



An Improved Hybrid Optimization Algorithm for Multimodal Benchmark Function for Hybrid PV/WT/ESS

¹A. M. Adua, ¹I. I. Alabi, ¹I. A. Araga, ¹Tajudeen Danjuma, ¹Umar Muhammed Jajere, ¹Abubakar Usman Sadik, ²Yau Alhaji Samaila

¹Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero, P.M.B.1144 Aliero, Kebbi State, Nigeria.

²Department of Electrical and Electronics Engineering, University of Maiduguri, Nigeria

ABSTRACT

The adoption of Renewable Energy Systems (RES) has taken a centre stage in recent years due to depletion in fossil energy resources, climate change, absence of electric energy supply to remote locations and the high connection cost due to long distance. Despite the abovementioned challenges, the implementation of RES is quite slow in many countries, due to its high capital cost and uncertainties. A more promising RES is the hybrid power system. This system incorporates multiple RES which increases the system reliability, minimizes the system cost and excess energy produced when optimally sized. Therefore, this work considered an optimized techno economic design of a standalone PV/Wind/Battery RES for power generation considering coordinate (13.0931°N, 7.2248°E) of Jibia Katsina state Nigeria, using Smell Agent Optimization (GWO) simulation software and Improved Hybrid Particle Swarm Optimization Graywolf Optimization Optimization (PSO-GWO) Algorithm. The simulation was carried out in three scenarios namely; PV/Battery, Wind/Battery, and PV/Wind/Battery. The Levelized Cost of Energy (LCOE) obtained from GWO were found to be ₦44.14/kWhr, ₦29.63/kWhr and ₦29.48/kWhr respectively, and that obtained from SAO were found to be ₦15.57/kWhr, ₦19.38/kWhr and ₦12.53/kWhr respectively. The Loss of Power Supply Probability (LPSP) obtained from SAO were found to be 0.0328%, 0.0021%, and 0.0137% respectively, while that of PSO-GWO were found to be 0.000236%, 0.000236%, and 0.000184% respectively, The Excess Energy (ExE) produced from GWO simulation were found to be 4,238kW, 7,710kW, and 3,523kW, respectively while that obtained from ISAO were 12.66297kW, 17.150kW, and 205.5742kW respectively. The result of PSO-GWO shows significant reduction in LCOE, LPSP and ExE, as compared to the GWO.

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INTRODUCTION

Technological development, increase in population and growing evidence of the global warming phenomena greenhouse gas emissions (GHG) have drawn the attention of this generation towards harnessing renewable energy sources (RES) (Zhou et al., 2010). RES have been identified as an effective option to solve power

supply problem of isolated and remote locations where the utility grid cannot reach, and there is no other source of energy (Nadjemi et al., 2016). RES are derived from natural resources such as solar, wind, geothermal, biomass, and so on. These sources of energy are considered the most abundant, as they can be found almost everywhere in the world (Safari et al., 2018), and

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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they will never run out, however they are uncertain and unpredictable (Kumar et al., 2020).

Hybrid power systems are the most reliable renewable energy sources, because these system combines multiple RES consisting of wind, PV, small hydro, geothermal and so on, to enhance the system reliability and performance (Haratian et al., 2018), and can also cater for sudden increase in load demand within the system which cannot be certified with a single RES (AlFalahi et al., 2017)

Nigeria is located between longitude 30 and 140 East of Greenwich and latitude 40 and 140 north of equator (Modu et al., 2018), the climate condition throughout the year is anomalously for both wind and solar energy power generation, which offer the best solution and hope to meet its present and future development requirements in general, and predominantly rural communities that are not connected to the grid (Sambo, 2009). However, hydropower is the only RES currently exploited and connected to the grid (Charles, 2014). According to International Energy Agency (IEA), only 10% of rural communities and about 30% of Nigerians total population have access to electricity (the third largest country without access to Electricity) (Ugwoke et al., 2020). Therefore, this work considered an optimized techno-economic design of a standalone hybrid PV/Wind/Battery RES for power generation considering coordinates (13.0931°N, 7.2248°E) of Jibiya Katsina State Nigeria using Graywolf optimization algorithm (GWO) simulation software and Particle Swarm Optimization Graywolf Optimization (PSO-GWO) Algorithm. This method employed will increase the system reliability, minimize the system cost and excess energy produced when optimally sized.

LITERATURE REVIEW

Kaabeche et al. (2011) presented a sizing optimization of grid-independent hybrid photovoltaic/wind power generation system. Naturally, renewable resources namely; wind, PV cells and battery bank were used in optimal sizing of hybrid renewable power generation 12 systems. The proposed model takes into account the sub models of the hybrid system, the Deficiency of

Power Supply Probability (DPSP) and the Levelised Unit Electricity Cost (LUEC). As a result of integration of these models, the sizing optimization of grid independent hybrid PV/wind power generation system was achieved technically and economically based on the system reliability requirements. Residential household located in the area of the CDER (Center for Renewable Energy Development) located in Bouzaréah, Algeria (36.480N, 3.10E, 345 m) was analyzed to supply a techno-economic power. However, solar and wind energy are unpredictable in nature and dependence on weather and climatic changes. Therefore, off-grid photovoltaic (PV) or wind energy systems do not generate usable energy for significant portion of time during the year. Nevertheless, the battery devices used in the work are limited to short life span, energy losses during loading, decrease in efficiency due to ageing.

Mamaghani et al. (2016) presented a work on techno-economic feasibility of photovoltaic, wind and diesel hybrid systems for an off-grid system case study of Colombia rural electrification. The work was aimed at analyzing the relevance of photovoltaic (PV) panels, wind turbines and diesel generators in an off-grid hybrid power generation for rural electrification in three off-grid areas in Colombia through dissimilar climatic characteristics. The areas have been selected based on the "Colombia's development plan 2011-2030 for non-conventional sources of energy". First, diverse configurations of wind turbine, PV, and diesel generator were modeled and optimized to ascertain the most efficient energy and cost-effective configuration for each location. HOMER software was used to carry out a techno-economic feasibility of the planned hybrid systems, looking at the net present cost, initial capital cost, and cost of energy as economic indices. However, the work revealed an 13 interesting results except that a notable obstacle of using diesel generator impedes due to difficulty in supplying the diesel fuel to these remote areas, high maintenance and operation, carbon emission and dynamic fuel price variation.

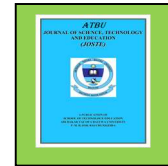
Ani (2016) worked and presented a paper on design of a reliable hybrid (PV/Diesel)

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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power system with energy storage in batteries of a residential village. The paper reported the worked on photovoltaic (PV) hybrid system and simulated as an option to diesel generator for a residential home located in Southern Nigeria. The hybrid system was designed to defeat the issues of climate change, guarantee a reliable power supply and to enhance the whole system efficiency through the incorporation of the battery bank. The system design viewpoint maximized the system size using conventional simulation tool and delegate insulation data. The system consist of 15kW PV array, 21.6kWh (3600 Ah) worth of battery storage, and a 5.4kW (6.8 kVA) generator. The paper also sorted a detail analysis of the energy flows through the system and analyzed all losses generated by PV charge controller, battery storage round-trip, rectifier, and inverter conversions. The simulation results of PV/diesel/battery were compared with diesel/battery, which show that the capital cost of a PV/diesel hybrid resolution with batteries is almost three times elevated than that of a generator and battery arrangement, but the net present cost representing cost of lifetime of the system is less than one-half of the generator and battery configuration. However, the method adopted in achieving the optimal reliability, economy and environment was determined through complex mathematical computation. As such the method looks classical and hence high computational time.

Sawle et al., (2017) worked on "Review of hybrid renewable energy systems with comparative analysis of off-grid hybrid system". PV and wind hybrid were created to be the 14 most rewarding solution for the failing usual energy sources. Whereas these options sources of the energy have a lot of significant rewards such as cost of energy and feasibility etc. The behaviours of these sources of being cost effective and stable were likely due to their corresponding nature as compared to independent energy systems. The work presented provided an idea on different combinations, control strategy, techno-economic analysis and societal effect. The wok also presented a remote area of Barwani, India as case study and results

were compared using Homer and PSO. The resulting analysis revealed that combinations of hybrid system were mainly techno economical feasible solution with regard to cost of energy, renewable portion, maximum renewable dispersion, levelized cost, operating cost, mean electrical efficiency, and carbon emission along with various hybrid system combinations using PSO as compared to HOMER. Nevertheless, both PV and wind sources are reciprocal to each other, as such taking them as a hybrid renewable combination for the generation of power is not feasible for their dependency on climate condition. Babatunde et al., (2017) have presented a paper on standalone hybrid renewable energy system for the remote areas, a case study of healthcare centers of six geo- political zone in Nigeria. The studied the optimal hybrid renewable standalone energy system model that supplied the above mentioned healthcare centers. A technical and economic assessment was conceded to discover the optimal standalone hybrid energy system combinations using photovoltaic (PV), wind, diesel generator and battery. Owing to the governments' fuel financial backing in many developing countries, the fuel price is reduced and not a true indication of what is accessible in a deregulated market. Where the study considered the consequence of subsidy exclusion by carrying out a sensitivity analysis on the fuel price. The results indicated that across all aforementioned locations considered, PV/diesel/battery 15 system is the most economically viable with a net present cost and renewable fraction (RF) ranging between \$12 779 and \$13 646 and 70%-80% respectively. The cost of energy (COE) is also estimated to range between 0.507 and 0.542 \$/kWh. However, it has an interesting results but characterised by some shortcoming such as in ability to consider the environmental aspect which will minimize the carbon emission, as such the system is not wholly considered optimal.

Samy et al., (2018) study on a flower pollination optimization algorithm for a standalone PV-Fuel cell hybrid renewable system. The research work deals with a techno-economic viability work for a standalone solar photovoltaic fuel cell (PV/FC) hybrid systems. The hybrid

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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electrical energy system was investigated for supplying electric power to the remote areas and isolated built-up regions in Egypt. To accomplish this target, all the equipment arrangement were modeled, simulated and the region data under study was gathered. The objective function was formulated based on the total annual cost (TAC). Flower Pollination Algorithm (FPA), as a competent and modern metaheuristic optimization technique, anticipated to approximate the optimum number of both PV panels and the FC/electrolyzer/H₂ storage tanks set compulsory where the least total net present value (TNPV) was reached. The loss of power supply probability (LPSP) was considered to improve the performance of the anticipated design. The outcome of the variation of FC, electrolyzer, H₂ storage tanks and the PV power arrangement initial cost on the Levelized cost of energy (LCOE) was obtained through a complete sensitivity analysis using Matlab program, the mathematical simulation results obtained using FPA algorithm have been compared to the equivalent outcomes although using the artificial bee colony (ABC) and the Particle Swarm Optimization (PSO) techniques. Based on the simulation analysis results, the 16 FPA Algorithm has the fewer execution time and good rendering between the previous algorithms. In addition, the best system composition was acquired using FPA with the best hybridization of 27 solar PV, 28 FCs, 58 electrolyzers and 37 H₂ storage tanks for an LPSP and PEE of 1.52% and 4.68% respectively. The organization of TNPV is \$3,244,897 with the LCOE of 0.334 \$/kWh. However, the results of the proposed method indicated that the fuel cell acquires 59% of Total Net Present value (TNPV) of the system. This contributed in high system cost which need to be minimized drastically by another optimization technique with a stronger characteristic.

Abdin and Merida (2019) worked on techno-economic analysis for hybrid energy systems for off-grid power supply and hydrogen production based on renewable energy. The study determined the minimum cost of energy (COE) for five diverse areas: Squamish, Canada, Los Angeles and Golden, USA and Brisbane and

Adelaide in Australia through renewable energy systems. Hybrid Optimization Model for Multiple Energy Resources (HOMER Pro) was used to simulate the optimum size of system components and discovered the cost-effective configurations based on particular area. When considering minimum COE, the result shows that combination of PV, WT, a battery bank, an electrolyser and a hydrogen tank was 0.50\$/kWh at Golden, Colorado, USA. Moreover, the minimum COE was 0.78 \$/kWh without a battery bank at the same area. In this case, the cost increase is due to the capital cost of system components, mainly the hydrogen technologies. The results of this study propose that hydrogen has economic benefits over batteries for long-term energy storage in off-grid energy systems except that the cost of hydrogen tank construction is expensive; as 17 such LCOH is extremely high. Moreover, the load data for hydrogen production is not available but scaled to 70kg/day which lead to locally optimum LCOE.

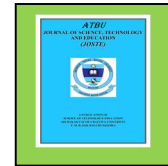
Kaluthanthrige et al.,(2019) presented a paper titled "Optimal Sizing and Performance Evaluation of a Hybrid Renewable Energy System for an Off-Grid Power System in Northern Canada". In their work, suitable component choice, best sizing of the grid configuration and performance assessments with regard to economic, environmental and technical paradigms were conducted in the process. A HOMER software-based grid optimization was used to optimally overhaul a remote standalone power system in Northern Canada. Three scenarios namely; Battery-Diesel, PV-Diesel and PV-Diesel-Battery were evaluated under dissimilar topologies to assess the optimum diesel-based generation facility. The results show that PV-Diesel-Battery topology has a highest renewable penetration levels in achieving the envisioned settlement. A renewable penetration level and fuel savings up to 21% and 22% were achieved with 0–0.5% reductions in Levelized cost of electricity in comparison with the existing diesel-based power system. However, the work provided an interesting result but characterized by some shortcomings as follows; the heat recovery effect with regard to the diesel generator output was not

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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considered in the study which lead to local optimum result environmentally. Moreover, the HOMER software used does not model electrical transients which involve extraordinarily small time steps

Gebrehiwot et al., (2019) a paper was presented on optimization and cost-benefit evaluation of hybrid power systems for standalone remote area electrification in Ethiopia. The systems were progressively more being distributed in Ethiopia, but these systems were not the best due to their irregular power supply. This study evaluated the prospective of a hybrid system in the electrification of a remote area in Ethiopia. The Hybrid Optimization of Multiple Electric Renewable model (HOMER) software was employed to ascertain primary data, build up a load profile and classify the optimal least cost of energy and net present cost alternative for the village. A sensitivity analysis was run to obtain the effect of variations in solar radiation, wind speed, and diesel price on optimal system configurations. The results demonstrate that a hybrid system with a combination of photovoltaic array, wind turbine, battery and diesel generator is the best option from an economic point of view with regard to cost of energy and net present cost. To meet the village's daily peak demand of 19.6 kW, energy generation cost is approximated at 0.207 dollars per kw/hr and NPC at 82,734 dollars. The best system allows for a decrease of 37.3 tons of carbon dioxide emissions compared with diesel-only in generating the electricity per year. However, the work had an interesting result except that the system cost was high due to improper components sizing of the combination that gave optimum results in terms of cost of energy and net present cost. Li et al., (2020) worked on optimal design and techno-economic analysis of a solar-wind biomass stand-alone hybrid power system for remote rural electrification in west China. The work demonstrated the techno-economic viability of stand-alone hybrid renewable energy system for remote rural electrification by conducting optimization and sensitivity analysis. Daily and seasonal features of energy supply as well as component sizes and patterns of remote rural

areas are considered. Diverse combinations of PV panels, wind turbine and biogas generator are modeled and optimized in Hybrid Optimization Model for Electric Renewable (HOMER). The most cost effective composition was achieved in a hybrid power system consisting; solar, wind, battery and biomass as compared to pv/biomass/battery and wind/biomass/battery. Moreover, the issue of environmental impact was not considered in the work due to carbon emission as a result of using biomass diesel generator which 19 contributes to climate change. Furthermore, the HOMER software achieved the results in not less than 8hrs as a result of full search space instead of restricted search space and this lead to high computational burden.

Ghaffari and Askarzadeh, (2020) worked on a paper titled "Design optimization of a hybrid system subject to reliability level and renewable energy penetration". In this work, design optimization of hybrid power generation systems which utilize renewable energy assets has received a considerable attention. The work presents a competent and strong optimization approach of a hybrid system comprised of Photovoltaic (PV) panel, diesel generator and Fuel Cell (FC). The proposed approach is a modified version of Crow Search Algorithm (CSA) upon which awareness probability is improved through an adaptive approach. While sizing, the total net present cost (TNPC) is reduced based on two constraints namely: Loss of Power Supply Probability (LPSP) and Renewable Energy Portion (REP). Simulation results demonstrate that REP has a significant impact on TNPC of the designed system, optimal combination of PV, diesel generator, FC, electrolyzer and hydrogen tank leads to providing a reliable and cost-effective hybrid power generation system. It also used CSAP to find more capable and robust results than original CSA, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). However, the research work provides a promising result but characterised by carbon emission as such environmental pollution is not considered this will increased the global warming of environmental problems which is part of mandate of the world that need to be reduced drastically if not wholly

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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eradicated. Also the issue of fluctuation of a fuel price and high maintenance cost matters a lot while co-opting diesel generator as part of power system hybridization.

In conclusion, the above mentioned reviewed literatures had interesting results but characterized by some short coming as follows: unpredictable in nature, dependence on weather and climatic changes, limited short life span of battery, carbon emission and dynamic fuel price variation. high computational time, high system cost and unavailability of load data for hydrogen production. However, to utilize the hybrid RES effectively and economically, optimal sizing of the system with lowest cost of energy is to be carried out. This research is aimed at designing an Optimized Techno-Economic Standalone Hybrid Renewable Energy System for Power Generation using HOMER software and AFSA Algorithm in order to address the aforementioned issues.

2. Modeling of the PV/WT/BS system

The independent PV/WT/BS system typically consists of the following primary subsystems, including REs, battery storage, converter, bidi-rectional inverter and load profile, as shown in Fig. 1. These are strongly relied on accessibility of meteorological data, techno-economic criteria, and amount of required load, which might lead to significant variations in the outcome.

2.1 Modeling of PV model

The power output of the solar photovoltaic field is determined by the number of solar panels N_{PV} , the nominal power of each solar panel under standard test conditions (PSTC), solar radiation ($G(t)$), cell temperature ($T_C(t)$), and the various losses caused by the efficiency of the converters, cables, and so on (Losses). Equation (3.1) gives the expression for calculating the power generated by the PV field over time.

$$P_{PV}(t) = N_{PV} \times P_{STC} \times \frac{G(t)}{G_{ref}} \times [1 + \alpha_p \times (T_C(t) - 25)] \times F_{losses} \quad (1)$$

In this equation, α_p is the temperature coefficient and G_{ref} is the irradiance corresponding to

standard measurement conditions (STC), which has a value of 1000 W/m². Equation (3.2) is used to calculate the temperature T_C of the cells.

$$T_C(t) = T_a(t) + \left(\frac{NOCT - 20}{800} \right) \times G(t) \quad (2)$$

The main constrain in design of the PV array is the area and this constrain area which is available for setting PV array in maximum power and maximum current. With an initial cost and the life time of the project is considered to be equal to the life span of the PV modules the replacement cost of the PV array is negligible

2.2 Modeling of wind turbine model

The wind field's energy depends not only on the wind velocity at t , but also on the technical characteristics of the wind turbine model used. Equation (2.3) is employed to calculate the wind field's output power [20].

$$P_{WT}(v) = N_{WT} \times \begin{cases} 0, v < v_{ci} \\ P_{rated} \times \frac{v - v_{ci}}{v_r - v_{ci}}, v_{ci} \leq v \leq v_r \\ P_{rated}, v_r \leq v \leq v_{co} \\ 0, v > v_{co} \end{cases} \quad (3)$$

Using Equation (3.4) [14], the wind speed v at height H can be determined based on the known wind speed v_0 at height H_{10} .

$$v(H) = v_0 \times \left(\frac{H}{H_{10}} \right)^\alpha \quad (4)$$

Here, α represents the Hellmann exponent, which can be calculated with Equation (5).

$$\alpha = \frac{0.37 - 0.088 \cdot \ln v_0}{1 - 0.088 \cdot \ln(H_{10}/10)} \quad (5)$$

The main constraint that has been considered in the design of the wind system is its rotor swept area, this value is constrained by both budget and the available area for the project implementation. Usually, the life time of the wind turbine is shorter than the lifetime to PV array, so it is necessary to purchase new wind turbine to replace the existing ones. The number of times the wind turbines need to be replaced will represents the life of the wind turbine. The salvage value of the wind turbine is assumed to decrease linearly when the turbine operates along its lifetime.

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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2.3 Modeling of battery model

SMESs can store excess or surplus energy produced by the hybrid system and release it when needed to meet peak load demand, rather than limiting it when load demand is low. This can be done until long-term energy sources are connected to the system during the day. In other words, SMESs can act as loads to store energy while charging and generators to release or transfer energy while discharging. Reactive power can also be delivered or absorbed. The SMES had two modes of operation, as explained below [24].

a. Charging mode: When the hybrid system power P_{sys} exceeds the load demand P_L (i.e., $P_L - P_{sys} < 0$), this mode of operation happens.

$$P_{exch}(t) = \max \left\{ -\Delta P(t), \frac{(E_{exch}(t-1) - E_{exch-max}(t))}{\Delta t \times \eta_{ch}}, -P_{exch-rated} \right\} \quad (6)$$

$$E_{exch}(t) = \min \{ (E_{exch}(t-1) - P_{exch-ch}(t) \times \Delta t \times \eta_{ch}), E_{exch-max} \} \quad (7)$$

b. Discharging mode: When the load demand P_L is higher than the hybrid system power P_{sys} (i.e., $P_L - P_{sys} > 0$), this mode of operation happens.

$$P_{ex}(t) = \max \left\{ |\Delta P(t)|, \frac{(E_{exch}(t-1) - E_{exch-min}(t)) \times \eta_{dis}}{\Delta t}, P_{exch-rated} \right\} \quad (8)$$

$$E_{exch}(t) = \max \left\{ \left(E_{exch}(t-1) - \frac{P_{exch-dis} \times \Delta t}{\eta_{dis}} \right), E_{exch-min} \right\} \quad (9)$$

State of charge (SOC) represents an index of the energy stored in the SMES, with an initial value ($SOC_{initial}$) to be optimized for each SMES serving different load models [25].

RESULTS AND DISCUSSIONS

The results obtained from the hybrid systems sizing using the improved smell agent optimization are presented. The lower and upper bound of the decision variables were set as 1 and 1000 respectively. The three combinations which were implemented in GWO-PSO were also considered for the PSO-GWO simulation. For

each configuration a total thirty independent runs were conducted. The statistical analysis of the results obtained for these runs are discussed in the following subsections.

PROPOSED METHODOLOGY

This section discusses the methodology adopted in achieving the set objectives. In order to carry out the project input data of load profile, solar irradiance, wind speed and temperature were collected. Figure 4.1 shows the average load data of the location of interest.

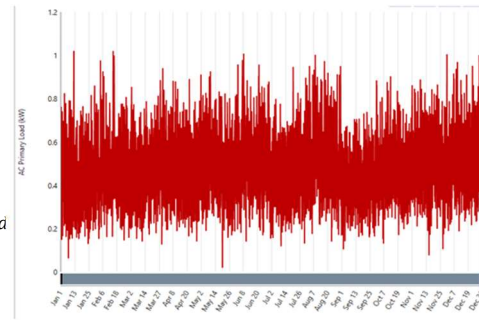


Fig. 1: Three years Load Profile

Satellite meteorological data for Jibia Katsina State Nigeria, obtained from NASA is used to model the developed methods. This actual data is given in Figure 2 and 3

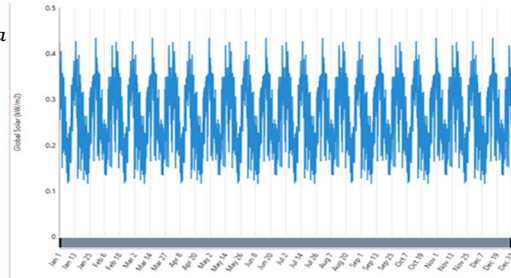


Fig.2: Jibia Solar Insolation

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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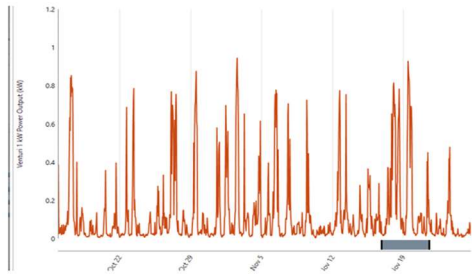


Fig 3: Jibia Wind Speed Data

The metrological data given in Fig.3 shows the wind speed and solar insolation obtained hourly for a period of three years.

3.1 Optimal Sizing Using PSO-GWO Algorithm

The PSO-GWO is a novel metaheuristics algorithm developed to mimic the intelligent behaviours of an agent trailing a smell source (Ahmed T Salawudeen et al., 2018; Salawudeen et al., 2020). To validate the results obtained using the ISAO, the PSO-GWO was used to search for the optimum combination of the renewable energy resources which attain the minimum annual cost while satisfying the energy demand of the selected hospital. The procedure employed to design the PSO-GWO based hybrid renewable energy generation system are detailed as follows:

Objective Function Formulation

The objective function considered in this work is a tri-objective optimization problem where the aim is to minimize the Levelized Cost of Energy (LCOE), Loss of Power Supply Probability (LPSP) and Excess Energy Generated. The individual objective functions can be expressed as follows:

Results analysis for PV/Battery configuration

This section presents the results obtained using the smell agent optimization for the PV and Battery configuration. Though the statistical analysis of the results using best, average and standard deviation were carried out, only the best result obtained were presented in this section. This discussion was made for the discussion purposes only. In the subsequent discussion which will be carried in the latter subsection, detail results will be presented. Table

4.16 gives the best results obtained by PSO-GWO for PV/Battery configurations.

Table 1: Summary of the best results obtained by PSO-GWO for PV/Battery configuration

S/N	Parameters	PSO-GWO
1	N_{PV}	988
2	N_{WT}	—
3	N_{BAT}	1000
4	PV Cost	₦ 19,103,266.46
5	WT Cost	—
6	Battery Cost	₦ 9,028,132.57
7	Conv/Inv Cost	₦ 44,884.97
8	Total	₦ 28,808,890.28

From Table 1 it can be observed that the PV/Battery systems can be designed to meet the required load demand for a total annual cost of 28.8million Naira. For this design, a total of nine hundred and eighty-eight PV panels, one thousand batteries with a design PV cost of 19.1million Naira and battery cost of 9.0million naira respectively. For this configuration, the number of converters required is three. The percentage cost component of the hybrid resources is 91.14% for PV panels, 8.59% for battery and 0.16% for converters respectively. The convergence behaviour of the smell agent optimization showing the minimization procedure of the total annual cost is given in Figure 1

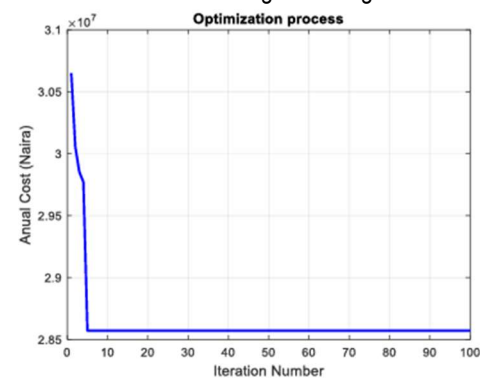


Fig.4: Convergence Characteristics of PSO-GWO

From Figure 4, it can be observed that the PSO-GWO requires only about six iterations to converge to the optimum solution. The

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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convergence in this case implies the iterations point at which the objective function value (Total Annual Cost) does not change again. This convergence was attained after about 0.194525 seconds.

Results analysis for Wind/Battery configuration

This section presents the results obtained when the smell agent optimization is used to optimized the Wind/Battery combinations. Statistical results were obtained and for the purpose of this discussion, the best results obtained over thirty independent runs are presented in Table 2:

Table 1: Summary of the best results obtained by PSO-GWO for Wind/Battery configuration

S/N	Parameters	PSO-GWO
1	N_{PV}	—
2	N_{WT}	300
3	N_{BAT}	250
4	PV Cost	—
5	WT Cost	₦ 26,818,721.49
6	Battery Cost	₦ 2,257,033.14
7	Conv/Inv Cost	₦ 44,884.97
8	Total	₦ 29,753,245.89

From the Table 2, it can be observed that for the Wind/Battery configuration, the total annual cost obtained by GWO is about 29.7million Naira. A total of three hundred PV panels and two hundred and fifty battery is sized to achieve the stated annual cost. The percent cost component of each renewable resources is 67.31 % for wind turbine, 32.34% for Battery and 0.16% for converters respectively. The convergence characteristics of smell agent optimization on this configuration is given in Fig.5.

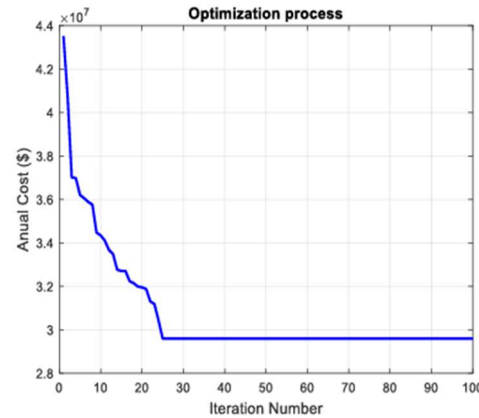


Fig.5: Convergence Characteristics of PSO-GWO

From Fig.5, it can be observed that, for the wind/battery configurations the PSO-GWO took about twenty-five iterations to converge to the optimum of total annual cost. Comparing the wind/battery configurations with the PV/battery configurations, it can be seen that the PSO-GWO takes longer to converge to an optimum solution in the wind/battery configurations. This is expected as the power model of the wind turbine appears to be more computational complex than that of the photovoltaic power model. This computational complexity is also obviously seen as the PSO-GWO took 0.255971 seconds to complete the optimization processes for the wind/battery configurations. This is 75.99% more computational time than the PV/battery configuration.

Results analysis for PV/Wind/Battery configuration.

This section presents the results obtained when the smell agent optimization is used to optimized the hybrid system containing the wind PV, Wind turbines and Battery systems. Statistical results were also presented, but at the main time only the best results are discussed in this subsection. Table 3, gives the summary of the best results obtained for PV/Wind/Battery configurations.

Table 3: Summary of the best results obtained by ISAO for PV/Wind/Battery configuration

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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S/N	Parameters	PSO-GWO
1	N_{PV}	185
2	N_{WT}	236
3	N_{BAT}	226
4	PV Cost	₦ 3,577,028.64
5	WT Cost	₦ 21,097,394.24
6	Battery Cost	₦ 2,040,357.96
7	Conv/Inv Cost	₦ 59,846.63
8	Total	₦ 26,774,627.47

It is seen from Table 4.18 that the hybrid system containing PV/Wind/Battery obtained the most economical design compared to the PV/Battery and Wind/Battery system. The hybrid system obtained a total annual cost of 26.7million Naira. This is achieved for a one hundred and eighty-five PV panels, 236 wind turbines and two hundred and twenty-six batteries. The cost percentage by each sizing component are 13.36%, 78.80%, 7.62% and 0.22% for PV panels, Wind turbines, batteries and converters respectively. The convergence behaviour of smell agent optimization for the PV/Wind/Battery configurations is given in Fig.6

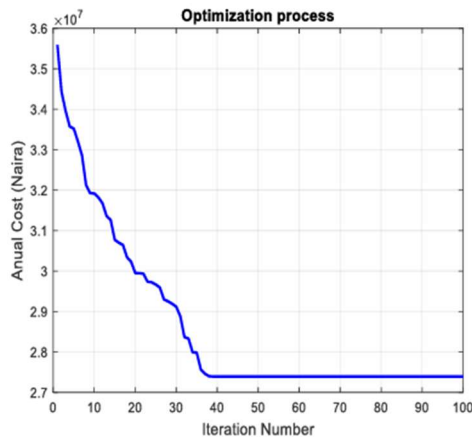


Fig.6: Convergence Characteristics of PSO-GWO

From Fig.6, it can be observed that, the PV/wind/Battery configurations required about thirty-eight iterations to converge to the optimum annual cost. Comparing with the PV/battery and wind/battery configurations, the PSO-GWO requires about 84.21% and 34% more iterations to converge to the optimum annual cost of

PV/Wind/Battery configurations. This can be interpreted as though, the PV/Wind/Battery configuration is more complex system compare to the other systems. This complexity is also supported by the average run time required by the PSO-GWO to complete the optimization process of the hybrid system. For this configuration, the PSO-GWO requires 0.456762 seconds to complete the optimization process. This is about 56.04% and 42.59% more complex than the PV/Battery and Wind/Battery configurations respectively. Table 4 shows the statistical results containing the average, best and standard deviation obtained for thirty independent runs.

	Indices	PSO-GWO
	Average	₦42,948,174.70
PV/Wind/Battery	Best	₦25,800,877.30
	Std	10,938,586.76
	Average	₦46,723,643.89
PV/Battery	Best	₦28,808,890.28
	Std	6,040,314.02
	Average	₦49,396,001.63
Wind/Battery	Best	₦29,753,245.89
	Std	7,311,993.38

From the statistical analysis given in Table 4.19, it can be observed that in any of the hybrid system, the PSO-GWO still obtained the smallest average, and best total annual cost results for PV/Wind/Battery configurations. In the same vein, the results obtained for PV/Battery also shows a better total annual cost in terms of average and best results when compare with that of the Wind/Battery. However, the standard deviation showed that the results obtained for PV/Battery configurations is more stable, than that of the PV/Wind/Battery and Wind/Battery respectively

CONCLUSIONS AND RECOMMENDATION

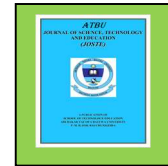
This work presents new optimization methods for sizing off grid hybrid renewable power system using Particel Swarm Optimization Graywolf Optimizatio (PSO-GWO) Real meteorological data for Jibia Katsina State Nigeria, obtained from NASA is used to model the developed methods. Different sizing configuration consisting of PV/Battery, Wind/Battery and PV/Wind/Battery were considered.

Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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Comprehensive comparative study was carried out between the PSO-GWO and the GWO using TAC, LCOE, LPSP and ExE as performance metrics. Results analysis shows the effectiveness of both approaches

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Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.

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Corresponding author: Abba Muhammed Adua.

✉ abbamuhammadadua@yahoo.com

Department of Electrical/Electronics Engineering, Faculty of Engineering, Kebbi State University of Science and Technology, Aliero.
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