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Sizing and Implementation of a Standalone Solar Photovoltaic System for a Three-Phase Submersible Pumping Machine

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Research Article

Abstract

The solar photovoltaic system is an alternative power supply source that could aid the economic growth of a nation. However, improper sizing of the system leads to a high installation cost and a low level of penetration in the energy mix. This study focused on the appropriate sizing and implementation of a standalone solar system for a three-phase pump machine in a farm in Ilorin, Nigeria. The pump rating was determined manually as 20HP, with a flow rate of 180,000 L/h. Consequently, the daily load and solar global horizontal irradiance data were acquired and used for sizing the PV system using HOMER Pro software. Fifty-six solar panels with a total area of 120.4 m2 were proposed and installed to achieve a total power of 22.4 kW required for the machine's operation. The levelised cost of energy was 0.4007 \$/kWh as against the cost of energy when the farm was running on generators with an energy cost of 4.170 \$/kWh. The economic analysis of the system for the farm shows the Net present cost and cost of energy of the system configuration are \$28,341.91 and 0.4007 \$/kWh, respectively.

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Keywords

Solar photovoltaic system, Optimum sizing, Three-phase pumping machine, Power supply.

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Nomenclature

LCoE	Levelised cost of energy [\$/kWh]	$\eta_{pumpinv}$	Solar pump inverter Efficiency (%)
crf	Cost recovery factor	E_L	Energy consumption [kWh].
HOMER	Hybrid optimization model for electric renewables	ρ	Water density [kg/m^3]
NASA	National aeronautics and space administration	GPM	Gallon per minute
NPC	Net present cost	V_{peak}	Peak voltage [v]
C_{NPC}	Total net present cost	*TDH*	Total dynamic head
PV	Photovoltaic	$C_{op\,\&\,om}^{fc}$	Operation and maintenance cost of fixed cost
RES	Renewable Energy System	$C_{op\,\&\,om}^{PV}$	Operation and maintenance cost of PV
Q	Volumetric flow rate of the pump [m^3/h]	$C_{op\,\&\,om}^{inv}$	Operation and maintenance cost of inverter
H	Operating head [m]	$C_{op\,\&\,om}$	Operation and Maintenance Cost
η	Efficiency of PV generator [%}	C_{CT}	Total Capital Cost
η_{pump}	Pump set efficiency [%]	C_{PV}	Capital cost of operating the photovoltaic
g	Specific gravity m/s^2	C_{inv}	Capital cost of operating the inverter
V_{rms}	Root mean square value of the voltage [v]	C_f	Fixed Cost
C_y	Total yearly Cost	FC	fuel cells
x	Life time of the system	DC	Direct current
r	Interest rate per annum.	MGT	Micro Gas Turbine
AC	Alternating current	L/hr	Liter/hour
NREL	National Renewable Energy Laboratory	E_d	The daily PV energy

1. Introduction

Electricity supply is essential to a country's human capital development and technological sustainability (Fang & Chang, 2016; Smith & Myers, 2018). It is required to drive economic growth and improve the standard of living, especially in the industries where goods and services are produced. Typically, electricity is generated by the utilities owned by the government or private sector at a cost to the consumers. The major sources of electricity generation are from coal and oil, which are fossil fuels, and non-renewable energy sources. Significantly, fossil fuel generates CO2 emission, polluting the environment and posing a health hazard (Jacobson et al., 2019; Zoundi, 2017). The contribution of fossil fuels to the production of electricity worldwide in the last 22 years ranges between 61% and 68% (Sönnichsen, 2021). Precisely, it stands at 61.75% in 2021, which is about 0.36% higher than the previous year. In addition, the cost of fossil fuel has gone up, thereby increasing the cost of energy production, which has to be paid for by the consumers. However, significant progress has been made over the last decade to reduce the quantity of CO_2 emissions from fossil fuels with alternative energy sources such as solar photovoltaic (PV) and wind energy which are eco-friendly. Reports show that the penetration of renewable energy in the power mix increased to nearly 28% in the first quarter of 2020 from 26% in the first quarter of 2019, thereby improving the supply and availability of power to consumers. Indeed, solar PV and wind generation stand at 9% within this period (IEA, 2020). These have been attributed to the significant decrease in the prices of solar PV system components on one hand and the increasing cost of fossil fuels, such as coal and gas, on the other hand. Despite this, most of the world's population still lacks access to electricity, specifically in the rural areas of underdeveloped and developing countries.

One such country is Nigeria, where most of its population lacks an adequate electricity supply. The power system supply in Nigeria is centralised, grid-connected and generated substantially from gas, accounting for about 81.53% of the total generated power in the country (Adebulu, 2021). The power supply in Nigeria has been epileptic as the electricity supply fails to grow linearly with the population. The population of Nigeria is estimated to be about 218 million ("Nigeria Population," 2022); of this number, about 48% lives in rural area. However, about 92 million, representing 42% of the population, lack access to electricity. The 52% expected to access electricity could not do so due to an epileptic power supply caused by several factors (Aduloju, 2022; Udegbunam, 2022). Regrettably, irregular power supply has hurt the economy, leading to low production, higher costs for goods and services, business closures and relocation of companies out of the country (Ugwa, 2020). Those who could not relocate substantially rely on diesel-generating sets to power their properties. Unfortunately, the cost of diesel oil has increased exponentially, asides from the emission of CO_2 effect on the environment. Thus, there is a need for an alternative power supply source that can meet the demand at a reasonable cost.

Solar PV has been identified to supply adequate electricity as a backup, either as a standalone system or hybridised with other power sources (Abd El-Sattar *et al*., 2022; Chennaif *et al*., 2021; Luna-Rubio *et al*., 2012; Wong *et al*., 2019). Fortunately, Nigeria is naturally blessed with abundant sunshine, primarily required for solar PV system operation. The solar radiation in Nigeria stand at a daily average of about 5.25 kWh/m2/day (Idowu *et al*., 2013), and as such, Nigeria is a potential hub for solar PV electricity production if the potential is adequately harnessed. This is shown in steps taken by the government toward improving the infrastructure and the enabling environment to make solar energy accessible and affordable (Agency; Elumoye, 2022). However, getting appropriate sizing of solar power components, such as the numbers of PV arrays and battery size that yield minimum cost, has been a subject of concern. This has led to different optimisation techniques for sizing solar PV systems in the last decade. For instance, undersizing a PV inverter to reduce the cost of solar systems has been proposed in (Väisänen *et al*., 2019). The inverter size calculations were done using historical meteorological data and the current PV system cost distribution. The optimum ratio of array-to-inverter was determined and the ratio of the economic loss from the clipped energy to the economic gain from the decreased system estimated. The optimization of the power ratios leads to lower electricity production costs. Jakhrani *et al*. (2012) proposed an analytical model, based on algebraic equations, for determining the optimum sizing of standalone photovoltaic systems. The model uses monthly mean daily solar radiation data and meteorological characteristics such as ambient temperature, sunshine duration and relative humidity to calculate the system costs

Furthermore, an optimal unit sizing for a standalone microgrid consisting of wind turbine has been proposed (Zhao et al., 2014). A method based on a genetic algorithm was used to solve the sizing optimization problem with multiple objective functions. The proposed method was applied to developing a microgrid system in China. Optimum sizing of a standalone photovoltaic system with energy management has been proposed (Semaoui *et al*., 2013). The model, which was simulated in a Matlab-Simulink environment, consists of the PV system, the load management and the optimization criteria. The two optimization criteria considered are the loss of power supply probability concept and the energetic cost for the economic evaluation. The energy consumption pattern, storage capacity, weather conditions and PV array peak power were used for the simulation.

The feasibility and techno-economic evaluation of a standalone hybrid renewable energy system, based on HOMER software, to supply the electrical energy required for a seawater desalination plant has been proposed (Rezk *et al*., 2020). The hybrid combinations are solar PV/ fuel cells/ batteries system, PV/ batteries system and PV/ fuel cells with a hydrogen storage system. The net present and energy costs were considered, and PV/FC/BS configuration proved the best. Mahesh and Sandhu (2020) proposed a genetic algorithm with an energy filter algorithm for optimal sizing for a grid-connected system. The constraints considered include loss of power supply probability and fluctuations in power injected into the grid. The result of the approach, when evaluated in a case study, without a filter, with an already existing filter and with the proposed filter, shows that the energy filter algorithm gave a cost-effective combination of the system components and satisfied the constraints.

Khatib *et al*. (2012) proposed the sizing of a standalone PV system based on the desired loss of load probability and the optimum PV array capacity for the PV array and battery storage size, respectively. The system energy flow was analysed, and the MATLAB fitting tool was used to fit the resultant sizing curves in order to derive general formulas for optimal sizing. Optimal sizing of hybrid renewable energy systems under smart grid theory has been proposed in (Eltamaly *et al*., 2016). A load-shifting technique consisting of high and low-priority loads was used to arrive at the lowest cost of generated energy at the highest reliability. The program was simulated and implemented in MATLAB software. The simulation results confirmed that dividing the load into high and low priorities reduces the size of the system, the price of kWh generated from the system increases the system's reliability. Ridha, Gomes, Hizam, *et al*. (2020) proposed a multiple scenario multi-objective salp swarm (SS) optimization method for sizing a standalone PV system. The target was to obtain the pareto optimal solutions by minimising two conflicting objectives. Loss of load probability and life-cycle cost are considered for the pareto front. Salp swarm penalty-based boundary intersection, SS non-scale, and multi-objective salp swarm non-dominated roulette wheel algorithms were used. The sizing of a standalone photovoltaic system based on a differential evolution multi-objective algorithm (DEMO) integrated with hybrid multi-criteria decision making (MCDM) methods has been proposed (Muhsen et al., 2019). The DEMO optimises the system configurations by minimising technical and cost objective functions, while MCDM orders the preference of configurations based on the loss of load probability and life cycle cost of the system.

Furthermore, adaptive differential evolution based on a multi-objective optimization algorithm has been proposed to optimise the configuration of the off-grid solar PV system (Ridha, Gomes, Hazim, et al., 2020). The performance of the proposed solar PV system is analysed using lead-acid, absorbent glass mat (AGM), and lithium-ion batteries. The results show that the optimal configuration based on lead-acid has less fitness function, life cycle cost, levelised cost of energy, with a high level of loss of load probability, and hence is suitable for real-world applications. Moghaddam *et al.* (2019) proposed an improved crow search algorithm to design a standalone hybrid PV/wind/battery system. The objective function was the net present cost, which includes the investment, replacement, operation, and maintenance costs. At the same time, the decision variables are the number of PV panels, wind turbines and batteries, the capacity of transferred power by inverter, the angle of PV panels, and wind tower height. The performance of the algorithm compared with the crow search algorithm is better. Okoye and Solyalı (2017) proposed an optimization model using integer programming for standalone PV systems in residential buildings. The model determines the optimal number of PV modules and batteries as well as the economic feasibility of the system through annualised cost. The success of the model is evaluated through a case study in Bursari, Nigeria.

Optimal sizing of a standalone hybrid PV/Wind/MGT/Battery system has been proposed for electric and thermal loads of an off-grid community using HOMER software (Das & Hasan, 2021). The use of the recovered excess energy waste heat and different power management strategies were considered in the model using HOMER software. Also, load following and cyclic charging are studied and compared while sizing the system's hardware components. Appreciable benefits in cost, reduction in CO2 emissions and renewable penetrations were achieved based on the results.

The reviews thus far show various applications of HOMER to optimise the photovoltaic renewable energy system. However, the techno-economic of a standalone PV system operating a three-phase submersible pump has not been critically examined. Therefore, this study focuses on the techno-economic, sizing and implemention of a standalone solar PV system to power a three-phase submersible pump for a fish farm in Ilorin. A new evaluation of the farm capacity is carried out based on manual computation and HOMER Pro software. The former was used for the pumping machine estimation, while the latter was used to optimise the solar PV system.

2. Methodology

2.1 Site Description

Super farm, located in Ilorin, Nigeria, is one of the leading fish farms using the Asa River for farming. The farm was established in 2012 and is situated on latitude 8.2635^0N and longitude 4.3222^0E. Asa River is purposely used for agriculture ranging from farming, fishing and poultry, being the major river connecting different local governments in Kwara State. The river is approximately 56 km long with a maximum width of around 100m within the dam site, and its total catchment area is about 1,037 km^2 (Balogun & Ganiyu, 2016). Super farm has fifty-six functioning ponds with dimensions of 40ft by 15ft by 5ft. The farm uses seven sets of petrol engines to supply twenty-eight ponds out of the fifty-six available ponds. Each pump uses approximately 1.3 L/hr of petrol at $ 0.464. Since the farm operates 9hrs a day, the total litre per day used to operate the machines is 81.9 L/day. Therefore, without considering the operation and maintenance cost, the hourly energy cost for operating the petrol engines is $ 4.16 $/kWh. However, due to the high price of fossil fuel, the environmental hazards it entails, and the advantages of solar PV power supply, the company decided to operate the twenty-eight ponds on standalone solar power systems to power the ponds.

2.2 Pump Size Estimation

The head of the pump and the amount of water discharge are essential parameters in selecting a pump. The pump head was estimated by measuring the distance between the delivery sites (pond), the pump's submerged depth and the head losses across the piping system. The shortest route is ensured to reduce the head requirements. Figure 1 shows how this was achieved. The estimated flow rate of the selected twenty-eight ponds was 173,736 litres per hour and was used as a benchmark for designing the three-phase sewage pump.

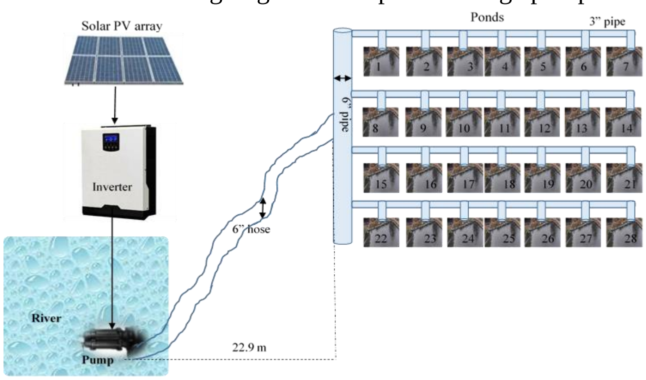


Figure 1 Schematic diagram of water-pumping system

The total elevation head is 22.9 m based on the position of the pump depth in the river and the farm's undulating topography. A 6" pipe at 2,895.6 L/min or 764.9 GPM with a corresponding frictional loss of 2.9 m was used. The equations adopted in the system modelling are detailed in (Biswas & Iqbal, 2018; Miran *et al.*, 2022; Riayatsyah *et al.*, 2022).

Therefore, the total dynamic head is given as:

$$TDH = \text{Elevation Head} + \text{Friction Head Loss} \quad (1)$$

$$TDH = 22.9 + 2.9 = 25.8\text{m}$$

The power of the motor is expressed as:

$$Motor\ power(kW) = \frac{Q \times H \times \rho \times g}{\eta_{pumpset} \times 3600 \times 1000} \quad (2)$$

where

Q = 173.736 m^3 /h, ρ = 1000 kg/m^3, g = 9.81 m/s^2, H = 25.8 m, and the motor pump efficiency $\eta_{pumpset}$ is assumed to be 80% (Harrison & On, 2011).

$$Motor\ power(kW) = \frac{173.736 \times 25.8 \times 1000 \times 9.8}{0.8 \times 3600 \times 1000} = 15.2kW$$

Table 1: Motor specification on the nameplate

Description	Data		Description	Data
Power	20HP		Voltage	415V
Flow rate	180,000 L/h		Speed	1,450 rpm
Current	29A		Outlet Diameter	150 mm
Frequency	50Hz		Pump Efficiency	80%
Head	25m			

Table 1 shows the pump's motor specification, and Figure 2 shows the water pump used for the selected site.

Figure 2: Water pump

2.3 Sizing of the solar photovoltaic System

Solar PV is viewed as a semiconductor absorbing the sunlight energy in the form of photons and converting the ray of the sun to voltage via the electron's movement. PV cells are configured as modules and coupled to form a PV array. Multiple PV arrays are wired together in series or parallel to produce the required power. Therefore, accurate sizing of solar panels should be ensured to generate the required maximum power. The PV system power output is expressed as:

$$P_{pv} = \text{Solar Irrandiamce} \times \eta_{pv} \times \text{Solar Panel Area} \quad (3)$$

The peak voltage generated from the solar PV to power the solar pump inverter can be written as:

$$V_{peak} = V_{rms} \times \sqrt{2} \quad (4)$$

$$= 415 \times 1.4142 = 586.89V$$

The solar system is designed to operate for 9 hours from 8 am to 5 pm. it is expected to lift 1,620,000 litres of water per day. The pump consumes a total of 136.8 kWh/day. Considering the total system losses of 16.5%, shading (7%), thermal losses (4.5%), dust and dirt (2%), dc cable loss (1%), AC Cable losses (0.5%), and solar radiation (1.5%) (Bruce, 2022). Thus, the daily PV energy E_d becomes:

The daily PV energy $E_d = 136.8 \times 16.5 = 22,572\,\text{kW}$

A 400watts, 42 V by 9.52 A monocrystalline cut cell solar panel was selected in order to achieve the total PV energy demand. Therefore, the total number of PV panels required is approximately equal to 56. This number of panels was installed and arranged in a series-parallel configuration. Fourteen numbers were put in series to give an output of 9.6 A, 588 V. Four sets of fourteen solar panels in series were arranged in parallel to provide a total output of 588 V, 38.08 A, giving a total output energy of 22.4 kW. Table 4 shows the total cost of solar PV data.

Table 4: 22.4 kW Solar PV System data.

Description	Data
Capital cost	20,200 US$
O&M Cost	300 US$/year
Replacement cost	8,000 US$
Lifetime	25 years

2.4 Mathematical model of Solar Pump Inverter

The solar pump inverter converts the DC power into an AC to supply the three-phase submersible pump. The inverter model for the photovoltaic generator is given as:

$$P_{out\_ivt} = P_{pv} \times \eta_{solar\ pump\ inverter} \tag{5}$$

The sizing of the solar pump inverter depends on the motor's HP rating, peak voltage, current, frequency and speed. Typically, in choosing the size of the inverter, a tolerance of 25% to 50% is allowed as part of the design to overcome the in-rush starting current of the pump. Therefore, the inverter capacity is selected as 22 kW (46% bigger than the motor size) to overcome the start current of the pump. Table 2 shows the specifications and economic data of the solar pump inverter selected to power the pumping machine.

Table 2 Solar Pump Inverter data.

Description	Data
Model	SV500-022-4t
Product name	SINCR
Power	22kW
Voltage	380V
AC output	AC 3PHP 380-480V 50/60Hz
Input Current	46A
Solar Input	DC 250-800 Voc
Capital Cost	957,000 US$
Replacement Cost	600,000 US$
O&M Cost	50 $/year
Efficiency	98 %

3. The proposed standalone energy system

Figure 3 shows the proposed standalone solar PV system, which consists of solar PV arrays, PV combiner box, a breaker switch, three phase solar pump inverter and a three-phase pumping machine.

Figure 3. The proposed block diagram of the hybrid system

The economic modelling of the system can be estimated by considering the annual project cost, which involves the Net Present Value (NPV) and the Levelised Cost of Energy (LCOE) in \$/kWh.

3.1 Net Present Cost (NPC)

The total net present cost equals the value of all expenditures minus the current value of all income over the system's lifespan. The total NPC is calculated by adding the total discounted cash flows in each year of the project's life cycle as:

$$C_{NPC} = \frac{C_y}{CRF\,(r,x)} \tag{6}$$

3.2 Total cost in a year

The annualised cost of a component is the cost that gives the same net present cost as the actual cash flow sequence associated with that component if it were to occur equally in every year of the project's lifetime. The total yearly cost is given as:

$$C_y = (C_{ct} \times C_{crf}\,(r,x)) \tag{7}$$

3.3 The total capital cost

Capital cost is the fixed or one-time cost of designing and installing the standalone system. The total capital cost C_{CT} for the proposed combination of the standalone system is given as:

$$C_{ct} = C_{pv} + C_{inv} + C_{fc} \tag{8}$$

The capital recovery factor, which is a ratio that is used to assess the annual present value, is expressed as:

$$C_{crf}\,(r,x) = \frac{r(1+r)^x}{(1+r)^x - 1} \tag{9}$$

3.3 Annual Operation & Maintenance cost

The total operation and maintenance cost of the system is the sum of the operation and maintenance costs of each system component and is calculated as:

$$C_{op\&ma} = C_{op\&ma}^{pv} + C_{op\&ma}^{inv} + C_{op\&ma}^{fc} \tag{10}$$

3.4 The levelised cost of electricity by the standalone system

The *LCOE* is the average cost per kWh of useful electrical energy produced by the system and expressed as:

$$LCOE = \frac{C_y}{E_L} \tag{11}$$

3.5 HOMER Optimization Tool

Numerous optimization studies of different configurations of renewable off-grid and grid-tied systems have been conducted using HOMER software, developed by the National Renewable Energy Laboratory. HOMER performs the technical and financial estimations for hybrid systems during a particular lifetime of a project under assessment. Accurate data about the initial investment, operating and maintenance costs, and the costs of replacing system components are essential for the simulation. This study utilises HOMER and the Schematic diagram of the standalone solar PV power system in HOMER for this study is shown in Figure 4.

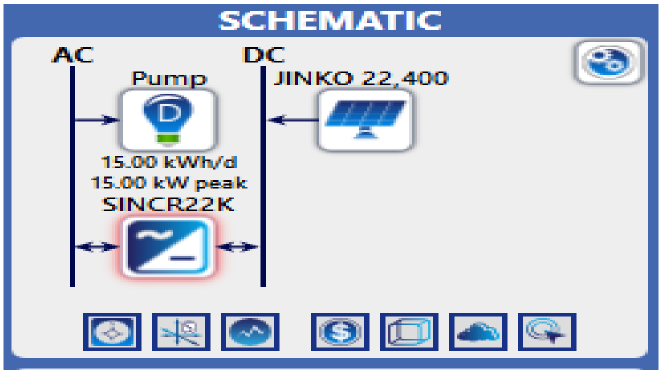


Figure 4: Schematic diagram for the stand-alone power system in HOMER for the study area

3.6 Input variables used in the simulation

3.6.1 Daily load pattern of the farm

The daily load consumption pattern of the farm is shown in Figure 5. The load pattern was derived based on the machine power ratings and hours of operation. The load metric is shown in Table 3.

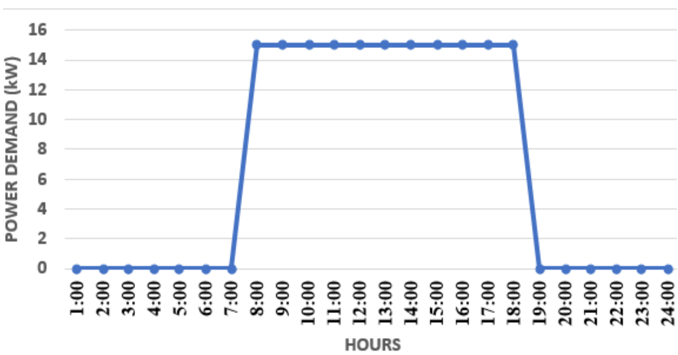


Figure. 5: Daily load pattern of the case study

Table 3. The load metrics/baseline.

Metric	Baseline
Average (kWh/day)	15.00
Average (kW)	15.00
Peak (kW)	15.00
Load factor	0.15

3.6.2 Study site solar irradiance data

The solar irradiance profile of the farm over one year is presented in Figure 6.

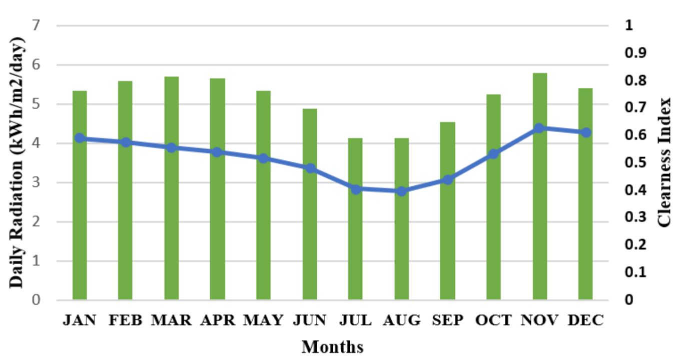


Figure 6: Solar irradiance profile

The weather data were from the Surface Meteorology and Solar Energy database hosted on the National Aeronautics and Space Administration (NASA) website. The data was generated by entering the geographical location of the farm; 8.26° latitude and 4.32° longitude of the site. From Figure 6, the monthly average irradiance value is minimum in July, with an average value of 4.24 kWh/m2/day, and the maximum in November is 5.93 kWh/m2/day.

4. Result and Discussion

The combination of PV/converter was simulated using HOMER Pro, and the monthly electrical power generated was used to calculate the monthly flow rate in L/hrs, as presented in Table 5.

Table 5: The monthly power generated by PV with respect to the flow rate

Month	PV (kW)	Flow rate (L/hr)
Jan	16.33	115,270.59
Feb	16.82	118,729.41
Mar	16.55	116,823.53
Apr	16.09	113,576.47
May	14.27	100,729.41
Jun	13.63	96,211.76
Jul	12.41	87,600.00
Aug	12.47	88,023.53
Sep	13.53	95,505.88
Oct	15.57	109,905.88
Nov	17.57	124,023.53
Dec	16.7	117,882.35

The power generated by the PV in November and July stand at 17.57 kW and 12.41 kW corresponding to 124,025.53 L/hr and 87,600 L/hr, respectively. This is due to the irradiance of the sum during these periods.

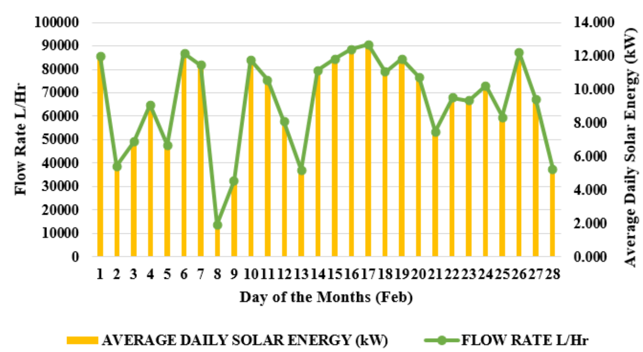


Figure 7: Daily power output of solar PV and the flow rate for the month of February

Figure 7 and Figure 8 illustrate a typical daily power output of solar PV and the flow rate/day for February representing the dry season and July, representing the raining season, respectively.

The flow rate is 85,412 L/hr on the first day in February as against that of July, which is 50,536 L/hr. The lowest flow rate experienced on the 8th day of February was 13,599 L/hr and on the 21st day of July was 17,349 L/hr. Similarly, the highest flow rate on the 17th day of February is 90,489 L/hr and on the 9th day of July, is 85,199 L/hr.

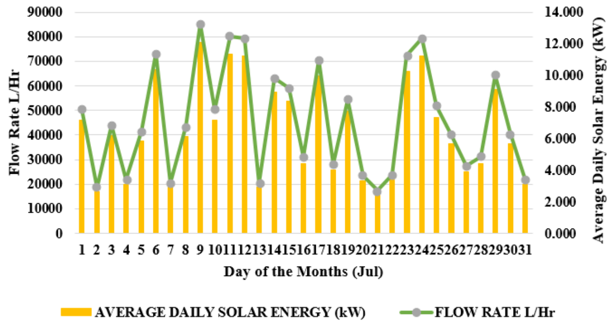


Figure 8: Daily power output of solar PV and the flow rate for the month of July

The economic analysis of the system for the farm is shown in Table 6. The NPC and COE of the system configuration were found to be $28,341.91 and 0.4007$/kWh. This indicates a significant reduction in COE compared with petrol COE of 4.16 $/kWh as noted in section 2.1.

Table 6 Economic characteristics of optimized PV Systems

System combination	PV/Converter
NPC	$28,341,91
COE	0.4007 $/kWh
Initial Capital cost	$22,811
System combination	PV/Converter
NPC	$28,341,91

Figure 9 shows the levelised cost of energy for the farm. Running the case study on PV/inverter will produce the lowest levelised cost at 0.4007 $/kWh with no emission compared to the existing source of the energy cost of 4.17 $/kWh and produce a lot of environmental hazards.

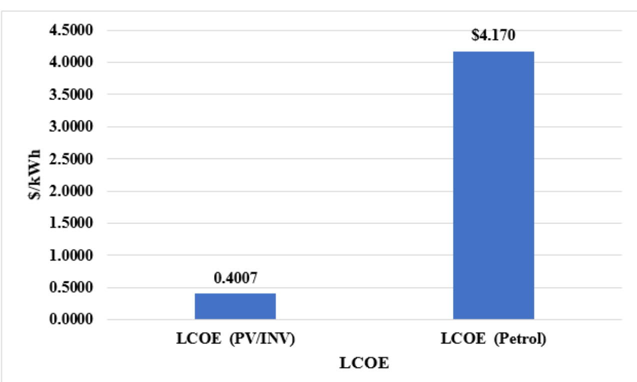


Figure 9: Levelised cost of energy for the proposed system and the existing system

4.1 Project implementation

The standalone solar PV system was implemented based on the calculated system components. Figure 10 (a) shows galvanised pipes installed in the marked area. The planks and hangers are fixed on the reinforced poles to hold the solar panels. Figure 10 (b) shows the arrangement and fixing of the solar panel on the plank roof. The total area the solar panel occupies is 9.62 m by 18.8 m.

(a)

(b)

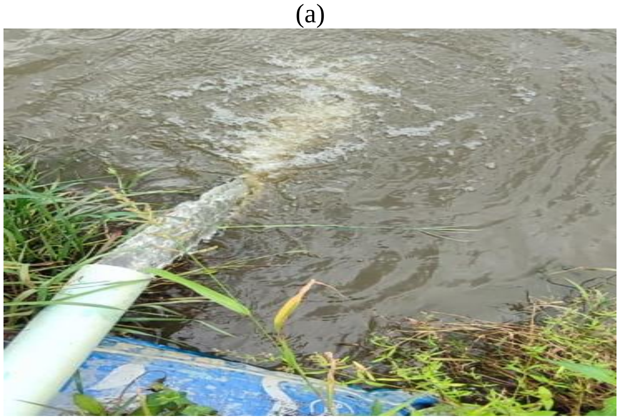
Figure 10: Mounting of Solar panel on the roof rack

The accurate positioning of the solar PV array was ensured to an average tilt angle 22^o (Ajao *et al.*, 2013) to have maximum irradiance for maximum power generation. The solar panels were connected in series-parallel configuration using 10mm2 twin flex copper wire through a DC breakers as stated in section 2.3. The voltage and current were tested to achieve the total power delivered to the solar pump inverter. The inverter was connected to the pump using a 10mm2 4 core flex copper wire. The submersible sewage pump was cased with metals and submerged in the river at an appreciable distance to the ground level to protect against mud. The overall system was tested, and the standalone solar PV operated optimally. Figure 11 depicts the solar pump inverter during operation.

Figure 11: Solar pump inverter during operation.

Figure 12 (a) shows the pond area, while Figure 12 (b) shows the water flow to the pond during the system's operation.

(a)



(b)

Figure 12: Water flow rate during PV/Inverter operation

5. Conclusion

This study carried out the optimal sizing and implementation of a standalone solar PV system to power a three-phase submersible pump at super farm Ilorin. The daily load and solar GHI data were acquired and used for sizing in the HOMER Pro environment. The pump rating was manually calculated, and a 20HP, three-phase pump motor with a flow rate of 180,000 L/h was proposed and used. Based on the pump's rating, a corresponding solar inverter and the required solar panels were estimated. Fifty-six solar panels with a total area of 120.396 m2 were proposed and installed to attain a total power of 22.4 kW required for the pump's operation. The installed system is economically viable and free of emissions. The levelised cost of energy is 0.4007 $/kWh as against the cost of energy when running a generator with an energy cost of 4.170 $/kWh. The economic analysis of the system for the farm shows the NPC and COE of the system configuration to be $28,341.91 and 0.4007 $/kWh.

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