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Research Article

A Nobel LLDI Index for Optimal Deployment of RERs Based HES: A Case Study for UDUS

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Abstract—Renewable energy resources (RERs) especially of Wind energy and PV system (together with battery storage system BSS) plays a key role in mitigating carbon emission by deploying and integrating the RERs as hybrid energy system (HES) to existing conventional power system. To ensure reliable and efficient energy solutions of the HES, the deployment is mostly formulated as multi objective optimization problem. To enhanced the optimal capacity deployment of RERs devices, an improved objective function based on proposed lost load dump load index (LLDLI) is proposed. Solution of the optimization problem for the proposed using particle swamp optimization (PSO) in MATLAB/Simulink shows that the convergence rate of the proposed method is faster than the conventional method, thus indicating that the proposed method is more efficient and requires less iteration count to converge to optimal solution. In addition, the case study of Usmanu Danfodiyo University Sokoto (UDUS), Nigeria distribution system which is used as the test system shows that system supply reliability increased by 17.5% for the HES, the deployment and operational cost is minimized by 35% while the contribution of the of the RERs in the HES system is significantly increased to 40%, while significantly minimizing power losses. Conclusively, the proposed method is more robust and efficient for the deployment of HES system to existing power distribution system.

Keywords—RERs, Wind energy, PV system, BSS, HES PSO, LLDI

1. Introduction

Electrical power system will continue to play a vital role in the global economy for improved human development and industrial need [1], and the UN framework for low carbon emission and sustainable development goal [2], the gases have negative effects on mankind and environment [3]. As demand for electrical power increases, the sector is faced with challenges, especially the quest for low carbon economy to reduced carbon emission from conventional power system, limiting cost of generation and increased reliability and efficiency of supply. For these reasons, the share of renewable energy resources or inverter-based resources-IBR (such are wind energy, solar photovoltaic system and distributed generation) in the energy mix of most countries is growing; hence of carbon neutrality for power system generation [4] [5], [6], [7], [8]. Since the renewable energy resources or IBR are available in remote places [9], it is easier to deploy them to cater the need for millions of people in isolated and remote areas for clean and efficient electric power generation. However, renewable energy resources will have effects on the conventional grid due variability of the weather condition, which will have effect on the generated power. Therefore, it is necessary to incorporate renewable energy resources with conventional energy sources such as diesel to build a hybrid energy system that will improve system reliability and support the system in case of weather fluctuation, to cater for the base and peak load [10].

Various researches indicated that, integrating renewable energy resources (solar, wind and battery storage) within the existing energy mix system (diesel and conventional grid), will help reduced capital investment, energy costs and improve system reliability, particularly in developing countries while reducing carbon emission and improving power supply [11]. Other previous work analysed the economic feasibility of integrating renewable energy resources with conventional power system to reduced overall cost. For instance, a combination of PV/diesel system with flywheel energy storage is investigated by [12] the investigation reveals that by reducing the operation of diesel generators the hybrid system could minimize fuel consumption, total Net Present Cost (NPC), Cost of Electricity (COE), and CO2 emissions [12].

A hybrid energy system (HES) is the combination of two or more composite energy resources for electric power generation. It could be a combination of two or more renewable energy resources plus energy storage devices such as battery with conventional power source such as diesel generator, gas turbine or electric grid [13]. HES is important concept in integration of renewable energy resources, because it involves the optimal allocation of resources to balanced demand and supply, while maintaining system stability, reliability at minimal cost and losses. The HES is mostly formulated as an optimization problem, which is mostly solved using metaheuristics techniques to obtained an optimal allocation of HES resources for reliable and efficient electric power generation. Similarly, an optimal system design must be economical and reliable, and this can be achieved with the help of proper selection of components of the system. Thus, an optimizing sizing method is necessary to design an efficient and economical HES [15], for optimal resource allocation. Sequel to these, the two most important concerns for any hybrid systems are the system's power reliability during varying environmental condition with its effects on system stability and the overall cost of the system with its relation to running cost. Most of the authors tried to optimize either or both [16]. Optimization methods are being employed for optimal sizing and sitting of energy resources, the methods includes: (1) software tools (2) conventional techniques such linear and non-linear technique (3) non-conventional techniques such as metaheuristics techniques and (4) hybrid techniques a combination of conventional and non-conventional technique. The non-conventional techniques have advantages such as flexible, adaptability and robustness in handling multi-objective optimization problems, as compared to other techniques.

For the research an optimization problem with constraint will be formulated for the HES using RERs devices plus the conventional DG system. The significant of the research is to improve the share of RERs in the system while maximizing reliability and minimizing overall cost.

The paper is organised as follows: section 1 discussed the introduction of HES, section 2 contains the related work on HES concept, section 3 contains the theoretical concept of HES and its components mathematical model in details, section 4 contains the procedure which includes both the conventional and proposed methods, section 4 contain the results and discussion and section 5 contain the conclusion and future scope.

2. Related Work

Various works were presented on optimal sizing of HES. The authors in [15], [16] and [17] presented a work on optimization problem of a hybrid energy system of wind turbine/PV/battery energy system using PSO, the work in [18] also employed PSO with a combination of Wind/Tidal/PV/Battery energy system for a remote area. The authors work in [19], [20] and [21] employed Homer optimizer for an off-grid and grid connected systems for renewable energy allocation respectively in order to obtain a cost effective and a reliable system operation. Another optimization problem was employed by [22] to obtain an efficient sizing of a HES combination of PV/wind using genetic algorithm which aimed to minimize the cost of the system while ensuring load requirements are meet. The authors in [23] developed a software for feasibility study to determine the solar radiation of a given region, hence the expected output of a given PV system at a given time.

The work in [24] conducted a research on optimization for an academic institution employing HOMER software, the works simulated two scenarios via different combination of energy sources, but the result indicated that, using renewable energy sources with conventional DG appeared less expensive than using conventional DG alone.

The work in [25] proposed optimal planning of Stand-Alone hybrid green power systems using PSO algorithm with combination of PV/wind/electrolyzer and a fuel cell (FC). The work in [26] employed a hybridization of three non-conventional optimization technique viz; the Harmony Search (HS), Jaya and particle swarm optimization (PSO) algorithms in optimal allocation of a HES combination of Wind-Photovoltaic-Biomass-Battery technologies. While the work in [8] proposed parallel multi objective PSO-based approach (PPSO), a merger of four optimization techniques to optimally design a HES of photovoltaic/diesel/battery as a Nano-grid.

Another approach was proposed by [27] for optimizing a standalone HES, employing four different set of optimization techniques. Combination of PV/wind/BESS were simulated with each of the metaheuristics technique of ant colony optimization (ACO), flower pollination algorithm (FPA), genetic algorithm (GA) and particle swarm optimization (PSO). HOMER pro and integrated CRITIC-PROMETHEE II approaches was utilized by [28] to examine six scenarios that had various combinations of the grid, diesel, and renewable energy resources of solar PV, wind, biogas, and battery. The work in [29], [30] and [31] employed Homer energy to investigate the technoeconomic performance and environmental effect of the system. The work in [32] combined grid connected and off grid system to investigate the reliability and cost analysis of the two combinations.

Most of the work reviewed, the researchers focus on reducing cost of the system without considering the effect of excess power generation and its effect on system reliability, performance and atmospheric effect on the system. To enhanced the optimal allocation of renewable energy resource of PV system, wind energy and battery storage system (BSS) together with the conventional diesel generator (DG) for the HES, a novel index referred to lost load dump load index (LLDLI) is proposed to enhanced the conventional optimization method in other to obtain optimal solution for allocation of RERs devices for the HES, while minimizing operational cost of the conventional energy resources at the same time enhancing system reliability and reliability. The proposed method will be reduced both deployment and operational cost, reduced power loss while improving the reliability and quality of electric power supply by the HES.

3. Theory

3.1 Introduction to Hybrid Energy System (HES)

The HES consist of renewable energy resources of solar PV, wind turbine, and battery energy storage and a combination diesel generating system. The power generated by the renewable energy resources are converted to DC voltage at a common DC bus before been feed to the AC bus via the central inverter. The AC bus consist of the diesel generating system, power been generated from the renewable energy resources, the AC load and the proposed dump load (which can be used for other purposes such as heating or battery charging). The excess power generated by the renewable energy components is used to charge the battery. In an event where the generated power cannot meet the load demand, the BSS is used to provide the required power demand. However, if the generated power and the stored power cannot meet the load requirements, the diesel generating systems come up to provide both the base and peak load demand. The diagram of HES for the overall system is depicted in Figure 1.

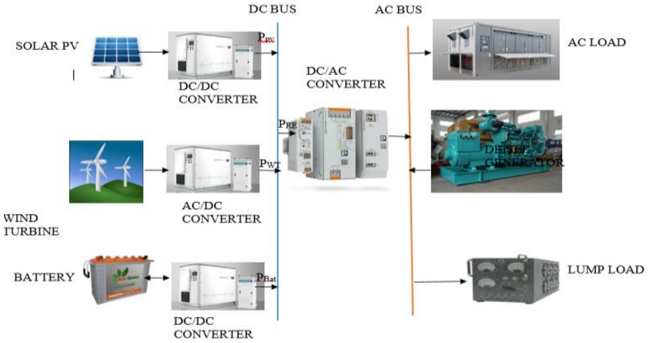

Figure 1. Diagram HES for the overall system

3.2 PV System Modeling

The output of the PV system depends on the solar radiation and the cell temperature of the. The power output is governed by equation 1 [5].

$$P_{pv} = \frac{G \times P_r \times \left[1 + K\left(\left(T_a\left[\left(CT-20\right)/800\right]G\right) - T_r\right)\right]}{G_r} \quad (1)$$

Where P_{PV} and P_r are the output power of the PV (depending on atmospheric condition) and the manufacturer rated power in watts (W) at the standard test condition (STC), respectively. K represent the temperature coefficient, defined as (-3.7×10^{-3}(1/°C)). T_r represent the reference cell temperature (°C) at STC, T_a represents the ambient temperature (T_a =25 °C); G defined the solar radiation (W/m^2) at given atmospheric conditions; G_r defined the reference solar radiation at STC (G_r =1000W/m^2); CT is the nominal operating cell temperature. The inverter efficiency of the PV system is given by equation 2 [33]. With the respective parameters given as the equations 3 through 5.

$$\eta_{inv} = \frac{P}{P + P_0 + kP^2} \quad (2)$$

$$P = \frac{P_{out}}{P_{Nom}} \quad (3)$$

$$P_0 = \frac{\frac{10}{\eta_{10}} - \frac{1}{\eta_{100}} - 9}{99} \quad (4)$$

$$k = \frac{1}{\eta_{100}} - \eta_0 - 1 \quad (5)$$

Where η_{10} *and* η_{100} are the inverter efficiency value at 10% and 100% of its nominal rated power.

3.3 Wind Energy System Modeling

Due to variability of wind speed within short period of time, wind generator output power, the measured wind speed at reference height is first converted to corresponding wind turbine (WT) hub height. The power law equation is governed as equation 6 equation [5].

$$\frac{V_1}{V_2} = \left(\frac{h}{h_r}\right)^{\alpha} \quad (6)$$

Where h (m) defined WT hub height, and h_r (m) defined as WT reference height. V_1 (m/s) defined as the wind speed at WT hub height and V_2 (m/s) defined as the speed at the reference height. α is the power-law exponential (also known as Hellmann exponent, wind gradient, or power law exponent). Wind turbine output power can be modelled as conditional equation as in equation 7:

$$P_{WT} = \begin{cases} o \\ if\ v \prec v_{c-i} \\ v^3\left(\frac{p_r}{v_r^3 - v_{c-i}^3}\right) - p_r\left(\frac{v_{c-i}^3}{v_r^3 - v_{c-i}^3}\right) \\ if\ v_{c-i} \le v \prec v_r \\ p_r \\ if\ v_r \le v \le v_{c-o} \\ 0 \\ if\ v \ge v_{c-o} \end{cases} \quad (7)$$

Where P_r (kW) defined as rated power of the WT, V_{c-o} (m/s) defined as cut-out speed of the WT, V_r (m/s) is defined as nominal speed of the WT , V_{c-i} (m/s) is defined as cut-in speed of the WT and V (m/s) is defined wind speed at a given time interval.

3.4 Battery Energy System Modeling

Battery energy storage system consist of the battery and its control system for charging and discharging. The main function of BSS is serving as back -up for storing excess renewable energy at period of low demand and also to use the stored energy at period of high load demand or low renewable energy generation. The battery capacity is designed based on desired day of low to zero renewable energy availability and energy demand based on the equation 8 [5].

$$C_B = \frac{P_{load} \times AD}{\eta_{Bat} \times DOD \times \eta_{inv}} \tag{8}$$

DOD is defined as depth of discharge usually (80%), η_{inv} defined as inverter efficiency usually (95%), η_{Bat} is defined as battery efficiency usually (85%) and AD defined as number of autonomy day, which is based on system capacity requirement.

State of charge of the battery at a given time interval (t) is defined as SOC(t) with maximum and minimum state respectively. When any of the RERs produces excess or deficit energy, this excess or deficit energy denotes the power that is either absorbed or delivered by the battery. This can be expressed as equation 9.

$$P_{Bat}(t) = P_{pv}(t) + P_{WT}(t) - \frac{P_{load}(t)}{\eta_{inv}} \tag{9}$$

When $P_{Bat}\left(t\right) \prec 0$ it indicates low demand or low generation by RERs, else $P_{Bat}\left(t\right) \succ 0$ indicates a surplus in power generation by RERs at a given time instance.

Moreover, the charging of the BES occurs at a time when $SOC\left(t\right) \prec SOC_{\max}$ and when $\left(P_{PV}(t) + P_{WT}(t) > P_{load}(t)\right)$. Thus; $SOC\left(t\right)$ can be as defined as equation 10. And when there is less in power generation or high demand, then $SOC\left(t\right) \succ SOC_{\max}$ which implies the battery energy storage will discharge the energy stored to meet the load demand as defined in equation 11.

$$SOC(t) = SOC(t-1)\left(1-\gamma\right) + \left(P_{Bat}(t) \times \eta_{Bat}\right) \tag{10}$$

$$SOC(t) = SOC(t-1)\left(1-\gamma\right) + \left(-P_{Bat}(t) \times \eta_{Bat}\right) \tag{11}$$

Where γ is the self-discharging rate of the battery storage system.

3.5 Diesel Generator Modeling

The diesel generator (DG) can serve as source to meet the requirement for the base and peak load in the event of low or zero generation by RERs. The fuel consumption rate is modelled as equation 12 [5].

$$F(t) = aP_{DG}(t) + bP_r \tag{12}$$

P_{DG} is defined as generated power (kW), $F(t)$ is defined as fuel consumption rate in (L/hour), P_r is defined as rated power (kW) of the DG. While a and b are constant parameters in (L/kW), which represent the coefficients of fuel consumption, and can be approximated to 0.246 and 0.08415, respectively [5]. Also, the efficiency of the DG can be calculated as equation 13.

$$\eta_{overall} = \eta_{break-thermal} \times \eta_{generator} \tag{13}$$

3.6 Particle Swamp Optimization (PSO) Technique

The important task of any optimization problem involving HES is to find the optimal solution for allocation of RERs that will meet the required demand of the HES for efficient and reliable power generation, one of the metaheuristics techniques used is particle swamp optimization (PSO) The particles swam optimization (PSO) technique was developed by Eberhart and Kennedy in 1995 for solving non-linear, multidimensional optimization problems [34].

The searching strategy of PSO algorithm mimicking the social behaviours of birds flocking or fish schooling, where each particle position of the swarm acts as a potential solution of certain optimization problem. PSO algorithm is employed to intelligently select optimal parameters from N particles. The initialization matrix contains N particles dispersed in a search space of D-dimension [34].

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At the k^{th} iteration in the searching process, the i^{th} particle stores its historical best position P_{best} as represented by $\left(p_b(k) = p_{i1}(k), p_{i2}(k)......p_{iD}(k)\right)$ and its global best particle P_{gb} as denoted by $\left(p_{gb}(k) = p_{gb1}(k), p_{gb2}(k)......p_{gbD}(k)\right)$. The process of displacement of each particle is achieved by the following rules [19].

- The particle tends to take the direction of its current velocity
- The particle tends to move toward its best position
- The particle tends to move to the best position reached by its neighbors

Similarly, the position of the particle will be updated to reach the global optimum based on the corresponding velocity vector. Moreover, the velocity and the position vectors of the particle at the iteration k will be determined by the equations 14 and 15 respectively. Where k is the number of the current iteration w is the inertia weight and are the acceleration coefficients respectively, cognitive and social parameters and are two uniformly distributed random numbers between (0, 1) [5]. Figure 2 depicts the flowchart of solving HES problem using PSO.

$$V_i(k+1) = wV_i(k) + c_1 r_1 \left(p_b(k) - x_i(k)\right) + c_2 r_2 \left(p_{gb}(k) - x_i(k)\right) \quad (14)$$

$$x_i\left(k+1\right) = x_i\left(k\right) + V_i\left(k+1\right) \quad (15)$$

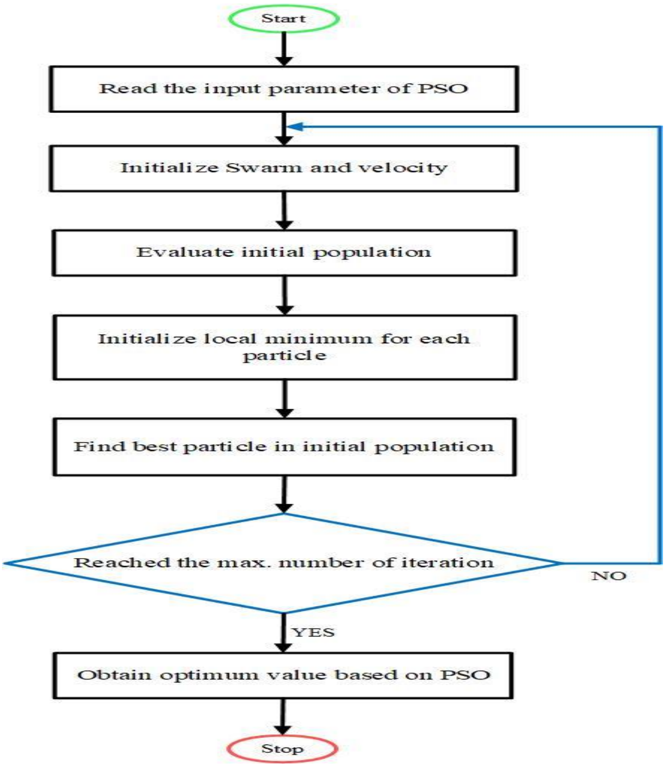


Figure 2. Flow chart of solving HES problem with PSO

4. Method

4.1 Conventional Method of Objective Function Formulation

The conventional objective is formulated using the following indices: levelized cost of energy (LCOE), loss of power supply probability (LPSP) and renewable factor (RF). The objective function is formulated as equation 16.

$$\min\left(OF = w_{LCOE} LCOE + w_{LPSP} LPSP + w_{RF} RF\right) \quad (16)$$

Levelized Cost of Energy (LCOE): It includes the initial, operational and maintenance costs of the system. It is the price of each unit of energy produced ($/kw). To convert the initial cost into an annual capital cost, the capital recovery factor CRF is given as [28]. With I is the interest rate and n as the life span of the system components. Equations 17 through 19 represents the LCOE index [35].

$$LCOE = \frac{\left(C_{PV} + C_{WT} + C_{DG} + C_{BES}\right)CRF}{\sum_{t=1}^{8760} P_t^{Load}} \quad (17)$$

$$LCOE = \frac{\left(NPC\right)CRF}{\sum_{t=1}^{8760} P_t^{Load}} \quad (18)$$

$$CRF = \frac{i\left(1+i\right)^n}{\left(1+i\right)^n - 1} \quad (19)$$

Cost of Solar PV $\left(C_{PV}\right)$ is defined as equation 20, with C_{PV}^{Cap} as the capital cost of the PV panel and $C_{PV}^{O\&M}$ is the operation and maintenance cost of the PV panel. Cost of inverter $\left(C_{INV}\right)$ system is defined as equation 21, with C_{INV}^{Cap} as the capital cost of the inverter system and $C_{INV}^{O\&M}$ is the operation and maintenance cost of the inverter system.

$$C_{PV} = \left(C_{PV}^{Cap} + C_{PV}^{O\&M}\right)P_{pv} \quad (20)$$

$$C_{INV} = C_{INV}^{Cap} + C_{INV}^{O\&M} \quad (21)$$

Cost of wind turbine $\left(C_{WT}\right)$ is defined as equation 22, with C_{WT}^{Cap} is the capital cost of the wind turbine and $C_{WT}^{O\&M}$ is the operation and maintenance cost of the wind turbine. Cost of battery energy storage system $\left(C_{BES}\right)$ is defined as equation 23, with C_{BES}^{Cap} is the capital cost of the battery energy storage system $C_{BES}^{O\&M}$ is the operation and maintenance cost of the battery energy storage system. Cost of diesel generator $\left(C_{DG}\right)$ is defined as equation 24, with C_{DG}^{Cap} is the capital cost of the diesel generator and $C_{DG}^{O\&M}$ is the operation and maintenance cost of the diesel generator.

$$C_{WT} = C_{WT}^{Cap} + C_{WT}^{O\&M} \quad (22)$$

$$C_{BES} = C_{BES}^{Cap} + C_{BES}^{O\&M} \quad (23)$$

$$C_{DG} = C_{DG}^{Cap} + C_{DG}^{O\&M} + C_{DG}^{Fuel} \quad (24)$$

Loss of power supply probability (LPSP): The probability of the HES to meet the load demand at a given time instance is defined by the LPSP. The LPSP is a reliability index, which indicates the probability of the HES to meet the energy demand. The LPSP value must be less than 5% based on the literature. It can be expressed equation 25 [5]. All the parameters have their definitions as defined above at a given tim instance.

$$LPSP = \frac{\sum P_L\left(t\right) - \left(P_{PV}\left(t\right) - P_{WT}\left(t\right) + P_{DG}\left(t\right) + P_{Bat\min}\right)}{\sum P_L\left(t\right)} \quad (25)$$

Renewable factor (RF): Renewable factor (RF) is defined as the ratio between the diesel generator power to the power generated by RERs at a given time. The best system is aimed to minimize the utilization of diesel generator, and hence minimize the operation cost and CO_2 emission. It can be express as equation 26, all parameters have their definitions as defined above.

$$RF\left(\%\right) = \left(1 - \frac{\sum P_{DG}\left(t\right)}{\sum P_{PV}\left(t\right) + P_{WT}\left(t\right)}\right) \times 100 \quad (26)$$

4.2 Proposed Method of Objective Function Formulation

The LLDLI is proposed as to be the ratio between the loss power to the dump load. This will help to balance the system to avoid sub optimal selection of RERs components that will generate unwanted excess power by the system. The LLDLI will also monitor and maintain a minimum LPSP, equation 27 represents the proposed index. Substituting equation 27 into equation 16, equation 28 is the proposed objective function, which is used to enhanced optimal allocation of HES resources, therefore making the system more cost effective with reduced loss, while maintaining the quality and reliability of electric power generated and an additional feature called the Loss Load Dump Load Index (LLDLI). The LLDLI is the ratio between the lost load and the dump load. P_{LOAD} is defined as the total load demand and P_{EXT} is the excess power generated by the system.

$$LLDLI = \left| \frac{\left(\Sigma \left| P_{EXT} \left(P_{EXT} \le 0 \right) \right| \right)}{\Sigma P_{LOAD} - \Sigma \left(P_{EXT} \ge 0 \right)} \right| \tag{27}$$

$$\min \left(OF = \left(w_{LCOE} LCOE + w_{LPSP} LPSP + w_{RF} RF \right) + \left(w_{LLDLI} LLDLI \right) \right)$$
(28)

The system constraints are the high percentage of the renewable factor, minimum or zero LPSP and the renewable energy resources design constraints including the BES system, which will ensure optimal energy generation. Thus, the main objective function is minimizing the system operational cost. Equations 29 through 31 are the constraints for the proposed objective function of the HES.

$$0 \le RF \le 100 \tag{29}$$

$$\left| LPSP \right| \le 0 \tag{30}$$

$$\begin{cases} 0 \le N_{PV} \le 7451 \\ 0 \le N_{WT} \le 500 \\ 0 \le N_{BES} \le 1563 \end{cases} \tag{31}$$

The flowchart of the HES optimization solution is depicted in Figure 3, while the PSO optimization parameters used for the study are given in Table1.

Table 1. PSO Simulation Parameters

Parameter	Value
Population size	50
Maximum number of iterations	100
Cognitive parameter c_1	1
Social parameter c_2	3

5. Results and Discussion

Simulation studies were conducted for the HES multi-objective optimization problem; the optimization problem is solved using PSO in MATLAB R2018a software on a TOSHIBA PC with 8GB RAM, 1.8GHz intel core i5 processor. Simulation studies were conducted for both the conventional and proposed objective function. The optimization is run for each combination using 50 number of swarms as the population size and 100 iterations. The conventional and proposed methods were used to find the optimal solution and the optimal sizing and allocation of RERs and the conventional DG allocation. The proposed method is compared with the conventional method; with the proposed method, the indices of the HES optimization problem were minimized; thus, indicating enhanced optimal allocation of RERs resources.

As depicted in table two, the LCOE index of the conventional method is larger than the LCOE index with the proposed method, thus indicating an optimal solution is achieved in terms of overall cost reduction of 35% for the HES. In terms of the LPSP index, the solution indicates that the overall supply reliability is enhanced by 17.42%, since the index with conventional method is greater than the index with proposed method. For the REF index, the contribution of the RERs in the system is increased by 40%, since the index with conventional method is much lower than the index with the proposed method. For the proposed method, the value of LLDLI index of 0.339373 indicates that by reaching an optimal solution for the RERs, less power loss is achieved, hence enhancing the HES optimal performance.

Convergence rate of the PSO is faster with the proposed method, as compared with the conventional method. Thus, the LLDLI index results to more efficiency in the objective function with less iteration count required to converge at an optimal solution. Figure 3 depicts the convergence characteristics of the PSO using both methods.

Table 2. Comparison Indices for the Conventional and Proposed Method

Objective Function	LCOE	LPSP	REF	LLDLI
Conventional	0.246972	0.295228	6.308086	-
Proposed	0.160518	0.243792	3.798826	0.339373

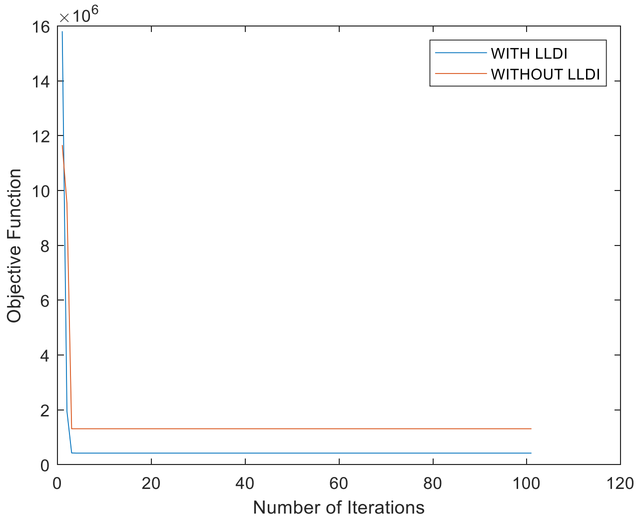
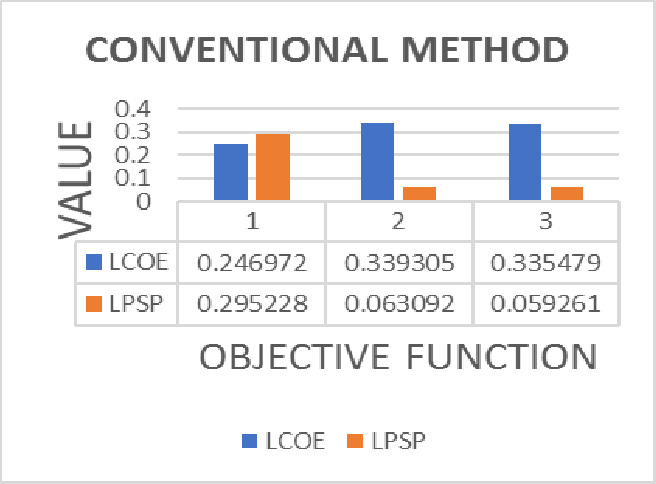


Figure 3. Convergence characteristics of PSO with both methods

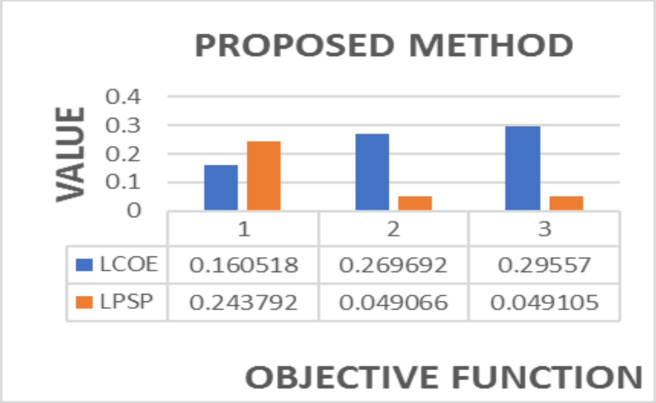
Figure 4 and Figure 5 depicts the comparison of LCOE and LPSP for conventional and proposed method at various values respectively. From the comparison it can be deduced that a reduction in index value at different value with the proposed method indicates that overall cost is reduced, while enhancing supply reliability. Thus, proposed LLDLI improves HES reliability and reduced overall cost.

Optimal solution obtained shows that best configuration of RERs and conventional energy resource are showing a total of 7451units of PVs, 500 unit of WT, 1563 units of BES and 8 units of DG respectively will be deployed; to supply the load demand of approximately 2500kW. From figure 6, the average power contributed by each RERs are, 2,459kW PV, 2,500kW WT, 2,800kW DG and 2,501kWh battery. If the total power generated satisfied the load, and the excess power will be used to charge the battery storage system.



	1	2	3
■ LCOE	0.246972	0.339305	0.335479
■ LPSP	0.295228	0.063092	0.059261

Figure 4. Results of LCOE and LPSP with Conventional Method



	1	2	3
■ LCOE	0.160518	0.269692	0.29557
■ LPSP	0.243792	0.049066	0.049105

Figure 5. Results of LCOE and LPSP with Proposed Method

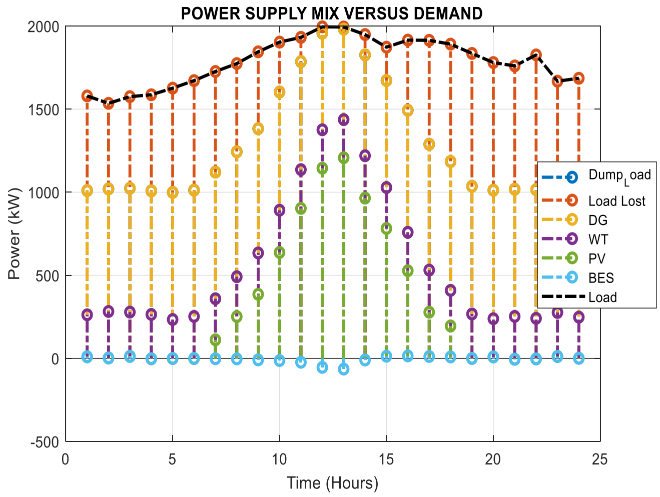


Figure 6. Output Power Supply of the HES Components

While figure 7 depicts the variation of LCOE with respect to LPSP using the proposed method, as can be seen, as the cost decreased the supply reliability increased, thus indicating optimal solution to HES configuration. Figure 8 shows the variation of the proposed objective function with respect to LPSP, both are increasing in commensurate manner, thus indicating less power loss while improving supply reliability. While figure 9 depicts the variation of proposed LLDLI with respect to LPSP, the variation indicates a linear relation between the indices, thus it shows that as the power loss decrease, the supply reliability is increased.

Figure 10 shows the variation of RERs components and DG resource with respect to the LPSP using the proposed method, it indicates that as the contribution of individual slightly varies with reliability of supply. While figure11 shows the variation of HES system component with respect to LPSP, the results shoes that the system cost varies slightly with reliability of supply.

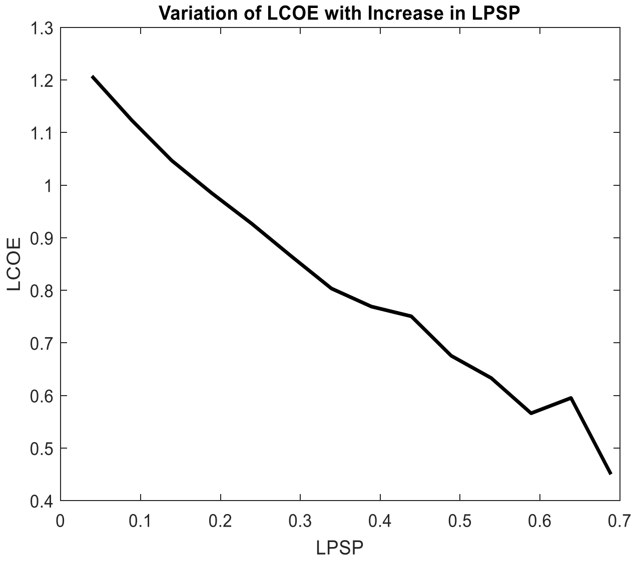


Figure 7. Variation of LCOE with increase in LPSP

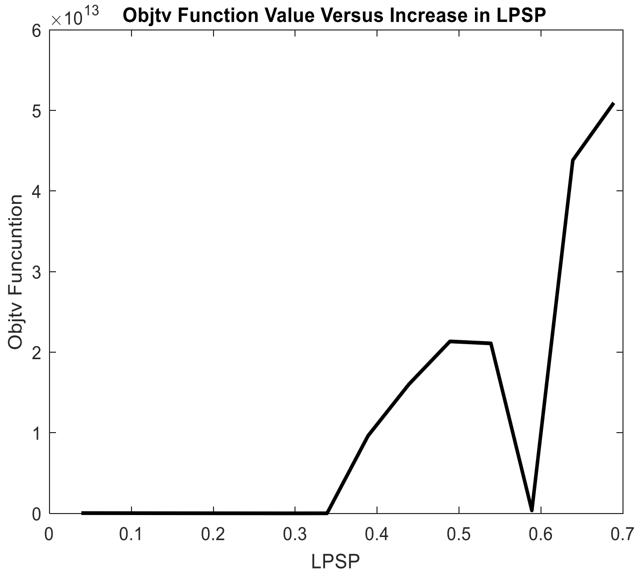


Figure 8. Variation of objective function with increase in LPSP

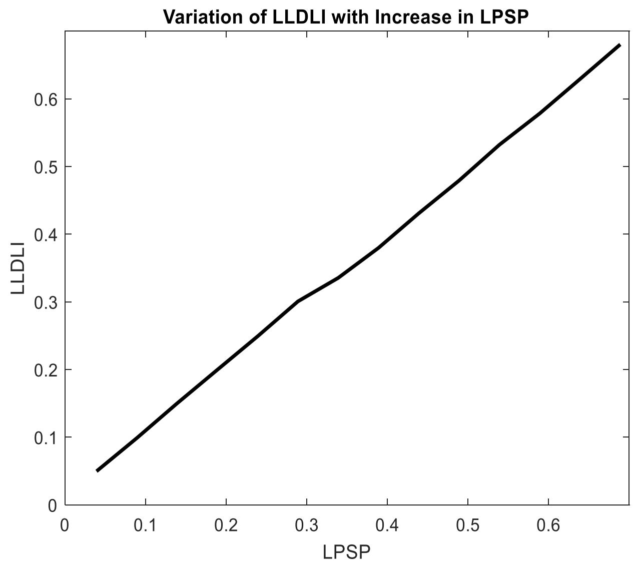


Figure 9. Variation of LLDLI with increase in LPSP

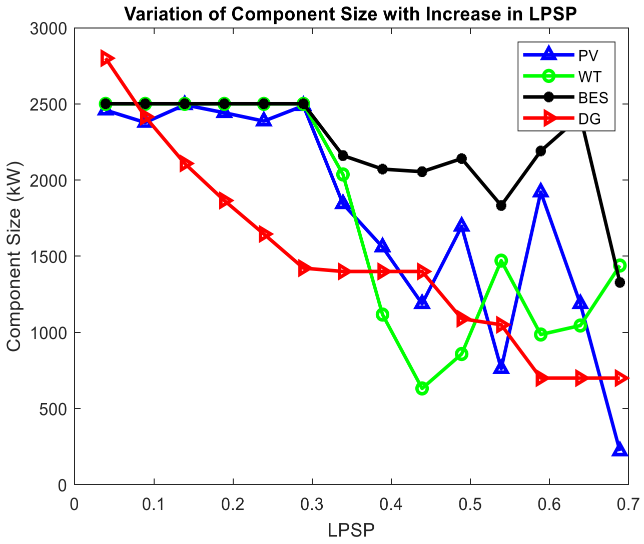


Figure 10. Variation of components size with increase in LPSP

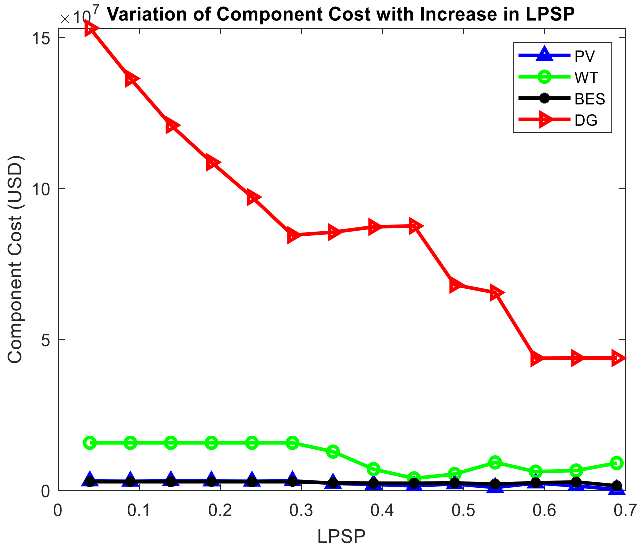


Figure 11. Variation of components cost with increase in LPSP

6. Conclusion and Future Scope

The quest for low carbon economy and the need to improve human development index in terms of low energy poverty especially in rural areas global south nations, leads to deployment of renewable energy resources (RERs) especially of photovoltaic (PV) and wind system to an existing distribution power system. The RERs are integrated to an existing diesel generator system (DG) or power grid as hybrid energy system (HES). The HES system in power system is mostly formulated as an optimization problem, which is usually solved using metaheuristics techniques such as PSO in other to find the optimal solution for the best configuration of RERs devices. The research work proposed a novel index known as lost load dump load index (LLDLI), which main function is to minimize the power loss, while improving reliability of supply and decreasing overall cost of the HES system.

Solution of the objective function using the proposed index via PSO shows that optimal solution is achieved via fast convergence; while best configuration of RERs devices are fund, while at the same time taken cognizance of cost minimization and reliability of supply maximization. The proposed method is used as a case study for distribution system of Usmanu Danfodiyo University Sokoto (UDUS) in Sokoto Nigeria. Simulation studies shows that the proposed method enhanced reliability of supply, overall cost of the HES, RERs contribution and power loss reduction by 35%, 17.42%, 40% and 33.93% respectively. Also, various simulation studies conducted verified the novelty of the proposed LLDLI index in terms of conventional LCOE, RERs components, and objective function variations were all improved. Conclusively, HES requires careful planning to meet the reliability and stability of supply while minimizing overall cost of deployment and running cost.

Future scope should include optimization of energy management considering electric vehicle, hosting capacity of the university distribution system to 100% renewable integration and electric market design including peer to peer (P2P) trading.

Data Availability

Data is available for the wind speed and solar radiation via Nigeria Metrological Agency (NIMET) website at https://nimet.gov.ng

Conflict of Interest

Authors declare that they do not have any conflict of interest.

Funding Source
None

Authors' Contributions

Nasiru Abubakar: Conceptualization; Data collection; Data analysis; Methodology; Simulation; Validation; Visualization; Writing—original draft. Inuwa Barau Inuwa: Conceptualization; Methodology; Simulation; Drawings;

Writing-review-editing. Zahraddin Umar Dahiru: Investigation; Supervision; Simulation; Validation.

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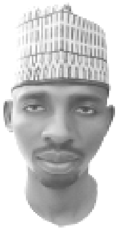

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