Optimal Power Scheduling of Hybrid Power System

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***Abstract*—Integration of renewable generation in distribution system provides energy security i.e. continuously satisfied load, substantial cost savings, and reduction in greenhouse gas emissions. The present work formulates a mathematical model for power scheduling of a hybrid power system connected to a distribution grid, combines solar PV/wind/diesel power resources with battery storage. The formulation of our model is considered by the minimization of total fuel cost and the minimization of Total Transferred Power Transaction Cost of the distribution grid, which has been optimized by using the particle swarm optimization technique. In addition to this, the battery cost is optimized, where the numerical test is performed on the High Renewable Penetration(HRP) 38 test system for 24hr. The obtained results are also compared with the Grey Wolf Optimization technique.**

***Index Terms*—Power scheduling, Hybrid power system, Renewable generation, Optimization**

I. Introduction

Energy is the driving force for the Sustainable development of any country so this sector plays a very essential part in the growth and economy of the country. Due to the distance from power producing plants, electricity supply to rural areas has long been a serious concern. These communities rely on microgrids for power. Microgrids have traditionally relied on diesel generators and diesel generators as backup generators to generate electricity, but with advancements in grid technology, renewable energy sources such as wind and solar energy resources, as well as energy storage systems (ESS), have begun to be integrated as controllable entities that can operate in islanded or grid-connected modes. For this, combine different power resources such as photovoltaic systems (PV), wind turbines (WT), micro-turbines (MT), storage batteries (SB), diesel generators, and fuel cells (FC) to improve hybrid supply reliability and overcome the negative impacts of intermittent sources on the grid reliability and power quality.

Location where grid power availability is poor, Grid-independent hybrid renewable energy systems (HRESs) become cost-effective and eco-friendly. A hybrid photovoltaic(PV)/wind/diesel/battery system are modeled and simulated [1] and hydrothermal generation scheduling with several objectives in the immediate term(HTGS) with weighting approach together with Predator-prey optimization (PPO) and Powell's pattern search (PPS) [2] has become customary to minimize fuel costs of thermal and to attenuate the daily operation cost. Besides to achieve this genetic algorithm(GA) [3] is applied on hybrid renewable energy system which has PV, wind generator and batteries and to reduce the electricity bill of the customer, a traditional method, Interior Point (IP) Method and GA [4] has been applied on a hybrid photovoltaic-battery system connected within the premises of a residential customer.

A revolutionary concept known as prosumer microgrid (PMG) (a consumer who generates and consumes energy at the same time) has been proposed to facilitate the event of DG devices. Within the energy sector, the rising concept of PMG has resulted in a revolution in energy management. Through the use of the energy storage system (ESS) and generation power resources, the energy system's designers would be able to ensure that demand was met at all times. PMG requires an online energy management system to control ESS or the battery storage system (BSS), maximise profitability, and reduce operation and emission costs (EMS) [5]. The optimal operation of PMGs may be hampered by weather-related uncertainties in load consumption and renewable DG unit output power. As a result, recent research efforts have been interested in anticipating weather characteristics and load demand to increase the PMGs' optimal functioning. For Wind and solar parameter prediction different machine learning algorithms [6], were applied with Artificial Neural Network (ANN) [7].

Availability of Power is one of the biggest concerns in the field of renewable energy because these energies are uncertain and at the time of demand, these are unavailable. Due to this unpredictable nature, grid-connected hybrid power systems are preferred. To satisfy load demand, minimize operation cost and emission cost, a Regional Renewable Electricity Economic Optimization Model (RREEOM) [8] has run for three different storage technologies: centralised hydrogen, centralised batteries, and grid integrated vehicles (GIV) and for wind power, thermal power, and cascaded hydroelectric systems, a strong security-constrained unit commitment model is constructed [9]. A Mixed Integer Linear Programming (MILP) problem

[10] has been suggested to optimise the revenue received by selling energy generated by PVs. Many researchers have focused on Microgrid energy management which includes demand response, the uncertainty of renewable power output and load demand [11]. Various optimization technique has been proposed to satisfy load demand, minimize operation cost and emission cost i.e. a novel sine cosine algorithm (SCA) [12] has been implemented where clean wind energy has been integrated with the hydrothermal scheduling problem, Genetic Algorithm (GA) [13] and Two-Point Estimate Method (2PEM) has been applied on thermal-wind-solar power system with storage and a niche particle swarm optimization (NPSO) [14] is proposed to reduce the impact of wind and PV power's volatility on the power grid on the Hydro-photovoltaic-wind-battery system. Along with this different optimization tools like HOMAR [15], iGOGA [16] has been used for a different combination of power resources.
Following a review of a wide range of literature it was discovered that a wide range of research areas revolve around the integration of renewable sources and another source of energy in the electrical grid, traction field, or micro grid. This will provide optimum supply stability, fuel and cost savings, and provide a high level of energy security through a mix of generation technologies. The authors of [17] offered a method to optimal power flow (OPF) problems for hybrid power systems using renewable energy sources such as wind and solar power, but they did not include an energy management strategy and power storage, therefore power exchange between production, grid and storage were absent. We have a hybrid system with storage connected to grid in this study, and the change of each source with the load is examined, which is what inspires our approach.
The rest of this paper is explained in different sections. Section II presents the problem formulation; system description, models of energy sources and energy storage and mathematical formulation of optimization function are explained. Section III discusses the optimization technique, whose result is compared in section IV and the conclusion is in Section V.

II. PROBLEM FORMULATION

A. System Model

Fig.1 shows a typical design of a grid-connected hybrid source system and the parameters of this model are provided in Table I. The dataset used for analysis of our system is HRP(High Renewable Penetration)-38 test bus system from IEEE DataPort [18] is used to determine the efficacy of the suggested optimum scheduling strategy, which takes into account PV generators, wind generators, diesel generators, and storage. This 38 test bus system provides the capacity factor of solar PV and wind power generators, as well as load data. And, the hybrid generation system will be linked to the main grid, which will provide power to the load and all PV and wind producers will employ Maximum power point tracking (MPPT) method.

TABLE I: The Model's Parameters

Parameters	Value
Number of time slots(T)	24(hr)
Time between intervals	1(hr)
The total number of PV arrays	21
Total number of WT	39
Energy-sale cost	1.147 ($/kWh)
Cost of purchasing energy(night) Cost of purchasing energy(day)	0.307 ($/kWh) 0.617 ($/kWh)
PV arrays' maximum power ($P_{PV,max}$) for i = PV1 to PV14 for i = PV15 to PV21	 0.733 (p.u.) 0.585 (p.u.)
Max WT power($P_{WT,max}$)	0.3923 (p.u.)
Scaled base	5 kW
a b c	0.246 0.0815 0.4333
Battery's maximum power	1 (p.u.)
Minimum State of charge(SOC_{min})	50 ($0.2 * P_{b_{max}}$)
Maximum State of charge($S0C_{max}$)	100 % ($P_{b_{max}}$)
Initial Condition of SOC	70 %
Max. power from utility	15KW
Battery cost per KWh	0.1

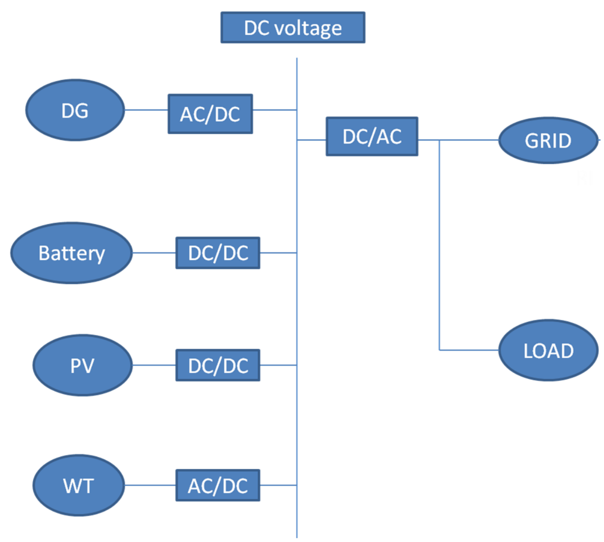

Fig. 1: Typical configuration of the grid-connected hybrid energy source system.

B. Hybrid system components description and operation

In this energy management strategy, The load is satisfied first by the sum of PV, Wind, Grid, and diesel power, and excess energy charges the batteries if their state of charge is in the stated minimum and maximum SOC ranges in this energy management approach. When demand exceeds the generated power from these power resources and the battery, the battery is initially operated, and it is in the discharging phase. A further increase in demand will update the grid and diesel power which also affect the charging and discharging cycle of battery. In the section below, the mathematical models of the system's many components (power sources) are presented:

1) Wind energy : Wind energy is abundant in the environment and is free of any cost factor that may be used to generate electricity. The kinetic energy of moving air is converted into mechanical power by wind energy systems.

The wind power generation (P_{WT}) is,

$$P_{WT} = P_{wr} * Cf_w \quad (1)$$

where:
P_{WT} power generated by wind turbine
p_{wr} wind generator rated power
Cf_w capacity factor of wind power generator

2) PV energy: PV materials and devices convert sunlight into electrical energy via a natural phenomenon that occurs in particular types of materials known as semiconductors.

The solar power generation (P_{PV}) is,

$$P_{PV} = P_{sr} * Cf_s \quad (2)$$

where:
P_{PV} power generated by PV system
P_{sr} solar generator rated power
Cf_v capacity factor of solar power generator

3) Diesel generator [1]: The Fuel cost model ($F_{th}(p_i)$) is,

$$F_{th}(p_i) = \sum_{i=1}^{n_t}(c + b \times p_i + a \times p_i^2) \quad (3)$$

where a, b, c are the parameters related to any DG's fuel consumption curve, P_i is the output power.

4) Battery storage system: The battery is used to balance electricity between supply and demand, as well as to store energy. Because of the charging and discharging processes, which are determined by calculating net energy and state of charge, the battery's input power can be negative or positive. Net Energy = $load(P_l) - (P_{WT} + P_{PV} + P_{grid} + P_i)$

Charging state (Net energy<0 and SOC<SOC_{max})

$$E_{ch} = max(Netenergy, (SOC - SOC_{max})) \quad (4)$$

$$SOC = SOC - E_{ch} \quad (5)$$

$$E_b = E_{ch} \quad (6)$$

where:
E_{ch} is charging amount of battery.
E_b is incriminate amount of the battery.

Discharging state (Net energy>0 and SOC>SOC_{min})

$$E_{dch(T)} = min(Netenergy, (SOC - SOC_{min})) \quad (7)$$

$$SOC = SOC - E_{dch} \quad (8)$$

$$E_b = E_{dch} \quad (9)$$

where:
E_{dch} is discharging amount of battery.
E_b is incriminate amount of the battery.

Battery Cost: Discharge is the power that is bought from the customer while the charge is calculated from a diesel generator.

$$B_c = E_{dch(T)} * BS_T \quad (10)$$

where : B_c is the cost of battery($).
BS_T is the battery cost per KWh.

5) Grid energy: Time of Use pricing scheme has been used for calculation of grid cost, cost of energy export, and import from distribution grid.

$$G_c = GP * \textit{Cost of selling/buying energy} \quad (11)$$

where; GP is the grid power.
G_c is the cost of Grid($).

C. Objective Function

The purpose of this objective is to lower the cost of fuel and also minimize the total transferred Power transaction Cost of the grid. In addition, as a supplemental function, the third term is incorporated as a battery cost on our target function to optimise battery size. As a result, the following objective function has been defined:

$$\sum_{min} E_p = F_{th}(p_i) + G_c + B_c + abs(E_{dump}) * 100 \quad (12)$$

Subjected to constraints:

Power balance: $P_i + P_{WT} + E_b + P_{PV} + P_{bgrid} - P_{sgrid} = P_l$

$$Variablelimits = \begin{cases} 0 \leq P_i \leq P_{i,max} \\ 0 \leq P_{PV} \leq P_{PV,max} \\ 0 \leq P_{WT} \leq P_{WT,max} \\ SOC_{min} \leq SOC \leq SOC_{max} \\ P_{grid} \leq P_{grid_{max}} \end{cases}$$

where, E_p is the price of electricity; P_{bgrid} is the purchased electricity from power grid to microgrid; P_{sgrid} is the selling electricity from power grid to microgrid and the load demand P_l is satisfy by the generation from renewable sources, grid supply and storage. Excess power is given back to the grid.

$$E_{dump} = P_l - (P_i + P_{WT} + E_b + P_{PV} + P_{bgrid} - P_{sgrid}) \quad (13)$$

The power balance constraint of the objective function is handled by assigning the weight to E_{dump}, which indicates the unmet load demand.

III. Optimisation techniques

A. Particle swarm optimisation(PSO)

PSO is a population-based optimizer considered one of the evolutionary computational algorithms which depend on the intelligence of the swarm. It was introduced by Kennedy and Eberhart in 1995. In the PSO algorithm, the parameter settings include population size N=3000, acceleration constant c1 = c2 = 2; r1, r2, randomly generated value vary between [0, 1]; w is inertia weight. The maximum number of iterations itermax(t) = 300 [14].

The PSO algorithm consists of two expressions personal best position(P_{best}) and global best position(P_{gbest}). In every iteration its updates every particle position (x) and velocity (V) according to the given equation.(14).

$$V_{t+1} = w * v_t + c_1 * r_1 * (p_{best(t)} - x_t) + c_2 * r_2 * (p_{gbest(t)} - x_t) \tag{14a}$$

$$x_{t+1} = x_t + V_{t+1} \tag{14b}$$

B. Gray wolf optimisation(GWO)

GWO is a metaheuristic and population-based algorithm proposed by Mirjaliali Mohammad and Lewis, 2014 depends on the hunting behavior of gray wolves. It is adapted for Power Scheduling Problem [19]. When designing GWO, mathematically model the social behavior of wolves by considering fittest solution as alpha, Second, and the third fittest solution is beta and delta respectively(θ) and the rest of the candidate is assumed as omega. $\vec{A}_k$ & $\vec{C}_k$ are coefficient vectors, here encircling and hunting is done through $\vec{D}_k$ & $\vec{X}_{new}$,respectively along with new population are computed where, rd is a random number produced, and $\vec{a}_{gwo}$ changes linearly from 2 to 0 with each iteration.The entire process is described in [20].

$$\vec{A}_k = 2 \cdot \vec{a}_{gwo} \cdot \vec{rd} - \vec{a}_{gwo} \tag{15a}$$

$$\vec{C}_k = 2 \cdot \vec{rd} \tag{15b}$$

$$\vec{D}_k = |\vec{C}_k \cdot \vec{X}_p - \vec{X}_k| \tag{15c}$$

$$\vec{X'}_k = \vec{X}_k - \vec{A}_k \cdot \vec{D}_k \tag{15d}$$

$$\vec{X}_{new} = \frac{\sum_{k=1}^{3} \vec{X'}_k}{3} \tag{15e}$$

IV. Results and Discussions

The problem is optimised using the MATLAB software by applying the PSO and GWO algorithms presented in the previous section to the system. Each search agent of the optimization technique contains 24-hr, two variables; diesel generator power and grid power at each hour. Optimize these variables along with battery power as a complement to other values. For this, we used cost analysis to illustrate the efficiency of PSO by considering certain number of renewable sources and battery at a time changes in cost. All of these resources are linked to a grid that restricts the purchase and selling of electricity to the utility grid. This notion is explained through four cases:

- **Case 1:** Considering Diesel/Battery and Grid
- **Case 2:** Considering PV/Diesel/Battery and Grid
- **Case 3:** Considering Wind/Diesel/Battery and Grid
- **Case 4:** Considering PV/Wind/Diesel/Battery and Grid

The comparison of all cases containing different combinations of hybrid generation systems is shown in Table II. From given table, it is concluded that when both sustainable sources of energy, solar and wind, are present, the cost is lowest when compared to other cases. Because the costs of wind and solar PV power generating are lower than the costs of conventional thermal power generation, so that they are scheduled to produce the maximum amount of energy.

TABLE II: Comparing different scenarios/PSO

Cases	Fuel Cost($)	Price Electricity($)
Case 1	22453.9867	22758.0909
Case 2	15443.2196	15747.6646
Case 3	18083.3805	18308.7384
Case 4	11950.4928	12175.7587

The power profile of the diesel generator, solar panels, wind turbine, grid, battery, and the load along with dump energy is shown in Fig.2 and Fig.3 is conclude that for different studies of case 4.

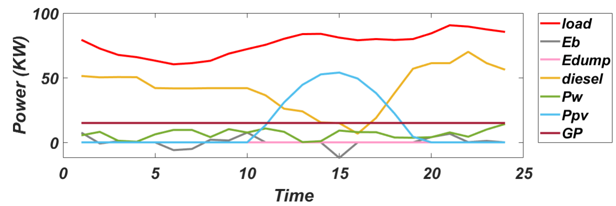

Fig. 2: Power profiles of hybrid power system using PSO

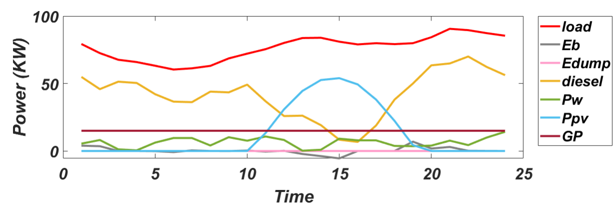

Fig. 3: Power profiles of hybrid power system using GWO

The total load demand for 24 hours is 1833 KW which is met by different power sources, the power generation from these sources is shown in Table III.

TABLE III: Optimal Configuration of System in Different Cases using PSO

Cases	P_{PV} (KW)	P_{WT} (KW)	P_i (KW)	E_b (KW)	GP (KW)
Case 1	0	0	1447	26	360
Case 2	309	0	1199	-35	360
Case 3	0	155	1300	18	360
Case 4	309	155	1054	-45	360

The energy management strategy for a multi-source system provides a continuous power supply to the customers, as detailed below for case 4:

Study 1: optimizing price electricity objective function considering solar PV, wind, diesel power generation, and storage connected to the grid by applying PSO

In this case study, the price of electricity has been optimized using PSO, the convergency curve is shown in Fig.4.

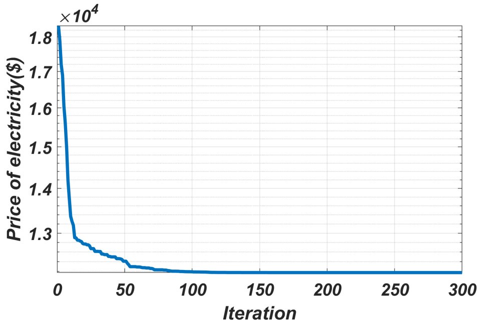

Fig. 4: PSO convergency

TABLE IV: Table shows optimal values of variables obtained from the defined objective functions by applying PSO

Variables	values
Total Fuel Cost($)	11950.4928
Total Transferred Power Transaction Cost($)	222.12
Total Battery Cost($)	3.1459
Price electricity($)	12175.7587

For a specific load, the optimal fuel cost of 11950.4928$ along with grid net cost and battery cost is shown in Table IV. Apart from that, we can see from the results that solar is available during the day, as shown in Fig.5; the excess load is met by solar PV module when generation from diesel and wind is low, as shown in Fig.7 and Fig.6, respectively; and extra energy is provided to the battery bank to charge.

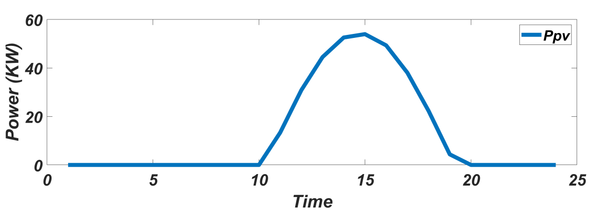

Fig. 5: Solar Power (KW)

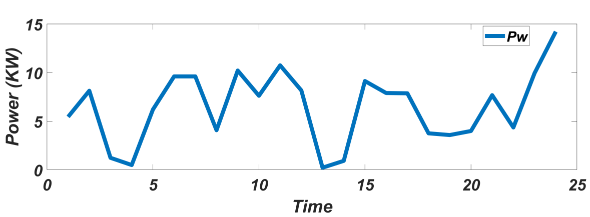

Fig. 6: Wind Power (KW)

Other power resources (diesel, wind, and battery) are utilized to supply energy to the load throughout the night when solar power production is low. The peak of diesel from Fig.7 indicates that at the during off-peak hour of solar, maximum power is taken from diesel. The charging-discharging characteristics of the battery are shown in Fig.8 has been conclude

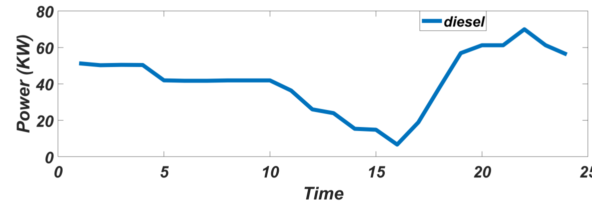

Fig. 7: Diesel Power(KW)

that SOC of the battery seen from Fig.9 varies in accordance with the variation of it's power. Due to the uncertain nature of renewable sources and the power peak of the load, there is a variation in the power and state of charge of the battery. When solar energy is at peak, the battery is charged up to maximum SOC then it is going to decrease otherwise there is a dept of discharge of 20%.

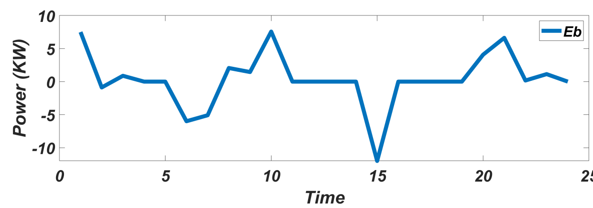

Fig. 8: Power Of Storage (KW)

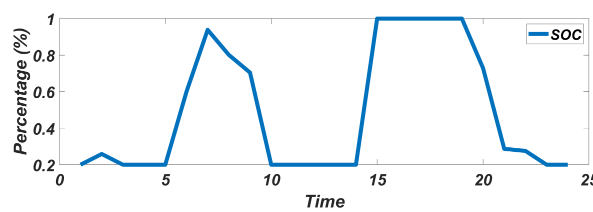

Fig. 9: State of Charage of battery(%)

Fig.10 indicates that the excess power is taken from the grid which increases the power transaction cost of the grid.

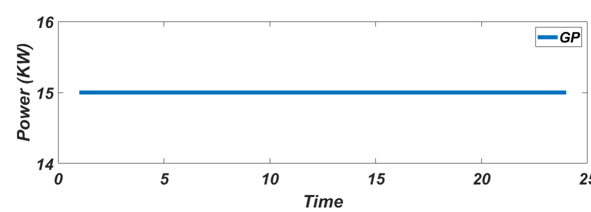

Fig. 10: Grid Power (grid import/export power(KW))

The difference between load and generation is called dump energy in Fig.2 and Fig.3 shows zero dump energy which means the load is always met in both the cases and the excess power has been taken from grid refer to Fig.10.

Study 2: optimizing price electricity objective function considering solar PV, wind, diesel power generation, and storage connected to the grid by applying GWO

In this case study, the price of electricity has been optimized using GWO. The convergence graph of GWO is given in

Fig.11, which shows that the price of power is optimised to 12279.0659($) after a few iterations.

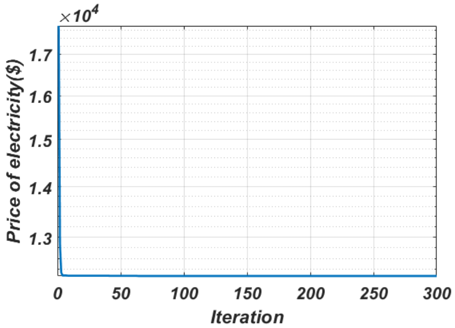

Fig. 11: GWO convergency

Similarly for a specific load, the fuel cost(12054.9014$), grid net cost, and battery cost while using GWO, are shown in Table V.

TABLE V: Optimal values of variables obtained from the defined objective functions by applying GWO

Variables	values
Total Fuel Cost($)	12054.9014
Total Transferred Power Transaction Cost($)	222.12
Total Battery Cost($)	2.0445
Price electricity($)	12279.0659

From Table IV and Table V, it is clear that the optimization impact of the PSO is superior in comparison to the GWO by viewing fitness function in terms of cost.

V. CONCLUSION

The major goal of this work is to offer consumers with a reliable power supply at a low cost by integrating solar, wind and diesel power generation system with storage in addition to the grid's existing power supply. The conclusions of this work are summarized as follows:

- A hybrid power system's efficient power scheduling is based on different modes of operation.
- Modeling a wind-solar-diesel power supply system with battery storage coupled to the distribution grid is demonstrated.
- To obtain the best solution of the system in terms of cost for power scheduling, two different optimization technique, PSO and GWO has been applied.
- Price of electricity is defined as objective functions and examined for different cases.
- Price of electricity include fuel cost of the conventional generator, grid cost which is the cost of obtaining electricity from the grid vs the cost of supplying energy to the grid and battery cost.
- When the results of the cost values were compared between PSO and GWO, PSO produces better results.
- The case, which includes all power resources (solar, wind, diesel, battery, and grid) has the lowest price of electricity to meet load demand.

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