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Development of Photovoltaic/Diesel Generator/Battery Hybrid System Using Hybrid Particle Swarm Optimization/Elite Opposition Based Learning

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Abstract: Steady power supply has been a big Challenge in Nigeria, couple with rising cost of electricity, poor and unreliable power supply, Therefore, there is need to exploit other alternatives such as renewable energy, which offers viable, cheap and clean alternative. In view of this, this research work proposes the development of an optimal sizing of a Photovoltaic/Diesel Generator/Battery Hybrid system using a hybrid Particle Swarm Optimization/Elite Opposition Based Learning algorithm: A case Study of Ibrahim Badamasi Babangida University Library Lapai, Niger State. This study, aim to harness the potential of renewable energy sources such as solar to minimize the cost of energy production used in the library. PSO, enhanced with EOBL was used for optimal sizing of the various components where net present cost is the main criteria while MATLAB was used for simulation analysis. Hybrid power system was achieved by combination of two energy sources which are solar and generator. The result gotten from this work shows a reduction in cost of energy (COE) though the initial investment cost seems to be high. The installation cost when running only generator was estimated to be 21,000$ while that of hybrid system was 122,130$, but in the long run it is cheaper and more reliable, the generator was rated 50KW while the COE was estimated to be 0.755$/KWh when running on only generator and 0.52$/KWh when running the hybrid system also the operating cost for generator only was 77792$ per year and that of the hybrid system was 4484$ per year.

Keywords: Photovoltaic, Diesel Generator, Hybrid System, Hybrid Particle Swarm Optimization, Elite Opposition Based Learning

INTRODUCTION

Consistence in the electrical power supply is essential in learning facilities or institutions, of which its deprivation can disrupt the learning process. The availability of electrical power from nonrenewable energy sources decreases with an increase in population growth and cost due to higher consumption rates. Therefore, the world is now shifting towards renewable energy (Pirhaghshenasvali & Asaei, 2014). Recently, the hybrid electric power system is appreciably been employed to provide electrical power in areas or facilities where electric power disruption is undesirable (Olatomiwa *et al.*, 2015). However, sufficient renewable energies are located base which has been the challenge facing renewable energy sources, thus hybrid of non-similar sources will improve availability. It is important to mention that access to modern energy services is key to the advancement of the education sector, which is the motivation for this current study. This study intends to propose a hybrid PV/diesel/battery power system for use in an academic environment. In particular, IBB University was selected as a case study for this research. It is argued that in a learning farcicality like IBB University's library where different learning process is on-going, undisrupted electrical power supply is considered vital. In addition, switching from one source of energy supply has to occur unnoticed. Particle swarm optimization(PSO) has recently been used for optimal sizing of PV, battery banks, and diesel generators (Pirhaghshenasvali & Asaei, 2014). Fossil fuels are known for emissions of carbon dioxide when burnt and thereafter, harming our environment. Also, the steady increase in power consumption and challenges of depletion of conventional energy sources has motivated many researchers to search for alternative means of power generation. The Micro-Grid (MG) provides a promising alternative for sustainable and environmentally friendly electrification of isolated communities that are far from the conventional grid. Electricity provision by Distributed Generators (DG) is considered to complement the inadequate power supply by the existing utility. However, appropriate sizing of the DG and other components has been a major challenge and thus has attracted researchers' interest. Therefore, this study intends to employ the PSO/EOBL algorithm to find an appropriate sizing for a case study of IBB University Library, Lapai. Generally, the PV power potential of the case study area can be seen from the region it belongs to according to the map shown in Fig 1.

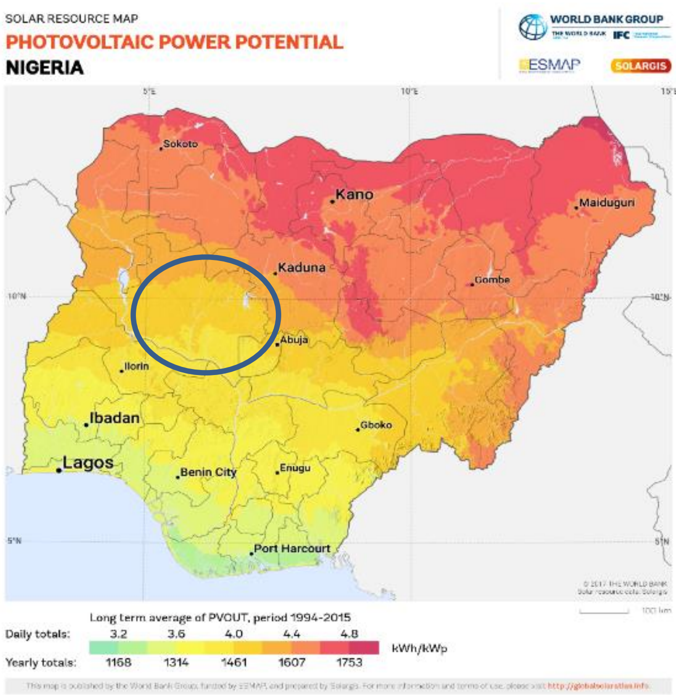

Fig. 1 PV Potential of the Various Region in Nigeria (SolarGIS, 2017)

The location understudy can be seen from the map to have potential ranging from 3.6 to 4.4kwh, thus making it a viable location for PV power generation. In particular, the monthly average daily solar irradiance for the Lapai community, in the year 2017-2018, is shown in Fig 2.

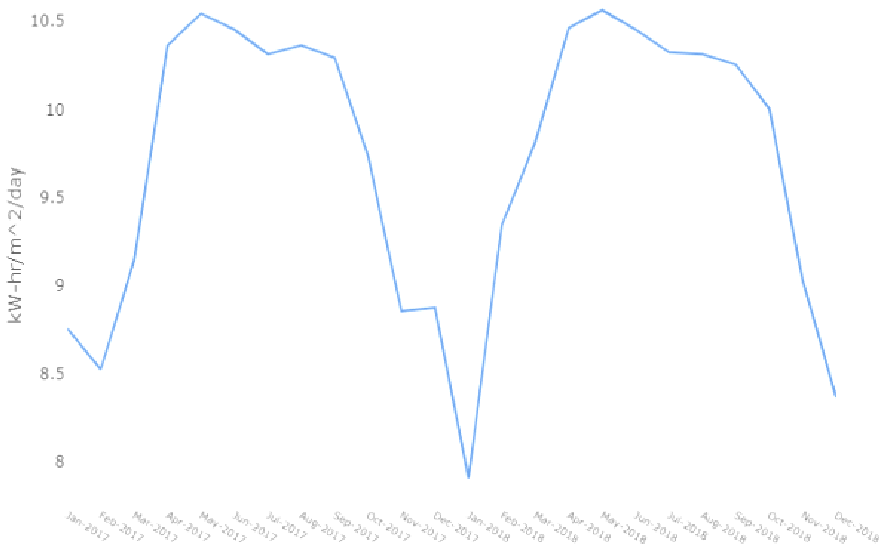

Fig. 2 Monthly-Averaged Daily solar radiation data of Lapai for the year 2017-2018 (SolarGIS, 2017)

It is discovered that PSOs suffer from high computational complexity and slow convergence speed (Hassan *et al.*, 2015). This proposal presents a hybrid of photovoltaic (PV), diesel generator, and battery banks using a hybrid of particle swarm optimization (PSO) and Elite Opposition Based Learning (EOBL) strategy. The PV will be used as the primary source of electrical power while the diesel generator and battery banks will be used as alternative sources of electrical power. The hybrid of PSO and EOBL was used for the improvement of optimal sizing of the PV, battery banks, and the diesel generator. The main idea of an opposition-based algorithm is that it generates the opposition solution of the current solution. Elite means the choice or best of anything considered collectively (Oxford dictionary). EOBL evaluates the current solution and opposition solution at the same time and chooses the better one to enter the next iteration. EOBL makes full use of the characteristics of the elite individuals to contain more useful search information than the ordinary individuals which improves the diversity of the population to a certain extent (Zhang *et al.*, 2017). Thus the use of EOBL is capable of improving the performance of PSO, which can eventually increase the global convergence of the algorithms and optimize the sizing of the PV, diesel generator, and battery banks.
This paper is aimed at developing a Photovoltaic/Diesel Generator/ Battery hybrid energy system using hybrid PSO/EOBL, using Ibrahim Badamasi Babangida University (IBBU) Library Lapai as a case study.

This section presents a literature review on the subject matter and this comprises the overview of the fundamental concept and as well as a review of related works. Most of the pertinent works and the fundamental theories that will be used for the success of this research will be reviewed under the fundamental concepts subheading, after which related works are reviewed. The concepts that are fundamental and pertinent to understanding optimization techniques are reviewed. These include the PSO and EOBL techniques as well as other basic concepts related to hybrid power systems. When photons of sunlight hit the silicon semiconductor material of the solar cells, electrical energy is generated. This is an effect known as the photovoltaic effect. Northern Nigeria lies within a high sunlight belt and therefore has enormous solar energy potential (Olatomiwa *et al.*, 2015). The solar system uses a solar panel that consists of solar cells connected in series/parallel to generate dc power (Olatomiwa & Mekhilef, 2015). The power output of the PV panel was modeled in (Olatomiwa and Mekhilef, 2015). Let P_{out} be output power of the PV cell, P_{ref} be the rated power at reference condition, R is solar radiation in W/m², R_{ref} is the solar radiation at standard temperature condition (equals 1000W/m²), T_{ref} is cell temperature at reference condition (usual equals 25°C). Thus

$$P_{out} = P_{ref} \times (R/R_{ref}) \times \left[1 + K(T_c - T_{ref})\right] \quad (1)$$

Where, $T_c = T_{amb} + (0.0256 \times G)$, T_{amb} is ambient temperature and K is the temperature coefficient of the PV system.

PV converts the light directly in the sun to electricity. This results from the use of semiconducting materials that exhibit the popular photovoltaic effect. Thus PV panels work based on a combination of multiple solar cells working together to convert the solar energy to electricity. The types of PV include monocrystalline, polycrystalline, and amorphous. However, mono and polycrystalline are the most commonly used in conventional environments. Monocrystalline is the purest type of solar cell. It is made from a monocrystalline silicon material. It is one of the most efficient solar panels in use today. It has high power output and occupies less space and lasts the longest (20 years and beyond), however, it is the most expensive. It is slightly less affected by temperature when compared to polycrystalline (Bagher, Vahid, & Mohsen, 2015). Polycrystalline solar panels are made from polycrystalline silicon, thus it is not as pure as monocrystalline solar panels. It is cheaper than monocrystalline solar panels and has an efficiency ranging from 13-16%. It has a shorter lifespan when compared to the monocrystalline type. The choice between these popular types of solar panels depends on the specific situation (Bagher *et al*., 2015). Monocrystalline can provide space efficiency at a slightly higher cost with output power the same as that of polycrystalline. To realize uninterrupted electrical power to the case study site, a conventional source of electrical energy has to be hybrid with the renewable energy source. Diesel generator has been known to act as a steady source of energy (Olatomiwa *et al*., 2015). The fuel consumption of the diesel generator needs consideration for power balancing required for optimum system operation. The fuel consumption of the DG can be modeled as given in equation (2):

$$F_g = \beta_g \times P_{ref} + \alpha_g \times P_{out} \tag{2}$$

Where, $F_g$fuel consumption is the rate in litter/hour, P_{ref} is the nominal power of the diesel generator, P_{out} is the output power andβ_g,$\alpha_g$are coefficients of the fuel consumption curve as defined by the user measure in L/KW. Battery banks are necessary to store electric energy from the solar source for optimum utilization. It is also used as backup when switching from one source to another to maintain an uninterrupted electrical power supply. A battery bank is a setup by a combination of several single batteries. This can be connected either in series or parallel depending on the design requirement on the voltage level of the inverter. A battery is a collection of one or more cells that undergo a chemical reaction to provide the flow of electrons in the cell circuit. This eventually provides electric current in form of DC. Several research advancements or breakthrough has been achieved in the area of battery design. This was as a result of the need to store energy-generated energy for later use. Only DC energy can be stored in batteries, however, most appliances require AC energy, thus the need for a power inverter which will be discussed in the next section. Generally, batteries can be classified into primary and secondary. Primary batteries cannot be recharged, while secondary batteries can be rechargedd after the stored energy have been consumed (Emmanuel, 2018);

1. Lithium-ion(Li-ion)
2. Nickel Cadmium(Ni-Cd)
3. Nickel-Metal Hydride(Ni-MH)
4. Lead-Acid

Each battery types have various strength and weakness. In particular, a Lead-Acid battery is low-cost when compared with the other types, but heavy in terms of weight. Thus, they are not used for a portable devices. Lithium-ion battery is most popularly used for a portable devices. Some of the features of Lead-acid batteries include; very low energy to volume, low energy to weight ratios, relatively large power to weight ratio. These properties make it possible for lead-acid batteries to be able to provide or supply huge surge currents whenever needed. Fig. 3, can be followed in making the best choice of battery depending on the application.

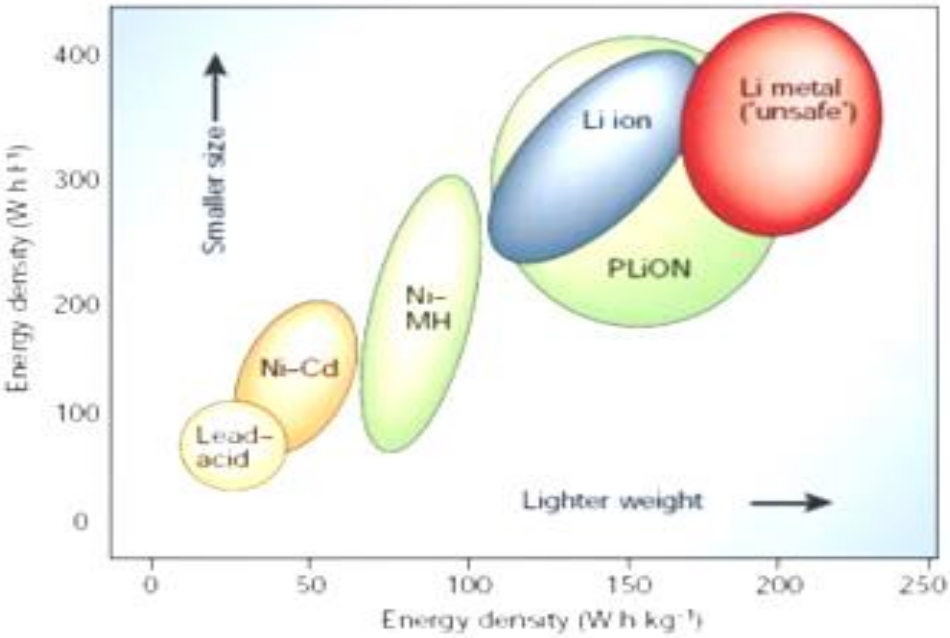

Fig. 3 Plot Showing the Different Batteries and their Properties (Emmanuel, 2018)

Power inverters are a device used to convert DC power to AC. The DC source is usually from the battery or any other form of DC source. Power inverters are used to provide uninterrupted power supply for household or industrial use. They are available in different types, voltages, and capacities. The DC source voltage usually exists in low voltage, thus there is a need to step it up to the required voltage level. However, it is not easy to step up DC voltage, thus, the voltage is first converted to AC using oscillator circuits. The AC output is then stepped up using a transformer. Different types of inverters exist according to the output waveform. These include; square wave inverter, modified sine wave, and sine wave inverters (Mohankumar, 2016). Another form of power inverter classifications also exists; these include but are not limited to classification according to the source (current or voltage), classification according to load type, and classification according to different Pulse Width Modulation technique (PWM) (Kansagara, 2018). The three waveforms discussed are shown in Fig 4.

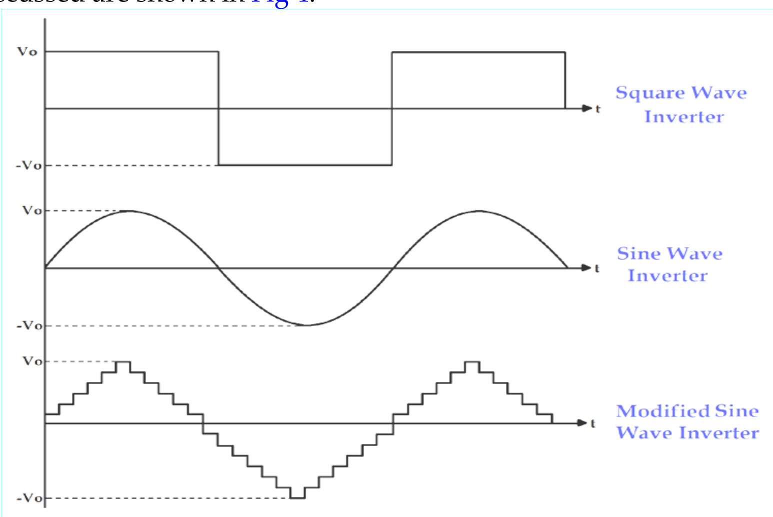

Fig 4. The different types of the inverter waveform (Kansagara, 2018)

Fuses are the oldest power system protection device used to protect the electrical circuits against short circuits and over-voltage. It can have different forms, shapes, and ratings depending on the intended application. Thus, different types of fuses exist depending on the current ratings, low voltage or high voltage applications. For example, low voltage application fuse can be; semi-enclosed, cartridge, and high rupturing capacity fuses (Tawfeeq, 2018). However, high voltage type fuse can be either of the following; open type, enclosed type, and spring type. This type of fuse can handle voltage up to 33kV. A Circuit breaker (CB) is an automatically operated electrical switch that is designed to protect an electrical circuit from damage as a result of overvoltage or short circuit. One major advantage of the circuit breaker is that it can be reset, unlike a fuse which operates once and has to be replaced (Tawfeeq, 2018). Circuit breakers can be reset either manually or automatically to resume normal operation. They are made in different sizes ranging from the one that can be used for home appliances to that of large switchgear for high voltage application. CBs operate based on magnetic, thermal, or thermomagnetic mechanisms. Types of CB depending on its underlying technology include; miniature circuit breaker (MCB), molded case circuit breaker (MCCB), and air circuit breaker (ACB). Meanwhile, other types of circuit breakers also exist, these include; oil circuit breaker vacuum and air-blast circuit breaker. Charge controllers are used to regulating the amount of electrical energy charged into the battery. They are also designed to prevent the battery from excessive charging. There are different types of solar charge controllers. These include; simple 1 or 2 stage controls, Pulse width modulation (PWM), and maximum power point tracking (MPPT). Though, PWM and MPPT are the most popularly used charge controllers with different ranges and capacities available in the market. MPPT can achieve this through an adaptive algorithm that follows the maximum power point of the PV array and then adjusts the incoming voltage to maintain the most efficient amount of power for the system.

MATERIALS AND METHOD

The methodology employed in this paper is outlined as follows.

1. Collection of solar insolation and ambient temperature data of the proposed site from NASA weather database based on the site latitude and longitude in degree, and the data have gotten was shown in Fig 5.
2. Obtained load profile of the Study area (electrical equipment, lightings/security lights, TVs, laptops, printers, photocopier, and other electrical appliances) use in the proposed research site with each equipment power ratings and hours of usage per day, the data plotted are shown in Table 1.

Table-1 Load profile for the site

S/N	Appliance	Rating (w)	Unit	Hours	Total Power (w)
1	Celling Fan	70	100	12	7000
2	Lighting Point	15	200	12	3000
3	TV	220	5	8	1100
4	Security Light	100	2	12	200
5	AC	1492	4	8	5968
6	Desktop	250	10	8	2500
7	Laptop	60	10	6	600
8	Printer	200	2	3	400
9	Photocopier	350	1	3	350
10	Decoder	30	3	8	90
11	Fridge	150	1	8	150
			Total Power in KWh		21.36

3. Formulation of the hybrid PSO/EOBL algorithm for sizing of the PV, diesel, and battery system and implementation of the algorithm in MATLAB/Simulink environment

4. Comparison of per-unit cost of energy production by hybrid renewable energy system to that of operating cost of conventional fossil fuel using HOMER software.

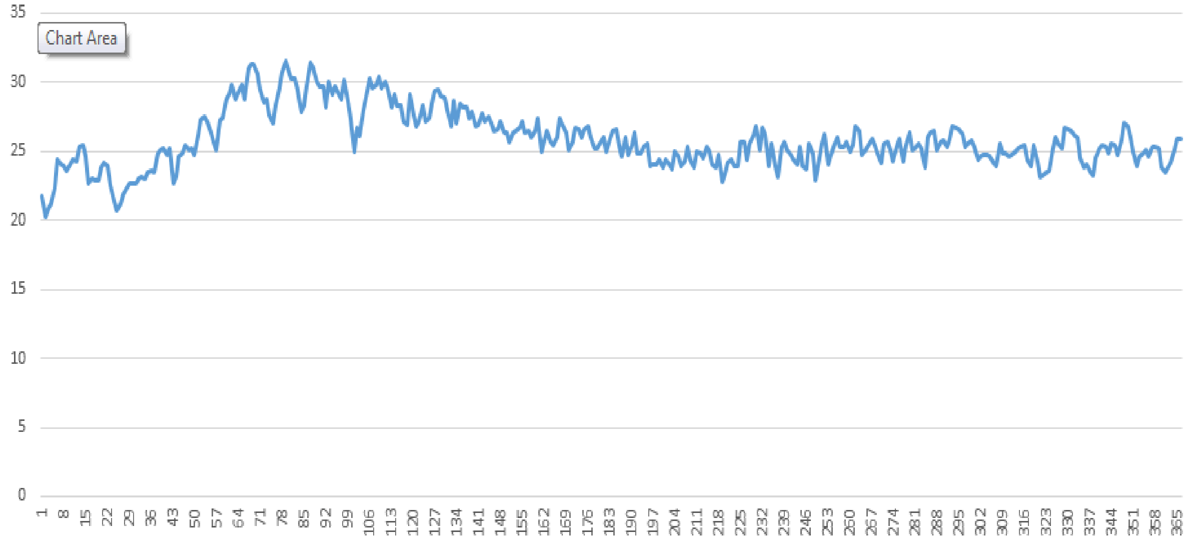

Fig. 5 The Temperature data for the proposed site

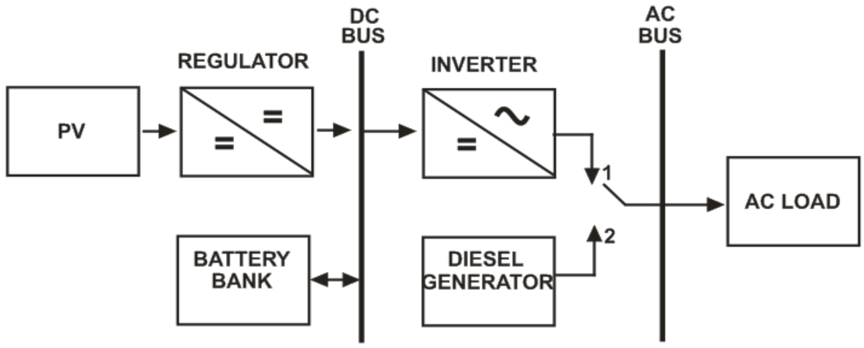

Fig. 6 The designed hybrid system

The MATLAB simulation was done to implement PSO/EOBL algorithm and the flow chart was presented in Fig. 7.

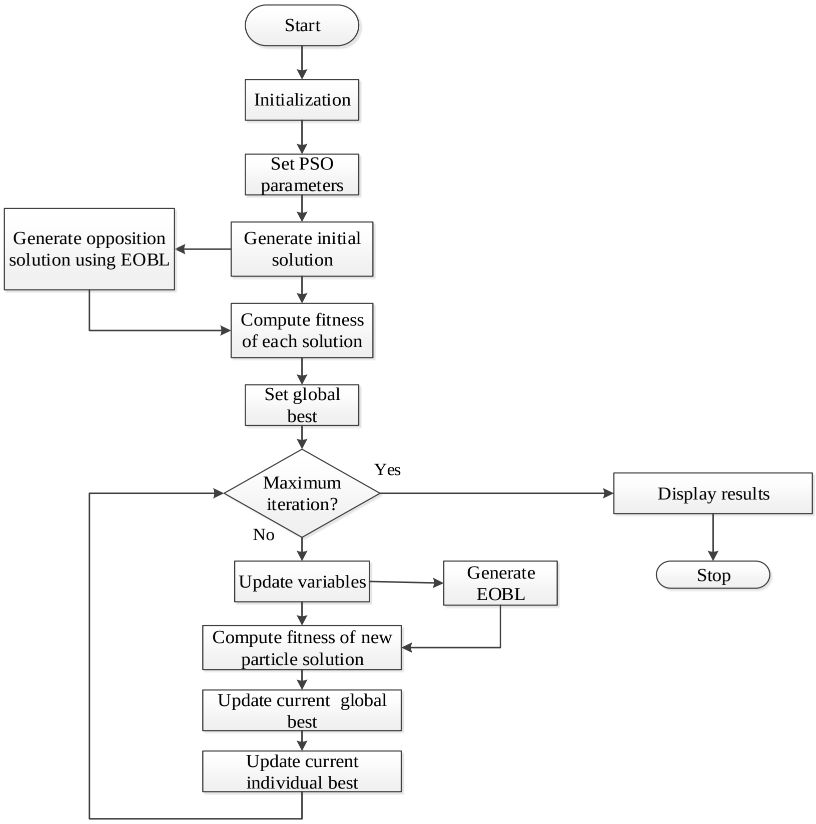

Fig. 7 Flowchart of the proposed PSO/EOBL algorithm

RESULTS AND DISCUSSION

The library of IBB University was considered in this work for simulation, the hourly load pattern of a day was considered for the simulation and the load patter was assumed to be fixed. Figure 4.1 shows the load pattern**.** The investment and installation cost of the system were considered to be 122130.3$, the operation cost of the hybrid system is considered to be 4483.57$ per year. The summary of the cost based on the HOMER and PSO/EOBL optimization of the hybrid system is given in Table 2, while that of the generator only is given in Table-2.

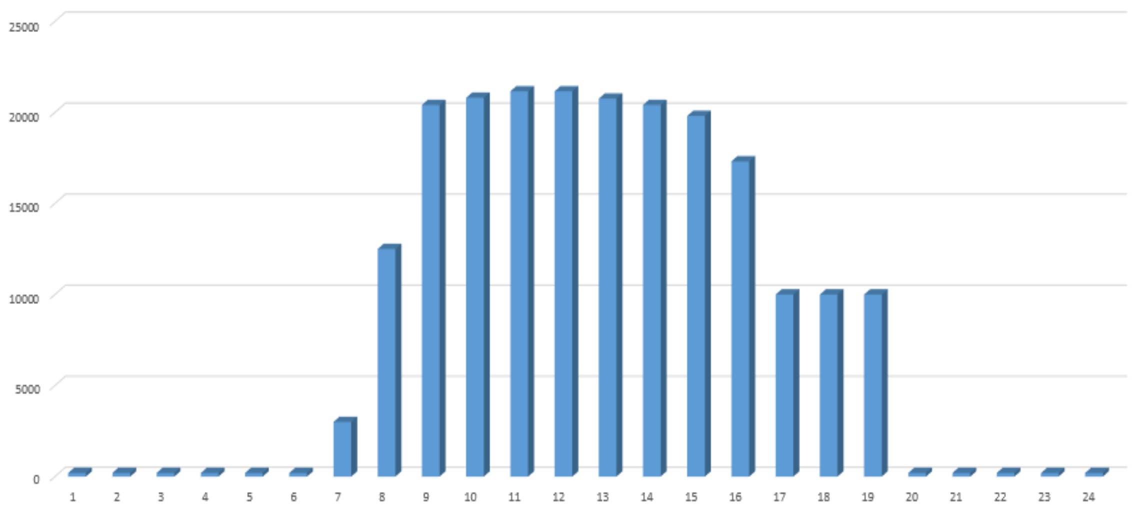

Fig. 8 Load pattern of the library

Table-2 Result gotten from Homer and that of PSO/EOBL

MATERIALS	RESULT FROM HOMER	RESULT FROM PSO/EOBL
Inverter mean output(KW)	40.900725	40.900761
Diesel Generator(KW)	50	50
No of Photovoltaic cells(Solar)	20	20
Loss of load Probability	nil	0.0026827
Renewable factor	0.972	0.3731
Total no of Batteries	19.3342	19.1667
Cost/COE ($/day)	0.520532	0.5298
Cost/NPC ($/year)	180091.7	180091.7
Installation cost($)	122130.3	nil
Operating cost per year($)	4483.574	4233.4367
Generator total fuel(L/Year)	1188.268	nil
Generator total cost for fuel($/Year)	1188.268	nil
Gen. O. & M. Cost ($/year)	349.5	nil
PV/Capital Cost ($)	55103.54	55103.54
PV/Production (kWh/year)	183349.9	nil
Battery Autonomy (hour)	21.64703	nil
Bat. Annual Throughput (kWh/year)	35421.21	nil
Battery Nominal Capacity (kWh)	433.3464	433.3464
Bat. Usable Nom Capacity (kWh)	260.0078	nil

Table-3 Result gotten for generator only

MATERIALS	RESULT FROM HOMER FOR GENERATOR ONLY	RESULT RFOM PSO/EOBL FOR GEN ONLY
Generator (kW)	50	50
Cost/COE ($/day)	0.7547821	0.752341
Cost/NPC ($/year)	1026666	1026666
Cost/Operating cost ($/year)	77792.64	69789.98
Cost/Initial capital ($)	21000	21000
System/Total Fuel (L/year)	53023.5	nil
Gen50/Hours	8760	8760
Gen50/Production (kWh)	141280.2	141280.2
Gen50/Fuel (L)	53023.5	nil
Gen50/O&M Cost ($/yr)	13140	nil
Gen50/Fuel Cost ($/yr)	53023.5	nil

Fig. 9, shows the convergence characteristics of the PSO/EOBL algorithm for the PV-GEN-BATTERY system and it indicates that it converges at less than 50 iterations, and the cost of energy becomes stable at less than $0.5 per day. Fig. 10, shows the convergence characteristics of the PSO/EOBL algorithm for the GEN-ONLY system and it indicates that it also converges at less than 25 iterations, and the cost of energy becomes stable at less than $1 per day. This shows that the hybrid system is cost-effective than the generator only.

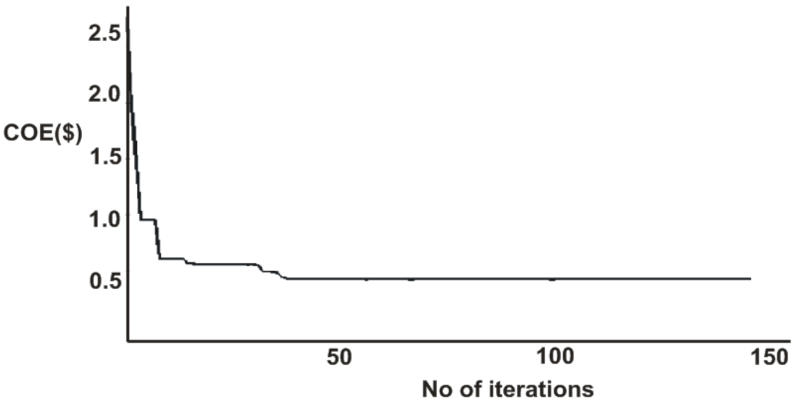

Fig. 9 Convergence characteristic of PSO/EOBL algorithm for PV-GEN-BATTERY system

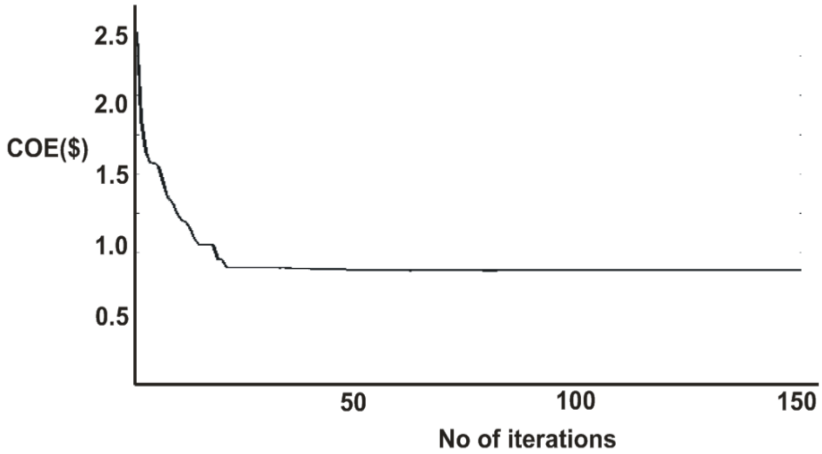

Fig. 10 Convergence characteristic of PSO/EOBL algorithm for GEN-only system

CONCLUSION

A stand-alone hybrid energy system that includes PV, diesel generator, and batteries for a library in IBBU Lapai, a design that is mostly relies on the renewable resources. The focus is on the proper modeling of the subsystems and proposing an operating strategy that maximizes the share of renewable sources in the energy provision. Various costs including the investment, installation, maintenance, and fuel costs are minimized while ensuring the availability of the energy demand to the library. The simulation results show the effectiveness of the proposed optimization method in finding the optimum design. This model demonstrates that different energy sources can be used simultaneously to power off-grid practical applications.

CONFLICT OF INTEREST

I, Usman Mohammed Baba, the lead author in this manuscript wish to state that, this research work is our original work. And, has not been submitted or published in any publishing house before now and therefore, there is no conflict of interest with this manuscript to the best of our knowledge.

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