Modelling and Optimization of Cost Function for Hybrid Power Generation System using Genetic Algorithm

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Abstract: -Recently, there has been a growing demand for clean, reliable and cost-effective energy especially in energy-deficient areas. The high cost involved in generating power in Nigeria is very alarming. Thus, reducing this cost is very imperative and critical to the overall economic benefit of the country. This study presents mathematical models and simulation of a grid connected hybrid energy system consisting of solar-diesel based hybrid energy system for overall cost minimization. In this study, the optimal energy cost of renewable generating systems are evaluated using the genetic algorithm optimization technique. Two cost models were developed for this study. The first model considers the use of diesel generator only to produce power and the second model considers the optimized systems which include the solar power generation and the diesel power generation. The result showed that the cost of generating a kWh of energy dropped from USD 65.789 in scenario 1 to USD 0.132 in scenarios 2. From the value obtained in scenario 2, it can be inferred that the combination of solar and diesel for power generation is a more reliable, environmentally friendly and cost-effective strategy for producing energy.

Key-Words: Hybrid Energy System, Victor Attah International Airport, Air Field Lighting, Localizer, Genetic Algorithm, Green House Gas.

1 Introduction

Energy is the single most important factor in the socio-economic development of man. It is a critical factor for economic growth of any country [1]. There is hardly any activity that is independent of energy [2]. It brings about improve wellbeing of citizens, particularly among emerging economies. It is envisaged that demand for electric energy will triple by 2050 [3]. [4] reports that energy commodities facilitate economic development by increasing productivity and income as well as creating employment. According to the world economic forum in 2012, the energy industry in the United States supported a total value added to the national economy of more than US$1 trillion, representing 7.7 per cent of US GDP. It is expected that the demand for electric energy will continue to increase. All the energy on earth comes primarily from solar energy [5].

Energy comes in the form of conventional and renewable sources. The conventional sources are depletable, non-renewable, harmful to the environment and expensive. [6] reports that conventional power grid only permits a one-way flow of power from major electricity generators to consumers. On the other hand, the renewable sources are inexhaustible, environmentally friendly and inexpensive [5].

Though, the population density in Nigeria is high, the country is richly endowed with abundance of both distributed renewable and non-renewable fossil fuels, solid minerals, sun, wind, hydro etc. that could, according to recent estimations, largely surpass the fast-growing energy demand. However, despite these huge energy deposits, the country is still grappling with the problem of high energy cost. Experts believe that with the abundance and potentials of these energy resources, there is really no reason why Nigeria should be experiencing high cost of energy. More so, in terms of the renewable energy resources, the amount of solar radiation and wind energy received across the country is relatively high and with minimal variability, which indicates that these energy sources are attractive power sources which result in overall cost reduction.

High cost of energy is seen as one of the major challenges to economic growth in Nigeria. The vast majority of Nigeria's population rely largely on small-scale generators popularly called "I pass my neighbour" to power their businesses as well as their homes. About $14 billion is spent annually on small-scale generators [7]. This includes operation and maintenance cost. Also, according to [7] the International Monetary Fund (IMF) says that a lack of access to reliable power costs Nigeria an estimated $29 billion a year. Imagine the positive effects this will bring if such amount is ploughed into the power sector. The need to provide a reliable and cost-effective energy strategy is therefore imperative. Several authors have proposed optimization algorithms to solve the problem of cost minimisation. [8] propose an optimal operation of virtual power plant, an EMS for controlling a virtual power plant (VPP). The objective here was to manage the power flows to minimize the electricity generation costs and to avoid the loss of energy produced by renewable energy sources. The VPP is composed of combined heat and power plants, wind parks and a photovoltaic plant. The surplus energy generated by renewable units is used for the operation of both a desalination plant and an electrolyzer that provide hydrogen for industrial processes.

[9] described an energy management system based on day-ahead power scheduling for a micro grid (photovoltaic panels, gas turbine) that considers the power prediction and load forecasting. The EMS provides the real-time power set points for micro grid units and coordinates the droop controllers for the primary frequency control.

[10] presented a model for optimal energy management with the goal of cost and emission minimization based on the operation strategies of the hybrid distributed generator.

In the recent past, Artificial Intelligence (AI) techniques have been discussed in literatures to solve power systems problems [11, 12]. Recently, global optimization techniques have been applied to HES. Genetic algorithms (GA) are like neural networks which have their advantages and disadvantages. In this paper, the genetic algorithm (GA) technique was used to obtain an improved cost-effective outcome. [13] present an energy management design and control strategy based on GA. [14] use GA for energy management control.

In the face of this rising cost of energy and the fact that massive investment is required to overhaul the power sector in Nigeria, optimization of energy cost readily comes to mind. Optimization of energy cost offers modern solutions to reliability, availability and cost effectiveness. It is designed to meet a wide range of requirements and application in order to produce more energy, waste less energy, comply with all regulations. Using renewable energy resources for sustainable power generation is the ultimate goal. However, they rely on one factor to perform - the weather. The unpredictable, ever-changing nature of the weather makes it difficult to ensure consistent energy production and availability. Providing a good energy mix consisting of both renewable and conventional resources will bring about the needed cost optimization.

The rest of the paper is organized as follows: Section II shows the related works. In Section III, the methodology, including the cost model of the hybrid energy system is presented. In section IV, the simulation results are presented and analysed under the different scenarios. Section V concludes the study.

2 Hybrid Energy System

Application of renewable energy for power generation has several benefits (such as clean energy, reduction of electricity cost) but its intermittency has led to special attention on the mix of renewable energy systems (an electricity production system which consists of a combination of two or more renewable types of electricity generating source) and hybrid systems (an electricity production system which consists of a combination of two or more types of electricity generating source which one of the sources must be diesel generator) [15]. In essence, employing solely renewable energy resources for power generation is risky and not advisable since it is discontinuous in nature. The use of conventional sources no matter how reliable they may be, are expensive and produce harmful effects around the world mainly evidenced as global warming which is caused by the consumption of fossil fuels (transportation system and thermo-electric plants) producing a lot of tons of greenhouse effect gases [16]. According to [17], the greenhouse gas (GHG) emission of electric power sectors around the world is about 1/3 of the total world GHG emissions, indicating the significance of the electric power sector in the global warming issue.

Hybrid energy system (HES) concept in recent times, has drawn more attention for electrification of isolated or energy-deficient areas [18]. HES has become increasingly popular in the energy sector due to the numerous and distinct advantages it offers to customers and utilities over the single energy system which include but not limited to the following. It improves efficiency to greater reliability, reduces environmental impact and eventually reduces cost of electricity. The sources together can supply power and if any decrease in power occurs, in any one, the other source can compensate for the first. Also both system together can supply higher loads if required. More so, the excess power generated, can also be stored in a battery for future use [2]. According to the green energy production emerging policies, cogeneration power plant schemes integrating renewable and conventional electrical power sources stand as the most viable solutions [17]. For reliable supply of power in remote locations or power deficient areas, it is necessary to design and set up HES, which combine the advantage of two different energy technologies. These could be either two renewable technologies or a renewable and a conventional energy or fossil fuel technology. [2] reports that a hybrid energy system such as so lar and diesel generator or wind and diesel generator would ensure that power supply can be maintained at an optimum level during cloudy days for a PV system and at low wind conditions for wind electric generators.

Running a system such as an airport with a single energy generation source is therefore a very huge risk in terms of reliability and cost-effectiveness. Considering the fact that safety is a critical factor in establishing and running an airport, having different sources of energy generation is of paramount importance. The Victor Attah International Airport (VAIA), Uyo, Nigeria can boast of a steady power supply. However, the major challenge confronting it, is the high cost involved in generating power for the airport. This is evident in the fact that VAIA runs continuously on diesel generators leading to a high cost of operation and maintenance and a high emission of dangerous gases especially carbon IV oxide, CO_2 which is hazardous to the environment and in turn affects human health. The use of HES has therefore been proposed to reduce the cost of power in VAIA.

3 Materials and Methods

The HES consists of a photovoltaic cell, energy storage system, which is a lithium battery in this case, the diesel generator, which serves as a backup and the load demand for VAIA, Uyo, Nigeria as shown in Fig.1. The HES works in grid-connected mode.

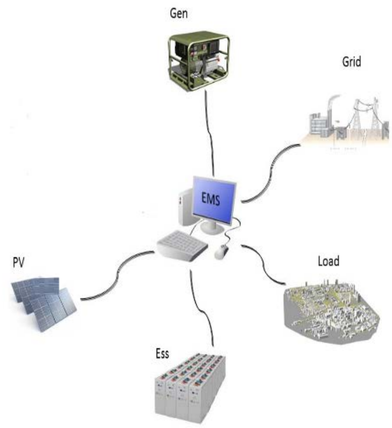


Fig. 1. Basic Diagram of the Proposed Hybrid Energy System

The purpose of this study is to develop a system that is cost-effective, sustainable and reliable taking into account the availability of solar renewable energy.

The methodology adopted for this research includes but not limited to the follows:

i. The case study of the research.
ii. Date collection
iii. Economic Models of the Energy Resources.
iv. Development of Cost Optimization Function

3.1 Case Study

The case study used for this research is the Victor Attah International Airport (VAIA) which is located within three local government areas – Uruan, Nsit Atai and Okobo (which has a large chunk of the area) in Akwa Ibom State, Nigeria with coordinates 4^{o}52’25” N and 8^{o}05’40” E. The VAIA is located majorly in Okobo, one of the major coastal towns in Nigeria bordering the Atlantic Ocean and provides an attractive proposition for the generation of energy using wind and solar sources. The airport does not have access to grid power at the moment but its source of power comes only from generators.

3.2 Data Collection

There are two parameters having a high impact on the solar PV output power. These are the solar radiation and ambient temperature. The ambient temperature plays an important role in the performance of PV modules [8]. Accurate measurement of ambient temperature data is therefore very essential. The amount of solar radiation received in the area is relatively high, which indicates that the solar energy system is an attractive power source. The mean daily temperature and solar radiation data used in this study were obtained from the Meteorological Department of the VAIA for a period of three years (2016 - 2018). The required daily load profile used in this study was obtained from the airport maintenance engineering department of the VAIA. The required load for the case study is 102,262.28mWh per day as shown in table 1.

Table 1. The Load Capacity and Energy Demand Per Day for VAIA, Uyo.

Load Area	**Load Cap. (kW)**	**Operation period**	**Energy Demanded (kWh/d)**
Cont. Tower	351.4	24	8433.6
Admin Blk.			
Interim	383.8	8	3079.4
Term.	395.8	24	9487.2
Clinic/Met/			
Substation	89.5	8	7.6
CVOR			
Station	9.8	24	235.2
LLZ Station			
G.P Station	9.8	24	235.2
Mopol			
camp/	9.8	24	235.2
Fuel Station	7.2	24	172.8
AFL			
Access gate/			
Police stat.			
Water Treat	445	3	1335
Plant	9.47	24	227.3
Street Light			
MRO/ECC/			
Fire Station	6.5	2	13
Int.			
Terminal			
Cargo	62.5	12	750
Terminal	992.6	24	23822.4
	2203	24	52872
	27	24	648
Total	**5003**	**273**	**102262.3**

3.3 Economic Models of Distributed Energy Resources

It is absolutely important and necessary to determine the investment outlay of each of the generation components before undertaking the project. The unit cost of solar and diesel generator power can be determined by knowing capital component as w ell as t he operating costs. The proposed load capacity for the case study under review is about 5MW. The various sources are discussed in the succeeding subsection.

3.3.1 Photovoltaic Energy Resource Cost Model

The economic model of the solar generation system consists of the PV module, battery storage and the inverter. The solar irradiance in this study was obtained from the Victor Attah International Airport, Uyo. The potential of electricity generated annually was determined using the Shah *et al.* expression given in [1] as:

$$E_{pv} = A_{pv} \times \mu_{pv} \times I_t \times PR \quad (1)$$

where E_{pv} = electricity generated (or potential of electricity generated) by the panel annually, A_{pv} = area of the panel, μ_{pv} = efficiency of the panel, I_t = mean annual amount of solar radiation received on a tilted panel and PR = performance ratio accounting for the losses incurred. The efficiency of the panel was determined using the Shah *et al.* expression given in [1] as:

$$\mu_{pv} = \mu_r \left[1 - \beta_r \left[T_{AMB} - T_r + (T_{NOM} - T_{a.NOM}) \frac{R_T}{R_{NOM}}\right]\right] \quad (2)$$

where μ_r = referenced efficiency of the solar panel (to be provided by the manufacturer), β_r = temperature coefficient of solar panels, T_{AMB} = ambient temperature, T_r= referenced temperature of the solar panels, T_{NOM} = nominal operating temperature, $T_{a.NOM}$ = ambient nominal operating temperature of the solar cell.

3.3.1.1 Cost of Energy with Solar PV

The cost of generating electricity with PV cell was determined using the Shah *et al.* expression given in [1] as:

$$C_{pv} = (\textstyle\sum_{i=1}^{n} \frac{IC_{pv} + MC_{pv}}{(1+r)^2}) / (\sum_{i=1}^{n} \frac{E_{pv}}{(1+r)^2}) \quad (3)$$

where IC_{pv} = installation cost, MC_{pv} = maintenance cost, E_{pv} = amount of electricity generated in one year in kWh, r = discounted rate and n = operational lifespan of the system.

3.3.2 Diesel Generator Energy Resource Cost Model

The capital cost for the generating set includes purchasing cost, transportation cost, installation cost, etc. while the running cost includes the maintenance cost and the fuelling cost.

Maintenance cost can be calculated using the Otasowie *et al.* expression given in [20] as:

$$LCC\ (mcte) = AMC\left[\left(\frac{1+F_E}{R_D-F_E}\right)*\left(1-\left(\frac{1+F_E}{1+R_D}\right)\right]^N \quad (4)$$

where AMC = annual maintenance cost, LCC = life cycle cost, F_E = escalation rate. A value of 10.5% is considered. R_D = discount rate. A value of 9.5% is considered. N = lifetime of the generating set, annual routine service cost is 5% of generator cost.

Running cost can be calculated using the Otasowie *et al.* expression given in [20] as:

$$LCC\ (running) = ARC\left[\left(\frac{1+F_E}{R_D-F_E}\right)*\left(1-\left(\frac{1+F_E}{1+R_D}\right)\right]^N \quad (5)$$

where ARC = annual running cost, LCC = life cycle cost, F_E = escalation rate taking a value of 10.5%, R_D = discount rate. A value of 9.8% is considered, N = lifetime of the generator. Annual routine service cost is 5% of generator cost.

3.3.2.1 Life Replacement Cost Model for Generator

Replacement cost can be calculated using the Otasowie *et al.* expression given in [20] as:

$$LCC\ (replacement) = C_{GR}\left[\left(\frac{1+F_E}{R_D-F_E}\right)*\left(1-\left(\frac{1+F_E}{1+R_D}\right)\right]^N \quad (6)$$

where LCC= life cycle cost, F_E= escalation rate taking a value of 10.5%, R_D = discount rate. A value of 9.5% is considered, N = lifetime of the generating set usually taking as 5 years.

C_{GR} = generator replacement cost and can be calculated using the Otasowie *et al.* expression given in [20] as:

$$C_{GR} = \frac{C_{G1}}{Y_R} \quad (7)$$

where C_{G1} = cost of generator for one replacement, Y_R = replacement year.

3.3.2.2 Cost Model Per Kwh of Diesel Generator

The per kwh cost of diesel engine can be determine using the Otasowie *et al.* expression given in [20] as:

$$C_T = \frac{C_C + C_{LF} + C_{LRS} + C_{NL}}{N + 365 + P_R} \quad (8)$$

where C_T =cost per KWh, C_C = total capital cost, C_{LF} = Life fuel cost, C_{LRS} = Life Routine Service Cost, P_R = required power, N = lifespan of the generator

3.4 Development of Cost Optimization Function

To determine the optimal output power set points for the distributed energy resources, an efficient optimization method has been adopted.

3.4.1 Objective Function

The objective function of the system is used to determine the total operating cost of the system. The genetic algorithm optimization tool was used to optimize the total cost of operations and to properly assign the operation of the hybrid generation plant to ensure 24 hours uninterrupted power supply. The objective function for this research is a two pronged approach considered below.

3.4.1.1 Generator Only Scenario

This scenario involves the use of only generator to generate power for the case study. The cost is given by:

$$C = bC_{DG} + \left[\left(\frac{b}{x}\right)\right]d \quad (9)$$

$$b \geq 0 \quad (10)$$

where b = total volume of diesel required for the period of time, x = volume of diesel required for the year, d = Unit purchase and installation cost of diesel generator, C_{DG} = Running cost of generator which includes the cost of diesel and cost of maintenance.

3.4.1.2 PV and Generator Combination

This scenario involves the combination of PV and diesel generator. Here the energy generated by the PV (for about 8 hours) is utilised during day and also stored in the ESS for use at night. Also, the quantity of the solar panel required is increased. The diesel generator operates as a backup majorly at night when there is no solar and grid power. The effect of the diesel generator in this case is very minimal and can only be used to supply power when the stored energy has been exhausted. The optimized cost is given as:

$$C_{GA,opt} = aC_{PV} + bC_{DG} \quad (11)$$

$$a, b, c \geq 0 \quad (12)$$

where a = total number of panels needed to produce the required energy from solar, b= total volume of diesel required for the period of time, x = volume of diesel required for the year, d = unit purchase and installation cost of diesel generator, C_{DG}= running cost of generator which includes the cost of diesel and cost of maintenance, C_{PV} = cost of solar panels.

The constraints considered for the different resources to generate the required energy are stated as follows:

For solar PV:

$$aE_{PV} \leq \frac{nE_T}{3} \quad (13)$$

Where E_T = total energy demand of the case study which is to be generated by the respective sources, E_{pv} = total energy produced by the solar panel for the case study.

For diesel generator:

$$b.\frac{E_{DG}}{103.5} \geq 0.2nE_T \quad (14)$$

Where E_{DG} = total energy produced by the generator for the case study.

k = Volume of diesel consumed per hour, E_{pv} = Total energy produced by the solar panel for the case study, E_{DG} = Total energy produced by the generator for the case study.

3.5 Specification of the Input Parameters

Table 2. Input parameters and unit Cost of different items

Description	Specification
PV System	
Unit Cost	$ 263.89
Charge Controller	$83.33
Installation Cost	$ 55.56
Replacement Cost	$ 347.22
Lifetime	25 years
Batteries	
Model	Deep Cycle
Nominal capacity	200Ah
Unit Cost	$ 194.44
Replacement Cost	$ 194.44
Lifetime	5 years
Diesel Generator	
Unit Cost	$ 35,000
Maintenance Cost	$ 272.22
Diesel Cost	$ 0.625
Replacement Cost	$ 35,000
Lifetime	5 years
Inverter	Unit Cost
Replacement Cost	$ 125
Lifetime	5 year
Grid	$ 0.142

4 Results and Discussion

The results obtained for the two scenarios are discussed in the succeeding subsection

4.1 Results

The HES was optimized under two different scenarios as considered in the previous section. The optimal economic costs of the two scenarios were investigated and simulated with the real data profiles. The total energy generated by the two scenarios were examined to investigate the ability of the available energy to satisfy electric load demand throughout the period of 25 y ears considered. The quantity of diesel consumption, the number of PV panels and the unit of energy from the grid required in the different scenarios were also investigated.

4.1.2 Generator-only scenario

Here, only diesel generator is used to produce power for the case study. The cost, energy and volume of diesel required on a yearly basis for a period of 25 years is presented in Figures 1, 2, 3.

Fig. 2. Optimal cost of generation for generator only scenario

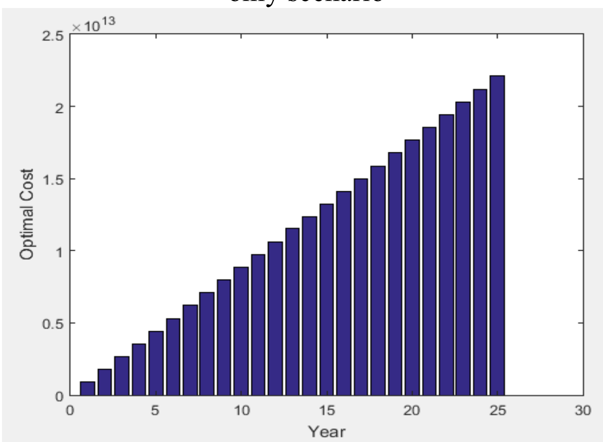


Fig. 3. Total energy generated by generator only scenario

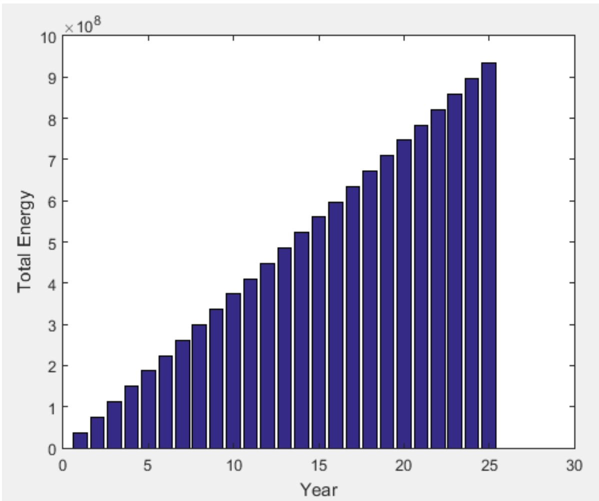
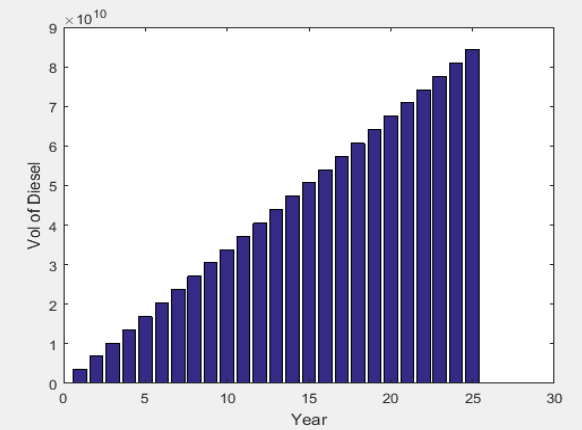


Fig. 4. Volume of diesel required for power generation for generator only scenario



4.1.3 PV and Generator Combination

Here, a combination of PV and diesel generator is used to produce power for the case study. The optimized cost, energy and volume of diesel required on a yearly basis for a period of 25 years is presented in Figures 5 - 7.

Fig. 5. Optimal cost of generation for PV/Diesel generator combination

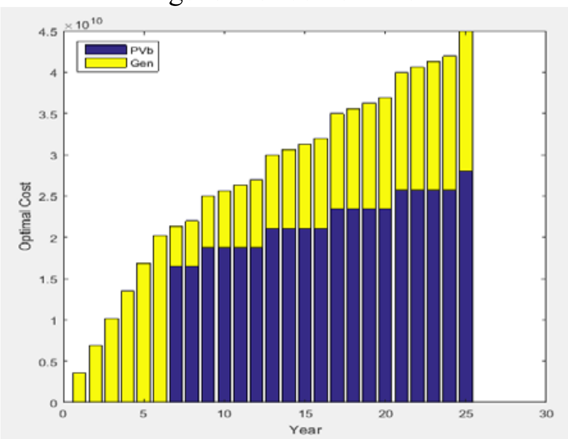


Fig. 6. Total energy generated by PV/Diesel combination.

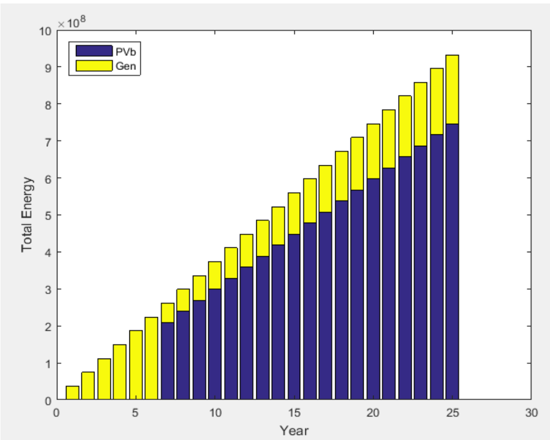
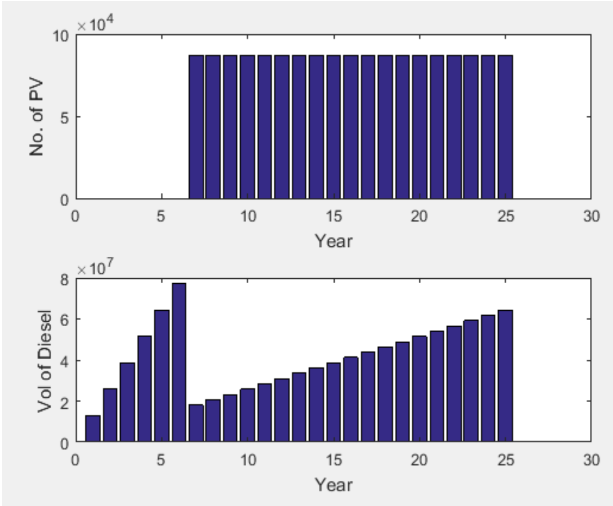


Fig. 7. No. of PV and Vol. of diesel required for generating power for PV/Diesel generator combination



4.2 Discussion

From Figures 1, 2 a nd 3, the total cost of generating power, the total energy generated and the total volume required with diesel generator only increases linearly, with maximum of $62.5 billion, 950 megawatts and about eighty-five billion liters (85 BL) at the 25th year respectively. It is also observed that cost increases as the energy increases over the years. The unit cost of producing 1kwh of energy is: $\frac{62.5 \text{ billion}}{950 \text{ megawatts}} = \$\ 65.789/\text{kwh}.$

From Figures 4, 5 a nd 6, the total cost of generating power, the total energy generated and the total volume required with diesel generator only increases linearly, with maximum of $125 million, 950 megawatts and about sixty million liters (60 ML) at the 25th year respectively. It is also observed that cost increases as the energy increases over the years. The unit cost of producing 1kwh of energy is: $\frac{125 \text{ miillion}}{950 \text{ megawatts}} = \$0.132/\text{kwh}.$

In the future, this study would look to incorporate more renewable resources that will arrive at the most cost effective strategy for power generation for the case study.

5 Conclusion

This study presents an optimization and evaluation of the different scenarios considered for the generation of electrical power in the Victor Attah International Airport, Uyo using PV/diesel. The two different scenarios considered for this study includes the generator only scenario and the

PV/diesel generator combination (the optimized scenario). Genetic algorithm was used to optimize the models.

The cost analyses results show that the cost of generating 1 kilowatt hour of energy in scenario 1 is $65.789 and it is $0.132 for scenario 2, which is also the optimal result for the case study. This study aids in decision making towards a sustainable energy mix for VAIA in a cost-effective manner and in a manner that reduces the impact of high emission of dangerous gases to the environment.
The future scope of this work is the incorporation of more renewable resources that will possibly arrive at the most cost effective strategy for power generation for the case study.

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