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Life Cycle Cost Evaluation of Hybrid Power System at Peak Load Scenario, Using War Strategy Optimization

[1]Dawodu M.O., [2]Adepoju G.A., [1]Ogunfowora A.R., [1]Sadiq A.I., [1]Balogun M.O.

1.Lagos State University of Science and Technology, Ikorodu. 2. Ladoke Akintola University of Technology, Ogbomoso.

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ABSTRACTS

This paper presents economic evaluation of hybrid power system (HPS) according to daily electrical load demand and the solar resource potential of two remotes communities (Alapa and Okolo) in Ibarapa local government in Oyo state, Nigeria. It employs an optimal sizing algorithm, War Strategy Optimization (WSO), in MATLAB 2021a environment and Hybrid Optimization Model for Energy Renewable (HOMER) as bench mark software for economic evaluation at peak load condition. Finding shows the estimated peak load consumption, daily load consumption and average annual solar irradiation of the village were determined to be 31kW, 311kWh/day and 14.23 kWh/m^2 respectively.Also, the results of the Alapa and Okolo at peak load demand for WSO-HPS using LCC and LLP were ($195,958.99; 0.0000) and ($211,753.16 ;0.0000), respectively, while that of the HOMER-HPS were ($197,714.84;0.0009) and ($233,649.48; 0.0005). This showed the WSO-HPS based to have reduced LCC and zero LLP that indicated that the load was fully met. This research has developed a WSO based HPS, for economic evaluation of HPS at zero loss of load probability. The WSO is applicable in design of off-grid hybrid power system.

Keywords: Life Cycle Cost, Hybrid Optimization for Model Electric Renewable, Loss of Load Probability, War Strategy Optimization

I. INTRODUCTION

One feature of HOMER software is the ability to compute system's (Life Cycle Cost) LCC. Three cost entities—Capital Cost (CC), Replacement Cost (RC), and Operation and Management (OM) Cost—are used in the system LCC calculation. When making investing decisions, they are aware of them. OM and RC are for future consideration, whereas CC is known at the time of investment. PV array cost,balance of system (BOS) expenses, chargers, inverters, storage batteries, controllers, and PV module support structure are all included in CC.Both fixed and variable costs are included in OM. Variable expenses, such as wear, fuel, and tear, are tied to the system output, but fixed costs, such as site insurance, insurance, and routine safety, are unrelated.(Raghuwanshi and Arya 2020; Agrawalet al., 2011).

Many researchers have utilized prevailing software modellike "Hybrid Optimization with Genetic Algorithm" (HOGA) and "Hybrid Optimization Model for Electric Renewable" (HOMER)to design HPS. In various recent works, consideration for evaluation of advantages, simulation scopes, software limitations, and types of system configurations were not done. The problem of many optimization techniques is the fact that they failed to take into account, the optimization constraints such as reliability constraints, land size constraints and power balanced constraints among others in the design of HPS (Jamil et al., 2012). In this work, considerable effort has been focused on the evaluation of HPS using War Strategy Optimization (WSO) algorithm and Homer Optimization for Multiple Electric Renewable based on LCC at peak load condition.

II. LITERATURE REVIEW

For a solar/diesel/battery HPS, Aziz et al. (2019) examined the likelihood of a combined dispatch (CD) control technique by combining the load following (LF) approach with cycle charging

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(CC).HOMER software being an optimization study tool, was used to examine the techno-economic and eco-friendly performance of the suggested system design under LF, CC, and CD strategies.According to simulation data,CD method outperforms the other two strategies in terms of environmental performance and has lower net current cost values. Nevertheless, no intelligent systems optimization was done on the system design.

Thirunarukkarasu and Sawle (2020) observed the results of simulation and optimization of an HPS; solar/diesel/battery that generates electricity using HOMER. The optimal scenario analysis solution at NPC $16936, COE 0.319$ / kWh, and a cost of work of $872.61 was less expensive than the basic case structure with COE $0.672. This configuration included a 3.45 kW photovoltaic system, a 2.30 kW diesel generator, 10 kW batteries, and a 1.01 kW power converter with load following technology.

Using HOMER, Oladigbolu et al. (2020) considered the likelihood of implementing a hybrid solar/hydro/diesel/battery system to supply off-grid electricity to a typical rural hamlet in Nigeria. Throughout the simulation process; sensitivity analysis and four distinct system configurations were examined in order to determine the most suitable and cost-effective choice. According to the simulation results, the hybrid solar/hydro/diesel/battery systemwas the best option with the least net present cost and superior technical performance, making it the perfect system for clean energy development and rural electrification.

Using PVsyst, Al-Qahdan et al. (2021) demonstrated the best possible design for a solar/battery system for a university building. 320 numbers of 296 Ah batteries and 340 pieces of solar panels with a rated output of 370 Wp were needed to meet the power needs.Technically, the system could produce 168,989 kWh of energy for the load because of its high solar percentage, performance ratio, and specific yield output. Economically, the system could save RM 61,801 year by not using the grid for energy, and sustainably, it could avoid 117 tons of CO2 annually by using energy from the sun.

For a rural hamlet in Kajola, Nigeria, Osalade et al. (2022) used HOMER to perform anOff-grid solar photovoltaic (PV)/biomass/diesel/battery hybrid system viability and techno-economic analysis. It was determined that six HPS were technically viable possibilities for Kajola village's electricity generation. NPC, COE, emissions, RF, capacity constraints, and unmet load are some of their distinctive features. The best configuration, according to the results, was the PV-BG-BB hybrid system. Due to the hybrid power system's complete reliance on alternative energy, this design is a good choice for deployment. For Kajola village, the investment is rewarding.

With a minimal COE of $0.178 kWh and a minimum NPC of $232,863, the system is viable. The scheme would be a robust venture opportunity, according to the economic criterion of a high percentage return on investment (ROI) and a simple payback period. The ROI is 328.6 percent, which is phenomenally large and encourages venture even though the initial cost is considerable. When investors start to see a return on their venture, less than a year is also the breakeven point.

Ancient war plans served as the inspiration for Ayyarao et al.(2022) novel stochastic optimization method, "War Strategy Optimization." In order to update the soldier's current position, this algorithm has developed two war strategies. An adaptive weight mechanism has been added to the approach, which switches between solutions (soldiers) and is updated based on the soldier's rank during the updating phase. The exploration and exploitation phases are fairly balanced by the WSO algorithm. Future research can apply the proposed war strategy optimization technique to multi-objective functions and expand it to include a multi-objective feature.

A fuzzy logic Energy Management System (EMS) designed for a Hybrid Energy System (HES) to regulate the various energy sources and operating modes was proposed by Olaleye et al. (2023). The outcomes demonstrated the effectiveness and efficiency of the approach taken to control the demand for loads and energy sources. By using fuzzy logic approaches, the controller's performance can be easily changed. In complex, nonlinear, or undefinable systems for which there is solid practical experience, it works better than other controllers. Higher performance, fast operating mode switching across a variety of energy sources, and the capacity to react to various load demand types at any given time are all features of the fuzzy logic energy management techniques employed here (i.e. the output variation does not depend on time variation). Additionally, the technique guards against both overcharging and undercharging of the energy storage unit.

When scaled appropriately; it can meet load demand and sell electricity to the grid (i.e.,

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selling excess power first), which lowers fuel consumption and lessens the requirement for frequent backup generator use. Adding a standby generator improves system resilience because renewable energy sources are erratic and sporadic. Lastly, the proposed HES and EMS design is suitable for small-scale commercial and residential applications worldwide.

III. METHODOLOGY

3.1 Feasibility study of Ibarapa community for solar energy potential

This research is based on the evaluation of the HPS at peak load based on LCC. Feasibility study of the study area was carried out, using a well- structured questionnaire to deduce the load demand and solar energy resources were sourced from the International Institute of Tropic Agriculture (IITA). Mathematical modelling of HPS processes and output power were carried out. The LCC-based problem goal was developed, and then WSO optimization was performed using MATLAB 2021a and HOMER as benchmark software in a peak load scenario.

3.2 Mathematical modeling of hybrid power system

The PV array, diesel generator, battery bank, charge controller, DC/AC inverter, and loads are the fundamental parts ofHPS. The system's output and operations were modeled mathematically in order to optimize the system.

3.2.1 Solar PV modeling

The solar PV was modeled, using equations (3.1) to (3.10), based on single diode model and the maximum output power calculated by maximizing equations (3.11) to (3.12), according to Waker (2020) is given as:

$$I(T,G,V) = I_{ph} - I_o\left(e^{(V+IR_s)/nV_{th}} - 1\right) - (V + I.R_s)/R_{sh} = I_{ph} - I_D - I_{sh} \quad 3.1$$

Where variables are calculated as:

$$I_{ph} = I_{ph0}.G/G_{nom} \quad 3.2$$

$$I_{ph}(T) = I_{ph} + K_0(T - T_{meas}) \quad 3.3$$

$$K_0 = [I_{ph}(T_2) - I_{ph}(T_1)]/[T_2 - T] \quad 3.4$$

$$I_0 = I_{SC(T_2)}.(T/T_1)^{3/n}.e^{-\frac{E_g}{V_s}\cdot\left(\frac{1}{T}-\frac{1}{T_1}\right)} \quad 3.5$$

$$I_0(T_1) = I_{SC(T_1)}/\left(e^{-\frac{qV_{OC}(T_1)}{nkT_1}} - 1\right) \quad 3.6$$

$$R_s(T) = -dV/dI_{Voc} - 1/\left(I_0(T_1).q/nkT_1.e^{-\frac{qV_{OC}(t)}{nkT_1}}\right) \quad 3.7$$

$$R_{sh} = V_{OC}/[I_{ph} - I_0\left(e^{-\frac{qV_{OC}}{nkT_{meas}}} - 1\right)] \quad 3.8$$

$$R_{sh}(T) = R_{sh}.(T/T_{meas})^{\alpha} \quad 3.9$$

Photogenerated current at the nominal radiation, I_{ph0}. $I_D$is the diode dark current. Shunt current, I_{sh}. G is solar radiation in W/m^2. Radiation of the PV module, G_{nom}. n is the ideality factor. Electron charge, e. Boltzmann's constant, k. $E_g$is the energy gap for the semiconductor. Short-circuit current temperature coefficient, K_0. $N_s$is the number of cells connected in the series, and $N_p$is the number of cells connected in parallel, which are sourced from the data provided by the manufacturer; Vth is the thermal voltage that is calculated using the equation below:

$$V_{th} = nkT_c/e \quad 3.10$$

The PV module's output is influenced by many factors; the highest output power is obtained by optimizing equation (3.12). Equation (3.11) is used to determine the PV array's output. (Yusri et al., 2021).

$$P_{PV\_Array}(t) = N_{PV}.P_{PV\_max} \quad 3.11$$

The number of PV modules in the array is known as the N_{PV}. The load is powered by the PV array's output, and the battery is charged or discharged by the deficit. The maximum power required for the load is;

$$P_{Load}(t) = \frac{P_L(t)}{\eta_{inv}} \quad 3.12$$

inverter efficiency is η_{inv} and the load power, is P_L.

3.2.2 Battery storage system modeling

The power differential between solar panel andload is used for modelling the battery power, using equation (3.13-3.14); according to Dufo-Lopez etal. (2014):

$$P_{Battery}(t) = P_{PV}(t) - P_{Load}(t) \quad 3.13$$

The battery is charged if power is positive and discharged, when the power is negative. Battery capacity is thus:

$$C_R(t) = C_R(t-1) + \frac{P_{Battery}(t).\Delta t.\eta_{battery}}{V_{battery}}, for\ 1 < t < 24 \quad 3.14$$

the battery efficiency, typically 80%, of day i is represented by $\eta_{battery}$, and the time sampling, Δt, is one hour. The obtainable battery capacities (Ah) at hour t and t-1 are $C_R(t)$ and $C_R(t-1)$, respectively. $V_{battery}$ stands for battery voltage.

3.2.3 Charge controller process modeling

The optimization constraints, ensures the battery is not discharged or over charged below the minimum state of charge, using equation (3.15-3.16) according to Dufo-Lopez etal. (2014), is given as:

$$C_{R\_min} < C_R(t) < C_{R\_max} \quad 3.15$$

The lowest and highest capacities of the battery bank are $C_{R\_}$ min, and $C_{R\_}$ max, with lowest capacity expressed as:

$$C_{R\_max} = DOD.\ C_{R\_N} \quad 3.16$$

the depth of the discharge, DOD and the nominal capacity, C_{R_N}

3.2.4 The Inverter process modeling

Equations (3.17-3.19) shows the rectifier model according to Yazdanpanah, 2014, is given as in;

$$E_{REC\_OUT}(t) = E_{REC\_IN}(t) \times \eta_{REC} \quad 3.17$$

$$E_{REC\_IN}(t) = E_{SUR\_AC}(t) \quad 3.18$$

Hence, at a time t,

$$E_{SUR\_AC}(t) = E_{DEG}(t) - P_{LOAD}(t) \quad 3.19$$

Where:

$E_{REC\_OUT}(t)$ rectifier hourly energy production in kWh

$E_{REC\_IN}(t)$ rectifier hourly energy input in kWh

η_{REC} efficiency of the rectifier

$E_{SUR\_AC}(t)$ diesel generator's hourly energy generated byin kWh

$E_{DEG}(t)$ quantity in kWh of excess AC energy sources

3.2.5 Diesel generator modeling

Equation (3.20-3.21) showsthe energy generated by the DG with conversion efficiencyη_{DG} from fuel to electricity, according to Hocaoglu (2012), is given as:

$$E_{DG} = \eta_{DG} E_{ff} \quad 3.20$$

The total energy content, E_{ff} of oil is approximately proportional to the volume of oil.

In time t, the energy generated by the DG is given in (2.18) (Bhargava et al.,2014);

$$P_{GDG} = P_{QDG}(t) \times N_{DG} \eta_G \quad 3.21$$

Where;

P_{GDG} the DG system power output from,

P_{QDG} the nominal power in kW of the DG

N_{DG} the DG systemtotal number

η_G DG efficiency

The rating and sizing of the generator was determined by the load demand. The DG was rated and sized to provide load with needed power at all cases of operational dispatch strategy.

3.3 Problem formulation for the HPS

In this study, the sizing of the individual components making up the HPS was treated as an optimization problem and formulated as anoptimization issue with only one objective,to ascertain the optimum configuration of the HPS model that guarantees a reliable and continuous supply of electrical energy at the least cost.

The Loss of Load Probability (LLP) and total system cost are utilized to model the issue. Therefore, the Life Cycle Cost (LCC) is the objective function that needs to be reduced. Number of photovoltaic (PV) modules, the slope angle of the PV modules, the battery capacity, the starting and stopping positions of the diesel generator (DG), and the converter capacity are the control variables. In HPS design and problems, the control parameter values are adjusted for high reliability and at the lowest life cycle cost.

The life cycle analysis was conducted based on the component of the system with the longest lifespan. While the storage batteries can last up to 10 years, the PV modules used have an ideal life cycle of about 25 years. The batteries must be changed every ten years due to their 25-year maximum life cycle. Two crucial factors were taken into account for upcoming estimates: the rate of inflation and the rate of discount. The discount rate (d) indicates the decline in component costs with future mass production, but the inflation rate (i) shows the pattern of cost increases over the entire system life. A 10% inflation rate and 8% discount have been chosen for this study.

Three cost entities—Capital Cost (CC), Replacement Cost (RC), and Operation and Management (OM) Cost—are used in the system LCC calculation. When making investing decisions, they are aware of them. OM and RC are for future consideration, whereas CC is known at the time of investment. The cost of the PV array, balance of system (BOS) expenses, chargers, inverters, storage batteries, controllers, and PV module support structure are all included in CC.Both fixed and variable costs are included in OM. Variable expenses, such as wear, fuel, and tear, are tied to the system output, but fixed costs, such as site insurance, insurance, and routine safety, are unrelated. (Agrawal, 2011; Raghuwanshi and Arya, 2020).

Time value is taken into account because cost calculation is dependent on system lifespan. Two factors affect the value of money over time:

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the discount rate (d) and the rate of inflation (i). Inflation occurs when the value of money gradually decreases. If the product costs Cp, then Cp(1+i) will be Cp a year later, and so on. Based on the inflation rate, equation (3.22) provides the future cost of n year C (n) (Kolhe, Kolhe, and Joshi 2002).

$C(n) = C_p(1+i)^n$ 3.22

The interest rate is the rise in the value of money relative to its present value, whereas the discount rate is the increase in the value of money related to its future value, as shown in equation (3.23).

$$\text{Discount rate}(d) = \frac{future\ \ value - present\ \ value}{future\ \ value} \quad 3.23$$

Equation (3.24) shows the increase in the value of money in n years, M(n), as a result of the discount rate, d (Kolhe, Kolhe, and Joshi, 2002).

$M(n) = M_o(1+d)^n$ 3.24

where Mo is the monetary value. The value of the money increases when the discount rate exceeds the rate of inflation.

The amount of money that must be invested now, less inflation and discount rates, in order to purchase the thing in n years is known as present worth (pw). Because of rising inflation and a rising discount rate (which is supposed to be higher than the inflation rate), the cost of a product will not be the same in its future RC.

The PW factor for future one-time investment is given by equation (3.25), which is the ratio of the future value of the product to its future cost (Kolhe, Kolhe, and Joshi 2002; Choi et al. 2018).

$$p_f = \frac{\text{Future Cost}}{\text{Future Value}} = \frac{(1+i)^n}{(1+d)^n} = (\quad 3.25$$

Equation (3.26) provides the present value of the one-time investment one year later, followed by the product's present cost.

$$pw = C_o p_f = C_o\left(\frac{1+i}{1+d}\right)^n \quad 3.26$$

In LCC analysis, fuel and maintenance expenditure costs are necessary. Equation (3.26) provides the PW of future investment when recurrent investment is anticipated once a year.

According to Choi et al. (2018), the present value of recurrent investment for the system lifespan is therefore provided by equation (3.27) when the investment is made at the start of the year.

$$pw_{re\_beg} = C_o + C_o\left(\frac{(1+i)}{(1+d)}\right)^1 + C_o\left(\frac{(1+i)}{(1+d)}\right)^2 + \ldots - \quad 3.27$$

Additionally, equation (3.28) provides the PW of recurring investment throughout the system lifespan when the investment is completed at the end of the year. (Choi et ai., 2018)

$$pw_{re\_beg} = C_o\left(\frac{(1+i)}{(1+d)}\right)^1 + C_o\left(\frac{(1+i)}{(1+d)}\right)^2 + \ldots + C \quad 3.28$$

According to Raghuwanshi and Arya (2020), the LCC of the energy system is the sum of the current values of all product costs over the course of the product's lifetime.

LCC = CC + OM + RC + FC 3.29

where RC is the present value of the replacement costs, FC is the fuel cost, OM is the present value of all future operations and maintenance, and CC is the capital costs.

The developed HPS's optimal configuration was found to keep the Loss of Load Probability (LLP) within a certain range. It was evident from the work of Jali et al. (2015) that an LLP of one (1) indicates that the load is never met, whereas an LLP of zero (0) means that the load was met in full. In order to minimize the cost objective, the reliability objectivealso known as the LLPwas deemed to be a significant restriction. Therefore, the following design restrictions were applied to the objective function that needed to be minimized.

3.4 Design constraints for the HPS

(1) The Power Balance Relation: First, as stated in Equation 3.30, total power demand, P_D, must be greater than or equal to the total power supplied by the PV system at any given moment, t.

$P_{pv}(t) + P_{Batt}(t) = P_D(t)$ 3.30

(2) Land Size Based Constraints: The available PV array area (Apv) determines the PV system's output power. To regulate the PV system's output, Apv was chosen as a design variable and adjusted throughout the optimization process. Equation 3.31 provides the Apv's upper and lower bounds.

$A_{pv.\ min} \leq Apv \leq A_{pv.\ max}$ 3.31

(3) Limitations on Battery Capacity: When charging and discharging the proposed battery system, some limitations were considered, such as the batteries' State of Charge (SOC) (P Batt(soc)); these should not surpass the storage batteries' capacity but rather the lowest allowable storage level (P Batt(min)). Furthermore, the maximum permitted storage capacity (P Batt(max)) shall not

be exceeded by P Batt(cap). The equations (3.32-3.34) formulate this limitation.

$P_{Batt(min)} \leq P_{Batt(soc)} \leq P_{Batt(max)}$ 3.32

$0 \leq P_{Batt(cap)} \leq P_{Batt(cap)(max)}$ 3.33

$P_{Batt}(t) \leq P_{Batt(max)}$ 3.34

(4) The reliability Objective Constraint: It was thought that the reliability objective was an inequality constraint that needed to be met. The expression for it is equation (3.35).

$$LLP = \frac{\sum_{i=1}^{n} hours\,(I_{sup\;ply} < I_{demand}\;\;(t)}{n} \quad 3.35$$

(5) Non-Negativity Constraint: Equations (3.36) and (3.37) guarantee that the choice variables are non-negative as electrical power can only travel in one direction.

$1 \leq N_{pv} \leq N_{pv,\,p\,max}$ 3.36

$1 \leq N_{Batt} \leq N_{Batt,\,p\,max}$ 3.37

Where PV panels no is $N_{pv}$and battery system no is N_{Batt}

(6) Constraints on individual capacity: The power supply and consumption of each generator must be less than or equal to the installed unit's capacity, as determined by Equation (3.38).

$P_j(t) \leq Cap_j$ 3.38

Where;

the unit capacity of each generating unit isCap_j

(7) Unit generator limit: The hourly production of each generating unit was therefore limited between the minimum and maximum generation Equation (3.39), to prevent collapse and damage to each generating unit.

$P_{j\,min} \leq P_j(t) \leq P_{j\,max}$ 3.39

3.5 Simulation of the hybrid power system using HOMER

The project lifetime, the hourly demand profile, the initial cost of each component (diesel generators, batteries, converters, and renewable energy generators), the price of diesel fuel, the annual real interest rate, and, and other inputs were used to model HPS using HOMER (Table 3). Software simulated 8760 hours in a year.

The following describes the procedures used to simulate the HPS system with HOMER:

Step 1: Systemdetails, the capital cost, fuel, load data, and resource data, replacement cost, operation and maintenance cost, were inputted.

Step 2: Using expression (3.11), photovoltaic (PV) system's power output for hour t was calculated; Recall;

$P_{RES}(t) = P_{pv}$ 3.40

Andload consumption/demand in an hourly time step was used to evaluate the intended load demand, PL(t).

Step3: A comparison was made between accessible battery State of Charge (SOC) and load demand, P L(t), at that hour andtotal generated power, PRES(t).

Step4: If [$P_{RES}(t) > P_L(t) / \eta_{inv}$] and [SOC(t-1) < SOC_{max}], then system supplied.

Equation (3.13) is used to supply power to load and chargebattery. The State of Charge (SOC) of battery was therefore updated.

Step5: If [$P_{RES}(t) > P_L(t) / \eta_{inv}$] and [SOC(t-1) ≥ SOC_{max}], the system stopped charging battery, satisfy load and dump excess power. Where $P_{Dump}(t) = P_{RES}(t) – P_L(t)/ \eta_{inv.}$

Step6: If $P_{RES}(t) = P_L(t) / \eta_{inv,}$ system supplied power to the load only.

Step7: If [$P_{RES}(t) < P_L(t) / \eta_{inv}$] and [$DOD_{(t-1)} < DOD_{max}$], then system supplied power to the load by discharging battery using Equation (3.13) to cover the deficit in load power.

Where [$P_{BESS} = P_L(t) / \eta_{inv} - P_{RES}(t)$].

Step 8: If [DOD(t) ≥ DOD_{max}], system stopped battery discharging. Set DOD(t) = $DOD_{max}$and calculate deficit in the load power.

Step 9: If [$P_{RES}(t) \leq P_L(t) / \eta_{inv}$] and [$DOD_{(t-1)} \geq DOD_{max}$], system stopped battery discharge and calculate power deficit using;[$P_{deficit}(t) = P_L(t) - P_{RES}(t).\ \eta_{inv}$].

Step 10:In order to supply load and charge batteries, Diesel Generator (DG) is then turned on.

3.6 Implementation of WSO for optimal sizing of HPS system

Optimal sizing of PV, DG and Battery using WSO algorithm was carried out in MATLAB environment (R2021a) to minimize the Life Cycle Cost (LCC) and improve Loss of Load Probability (LLP). The optimization was allowed to operate until the maximum number of iterations was attained.

The stepsinvolved in the optimization of the HPS using WSO are outlined below:

Step1: Load profile data, solar irradiance and the temperature of the proposed site, was inputted.

Step2: WSO setting parameters was initialized such as: army size, ranks of each soldier, dimension of the problem (R) and the maximum number of iterations.

Step3: The fitness of each soldier was calculated using Equation (3.29).

Step4: The king and chief commander were selected.

Step5: Exploitation: the position of each soldier was updated using:

$X_i(t+1) = X_i(t) + 2 \times \rho \times (C - K) + r \times (W_i \times K - X_i(t))$ 3.41

Step6: Exploration: the position of each soldier was updated using:

$X_i(t+1) = X_i(t) + 2 \times \rho \times (K - X_{rand}(t)) + r \times W_i \times (C - X_i(t))$3.42

Step7: The fitness of each soldier was estimated using equation (3.29). If the current fitness was better than the previous, the weight was updated using Equation (3.43), else update the king and chief position.

$W_i = W_i \times \left(1 - \frac{R_i}{Max\_iter}\right)^{\alpha}$ 3.43

Step8: The weak soldiers were identified and relocated using Equation (3.44) and (3.45):

$X_w(t+1) = Lb + rand \times (Ub - Lb)$ 3.44

$X_w(t+1) = -(1 - randn) \times (X_w(t) - medianX + K$ 3.45

Where Lb and Ub are the lower and upper boundary respectively

Step9: The stopping criterium was checked, if the number of iterations was less than the maximum number of iterations, then go to Step3, else go to Step10.

Step10: The optimum position was printed and the best fitness which was the optimum sizing of the component of theHPS system and the least value of the objective function considered respectively.

Step11: Stop

IV. RESULTS

4.1Feasibility study of Ibarapa community for solar potentialand daily load demand

The results of study conducted to evaluate the solar energy potential and daily load demand are both presented in Table 1 and Table 2 respectively. Table 3 is the simulation parameters and Figure 1; the daily load variations.

4.2 Optimal sizing result of the developed WSO HPS and HOMER HPS for peak loaddemand scenario.

The results of optimal sizing of the developed WSO HPS and HOMER HPS for peak load demand scenario are presented in Table 4 and Figure 2 represents the relationship based on LCC.

V. DISCUSSION.

Table 3 shows the adopted simulation parameters used in this paper, while Table 1 shows hourly solar irradiance data during the 12 months of the year as sourced from International Institute of Tropical Agriculture website(www.iita.ng). The data covered the two climatic seasons of the year: the dry season, which runs from November to March, and the rainy season, which runs from April to October. From Table 1, it could be deduced that the maximum solar radiation occurred in March while the minimum radiation was recorded in the month of August.

With an average annual value of 14.23kWh/m^2, six distinct months had values above the annual value and six below it. And based on the measured solar radiation potential of the studied area, as shown to vary between 10.7kWh/m^2 in August and 16.6 kWh/m^2 in March, hence the need for hybridization of PV and DG, to guarantee a more reliable supply all through the year. The DG is used to compensate for the loss of load during the time of low irradiation.

Table 1: Solar resources assessment for Ibarapa Community

Month	Maximum Possible Sunshine Hr (per day)	Actual Sunshine Hr (per day)	Solar Radiation kWh/m^2/day
January	11.62	6.70	13.3
February	11.76	6.99	15.2
March	11.96	6.26	16.6
April	12.17	6.66	16.3
May	12.34	6.73	16.1
June	12.43	5.74	14.8
July	12.39	3.57	11.9
August	12.23	3.73	10.7
September	12.03	5.90	12.8
October	11.82	5.85	14.2
November	11.65	7.08	15.1
December	11.57	7.15	13.7

Source:(www.iita.ng)

Table 2: Daily load demand evaluation

Hours	Alapa low (kW)	Alapa peak (kW)	Okolo low (kW)	Okolo peak (kW)
1	11.00	16.00	13.00	18.00
2	11.00	16.00	13.00	18.00
3	11.00	16.00	13.00	18.00
4	11.00	16.00	13.00	18.00
5	11.00	16.00	13.00	18.00
6	11.00	15.00	13.00	17.00
7	6.00	11.00	8.00	17.00
8	2.00	11.00	2.00	13.00
9	2.00	11.00	2.00	13.00
10	2.00	11.00	2.00	13.00
11	2.00	11.00	2.00	13.00
12	2.00	11.00	2.00	13.00
13	2.00	11.00	2.00	13.00
14	2.00	11.00	2.00	13.00
15	2.00	11.00	2.00	13.00
16	2.00	11.00	2.00	13.00
17	16.00	11.00	18.00	13.00
18	16.00	11.00	18.00	13.00
19	21.00	29.00	23.00	31.00
20	21.00	29.00	23.00	31.00
21	21.00	29.00	23.00	31.00
22	11.00	16.00	13.00	18.00
23	11.00	16.00	13.00	18.00
24	11.00	16.00	13.00	18.00
TOTAL	218.00	362.00	248.00	414.00

Table 3: Simulation Parameters

Parameter	Value
Number of search agent	40
Maximum number of iterations	50
Inflation rate	10%
Discount rate	8%
Project lifetime (n)	25 years
Capital cost of PV	2500 $/kW
Operation and maintenance cost of PV	10 $/kW
Life span of PV	25 years
Capital cost of Battery	550 $/kW
Operation and maintenance cost of PV	10 $/kW
Replacement cost of Battery	550 $/kW
Life span of Battery	10 years
Depth of Discharge (DoD) of the battery	80%
Minimum State of Charge (SOC) of the battery	20%
Capital cost of DG	500 $/kW
Operation and maintenance cost of DG	0.003*500 $/kW
Replacement cost of DG	550 $/kW
Life span of DG	17250 Hours
Fuel cost of DG	1.5 $/l

Source: (Gilman & Lilienthal, 2009)

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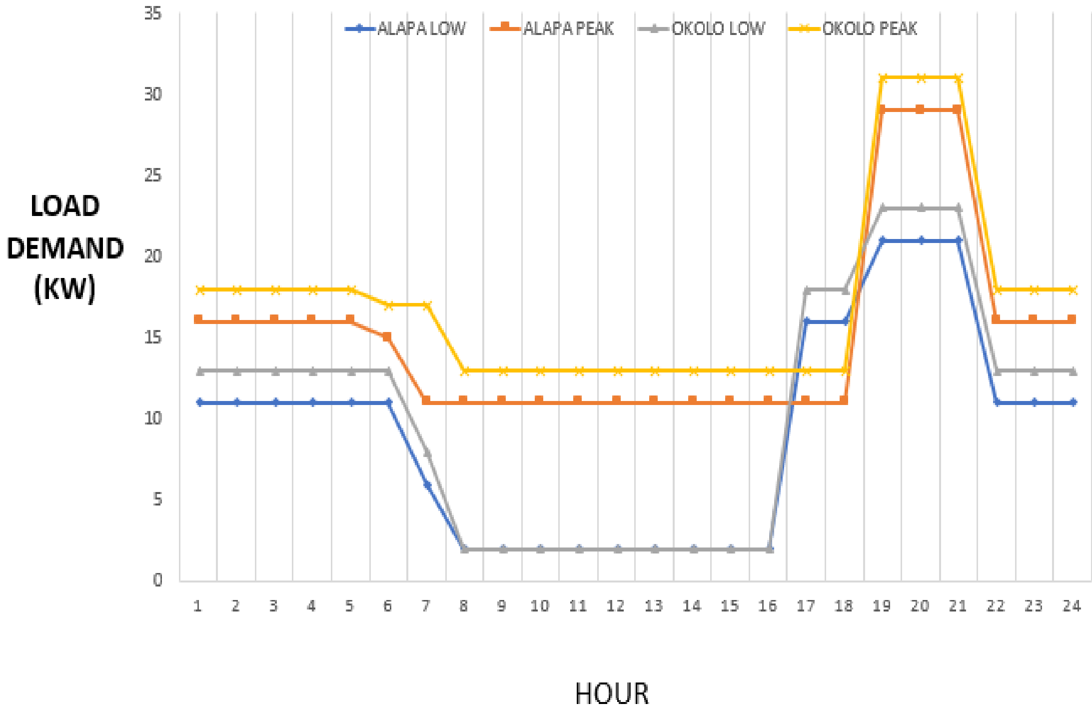

Figure 1: The Daily Load Demand for Alapa and Okolo Rural Community

Table 4: Results of PV/Diesel/Battery HPS at peak load scenarios

Description	PV/Diesel/Battery (WSO BASED)		PV/Diesel/Battery (HOMER BASED)	
	Alapa	Okolo	Alapa	Okolo
PV Panel(kW)	72	88	78	92
Battery (kW-hour)	48	68	52	72
DG (kW)	33	35	35	39
Hours of operation of DG:	109925	115125	125125	139925
Capital Cost ($)	22290.00	27490.00	139490.00	168420.00
Replacement Cost ($)	18261.20	21854.03	46257.16	50039.19
Operations and Maintenance Cost ($)	18436.33	19774.17	25802.76	30156.58
Fuel Cost ($)	140107.02	146704.13	150107.02	176704.13
Salvage Cost ($)	3135.57	4069.17	13835.12	14966.29
Life Cycle Cost (LLC) ($)	195958.99	211753.16	197714.84	233649.48
Loss of Load Probability (LLP)(%)	0.0000	0.0000	0.0009	0.0005

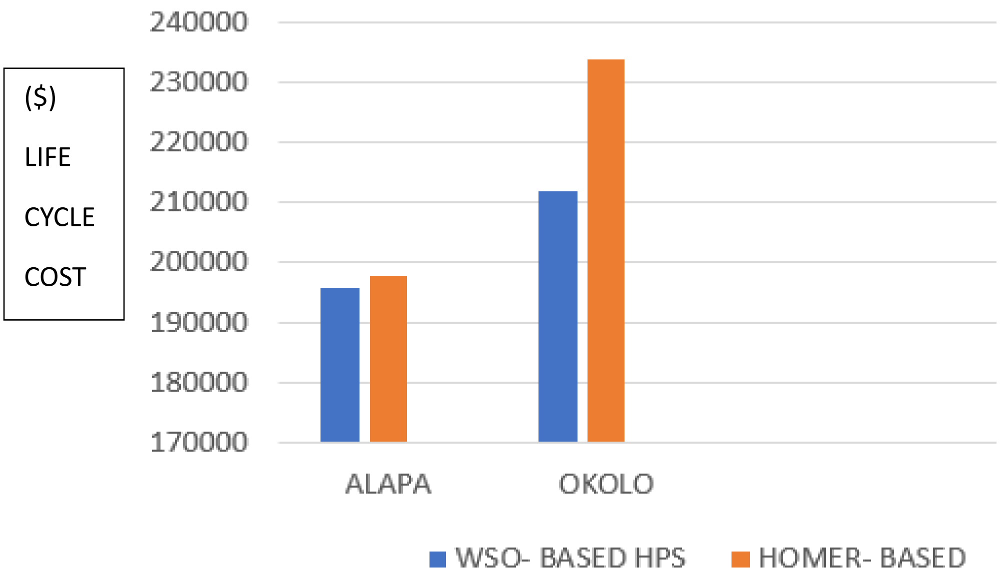

Figure 2: LCC Comparison for the cases considered for peak load demand.

Table 2 shows the hourly anticipated load demand for 60 households in Alapa and 100 households in Okolo, with the estimated peak load consumption and average daily load consumption being 31kW and 311kWh/day respectively. Figure 1 gives variation of load demand with time.

Table 2 shows that there are four different categories (farmer and non-farmer), representing low and peak load conditions in each of the village. Hence, from the two rural community, we could deduce that both had fairly stable load throughout the season. There was less power consumption between the hours of 7 am to 4 pm, since most villagers were assumed to be off to work. The peak hours were between 6 pm to 10 pm (evening time for the two categories). The load gradually dropped around 10 pm as many villagers were asleep.

Table 4shows results of the Alapa and Okolo (peak load demand) for WSO-HPS using LCC and LLP as ($195,958.99; 0.0000) and ($211,753.16 ;0.0000), respectively, while that of the HOMER-HPS as ($197,714.84;0.0009) and ($233,649.48; 0.0005). This showed the WSO-HPS based to have reduced LCC and zero LLP that indicated that the load was fully met. Figure 2 shows the relationship based on LCC at peak load demand for the two HPS.

VI. CONCLUSION

This study has investigated the techno-economic benefits of utilizing sustainable HPS system for electricity of Alapa and Okolo in Ibarapa rural community through extensive load audit and analysis. From findings, the estimated peak load consumption, daily load consumption and average annual solar irradiation of the village were determined to be 31kW, 311kWh/day and 14.23 kWh/m^2 respectively.

The results of the Alapa and Okolo (peak load demand) for WSO-HPS using LCC and LLP are ($195,958.99; 0.0000) and ($211,753.16 ;0.0000), respectively, while that of the HOMER-HPS are ($197,714.84;0.0009) and ($233,649.48; 0.0005). This showed the WSO-HPS based to have reduced LCC and zero LLP that indicated that the load was fully met

This research has developed a WSO based HPS which is capable of optimal sizing of hybrid power system with minimum life cycle cost and zero loss of load probability. The WSO is applicable in the design of off-grid hybrid power system.

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