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OPTIMAL SIZING OF HYBRID SOLAR-WIND POWER SYSTEM FOR APPLICATION IN HEIPANG COMMUNITY USING GENETIC ALGORITHM

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ABSTRACT

The design of a hybrid solar-wind power system is complex due to the non-linear correlation of the system parameters, which may lead to the over- or under-sizing, of the system. The objective of this study is to size the system to operate efficiently and affordably using MATLAB's genetic algorithm optimization technique. The objective functions for the optimization are loss of power supply probability, excess energy generated percentage, and the annualized cost of the system. The decision variables are the number of solar panels, wind turbine, and battery, wind turbine height, and solar panel angle of inclination, The results showed that the annualized cost, excess energy generated, and reliability of the system were reduced by 33.2%, 98%, and 30% respectively from unoptimized to optimized while the optimized system still met the load demand of the Heipang community. This shows the unoptimized system was oversized, hence the need for optimal sizing of a hybrid solar-wind power system.

Keywords: Excess energy; genetic algorithm; hybrid system; reliability; system cost.

INTRODUCTION

As a result of the increased complication of the hybrid energy system in comparison with the single energy system, the optimum design of the hybrid system becomes complex due to the stochastic nature of renewable energy supplies and load demand, irregular characteristics of the components, and the fact that the optimum configuration and control strategy of the system is correlated. This complication makes the hybrid systems arduous to design and analyze (Zhou, 2007). In order to efficiently and economically use the hybrid solar-wind power system, one optimal sizing method is necessary. The optimal sizing method will lower the initial cost of investment while increasing the reliability of the system. One of the challenges of designing a hybrid solar-wind power system is that there is a high tendency of under-sizing or over-sizing the designed system thereby being unable to meet designed objectives such as maximum reliability, the minimum cost of the system, and minimum excess energy generation. Increasing reliability will certainly result in an increase in the cost of the system and possibly excess energy generation. The reliability of the system is achieved by increasing the size of the system in terms of the number of solar panels, wind turbines, and batteries, which in turn increases the investment cost of the system. Thus, the optimization process which finds the best variables that maximize or minimize the objective function while satisfying the constraints (Sivanandam and Deepa, 2008), is used to select decision variables that will create an optimum trade-off among the design objectives.

The aim of this paper is to optimize the hybrid solar-wind power system designed for the Heipang community (Kpang, Tapo, and Tatu) using a Genetic Algorithm (GA) that dynamically searches for the best optimal system configurations.

This study was carried out at the Heipang community (Kpang, Tapo, and Tatu) in Barkin-Ladi L.G.A of Plateau State, Nigeria. It is located between longitudes 8° 50' E and 8° 59' E and between latitudes 9° 34' N and 9° 42' N (Land Survey and Town Planning, 2018). The geomorphology of Heipang can be generally classified as a plain land hence giving it the vantage position for the location of the airport.

Many researches have been conducted on the optimization of hybrid solar-wind power systems.

Yang *et al*. (2008) developed an optimal sizing method to optimize the configurations of a hybrid solar/wind system employing battery banks for application in a telecommunication relay station at Pearl River Delta Region, Hong Kong. Ahmad *et al*. (2013) created a hybrid system that employs a battery to store energy and an electrolyzer to create hydrogen. Battery, wind turbine, and PV module numbers served as the optimization`s decision variables as the LPSP technique was used to size the hybrid WT/PV/FC system. (Lian *et al*., 2019) reviewed the recent classification, evaluation indicators, and sizing methodologies of hybrid renewable energy systems (stand-alone and grid-connected). (Javed and Ma, 2019) propose a sizing methodology for autonomous hybrid solar-wind-battery systems based on key indicators of cost of energy (COE) and system reliability. A hybrid power plant, which consists of an off-grid PV and wind energy system to supply the demand for solar energy research center in Libya, was designed (Elbaz *et al*., 2019). Izdin.Hlal *et. al*. (2019) presented a methodology to size a Standalone Hybrid Renewable Energy System (SHRES) which combines solar PV, wind turbine (WT), and battery energy storage (BES) for application in rural areas. Masenge and Mwasilu (2020) proposed modeling and coordination control of a hybrid solar PV-wind power generation system together with optimal BESS using Mixed Integer Linear Programming (MILP). Osaretin *et al*. (2020) attempted to optimally size a renewable energy system to power an artificial lift for oil wells. Ghaithan *et al*. (2021) studied the optimization of a solar-wind-grid-powered desalination system in Saudi Arabia. A grid-connected hybrid solar-wind system is proposed to power a small-scale Reverse Osmosis (RO) desalination unit. (Shezan *et al*., 2022) study the selection of appropriate dispatch strategies for effective planning and operation of a microgrid. The following dispatch strategies were used: (i) load following (ii) cycle charging (iii) generator order, and (iv) combination dispatch. A new application of Equilibrium Optimizer (EO) is proposed for the design hybrid microgrid to feed the electricity to Dakhla, Morocco, as an isolated area (Kharrich *et al*., 2021). Ashagire *et al*. (2021) studied the optimal sizing of hybrid energy sources by using genetic algorithms and particle swarm optimization algorithms considering life cycle cost.

Previous researchers were able to achieve optimal design of hybrid power systems for different locations of different renewable energy resource potentials. This optimal design method can be replicated for the Heipang community which has different solar and wind energy resource potentials.

METHODOLOGY

Materials

The data used for optimization is 10-year minimum monthly average solar radiation, wind speed, ambient temperature data for the Heipang community obtained from the Nigerian Meteorological Agency office Abuja and an estimated hourly load demand profile for a typical day for Heipang community not connected to the grid (Kpang, Tapo, and Tatu) as obtained from the field survey. MATLAB and Excel software and Flash or Sun simulator are the tools used for analysis.

Method

Design Considerations

The design of the hybrid solar wind power system entails the sizing of the power generating systems to meet the load demand of the Heipang community not connected to the grid (Kpang, Tapo, and Tatu) based on the available renewable energy resources solar radiation and wind speed in the community. The daily estimated load demand of the community under study is assumed to be constant throughout the year for simulation purposes.

Design concept

The electric load demand survey shows that the total load of appliances of the Heipang community not connected to the grid (Kpang, Tapo, and Tatu) is 158.32 kW, and the total daily energy consumption is 710.59 kWh/day. Based on the percentage load-sharing strategy, the load is shared between solar and wind power generating systems (Ahammad, 2014).

Solar radiation incident normal to photovoltaic modules

The solar radiation incident normal to the photovoltaic plane is given as (Duffie *et.al.*, 2020):

$$G_T = G_b R_b + G_d\left(\frac{1+Cos\beta'}{2}\right) + G_m \rho\left(\frac{1-Cos\beta'}{2}\right) \quad (1)$$

Solar and wind energy potentials of the site

The available solar energy potential per unit surface area of the solar module in the Heipang community was determined using a power output model for a photovoltaic generator developed by Hybrid Optimization of Multiple Electric Renewables (HOMER, 2020) using equation (2) to (4).

$$P_{PV} = N_{PV} \times \frac{Y_{pv}}{1000} f_{pv}\left(\frac{G_T}{G_{T,STC}}\right)\left[1 + \alpha_p(T_c - T_{c,STC})\right] kW \quad (2)$$

$$\eta_{mp,STC} = \frac{Y_{pv}}{A_{pv} * G_{T,STC}} \quad (3)$$

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left[1 - \frac{\eta_{mp,STC}(1-\alpha_p \times T_{c,STC})}{\tau\alpha}\right]}{1 + (T_{c,NOCT} - T_{a,NOCT})\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \times \eta_{mp,STC}}{\tau\alpha}\right)} \quad (4)$$

The available wind energy potential per unit surface area of wind turbine system in Heipang community was determined using equations (5) and (6) below (Izdin.Hlal *et al*, 2019).

$$v = v_0\left(\frac{H_{WT}}{H_0}\right)^{\alpha_1} \quad (5)$$

The best-fit power output model for the wind turbine selected (F21-50) as determined in the course of this research is given as:

$$P_{wt} = N_{WT}\begin{cases} P_R \frac{v^{2.5} - v_C^{2.5}}{v_R^{2.5} - v_C^{2.5}} & v_C \le v < v_R \\ P_R & v_R \le v \le v_F \\ 0 & v < v_C ; v > v_F \end{cases} \quad (6)$$

Load sharing strategy of the solar-wind power system

According to equations (2) and (6), the power generated by the photovoltaic module per unit area is P_{pva} and power generated by wind turbine per unit area is P_{wta} respectively. Thus, the load shared by the solar power generation system and the wind power generation system of the proposed hybrid system are given by the equations (7) and (8) respectively.

Load sharing by the photovoltaic module of the hybrid system is (Ahammad, 2014):

$$P_{sh} = \frac{P_{pva}}{P_{pva} + P_{wta}} \times P \quad (7)$$

Where, P is the total load of appliances of Heipang community not connected to the grid (Kpang, Tapo and Tatu) in kW.

Load sharing of the wind turbine of the hybrid system is (Ahammad, 2014):

$$P_{wh} = \frac{P_{wta}}{P_{pva}+P_{wta}} \times P \tag{8}$$

Sizing and selection of photovoltaic module

The power from the photovoltaic module should be able to meet the percentage of load allotted to it based on the solar potential in the site. If the load allotted to the photovoltaic system is, then the number of photovoltaic modules required to serve the load is:

$$N_{PV} = \frac{P_{sh}}{P_{rs}} \tag{9}$$

Where; P_{rs} the power rating of the selected photovoltaic module.

The photovoltaic module randomly selected for this research work is the WON300 mono-crystalline model (http://www.wonderfulonline.en.alibaba.com). The solar panel is selected because of its relatively higher efficiency when it was tested and compared with other monocrystalline solar panels available in the market (NOA, 2018).

Sizing and selection of wind turbine

From equation (8) the load allotted to the wind turbine system is, thus, the number of wind turbines required to serve the load is:

$$N_{WT} = \frac{P_{wh}}{P_{rw}} \tag{10}$$

In this research, the wind turbines selected for the design is FD21-50 model www.ghrepower.com/en. It was selected because of its high-power output performances in the Heipang wind speed regime as analysed in the course of this research.

Sizing and selection of storage battery

Battery is used to store excess energy or supply when there is energy deficit. Battery life is affected by its depth of discharge. Deep cycle batteries can discharge from 15-50% of their capacity (Tharani, *et al*, 2018). The battery capacity to supply the full load demand is determined using the expression (Izdin.Hlal *et al*, 2019).

$$C_{wh} = \frac{E_L SD}{(1-DOD)_{max}\eta_{bat}} \tag{11}$$

The number of batteries in parallel:

$$N_{bp} = \frac{C_{wh}}{C_{ah} \times V_B} \tag{12}$$

The number of batteries in series:

$$N_{bs} = \frac{V_{system}}{V_B} \tag{13}$$

The storage battery selected for the design is Hoppecke 24 OPzVsolar.power 3500 - 48V. It is used in sectors with high charging and discharging operation load such as solar power applications (http://www.europe-solarstore.com/).

Sizing and selection of inverter

The DC/AC converter, also known as inverter is used to convert DC signal from the battery to AC signal to supply to load.

Inverter power $P_{INV}(t)$ is determined using the corresponding load power requirements, as follows (Wang *et al.*, 2017):

$$P_{INV}(t) = \frac{P_{load}(t)}{\eta_{INV}} \tag{14}$$

SKU- ATO-OGI-200kW inverter was selected for this research (https://www.inverter.com/200kw-pure-sine-wave- inverter).

Battery Capacity Model

The initial storage capacity of the battery is computed as (Sawle *et al.*, 2018):

$$C_{wh} = C_{bat}(t-1) = N_{BT} \times \frac{E_L \times S_D}{DOD \times \eta_{bat}} \tag{15}$$

In the case when the battery capacity reaches a maximum value, C_{batmax} , the control system stops the charging process.

During the charging process, when the total output of PV module and wind generators is greater than the load demand, the available battery bank capacity at hour t can be determined as (Izdin.Hlal *et al*, 2019):

$$C_{bat}(t) = C_{bat}(t-1).(1-\sigma) + \left(P_{PV}(t) + P_{WT}(t) - \frac{P_{load}(t)}{\eta_{inv}}\right).\eta_{batC} \tag{16}$$

Charging constraint

$$C_{bat}(t) \leq C_{bat\ max}$$

$$C_{batmax} = 1{,}512kWh$$

On the other hand, when the load demand is greater than the available energy generated, the battery discharges to compliment the energy deficit. Thus, the battery capacity at hour t can be expressed as:

$$C_{bat}(t) = C_{bat}(t-1).\,(1 - \sigma - \left(\frac{P_{load}(t)}{\eta_{inv}} - (P_{PV}(t) + P_{WT}(t))\right)\eta_{batD} \qquad (17)$$

Discharging constraint

$$C_{bat}(t) \geq C_{bat\,min}$$

$$C_{bat\,min} = DOD \times C_{bat\,max} \qquad (18)$$

Total Energy Generated by Hybrid Sola Wind Power System

The total annual energy generation by the hybrid solar wind power system is computed as follows:

$$\sum_{t=1}^{T} P_h(t) = \sum_{t=1}^{T}\left(P_{pv}(t) + P_{WT}(t)\right)\Delta t \qquad (19)$$

Where, T is the hours in a year, i.e., 8760; t is the time in hour; Δt -is the step of time used for the calculations (in this study Δt =1 hour).

Total Available Energy Generated for Load Demand

The total energy, $P_{total}(t)$generated by the wind turbine and PV generator at hour t to meet a demand at hour t is calculated as follows: i.e., energy generated by solar and wind plus the energy stored in battery.

$$P_{total}(t) = \left((P_{PV}(t) + P_{WT}(t)).\,\Delta t + C_{bat}(t-1) - C_{batmin}\right)\eta_{inv} \qquad (20)$$

Power Reliability Model Based on Loss of Power Supply Probability (LPSP)

The reliability of hybrid solar-wind power system can be measured using Loss of Power Supply Probability (LPSP) technique. LPSP is defined as the probability that an insufficient power supply results when the hybrid system (PV array, wind turbine and battery storage) is unable to satisfy the load demand (Sawle *et al*, 2018). Therefore, the loss of power supply probability for a period T, can be defined as:

$$LPSP = \frac{\sum_{t=1}^{T}\left[P_{load}(t)\Delta t - \left(P_{PV}(t) + P_{WT}(t)\right)\Delta t\right]\eta_{inv}}{\sum_{t=1}^{T} P_{load}(t).\,\Delta t} + \frac{\sum_{t=1}^{T}[C_{bat}(t-1) - C_{batmin}(t)]\eta_{inv}}{\sum_{t=1}^{T} P_{load}(t).\Delta t} \qquad (21)$$

Excess Energy Generation (EEGP)

The excess energy generated if not used for other purposes may be wasted. Excess Energy Percentage (EEGP) which is defined as the wasted energy divided by the total energy produced by the PV and wind generators during the considered period and is expressed as:

$$EEGP(t) = \frac{\sum_{t=1}^{T}[P_{total}(t)\Delta t] - \left(\frac{P_{load}(t)}{\eta_{inv}}\Delta t + \left(\frac{C_{bat\,max} - C_{bat}(t-1)}{\eta_{batC}}\right)\right)}{\sum_{t=1}^{T} P_{total}(t)\Delta t} \qquad (22)$$

Economic Model of Hybrid Solar-Wind Power System Based on Annualized Cost of System

Net present value (NPV) approach is used to find the total cost of the hybrid power system per kW of power generated by solar and wind power systems; per meter height of wind turbine tower and per kWh of battery capacity. The annualized cost of the hybrid system (including PV array and support frame, wind turbine, battery, wind turbine tower and balance of system) expressed as the annuity of net present value of the project over its life span is determined from equations (23) and (24):

$$ACS = [P_{PV} \times NPV_{PV} + P_{WT} \times NPV_{WT} + nBat \times NPV_{BT}] \times \left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] \qquad (23)$$

The following assumptions are made for the analysis: The current inflation rate of 21.34 % per annum is constant over a period of 20 years (www.tradingeconomics.com); the loan interest rate from banks of 17.01 % per annum maximum (www.cenbank.org) is constant over a period of 20 years; the salvage value of the solar and wind power system is negligible.

The annual real interest rate i is related to the nominal interest rate i' (the rate at which you could get a loan from banks or other financial institutions) and the annual inflation rate f by the equation (24), assuming is constant over the period of consideration:

$$i = \frac{i' - f}{1 + f} \qquad (24)$$

Replacement cost of battery

In the hybrid system, only the battery needs to be replaced periodically after some years during the project lifetime (20 years). Based on the selected battery that has a life cycle of 10 years (http://www.europe-solarstore.com/), it would be replaced once throughout the project life span. The future cost of battery considering the effect of inflation was determined using equation (25):

$$FC_{rep} = C_{rep} \times (1+f)^{N_b} \qquad (25)$$

Operation and maintenance cost of solar wind power system

The hybrid solar-wind power system operation and maintenance cost is often expressed as a percentage of the initial investment of the systems and was determined as the accumulated present value over the lifetime of the project, considering the effect of inflation f using equation (26):

$$APV_{Nop} = mC_I \times \left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] \qquad (26)$$

Optimal Sizing of Hybrid Solar-Wind Power System Using Genetic Algorithm

The optimization of the hybrid solar wind power system is done using genetic algorithm which is a mimicry of the mechanics of biological evolution. Genetic Algorithm (GA) is more suitable than the others optimization techniques due to its robustness in finding global optimal solutions (Zhou, 2007, Araoye *et al*, 2019), and it can solve problems that are mixed continuous–discrete variables, and discontinuous and non-convex design spaces efficiently (Anju and Rajender, 2015). The three objective functions in this study are:

-Minimizing loss of power supply probability (LPSP) objective function one equation (21)

-Minimizing excess energy generated percentage (EEGP) objective function two equation (22)

-Minimizing the annualized cost of the system (ACS) objective function three equation (23)

The decision variables for the optimization are; number of photovoltaic modules N_{PV}, number of wind turbine N_{WT}, and number of batteries N_{Bat}, slope angle of photovoltaic module β', and height of wind turbine H_{WT}. The restrictions that must be satisfied to produce an acceptable design are the design constraints. The design constraints in this research are;

$(N_{PV},\ N_{WT}) > 0$; $N_{bat} \geq 10$; $10m \leq H_{WT} \leq 50m$ and $0^o \leq \beta' \leq 90^o$.

In this study, the optimization of the hybrid solar-wind power system is a minimization process and is achieved by using written MATLAB codes for running the optimization. The genetic algorithm optimization flow chart is as shown in Fig. 1.

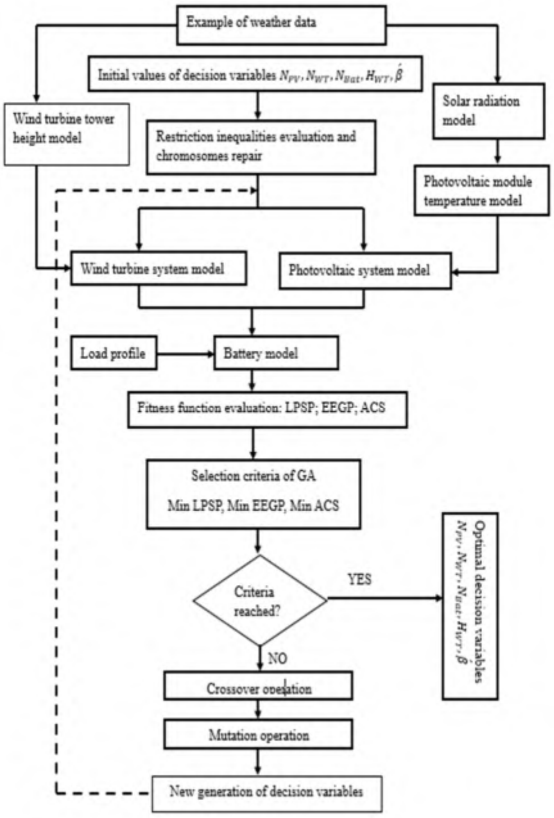

Fig. 1: Genetic algorithm optimization flow chart.

RESULTS AND DISCUSSION

Optimization of hybrid solar-wind power system

The pareto front, score histogram, stopping criteria, selection function and average distance between individuals are shown in Figs. 2a, 2b, 2c, 2d and 2e respectively. Fig. 2a shows a plot of the best solution, comparing objective functions one, which minimizes loss of power supply probability (LPSP) and objective function two, which minimizes excess energy generated percentage (EEGP), for every iteration. Here, two problems that depend on each other are being solved and at any point in time where the solution obtained for objective two independently cannot change without affecting objective one is called pareto front.

Fig. 2b shows the number of individuals that gave the best solution up to the last iteration for each objective function. The individuals represent the population of the chromosomes (the parameters being sized). For objectives functions two and three, the values of the population that give the best solutions are obtained of the optimization, and any population outsides these will not give the best solution. However, for objective function one, it still takes longer iteration to obtain the best population. In other word, it can be said that objective one is more complex. Fig. 2c shows the number of generations and there are 100 generations. It is called termination criteria. For this study, an in-bult genetic algorithm toolbox termination criteria of 100 is used.

Fig. 2d shows the plot of number of new children created against individuals. As it is evolving, new chromosomes are created, any new chromosomes that is better than the old one replaced the old ones. These new ones are called the children chromosomes and this are the new ones used to displace the old ones. For example, for individual number one, it created 3 children and individual number 2 it created 5 children. What this means is that, as the iteration is going on, 3 times and 5 times out of 100, new solutions are found that are better than the initial one for individual numbers 1 and 2 respectively. Fig. 2e shows the position of the chromosomes in the optimization space.

Figs. 3, 4 and 5 are plots of ACS, EEGP and LPSP against number of optimizations runs respectively. The essence of these plots is to determine whether or not the algorithm is having stable performance and is measured by the difference between the highest and lowest values of the plots.

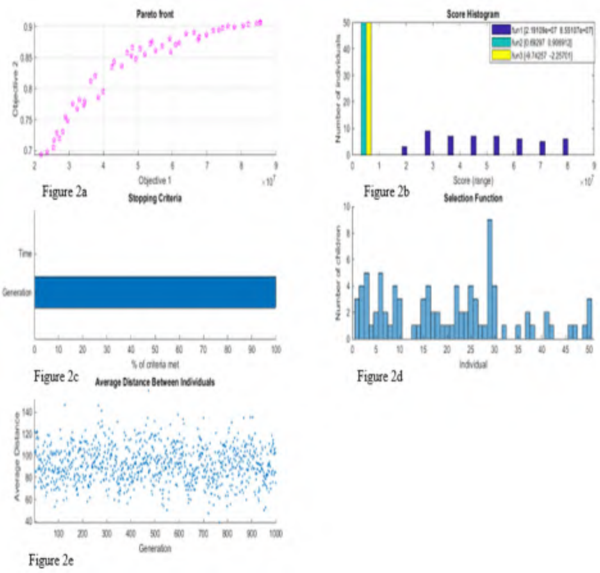

Figure 2a Figure 2b Figure 2c Figure 2d Figure 2e

Fig. 2: Display of Genetic algorithm optimization in MATLAB environment

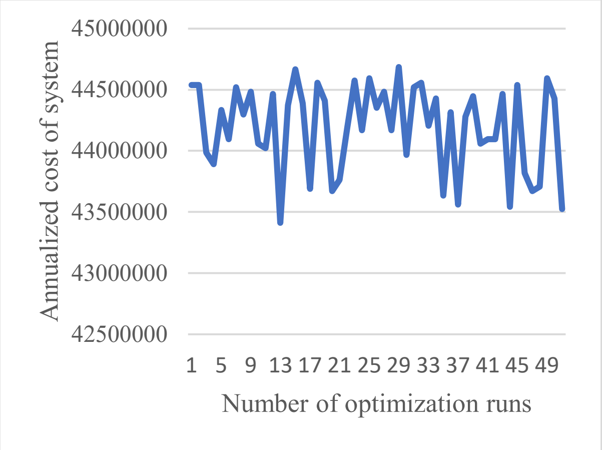

Fig. 3: A plot of Annualized cost of system against number of optimizations runs

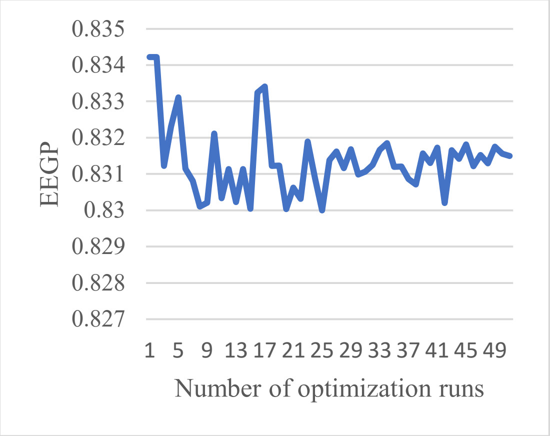

Fig. 4: A plot of EEGP against number of optimizations runs

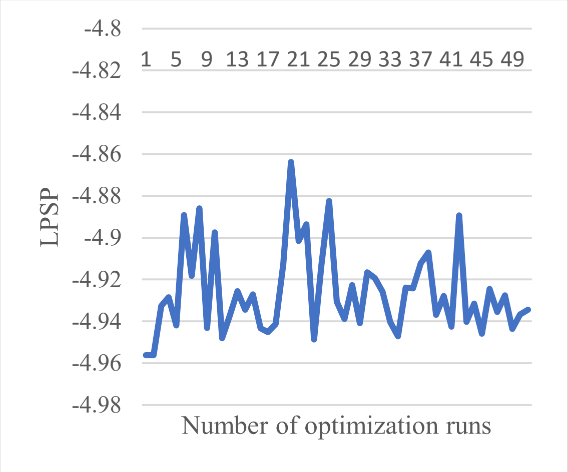

Fig. 5: A plot of LPSP against number of optimizations runs.

As shown in figures 3, 4 and 5, the range of values for ACS, EEGP and LPSP are 1,143,240, 0.0042, and 0.0924 respectively and all the remaining ones are within the tolerable values. This shows that at every time an acceptable solution is always obtained. This is because the margin is not high and is within the acceptable range, which is the essence of optimization. It is not an exact method but a method that will give you an acceptable solution.

The optimization gives the best results of the decision variables as: N_{pv} =60, N_{wt} =4, N_{bt}=70, H_{wt}=23 and β'=6^o,, with objective functions ACS, EEGP and LPSP as ₦ 43,523,759.47, 0.83 and -4.93 respectively. This is much less than the unoptimized designed hybrid power system which gives decision variables as: N_{pv} =283, N_{wt} =2, N_{bt} =120, H_{wt} =42 and β' = 9.6^o , with objective functions ACS, EEGP and LPSP as ₦ 66,384,285.32, -39.12 and -7.0 respectively.

Figs. 6 and 7 show the diagrams of unoptimized and optimized hybrid solar-wind power system respectively. From the diagrams, the number of wind turbines increased from 2 units in unoptimized to 4 units in optimized and the number of PV modules decrease from 283 units from unoptimized to 60 units in optimized thereby reducing the annualized cost from unoptimized to optimized by 33.2%.

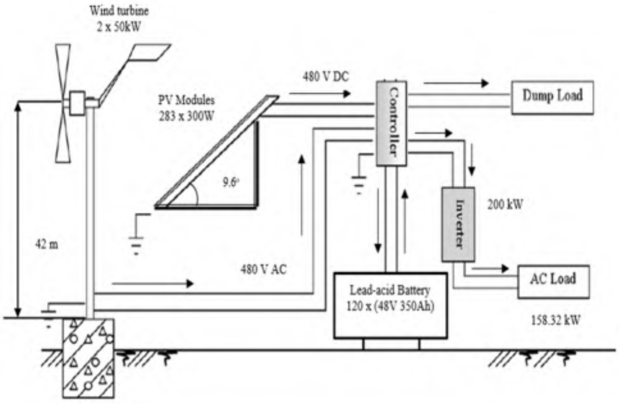

Fig. 6: Diagram of the designed unoptimized hybrid solar-wind power System

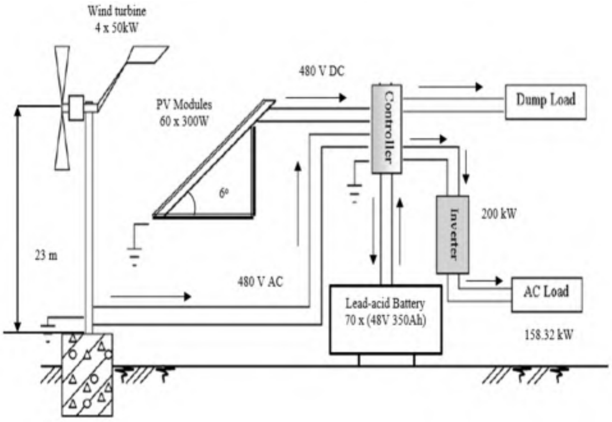

Fig. 7: Diagram of the designed optimized hybrid solar-wind power system

CONCLUSION

This paper used a multi-objective optimization technique based on genetic algorithm to optimally size a hybrid solar-wind power system with battery as a backup.1-year hourly solar radiation, wind speed and ambient temperature data and load demand data obtained from NIMET office Abuja and Heipang community respectively were used for the optimization. Genetic algorithm was employed to size the angle of inclination of solar panels and wind turbine tower height and the number of solar panels, wind turbine, and battery so as to present a trade-off among system reliability measured as loss of power supply probability (LPSP), annualized cost of system (ACS) and excess energy generated (EEGP) while meeting the load demand of the Heipang community. The method was able to optimize any given wind model, solar model and battery model for different locations. The unoptimized and optimized designed hybrid solar-wind power system were compared in terms of system reliability and cost. The results showed that the annualized cost, excess energy generated and reliability of the system were reduced by 33.2%, 98% and 30% respectively from unoptimized to optimized while the optimized system still meeting the load demand of Heipang community. This shows the unoptimized system was oversized, hence the need for optimal sizing of hybrid solar-wind power system.

NOTATIONS

A_{pv}- surface area of the solar module

B_A - annual benefit from sales of energy generated

C_{ah} - ampere-hour rating of the selected battery

C_{BAT}- battery investment cost per kWh

$C_{bat}(t)$- battery bank capacity (Wh) at hour

$C_{bat}(t-1)$- battery bank capacity (Wh) at hour t-1

$C_{bat\ min}$- minimum capacity of battery

C_{batmax}-maximum battery capacity

CF_{Hybrid} - capacity factor of the hybrid power system

C_I- initial cost of investment

C_{PV} - solar power investment cost per kW

C_{rep}- replacement cost of battery

C_{wh}- capacity of battery

C_{WT}- wind power investment cost per kW

DOD - depth of discharge

DOD_{max}- maximum depth of discharge of battery

E_L- electrical load

$EEGP(t)$- Excess Energy Generated Percentage

f - annual inflation rate

FC_{rep}- future cost of replacement of the battery

f_{pv}- photovoltaic derating factor

G_b- beam radiation on a horizontal plane

G_d- diffuse solar radiation

G_E-Hourly extraterrestrial solar radiation

G_m- Measured daily global solar radiation on horizontal surface

G_{sc}-Solar constant

G_T- solar radiation at inclined plane in W/m^2

$G_{T,NOCT}$ - Solar radiation at nominal operating solar cell

$G_{T,STC}$- incident solar radiation at standard test condition

H_0- reference height for measuring wind speed

H_{WT}- Wind turbine Hub height

i - annual real interest rate

i'-Bank interest rate

K_T- clearness index

n - investment payback period in years

N - project lifetime

N_{bp}- number of batteries in parallel

N_{bs}- number of batteries in series

N_{BT}- number of strings of battery

n_d-Number of the day in a year

N_{PV}- number of photovoltaic modules

NPV_{PV}- Net present value of solar panel/kW

NPV_{WT} - Net present value of wind turbine/kW

N_{WT}- number of wind turbine

m - percentage of operation and maintenance cost based on cost of initial investment

m_{PV} - solar power annual operation and maintenance cost per kW

solar-wind power system.

m_{WT} - wind power annual operation and maintenance cost per kW
P - Total load demand
P_{Hybrid} -Hybrid (solar wind) power generated
$P_{INV}(t)$- Inverter capacity
$P_{load}(t)$- power consumed by the load at hour t
P_{pva}- power generated by photovoltaic per unit area
$P_{PV}(t)$ - power generated by solar system at time t
p_R- Rated power of the wind turbine
P_{rs} - power rating of the selected photovoltaic module
P_{rw} - power rating of the selected Wind turbine
P_{sh}- Solar power system load share
P_{wh}- wind turbine power system load share
$P_{WT}(t)$- power generated by wind turbine at time t
P_{wta}- power generated by wind turbine per unit area
R_b- ratio of beam radiation on an inclined surface to that on the horizontal surface
T -operation time of hybrid solar wind power system
$T_{a,NOCT}$ - ambient temperature at nominal operating temperature
T_c- solar cell temperature in degree Kelvin
$T_{c,NOCT}$ - solar cell temperature under standard test condition
$T_{c,STC}$- solar cell temperature under standard test condition
v - wind speed at hub height
V_B- nominal voltage of the selected battery
v_C- cut-in wind speed
v_F- cut-out wind speed
v_0- wind speed measured at the reference height
v_R - rated wind speed
V_{system}- system voltage
SD - battery day of autonomy
Y_{pv} -Rated capacity of the solar module

GREEK SYMBOLS

α_p- temperature coefficient of power
α_1- power law exponent.
δ -Angle of declination
ϕ - latitude of the location
ω - hour angle
$\acute{\beta}$ - inclined angle of solar panel to the horizontal plane
ρ_g- diffuse reflectance of the surroundings
σ - self-discharge rate of the battery bank
η_{bat}-efficiency of battery
η_{INV}-Inverter efficiency
η_{batC} - battery efficiency during charging process
η_{batD}- battery efficiency during discharging process
$\eta_{mp,STC}$ -maximum power point efficiency under standard test
Δt - Time step used for the calculations
$\tau\alpha$ - solar transmittance-absorptance factor of solar module cover
ε - cost of energy generated per kWh

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