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Title: Modelling of an Intelligent Energy Management System and Hierarchical Power Shedulig Algorithim for a Solar Microgrid
Authors: **Onuorah Chukwuemeka[1] Obute Kingseley[2] Bayem Donatus[3] Arinze Chukwudi O.[4] Oranugo Charles[5]**

MODELLING OF AN INTELLIGENT ENERGY MANAGEMENT SYSTEM AND HIERARCHICAL POWER SHEDULIG ALGORITHIM FOR A SOLAR MICROGRID

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1.0 ABSTRACT
In Nigeria, where many regions experience significantly low electrification rates, microgrids have been implemented to provide electricity to rural communities. There is a pressing need to enhance and redesign the conventional energy management system, which necessitates the development of an energy management strategy aimed at optimizing the power exchange with the grid profile. This thesis presents an optimal configuration algorithm for the allocation of energy resources within a microgrid, utilizing data obtained from a microgrid situated in Nigeria. When compared to an existing design utilized in the experimental setup of this study, the newly developed algorithm demonstrated superior performance. Four distinct scenarios were analyzed; the simulation results indicated that in scenario one, the system operated without any costs, as all energy consumption was effectively met by the solar panel. In scenario two, the yearly projection revealed a total savings of N1,232,400 compared to the existing design, which incurred a daily operational cost of N27,600. For scenario three, the yearly savings amounted to N1,029,600 when juxtaposed with the existing design that had an operating cost of N9,900. Additionally, the system was evaluated to assess the extent of deviation between the supplied power and the load demand. The simulation results indicated that at 100 seconds, the error percentage for the existing design peaked at 7%, while the developed algorithm's error approached zero. The system's responsiveness to transitions between different scenarios was also analyzed, revealing that the developed algorithm reacted to changes in just 83 milliseconds. Furthermore, an assessment of the battery state of charge (SoC) indicated that the batteries managed by the developed algorithm consistently maintained a level above the acceptable threshold of 33%, in contrast to the existing design, which fell below this threshold during simulations.

1. Background to the Study
The provision of electricity to consumers is a critical factor influencing socio-economic development within any nation. Insufficient and restricted access to electrical supply hampers industrial growth and overall development. For a nation to achieve economic progress, a consistent power supply is essential. Recently, Nigeria has encountered a triad of challenges: unreliable and inadequate electricity supply, the necessity to reduce greenhouse gas emissions, and the imperative to maintain affordable energy for consumers. These issues have significantly impeded the country's economic advancement. Despite efforts by the previous administration to enhance power supply through the privatization of the power sector, electricity provision to households and businesses remains alarmingly inadequate (Olowosejeje, 2020). According to the World Bank in 2022, as referenced by Ojukwu (2022), Nigerian businesses incur annual losses exceeding $29 billion due to the poor state of power supply, leading to consumer hesitance in paying electricity bills. The unreliability of power has compelled numerous businesses and industries to depend on self-generated energy sources, including solar power. In 2006, President Olusegun Obasanjo's administration sought to address the issue of frequent outages through policy reforms and financial support for existing power generation initiatives. Additionally, the administration rebranded the National Electric Power Authority (NEPA) to the Power Holding Company of Nigeria (PHCN). However, despite the implementation of a Service Based Tariff in late 2020, which was accompanied by promises of improved power supply, many consumers in certain regions continue to experience inconsistent electricity availability (Jeremiah, 2022; InfoGuide Nigeria News, 2023).3Literature Review ‘Regad et al. (2020) addressed the issue of frequency control in microgrid systems

using a fractional order PID controller. The microgrid system they proposed included a variety of energy sources such as a Photovoltaic System, Wind Turbine Generator, Diesel Engine Generator, Fuel Cell, and different storage solutions like Battery Energy Storage Systems and Flywheel Energy Storage Systems. The primary goal of their research was to minimize frequency and power deviations by applying the proposed controller, which features five parameters that are optimized through specific techniques. The Krill Herd algorithm was employed to determine the optimal fractional order PID controller parameters, using the Integral of Squared Error as the optimization criterion. The study also compared the performance of the Krill Herd algorithm with the Genetic Algorithm, and the simulation results indicated that the Krill Herd-based controller provided superior performance, with fewer fluctuations in power and frequency deviations.

S. Islam et al (2024) Renewable energy resources (RES) are closely linked to grid stability problems. The main challenge of RES is the uncertainty caused by parameters such as irradiation, wind velocity, or temperature. In this connection, Multi-Objective Optimization (MOO) Algorithms can be used as an intelligent control system for a microgrid by ensuring continuity of power supply in case of grid failures. Based on grid reliability and local demand, MOO can make real-time decisions about disconnecting from the primary grid (islanding) and when to reconnect. It can help in MG control systems by optimizing energy storage systems (ESS) operation by determining when to charge and discharge them based on electricity prices, grid demand, and renewable energy availability. This survey discusses an MG and its different challenges with RES with Photovoltaic (PV) as a primary component and prominent energy sources such as a utility grid, Diesel Genset (DG), Wind Turbine (WT) and ESS. In this research, a unique classification approach of different problems in Microgrid (MG) is identified and discussed. This paper focuses on the MOO algorithms used in MG for their energy management systems (EMS) and technical and economic problems and investigates how MOO can play a significant role in solving such problems.

SYSTEM BLOCK DIAGRAM

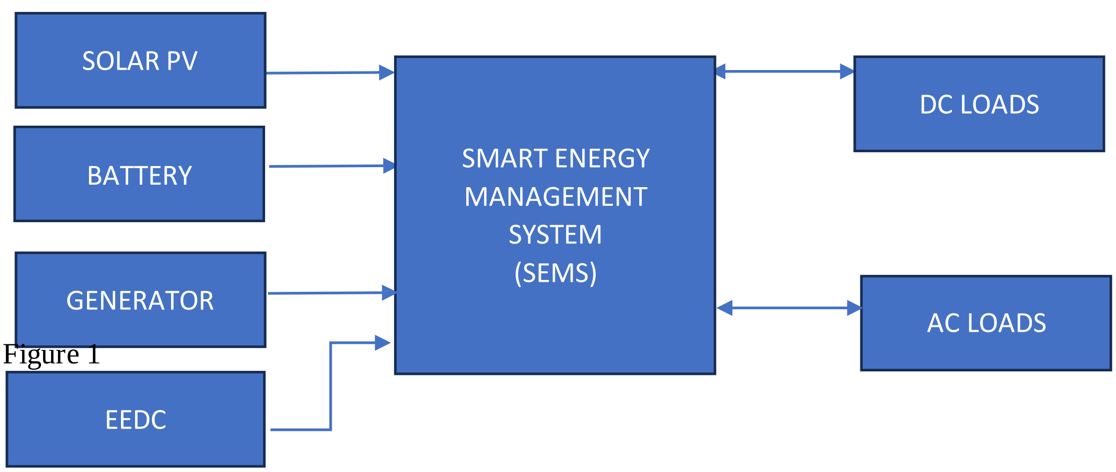

Figure 1

Figure 2 Front View Office of Mr. Commissioner Ministry of Power and Water Resources, Awka.

Battery and Inverter System

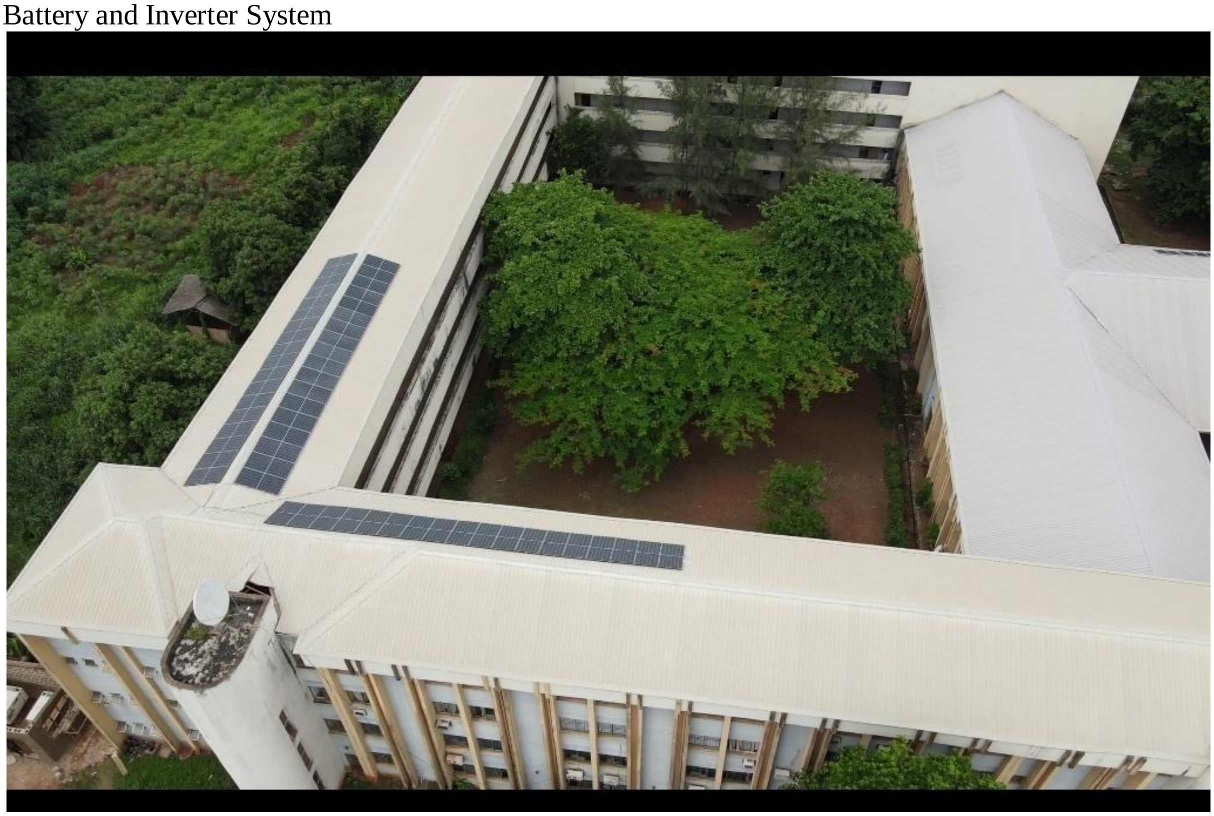

Figure 3 Block A of Anambra State Secretariat building, Awka.

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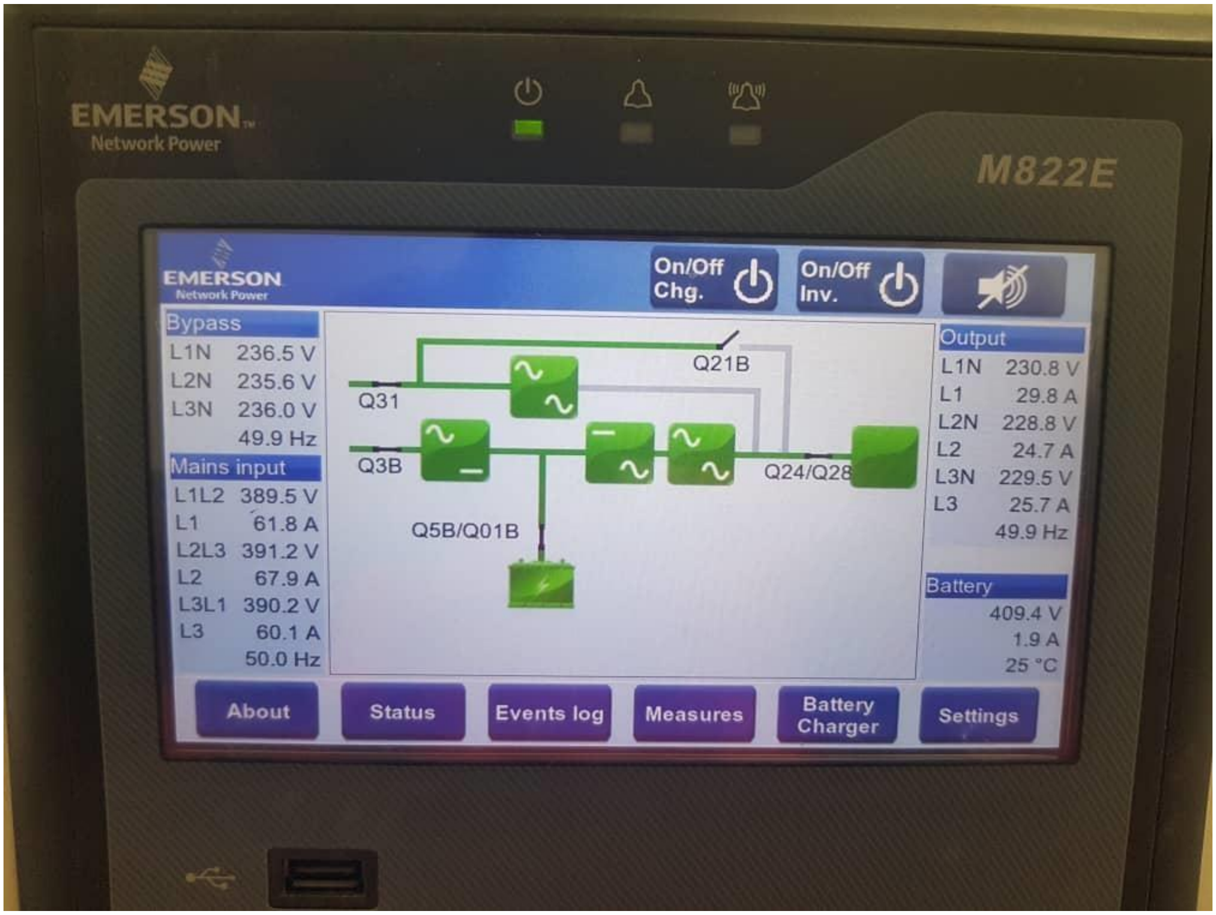


Figure 4 UPS Control screen

$$P_w = P_s Cos\psi \rightarrow P_s = \frac{P_w}{Cos\psi} \quad (3.1)$$

Since not all the load elements or appliances are rated in volt ampere, there is need to use equation (3.1) for power conversion. Also it can be shown that.

$$P_w = 0.746\, P_{hp} \quad (3.2)$$

Where, $P_w$is in kilowatt and $P_{hp}$the power as is expressed in horse power. That is, to convert power in horse power (hp) to volt-ampere (V) the following formula is derived. Substitute equation (3.16) into equation (3.2)

$$P_s = \frac{0.746\, P_{hp}}{Cos\psi} \quad (3.3)$$

The efficiency in any system is expressed as

$$\eta = \frac{output}{input} x\ 100\% \text{ (Expressed in percentage)} \quad (3.4)$$

This is written as

$$\eta = \frac{P_o}{P_i} x\ 100\% \quad (3.5)$$

Where P_o is the inverter output, P_i is the inverter input, η is the inverter efficiency. This implies that:

$$P_i = \frac{P_o}{y} \quad (3.6)$$

Also, load analysis involves the summation of all appliances and equipment under consideration.

$$E_C = \sum E_i \quad (3.7)$$

Where, E_C is the total energy of all appliances and E_i is the energy of each appliance. Also,

$E_{cd} = E_c \div \eta$ (3.8)

Where, E_{cd} is the consumer energy demand taking inverter efficiency into consideration. In order to be more accurate, the energy consumption of the inverter while on standby will be taken into consideration, this make equation (3.17) to be modified as

$E_{cd} = E_c \div \eta + (P_{st} \times T)$ (3.9)

Where, P_{st} is the standby power consumption and T is the time the inverter stays on in a day. By using the various formulae stated in this section, the load analysis for the various blocks is done.

The building is divided into three (3) blocks (containing different offices) with different load distribution. The load analysis of each block is conducted in this section. Appendix A contains the detailed load distribution of each of the blocks.

The power ratings are converted to the volt-ampere using equation (3.10). The various ratings are therefore calculated and shown in appendix B for each block. The total power is calculated by multiplying unit power by the quantity of each appliance. The energy consumed by each block was calculated using equation (3.1). From the calculation, the following data was obtained.

Table 1 Table of total energy and power of the different blocks

BLOCK	TOTAL ENERGY (E_c)	TOTAL POWER (P_o)
Block A	1055192.28VAH	124556.38VA
Block B	264618.63VAH	39995.54 VA
Block C	287,776.69 VAH	39879.90 VA

This P_o will be used to choose the required size of inverter that will be able to supply the load conveniently without overloading.

Having determined the total energy per block as given above, it is necessary to determine the battery bank requirement for each block. Considering the stand-by time, equation (3.23) can be modified to obtain:

$E_{cd} = (E_N \div \eta) + (E_S \times T)$ (3.11)

This means that the consumer energy demand depends on the energy consumed by the appliances, the efficiency of the inverter that will be used, the standby energy consumption (E_s) of the inverter and the time the inverter will stay on. The battery discharge is a quantity that depends on the consumer energy demand and the system voltage. Batteries come into the picture in case of insufficient power or absence of solar supply. The battery sizing is necessary for off-grid solar PV infrastructure. Solar PV systems typically require deep cycle batteries. These batteries have an advantage of rapidly charging and discharging to a low energy level, making them highly efficient.

The system voltage is the dc voltage that the inverter is designed with and it usually becomes high as the power rating is becoming high. The battery discharge is given as:

$D_B = \frac{E_{cd}}{V_s}$ (3.12)

Where D_B is the battery discharge in (Ah), E_{cd} is the consumer energy demand in (VAh) and V_s is the system voltage in volts (V). D_B is the amount of charge that will be needed for the running of all the appliances. Another important factor to consider in the battery bank design, is the Depth Of Discharge (D_OD). Draining the batteries completely is usually not advised as it decreases their lifespan. The Depth of Discharge (DOD) of the batteries is expected not to exceed 60% of the charge. This means that the battery can be discharged till 60% of its energy has been delivered. Maintaining this helps increase their lifespan. The percentage of battery capacity that will be used up per day by the load is given as:

$C_B = \frac{D_B}{D_O D}$ (3.13)

The D_OD is very important and should by carefully choosing because it is not good to drain all the charges in the battery.

For any off-grid Solar PV System it is not advisable to charge and discharge the batteries every day. The "days of autonomy" designs the battery rating based on number of days the batteries deliver power without a charge. This is the number of days that the system can sustain the load without being charged. Taking into consideration, the Days of autonomy, equation (3.26) is modified to give:

$$C_B = \frac{D_B \times D_A}{D_o D} \qquad (3.14)$$

Where D_A are autonomous days

Calculations were also carried out to accurately determine the number of batteries that should be connected both in series and in parallel to form the battery bank.

Assuming the unit battery capacity be represented by C_u and the number of battery to be connected in parallel in the battery bank is $N_{P,}$ then the number of batteries to be connected up in parallel is given as:

$$N_P = \frac{C_B}{C_u} \qquad (3.15)$$

To calculate the number of batteries in series N_s, we use

$$N_S = \frac{V_s}{V_u} \qquad (3.16)$$

Where

V_s Is the system voltage

V_u Is the battery voltage

The total number of batteries that will be needed for the system was obtained using:

$$N_T = N_P \times N_S \qquad (3.17)$$

Where N_T = is the total battery needed.

The battery voltage for the series connection, was obtained as follows:

$$V_{BT} = V_{B1} + V_{B2} + V_{B3} - - - - - - - + V_{Bi} \qquad (3.18)$$

Where V_{BT} is total voltage of the series connection and v_{Bi} is the voltage of the i_{th} battery. The current drawn by the batteries in series is obtained as:

$$I_{BT} = I_{Bi} \qquad (3.19)$$

Where I_{Bi} Is the current drawn from the i_{th} battery and I_{BT} is the current supply by the series connection.

For the parallel connection,

$$I_{BT} = I_{B1} + I_{B2} + I_{B3} + \cdots + I_{Bi} \qquad (3.20)$$

Where I_{BT} is total current of the parallel connection.

The battery voltage for the parallel connection, was obtained using the equation:

$$V_{BT} = V_{Bj} \qquad (3.21)$$

Where V_{Bj} is the voltage of the J^{th} battery, and V_{BT} is the voltage of the parallel connection.

After calculating the Ampere-hour rating of the batteries, the charge controllers rating of the system is decided. Charge controllers regulate the voltage and current coming from the solar panels going to the battery. The charge controllers helps to prevent the batteries from overcharging. Their efficiency varies based on the battery charge which helps to increase the efficiency and lifespan of the batteries. Two factors are incorporated in their design rating, which are:

1) The type of charge controller – Available in series and parallel
2) The I-V characteristics of the solar panel:

The fill factor (F_f) is a value that shows the quality of a solar module. It indicates how close the performance of a module is to the ideal situation. When F_F is close to unity (1), it means it is a good module. The fill factor is given as:

$$F_F = \frac{P_{MPP}}{V_{oc} \times I_{Sc}} \qquad (3.22)$$

Where I_{Sc} is the short circuit current, V_{oc} is the open circuit voltage

Substituting equation (3.37) into (3.38)

$$F_f = \frac{I_{mpp} \times V_{mpp}}{V_{oc} \times I_{Sc}} \qquad (3.23)$$

The quality of a solar panel is defined by its Efficiency, it shows the quality of a solar module and it is expressed as:

$$\eta = \frac{Total\ unit\ area\ radiation - Non\ usable\ radiation}{Total\ unit\ area\ radiation} \qquad (3.24)$$

$$P_e = RP_T \qquad (3.25)$$

$$P_r = CP_e \qquad (3.26)$$

Where P_r is the total radiation power, R is a constant that depends on reflection, recombination, resistance etc., P_e is the electrical power, C is a constant that depends on high temperature, operation out of Mpp, dust etc. Due to the aforementioned losses, it is necessary to compensate while deigning the PV array using the formula stated below. The photovoltaic array directly depend on the battery discharge therefore

$$C_D = D_B + 0.2D_b = 1.2D_B \quad (3.27)$$

The 20% increment will account for all the possible losses in the PV array. C_D is the PV charge demand. Also,

$$I_P = \frac{C_D}{h_s} \quad (3.28)$$

Where

h_s is the peak sun hour

I_P is the required PV current.

The peak sun hour is chosen from the established metrological data which depend on the location of the standalone system. The panel array peak voltage is obtained from:

$$V_P = V_{up} \times \frac{V_s}{V_{uu}} \quad (3.29)$$

Where

V_s is the system voltage,

V_{up} is unit panel peak voltage,

V_{uu} is unit panel voltage,

V_P is panel array peak voltage.

The panel array peak power is obtained using the formular:

$$P_{pp} = V_P \times I_p \quad (3.30)$$

Where P_{pp} is panel array peak power.

To calculated the number of PV panels to be used, the formula used is:

$$N_{pr} = \frac{P_{pp}}{P_u} \quad (3.31)$$

Where P_u is peak power of panel and N_{pr} is the number of PV panels needed

The total number of panels to be connected in series and parallel is obtained as follows:

$$N_{ps} = \frac{V_s}{V_{uu}} \quad (3.32)$$

$$N_{pp} = \frac{N_{pv}}{N_{ps}} \quad (3.33)$$

Where N_{ps} is the number of panels in series and N_{pp} is the number of panels in parallel. To obtain the total voltage and current of the panels connected in series and parallel, the following equations are used.

$$V_{PT} = V_{P1} + V_{P2} + V_{P3} - - - + V_{Pn} \quad (3.34)$$

Where V_{PT} is total voltage of the panels in series, and V_{Pn} is the voltage of the $\boldsymbol{n_{th}}$ panel. The current for panels in series connection is given as:

$$I_{PT} = I_{pi} \quad (3.35)$$

Where I_{PT} is the total current, and I_{pi} is the current of the $\boldsymbol{i_{th}}$ panel.

For panels in parallel connection,

$$I_{PT} = I_{P1} + I_{P2} + I_{P3} - - - + I_{PT} \quad (3.36)$$

Where I_{PT} is the total current of the panels in parallel. The total voltage of the panels in parallel is given as:

$$V_{PT} = V_{Pj} \quad (3.37)$$

RESULTS AND ANALYSIS

COST ANALYSIS

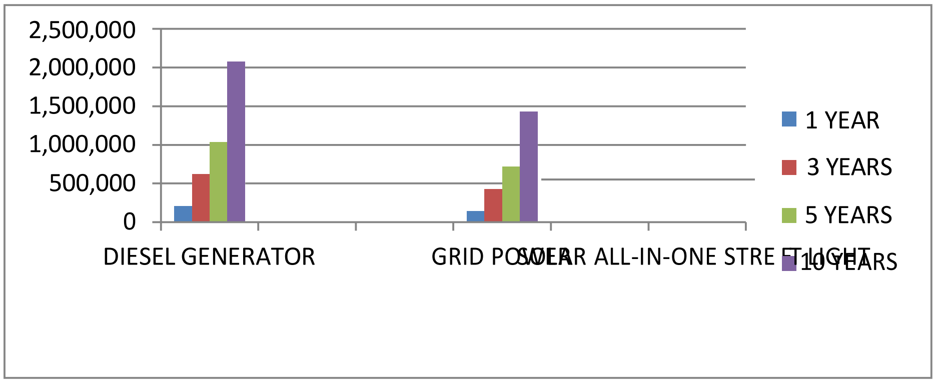
The cost analysis done is based on comparing the cost of using liquid fuel, energy from Grid and self generated power from solar mini-grid system. The outcome is presented in three scenarios,

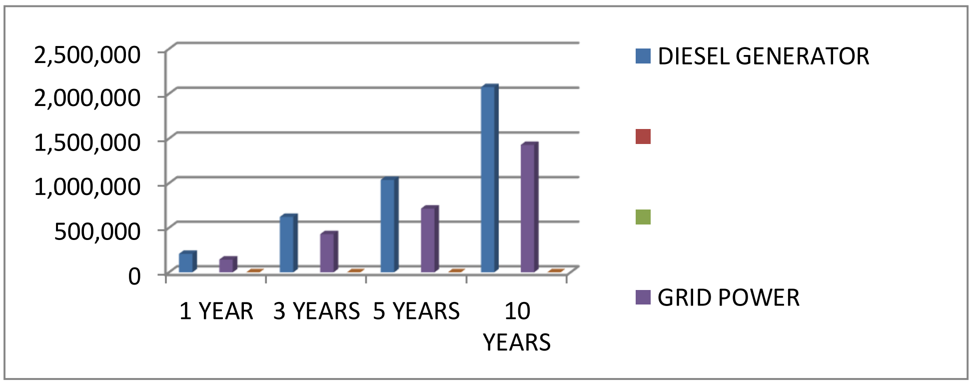
Immediate : 0-1 year

Short Term : 3 years

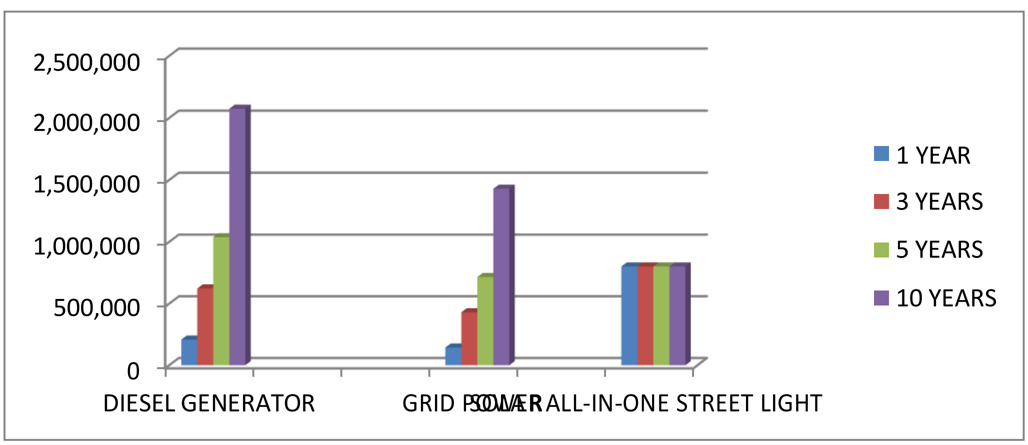
Long Term : 5- 10 years

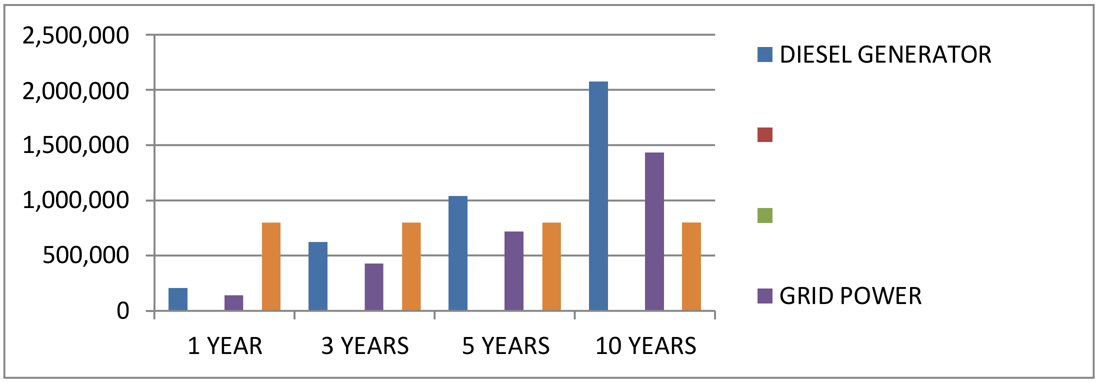
UNIT INSTALLATION COST FOR DIESEL GENERATOR AND SOLAR ALL IN

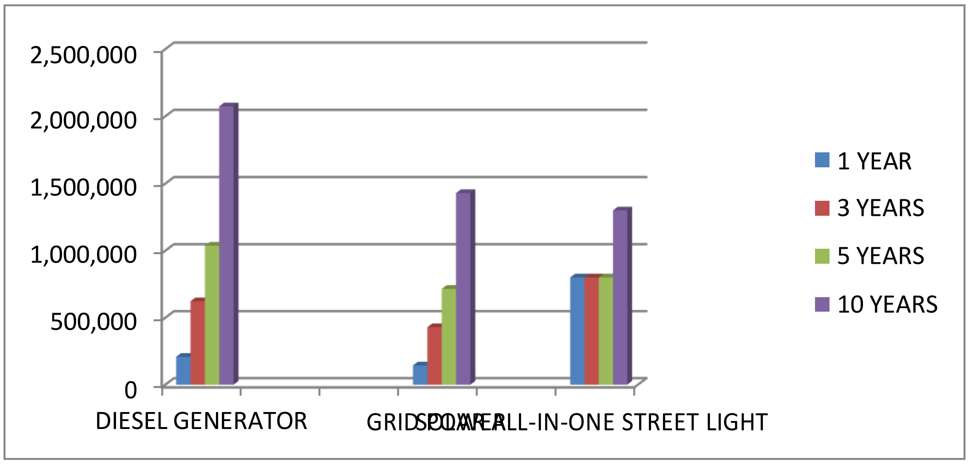


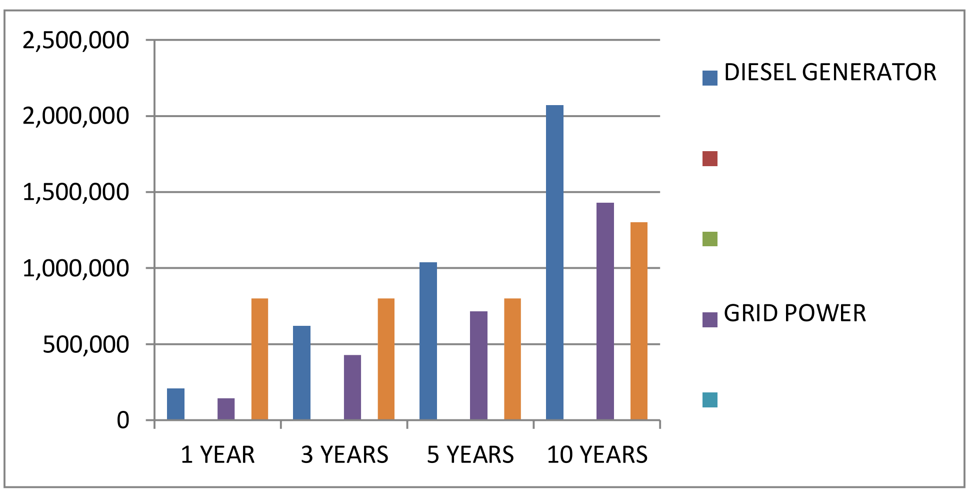


RUNNING COST VS INSTALLATION COST OF ONE SOLAR ALL-IN-ONE STREET LIGHT




2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1 YEAR
3 YEARS
5 YEARS
10 YEARS
DIESEL GENERATOR
GRID POWER


2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
DIESEL GENERATOR
GRID POWER
SOLAR ALL-IN-ONE STREET LIGHT
1 YEAR
3 YEARS
5 YEARS
10 YEARS


2,500,000
2,000,000
1,500,000
1,000,000
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0
1 YEAR
3 YEARS
5 YEARS
10 YEARS
DIESEL GENERATOR
GRID POWER

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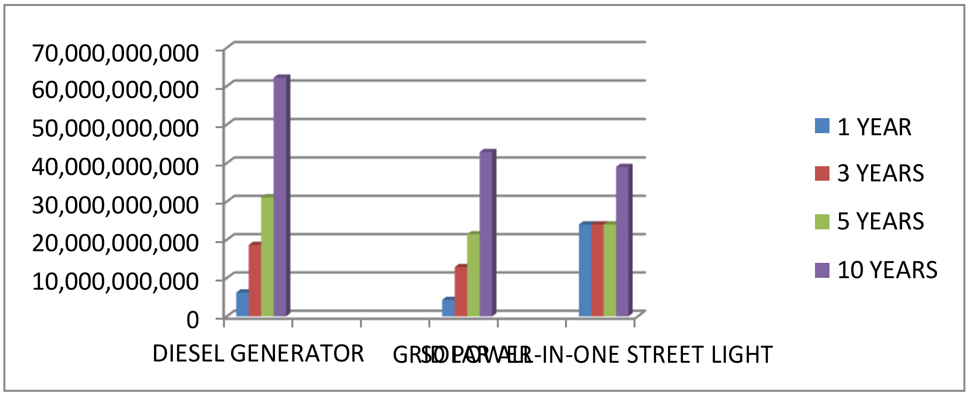
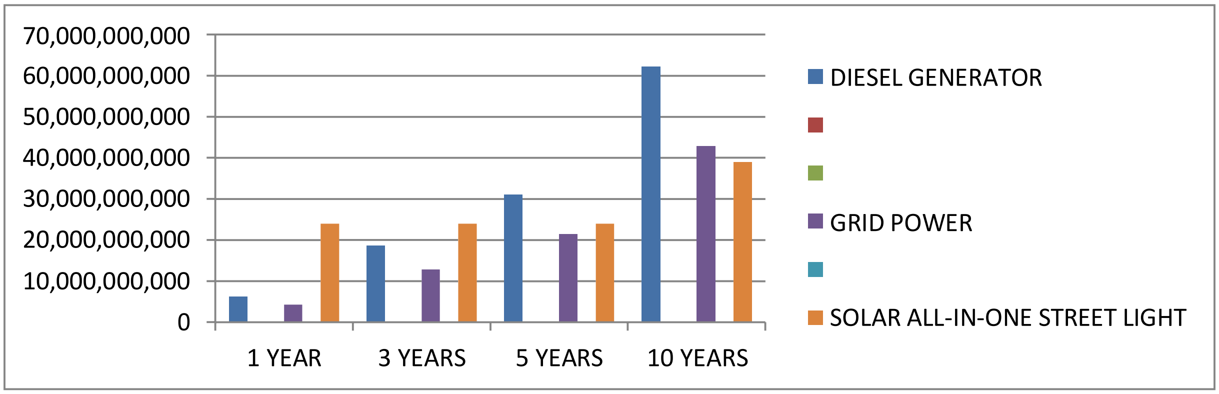
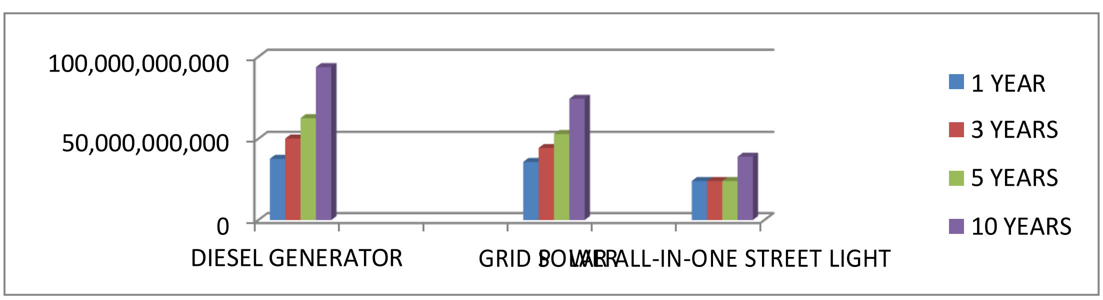
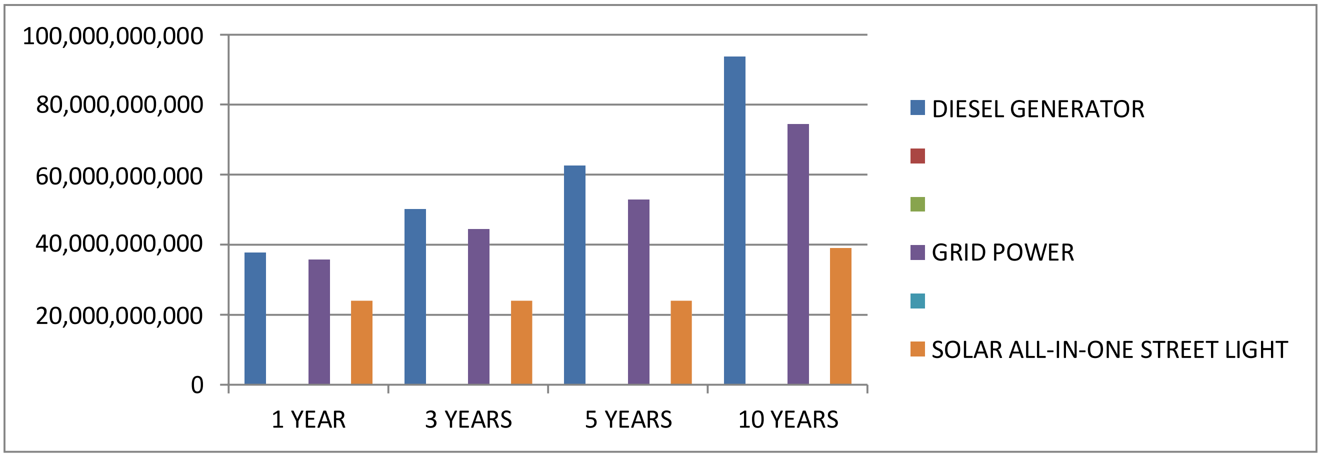


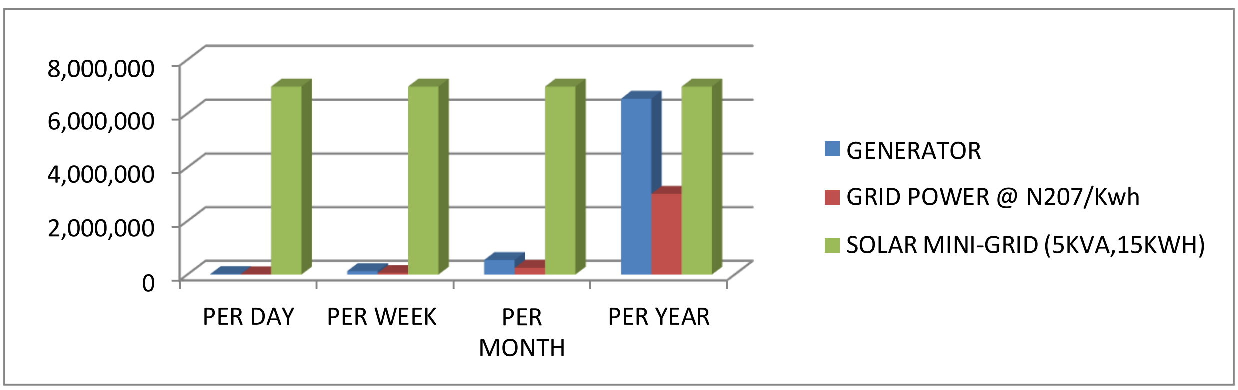


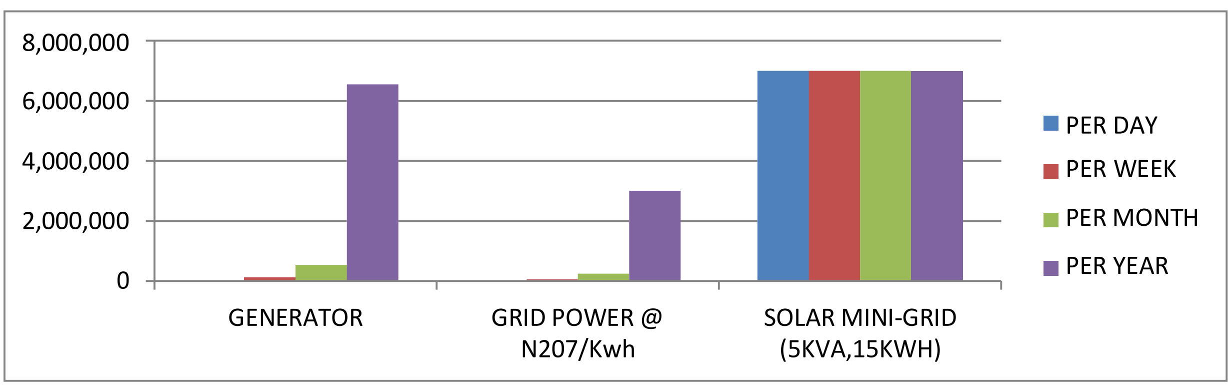
INSTALLATION COST WITH RUNNING COST FOR 30,000 STREET LIGHT THROUGH 10 YEAR PERIOD



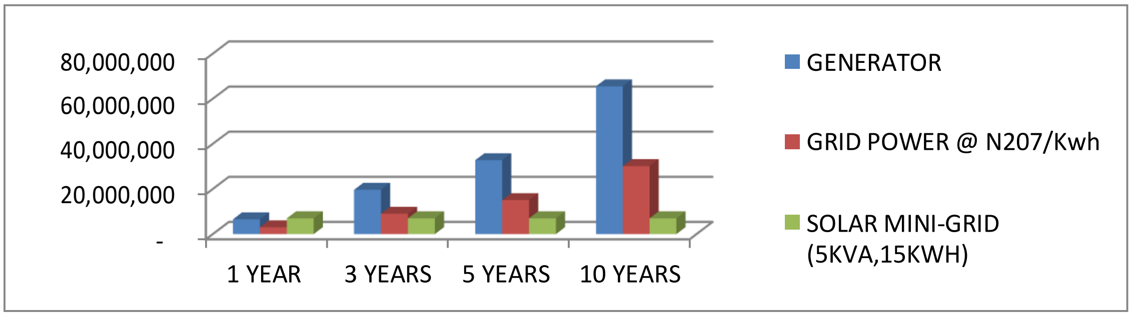


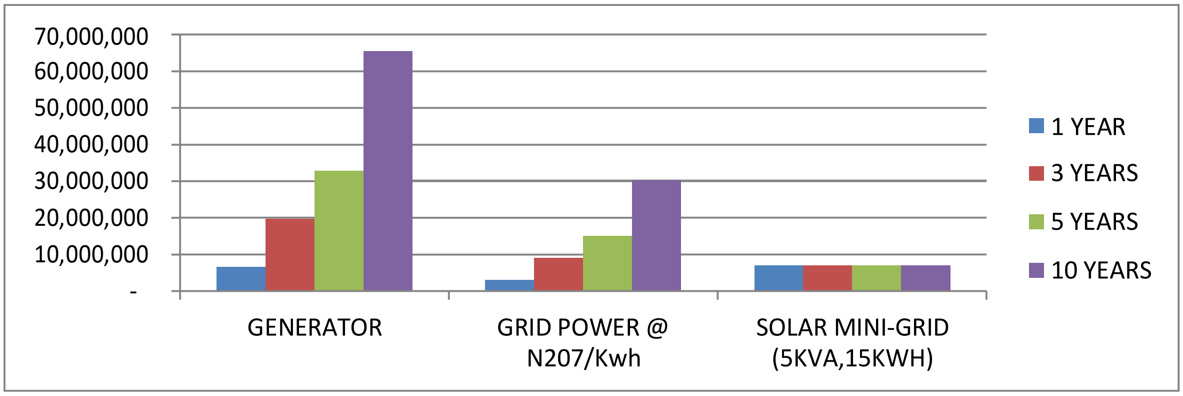
RUNNING COST AGAINST INSTALLATION COST OF SOLAR MINI GRID SYSTEM THROUGH 1 YEAR PERIOD





RUNNING COST AGAINST INSTALLATION COST OF SOLAR MINI GRID SYSTEM THROUGH 10 YEAR PERIOD





5.1 Conclusion

Several approaches (e.g., exact, stochastic, and predictive) have been proposed for energy management. Even though different techniques have been applied to solve this problem, nevertheless there seems to be scarcity in deep exploration of local and indigenous solar power generation and weather data unique to the African context while dealing with this issue. In this thesis, an optimal configuration algorithm for sharing energy resources in a microgrid using data collected from a microgrid located in Nigeria has been developed.

In comparison to an already existing design in the test bed used in this work, the algorithm developed in this work yielded a better result. Four different scenarios were considered; simulation results showed that for scenario 1, the system incurred no cost of operation, since all the energy used were effectively sourced from the solar panel. For scenario two, results showed that using a yearly projection, the system saved a total sum of N1, 232,400 when compared to the existing design that run on a daily cost of N27,600. For scenario 3, using a yearly projection, the system saved a total sum of N1, 029,600 when compared to the existing design that ran on an operating cost of N9,900. The system was also analyzed to determine the degree of deviation of the supplied power from the load demand. Simulation results showed that as at 100 seconds, the error percentage of the existing design spiked to 7% while that of the developed algorithm was tending to zero. The system response when switching between different scenarios was also examined, and it was discovered that the developed algorithm responded to the switch in just 80mS. The state of the batteries used for the design was also examined, and it was discovered that the battery SoC utilizing the developed algorithm never went below the acceptable 30% threshold as against the existing design that violated this rule during simulation.

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