International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 5 No. 5, May, 2015

Cost Comparison between Photovoltaic and Diesel Generator Water Pumping Systems

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ABSTRACT

Water is an essential ingredient of not only our domestic and industrial lives but also in other sectors such as schools, clinics, livestock and irrigation. In rural areas where there is near or total absence of electric grid system, and more water is needed than what hand or animal driven pumps can source, the options for powering water pumps are usually photovoltaic power systems or diesel generators. Unfortunately however, the choice between these two options of harnessing water is not usually a straightforward one. This paper presents an economic analysis comparison of separate photovoltaic and diesel generator water pumping systems in a remote Nigerian village. The goal of the analysis is to bring to focus which of these water pumping technology options is more cost effective and suitable to use in our rural areas. The life cycle costs of diesel generator based pumping systems increases at a rate of 300% over the predicted project life times compared to a much smaller rate of 40% for the photovoltaic based pumping system. Furthermore, the energy cost of photovoltaic based pumping system is about 28% lower than for a diesel generator based system. It is therefore fairly obvious from this result that on the basis of life cycle costing, photovoltaic based pumping systems are cheaper than diesel generator based pumping systems in the long term.

Key words: *Water Pumping System, Photovoltaic, Diesel Generator, Life Cycle Cost, Comparative Cost, Rural areas*

1. INTRODUCTION

Apart from air, water is of course one of the most important gifts of nature. It has dictated man's life and has and still controls man's continued existence [1]. Man has been harnessing water through a variety of power sources. The two most efficient and promising non-grid sources of power for harnessing water are photovoltaic power systems and diesel generators.

In remote areas where there is total absence of national electric grid systems, people still harness water through the use of hand or animal driven pumps. Such methods are obviously inefficient with very low achievable flow rates and the animals require feeding all year round. Photovoltaic power systems can be explored for the benefit of the communities instead of relying on inefficient and outdated pumping systems or costly national grid power system extensions.

Diesel generator is the most common non-grid water pumping power source, largely due to its low initial capital cost and fairly wide familiarity with the technology [2]. On the other hand however, photovoltaic power systems are less widely used due to their high initial capital cost and non-familiarity with this 'new' technology. The major goal of this research is to assess the long-term financial viability of these two competing water pumping systems. Records for fuel consumption, water flow, water pressure and water level were taken for a borehole at a diesel water pumping system in Malamfatori village of Borno state, Nigeria. These variables will be used to evaluate the complete performance of the diesel generator pumping system and also to determine its total and running costs. Comparison will then be made with a photovoltaic powered pumping system located at a distance of 2 km within the same village.

Photovoltaic power system water pumping for rural applications has had clear advantages within the last decade but the differences are becoming more striking in a world of rapidly escalating conflicts and fuel costs. Not only will some of the world's poorest and rural dwellers not be able to afford diesel for their generators, but living in a conflict zone, they cannot even be reached in the first place. (Malamfatori in Borno state, Nigeria is right now in the middle of Boko Haram conflict).

We show clearly from our findings in this paper and experience that photovoltaic powered water pumping is the most reliable and cost effective option when compared with diesel generator powered pumping systems.

2. DESCRIPTION OF THE INVESTIGATED WATER PUMPING SYSTEMS

Two water pumping systems were investigated – one is diesel generator powered while the other is photovoltaic powered. Both of these pumping systems are located within Malamfatori town but two kilometers apart. In what follows, a description of the components of each system is presented in sequel.

a. Photovoltaic Powered Pumping System

The investigated photovoltaic powered pumping system consists of the following main components:

b. Photovoltaic array:

The array consists of 32 M55 Siemens Modules connected in parallel and each rated 53 W. Thus the total installed capacity of the array stands at 1.696 kW and is similar to the micro-grid system installed in Ondo state, Nigeria [3]depicted in Fig. 1. It is a direct coupled system, in which electricity from the array is sent directly to the pump. In this system, overhead tank is used to store extra water for use during periods of little or no irradiance. The overhead tank attached to PV pumping system is similar to a solar pumping system installed in Sokoto, Nigeria [3] and is depicted in Fig. 2. The photographs of Figs. 1 and 2 are used because they are similar to the ones investigated in Malamfatori and since the photographs of the actual ones in Malamfatori could not be obtained due to the current Boko Haram conflict in the area.

4. ELECTRIC MOTOR

The motor used is a submersible dc brushless type. This type of motor combines the high efficiency of dc motors with low maintenance as opposed to brushed dc motors which require regular brush replacement.

5. PUMP

The pumping configuration used in this system is the helical rotor submersible pump, which is positive displacement pump mechanism that is mounted to the brushless submersible motor. The major advantage of this type of pump is its ability to last for many years with no regular maintenance. It also has a better daily delivery than centrifugal pump configurations due to the characteristic variable nature of photovoltaic power.

3. CONTROLLER

It is the electronic device which matches the photovoltaic power to the motor and regulates the operation, starting and stopping of the pump. The controller in this system is installed on the surface, although it is sometimes integrated within the submersible motor-pump unit. It is an ac controller (usually referred to as an inverter) that converts dc electricity from the array to alternating current electricity suitable for use by the motor.

A. Diesel Generator Powered Water Pumping System

The diesel generator powered water pumping system being investigated consists of the following main components:

a. Diesel generator: A dual cylinder, air-cooled, hand-starting Lister type diesel generator with a maximum continuous output power of 17 kW is used.

b. Pump element: Helical rotor pump type is used.

c. Pump head: The pump head is fitted above the center of the borehole while the rising main is fitted to the bottom of the pump head. The diesel generator is coupled to the pulley through belts. The pump head transfers the power of the diesel generator to the pump via a piston action.

d. Rising Main: consists of coupled 3 meter galvanized steel pipes each 50 mm in diameter with parallel thread. A shaft transfers the power down the center to the column through a piston action. The shaft is guided through bobbin bearings.

Figure 1: Typical Photovoltaic Array Arrangement for the Investigated Water Pumping System

Figure 2: Typical Overhead Tank for Water Storage

B. Cost Analysis

In order to compare different systems offering the same service/output, the life cycle costing approach is used. The life cycle cost (L_{cc}) of a system is the total 'lifetime' cost to purchase, install, operate, maintain, and dispose of that equipment. When used as a comparison tool between two systems, the process will show the most cost-effective solution between the two options.
The aim of this study is to compare the economic viability of photovoltaic powered water pumping systems and diesel generator powered water pumping systems. Net present value (N_{pv}) is used to calculate the life cycle cost of the two systems as presented in [4] and detailed hereunder.

$$N_{pv} = C_{ic} x\{1/1 + d\}^{l} \quad \ldots (1)$$

Where d = discount rate = Interest rate – Inflation rate
l = Project lifetime in years

The life cycle cost (L_{cc}) is given by equation (2) as follows:

$$L_{cc} = N_{pv} + M_c + E_c + O_c \quad \ldots (2)$$

Where M_c = Present maintenance cost
E_c = Energy cost
O_c = Present operating cost

The total annual cost (C_{ta}) is given by equation (3) as follows:

$$C_{ta} = L_{cc} x\{(1 + d)^{l} x\, d/(1 + d)^{l} - 1\} \quad \ldots (3)$$

The unit water cost (C_{uw}) is given by equation (4) as follows:

$$C_{uw} = C_{ta}/V_w \quad \ldots (4)$$

Where V_w = Volume of water pumped.

The energy cost (C_e) for running the system is given by equation (5) as follows:

$$C_e = C_{uw}/H \quad \ldots (5)$$

Where H = Total head including static head and losses.

a. Inputs to Costing Analysis

The diagram in Fig. 3 depicts an overview of the inputs to the life cycle costing analysis as structured in spreadsheet [5]. Using equations (1) to (5), the life cycle costs, unit water costs and energy costs for both the photovoltaic and diesel powered water pumps were determined and expressed in graph and bar chat forms as depicted in Figs. 4 – 6.

C. Useful Findings Regarding The Use Of Water Pumping Systems

A survey of the water pumping installation sites and interaction with users reveal a number of comparative differences regarding the use, security, and characteristics of the two pumping systems [5] as outlined in Table 1.

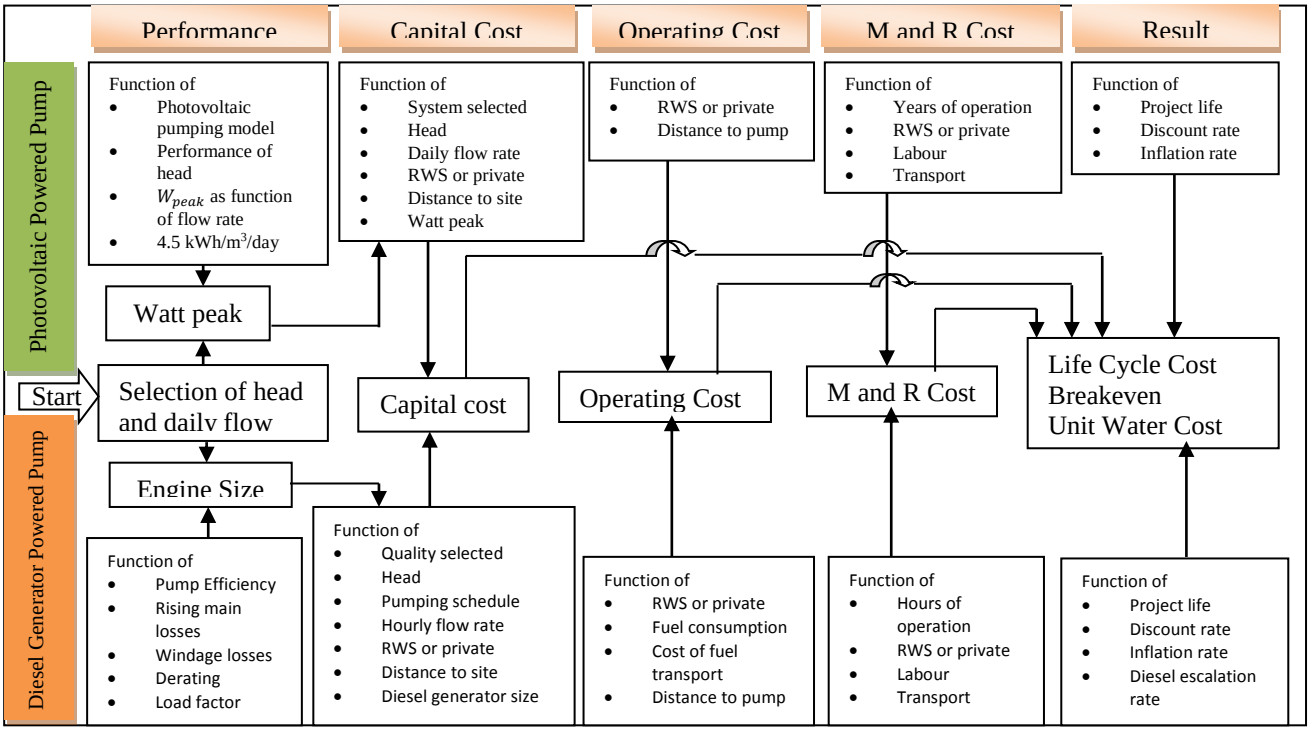

Figure 3: Spreadsheet Life Cycle Costing

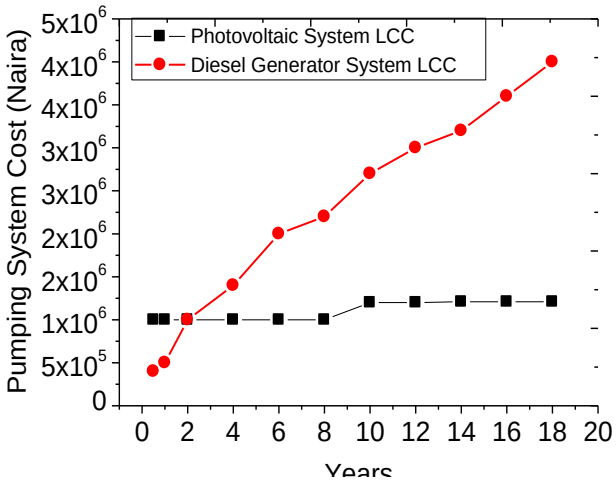

Figure 4: 18 Years Life Cycle Cost Comparison

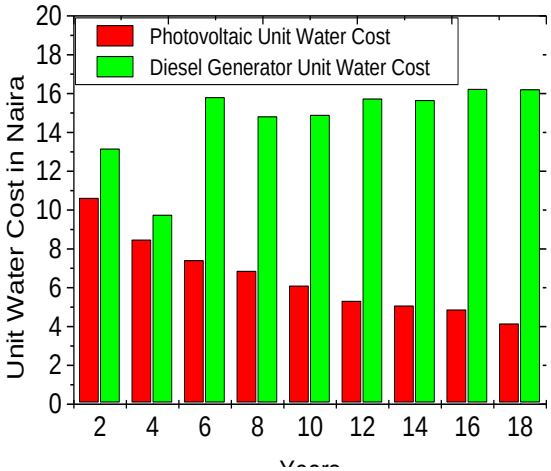

Figure 5: Photovoltaic versus Diesel Generator Powered Pump Life Cycle Cost Comparison.

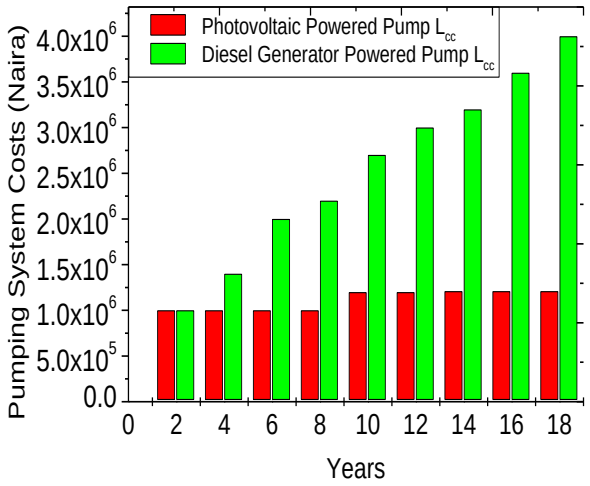

Figure 6: Photovoltaic versus Diesel Generator Powered Pump Unit Water Cost Comparison.

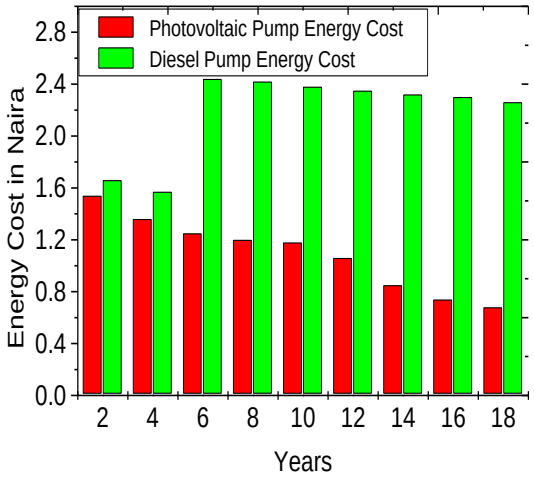

Figure 7: Photovoltaic versus Diesel Generator Powered Pump Energy Cost Comparison.

D. Discussion Of Results

The major cost findings of life cycle cost (L_{cc}), unit water cot (C_{uw}) and energy cost (C_e) for the two pumping systems are presented in Figs. 4-7. From Figs. 4 and 5, the L_{cc} costs within the first two years are similar for both PV and diesel generator pumping systems. However, the diesel generator L_{cc} cost increases astronomically in subsequent years. Both PV and diesel L_{cc} for 2 years are exactly the same, compared to the difference of ₦2.79 million after 18 years. The need to replace the diesel generator after 10 years, high maintenance and fuel costs are believed to be responsible for the very high L_{cc} of the diesel generator system despite the higher capital cost of the PV system.

The unit water cost (C_{uw}) for PV pumping system decrease with years unlike the fluctuating case for the diesel generator pumping system. Similarly, the energy cost (C_e) for the PV pumping system decreases with years while that of diesel pumping system fluctuates and much higher than that of the PV pumping system. The unit water costs for diesel generator pumping system are higher than those for PV pumping system by approximately 34.5%, while its energy costs are higher than those for PV pumping system by almost 72.1%.

Table 1: A survey of Comparative Perceptions between PV and Diesel Generator Pumping Systems

Perception/Finding	Photovoltaic Pumping System	Diesel Generator Pumping System
Cost	Perceived to be Expensive	Perceived to be generally affordable
Noise Generation	Quiet in operation	Noisy
Environmental Impact	Free from environmental impact	Suffers from Carbon emission and borehole contamination
Starting and running maintenance	Require no attention and starts automatically	Require regular maintenance and starts manually
Borehole size to pump type match	Suitable for weak boreholes	Unsuitable for weak boreholes
Corrosion	Corrosion is a problem due to poor quality of the steel riser pipes	Corrosion may be a problem but high grade stainless steel pumps are available
Volume of water	Perceived to pump insufficient volume of water	Perceived to pump sufficient volume of water
Maintenance skill	Maintenance skill is well established among users	Electrical and Electronics skill personnel are required
Flexibility	Less flexible in borehole to borehole transportation	More flexible in borehole to borehole transportation
Reliability	Less reliable due to obvious absence of redundancy, more difficult to repair and vulnerability to lightning strike	Perceived to be more reliable due to the inherent solid service infrastructure
Variable water demand	Storage tank are usually incorporated thus making the system more expensive	Can pump water on demand
Theft	Theft is a problem and the impact is grave due to the high capital cost of PV modules	Theft is a major problem but the financial impact is less felt

6. CONCLUSION

Although there is a general perception that diesel water pumping systems are generally affordable and that Photovoltaic powered water pumping systems are expensive, the result of this research has proved beyond reasonable doubt that diesel water pumping systems are indeed much more expensive than PV based systems in the long run. However, lack of funds to offset the initial capital cost and absence of skilled maintenance personnel may be constitute serious limiting factors in the use of photovoltaic pumping systems. The result obtained shows that photovoltaic

pumping systems are far more cost effective than diesel generator water pumping systems for periods exceeding 2 years. It is clear from the result that life cycle costs for PV increases at a much lower rate of just 40% compared to an increase of 300% for diesel generator pumping systems.
When considering a choice for a water pumping system, vital cost components such fuel costs, energy costs, source of funds and transportation to the site should be carefully analyzed before making a final choice.

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