Solar PV Electrification of Diesel Powered Boreholes

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***Abstract*— South Africa is experiencing little to no rainfall, as a result drought conditions are being experienced across the country. To date, five provinces are severely affected by the drought and declared disaster areas, this includes; KwaZulu-Natal as the province worst affected province. Other provinces include Free State, Limpopo, Mpumalanga and North West. The Department of Water and Sanitation has committed to the initial drought intervention projects in Kwazulu-Natal. Some of the emergency relief measures that are currently being implemented such as water tankers, borehole drilling and rehabilitation, water conservation and demand management as well as water source augmentations. Giyani is one of the area in the Limpopo province, which is affected by drought. The main aim of the project is to ensure that there is sufficient water for people in the Giyani area through implementation of boreholes. The project includes the electrification of the boreholes through Grid connected PV system as the back-up system in case of rainy conditions. The PV solar and the Grid will be co-generating in order to supply power to the boreholes. The project includes the design and Simulation of the system using PVsol software.**

***Index Terms*-- Boreholes, Water Tanks, PV Solar, Pump Motor, Grid, PV Panels.**

I. Introduction

The needs for water has arisen as a critical shortage at Giyani due to failure of Middle Letaba and Nsami dams. The water level at these Dams is very low and borehole being the main course of water in villages, it is a need that the existing boreholes be rehabilitated. Currently most boreholes in the area are diesel operational and those boreholes needs to be converted from diesel to electricity. The current pumps that these boreholes use are mono-pumps which are diesel engine driven. The main challenge with these diesels powered boreholes is that the cost of diesel is too high and the community does not have enough money to contribute to buy diesel. Other challenges are that the operation and the maintenance of these pumps are expensive and the municipality does not have resources to maintain these pumps, resulting in poor state of the borehole. The main aim of the project is to ensure that there is sufficient water supply in the Giyani area at a minimal operating cost.

II. DESIGN AND DEVELOPMENT

The Photovoltaic system is one of the most widely used renewable energy system [1]. Not only is solar power the solution to energy crisis but also an environmental friendly form of energy generation as compares to diesel. This system is easy to implement and environment friendly solution for irrigating fields. Electricity generated from fossil fuels such as coal, Oil and natural gas can cause many environmental problems [2]. The solar system requires minimal maintenance and attention as compared to diesel [3]. Even though there is high capital investment required for this system to be implemented, the overall benefits are high and in the long run this system will be economical. It is estimated that Solar PV water pumping system are more economical compared with diesel pump-sets [4]. A high efficiency solar panel is a device that converts photons of light from the sun into electricity [5]. A solar pumping system can be with or without battery backup. A basic and simple configuration of direct coupled type consists of PV panel, motor-pump unit and storage tank [6] as shown in figure 1 below. The advantage of the solar system in Figure 1 is that electrical storage is not essential as compared to other solar PV applications [7], Whenever the PV power is available, water is transferred to an overhead tank, which itself acts as a storage element instead of having batteries to store electrical energy.

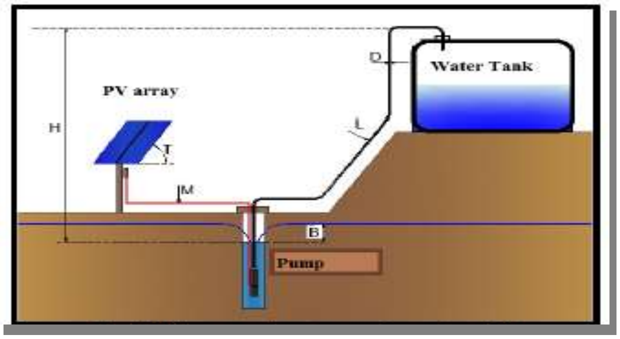

Figure 1: Basic Solar System for Boreholes [8]

Other design for Solar includes the use of an Inverter. Instead of connecting the PV system directly to the Pump Motor, an Inverter will be used to convert DC Power from the PV array to AC Power to supply a three-phase motor as indicated in figure 2. Using solar water pumping in the remote areas is of paramount importance because it is environmentally friendly, has low running cost, long life time when compared to diesel generators [9].

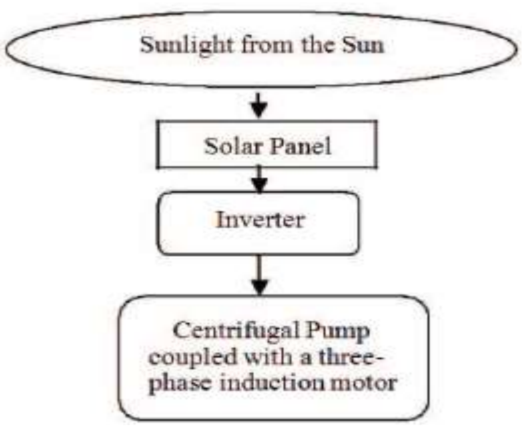

Figure 2: Schematic diagram of Solar System using an Inverter [10].

The amount of Power generated by the PV arrays depends on the solar radiance. At MPP the PV arrays is operated with maximum efficiency to produce the maximum output power. It is important to operate the system at MPP in order to get the maximum power from the solar energy. To determine the MPP, many MPPT methods have been used such as perturbation and observation (P & O) Methods, Incremental conductance method, Artificial Neural Network (ANN), fuzzy logic and other algorithms [11]. MPPT insures a PV system operates at maximum power of its solar cells at all times under variable insolation level as well as load [12]. The System will be designed without the use of batteries, the presence of batteries in the solar water pumping system has many disadvantages like decreasing the total life time of the system, increasing the system cost, decreasing the overall system efficiency and increasing the maintenance cost of the system due to high maintenance requirement of the batteries [13]. These reasons make water storage in tanks a better option than storing electric energy in the batteries, which is the reason why the water tank storage has been chosen to store water that people can use at night or on rainy days.

This project will be done differently as compared to most pumping system because it will consist of an AC Motor instead of a DC Pump, which means that an inverter will be used to convert DC from power produced by the Solar to AC Power to supply the AC Pump Motor. AC motor represents a reliable, low cost and low maintenance work required [13]. The solar arrays can last up to 20-25 years [14]. The only thing that needs to be replaced is the pump unlike the diesel-powered engine which require maintenance all the time. Table 1 shows the Comparison between the Solar PV and Diesel Pumps.

Table 1: Comparison between the PV Solar and Diesel-Powered Pumps

Type	**Advantages**	**Disadvantages**
PV Solar	Unattended Operation	High capital costs
	Low maintenance	Water storage is required for cloudy periods
	Easy Installation	Repair often require skilled technicians
	Long Life	High Capital cost
	Low Operation cost	
Diesel Pumps	Quick and easy to install	Fuel is expensive, resulting in high operation cost
	Low capital cost	Short life expectancy
	Can be portable	Noise and Fume Pollution

Photovoltaic is being employed around the whole world in most recent years. It is widely used in many applications in islands and remote areas. Using photovoltaic as the power source for water pumping is considered as one of the most promising areas of PV application [15]. Most of these solar pumping systems are used for irrigation, in these projects the pumping system will be used to supply people with water for domestic use.

The setup of a PV solar system is very flexible. Individual PV panels can be wired in series or parallel to obtain the required voltage or current needed to run the pump. The voltage and current output from panels wired in parallel is the exact opposite of series-wired panels. For panels wired in parallel, the current (amps) output is the sum of all the currents (amps) from the panels and the voltage is equal to the voltage output from an individual panel [16].

There are two basic types of solar powered pumping system, which is Battery coupled and direct coupled.

Battery Coupled Solar Pumping Systems

Battery coupled water pumping system consists of PV panels, Charge control, battery, inverter, AC Motor borehole pump and storage tank as shown in Figure 3. In this configuration, the battery is connected into the system so that it can store DC power during the day when there is enough sunlight so that it can be used during rainy season or at night when there is no sunlight. The Electric current produced by PV panels during daylight hours charges the batteries and the batteries in turn supply power to the pump anytime when water is needed. The use of batteries spreads the pumping over a longer period of time by providing a speedy operating voltage to the AC motor of the pump, thus during the night and low lights periods the system can still deliver a constant source of water. The use of batteries has its own drawbacks, batteries can reduce the efficiency of the overall system because the operating voltage is dictated by the batteries and not the PV panel. Depending on how well the batteries are charged, the voltage supplied by the batteries can be one to four voltage lowers than the voltage produced by the panels. To ensure the effectiveness of the system a battery coupled solar pumping system for boreholes will be used. The use of the batteries in system ensures water pumping even during low light periods, cloudy days and during the night also. However, its use increases the cost, complexity and can reduce the overall efficiency of the system as the batteries dictate the operating voltage rather than the PV panels [17].

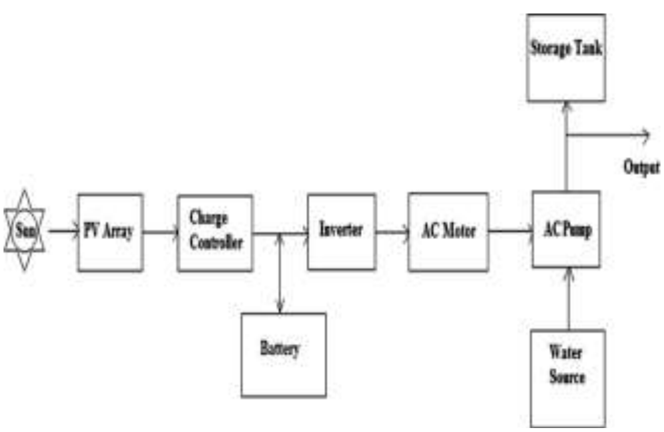

Figure 3: Battery coupled solar pumping system [18]

Direct Coupled Solar Pumping System

In direct coupled pumping systems electricity from the PV modules is connected directly to the pump as shown in figure 4. Direct coupled solar pumping system means that the batteries are not included in the system and the DC power produced by the PV array is connected directly to the DC Motor Pump. This system can only pump water during the day when there is enough sunlight. The amount of water pumped is totally depended on the amount of sunlight hitting the PV panels because the intensity of the sun which it strikes the PV panel changes through the day. For instance, during optimum sunlight period (late morning to late afternoon on bright days) the pump will operate near 100% efficiency with maximum water flow. However, during early morning and late afternoon pump efficiency may drop by as much as 25 % or more under these low light conditions while during cloudy or rainy days the pump efficiency will drop even more. In Direct coupled pumping system, water storage capacity is very important because extra water must be stored on sunny days for when the sun is low.

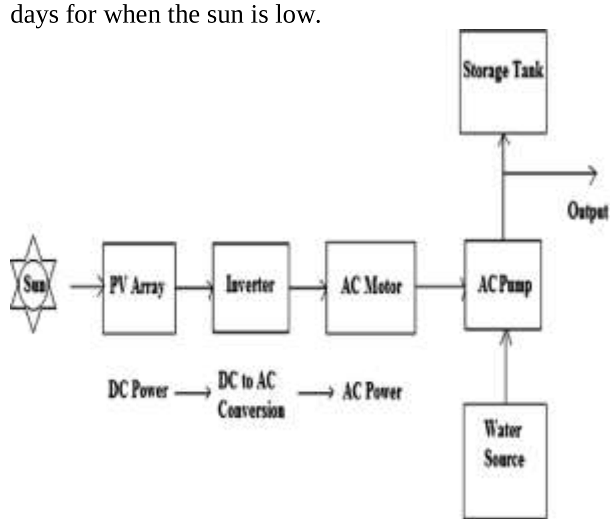

Figure 4: Direct coupled solar pumping system [18].

III. SYSTEM DESIGN AND DEVELOPMENT

Proposed practical design or strategy

Figure 5 below shows the proposed PV solar design for the electrification of boreholes.

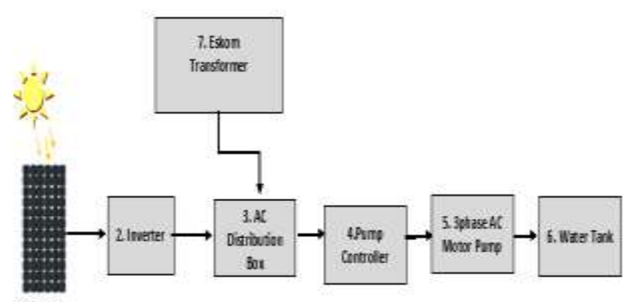

Figure 5: Block diagram of proposed solar pumping system for boreholes

1. Sun will shine onto the Solar panel; the Solar panel will then convert the Sun into DC power which will be supplied to the inverter.
2. The Inverter will convert DC Power to AC Power. Power will then be transferred into via a cable to the AC distribution box.
3. AC Distribution Box will allow the both the PV solar and Eskom power to supply the load.
4. From the AC DB, Power will be supplied to the Pump Controller and from the Pump Controller it will be supplied to the AC Three Phase Pump. Pump Controller are used as the protection for the pump
5. The Pump will pump water from underground to the surface into the water tank.
6. The water Tank will be used as the storage of water.
7. Eskom Power will be cogenerating with the PV Solar system to supply the load.

The Solar System that will be design will supply the six boreholes at Mushiyane Village. One Solar System and One Transformer will supply all of the boreholes as shown in the Single line diagram in figure 6 below.

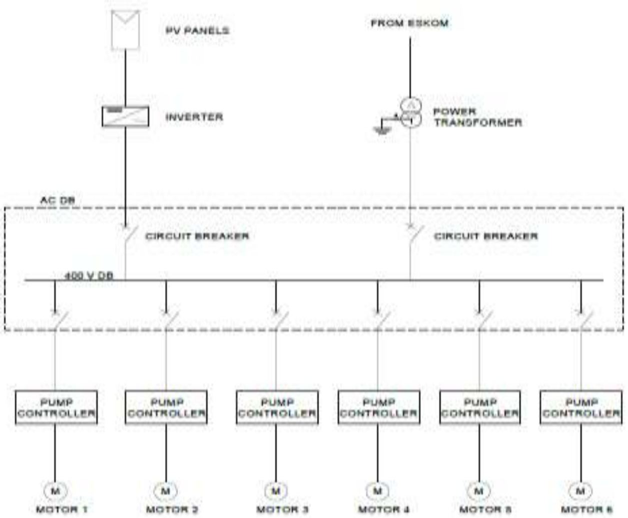

Figure 6: SLD for the boreholes

Motor Sizes

The system will supply six motors with the load sizes as specified in table 2. The motors to be supplied are CRI motors because they are cheap, easy to install and effective. AC Motor is selected because of the advantages it has as compare to the DC pump and Single-Phase pump.

Motor Specification:

The Model and the rating for the motor according to the CRI pumps Data sheet are as follows:

Table 2: Pump Model and Motor Rating

Borehole Number	Pump Model type	Motor Power	Voltage Rating	Full Load Current	Starting Current
Borehole 1	W6A-110T	11 kW	400 V	25 A	102 A
Borehole 2	W6A-75T	7.5 kW	400 V	18.5 A	70 A
Borehole 3	W6A-55T	5.5 kW	400 V	13.5	52
Borehole 4	W6A-185T	18.5 kW	400 V	42.5	188
Borehole 5	W6A-110T	11 kW	400 V	25 A	102 A
Borehole 6	W6A-150T	15 kW	400 V	33 A	148 A

Total Load

The Total Load is calculated by adding the size of power rating for all the motors for the three Boreholes.

Load Power:

$$Load\ (kW) = 11 + 7.5 + 5.5 + 18.5 + 11 + 15 \quad (1)$$

$$Total\ Load\ (kW) = 68.5\ kW$$

A safety factor of 1.25 to allow for future expansion.

Total Load Power:

$$Total\ Load\ Power = 1.25\ \times 68.5 \quad (2)$$

$$Total\ Load\ Power = 86\ kW$$

PV Panels

The PV Panel will be design to supply the six boreholes motor sizes in Table 2. The PV Solar system should be able to supply power the load of 86 kW Power. The boreholes will run for 12 hours in the day, that is from 06H00 in the morning to 18H00 in the afternoon.

The energy required per day:

$$Energy\ (kwh) = Power\ \times Hours\ per\ day \quad (3)$$

$$= 86\ \times\ 12$$

$$= 1028\ kWh$$

The energy required per year:

$$Energy\ (kwh) = Energy\ \times No\ of\ days\ per\ year \quad (4)$$

$$= 1028\ \times\ 365$$

$$= 375\ 038\ kWh$$

PV Solar Material

The PV is made out of different material such as Polycrystalline, Monocrystalline and thin film. In this design, a Polycrystalline will be used. I have selected the Polycrystalline because of its high durability, lower cost and for the fact that it Performs well at high temperature.

Sizing of PV Panel

Most Solar Panels ranges from 100-320 W per panel. The Solar Panel is sized base on the Bundu Power Solar data sheet. I have chosen the PV solar from the Bundu Power Supplier because it's has low cost and its locally manufactured in South Africa. The output Power for each panel is 300 W.

- **Peak system Watts**

According to the information in the below table the solar radiation is 6.02 day and according to the data sheet the efficiency for the panels is 17.12 %:

$$kWp = \frac{E \times (1 + \frac{n}{100})}{Solar\ radiation} \quad (5)$$

$$kWp = \frac{1028 \times (1 + \frac{17.12}{100})}{6.02}$$

$$kWp = 200\ kW$$

The Peak System Watts is= $200\ kW$.

- **Number of Panels needed:**

$$No\ of\ panels = \frac{Peak\ System\ (Wp)}{Rating\ of\ each\ Panel\ (W)} \quad (6)$$

$$No\ of\ panels = \frac{200\ 000\ W}{300\ W}$$

$$No\ of\ panels = 667\ Panels$$

667 Panels will be used to give the give the total power of 200 100 kW. The nominal Voltage required by the inverter is 580 V dc, therefore I use the voltage to calculate number of panels in series and parallel.

$$Ns = \frac{Vdc}{Vm} \quad (7)$$

$$Ns = \frac{580}{36}$$

$$Ns = 16\ Panels\ in\ series$$

$$\mathrm{Np} = \frac{\text{Total number of panels}}{\text{Panels in series}}$$

$$\mathrm{Np} = \frac{667}{16}$$

$$\mathrm{Np} = 42\ Panels\ in\ parallel$$

Inverter

- **Sizing the Inverter**

The Total load for the system is 86 KW.

I have selected the Sunny Power Inverter Model 9000LT because these inverters come in 3 phases and they allow flexible design up to Megawatt sized systems. The Output Power for the Model is 9KW.

Number of Inverters needed:

$$No\ of\ Inverters = \frac{Load\ Power\ (A)}{Power\ Rating\ of\ each\ Inverter\ (A)} \quad (8)$$

$$No\ of\ Inverters = \frac{86}{9}$$

$$No\ of\ Inverters = 10\ Inverters$$

IV. SIMULATED RESULTS AND ANALYSIS

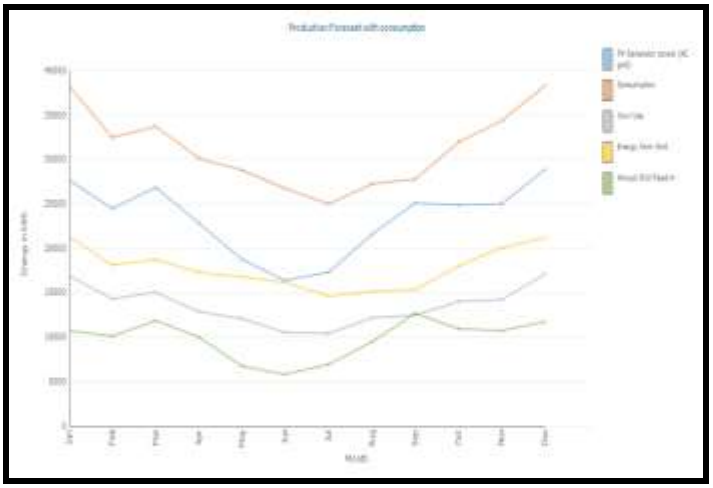

Figure 7: Production Forecast with consumption for 12 months

In the above figure 7 PV Solar is producing more power than the grid except in June, the PV Solar and the Grid are contributing the same amount of power. Bu from the graph we notice than during May to June the amount of Power generated by the grid is less than the amount generated in summer.

Performance Ratio

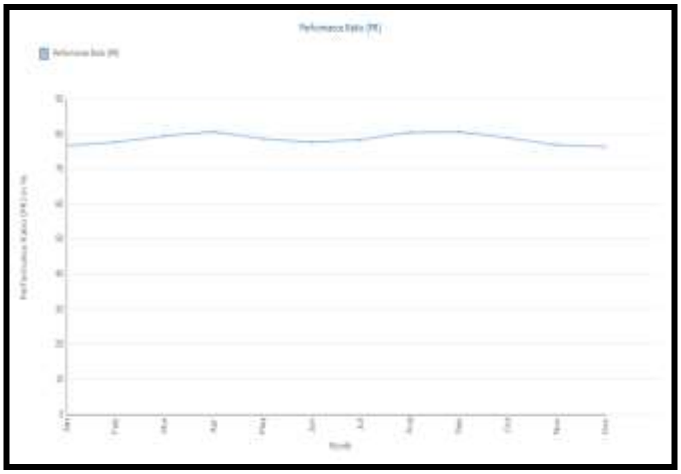

Figure 8: Performance Ratio of the system for the whole year

Figure 8 shows the performance of the system; the performance ration of the system is approximately 78 %. The performance of the system is stable during summer and winter periods. The stability was ensured by making sure that the Grid and PV both contribute to supply the load. The performance of the system is good therefore the requirement that the system must perform good has been met.

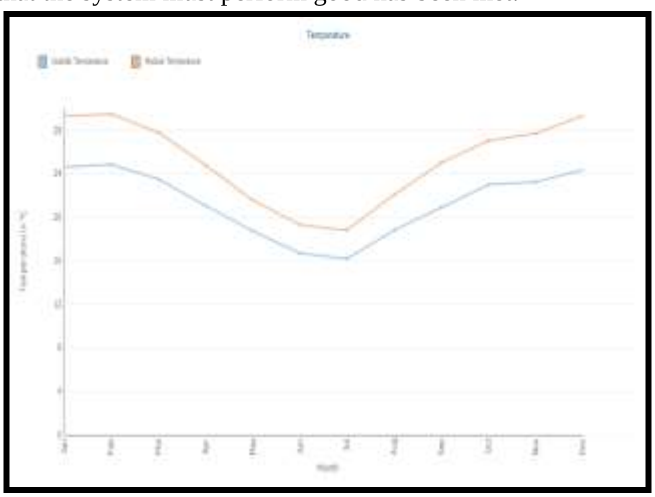

Figure 9: Outside and Module temperature

Figure 9 shows that the temperature of the PV Panel is dependent on the outside temperature, it is shown that the during winter when the outside temperate is low the PV Module is also low and in summer when the outside temperature rises the PV module as increases.

IV. ACKNOWLEDGMENT

The authors would like to acknowledge TUT Pretoria, providing necessary research infrastructure to conduct this research

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