electricity to its consumers and this will take care of about three-quarter of the total consumption. Out of this value one third is consumed between the hours of 12 midnight to 04:00. About two-thirds is needed between the hours of 11:00 to 16:00. These two periods will be the pump mode period.

Figure 7.1: The pattern of consumption of electricity in a typical South African home [123]

7.2 The Proposed Design

The proposed hybrid plant design is a micro hydro power plant size. The choice of average power generation is based on the target population and the power requirement of the target population. From in depth calculations based on average household consumption and a few cottage entrepreneurs in the target community, 300 kW is proposed. The design consumption is 100% dependant on the hydro electricity generation. As recommended in Chapter 6, the choice of research design is as a result of the outcome of the three scenarios presented in the chapter based on construction inputs, space, maintenance cost, and environmental impact.

The second scenario is chosen because of better generation output as a result of better pump and turbine efficiency. Also, there is a better maintenance structure, repairs can be performed on either of the two without necessarily disrupting generation or pump activity. During pumping mode, repair can be carried out on the turbine and also during generation mode. Work can be done on the pumps easily as shown in Figure 7.2. Another notable feature is that both the pump and the turbine connect to the lower reservoir using the same pipe, which reduces the cost of plant installation. Environmental impact and needed space are of moderate effect.

Less than half of the maximum energy consumption per day is consumed for about 8 hours between 2am-10am in Portugal [24]. The pattern is different in South Africa as shown in Figure 7.1 [123]. This will be one of the two pumping periods daily. The peak period is between 10am-4pm and 7am-10pm at night. From this analysis, we can conveniently have 8 hours of pumping into the upper reservoir to ensure filling. Also, we have 7 to 9 hours of extra power requirement from the PSH plant. From this we can allocate about 200 kW to pumping between the hours of 2am-8am, then 100 kW to pump between 8am-10am in order to have adequate generation quantity in the upper reservoir. We can calculate the volume V_p that can be pumped from the allocated power to pump water during the hours of pumping (this is done later in this chapter).

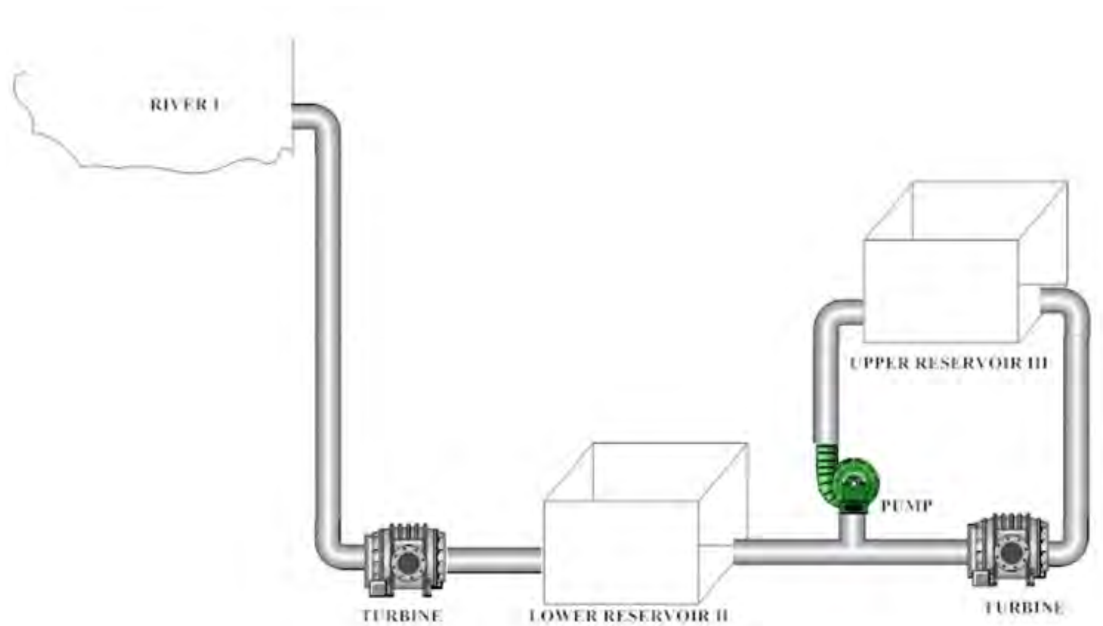

Figure 7.2: The proposed hybrid PSH plant design

There is a need to also identify that:

i. This system is to model power generation using hydropower and PSH hybrid.

ii. The design is a micro PSH.
iii. It is a controlled, continuous generation plant.
iv. The system is full hydro generated as a combination of conventional and PSH generation methods.
v. The PSH system is powered by the hydro system to avoid the menaces of multiple climatic impairments.

Therefore, the following will be taken into consideration:

i. A flowing river of suitable discharge capacity because discharge can be enhanced.
ii. Generation at the peak will be a combination of both systems.
iii. For this research the conventional method will be identified as ‗hydro plant' while the other is PSH.
iv. PSH is the controlling plant; it will release required energy to match demand per time as we know this system is to reduce energy waste during generation mode.
v. PSH is chosen because of the advantage of quick response to energy need.
vi. Generation at off peak will be hydro and addition of a certain amount of PSH.
vii. Hydro will power pumping mode at off peak, especially at night when demand is lowest, which will be released at peak time

It is an established fact that electrical load is at a peak in the daytime and low at night. While primary hydropower plant supplies electricity for the community at full capacity at all times, PSH supplies at a controlled rate to maintain demand load at all times. This is accomplished by considering active turbines according to demand and if demand is at maximum, all the turbines work, but if low redundant turbine(s) is or are shut.

A good knowledge of environmental power consumption patterns is necessary to have an optimally efficient plant. The design of the pumped storage hydropower is with a non-reversible turbine to address continuous flow back into the upper reservoir so that required quantity of power is achieved within the operation time. Energy stored in the upper reservoir is released into the penstock as needed per time. Since it is not a reversible turbine, the energy needed will be met by engaging a number of turbines that will deliver an expected quantity of power. This will serve as a control to power generation. It is the power needed that is produced. The features involved in a small pumped storage hydropower system are as listed by [124] which this research will consider as a guide.

7.3 The Design Components

i. Penstock to direct water to the turbine house.
ii. Water turbine to convert falling energy into mechanical energy.
iii. A system control device to ensure steady flow of electricity.
iv. Transmission lines to ensure generated power is delivered to expected consumer.
v. A tailrace to divert water from the turbine straight into the river.
vi. Pumps that lift water from the lower reservoir II to the upper reservoir III.
vii. Low and high reservoirs separated by the hydraulic head.

7.4 The Design Considerations

The first thing that needs to be considered in construction is the determination of the characteristics of the available water, namely, the height of the water source and the available water flow. Computing values for these will lead to the design and selection of the right equipment. Because most sites have peculiar characteristics which are needed in equipment selection, therefore, a specific set of parameters will be considered.

The higher the flow rate, the lower the pressure head and vice versa. This is vital in choosing the right turbine. This was reviewed comprehensively in Chapter 5.

$$P_g = \rho_w . g . Q_g . H_g . \eta_t \qquad (7.1)$$

$$P_p = \frac{\rho_w . g . Q_p . H_p}{\eta_p} \qquad (7.2)$$

From equation 2,

$$Q_p = P_p . \eta_p / \rho_w . g . H_p \qquad (7.3)$$

where:

P_g Rated generating power at PSH (kW)

η_t Turbine efficiency,

ρ_w Density of water (kg/m^3)

g Acceleration due to gravity constant (m/s^2)

Q_g Rated generating flow (m^3/s at the PSH

H_g Rated generating head in m at the PSH = 10m

P_p Pumping power (kW)

Q_p Pumping flow rate (m^3/s)

η_p Pump efficiency,

H_p Rated pumping head to reservoir III = 10m

H_L Losses in the line pumping line to reservoir III (m).

From equation 7.1:

$$Q_g = \frac{P_g}{\rho_w . g . H_g . \eta_t} \tag{7.4}$$

$$Q_g = \frac{300000}{1000 * 9.81 * 20 * 0.8} = 1.911 \text{ m}^3$$

$$V = \sqrt{2gH} \tag{7.5}$$

$$V = \sqrt{2 * 9.81 * 20}$$

$$V = 19.8 \text{ m/s}$$

$$Q = A * V \tag{7.6}$$

$$A = \frac{Q}{V} \tag{7.7}$$

$$A = \frac{1.911}{19.8}$$

$= 0.96 \text{ m}^2$

$$D = \sqrt{\frac{4A}{\pi}} \tag{7.8}$$

$$D = \sqrt{\frac{4 * 0.96}{\pi}}$$

$$D = 0.36 \text{ m}$$

Q	Flow (m^3/s)
V	Velocity of flow (m/s)
A	Surface area (m^2)
D	Inside diameter of the penstock (m)
f	Friction factor
g	Acceleration due to gravity (m^2/s)
L	Length of pipe in (m)

This is the theoretical diameter of the pipe, but the diameter is very small to generate the required power. Ideally, the losses should be less than 10% of the head. So, for a head of 20 m, the expected total head will be more than 19 m. For the plant design, the loss in the pipe is very small. Figure 7.3 is the Simulink model developed to compute the loss value

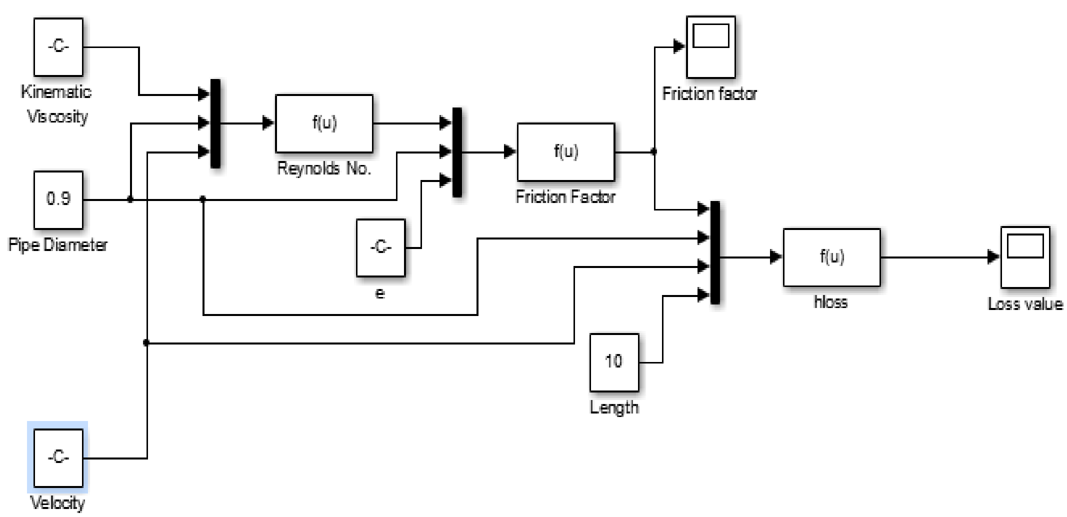

Figure 7.3: Computing loss in the generation pipe

h_L = 0.0727m

In order to achieve a reasonable pipe size, flow velocity should be minimised to between 1.5 m/s to 2.5 m/s [46]. By iteration, a velocity of 2 m/s was reached, therefore from,

$$D = \sqrt{\frac{4Q}{\pi V}} \tag{7.9}$$

$$D = \sqrt{\frac{4 * 1.911}{\pi * 2}}$$

$D = 1.22$ m

Therefore, the value of approximate inner diameter size is 1.2 m.

7.5 Proposed plant Parameters and Constants

The proposed hydropower plant characteristics are listed below:

- The turbine power generation output = 300 kW,
- Run-of river hydraulic head = 20 m
- Upper reservoir head = 10 m
- Pump efficiency = 0.85
- Turbine efficiency = 0.80

The constants used in the calculations include:

viii. Density of water at 20°C: 1 000 kg/m^3

ix. Acceleration due to gravity g, 9.81 m^2/s

x. Kinematic viscosity v, = 1.004 x 10^{-6}

xi. Relative roughness Ɛ = 0.045 x 10^{-3}

xii. Le/D value for a gate valve = 8

xiii. Le/D value for a 90° elbow = 30

7.6 Steps in Determining Design parameters

7.6.1 Allocate pumping power

At the first off-peak period, average available power for pumping from II to III = $\frac{2 * 300000}{3}$

= 200 kW

At the second off-peak period, average available power for pumping from II to III = $\frac{300000}{3}$

= 100 kW

7.6.2 Calculate the flow at each power requirement and estimate average pumping *Q*

At 200 kW,

$$Q_{p1} = \frac{200000 * 0.85}{1000 * 9.81 * 10} = 1.733\ \mathrm{m}^3/\mathrm{s}$$

At 100 kW,

$$Q_{p2} = \frac{100000 * 0.85}{1000 * 9.81 * 10} = 0.8665\ \mathrm{m}^3/\mathrm{s}$$

The two flows derived described the working flow at each available power. The plant cannot be designed for one purpose in mind and using it for another. It is more appropriate to design a specific plant size that will be effective for both power conditions. By iteration, a value suitable for both conditions is,

$Q_p = 1.2\ m^3$

From Figure 7.1, the minimum pumping duration is 8 hours while the SHP generation is about 7 hours daily. It is equally necessary to state categorically that this pumping power is not a constant value, but changes with consumption of power.

Now, calculating the volume that will be pumped in 8 hours,

$V = Q * time$

$V = 1.2 * 3600 * 8$

$V = \ 34560 \text{ m}^2$

This is the volume to be pumped into the upper reservoir III at different available power, flow and system efficiencies and will also help in calculating the height of both the lower reservoir II and the upper III. The period of electricity generation will determine the flow from III. Back to Figure 7.1, maximum generation above 300 kW from the primary source takes place in 7 hours. This time can be changed as the consumption pattern changes. For this work purposes, 7 hours will be used to design generation mode parameters.

For generation mode flow,

$$Q_g = \frac{Volume\ in\ reservoir}{Time\ taken\ to\ generate} \qquad (7.10)$$

$$Q_g = \frac{34560}{7 * 3600} = 1.37 \text{ m}^3/\text{s}$$

$$Q_g = \ 1.37 \text{ m}^3/\text{s}$$

Both generation and pumping modes flows have been computed.

It will be noted that all calculations done so far in this chapter have not considered losses in the pumping line and the generation line, most especially in the pumping line which includes the suction line, valve, corners, delivery pipe and the exit.

7.6.3 Calculate losses in the pumping mode

To calculate the major and minor losses as described in equations (7.12) and (7.13), both the suction pipe and the delivery pipe diameters should be computed bearing in mind that the design should bear not more than 10% of the total head. The design delivery head is 10 m.

The distance between the two reservoirs is derived using the perfect Pythagoras ratio, Hypotenuse: Height: Length at 5:4:3.

To reduce losses of lifting water from II to III and at the same time increase generation, the suction line is made the ratio 3 while the delivery line is 4. This gives the value of the suction line to be approximately 7 m. At this distance, water would have gathered the significant energy needed for the lifting.

Computing the suction diameter uses equation (7.9), but before this can be done, Matlab-Simulink is used to compute values for D_s and D_d to give total losses of less than 1 m.

The listed parameters are involved in determining design values:

D_s: Suction pipe diameter

D_d: Delivery pipe diameter

V_d : Velocity of delivery line

V_s: Velocity of suction line

Re_d: Reynolds no. of the delivery line

Re_s: Reynolds no. of the suction line

f_s: Friction factor of the suction pipe

f_d : Friction factor of the delivery pipe

Using modified Colebrook's equation, given as.

$$\frac{1}{\sqrt{f}} = -1.8 * \log\left[\frac{6.9}{Re} + \left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right] \quad (7.11)$$

The total losses h_L can be divided according to the point of occurrence.

Major head losses, $h_{major} = f * \frac{l}{D} * \frac{V^2}{2g} (K_{suction} + K_{delivery})$ (7.12)

Minor head losses, $h_{minor} = \frac{V^2}{2g} * (K_{entrance} + K_{valve} + 2K_{bend} + K_{exit})$ (7.13)

From this expression,

$$h_L \, \alpha \, \frac{V^2}{2g} \tag{7.14}$$

But from equation (7.6),

$$V = \frac{Q}{A} \tag{7.15}$$

Substitute (7.15) into (7.14)

$$= \alpha \, \frac{\left(\frac{Q}{A}\right)^2}{2g} \tag{7.16}$$

Also,

$$A = \frac{\pi D^2}{4} \tag{7.17}$$

Substitute the value of (7.17) into (7.16)

$$h_L = \alpha \, \frac{16Q^2}{2g\pi^2 D^4} \tag{7.18}$$

Introducing the constant k,

$$h_L = k \, \frac{16Q^2}{2g\pi^2 D^4} \tag{7.19}$$

$$D^4 = k \, \frac{16Q^2}{2g\pi^2 h_L} \tag{7.20}$$

Substituting the value of π and g,

$$D^4 = k \, \frac{0.0827Q^2}{h_L} \tag{7.21}$$

$$D = \sqrt[4]{\frac{0.0827kQ^2}{h_L}} \tag{7.22}$$

To compute *D*, *k* has to be known which can be represented as

$$k = f \, \frac{L}{D} \tag{7.23}$$

To compute further, an iteration to achieve about 1 m losses is to be done, a Matlab, Simulink equation was designed for the purpose, values of *D* were iterated in from 0.5 m upward to achieve the most suitable *k*. This is done following Figure 7.4 below.

7.6.3.1 First, use D to compute the value of V

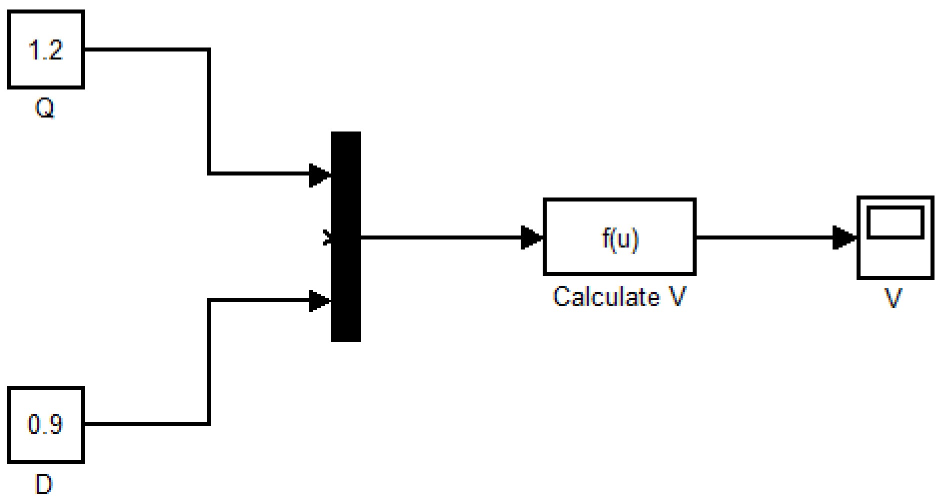

Figure 7.4: Simulink model to compute Volume (*V*) values

7.6.3.2 Generate the values of Re_s and Re_d

Reynolds number,

$$Re = \frac{V * D}{\vartheta} \tag{7.24}$$

$\vartheta = kinematic\ viscosity\ of\ water\ at\ 20°C$= 1.004x$10^{-6}$

$$Re_s = \frac{V_s * D_s}{\vartheta} \tag{7.24a}$$

Likewise, Re_d is calculated,

$$Re_d = \frac{V_d * D_d}{\vartheta} \tag{7.24b}$$

The relative roughness Ɛ = ε/D (7.25)

ε is usually constant for different engineering materials, but for a new steel, which is this research's option = 0.045 x 10^{-3}.

The computed values of V from Figure 7.4 will be substituted in equations (7.24) to find values for Re, likewise, the values of $\mathcal{E}_s$ and $\mathcal{E}_d$ computed. Both values are then configured into Figure 7.5 to find the values of the f_s *and* f_d.

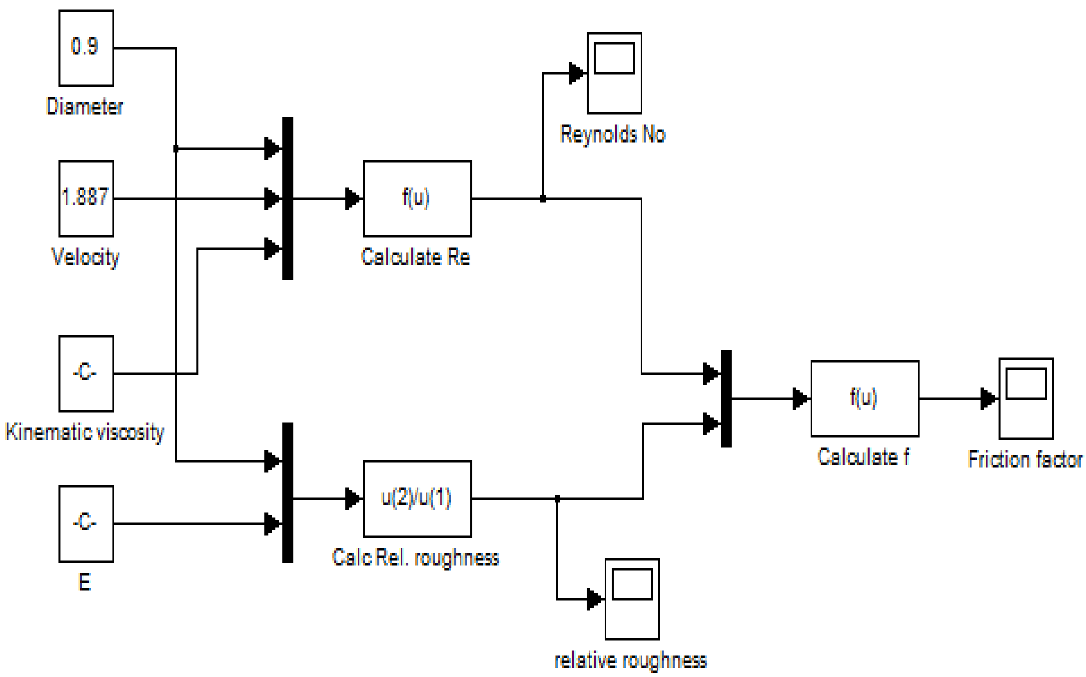

Figure 7.5: Simulink to compute *f* values at the points of losses

After computing values for V and f. Figure 7.5 now uses the generated values to compute h_L using another Simulink model.

7.6.4 Compute the value of h_L

i. Loss at the entrance, h_{L1},

$$= k_{en}\left(\frac{V_s^2}{2g}\right) \tag{7.27}$$

where $k_{en} = 0.5$

ii. Loss in the suction pipe, h_{L2}

$$= f_s * \frac{L_s}{D_s} * \left(\frac{V_s^2}{2g}\right) \tag{7.28}$$

iii. Loss at the gate valve, h_{L3},

$$= f_T * \frac{L_e}{D_v} * \left(\frac{V_d^2}{2g}\right) \tag{7.29}$$

iv. Loss at the two 90^o elbows, h_{L4}

$$= 2 * f_T * \frac{L_e}{D_e} * \left(\frac{V_d^2}{2g}\right) \tag{7.30}$$

v. Loss at the delivery pipeline, h_{L5}

$$= f_d * \frac{L_d}{D_d} * \left(\frac{V_d^2}{2g}\right) \tag{7.31}$$

vi. Loss at the entrance, h_{L6},

$$= k_{ex} \left(\frac{V_d^2}{2g}\right) \tag{7.32}$$

where $k_{ex} = 1$.

Matlab Simulink model in Figure 7.6 below explains step by step procedure of computing total losses in the pumping mode of the plant.

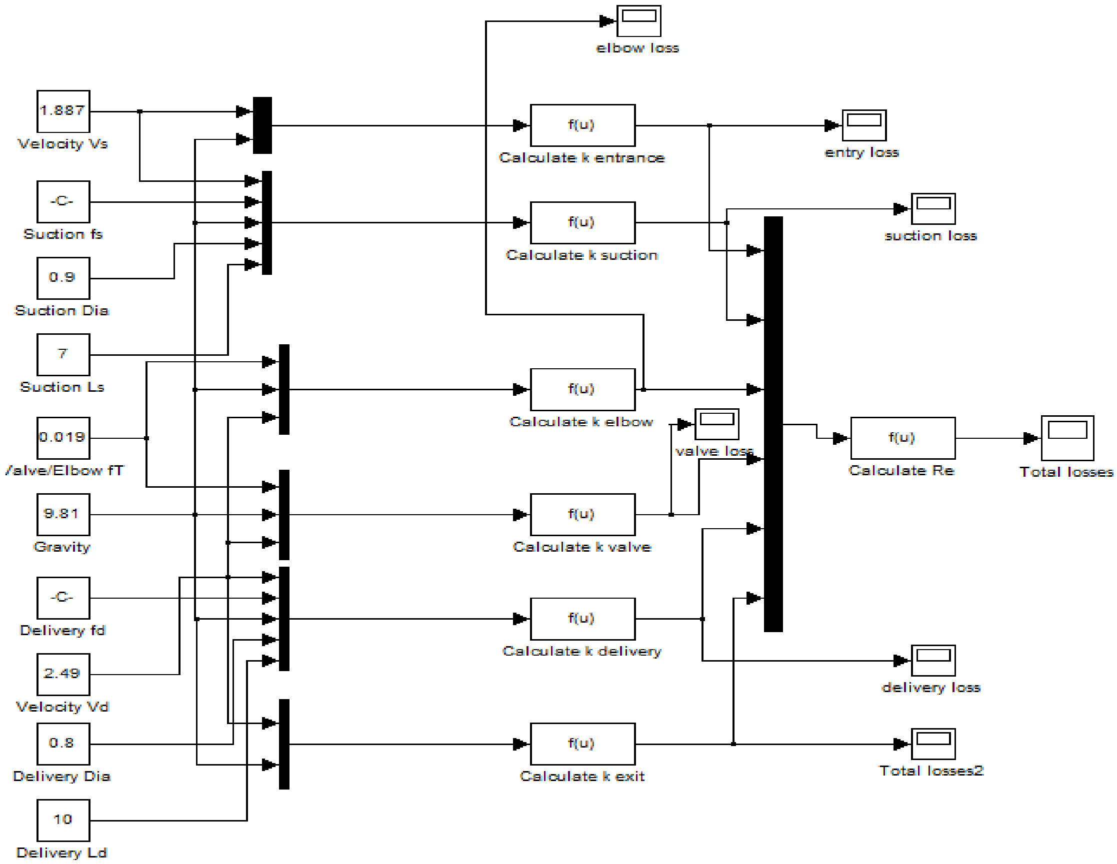

Figure 7.6: Simulink to compute the value of h_L

Results computed with the Simulink are given as:

$D_s = 0.9$ m

$D_d = 0.8$ m

$h_L = 0.879$ m

All these values computed will be used to design the proposed hybrid plant. Analytically, average power requirement for lift of water from II to III can be calculated using Equation 7.2.

$$P_p = \frac{1000 * 9.81 * 1.2 * 10.879}{0.85} = 150.668\ kW$$

This power required will not be available at every pumping period and that is why the valve has been placed to control volume per time that can be pumped at every possibility of unused excess power. At a low excess power, for example, 100 kW, a flow rate of 0.8 m^3/s is needed to accomplish this activity.

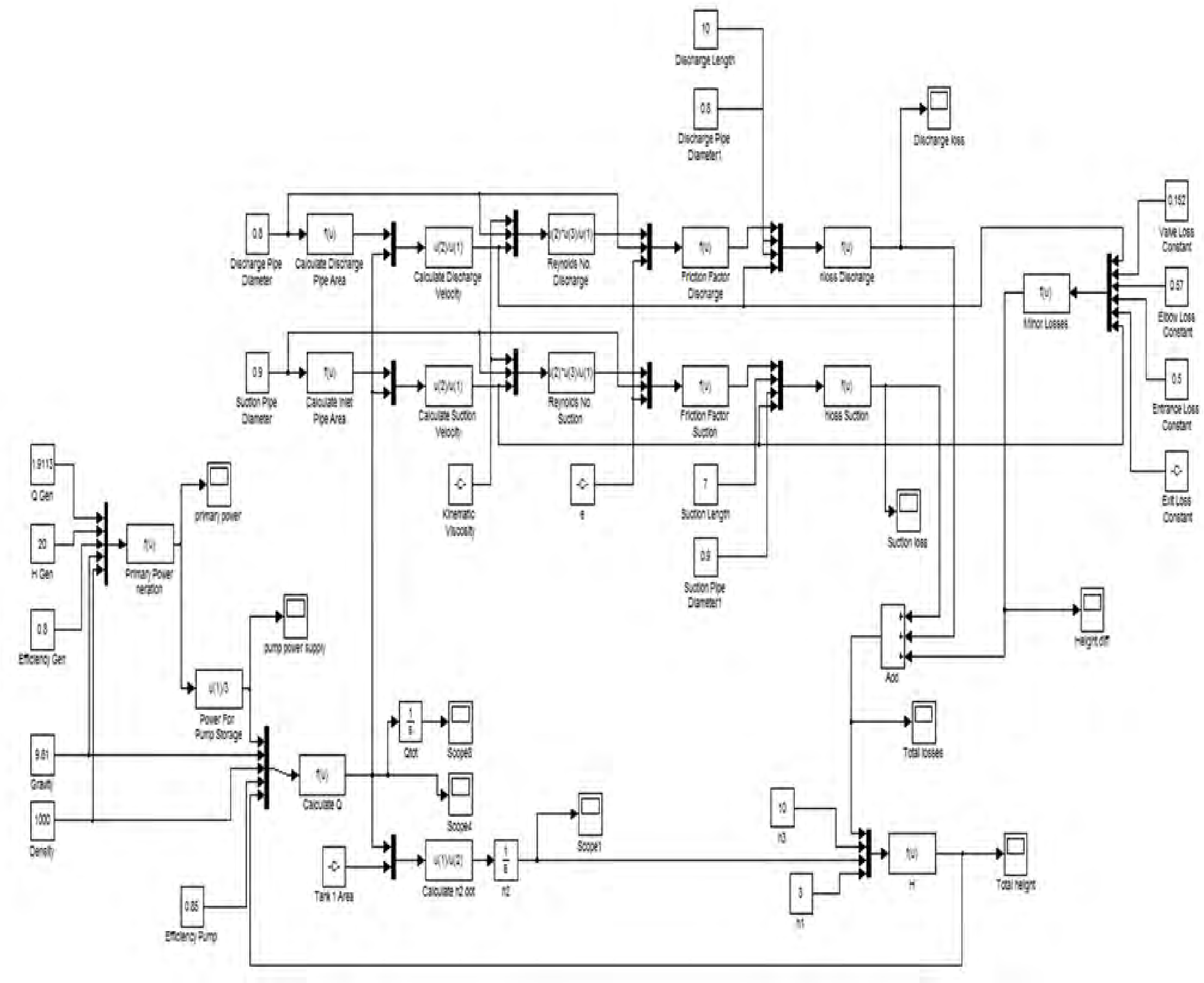

Figure 7.7: The primary power and the pumping mode model

7.6.5 PSH Generation mode Calculations

Generation height, H_g = 10 m + 3 m (Height of reservoir III at full capacity)

By considering losses in the generation pipe of PSH, iteration is conducted and output obtained using Figure 7.6. Figure 7.7 is the model developed to compute major design parameters during simulation. The result is described using Figure 7.8.

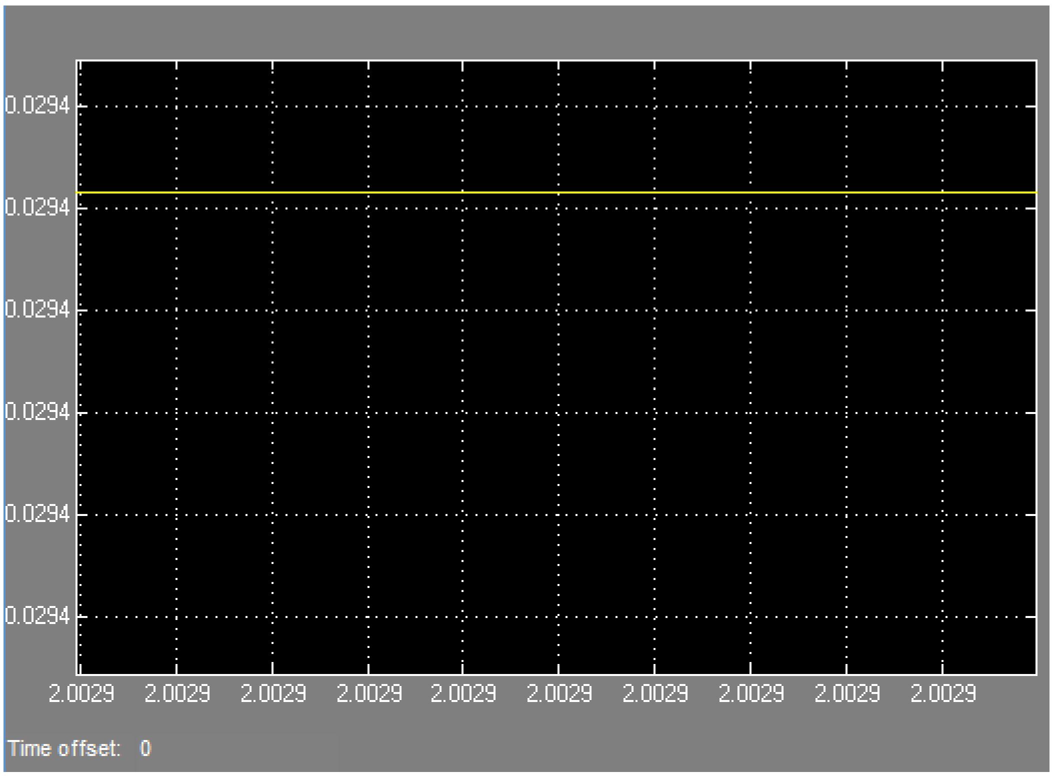

Figure 7.8: Loss in the PSH generation pipe

Turbine efficiency η_t = 80 %

Generation flow,

$$Q_g = \frac{Pumped\ Volume}{Generation\ time} \quad (7.33)$$

$$Q_g = \frac{34560}{7 * 3600} = 1.37\,\mathrm{m}^3/\mathrm{s}$$

Considering equation 7.1, generation at maximum reservoir efficiency with the listed values:

$$P_g = \rho_w . g . Q_g . H_g . \eta_t \qquad (7.1)$$

$$P_g = 1000 * 9.81 * 1.37 * 12.9706 * 0.8$$

$$P_g = 139.457\ kW$$

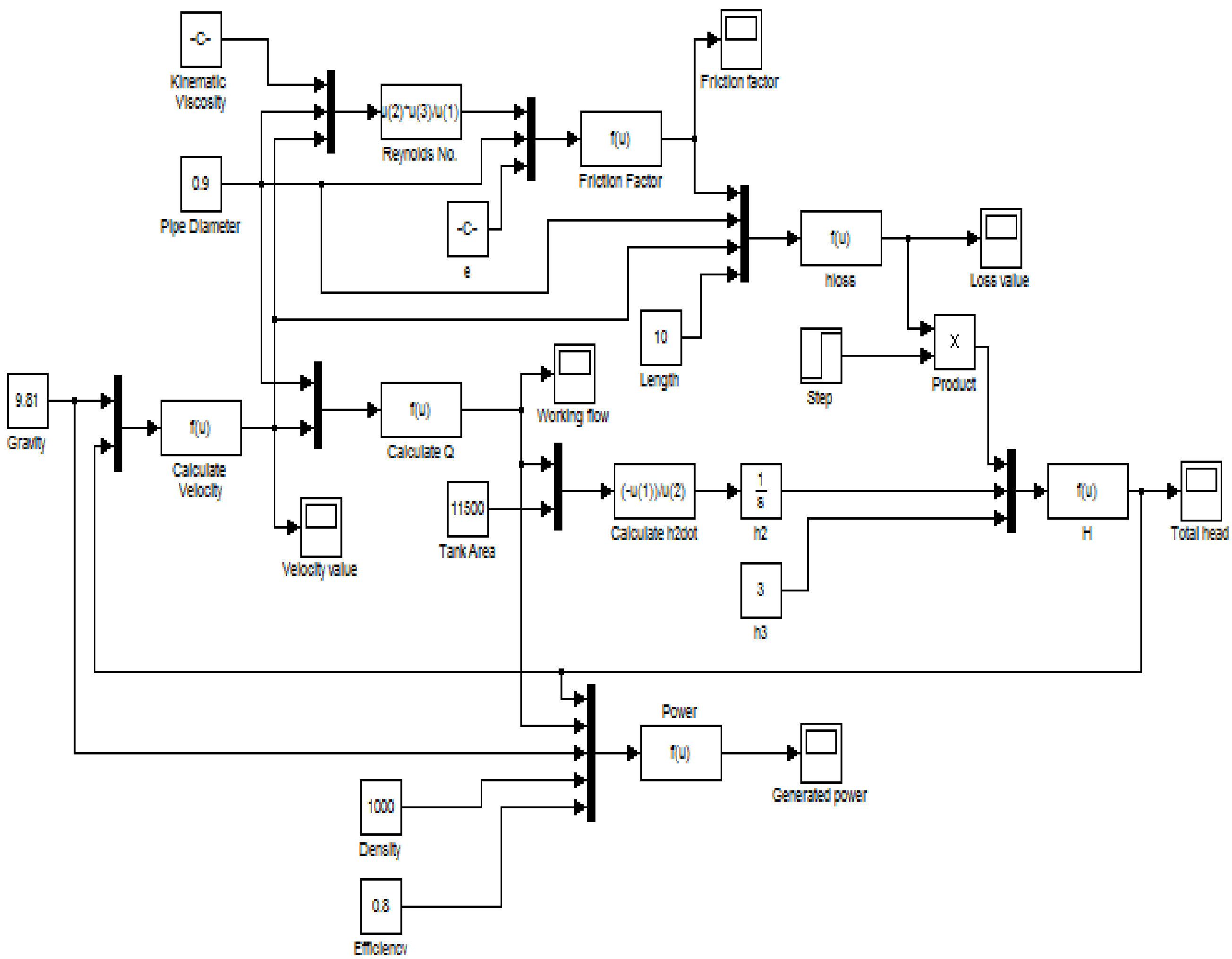

Figure 7.9: Pumped storage generation model

7.7 Model Simulation and Optimization

The behaviour of the system is observed by altering some of the parameters and in the process optimising the parameters using Figures 7.8 and 7.9. Final system design is carried out based on the outcome of the above modelling and simulation procedures. It may equally be demonstrated by testing parameters of design values in an existing small hydropower plant, existing PSH plant and to the value generated by the proposed design generated from Matlab. Seeking values of the design variables that best describe highest possible efficiency will lead to obtaining maximum value of the parameters to be optimised. Energy conservation is an important factor in designing a power system, especially in a stand-alone type. Therefore, what should be at the back of the mind of a power engineer is to put in place an ‗energy needed is energy generated' approach to overcome waste in the form of size, cost, and weight. One can then apply strategies that can be used to reduce the total amount of electrical power required to perform a given task.

There are other relevant parameters whose effects are slightly visible on the proposed hybrid plant. These include environmental conditions such as temperature, humidity and evaporation. These can affect the working condition of water because temperature has a direct effect on the density of water invariably affecting the working viscosity. Pump and turbine performance are also varied in the process.

This design is relevant in determining relevant parameters needed for plant sizing. It should be noted that the design is still subject to the topographical and existing layout factors of the proposed site for implementation of the project.

CHAPTER 8 : RESULTS AND DISCUSSIONS

8.0 Introduction

The design of the hybrid hydro plant was described in Chapter 7 considering relevant parameters. There is a need to also describe how the parameters affect one another as the plant begins to operate. The operation of the plant will be determined by the behaviour of the key factors. The relationship between these key factors will equally affect the plant efficiency. All these will be explained both in words and with relevant figures. Each of the systems that make the plant will be treated differently and also collectively for a thorough analysis.

8.1 Hydropower Plant

As expressed earlier, this study presents the drive by the authors to develop a hybrid hydropower plant. Different models and sub-models were developed using MATLAB Simulink to accurately generate analytic results that will properly describe the relationship and the interaction between connected parameters. The notable characteristic of the proposed model is the ability to operating as a complete standalone power generation plant. The plant is not limited to serving strictly as a standalone plant; excess generation may equally feed the main grid. The idea was to meet immediate customer demand first, then feeding the main grid as possible.

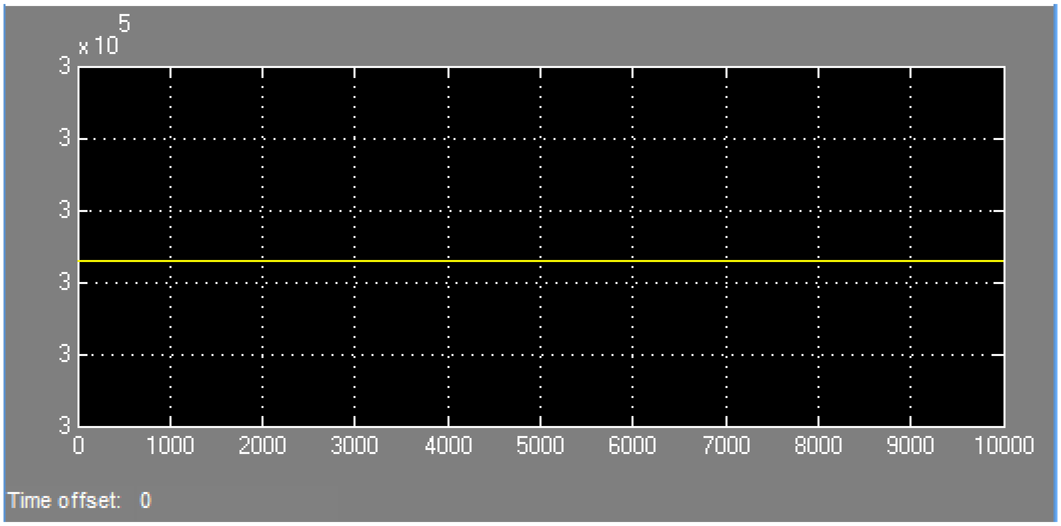

Figure 8.1: Primary power output of the hybrid plant

Figure 8.1 describes the detailed design output power of the proposed plant with capacity to generate about 300 kW. It is design with a flow that generates power continously and which is always available irrespective of the time of day. The source is from a dammed river.

8.2 Pump Mode

Obtaining plant diameter size and computing the losses in the pump mode line is the most critical aspect in the model. Based on the component parameters provided in Chapter 7, results from the Simulink models provide optimism regarding the effective implementation of the proposed design.

8.2.1 At two-third generation, 200 kW

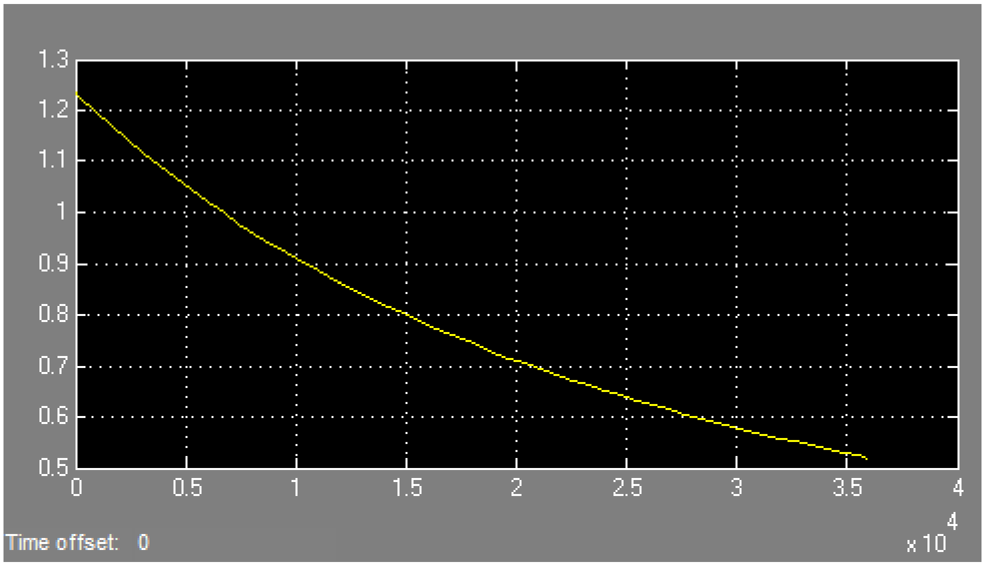

Figure 8.2: Overall losses during pumping operations

A major objective of this study was the sizing of the hybrid hydro plant. Figure 8.2 describes the detailed design of the total losses at peak period of the maximum available power and this shows the behaviour of the losses with time. This is brought as a result of the outcome of the friction factor both along the suction line and the delivery. Figures 8.3 and 8.9 describe the behaviour of the friction factor which reveals a good agreement between the two configuration results indicating that friction losses or factors reduce with increased pipe diameter.

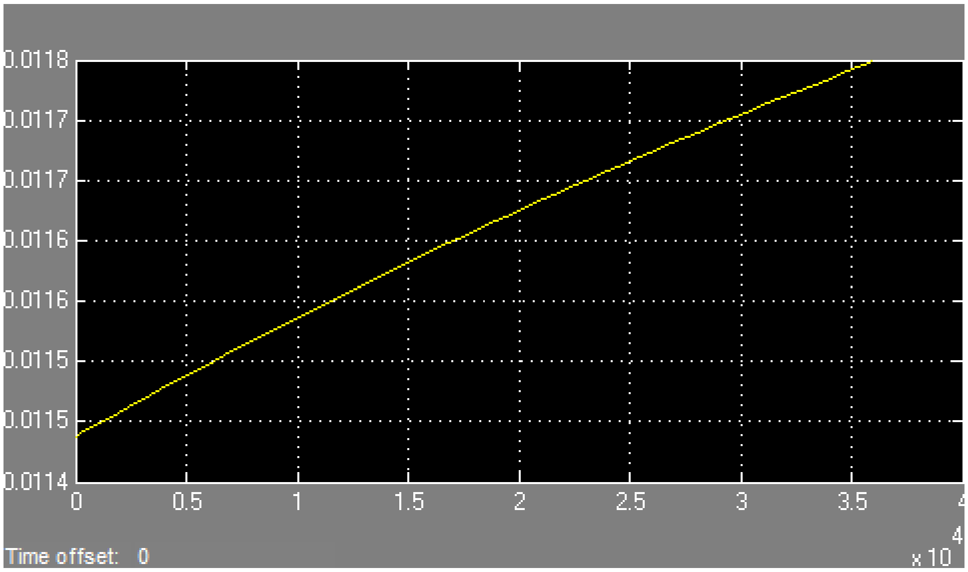

Figure 8.3: Friction losses in the discharge pipe

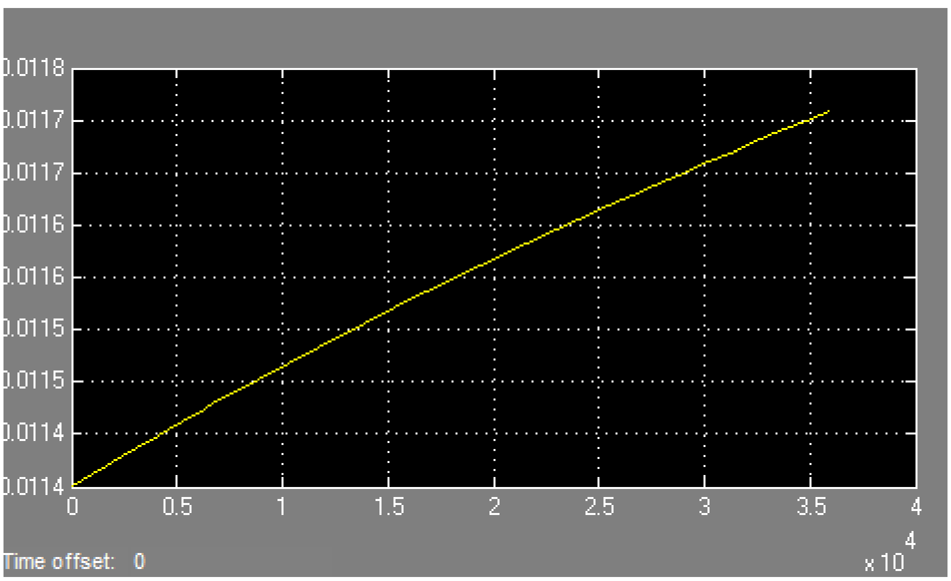

Figure 8.4: Friction losses in the suction pipe

At maximum pump power, Figure 8.5 depicts an increase in volume of III with time. Maximum tank volume is achievable within 1.8 x 10^4 seconds, which is about 5 hours. This is not achievable because power, flow rate and fluid velocity are not constant as seen in the Figures 8.5. Figures 8.6 and 8.7 describe the behaviour of volume and head as pump activity continues. Both volume and head increase with time while the flow decreases as expected with time as seen in Figure 8.8. Both the volume and the head will be attained within 5 hours of pumping from II to III.

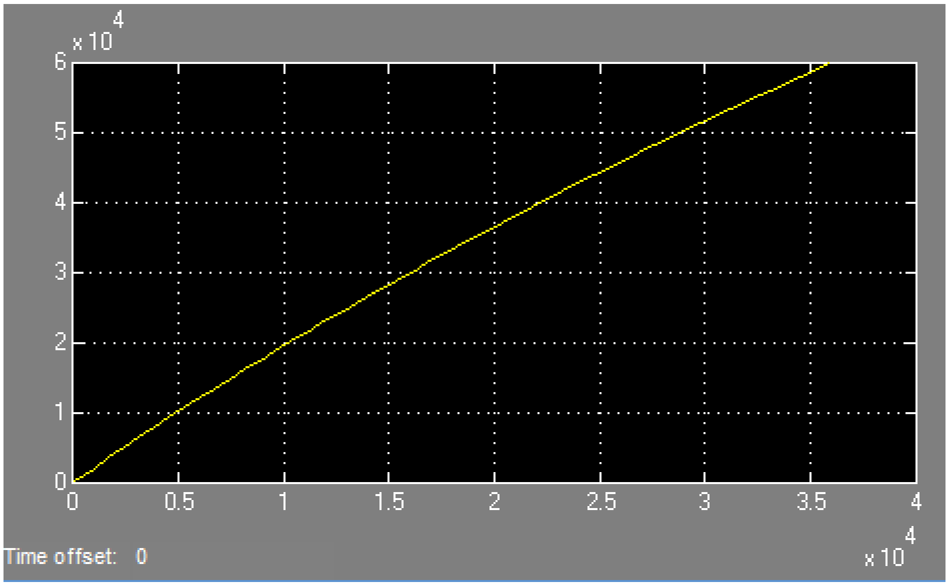

Figure 8.5: Volume pumped with time

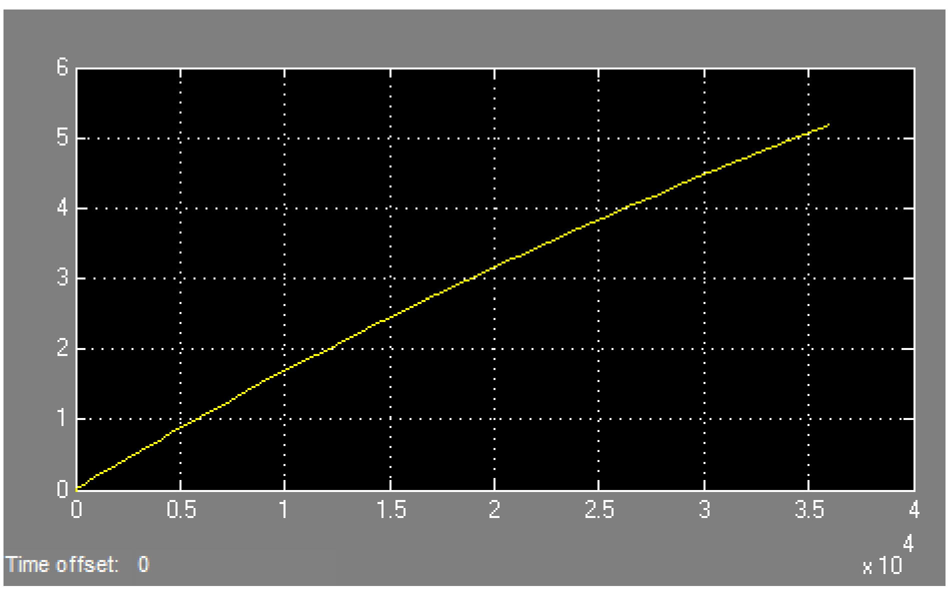

Figure 8.6: Attainable tank head during pumping mode

The simulation results reveal a significant reduction in the volume flow rate of the pump. This confirms that as the available power reduces, coupled with a proportional rise in the height of the upper reservoir III, which also indicate an increase in the total head, the flow reduces.

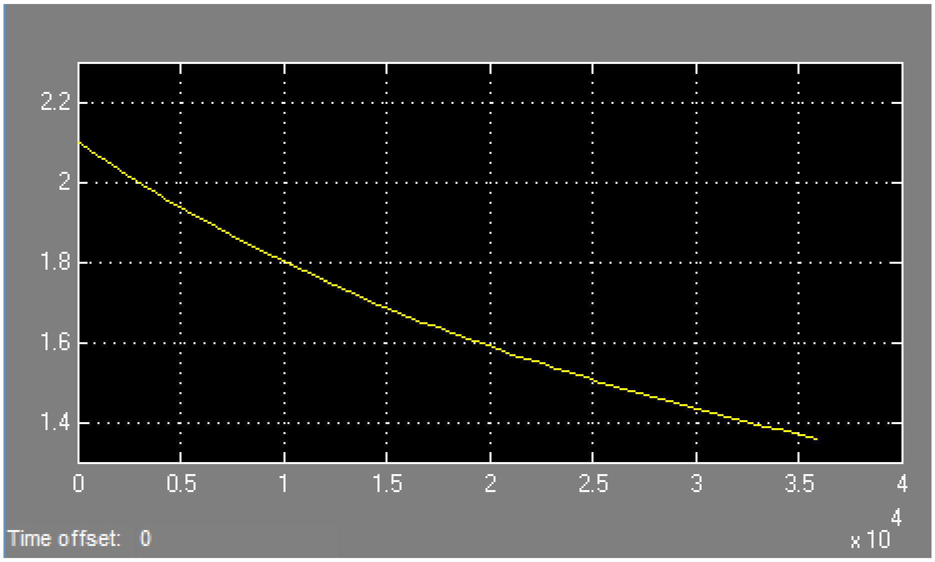

Figure 8.7: Flow in m3/s at maximum pump power

Table 8.1: The behaviour of selected parameters at 200 kW after 5 hours

D_s	D_d	V ($10^4 m^3$)	Q (m^3/s)	ΔH (m)	h_L (m)	H_T (m)	H^- (m)
1.2	1.0	3.50	1.680	3.00	0.293	10.350	0.259
1.0	0.9	3.40	1.660	3.00	0.480	10.450	0.415
0.9	0.8	3.317	1.6313	2.88	0.7435	10.623	0.635
0.8	0.7	3.16	1.583	2.75	1.200	10.950	1.000
0.7	0.6	2.925	1.500	2.548	2.013	11.555	1.6358

Table 8.2: The behaviour of selected parameters at 200 kW after 10 hours

D_s (m)	D_d (m)	V ($10^4 m^3$)	Q (m^3/s)	ΔH (m)	h_L (m)	H_T (m)	H^- (m)
1.2	1.1	6.1	2.3/1.4	5.4	0.55/0.2	7.6/12.5	0.48/0.1
1.0	0.9	6.0	2.2/1.4	5.2	0.85/0.32	7.9/12.5	0.74/0.28
0.8	0.7	5.8	1.95/1.35	4.9	1.8/0.85	8.8/12.75	1.55/0.72

D_s: Suction diameter
D_d: Delivery diameter
V: Volume in tank
Q: Volumetric flow
ΔH: Change in head
h_L: Total losses
H_T: Total head
H^-: Minor losses

Similar simulations were carried out using the developed models for different suction and delivery pipe sizes at different input power from the primary power source I to determine the most appropriate pipe sizes. A performance prediction model for the system at 200 kW, was conducted and the results expressed in Table 8.1 and Table 8.2.

The design suction and delivery diameters in this work are 0.9 m and 0.8 m respectively, based on the application of fundamental engineering equations with accounts in Chapter 7. The simulation results on the model show a very good degree of agreement. At larger pipe sizes, h_L values remain lower than the choice diameter with a progressive decrease as the diameter increases from 0.9 m to 1.2 m. At 1.2 m the value of the loss h_L has reduced to 0.293 which is less than the minor losses in the system. This value is not feasible in the design criteria. As the pipes diameters reduce from 0.9 m / 0.8 m, the values of the losses increase drastically to 2.013 m at 0.7 m and 0.6 m for both suction and delivery pipes respectively. At these pipe sizes, it is difficult to achieve the 34 560 m^3 reservoir III volume needed for optimum PSH generation. Likewise, the values of the head difference decrease with reduction in the pipe sizes. Another important parameter is the volumetric flow; the values obtained depict that with reduction in pipe sizes, flow also reduces bringing about an increase in the value of the corresponding head required to achieve the expected results.

8.2.2 At one-third generation, 100 kW

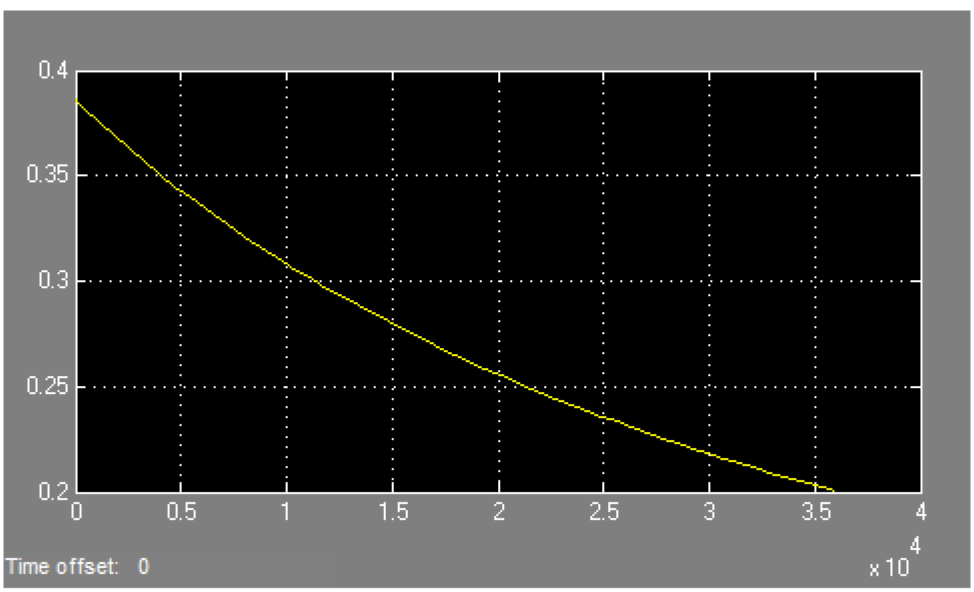

Figure 8.8: Overall losses in the pump mode at 100kW pump power

There is a considerable reduction in losses under the second model of available power of 100 kW taken from Figure 8.9. The control system will determine how the energy generation will flow. The automation described in Chapter 9 will be able to detect the right system to be switched on.

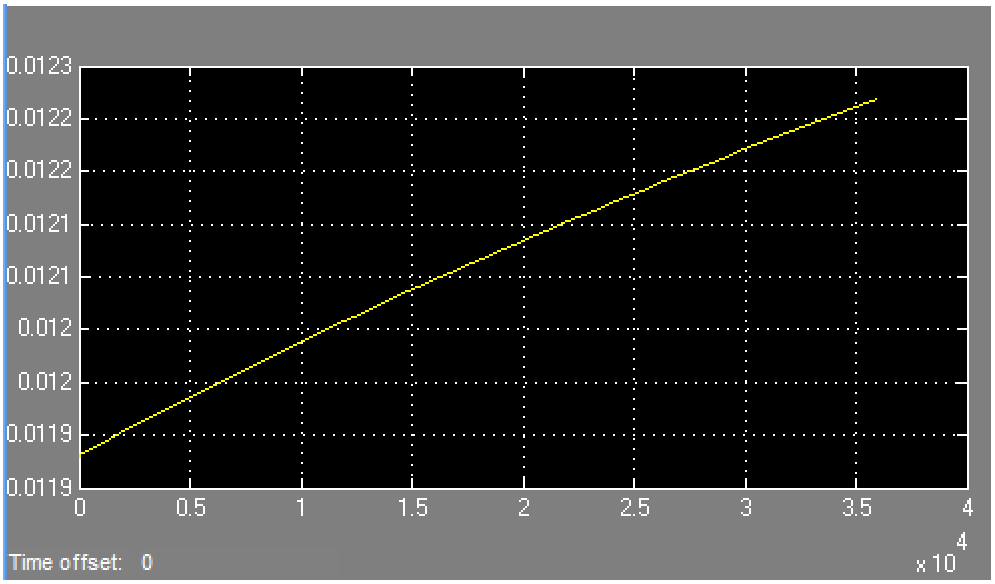

Figure 8.9: Friction losses in the discharge pipe

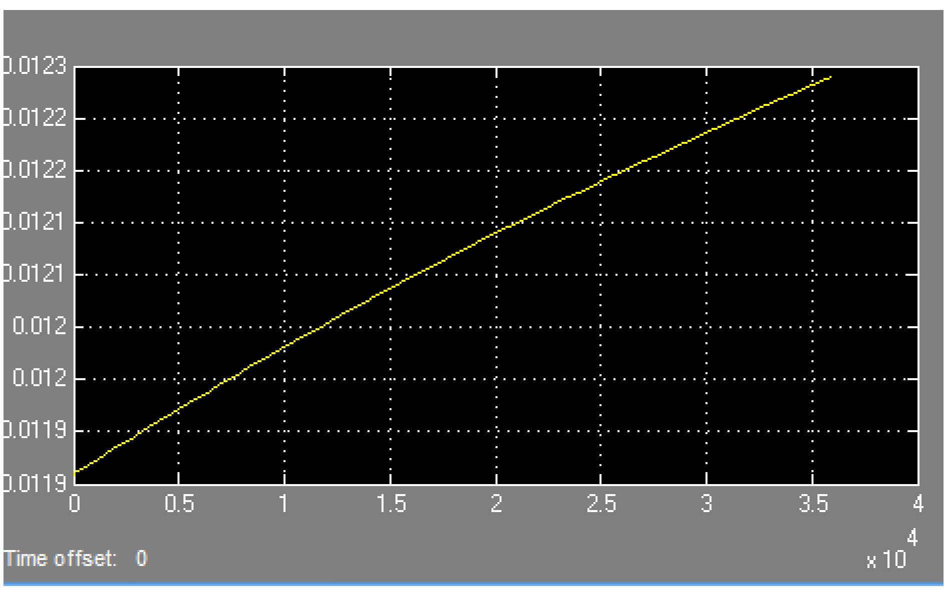

Figure 8.10: Friction losses in the suction pipe

The value of the friction factor increased at 100 kW which will invariably affect pump efficiency.

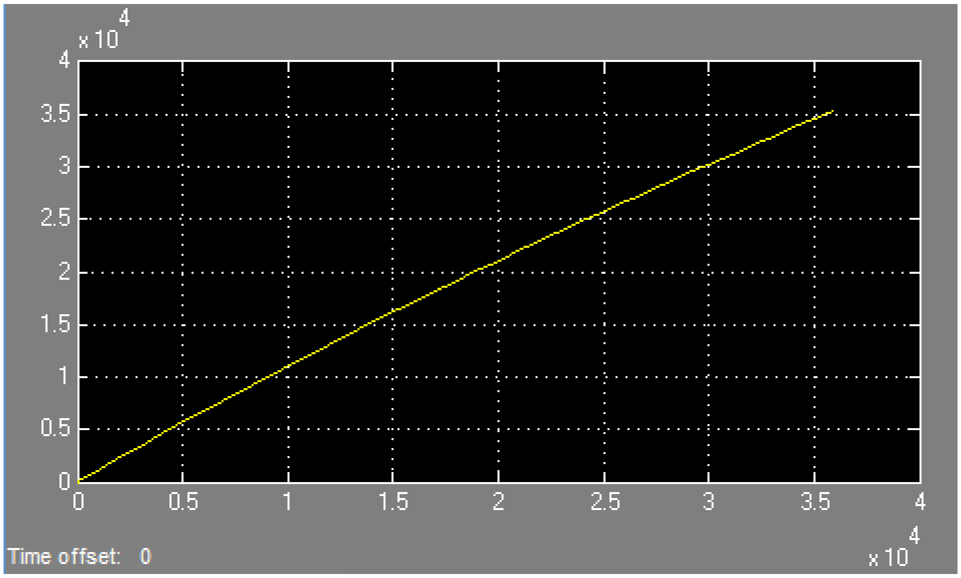

Figure 8.11: Volume pumped with time

It will take almost ten hours of pumping at the power required to achieve full reservoir capacity under this rate as seen in Figure 8.13. Both the head and the volumetric flow show similar behaviour with volume pumped apart from the flow reducing with time as described in Figure 8.14.

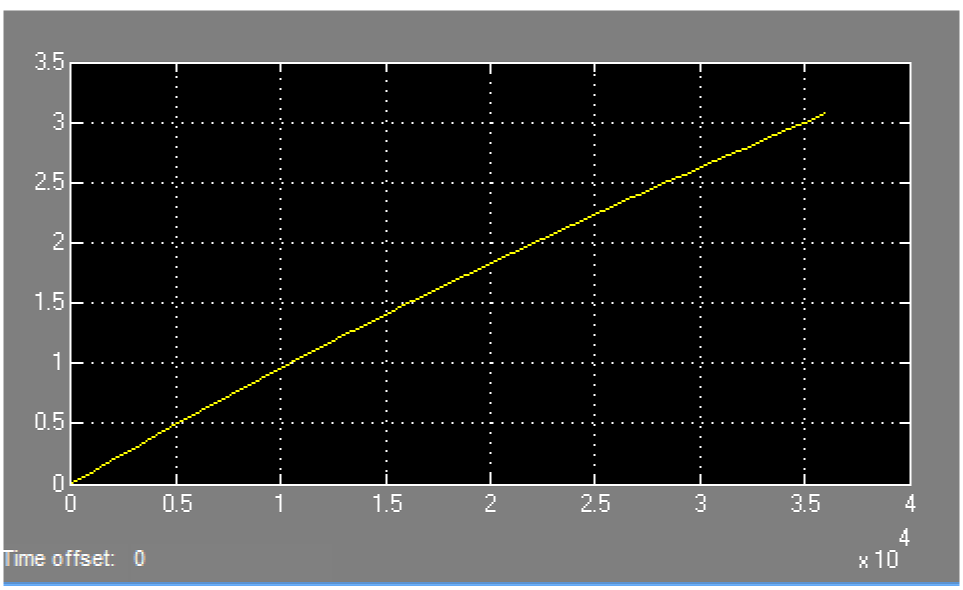

Figure 8.12: Tank head behaviour during pump mode

The flow reduces to the analytically calculated value obtained in Chapter 7. This model has described the main characteristics of the sizing parameters. Now, design parameterssuch as head, flow rate and reservoir dimension will be varied to be able to optimised the plant using the designed model.

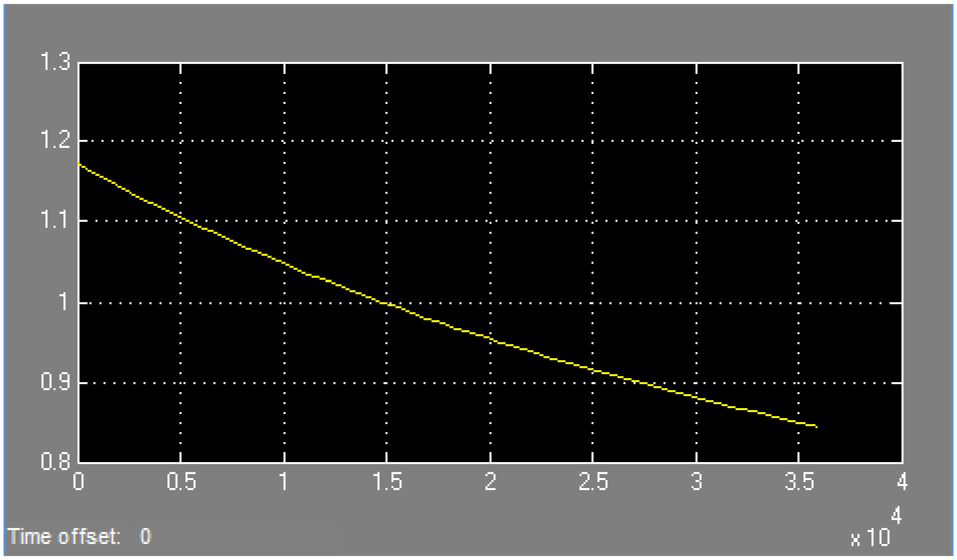

Figure 8.13: Flow in m3/s at maximum pump power

Table 8.3: The behaviour of selected parameters at 100 kW after 5 hours

D_s	D_d	V ($10^4 m^3$)	Q (m^3/s)	ΔH (m)	h_L (m)	H_T (m)	H^- (m)
1.2	1.0	1.952	0.985	1.7	0.1015	8.8	0.09
1.0	0.9	1.939	0.98	1.655	0.168	8.85	0.1477
0.9	0.8	1.917	0.97	1.65	0.265	8.924	0.2249
0.8	0.7	1.87	0.956	1.6	0.44	9.064	0.366
0.7	0.6	1.80	0.9282	1.56	0.7751	9.345	0.6265

Table 8.4: The behaviour of selected parameters at 100kW after 10 hours

D_s	D_d	V ($10^4 m^3$)	Q (m^3/s)	ΔH (m)	h_L (m)	H_T (m)	H^- (m)
1.2	1.1	3.5	1.2/0.8	3.5	0.15/0.08	7.2/10.2	0.135/0.06
1.0	0.9	3.5	1.19/0.85	3.5	0.25/0.13	7.25/10.2	0.22/0.11
0.8	0.7	3.3	1.15/0.84	3.0	0.62/0.35	7.5/10.3	0.52/0.28

8.3 Pumped Storage Hydropower Mode

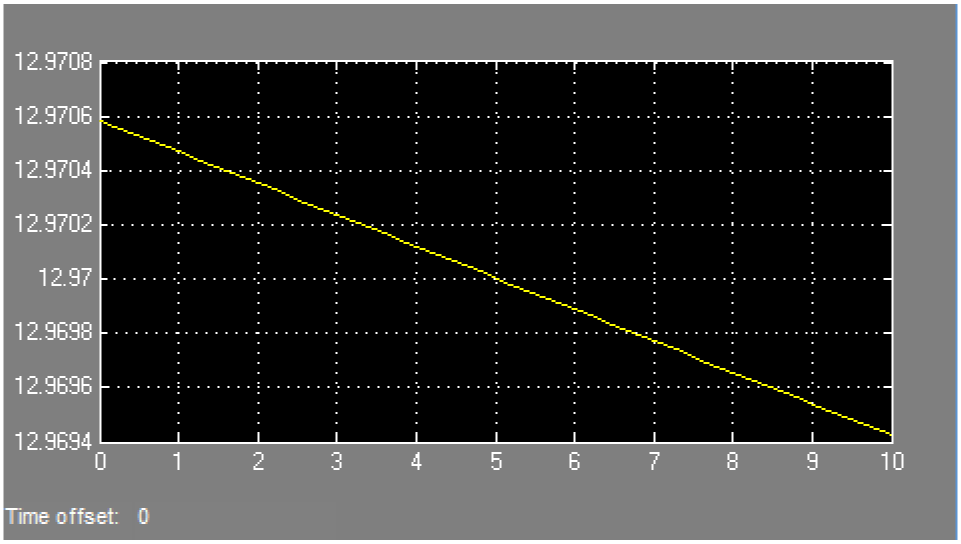

Figure 8.14: Generation height with time

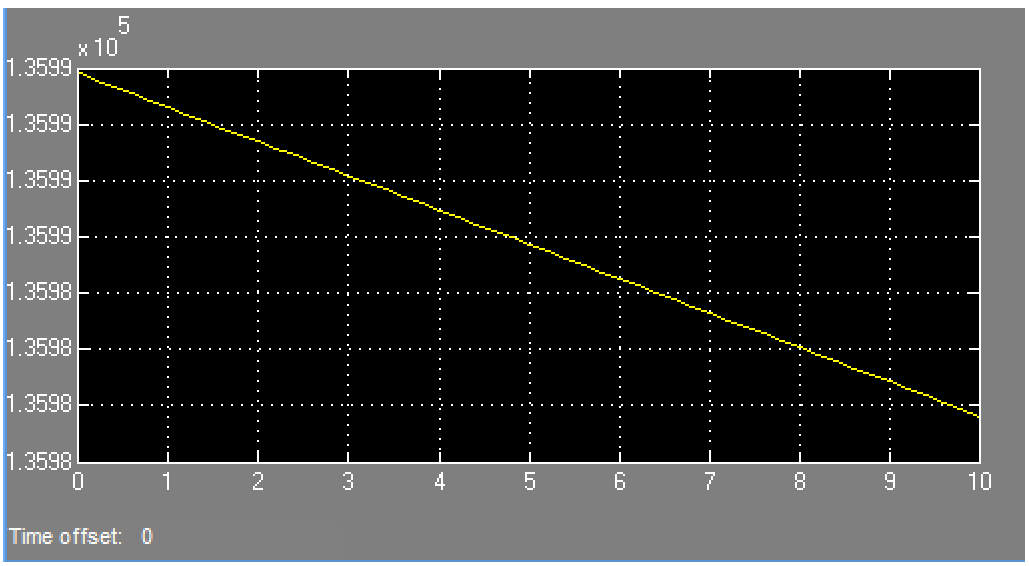

Figure 8.15: Power recoverable from the Pumped Storage Hydropower system with time

CHAPTER 9 : HYBRID PLANT CONTROL

9.0 Introduction

Optimisation is always at peak when suitable control systems are put in place, therefore control techniques will be used to further enhance both hydro generation and pumping modes of the designed hybrid hydro plant. This will ensure the system is automatically controlled for both base load and peak load management respectively. The control system is introduced to manage power generation, optimize economic performance of the plant and maintain good water resource management so minimize environmental impact on the river. On the part of the economic and technical aspects, a control system takes care of many problems associated with parameters related to variation in hydro plant operations. Such parameters include water flow, water head, efficiency coefficients (generator, pump, turbines etc.). Proper and accurate interaction of these parameters is actually a big challenge and that is why control is a big issue in maximizing system performance.

An auto-control system in a hydropower plant is necessary because when properly implemented will reduce maintenance costs thereby enhancing system reliability which will definitely result in efficient plant operations and invariably increase energy generation processes in the hydro plant. The automation is needed to minimise input waste, excessive pumping and PSH generation, which if not properly managed may result in experiencing operational challenges. It is also important to swiftly detect malfunctioning processes, ensuring that the faulty process is stopped so as to return to normal efficient operation.

9.1 Automatic Control System

The automated control system introduced to optimise plant efficiency is designed with two pieces of software: Flowcode version 5 and Proteus ISIS. Flowcode is a graphical programming tool developed to design complex electronic systems. It is chosen as a control tool for this work because of its user friendly ability to develop electromechanical systems quickly with graphical icons. Flowcode is used in this work to develop systems for control and measurement based on microcontrollers. The second software engaged in this control programme is the Proteus Virtual System Modelling (VSM). The choice is because it integrates perfectly microprocessor models and animated components which helps to facilitate simulation of whole microcontroller related designs. The other reason for this choice is that the interaction can be displayed with animated buttons and switches using LED and LCD indicators. It also works with codes and high level languages. For this work, C-codes and hexadecimal codes were used to analyse results.

The control system is designed to govern three parameters which determine plant operation and these parameters are time of specific operations, volume available and power available to support pump activity. The first parameter is time. Time controls the three systems together; which time of operation each has been allocated based on the consumption pattern in Figure 8.1. At low consumption, the pump begins to work and at peak consumption, PSH is switched on automatically. All these are expressed in Figure 9.2.

The second parameter of control is the volume. The lower reservoir will not experience difficulty of adequate water supply; in fact, there will be excess that will need to be discharged to flow and join the river course. The major concern is the water level in the upper reservoir III which can be full or inadequate by the set time for PSH operation to start. This now leads to the third parameter, which is the available power for pump operation. Effective pump operation is a function of the power consumption quantity per time. If available power is unable to lift enough water to III, PSH operation will be thwarted and if there is no control measure to manage this, continuous occurrence will bring about plant breakdown. To manage this effectively, this design introduces two floaters to handle that aspect.

In this research, the flow chart inputs are the three major systems that constitute the hydroplant hybrid, which are the pump, the pumped storage hydropower and the river run-off hydropower plant. Flowcode V5 AVR is used to develop a program on the microchip as shown in Figure 9.1. Figure 9.1 does not represent the full flowchart as it would take many pages for a full chart.

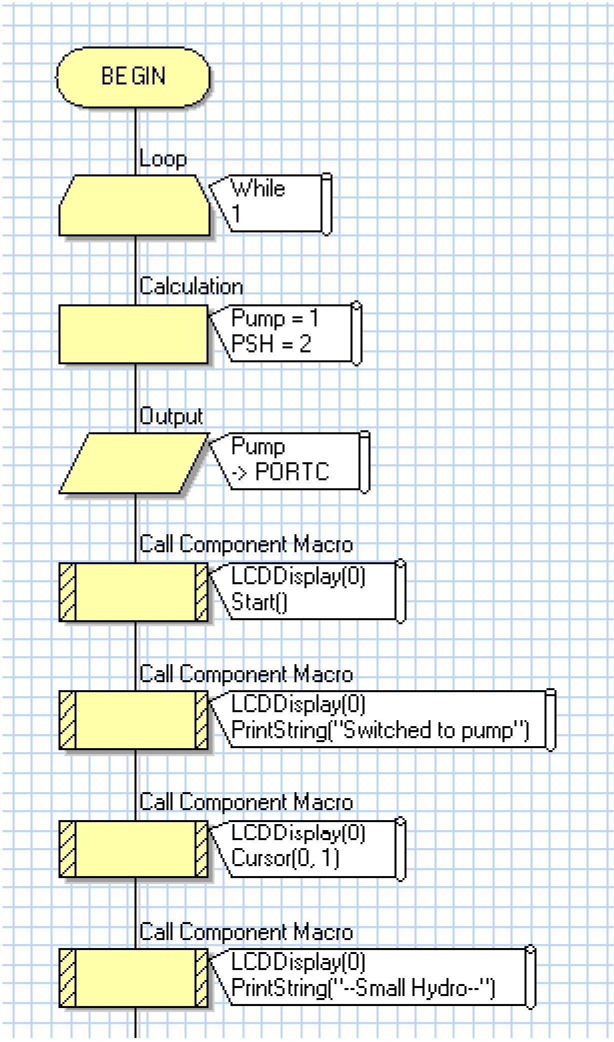

Figure 9.1: Flow chart showing some of the icons used in the Flowcode model

Writing the flowchart is to describe step by step the procedure of the program written to control activities of the three system inputs. For example, the program checks if the time is between 00:00 and 05:00, if yes, pump is switched on, but if no it is delayed to wait until the time for the next command. The same time is the set time at which only one-third of the generated power is consumed. This will automatically switch on the pump for water to fill reservoir III. Figure 9.2 describes in diagramatic form the allocation of time between the three inputs. The same process is repeated for plant operation between 06:00 to 10:00.

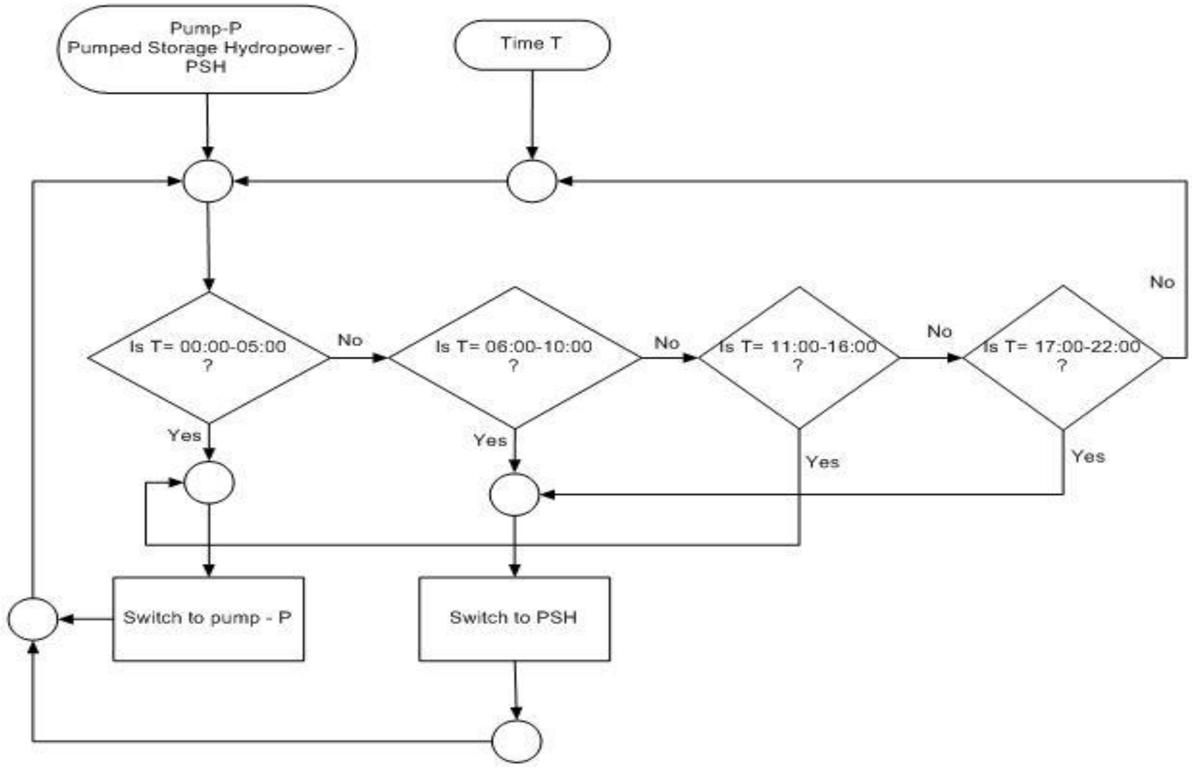

Figure 9.2: Time allocation chart to the three plant system

9.2 Automatic Control System Display

The Flowcode results display the performance of the plant in the Figures 9.3 to 9.5. Figure 9.3 indicates the period when only the primary hydropower is working, which means both the pump and the PSH are off.

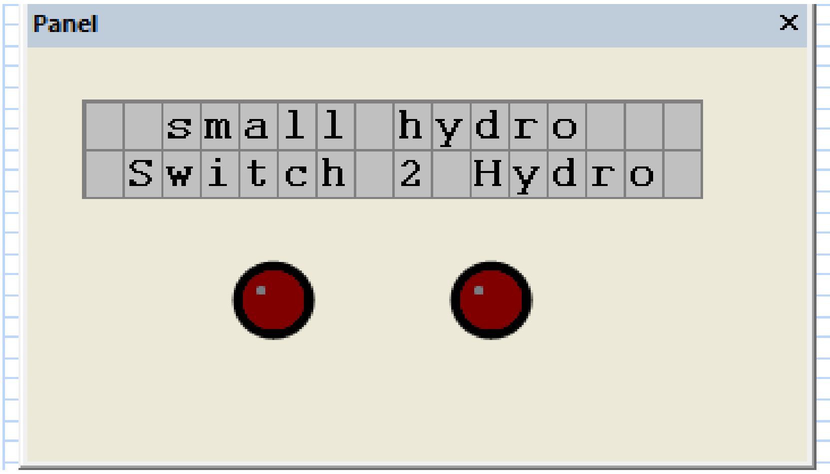

Figure 9.3: Display when both the pump and the PSH are off

The display provides an accurate result for every command that is yielded; this is displayed in the form given in Figure 9.3. From the figure, one can conveniently monitor the plant operations, Figure 9.4 displayed that, the pump is switched on, from Figure 9.2, this is expected between the period of 00:00 to 05:00 and 11:00 to 16:00 while Figure 9.5 displays the operation of the PSH system.

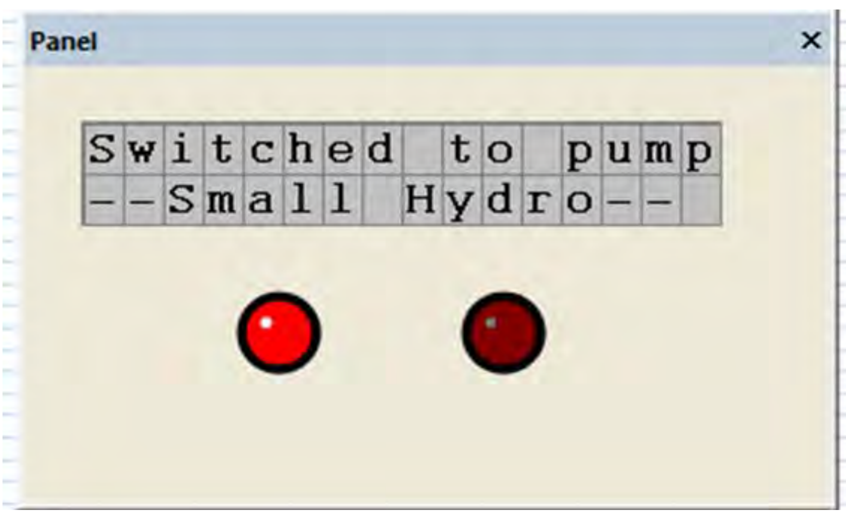

Figure 9.4: Display when the pump is on and the PSH off

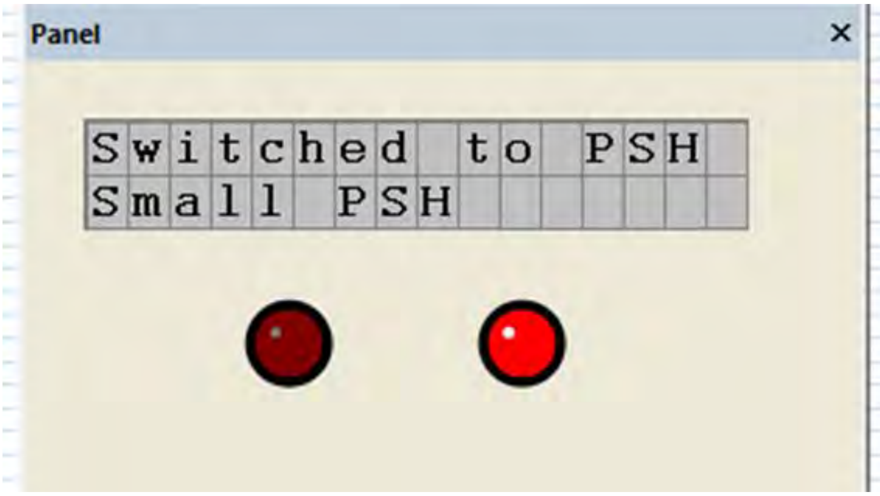

Figure 9.5: Display when the pump is off and the PSH on

Results generated from the Proteus are presented in Figures 9.6 to 9.10. In Figure 9.6, there is no display on the LCD screen, which reveals that both the pump and the PSH are not working. This means at that time only the hydropower plant is working. The system as described earlier has two floaters,namely, a top floater and a bottom floater, as is evident from Figure 9.6. The job of these floaters is to control the volume of water in reservoir III at all times. This is necessary for the PSH turbine to work effectively. The flowcode programme controls the time of either pump or PSH. If at a time PSH is to be switched on but the level of water in the reservoir is low, it may cause major damage to the system but even though it is PSH time immediately the water level reaches the minimum design level, the bottom floater switch will be off putting an end to PSH until there is enough water in III to generate.

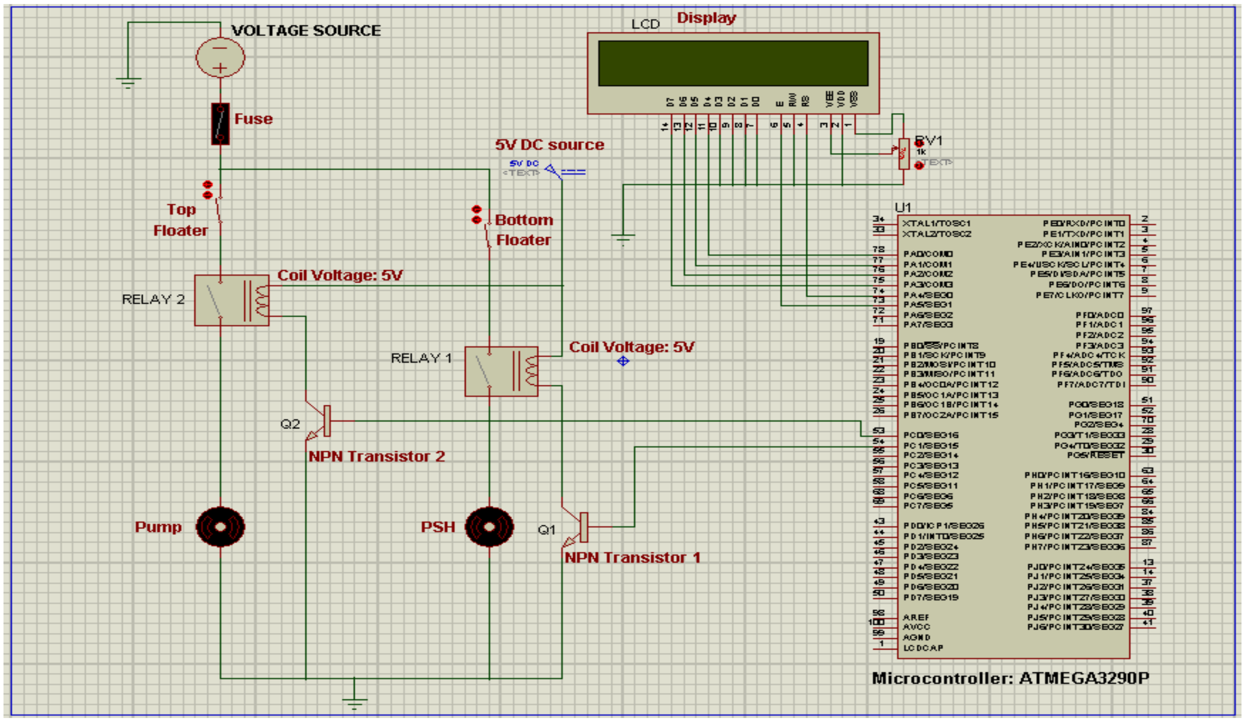

Figure 9.6: Basic layout of the energy control system without load

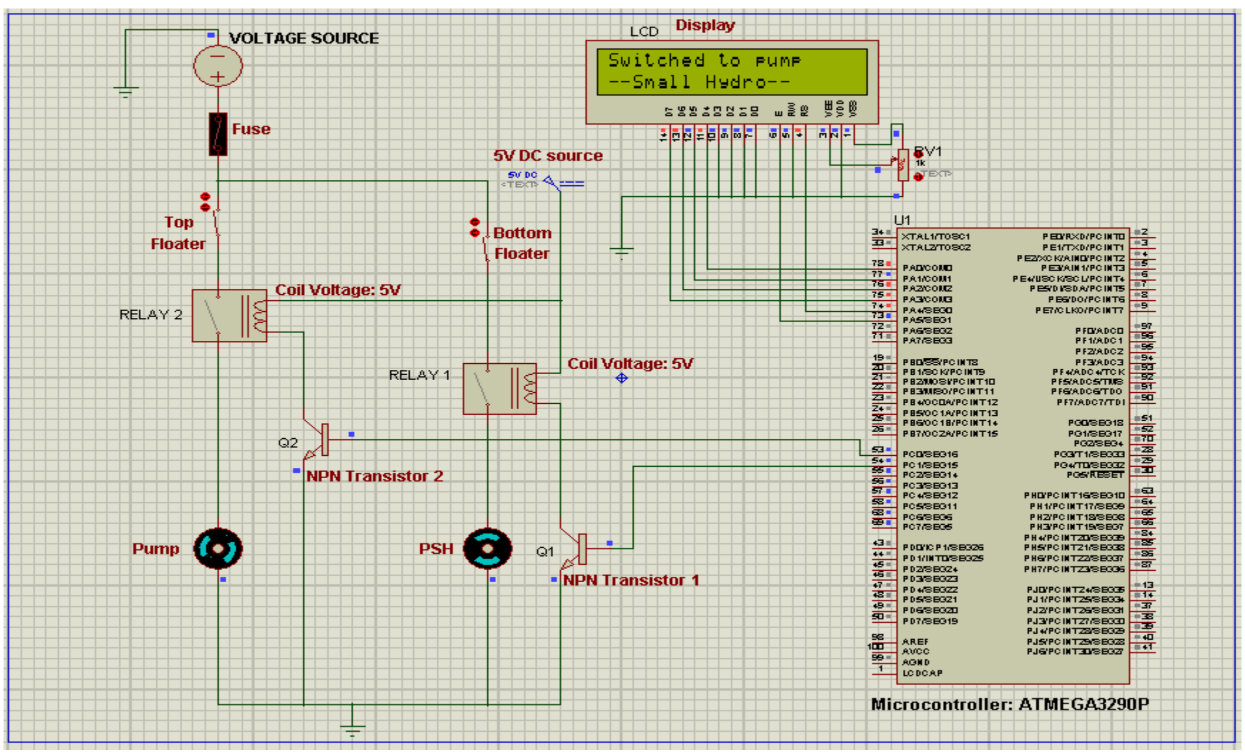

Figure 9.7: Energy control system when pump is switched on

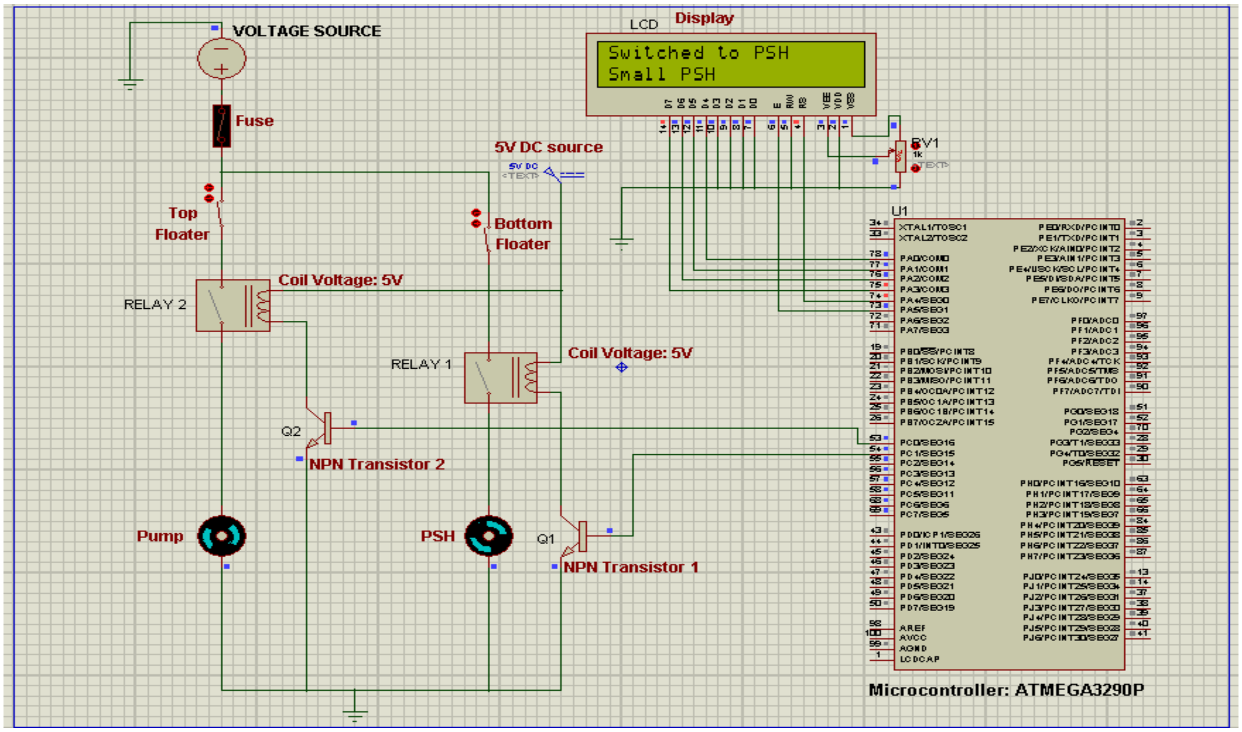

Figure 9.8: Energy control system when PSH is switched on

The same applies to the top floater which controls the water level during pumping mode. Reservoir II is larger than III and the flow from I is greater than that of II and III, which means there will always be more water to pump up each time. To avoid over filling of the upper reservoir III, immediately the water level reaches the position of the top floater, the pump will automatically switch off even if the system is in pumping allocation time. These floaters will help in controlling the volume of water available in III and to manage the plant for efficient outcome.

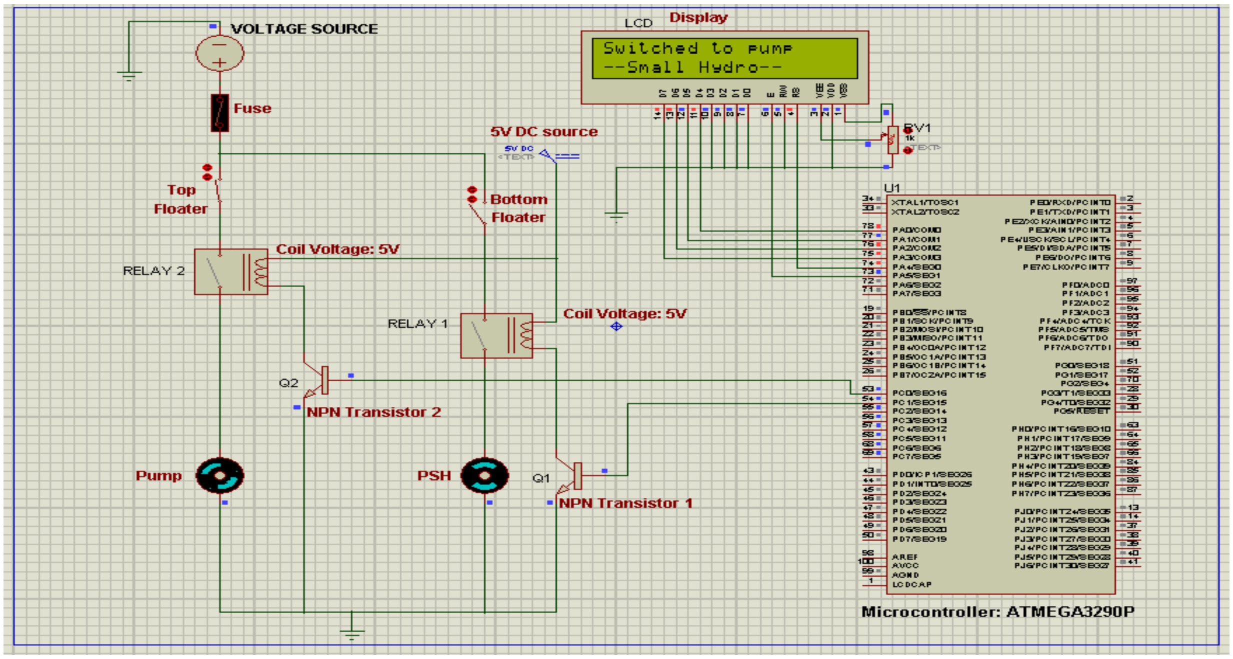

Figure 9.9: Energy control system when only top floater is switched on

For example, in Figure 9.9, pump activity will be allowed, because the bottom floater is switched off which is an indication that the water level in III is low. At this period PSH activity will be on hold as described in Figure 9.10 though the display reads PSH.

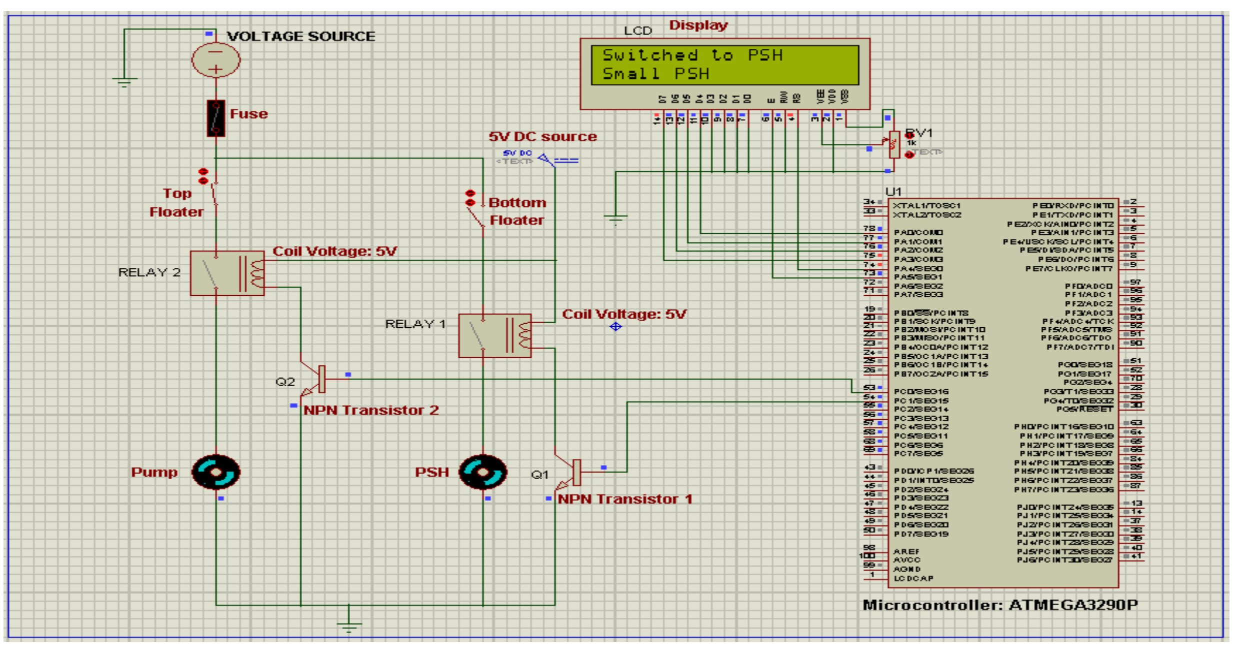

Figure 9.10: Energy control system when only bottom floater is switched on

9.3 Conclusion

The floaters provide an accurate result for balanced operation of the hybrid plant. The governing control strategy worked for the proposed plant with quick response at any given time any excess power was available from the primary hydropower plant. Flowcode and Proteus proved to be relevant in the management of the plant control. The display aspect provided ease of identifying which of the plant system was working at a particular time and which was not working. It would also reveal the reason why the expected one to be working is not working especially when it has to do with floater control.

CHAPTER 10 : CONCLUSIONS AND RECOMMENDATIONS

10.0 Introduction

This research has exposed the possibility of maximising electricity generation using only hydropower source. The results from the analysis is acceptable and suitable for implementation for more generation and less pollution effect.

10.1 Conclusions

The outcomes of the research conducted on the design of a micro hydropower hybrid plant have been positive as expected. Results obtained show high value relevance to solving challenges of non-availability and erratic supply of electricity facing rural communities dwellers in South Africa and other sub-Sahara African countries. This study was able to address the four trends challenging energy use of human societies as listed by [125]-[126] which include:

i. Continuous rise in electricity consumption as people transit from the old traditional sources of energy to the commercial forms of energy.
ii. There are steady developments bringing about improvements in the efficiency of energy technologies.
iii. Emphasis on fuel diversification and decarbonisation.
iv. Lowering GHG emission quantity and pollution generated from energy use.

Isolated energy generation and consumption is not recognised by all governments. That is why energy use and distribution is guided by different policies in different countries. This research has proven that energy generation within the locality of use especially in remote communities where the grid is not available is possible and will attract the same economic value.

The system made use of unused or rejected energy that cannot be saved to pump water until the need arises and is recoverable within a couple of minutes at a higher economic value as seen in the case of South Africa in Table 7.1. The simulations on the model corresponded the results to a high degree of success. The design head worked effectively and the models used in the work were able to give accurate and implementable outcomes. The results of simulation when compared reveal high confidence in the quality of the developed model. The performance prediction model developed for the turbine and the pump shows results within limits of good system efficiencies.

SHP is proven to be relevant and capable of generating adequate electricity for small communities in developing countries. SHP is available in large numbers and potential sites distributed all across the length and breadth of Africa; in South Africa where over 8000 potential sites have been identified, installation of such a hybrid system will go a long way toward easing the challenge of providing adequate, clean and renewable electricity at the set time of demand.

Combining two hydro generation systems of SHP as developed in this research will facilitate economic development in the communities where the plants are located. Small hydropower provides job opportunities to many within the plant location which is another reason for ensuring the implementation of this research.

The introduced control measure was highly effective in ensuring maximum use of rejected power, display of every plant activity, and managing the power plant to ensure that there was no breakdown. This would help to obviate regular plant maintenance that would be necessary without the control measure in place. The control technology interface is user friendly and capable of handling more complex hydropower activity so would only need an upgrade if there was further plant expansion.

10.2 Recommendations

From the outcome of this research, the development of water reuse technology in hydropower generation is recommended for installation in areas with available resource either isolated or grid feeding purposes.

The effect of the site on the environment is minimal. SHP is a technology that is environmentally friendly and requires minimum know-how. It is good source of steady income for private investors because the market is available. There is an increasing demand for electricity all over the world; the urge to acquire electronics is rising, many rural dwellers travel to have their phones and other rechargeable gadgets charged. Everyone desires a good life and many are willing to pay the price to have it.

From this research this hybrid will work perfectly with both small scale and large hydropower plants with the chief purpose of meeting peak energy demand.

This research proposes a large scale future research for potential site with suitable parameters that can be explored. It will equally look into the use of plastic lined cheap pipe material. This will reduce the cost of plant initial installation and also minimise losses in the pipes.

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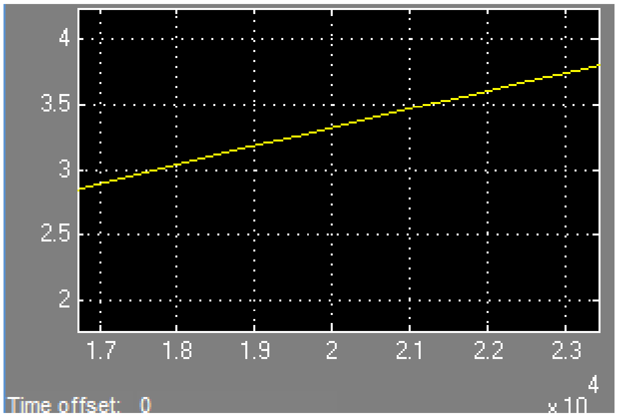
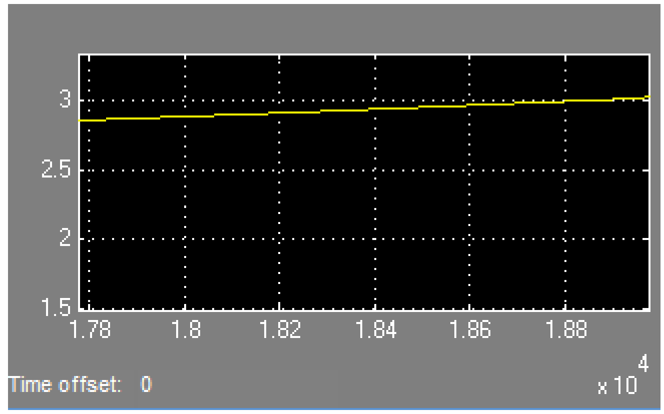
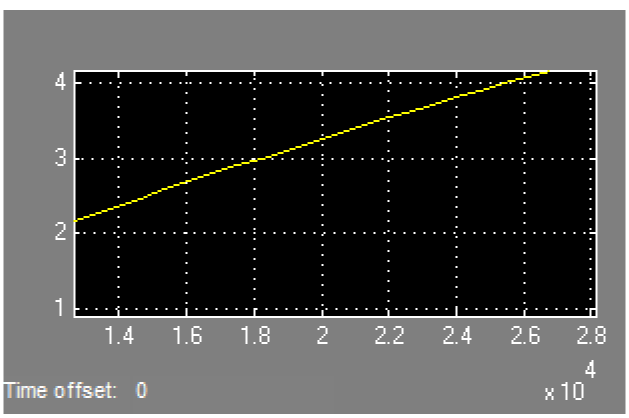
Appendix 1: The behaviour of head difference at 200 kW from reservoir II to III working for 5 hours at specific pipes size



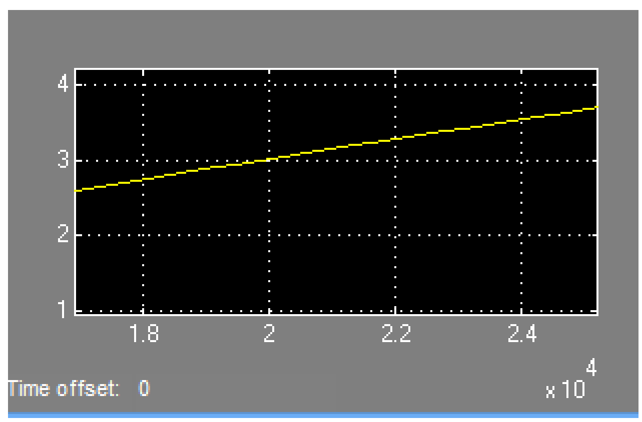
Head difference after 5 hours of pumping from II to III at 1.2m/1m



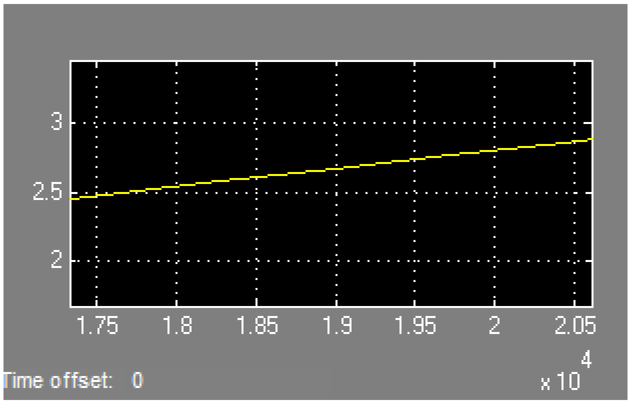
Head difference after 5 hours of pumping from II to III at 0.9m/0.8m



Head difference after 5 hours of pumping from II to III at 1m/0.9m

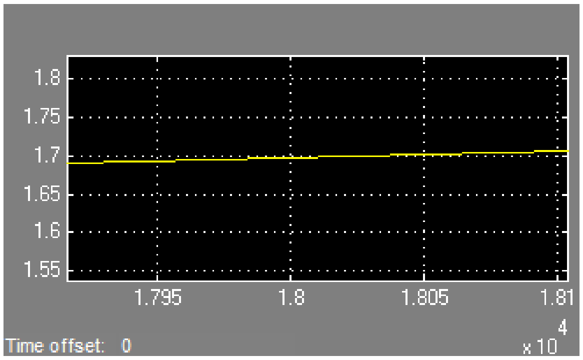


Head difference after 5 hours of pumping from II to III at 0.8m/0.7m

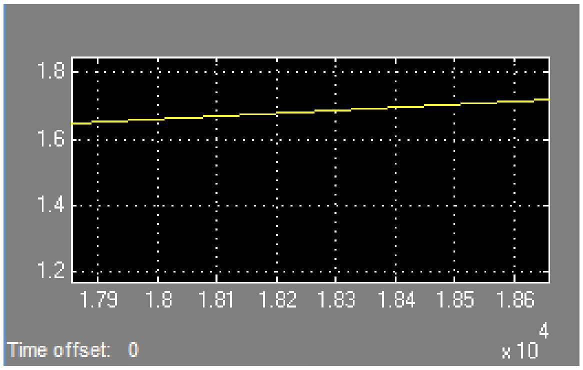


Head difference after 5 hours of pumping from II to III at 0.7m/0.6m

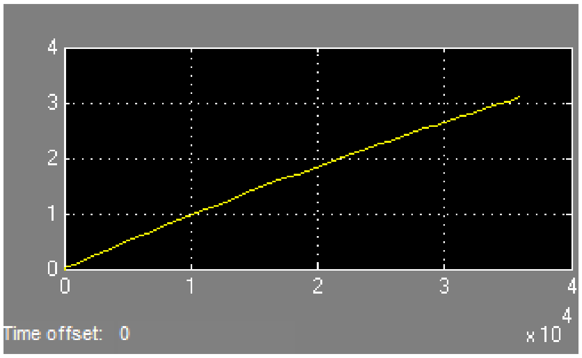
Appendix 2: Head difference behaviour at 100 kW from reservoir II to III working for 5 hours at specific pipe sizes



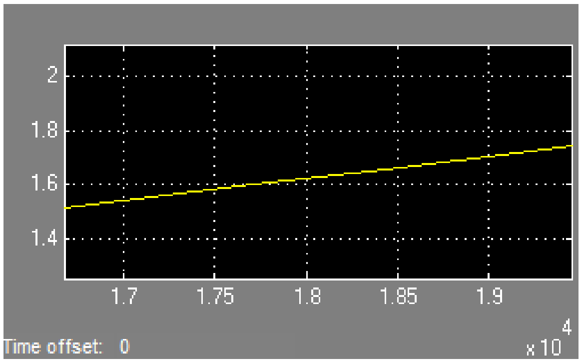
Head difference after 5 hours of pumping from II to III at 1.2m/1m



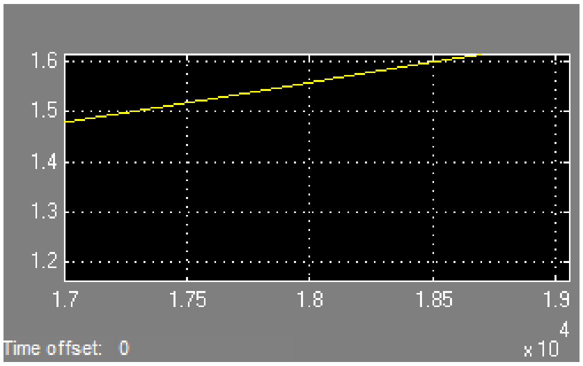
Head difference after 5 hours of pumping from II to III at 0.9m/0.8m



Head difference after 5 hours of pumping from II to III at 1m/0.9m

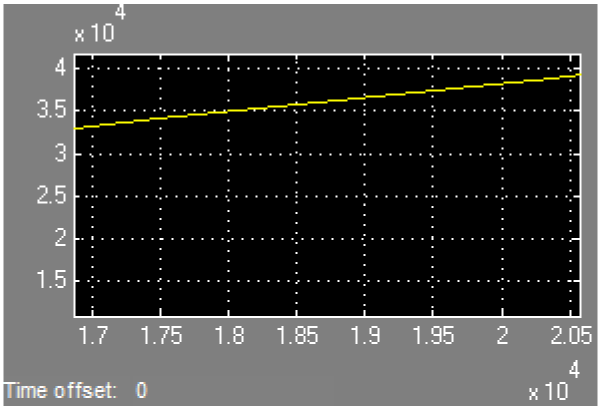


Head difference after 5 hours of pumping from II to III at 0.8m/0.7m

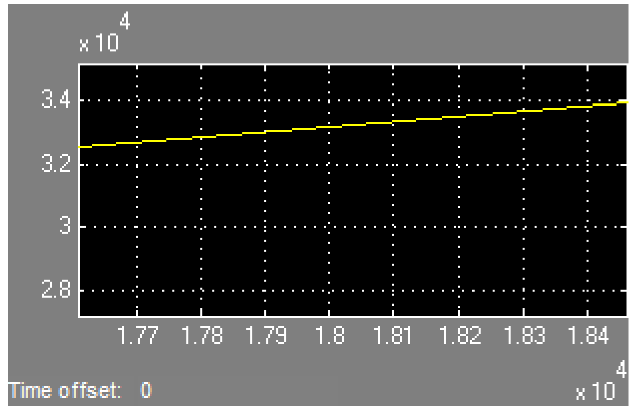


Head difference after 5 hours of pumping from II to III at 0.7m/0.6m

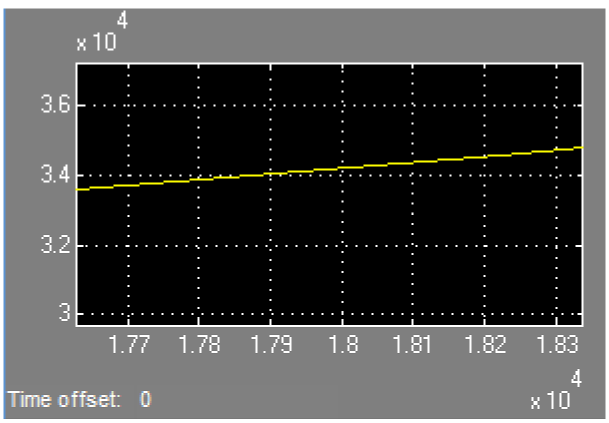
Appendix 3: Volume behaviour at 200 kW from reservoir II to III working for 5 hours at specific pipes sizes



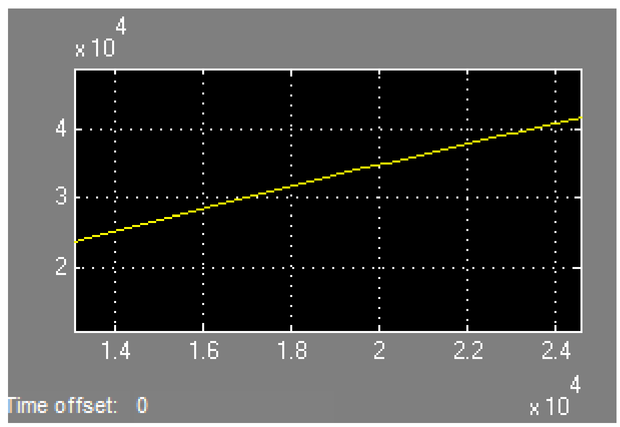
Volume after 5 hours of pumping from II to III at 1.2m/1m



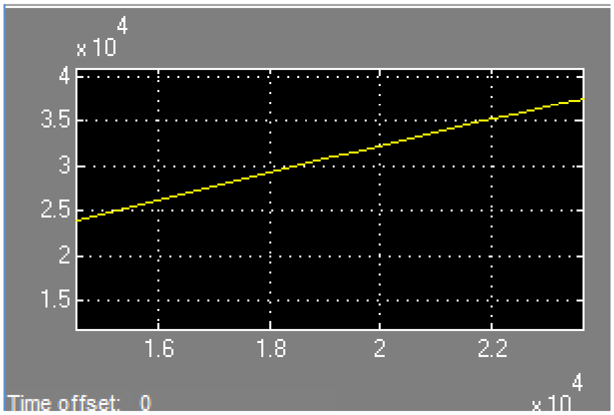
Volume after 5 hours of pumping from II to III at 0.9m/0.8m



Volume after 5 hours of pumping from II to III at 1m/0.9m

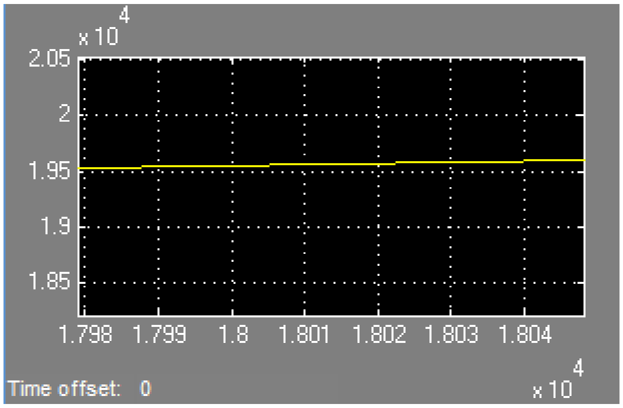


Volume after 5 hours of pumping from II to III at 0.8m/0.7m

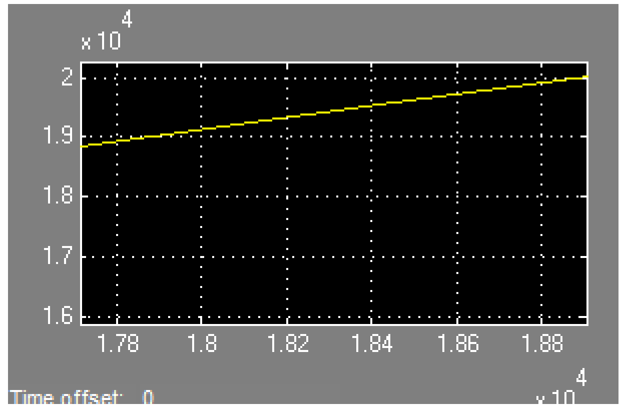


Volume after 5 hours of pumping from II to III at 0.7m/0.6m

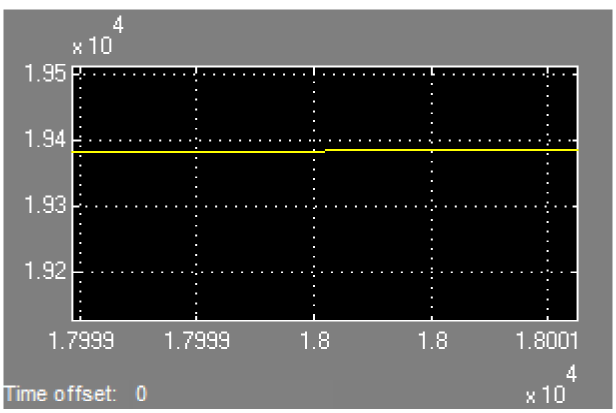
Appendix 4: Volume behaviour at 100 kW from reservoir II to III working for 5 hours at specific pipes sizes



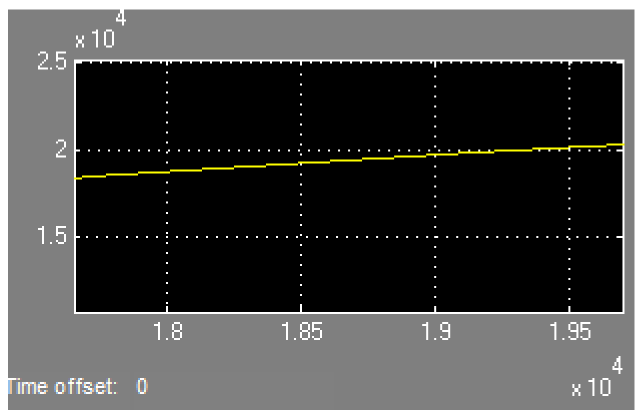
Volume after 5 hours of pumping from II to III at 1.2m/1m



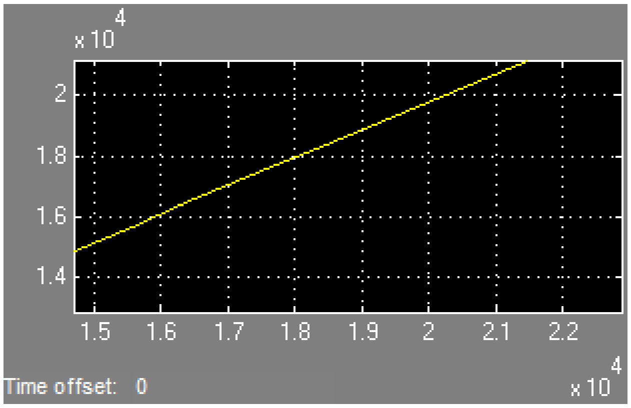
Volume after 5 hours of pumping from II to III at 0.9m/0.8m



Volume after 5 hours of pumping from II to III at 1m/0.9m

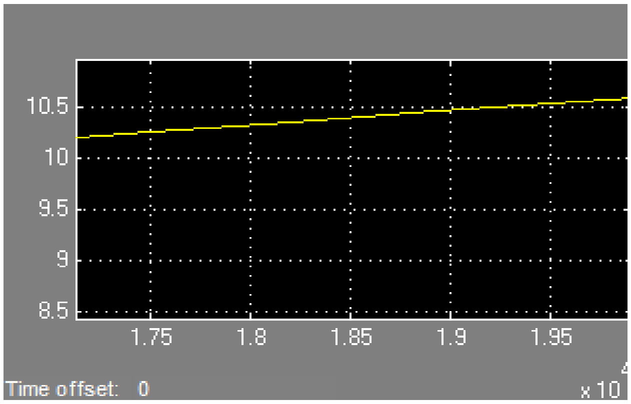


Volume after 5 hours of pumping from II to III at 0.8m/0.7m

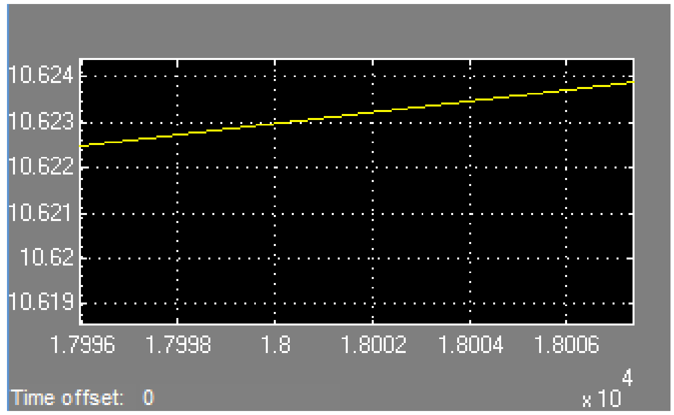


Volume after 5 hours of pumping from II to III
at 0.7m/0.6m

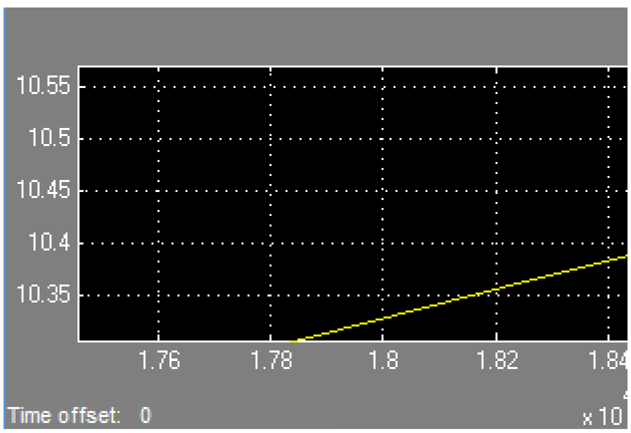
Appendix 5: Total head behaviour at 200 kW from reservoir II to III working for 5 hours at specific pipes sizes



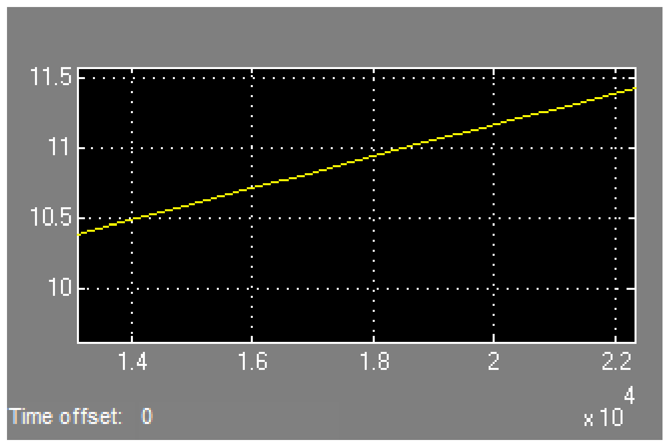
Total head after 5 hours at 1.2m/1m



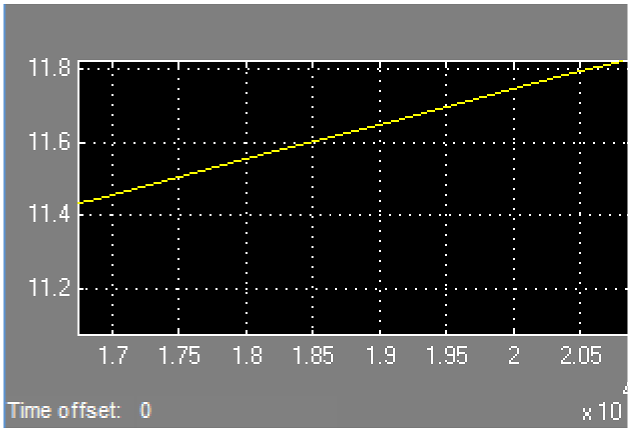
Total head after 5 hours at 0.9m/0.8m



Total head after 5 hours at 1m/0.9m

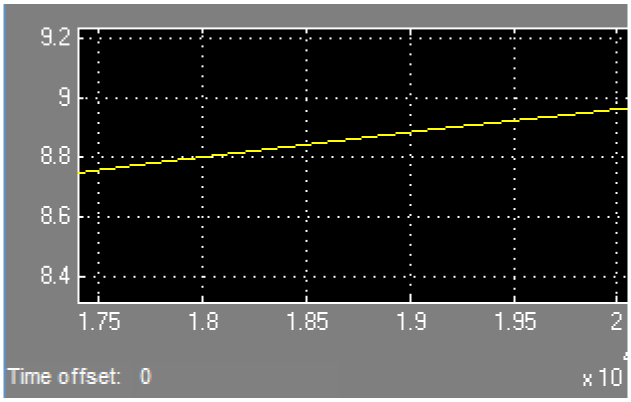


Total head after 5 hours at 0.8m/0.7m

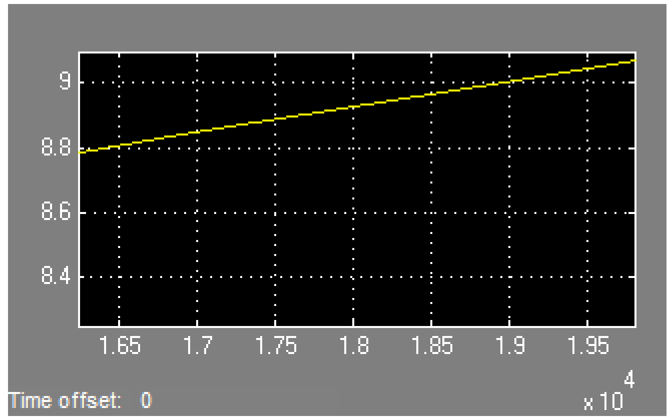


Total head after 5 hours at 0.7m/0.6m

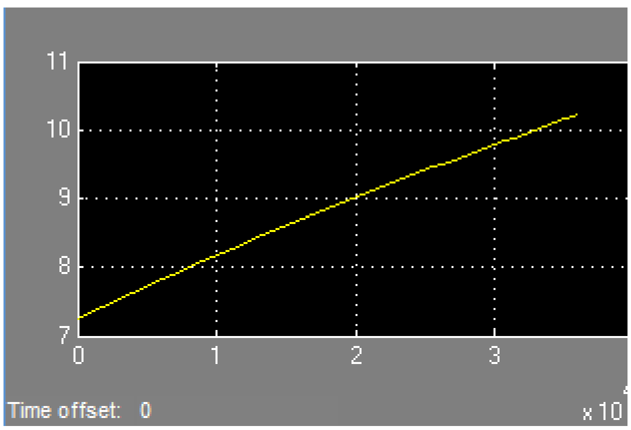
Appendix 6: Total head behaviour at 100 kW from reservoir II to III working for 5 hours at specific pipes sizes



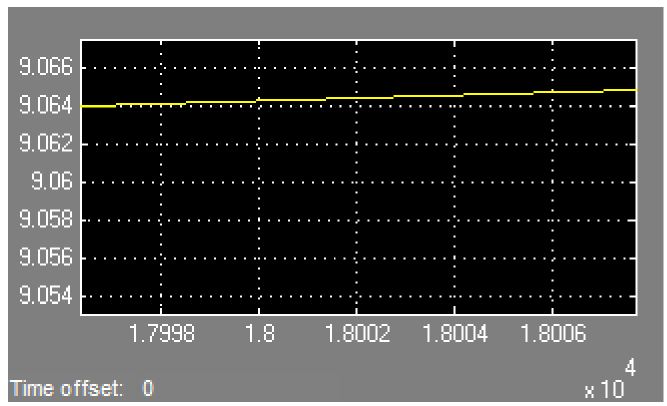
Total head after 5 hours at 1.2m/1m



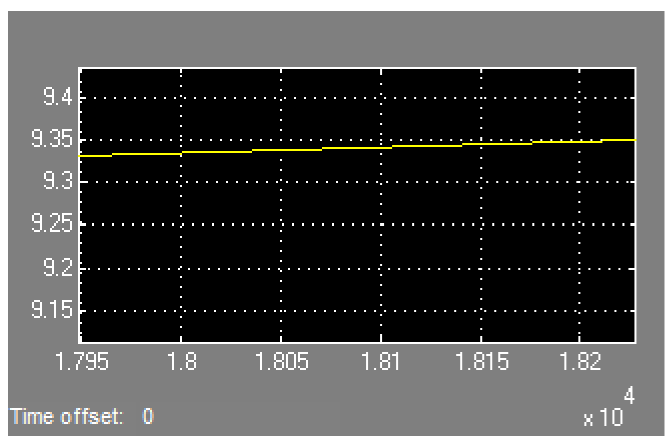
Total head after 5 hours at 0.9m/0.8m



Total head after 5 hours at 1m/0.9m

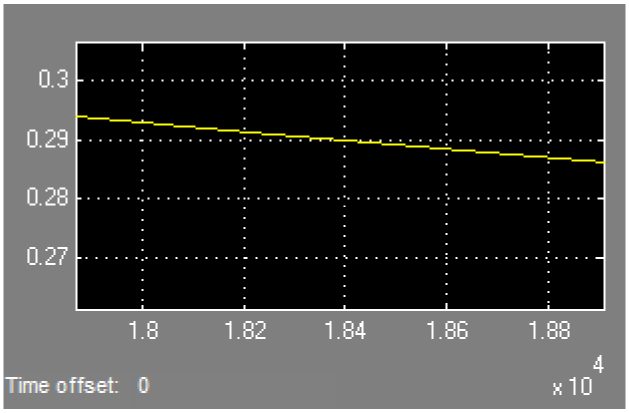


Total head after 5 hours at 0.8m/0.7m

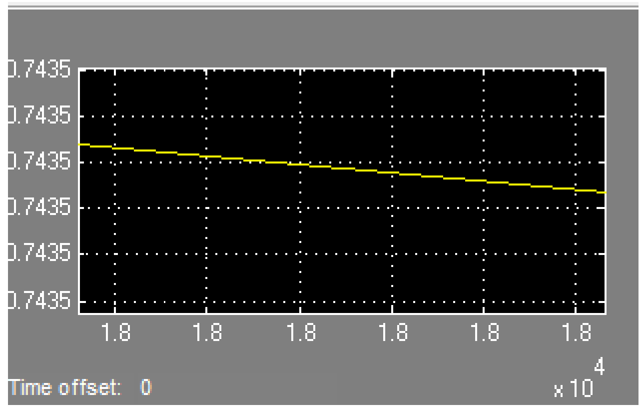


Total head after 5 hours 0.7m/0.6m

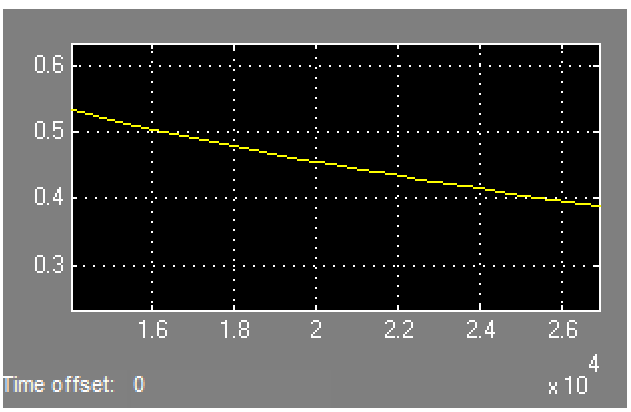
Appendix 7: Headloss behaviour at 200 kW from reservoir II to III working for 5 hours at specific pipes sizes



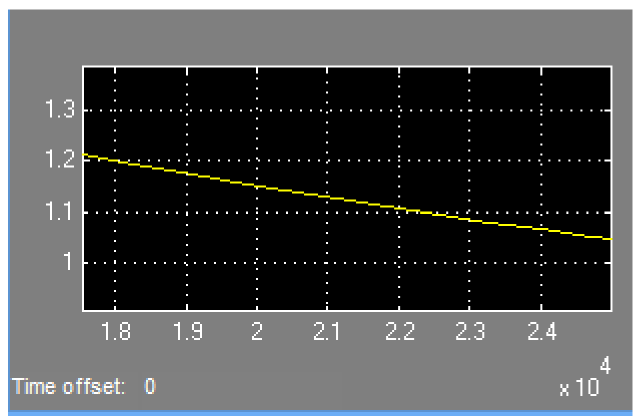
Headloss after 5 hours at 1.2m/1m



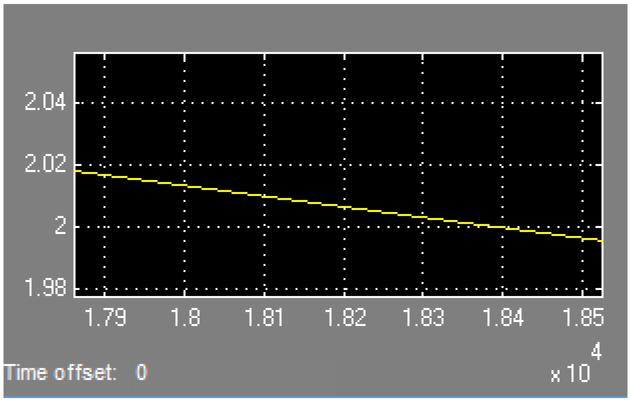
Headloss after 5 hours at 0.9m/0.8m



Headloss after 5 hours at 1m/0.9m

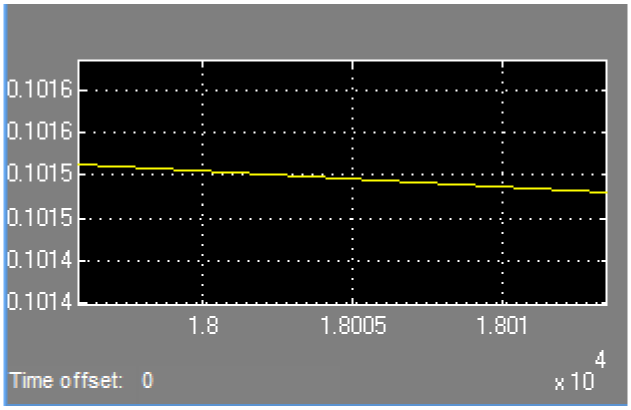


Headloss after 5 hours at 0.8m/0.7m

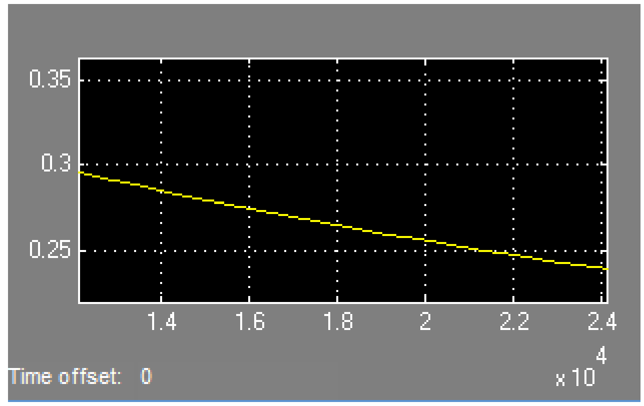


Headloss after 5 hours a 0.7m/0.6m

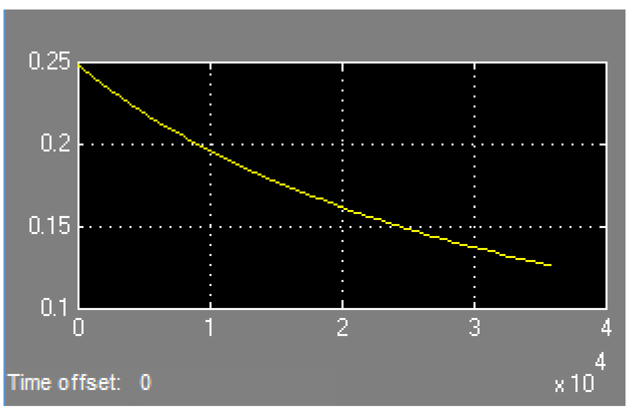
Appendix 8: Headloss behaviour at 100 kW from reservoir II to III working for 5 hours at specific pipes sizes



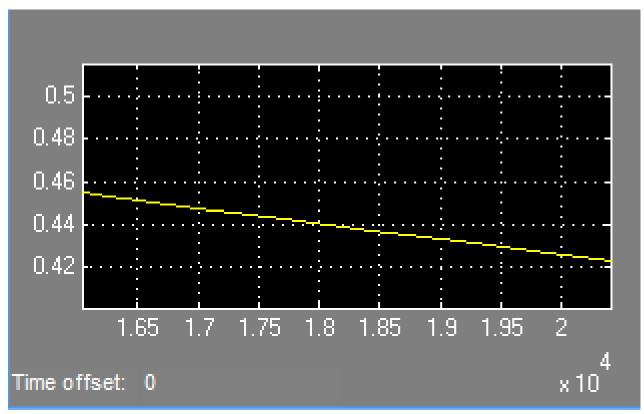
Headloss after 5 hours at 1.2m/1m



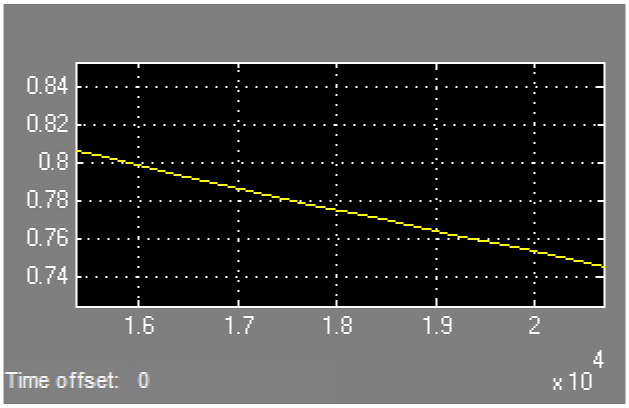
Headloss after 5 hours at 0.9m/0.8m



Headloss after 5 hours at 1m/0.9m

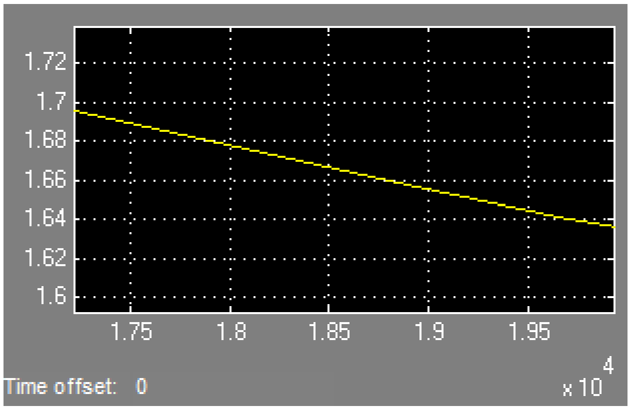


Headloss after 5 hours at 0.8m/0.7m

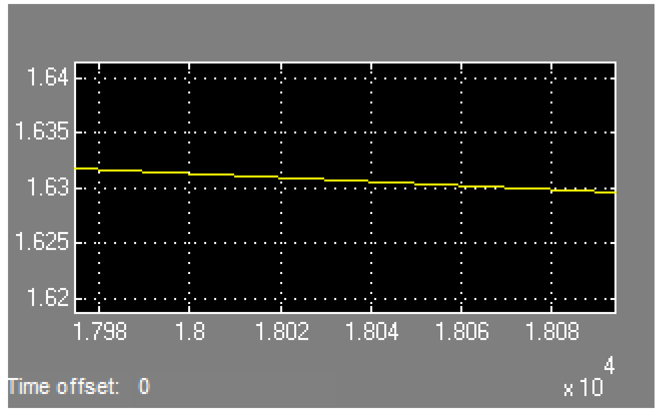


Headloss after 5 hours at 0.7m/0.6m

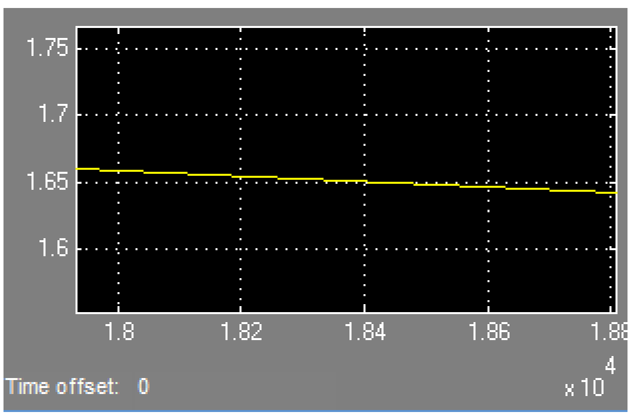
Appendix 9: Volumetric flow behaviour at 200 kW from reservoir II to III working for 5 hours at specific pipes **sizes**



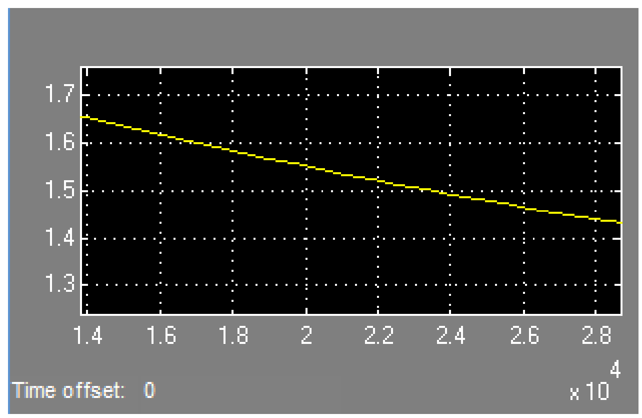
Volumetric flow after 5 hours of pumping from II to III at 1.2m/1m



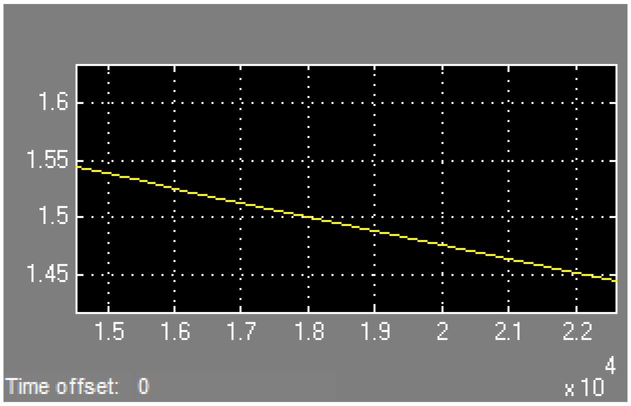
Volumetric flow after 5 hours of pumping from II to III at 0.9m/0.8m



Volumetric flow after 5 hours of pumping from II to III at 1m/0.9m

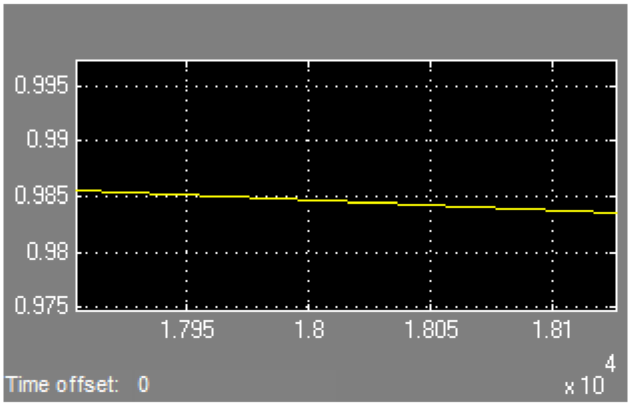


Volumetric flow after 5 hours of pumping from II to III at 0.8m/0.7m

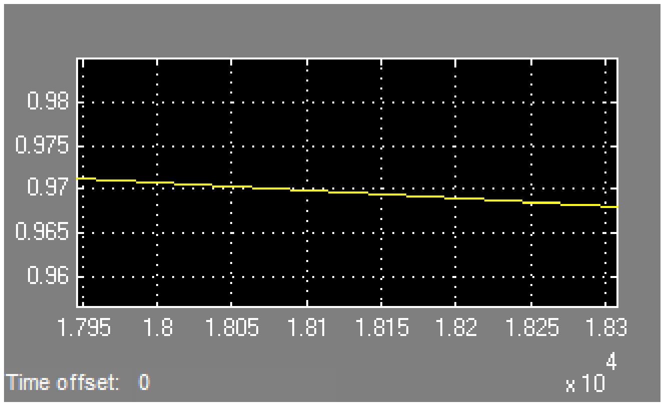


Volumetric flow after 5 hours of pumping from II to III at 0.7m/0.6m

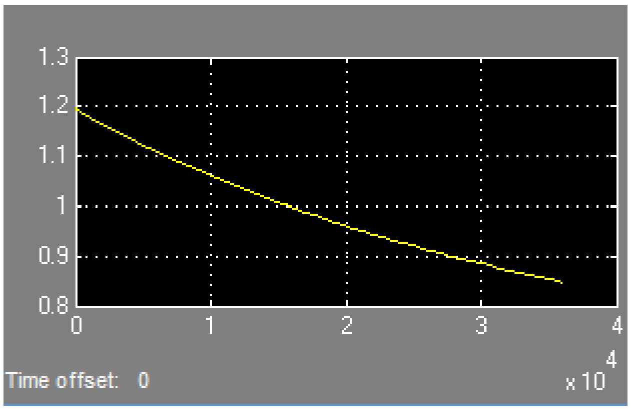
Appendix 10: Volumetric flow behaviour at 100 kW from reservoir II to III working for 5 hours at specific pipes sizes



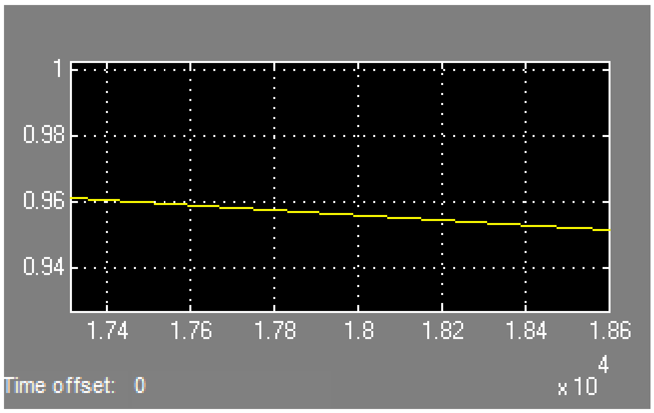
Volumetric flow after 5 hours of pumping from II to III at 1.2m/1m



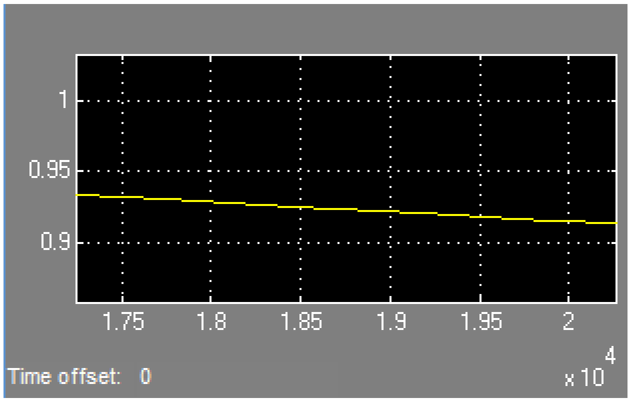
Volumetric flow after 5 hours of pumping from II to III at 0.9m/0.8m



Volumetric flow after 5 hours of pumping from II to III at 1m/0.9m



Volumetric flow after 5 hours of pumping from II to III at 0.8m/0.7m



Volumetric flow after 5 hours of pumping from II to III at 0.7m/0.6m