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RESEARCH ARTICLE

Energy Modeling and Optimization in a Radio and Television Broadcasting Facility

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ABSTRACT

This paper evaluates the energy consumption pattern of the Osun State Broadcasting Corporation, Osogbo, Nigeria. Using HOMER software, installation and operating costs of a renewable energy-based hybrid power system, over a multi-year lifetime, is investigated towards deployment of the hybrid at the broadcasting facility. Information dissemination is very important in the society, and requires propagation media. Broadcasting station is an important medium of dissemination, therefore, constant and cost-effective power supply needs to be put in place. By optimizing hybrid renewable energy systems, the choice of components is controlled and thus enable cost-effective power solution with the use of different combinations of renewable energy resources. In the study, four energy resources are considered for hybridization: Solar photovoltaic (SPV), diesel engine generator (DEG), wind energy converter (WEC) and battery energy storage system (BESS). The input parameters considered in the optimization are project lifespan; capital, operating and maintenance costs; and resource specifications. From energy audit, it is obtained that the ,peak electrical demand of the corporation's facility is 361.61kW, while the peak daily intake and annual mean use are 4577.38kWh and 835011.71kWh respectively. Four different configurations of the energy sources are recommended for their advantage cost effectiveness, with SPV/DEG/BESS hybrid taking the lead as the optimum configuration.

Index Terms—Cost of energy, hybrid, net present cost, optimization, techno-economic, total capital cost, total operating cost.

I. INTRODUCTION

Energy is an important ingredient of modern life, as it is the lifeline of our everyday life. However, energy is not free. It comes at a financial price for users and at an even bigger cost to the environment [1]. Therefore, energy can be aptly described as a significant factor for socio-economic development. The essence of the energy system is to make provisions for energy services that are desirable and may used for activities such as transportation, air-conditioning, lighting, refrigerated storage, indoor climate control, industrial processes, conversion of raw materials to final products, and selection of appropriate temperatures for cooking [1]. The energy chain to power these services starts with the extraction of primary energy [2].

Furthermore, the demand for energy is rapidly increasing everyday [3]. A published report revealed that there are two possible ways to resolve the problem of the rising energy demand [4]: the first is the generation and production of additional energy, while also exploring other alternative sources of energy production; the second is an efficient and more optimal utilization of available resources. The first approach is highly capital-intensive and time-consuming, and therefore, the second approach is highly recommended due to its affordability and its efficiency; with efficient energy usage, there is no need to produce additional energy [5]. Moreover, technologies are improving and various methods have been advanced for energy use and optimization. The efficient use of energy is currently one of the major challenges, because it impacts nearly every human activity such as vacation, leisure, entertainment, sports, hospitality, academic, commercial, and industrial activities [6]. The consumption of energy in residential buildings is fast increasing, making the efficient use of energy in the real estate sector a significant challenge. Recently, energy consumption and optimization, both in business centers and official buildings, have attracted much attention from researchers [7]. Most scholars have attempted to resolve this challenge, with the majority of these attempts having been made in the

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past decade [8]. However, the challenge of efficient energy utilization and optimization still remains, because the more the usage of electronic equipment in a building, the higher the consumption of energy [9]. A majority of the available energy management systems are concerned more with the substantial amount of energy utilized in the broadcasting facility, and not much has been done on energy management in such a facility. Therefore, this research developed a model that will cover the complete energy spectrum, such as energy supply, utilization, and optimization, in a broadcasting station. The model will also be used to identify and estimate energy loss or wastage that may be hindering optimization in the system.

Energy conservation provides the cheapest way to remedy the supply and demand gap with minimal capital investment. It also helps to improve the plant load factor of electricity-generating plants that will help in reducing the price of electricity. The need to monitor and lower energy use now receives even greater attention than ever before. The use of energy conservation approaches definitely reduces the general energy consumption [4]. According to [6], global warming is now a worldwide issue and one of the major reasons is the emissions produced from greenhouse gases. Emissions will continue to rise because of industrialization and the increasing need for electricity supply.

Though many novel methods have been employed for conserving energy, they also need to take into consideration the structural design of the building, in order to work according to design. Challenges occasioned by nonlinear features in the control parameters are also one of the shortcomings of conventional control systems [4]. [10] stated that studies have shown that most of the existing energy management systems focus on energy monitoring systems rather than systems with efficient utilization and optimization functions. Therefore, a study aimed at developing a bottom–up model which will focus on the efficient utilization and optimization of energy, especially at the consumption side, is highly expedient.

II. MATERIALS AND METHODS

Considering the duration and the wattage, the daily power requirement of group of equipment was estimated, and the yearly and peak daily power consumption for each group of equipment was calculated from the estimate. For convenience, the pieces of equipment were thereafter arranged by grouping similar electrical loads together, as shown in Table I.

The following materials were used in the collection, analysis, and presentation of data and the results that will be obtained from this study:

(i) Structured questionnaires,
(ii) HOMER Pro software, and
(iii) Digital clamped meter.

A. Administration of Structured Questionnaires

Structured questionnaires will be administered to selected members of staff who work in the administrative offices, staff personal offices, workshops, libraries, and technical areas across the length and breadth of the Osun State Broadcasting Corporation, Oke Baale, Osogbo. The structured questionnaires will be administered to collect data on the quantity of energy supplied to the Osun State Broadcasting Corporation buildings.

B. Determination of Energy Consumption

The data that was obtained from the administration of structured questionnaires was used to determine the power supply and consumption, through the application of some specific formula or methods according to [11] and [12]. Energy auditing was also carried out using the digital clamped meter. The load profile of the Corporation was also derived from the result of the energy audit

C. Location/Brief History of the Study Area

The Osun State Broadcasting Corporation, which is located in Osogbo, Osun State, Nigeria, consists of four stations (two radio stations and two television stations), and it all began on August 27, 1991. A television and a radio station of frequencies 559.25 MHz and 104.5 FM, respectively, are located in Osogbo; a radio station known as Orisun FM on frequency 89.5 FM is located in Ile-Ife; and a television station called New Dawn TV on frequency 479.25 MHz is located at Ibokun. The picture of the study area is shown in Fig. 1.

D. System Components Modeling

The components of the energy optimization system involve hybrid modeling, in order to achieve its performance under various circumstances. The following mathematical model is used to demonstrate the proposed hybrid renewable energy system (HRES) components:

TABLE I.
ARRANGEMENT OF ELECTRICAL LOADS

Identity	Class	Type of Loads
1	Lighting	Lamps include, but are not limited to, security lamps, office lamps, rechargeable lamps, and others
2	Technical Supplies	Television transmitter, radio transmitter, computer accessories, photocopier, and printers
3	Air-conditioners	Fans, AC units, and refrigerators
4	Computers	Intercoms, computers, mobile phones, network switch, and other communication devices
5	Entertainment System	TVs, DVD players, and decoders
6	Miscellaneous Equipment	Electric jugs, pumping machine

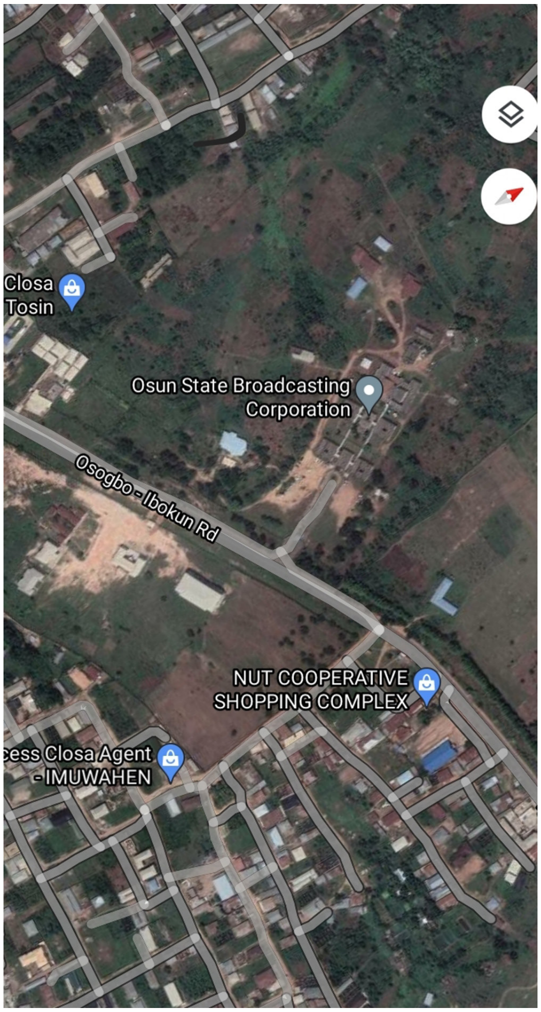

Fig. 1. Location of the study area.

1) Modeling of Solar PV System

This research utilizes the Canadian Solar MaxPower CS6X-325P. After an extensive literature research, two PV modules were selected. The two kinds of PV cells are defined by their production procedures and materials used [13]. The PV was based on the manufacturing techniques employed. Canadian Solar offers two types of solar cell in their Solar MaxPower CS6X-325P: monocrystalline and polycrystalline. While standard modules are known to have a very high degradation rate, the PV has excellent protection and durability. It is a dependable and long-lasting alternative throughout the lifetime. It obtains energy from the sun throughout the day, using PV technology.

To keep the surrounding temperature below the appropriate temperature, the PV panel must be positioned correctly with respect to the sun's rays, since both inadequate and excessive solar radiation can damage the PV panel's derating factor.

Table II shows the simulation parameters for the solar PV system used in this study.

TABLE II.
SIMULATION PARAMETERS FOR THE SOLAR PV SYSTEM

Parameters	**Values**
Capital cost ($)	300
Replacement cost ($)	100
Operation and maintenance cost ($/year)	5
Rated capacity (kW)	0.325
Lifetime (years)	25
Temperature coefficient	–0.41
Operating temperature (°C)	45
Efficiency (%)	16.94

TABLE III.
SIMULATION PARAMETERS FOR DIESEL GENERATOR (DEG)

Parameters	**Values**
Capital cost ($)	150 000
Replacement cost ($)	150 000
Operation and maintenance cost ($/op. hour)	5
Minimum load ratio (%)	25
Lifetime (hours)	15 000

2) Modeling of Diesel Generator

This research used a Generic 500 kW fixed-genset generator. The genset's specifications are shown in Table III. In Nigeria, the price of diesel is $0.59 per liter. The minimum load ratio to protect the engine exhaust system is set as 25%.

3) Modeling of BESS

This analysis reveals that 12VRE-3000TF batteries are being utilized. Table IV gives the techno-economic details. Batteries are crucial when renewable energy sources are not accessible, as they help provide stability, quality, and dependable power delivery. The discharge ability of a battery is computed using (3) [14].

$$P_{bi}(t) = E_{bi}(t-1)(1-\sigma) - [(E_{req}(t)/\eta_{bj} - E_{bih}(t)] \quad (3)$$

$Ereq(t)$ = energy required at time (t)

E_{bi} = total battery energy in time (t),

E_{bih} = PV component total energy generated

η_{bj} = converter efficiency,

σ = self-discharge rate.

TABLE IV.
SIMULATION FOR BATTERY ENERGY STORAGE SYSTEM (BESS)

Parameters	Values
Capital cost ($)	410
Replacement cost ($)	410
Operation and maintenance cost ($/year)	0
Round-trip efficiency (%)	80
Lifetime (years)	20
Throughput (kWh)	3581.60
Nominal voltage (V)	12
Nominal capacity (kWh)	3.11
Maximum capacity (Ah)	260

The capacity of a battery must be adapted in order for it to maintain enough charge to sustain a planned system when PV power is tailored, by using (4) [15].

$$C_{BAT} = [E_{load}(t){:}DA(t) \,/\, \eta_{bj}.\ \eta_{bat}{:}DOD(t)] \quad (4)$$

where:

η_{bat} = efficiency of battery

E_{load} = Avg. demand of energy (kWh/day)

DA = Autonomy day

η_{bj} = efficiency of converter

DOD = the battery's charge depth

The amount of energy accessible in a battery at any one moment is determined by its state of charge (SOC). The following formulas are used to compute energy and charge state:

$$E_b\,(t) = (t - \Delta t)\ E_b - P_b\,(t) \cdot \Delta t \quad (5)$$

$$SOC\,(t) = (t - \Delta t)\ SOC - (P_b\,(t) \cdot \Delta t\,/En) \quad (6)$$

$P_b\,(t)$ = Battery's power

En = battery nominal capacity.

4) Modeling of Conversion Unit
The converter used for this study is the Generic System Converter. In order for a hybrid energy power system to work, it must have a converter unit, which connects the various current applications. Table B contains all the information on the capital cost for the converter unit as well as the replacement cost utilized in this research. This time period is 15 years, with a percentage of 95 percent. The converter's power rating is calculated using (7).

TABLE V.
SIMULATION PARAMETERS FOR CONVERTER UNIT

Parameters	Values
Capital cost ($)	300
Replacement cost ($)	300
Operation and maintenance cost ($/year)	0
Efficiency (%)	95
Lifetime (years)	15

$$P_{con} = P_{peak}/\eta_{con} \quad (7)$$

where:

η_{con} = converter efficiency

P_{peak} = max consumption load

5) Modeling of the Wind Energy Converter
The wind turbine system used for this study is the Generic 10 kW and the mathematical model, which was obtained from the power curve of the wind turbine derived by the manufacturer. Table VI below shows the parameters for the WEC.

III. RESULTS AND DISCUSSION

The daily load profile of Osun State Broadcasting Corporation is presented in Fig. 2. The peak daily and annual energy use was estimated to be 45 77.38 kWh and 83 5011.71 kWh, while the Corporation daily power requirement was estimated to be 361.61 kW.

TABLE VI.
SIMULATION PARAMETERS FOR WIND ENERGY CONVERTER (WEC)

Parameters	Values
Capital cost ($)	50 000
Replacement cost ($)	50 000
Operation and maintenance cost ($/year)	500
Rated capacity (kW)	10
Hub height (m)	24
Lifetime (years)	20

Fig. 2. OSBC daily load profile.

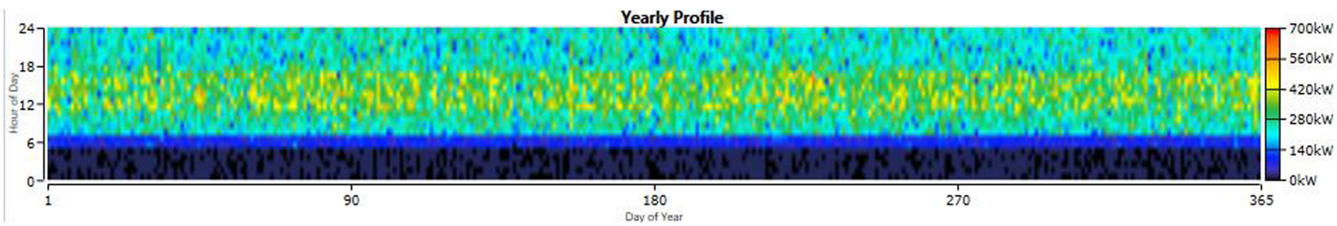

Fig. 3. Monthly average solar GHI data for OSBC.

While peak daily and annual energy use is 4577.38 kWh and 835 011.71 kWh, the Corporation needs 361.61 kW of electricity per day. The latitude and longitude of the research region (7°46.6′N and 4°35.4′E) were used to estimate the average solar irradiation and wind speed particulars of the area of study. The average wind speed and solar irradiation were calculated using HOMER Pro across these longitudes and latitudes. The monthly average solar global horizontal irradiance (GHI) graph is shown in Fig. 3. The maximum monthly solar irradiation level seen was 5.8 kWh/m^2/day in February, while the minimum level seen was 3.7 kWh/m^2/day in August. Furthermore, Table. VII shows where the simulation resources are. The estimated daily peak electrical demand (kW), the estimated peak daily intake (kWh), and the estimated annual mean use (kWh) for each section of the Corporation were computed and stated in Table VIII.

A. Simulation Results from the HOMER Method

Several possible setups and parameters are created when the simulation complete. Many combinations exist; four out of these combinations have been proposed, and the effects of each are explained below.

1) SPV–DEG–BESS Without WEC Combination

Allocations of energy sources for satisfying the requirement of energy demand in the research region include a mixture of solar photovoltaic (SPV) system, diesel engine, and battery energy storage system (BESS). The system may be described as consisting of 1424 kW photovoltaic

TABLE VII.
SIMULATION RESOURCES

S/N	Configuration Parameter	Equity
1	The project's life expectancy	25 years
2	Diesel fuel price (for DEG)	\$0.59/L
3	The average annual amount of solar radiation received	5.80 kWh/m^2/day
4	Wind speed averages each year	3 m/s
5	Output of the battery	12V/260 Ah per unit

TABLE VIII.
ESTIMATED SECTIONAL DEMAND AND CONSUMPTION

Sections/Departments	Estimated Daily Peak Electrical Demand (kW)	Estimated Peak Daily Intake (kWh)	Estimated Annual Mean Use (kWh)
Engineering	32.98	230.02	745 80.60
Programs	26.90	163.04	50 754.78
News	26.57	161.80	53 290.68
Radio and TV studio	77.42	1312.96	466 099.38
Radio and TV transmitter building	125.30	2236.56	44 468.69
Administrative	27.09	173.12	52 382.45
Marketing	27.55	193.29	59 948.13
Director general's office	17.80	106.59	33 487.00
Grand total	361.61 kW	4577.38 kWh	835 011.71 kWh

capacity and a 500 kW diesel engine, together with 2512 batteries. The anticipated energy consumption was estimated to 2 461 829 kWh/year. An additional 10.4% of surplus energy is available.

2) SPV–WEC–DEG–BESS Combination

In combination 2, SPV system, wind energy converter (WEC), diesel engine, and BESS are taken into account. For sizing purposes, the size of the system is defined as SPV, WEC, DEG, and BESS, which have system power ratings of 1461 kW, 1 unit, 500 kW, and 2502 units respectively. The anticipated energy consumption was estimated to 2 518 674 kWh/year. The excess energy percentage is 12.4%.

3) SPV–BESS Without WEC and DEG Combination

Combination 3, SPV–BESS, lacks WEC and DEG. The SPV and BESS are accounted for in the combination. The system sizes are assumed to be 1751 kW of SPV and 4720 units of BESS, with an estimated energy consumption of 2 907 626 kWh/year. Availability of extra energy is projected at 23.7%.

4) SPV–WEC–BESS, But Without DEG Combination

Combination 4 takes into consideration SPV, WEC, and BESS, but DEG is not considered. The system sizes, estimated as SPV, WEC, and BESS, were 1743 kW, 1 unit, and 4730 units. respectively. With regard to energy consumption, 2 899 030 kWh/year was estimated; and availability of surplus energy was estimated at 23.5%.

B. Component Simulation Results

1) Solar Panel Simulation Result

The solar PV system used for this study has a maximum power output of 1317 kW and a minimum output of 0 kW in a year. The PV penetration is 122% and the number of hours of operation is 4380 h/year.

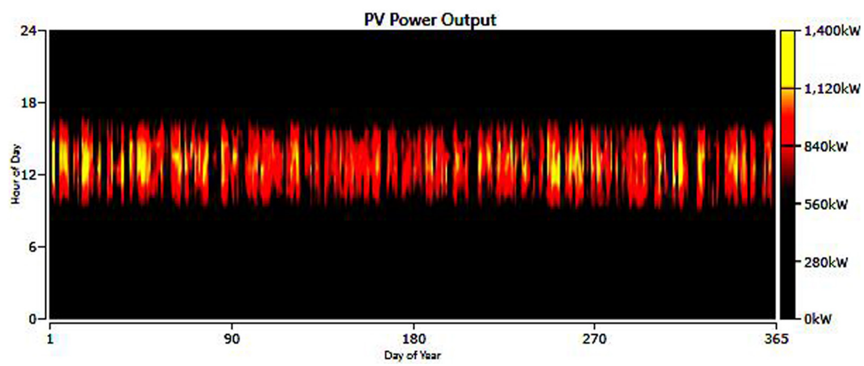

Fig. 4. PV power output.

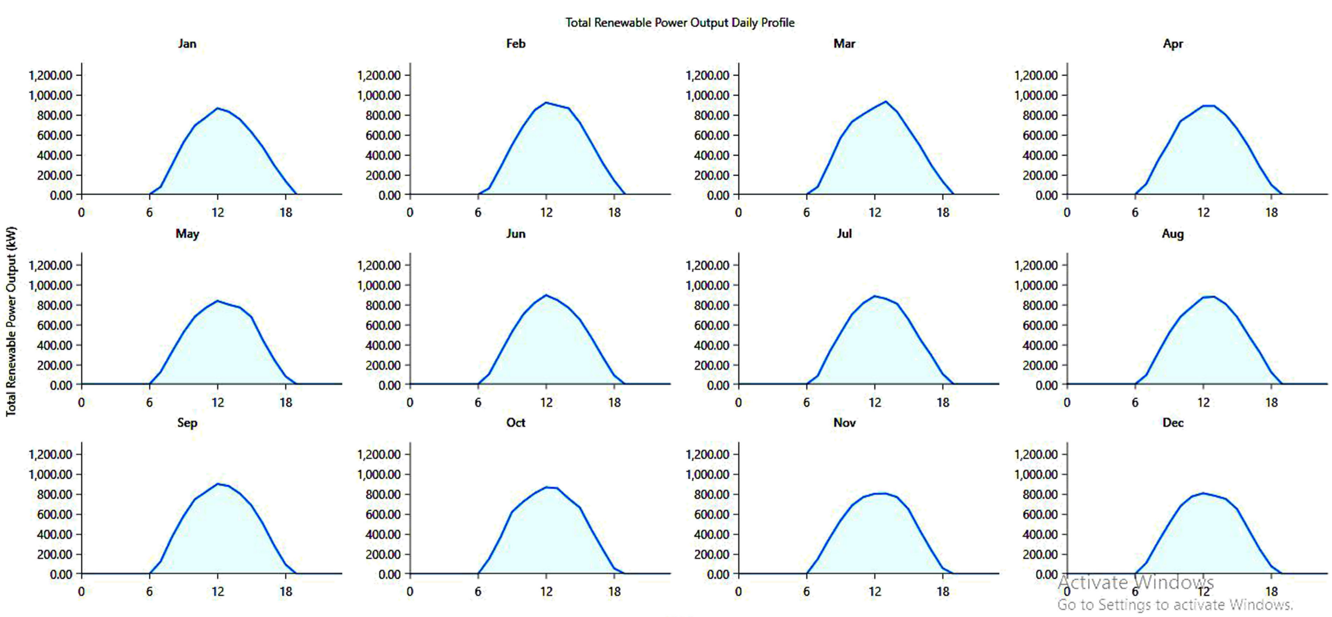

Fig. 5. Total renewable power output daily profile.

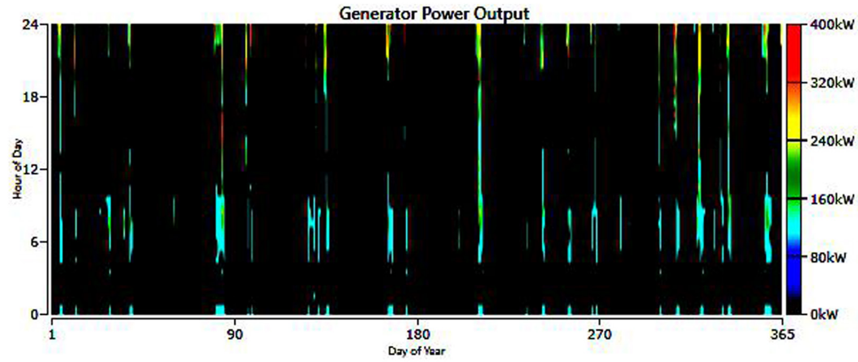

Fig. 6. Generator power output.

The plot showing PV power output for the year is shown in Fig. 4. The daily profile of total renewable power output is shown in Fig. 5. It can be seen that the majority of energy is generated from 9:00 hours to 17:00 hours.

2) Generator Simulation Result
Simulation of the generator output is presented in Fig. 6. The simulation result shows the hourly generator output in kW for the year. The total fuel consumed is 27 863 L/year, the average fuel per day is 76.3 L/day and the average fuel per hour is 3.18 L/h. The generator power output daily profile is presented in Fig. 7. It shows that the area requires generation of energy from a generator, mostly during morning and evening hours.

3) Battery Simulation Result
The battery SOC simulation is presented in Fig. 8, with high SOC falling mostly between 10:00 hours and 24:00 hours. The SOC daily profile is presented in Fig. 9.

4) Optimization Results
Fig. 10 shows the cost summary of all the components for combination 1. WEC gives the best overall price, at $415.82, while BESS gives the highest price of $1,693,661.42. The optimization result for the total operating cost ($) and the total capital cost ($) is given in Fig. 11 while the optimization result for the energy cost ($) and the total net present cost ($) is shown in Fig. 12 .

IV. CONCLUSION

Electric power supply system design relies on software modeling and energy audits. This is for powering the Osun State Broadcasting Corporation, Osogbo. DEG/BESS/PV is the optimum hybrid configuration, according to sensitivity analysis. DEG and PV work together to meet the power demands of the system; the converter subunit allows the PV array to directly provide the appropriate amount of electricity without emptying the battery. As a result, the battery bank and BESS unit will both have longer life spans, while simultaneously encouraging the DEG unit to engage in fewer, but more frequent on/off tasks.

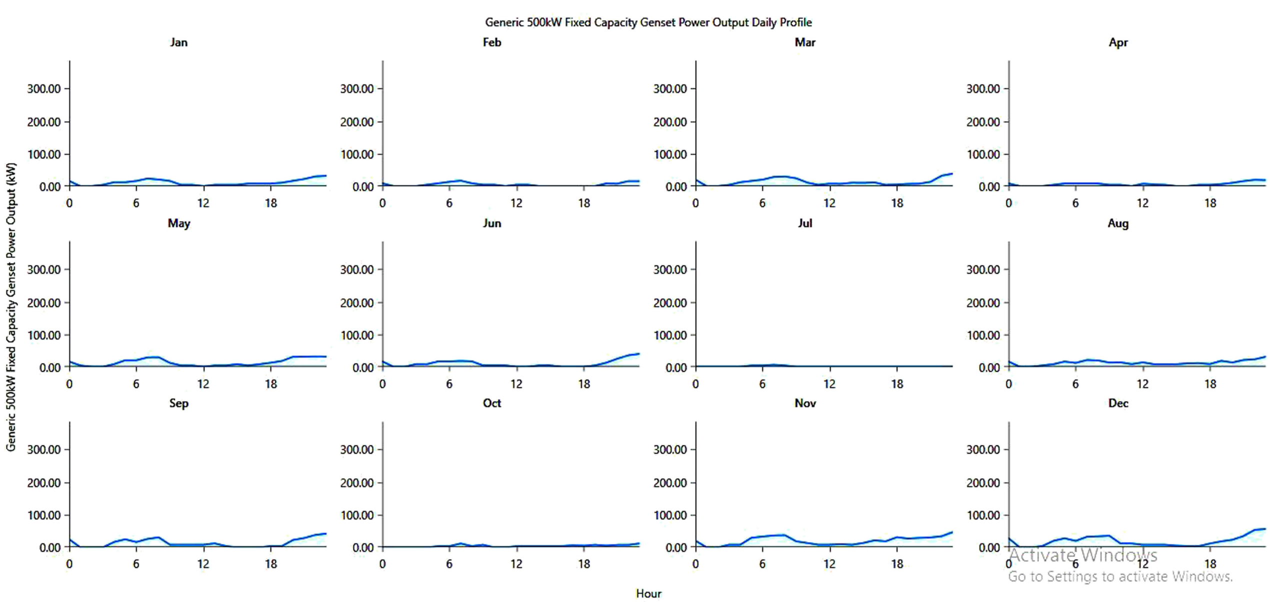

Fig. 7. Generator power output daily profile.

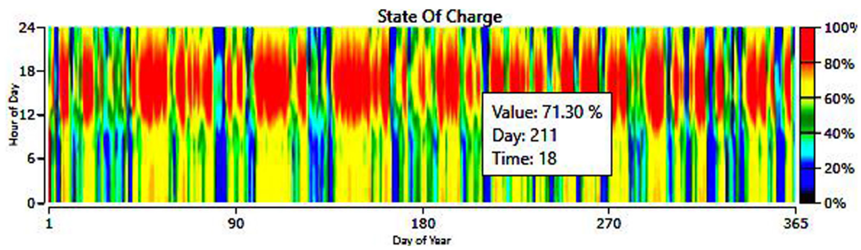

Fig. 8. State of charge.

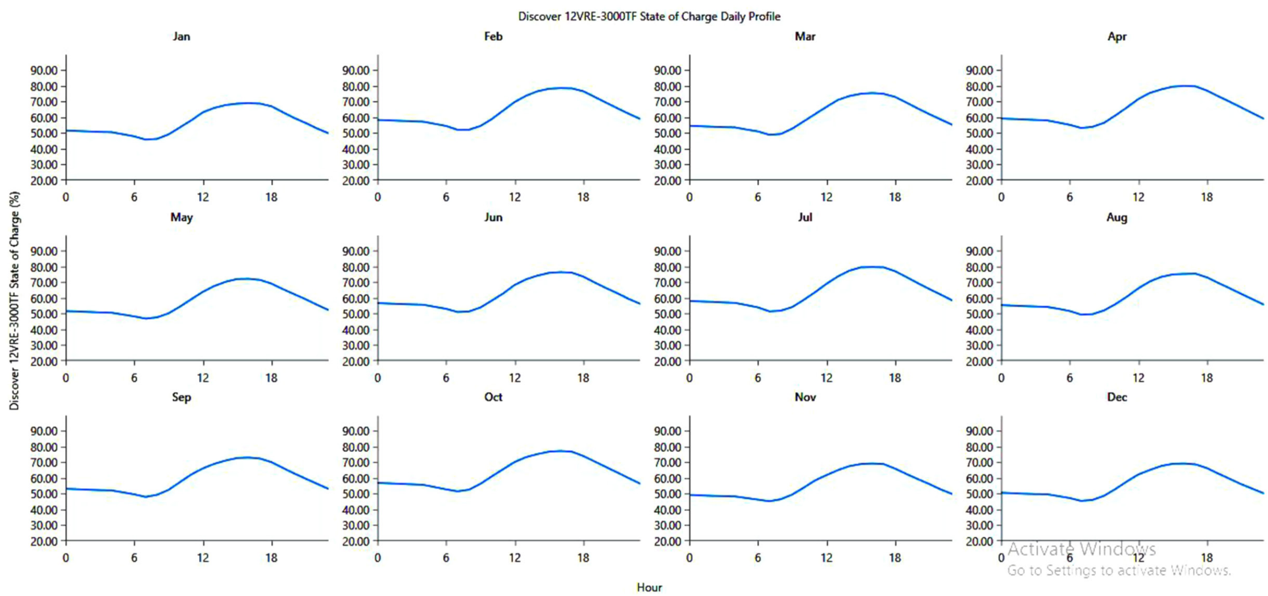

Fig. 9. State of charge daily profile.

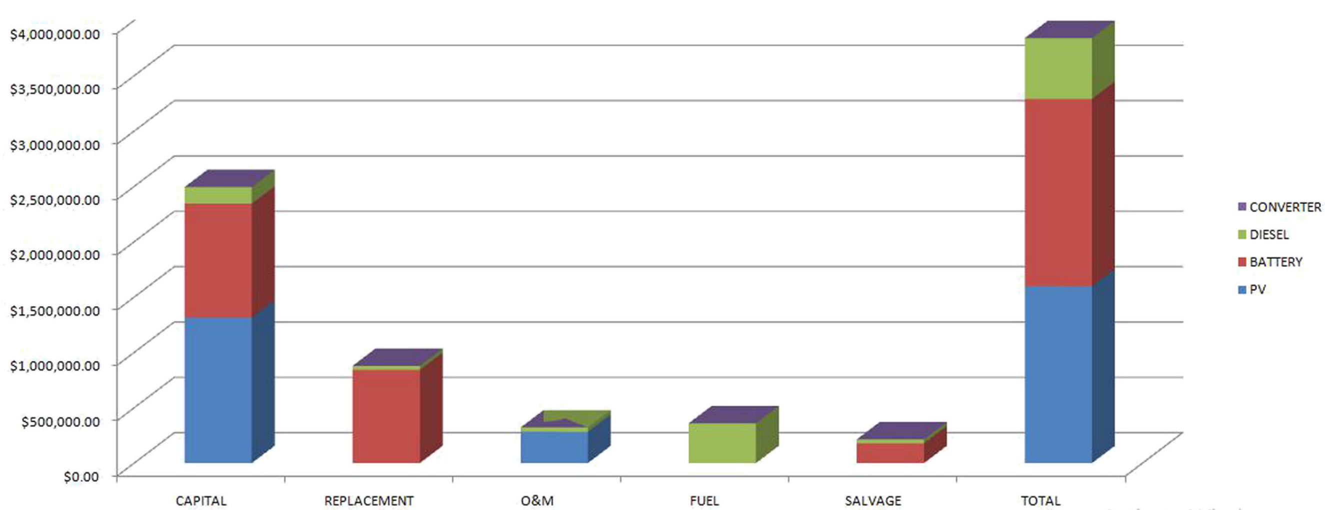

Fig. 10. General summary of cost of all the components of combination 1.

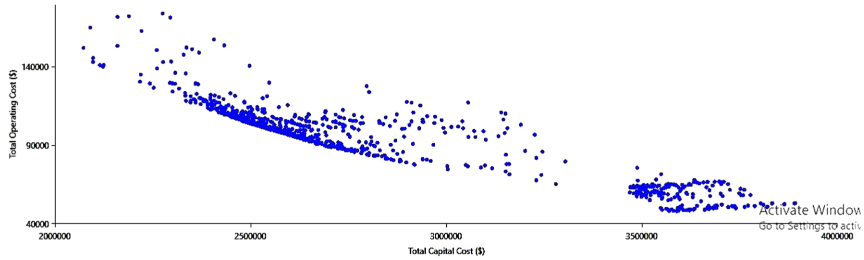

Fig. 11. Total operating cost ($) against the total capital cost ($).

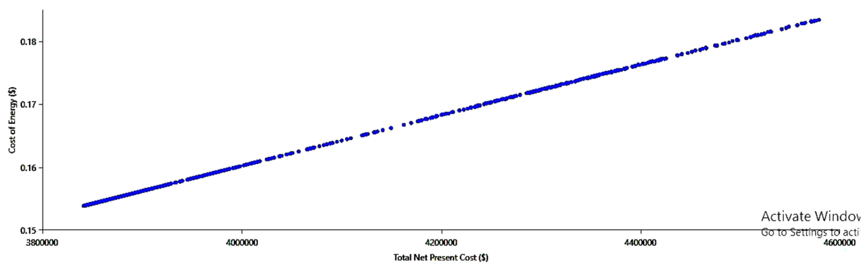

Fig. 12. Cost of energy ($) against the total net present cost ($).

Architecture							
CS6X-325P (kW)	G10	500kWGen (kW)	Dis12V	Converter (kW)	Dispatch	COE ($)	NPC ($)
1,424		500	2,512	722	LF	$0.154	$3.84M
1,461	1	500	2,502	743	LF	$0.156	$3.90M
1,751			4,720	888	LF	$0.168	$4.18M
1,743	1		4,730	886	LF	$0.170	$4.24M
594		500		776	LF	$0.320	$7.99M
587	1	500		894	LF	$0.322	$8.05M

Fig. 13. Optimization results by HOMER Pro.

HOMER Pro has also examined four different combinations of hybrid energy systems. The four combinations, which are: (1) SPV–DEG–BESS, often known as WEC-free; (2) SPV–WEC–DEG–BESS; (3) The SPV–BESS without WEC and DEG requirements; and (4) SPV–WEC–BESS without DEG. The total net present cost and cost of energy in the research region are both considered when making a decision based on the findings from these four combinations. HOMER is examined via four different HRES configurations. The first combination provides a minimum net present cost of $3.84 million and a cost of energy of $0.154/kWh.

Fig. 13 shows the optimization results by HOMER pro. The result of the sensitivity analysis shows that the first combination, a DEG/SPV/BESS hybrid, has many merits over the other four combinations. As its two energy sources, the diesel engine and the SPV array complement each other, and the converter subunit allows delivery of the needed amount of power directly from the PV array without running down the battery when there is enough solar radiation. As a result, the lifespan of the whole BESS unit and battery bank is increased, which also allows limited operation of the DEG unit. The first combination can therefore be considered as the most feasible means of power supply for the broadcasting station. The availability of both diesel fuel and solar radiant energy in Osogbo Nigeria made the option reliable.

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