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Optimisation of hybrid renewable energy using particle Swarm optimisation techniques

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Abstract
Rough estimate calculation of hybrid systems in determining the appropriate size and exact component selection has resulted in a high initial setup. It thus becomes a major challenge for potential users. Many users are interested in a cost-effective hybrid system with better performance and efficiency. Hence this research work utilizes a formulation of the Optimisation problem, developed from the hybrid system components to determine the most economical size of PV array, battery bank, and sustainable power rating of diesel generator. Hence, delivered a cost-effective and sustainable power supply for Community. This research aims to optimally size a photovoltaic (PV) panel, energy storage system (batteries) and diesel generator for the community. The objectives are; to utilize an existing model for the various components of the energy system, to utilize an algorithm coded using MATLAB software to determine the numbers of Photovoltaic (PV) panels, exact energy storage system and suitable generator size needed for the optimal configuration and reliability index, and to analyses the result of numbers of the panel, numbers of batteries power rating of generator and cost of total generated energy for the optimal design required for sustainable energy in community. The study will cover the optimal sizing of PV panels, battery storage system and the diesel system using Particle Swarm Optimization (PSO) and Differential Evolution (DE) by determining the numbers of appropriate solar PV panels, the rating of the diesel generator to be installed, the number of batteries to be installed, to determine total energy cost and reliability of the system. However, the study does not cover the component characteristics of inverter, charge controller analyses and placement in the community, India. Renewable energy development in Nigeria is key to sustaining human development. This study establishes an ideal size for photovoltaic (PV), diesel generators, and energy storage systems. The photovoltaic (PV) system is connected to a battery, which functions as an energy storage system, allowing for greater stability by storing extra energy and delivering the energy when required. At the same time, the diesel generator serves as the backup power source. Finally, the optimal sizing result was found to have satisfactorily catered for the load demand in with zero loss of energy probability and minimum Levelized cost of energy.

Keywords: Optimisation, renewable energy, PV, diesel, wind, PSO and DE

1. Introduction

The importance of developing alternative energy that is more available, reliable, cost-effective, and with reduced environmental hazard have been a major concern in most of the world. Securing sustainable energy has been of prime importance amidst climate change, diminishing fuel supply and global warming concerns (Amer *et al*., 2013) [2]. The creation of a sustainable electricity supply faces two obstacles (Calderaro *et al*., 2014) [4] the problems of how to generate and make electricity sufficient for the immediate users at a reasonable cost and how to increase efficiency through the use of more environmentally sustainable energy sources (Ohunakin *et al*. 2014) [19, 20]. Kamaruzzaman *et al*. (2019) [11] explained that reliable energy in less developed areas of the world is more demanding and contributes to infrastructure development for sustainable human development. Hence, it becomes imperative to harness and optimize power supply by utilizing locally abundant energy sources such as bio-waste, fast-moving water bodies etc., along with other sustainable non-conventional source.

Nigeria is located along the Atlantic Ocean's Gulf of Guinea between the Northern latitude of 9.082 degrees and the eastern longitude of 8.675 degrees. In contrast, the Ayetoro community in Ede south local government, Ede, Osun State, is located on the southern latitude of 7.727637-degree, western longitude of 4.428045 degrees and 955 feet above sea level (Geographic coordinate of Nigeria, 2020). Weather Spark (2020) shows that in the Ayetoro community in Ede, the daily average maximum temperature is 94°F, While the average minimum temperature is 70°F. This brings the average daily incident of reflectance solar energy to 4.85kWh. However, uneven reliability and unavailability of power supply problems arise in the use of the photovoltaic system when there is no sun; after the batteries used as storage system have been fully discharged, then users become helpless as a result of a change in weather (Mengi & Altas, 2015) [17]. The battery storage system is a critical solution to the intermittent nature of renewable energy production while also providing rapid ramping capacity to improve power system reliability and stability. The regulation of connected batteries as a storage system is constrained by physical and energy constraints, and the accumulated energy must be maintained within a preset range of operation (Moutis, 2019). Proper integration of batteries as a storage system yields more productivity than when they do not have any battery as storage.

Therefore, an alternative power supply source needs to be connected to the system to maintain continuous reliable and available power supply to the community. A diesel generating system is considered a backup to maintain the energy supply to the community. Proper component sizing and optimal combination of P.V. array and energy storage system such as battery with diesel for a hybrid system provide economical and sustainable electricity for urban and rural electrification (Ramli *et al*., 2018). This will eventually minimize the diesel generator fuel expense, operating time, energy storage system utilization optimisation, and the renewable share of the mix of energy sources for low-cost energy service in the rural community.

The sun is the only major and the largest source of energy that produces that is being received on the earth's surface. The energy produced is called solar irradiation (Solar Energy, 2019). The solar energy system has been harnessed for various uses such as solar heating, photovoltaic, and solar thermal energy, it requires modern technology, but the most commonly utilize the use solar P.V. system that can generate usable electricity from the incident of rays of sun on the panel (Harnessing Solar Energy 2017) [10]. There is enough opportunity available for the use of solar energy as a means of providing alternative power supply and to help fill some of the nation's significant energy shortage gaps in both the rural and urban areas where there is instability in power supply as a result of the availability of abundant solar energy irradiation in Nigeria (Newsom, 2012) [18].

2. Literature Review

The Photovoltaic (PV) system, also known as solar (PV) cell, was discovered when experimenting with silicon's various characteristics around the 1950s. Since its discovery, it has been utilized for commercial and industrial usage of powering satellite equipment in the early 1960s. It is a device that uses a mono process to convert irradiation energy from solar into electrical power energy (Solar energy, 2020) [21]. The solar cell is the most fundamental aspect of any photovoltaic system. Diodes, processors and transistors made from silicon are used in the design. By doing a p-n junction, energy is generated in the cell, which develops an electrical field in the cell crystal. An approximate value of 0.5 V is generated from the cell due to the incident of light on the solar cell, and the current produced ranges from 0-10A (Dufo-López & Bernal-Agustín, 2015) [6].

2.1 Energy Storage System

Recently, the development and installation of storage systems have been increasing exponentially worldwide (Li *et al*., 2015). Pumped hydro storage is the most utilized storage with a total of 92.6% utilization. In contrast, the Li-ion battery has the largest contribution of 89.0% in the electrochemical storage system. In comparison, Nas and Lead-acid batteries contribute 5.3% and 4.5%, respectively, as shown in figure 2.6. A flow battery, Supercapacitors and other forms of storage show a contribution of 0.9%, less than 0.1% and 0.3%, respectively (China Energy Storage Alliance (CNESA, 2020)).

2.2 Classification of Energy Storage System.

Storage systems used in renewable energy systems can be classified into five groups such as electrochemical, electrical, mechanical energy system, thermal and chemical energy storage (Yao, 2016) [22]. The electrochemical storage consists of Li-ion, Pb-A, Na-S, Ni-Cd, Flow battery, Redox flow etc. In contrast, the electrical storage consists of a capacitor, super capacitor, and superconducting magnetic system. Likewise, mechanical energy consists of Pump hydro, flywheel, and compressed systems. Figure 2.7 shows that thermal and chemical energy are subdivided into latent or heat storage and fuel cell. Selection of energy system storage is selected based on the data analysis obtained in terms of power capacity, lifetime, cost, system performance, mode of processing, maturity, reaction time, self-discharge time, system capacity, discharge time, and other related conditions that were available (Luo, 2015) [15].

2.3 Hybrid Optimization Algorithm Techniques

Numerical optimisation approaches for addressing renewable energy problems have risen in popularity. Several evolutionary programming techniques like Particle Swarm Optimization, Genetic Algorithms and Artificial Bee Colony are becoming more useful in solving simple and complex problems.

2.4 Particle Swarm Optimisation

Kennedy and Eberhart propose the techniques of the Particle Swarm Optimization technique. It is a metaheuristic optimisation algorithm that iterates over several search points, analogous to a GA search. The PSO technique was influenced by the collective intelligence of a group of people, much like the intelligence of a flock of birds, a herd of animals, or a school of fish swimming together. The PSO observes the individual's and population's best positions related to the algorithm's function. The terms best and best stand for the individual and group's best performances. The individual's current position is calculated using its original position and velocity. The objective function value is calculated for the new locations, and the PSO measures are repeated. Some of the review works performed by researchers on hybrid renewable energy using particle swarm optimisation are Abuzeid *et al*. (2019) [1] works on RES for residential applications using PSO searching methods to determine the optimal sizing. Cancelliere (2019) [3] developed a methodology for sizing HRES systems (solar-diesel), battery-backed in non-interconnected zones, and a sizing methodology using a PSO algorithm to minimize the Levelized cost of generated energy. This solution allowed photovoltaic generation with the battery storage system to minimize the rate of fuel consumption and the operational cost of diesel production. Kharrich *et al*. (2018) [13] investigated the optimal sizing and total annualized cost of two different locations using PSO techniques. The result shows in the design of a hybrid microgrid HRES system, in which the system was examined in two countries to determine their optimal economy and size. The optimisation was performed using the PSO algorithm. According to cost and pollution requirements, a hybrid solar energy system's optimal size is investigated by Charfi *et al*. (2018) [5] using the particle swarm optimisation technique.

2.5 Differential Evolution
Differential evolution is a technique that solves problems more effectively by repeatedly attempting to make a potential solution better in terms of a specified criterion for quality. These techniques, which make little to no assumptions about the problem being optimized and can search through huge spaces of potential solutions, are referred to as metaheuristics. However, using metaheuristics like D.E. does not ensure that the best solution will ever be identified (Price, 2005) [23]. DE maintains a population of candidate solutions and generates new ones by combining old ones following straightforward formulas. It then keeps the candidate solution with the highest score or fitness on the optimisation task. In this perspective, the optimisation problem is viewed as a "black box" that only provides a measure of quality for a potential solution, negating the necessity for the gradient (Talbi, 2009) [24].
Stages of differential evolution are briefly given below:

- Initialization
- Fitness evaluation
- Mutation
- Crossover
- Selection

2.6 Diesel Generator Sizing
Generator sizing is vital to any installation's performance. It demands a complete comprehension of electric power, its features, and the main specification of the electrical devices that make up the load demand. While analyzing the electrical load, the nameplate on each primary appliance determines the specifications for starting and operating watts, amps and voltage standards. For residential, commercial and industrial utilizations, a diesel generator with an output between 20 to 25 percent greater than the maximum power required should be used. It is feasible to generate a more consistent and potent output power. (Generator sizing guide, 2017) [9].

3. Methodology
1. Block Diagram of the Hybrid System
The hybrid model of solar PV and Diesel generator system will be implemented using the block diagram shown in figure 3.1.
The output of the diesel generator is directly connected to the load and rectified to serve as a charging source for the battery bank. The P.V. system is connected to the battery bank via the charge controller to check for excess battery charging, as shown in figure 3.2.

2. Simplified Single Diode P.V. Cell Model
The Simplified Single Diode PV Cell Model is shown in figure 3.3.

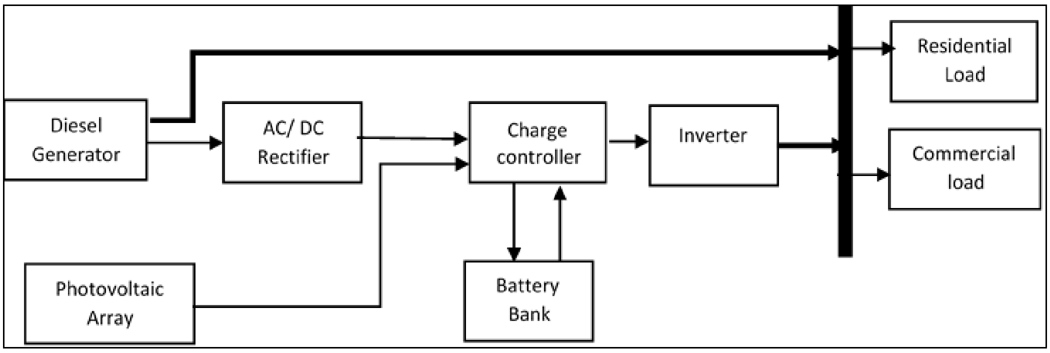

Fig 1: Block diagram of PV / Diesel generator system.

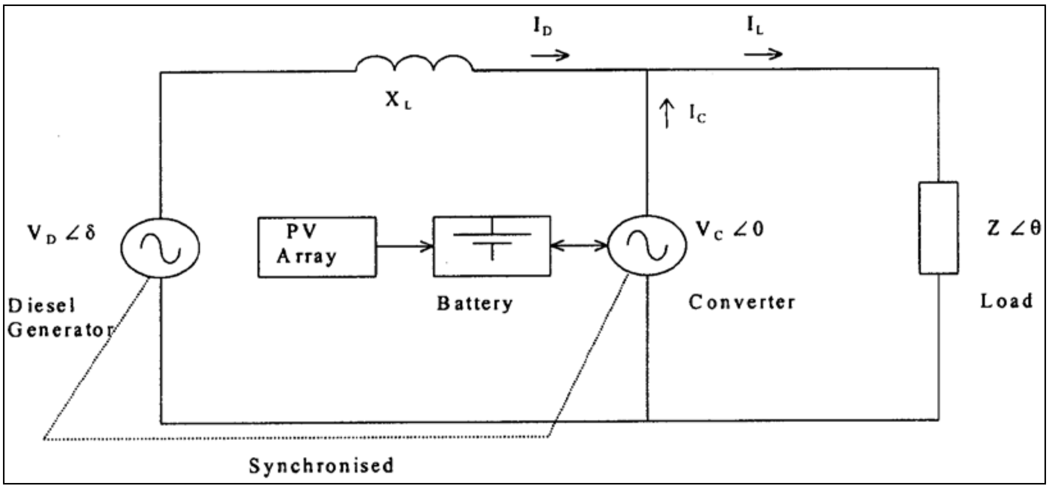

Fig 2: Equivalent circuit modelling of a hybrid P.V./Diesel generator system (Sabatha, 2015)

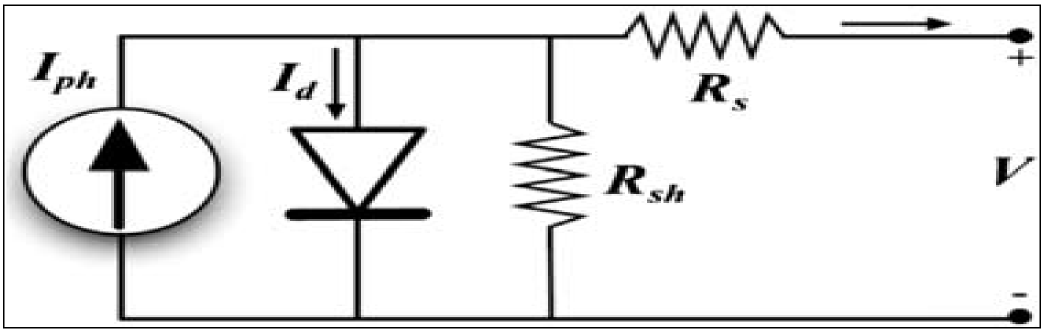

Fig 3: Simplified single diode PV Cell model

3. Solar Panel Modeling

$$I_{mp} = I_{sc} \left\{1 - C_1 \left[\exp\left(\frac{V_{max}}{C_2 * V_{oc}} - 1\right)\right]\right\} + \Delta I \quad (1)$$

$$V_{mp} = V_{max} + \mu_{v\,oc} * T \quad (2)$$

$P_{mp} = V_{mp} * I_{mp}$; Where; I_{mp} and V_{mp} = PV current and voltage respectively (3)

$$C_1 = \left[\left(1 - \frac{I_{max}}{I_{SC}}\right)\right] exp\left(-\frac{V_{max}}{C_2 * V_{oc}}\right) \quad (4)$$

$$C_2 = \left(\frac{V_{max}}{V_{oc}} - 1\right) * \left[In\left(1 - \frac{I_{max}}{I_{SC}}\right)\right]^{-2} \quad (5)$$

$$I = I_{sc} * \left(\frac{G_T}{G_{ref}} - 1\right) + \mu_{sc} * T$$

$$T = T_c - T_{c\,ref} \quad (6)$$

$$T_C = T_{amb} + \frac{NOCT - 20}{800}$$

Where; $G_{T.}$ is the irradiation value of the solar panel
T_{amb} is the ambient temperature
The value of Normal Operating Cell Temperature (NOCT) is available on the manufacturer's data sheet (Farahmand, 2017).

$$NoS_s = \frac{V_b}{V_0} \quad (8)$$

NoS_s Represent the number of series-connected solar P.V. panel, V_b represents the selected output dc voltage, and V_0 represent the design variable voltage.

4. Battery Energy System Modeling.

The battery energy system state of charge (SOC) is as represented in equation 9

$$SOC_{t+1} \le SOC(t) - P_d(t) / n_d + n_c P_c(t) \quad (9)$$

The minimum and maximum state of the state of charge as shown in equation 10

$$SOC_{min} \le SOC(t) \le SOC_{max} \quad (10)$$

Equation 11 shows that the charging and discharging of the battery bank cannot occur simultaneously.

$$S_c(t) + S_d(t) < 1 \quad (11)$$

The battery limit is as shown in equation 11

$$S_b(t) < S_{bm}(t) \quad (12)$$

$\Delta Pow(t)$ is the total power required for the load including diesel generator as shown equation 13

$$\Delta Pow(t) = P_{Load}(t) - P_{PV}(t) - -P_d(t) \quad (13)$$

The inverter efficiency is as given as

$$P_L(t) = P_i(t) / eff_{inv} \quad (14)$$

$$\Delta P(t) < 0 \quad (15)$$

Therefore,
When the battery is full, the diesel generator is switched off.

$$\Delta P(t) > 0 \quad (16)$$

The change in ΔP diesel generator and battery must supply the required energy needed

$$\Delta Pow(t) = 0 \quad (17)$$

The diesel generator is off, and the stored energy is on standby.

5. Diesel Generator Model

The diesel generator system operational cost for the design is as shown in equation 18

$$C_{DO}(t) = P_r(t) * A\, P_D(t) + BP_{RD}(t) \quad (18)$$

Where, A and B fuel curve coefficients

$P_r(t)$= fuel price

$P_D(t)$ = diesel generator output power (W) and
P_{RD} = diesel generator rated power (W)

6. Inverter System Model
In order to account for losses and enable the system to satisfy the highest load demand, the inverter rating capacity is built with a 20% increase (Farahmand, 2017).

$$Pow_{inv} = 120\,\%\, P_m \tag{19}$$

7. Formulation of Objective Function
In order to solve an optimisation problem, it is very important to identify the various decision parameters and their corresponding variables and formulate the objective function, which is subject to various sets of constraints to make the design sizing optimal.
The objective function is defined as the addition of P.V. panel (TC_{PV}), diesel generator (TC_D), inverter (TC_{inv}), and battery storage costs (TCB), as shown in equation 3.20 (Belfkira, 2011).

Where,

$$TC = TC_{PV} + TC_D + TC_B + TC_{inv} \tag{20}$$

Where maintenance and capital installation cost are considered

$$TC_{inv} = C_{pvC} + C_{pvI} + C_{pvM} \tag{21}$$

$$TC_B = C_{BC} + C_{BI} + C_{BM} + C_{BO} \tag{22}$$

i.
ii.

$$TC_D = C_{DC} + C_{DI} + C_{DM} + C_{DO} \tag{23}$$

$$C_{DO} = \sum_{1}^{365} \sum_{t=1}^{24} c(t) \tag{24}$$

8. Model of optimal Sizing.
min TC (x) = min (C_T (x) + C_M (x) + C_I (x) + C_D (x)) (25)

Where (x) = (N_p , N_b) and P_p (t) = P_L (t) (26)

$$SOC_{(t)} \geq SOC_{min} \tag{27}$$

$$SOC_{(t)} \leq SOC_{max} \tag{28}$$

$$SOC_{(t)} \geq SOC_{min} \tag{29}$$

iii.

$$0 \leq N_p \leq N_{p\,max} \tag{30}$$

$$0 \leq N_b \leq N_{b,\,max} \tag{31}$$

Where T.C. (x) is the total cost, is the summation of C_T.(x) system capital cost, C_M (x) the system component maintenance cost, C_I (x) the component installation cost and C_D (x) the total cost of the diesel energy generator as shown in equation 25 (Belfkira, 2011).

9. Annualized Capital Cost
The capital cost of the component is the product of the cost of installing and purchasing components and the capacity recovery factor (CRF). This applies to the calculation of P.V. solar and diesel generators utilised in the design, as shown in equation 32.

$$C_T\,(x) = C_T\,(x) \times CapRef(y.i) \tag{32}$$

Where
C_T (x)= is the initial capital cost of the design components.

10. Capital Recovery Factor
A typical factor used to calculate the component's present value is the capital recovery factor. The system component's useful shelf life is estimated in y years, while the interest rate value i placed on the component is shown in equation 33.

$$CapRef(y.i) = \frac{i(1+i)^y}{(1+i)^y - 1} \tag{33}$$

11. Annualised Maintenance Cost
The maintenance cost of the system component C_M (x) includes labour charges, maintenance, and another cost for the system to meet the design lifetime proposed, and it is expressed as in Equation 34.

$$C_M\,(x) = C_M\,(x) \times \frac{1}{(1+i)^y} \times CapRef(y.i) \tag{34}$$

12. Annualized Fuel Cost
The fuel cost is the volume of diesel used for powering the generator over a year (in litres) multiplied by the present cost of diesel ($\$/\,litres$). It is expressed as shown in equation 3.37.

$$C_D\,(x) = +C_D(t) \times \frac{1}{(1+i)^y} \times CapRef(y.i) \tag{37}$$

13. Levelized Cost of Electricity (LCOE)
It is defined as the calculated value of the average energy cost per kWh of the system's required energy, as shown in equation 38.

$$LCOE(\$/kWh) = \frac{TAC\ (\$/yr)}{Total\ energy\ generated\ (kWh/yr)} \tag{38}$$

14. Constraints
These are the set conditions that are essential for the system to satisfy the load demand for the generation of the design.
and discharging of the designed battery and majorly contributes to the duration of battery life cycle as shown in equation 40

$$SOC_{min} \leq SOC(t) \leq SOC_{max} \tag{40}$$

15. Loss of Load |Probability (LOLP)

Loss of load probability (LOLP) is a design system analysis that shows the probability that a system load will exceed the power supply from the system generation, normally occurring at some point each year. It is usually calculated using stochastic simulation of weather, load, renewable and outages. It is expressed in equation 41 (Adefarati *et al*., 2017).

$$LOLP = \frac{\sum (P_L - (P_{pv} + P_d))}{\sum P_L} \quad (41)$$

16. System Operational Strategies

The hybrid system combines renewable energy (solar) sources and a diesel energy generator as backups. As a result, power management tactics become extremely complicated. The energy generated from the solar P.V. source must feed the loads as a basic control guideline. Furthermore, when renewable resources are unavailable or insufficient to satisfy the demand, the battery bank should be able to provide the required power. As a result, the load demand would be covered by combining electricity supplied from renewable energy sources P.V. with energy stored in the battery. The hybrid system operation will have the RES as the primary power source, followed by a battery storage system and diesel generator. The operational strategy is based on the mathematical model of power flow. The strategy includes mainly charging and discharging the battery bank and all powers at a given time. First, the renewable energy, P.V. array output power $P_{pv}(t)$, is calculated and checked against the demand, P.L. (t).

The following scenarios occur within the operational strategies process.

i. When $P_{pv}(t)$ is greater than the demand, then the system is charging and, at the same time, feeding the load. This instance is called the charging phase of the system using P.V. output power. The change in P.V. output power is also monitored.

ii. If $P_{pv}(t)$ is less than the demand P.L. (t), the remaining $P_{pv}(t)$ will be used to charge the battery and is given by $P_{pv}(t)$ multiplied by the charge controller efficiency.

iii. Suppose the $P_{pv}(t)$ is greater than that of the demand, then the energy charging the battery is given by the Ppv(t) - P.L. (t) multiplied by the charge controller efficiency. The battery bank is always charged with renewable energy. After a certain iteration, the battery bank SOC is checked against the SOC_{max}, i.e., if the battery bank is charged completely. If the SOC < SOC_{max}, the battery bank will continue charging. If the battery bank SOC = SOC_{max}, the battery will stop charging and excess energy dump. If the system were in the grid, the energy dumped would be taken into the grid, reducing the electrical bill.

iv. When RES Ppv(t) is less than the load, the fully charged battery bank will take on the load provided it fulfils certain constraints. The battery SOC will be checked, if the SOC is greater than SOC_{min}, the demand will be fed from the battery, and the demand by the inverter efficiency will give battery power. If the battery bank SOC lessor equals SOC_{min}, the Diesel generator will start feeding the load and charging the battery bank. The battery charging power of the D.G. is the fraction of power after feeding the demand multiplied by the rectifier efficiency.

v. If the SOC is greater than zero or $SOC_{min,}$ the diesel generator will seize to operate. Since the time-based problem, the changes in nature can always change the operating strategy such that if the battery bank is not charged and D.G. is charging it, if the P.V. power changes, the D.G. will also give way for the RES to charge the battery bank.

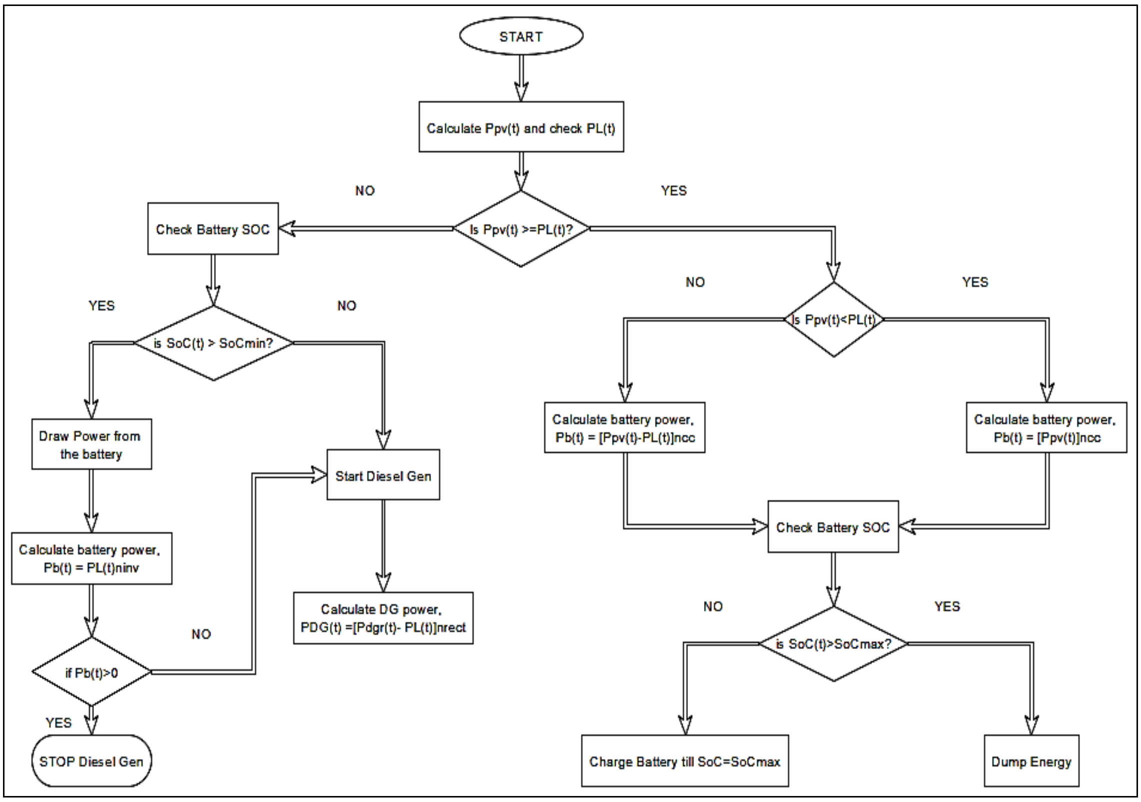

Fig 4: Flow chart of system operational strategies

4. Result and Discussion

4.1 Result Analysis and Discussion

The optimal sizing of P.V. and Diesel Generator with energy storage system research is conducted for an Ayetoro community in Ede Osun state. The community is located at the southern latitude of 7.727637-degree, western longitude of 4.428045 degrees and has a maximum load demand of 680 850 kW/hr. The load profile of the community is classified into the winter load (raining season) and the summer load (dry season). The winter is between June to November, while the summer period is between December and May the year. The load demand of winter has a peak load demand of 163.29 kW with minimum load demand of 45.04 kW, while summer peak load and minimum load demand are 148.28 Kw and 45.03, respectively, as presented in figure 5.

The community's solar irradiation indicates a reliable presence of solar energy Throughout the year, with maximum solar radiation of 1561.99 kWh / m^2 /day in the summer. The solar energy radiation is as shown in figure 6

The minimum temperature of the community is shown to be recorded in the middle period of the winter (rainy season) as 17.447 degrees Celsius while the maximum temperature is 38.44. This indicates that the temperature supports the radiation energy of the location. The hourly temperature of the community is shown in figure 7.

Particle swarm optimisation and differential evolution are two techniques that were used to model the system's optimal sizing. A one-time step simulation was used for an hour for yearly data on MATLAB R2018a. The configuration parameter of the two algorithms used is shown in table 5.

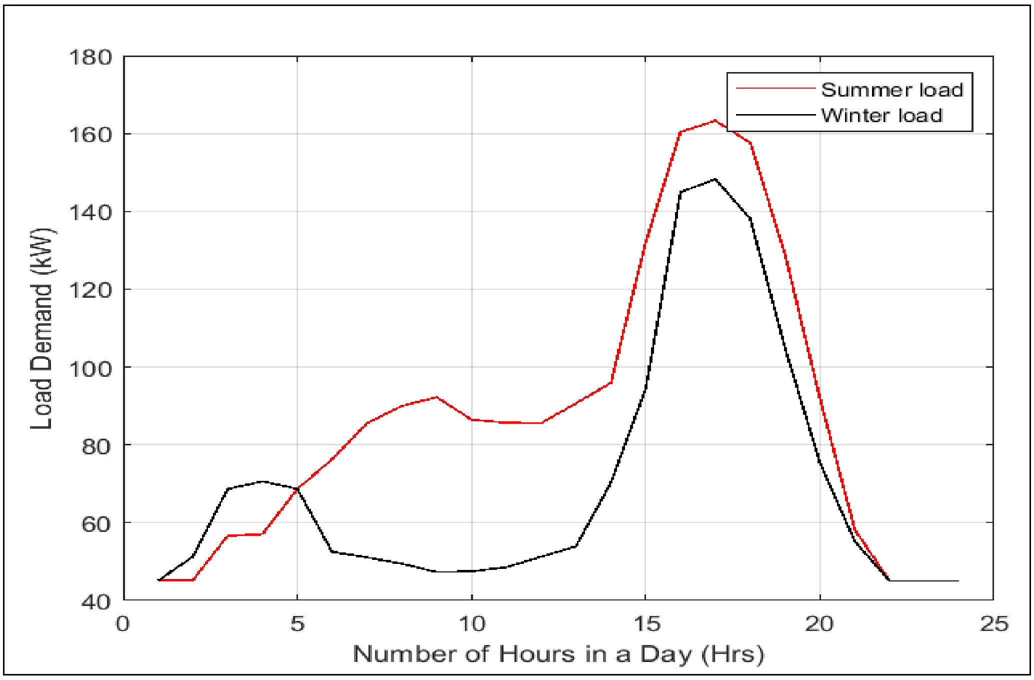

Fig 5: Winter and summer load demand profile of Ayetoro Community

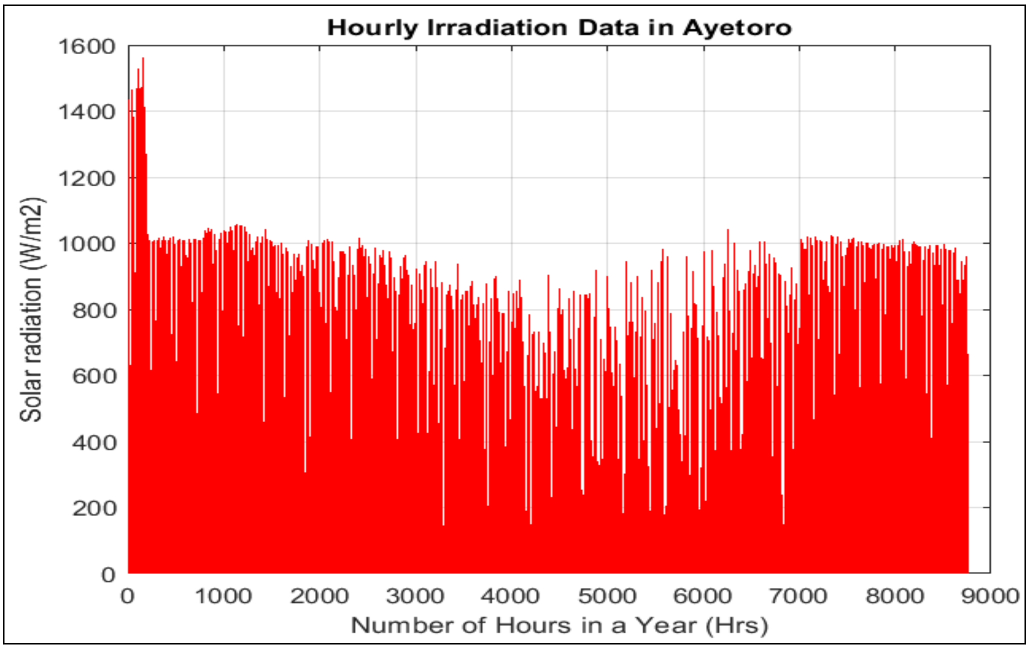

Fig 6: Solar radiation energy of Ayetoro Community

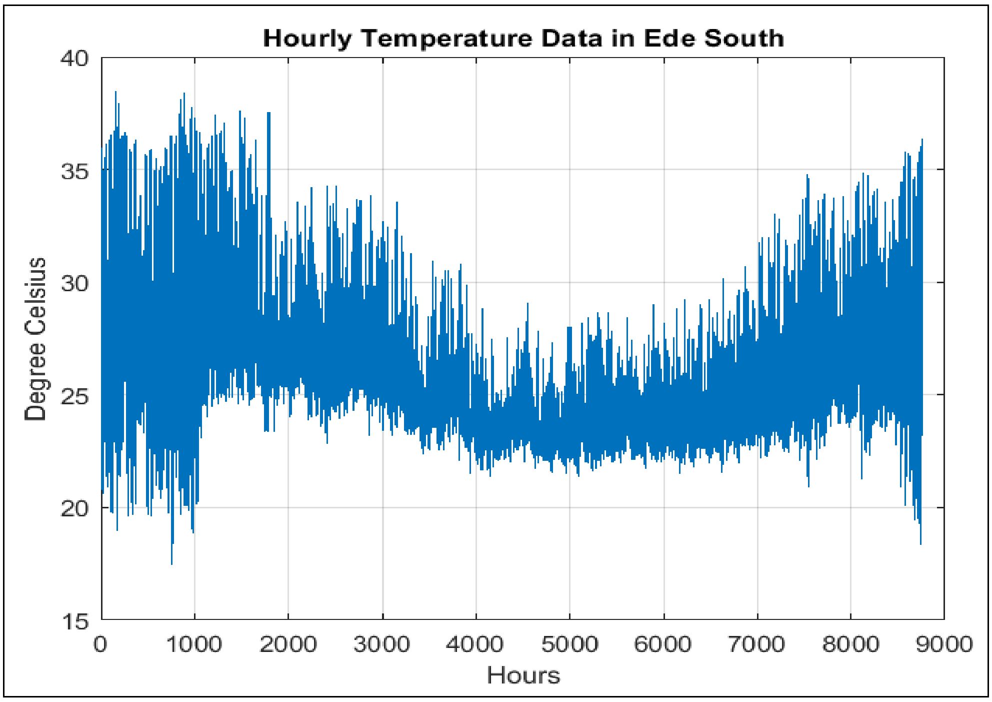

Fig 7: Hourly temperature data of Ayetoro Community

Table 1: Configuration of algorithm parameters and specifications.

Type of algorithm	Parameters	Value
PSO	Number of variables	2
	Minimum weight	0.4
	Maximum weight	0.9
	Numbers of iteration set	500
	Cycle limit	500
	Size of population	500
DE	Number of variables	2
	Size of population	48
	Crossover (Prob.)	0.9784
	Step size	0.6876

The two algorithms used to compare the result are simulated, and the number of solar P.V. panels required. The total battery unit and the minimum size of diesel generator needed for the community are 421, 44 and 163.2 kW. However, a 200-kW diesel generator is suggested for the community to enable tolerance in case of increased community load.

The conclusions reached by PSO show the lowest total annualised cost (TAC) of $38,322 compared to D.E. with a TAC of $38,643. The Levelized cost of energy (LCOE) optimal sizing for PSO and DE are 0.0563 and 0.0568, respectively. The cost analysis of the various components that make up the optimal sizing for the two-algorithm utilised is shown in Table 2. Graphical illustrations are presented in Figure 8. The convergence plot of the PSO and D.E. algorithms is presented in Figures 9 and 10. A weekly plot of the relationship between load demand of the community, battery charge and solar energy delivered is shown in figure 11. In contrast, the weekly plot of the relationship between load demand of the community, battery charge, battery discharge and solar energy delivered is shown in figure 12. Also, the weekly plot of the relationship between load demand of the community, battery charge, battery discharge and solar energy delivered, and SOC is shown in figure 13.

The State of Charge of the battery (SOC) shows that 53% in January rose steeply to about 68% in May. The rate of SOC to about 36% in September because of a drop in solar radiation in the winter (rainy season). The SOC finally rose to around 72%. Figure 14 and 15 show the weekly and yearly SOC of the battery.

Table 2: Cost analysis of the various components

Parameter	Particle Swarm Optimization (PSO)	Differential evolution (D.E.)
Number of Solar P.V. Required (kW)	421	426
Number of Battery Units	44	45
Minimum Total Diesel size Required (kW)	163.2895	163.2895
A total load of the community (kWh)	680,850	680,850
Battery In (Charge)	488,750	496,720
Battery Out (Discharge)	431,430	430,600
Total Solar Cost ($)	11878	12,006
Diesel Generator Cost ($)	735.6914	735.6914
Total Battery cost ($)	8446.90	8638.90
Power Inverter Cost ($)	17,262	17,262
LCOE ($/ kWh)	0.0563	0.0568
Total Annualized Cost ($/ yr)	38,322	38,643

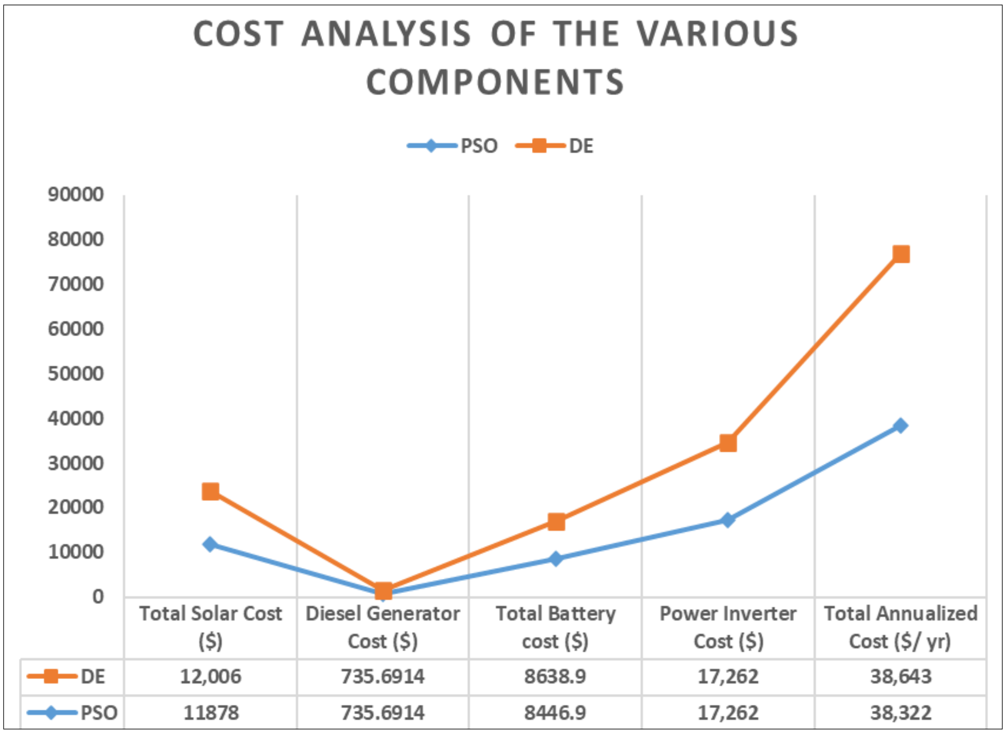

Fig 8: Cost analysis of the various components

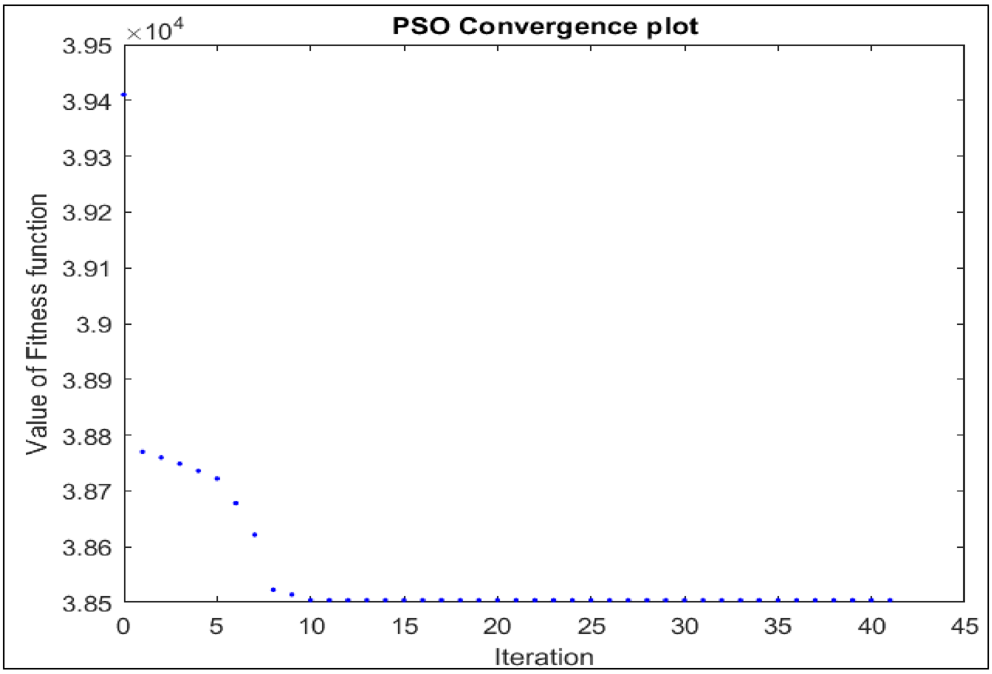

Fig 9: Convergence plot of PSO.

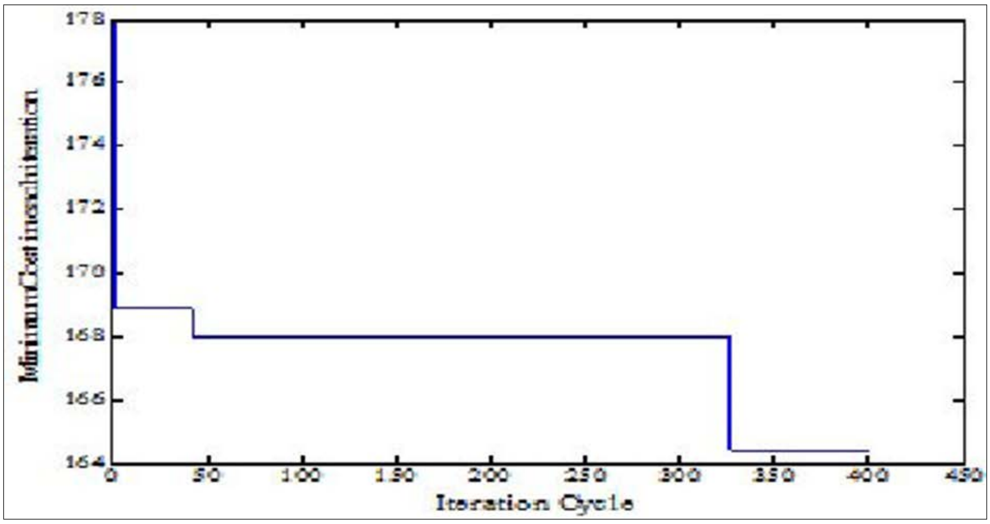

Fig 10: Convergence plot of D.E.

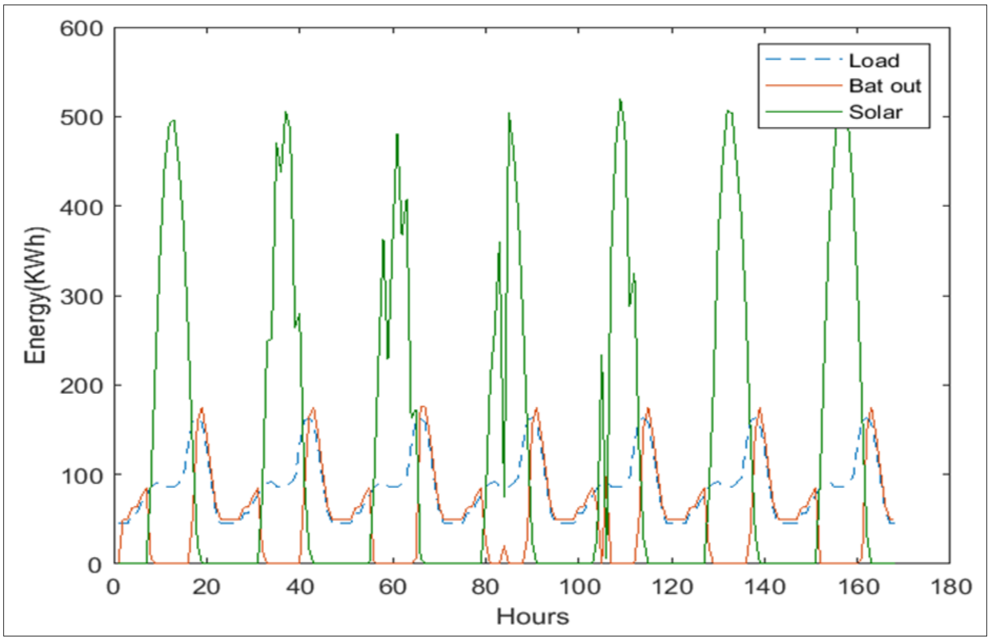

Fig 11: A weekly plot of the relationship between load demand of the community, battery charge and solar energy delivered

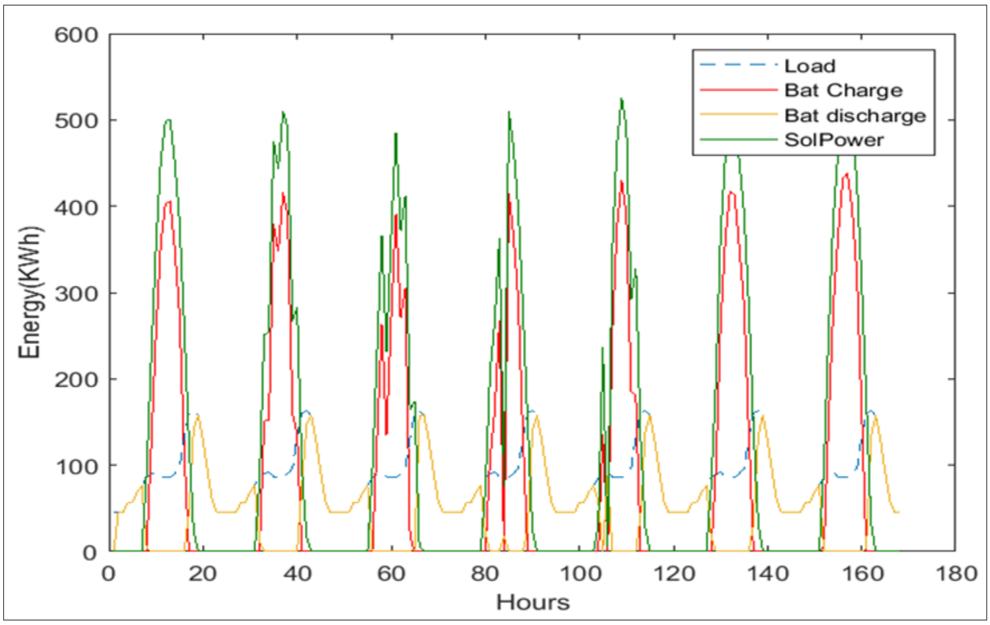

Fig 12: Weekly plot of the relationship between load demand of the community, battery charge, battery discharge and solar energy delivered

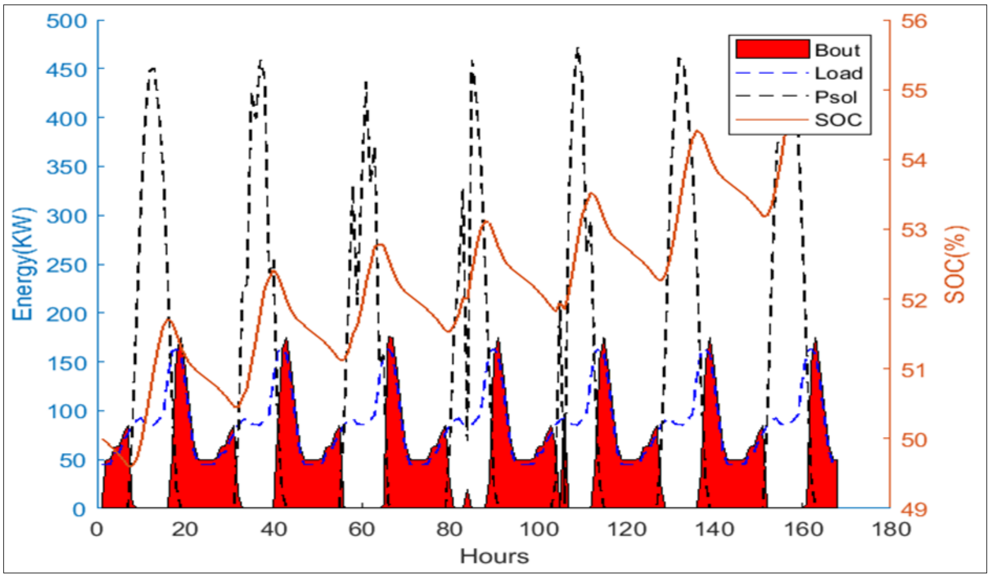

Fig 13: Weekly plot of the relationship between load demand of the community, battery charge, battery discharge, solar energy delivered and SOC

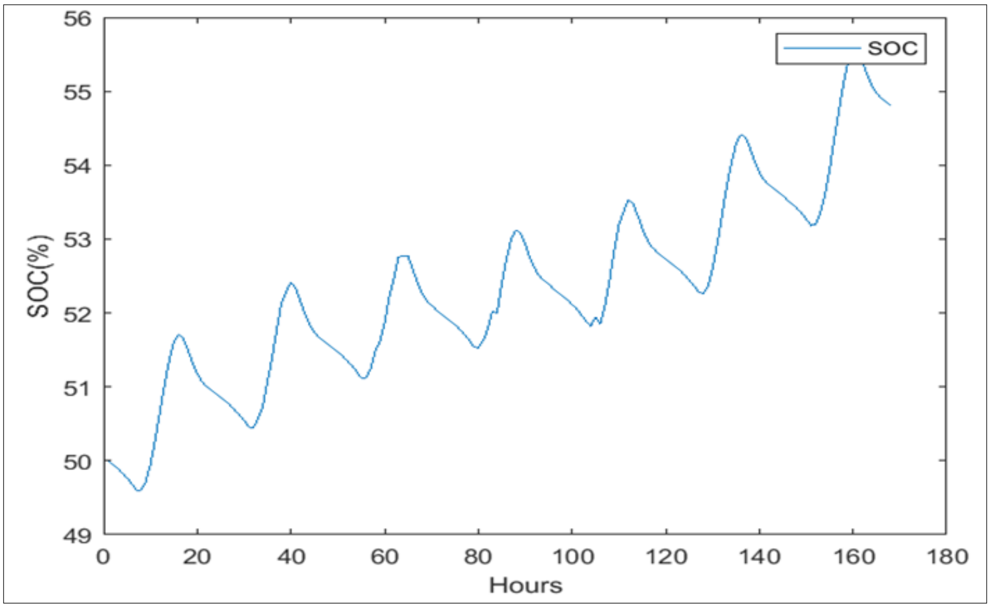

Fig 14: Weekly SOC plot of the battery

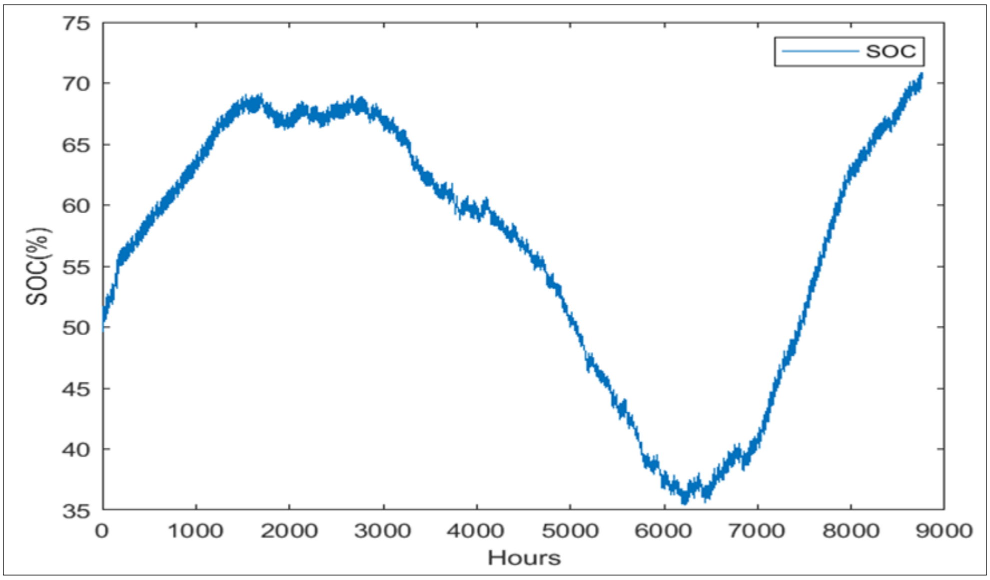

Fig 15: Yearly SOC plot of the battery

5. Conclusion

This research uses a metaheuristic approach to determine the optimal sizing of solar P.V. and diesel energy generators with energy storage systems (batteries) in the Ayetoro community. The utilised models of P.V. panels and the battery storage units were first discussed. Then, two algorithms, namely PSO and D.E., were presented with the configuration of their parameters and the algorithm's fundamental concepts were also utilised. PSO and D.E. optimised the system using the described sizing approach. The optimal sizing is achieved by collecting yearly solar radiation data and hourly temperature (ambient) from a trusted site online for the Ayetoro community. The load profile obtained from the community was used to run the three algorithms and the result obtained after simulations were compared. The output clearly shows that PSO has the best result with better performance than D.E. The diesel generator has zero operating hours due to the availability of enough radiation energy in the location. Finally, the optimal sizing result was found to have satisfactorily catered for the load demand in Ayetoro with zero loss of energy probability and minimum Levelized cost of energy.

1. Future researchers should incorporate other relevant renewable energy sources into the design to reduce the Levelized energy cost.
2. It is recommended that more than three types of algorithms should be used in future research work.
3. In future research, more in-depth evaluations should be done on the reliability index and sensitivity analysis.
4. The government should implement this research work in the Ayetoro community.
5. Other locations within the same geographical area should utilise the design.

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