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Grey wolf optimized economic load dispatch including battery storage in microgrid

Gray wolf, mikro şebekede pil depolama dahil optimize edilmiş ekonomik yük dağıtımı

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Grey Wolf Optimized Economic Load Dispatch Including Battery Storage In Microgrid

Highlights

- *The cost of the overall system is optimized effectively*
- *Load sharing is done effectively by means of GWO*
- *The dynamic EPD optimization is carried out using GWO for the both operating modes of the MG*
- *Grey wolf optimization (GWO) is used to optimize the microgrid system for effective dispatching of power to load with economic manner*

Graphical Abstract

The work done in the article summarized in following figure.

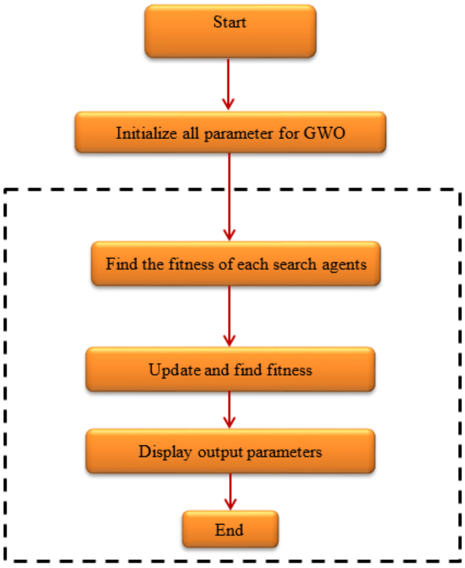

Figure. Graphical abstract

Aim

In last decades, grey wolf optimizer algorithm as a new meta-heuristic optimization technique plays major role in optimization of engineering problems such as load forecasting, controller parameter tuning and job scheduling. In this paper, grey wolf optimization (GWO) is used to optimize the microgrid system for effective dispatching of power to load with economic manner.

Design & Methodology

The model of microgrid system components are developed and investigated in the MATLAB/Simulink platform. The vital objective of the proposed grey wolf algorithm is to minimize overall cost of the microgrid operation.

Originality

The detailed investigation is carried out on power dispatch optimization and cost minimization for both modes, i.e. island and grid-connected modes of the microgrid system with considering the impact of running costs.

Findings

From the analysis, the cost of the overall system is optimized effectively, and load sharing is done effectively by means of GWO.

Conclusion

In this paper, the mathematical modeling of the PV panel, diesel engine, and battery in MG system along with EPD problem is developed and analyzed. The dynamic EPD optimization is carried out using GWO for the both operating modes of the MG, i.e. island and grid-connected modes.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Gray Wolf, Mikro Şebekede Pil Depolama Dahil Optimize Edilmiş Ekonomik Yük Dağıtımı

Araştırma Makalesi / Research Article

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ÖZ

Son yıllarda, yeni bir meta-sezgisel optimizasyon tekniği olarak gri kurt optimize edici algoritması, yük tahmini, kontrolör parametre ayarı ve iş çizelgeleme gibi mühendislik problemlerinin optimizasyonunda önemli bir rol oynamaktadır. Bu yazıda, gücün ekonomik bir şekilde yüke etkin bir şekilde dağıtılması için mikro şebeke sistemini optimize etmek için gri kurt optimizasyonu (GWO) kullanılmıştır. Mikro şebeke sistem bileşenlerinin modeli MATLAB/Simulink platformunda geliştirilmiş ve incelenmiştir. Önerilen gri kurt algoritmasının hayati amacı, mikro şebeke operasyonunun toplam maliyetini en aza indirmektir. Her iki mod için, yani mikro şebeke sisteminin ada ve şebekeye bağlı modları için, işletme maliyetlerinin etkisi dikkate alınarak, güç dağıtım optimizasyonu ve maliyet minimizasyonu üzerinde ayrıntılı araştırma yapılır. Analizden, genel sistemin maliyeti etkin bir şekilde optimize edilir ve GWO aracılığıyla yük paylaşımı etkin bir şekilde yapılır.

Anahtar Kelimeler: Gri kurt optimize edici, mikro şebeke, ekonomik güç dağıtımı, pil depolama, dağıtılmış üretim.

Grey Wolf Optimized Economic Load Dispatch Including Battery Storage In Microgrid

ABSTRACT

In last decades, grey wolf optimizer algorithm as a new meta-heuristic optimization technique plays major role in optimization of engineering problems such as load forecasting, controller parameter tuning and job scheduling. In this paper, grey wolf optimization (GWO) is used to optimize the microgrid system for effective dispatching of power to load with economic manner. The model of microgrid system components are developed and investigated in the MATLAB/Simulink platform. The vital objective of the proposed grey wolf algorithm is to minimize overall cost of the microgrid operation. The detailed investigation is carried out on power dispatch optimization and cost minimization for both modes, i.e. island and grid-connected modes of the microgrid system with considering the impact of running costs. From the analysis, the cost of the overall system is optimized effectively, and load sharing is done effectively by means of GWO.

Keywords: Grey wolf optimizer, microgrid, economic power dispatch, battery storage, distributed generation.

1. INTRODUCTION

Distributed generation (DG) is focused on renewable energy resources and its economic load dispatch problems are getting more attention in the microgrid (MG) system. There are a lot research on the cost-effective operation of MGs have been established because they are environmentally sustainable, versatile and provide better quality of power [1-3]. Dynamic and static load dispatches are group of economic dispatch for power systems. However the dynamic load dispatch is favored to the steady approach these days since this approach not only minimizes costs although it assists to communicate among all DGs [4,5]. However, owing to volatility, instability and unpredictability in renewable resources, the objective role of economic dispatch with a competitive approach is diffic ult to solve in MGs [6,7].

Solar PV technology helps to generate power with lowest cost and also enhance the environment factor to the environment. PV energy volatility, however creates numerous issues, for example, economic losses from the hybrid power grid [8,9]. The economic dispatch of the complex MG system considered two related operating modes, such as grid connected mode and island modes, taking into account of renewable source abrupt changes due to change in environment conditions [10-12]. The dynamic programming approach responds extremely rapidly, helping to calculate the functionality of MG's in long-term and short-term operation of the MG system. The island mode with an energy storage device offers economic benefits and provides MG safety [13,14]. The scheduling of MG resources involves photovoltaic with battery energy storage, diesel engines with rotating reserve restrictions. Multi-objective optimization is carried out by addressing the environmental dilemma of MGs [15,16]. The MG is composed of two section – electric power section and information section. The economic power dispatch (EPD) issues based on user energy management system are analyzed and discussed in these two sections. In grid-connected MG system with EPD, quadratic programming is used to optimize power

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and battery energy scheduling. The economic battery scheduling dependent on EPD in grid-connected mode and it reduces the total operating cost of the MG system [17,18]. The Monte Carlo simulation approach is used to test the suitability of MG in an island mode operation, combined with the PV energy operating reserve. The particle swarm optimization technique is utilized to solve EPD problem in power systems with considering of nonlinear characteristics of the generator. These approaches help to more easily achieve higher performing solutions [19]. In last decades, grey wolf algorithm plays major role in optimization of engineering problem such as load forecasting, controller parameter tuning and battery scheduling problem [20]. In this paper, GWO is used to minimize the fuel cost, maintenance cost, operating cost of the MG system. Mathematical simulation of the MG with complex economic power dispatch problem is developed in MATALB/Simulink. The MG system which is considered in this research work contains of: PV generation unit; battery energy storage device and diesel generator. This system operated in island mode and grid-connected mode. The numerous restrictions are taken into consideration in order to enhance the MG system's performance and reliability. Analysis is conducted by considering the results of operating, maintenance and fuel cost for the scheduling of the systems in both modes. The paper organized as follows: modeling of MG is presented in the section 2. In the section 3, the GWO is explained. The simulation results and discussion are provided in the section 4. The work conclusion is formulated in the section 5.

2. MICROGRID MODELING

MG consists of the following main parts: i) distributed generation units; ii) distributed energy storage devices; iii) flexible loads; iv) the point of common coupling; v) static switch. Mathematical models of DGs, battery and loads in GWO formulation is considered as follows:

2.1. Solar PV generation of power and calculation of solar PV costs

The photovoltaic (PV) panel output power is calculated using Equation (1) adopted from,

$$P_{PV} = 3.24 \times N_{PV}[1 - 0.0041 \times (T_{PV} - 8)] \times G_h \quad (1)$$

where: N_{PV}– generating capacity of PV panels, T_{PV}– temperature, G_h– solar irradiance at h time (kW/m^2). The clean energy subsidy includes state tax and federal solar panel incentive incentives. Therefore, the consideration of renewable energy conversion helps in the lowering of solar investment costs. The reduced investment costs due to the renewable energy conversion is estimated as follows

$$C'_P = C_P - (C_P \times S_h) - [C_P \times (1 - S_h) \times F_h] \quad (2)$$

where: C_P is the true investment expense ($/kW), S_h is a national tax subsidy (percent) and F_h is a state tax subsidy.

2.2. Battery charging and discharging modeling

The formula for charging of Battery ($E_B(h) < 0$):

$$Q_C(h) = (1 - \alpha) \times Q_C(h - 1) - (E_B(h) \times \Delta h \times \eta_h) \quad (3)$$

$$-\eta_h \times E_B(h) \leq L_C \times Q_{Cmax} \quad (4)$$

The formula for discharging of Battery ($E_B(h) > 0$):

$$Q_C(h) = (1 - \alpha) \times Q_C(h - 1) - (E_B(h) \times \Delta h \times \eta_{h1}) \quad (5)$$

$$\frac{E_B(h)}{\eta_{h1}} \leq L_d \times Q_{Cmax} \quad (6)$$

Where: $E_B(h)$ – charging power, η_h – charging efficiency, η_{h1} – discharging efficiency and α–self-discharge. These variables are expressed in percentage per hour. L_C and L_d are charging and discharging rated capacity of battery, respectively [Ampere-hours]. Q_{Cmax}, $Q_C(h)$, $Q_C(h - 1)$ reflects the maximum capacity of the battery, the charge status of the battery in h and $h - 1$ cycles respectively [21].

2.3. Economic Load Dispatch of Microgrid

For the MG, the device operating cost of MG is listed below:

$$MG = MGC_{fuel} + MGC_{OM} + MGC_{DC} + GI\left(\sum Y_h^r R_h^r + C_{grid} + C_{diesel}\right) \quad (7)$$

$$MGC_{fuel} = L_{fc} \times E_i(h) \quad (8)$$

$$MGC_{OM} = L_{OM} \times E_i(h) \quad (9)$$

$$MGC_{DC} = \frac{DC}{E_{imax} \times 8760 \times FC} \times E_i(h) \quad (10)$$

$$DC = \frac{(I\_cost \times b \times (1+b)^m)}{((1+b)^m - 1)} \quad (11)$$

$$C_{grid} = a_2 + a_1 \times P_{G1} + a_0 \times {P_{G1}}^2 \quad (12)$$

$$C_{diesel} = a_2 + a_1 \times P_{G2} + a_0 \times {P_{G2}}^2 \quad (13)$$

Where MGC_{fuel}, MGC_{OM}, MGC_{DC}, C_{grid} and C_{diesel} illustrates the expense of fuel consumption, cost of service maintenance, cost of depreciation, cost of the grid and cost of diesel gen-set, respectively. P_{G1} and P_{G2} are power sharing of the grid and diesel gen-set of the system. The a_0, a_1 and a_2 are constant values. The spinning reserve price and the purchase power respectively reflect Y_h^r and R_h^r. GI is equal to one and zero respectively in grid connected and island mode. $E_i(h)$ reflects the output power of the DGs, L_{fc} and L_{OM} reflects the fuel usage, operation control coefficients. FC, DC and I_cost reflect the power factor, the cost of depreciation in kilowatt hours and the cost of installation, respectively. b represents the rate of interest equal to 8% and m represents the lifetime of DGs.

2.4. The primary objective feature of the microgrid system's economic load dispatch

For the complex economic dispatch of MG, the goal function is to minimize the aggregate cost with optimum detailed benefits.

$$minimize\ C_T = MG \quad (14)$$

The constraints used in MG:

$$\sum_{i=1}^{N} E_i + P_{G1} + P_{G2} + E_B = P_{load} \quad (15)$$

$$E_{imin} \leq E_i \leq E_{imax} \quad (16)$$

$$P_{G1min} \leq P_{G1} \leq P_{G1max} \quad (17)$$

$$P_{G2min} \leq P_{G2} \leq P_{G2max} \quad (18)$$

$$E_{Bmin} \leq E_B \leq E_{Bmax} \quad (19)$$

$$Q_{Cmin} \leq Q_C \leq Q_{Cmax} \quad (20)$$

Where: $E_{imin}\ and\ E_{imax}$– minimum and maximum limits of power generated by solar PV. $P_{G1min} and\ P_{G1max}$– minimum and maximum limits of power sharing of the main grid. $P_{G2min} and\ P_{G2max}$– minimum and maximum limits of power sharing of the diesel gen-set. $E_{Bmin}\ and\ E_{Bmax}$– minimum and maximum limits of power sharing of the battery. $Q_{Cmin} and\ Q_{Cmax}$– minimum and maximum limits of charge of the battery set at 10% and 90% of the total power, respectively.

The MG consumes electricity from the main grid if the P_{G1} is positive, and MG gives power to the main grid if the P_{G1} is negative. Similarly, the battery gets discharged if E_B is positive, and the battery gets charged if $E_B$is negative. The objective function mentioned in the equation (7) is optimized using grey wolf algorithm..

3. GREY WOLF OPTIMIZATION

A new population is based on the methodology of swarm intelligence, called the grey wolf optimizer, inspired by the nature and grey wolf attributes described in this section. In research GWO methodology have applied by Mirjalili et al [20].

A. GWO Algorithm in Microgrid Economic dispatch

The step-by-step GWO algorithm method for optimization of MG is given as follows:

1. Initialize all GWO algorithm input parameters, such as search agents-no (population size), number of control variables (problem dimension) by controller form, upper and lower search space limits, number of parameters of elitism, and total number of generations.

2. Search agents of grey wolves (i.e., power sharing of main grid, diesel gen-set) are randomly generated between upper and lower boundaries in the search space during the initialization process.

3. Calculate the fitness of every search agent in the search space and assign alpha, beta, delta wolves.

4. Updating the alpha, beta, and delta positions.

5. Update the search agent locations.

6. Finally, for each search agent, change the control variables (power generation of main grid, diesel gen-set).

7. Check whether every search agent moves outside the search space and the randomly generated viable solution set is replaced by infeasible solutions.

8. For the next generation, sort the quest agent positions acquired in step 5 from the best value to the worst value and use them.

9. Switch to step 4 before fulfillment of the completion criteria.

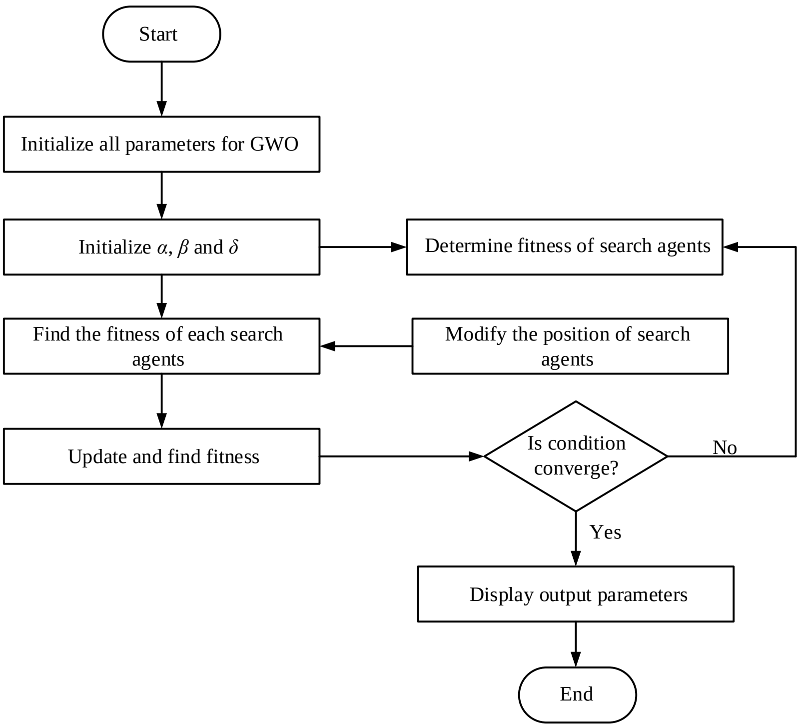

Figure 1. Flow chart for GWO

The flow chart of the optimal power generation of the MG using GWO algorithm is shown in Figure 1

4. SIMULATION ANALYSIS OF ECONOMIC LOAD DISPATCH IN MICROGRID

In this section, simulation of economic load dispatch of MG is explained in detailed. The specifications of MG are shown in the Table 1.

Table 1. Specification of MG

Component	Name	Size	Unit
Generator	Kohler 410kW Standby	410	kW
PV	Generic flat plate PV	36.6	kW
Battery Storage	Hitachi LL1500-W	40	kW
System Inverter	ABB Pro33	33.0	kW
Load		1300	kW

Fuel usage coefficient, operation control coefficients, capacity factor, the cost of depreciation in kilowatt hours, the cost of installation, the rate of interest and lifetime of DGs are presented in the Table 2.

Table 2. Operating cost parameters of MG

Description	Value	Unit
Fuel usage coefficient (L_{fc})	0.8	$/kW
Operation control coefficient (L_{OM})	0.4	$/kW
Capacity factor (FC)	0.9	-
Cost of installation (I_cost)	1.02	$/kW
Rate of interest *(b)*	0.08	%
Lifetime of DGs *(m)*	100	Years

The fuel cost coefficient of the grid and diesel gen-set are given in Table 3.

Table 3. Fuel cost coefficient of grid and diesel gen-set.

Description	a_0	a_1	a_2
Grid	0.004	5.3	500
Diesel Gen-set	0.042	7.8	101.5

Limit constraints for the different source of MG are shown in Table 4.

Table 4. Limit constraints for the different source of MG

Description	Minimum	Maximum	Unit
Main Grid Power	-800	+800	kW
Diesel Gen-set	0	400	kW
PV Panel	0	36.6	kW
Battery	0	40	kW
State of charge of battery	20	100	%

In this table the local load of MG is 800 kW. Positive sign indicates the power supply from main grid. Negative sign indicates main grid receives power from MG.

The hourly spinning reserve and purchasing power price are shown in Figure 2.

Figure 2. Spinning reserve and purchasing of power price.

Hourly generated PV power of April 1, 2019 is shown in Figure 3, and monthly generated PV power for 2019 is shown in Figure 4.

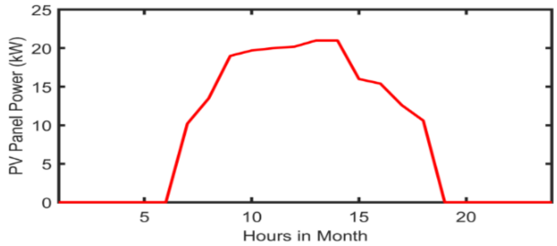

Figure 3. Hourly output power of PV panel (1st April 2019).

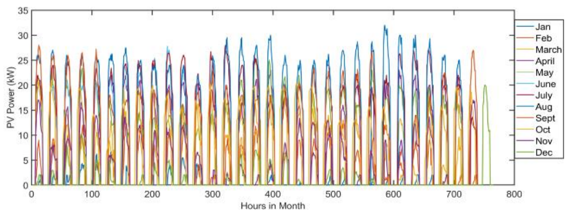

Figure 4. Monthly output power of PV panel.

The grey wolf algorithm for economic load dispatch of MG is developed in the MATLAB using m-file script. The developed code is executed for all possible operating conditions. The optimization result for the 1st April 2019 is shown in Figure 5 and provided in the Table 5.

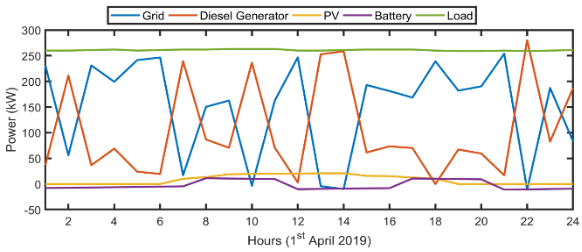

Figure 5. Grey wolf optimized result of MG

Table 5. The optimization result for the 1st April 2019

Hour	Load (kW)	PV power (kW)	Battery power (kW)	Main grid power (kW)	Diesel gen-set power (kW)	Total cost of generation ($/kW)	Mode of operation
1	260	0.0	-7.8	230.7	37.1	2392.4	Battery charging + main grid power supply + diesel gen-set
2	260	0.0	-7.3	56.1	211.2	4449.6	Battery charging + main grid power supply + diesel gen-set
3	261	0.0	-6.8	231.1	36.7	2391.6	Battery charging + main grid power supply + diesel gen-set
4	262	0.0	-6.2	199.2	69.1	2589.7	Battery charging + main grid power supply + diesel gen-set
5	260	0.0	-5.6	241.4	24.2	2331.6	Battery charging + main grid power supply + diesel gen-set
6	261	0.0	-5.0	246.5	19.5	2348.2	Battery charging + main grid power supply + diesel gen-set
7	262	10.2	-4.5	17.1	239.2	4997.9	Battery charging + main grid power supply + diesel gen-set + PV
8	262	13.5	11.3	150.4	86.8	2522.8	Battery discharging + main grid power supply + diesel gen-set + PV
9	263	19.0	10.7	162.6	70.7	2371.4	Battery discharging + main grid power supply + diesel gen-set + PV
10	263	19.7	10.2	-3.3	236.4	4826.7	Battery discharging + main grid receives power + diesel gen-set + PV
11	263	20.0	9.7	162.6	70.7	2378.7	Battery discharging + main grid power supply + diesel gen-set + PV
12	260	20.2	-10.0	246.6	3.2	2218.9	Battery charging + main grid power supply + diesel gen-set + PV
13	260	21.0	-9.5	-4.2	252.7	5295.5	Battery charging + main grid receives power + diesel gen-set + PV
14	261	21.0	-8.9	-9.8	258.6	5463.4	Battery charging mode + grid receive power + diesel gen-set + PV
15	262	16.0	-8.4	192.9	61.5	2459.3	Battery charging + main grid power supply + diesel gen-set + PV
16	262	15.4	-8.0	181.2	73.4	2547.7	Battery charging + main grid power supply + diesel gen-set + PV
17	262	12.6	10.8	168.5	70.1	2390.1	Battery discharging + main grid power supply + diesel gen-set + PV
18	260	10.6	10.3	239.1	0.0	2123.2	Battery discharging + main grid power supply + diesel gen-set + PV
19	259	0.0	9.8	182.0	67.2	2442.7	Battery discharging + main grid power supply + diesel gen-set + PV
20	259	0.0	9.2	190.3	59.5	2388.7	Battery discharging + main grid power supply + diesel gen-set
21	260	0.0	-10.9	254.0	16.9	2353.2	Battery charging + main grid power supply + diesel gen-set
22	259	0.0	-10.3	-10.8	280.1	6062.7	Battery charging + main grid power supply + diesel gen-set
23	260	0.0	-9.7	187.1	82.6	2680.2	Battery charging + main grid power supply + diesel gen-set
24	261	0.0	-9.2	83.3	186.8	4034.0	Battery charging + main grid power supply + diesel gen-set

From the Table 5, the operation of MG classified into six and each mode is highlighted in different color for better understanding of the optimized data. The negative sign of battery power indicates the concept of battery charging and positive sign indicates the battery discharging concept in the MG. The positive sign of grid power indicates the power is supplied from main grid to MG load and negative sign of grid power indicates the power is received from MG to main grid. From the analysis, the cost of the overall system is optimized, and load sharing is done effectively by means of GWO. The results illustrate that GWO is effectively optimized the economic load dispatch of the considered MG system.

5. CONCLUSION

In this paper, the mathematical modeling of the PV panel, diesel engine, and battery in MG system along with EPD problem is developed and analyzed. The dynamic EPD optimization is carried out using GWO for the both operating modes of the MG, i.e. island and grid-connected modes. To increase the output and reliability of the MG, the restrictions of the rotating reserve are also included. The grid-connected mode is favored over the island mode, since it is very difficult to provide an efficient battery consumption solution. For the service, a battery with effective backup is needed in islanded mode. In the grid-connected mode, as per scheduling schemes, the overall cost of the MG device decreases by means of GWO. The dilemma is conceived by taking into account the variables of supply of power from renewable energy sources, stocks and cost differences of the grid. The detailed investigation is carried out on power dispatch optimization and cost minimization in island mode and grid-connected mode of the MG system for all scheduling scheme with taking into account the impact of running costs. The PV panel is given preference in both modes because its service and pollutant treatment are lower than other grids. Cost minimization of the least environmental impact is carried out in this article. In islanded mode, instead of the grid, the battery is used and its power impact on the EPD is addressed. The battery starts to charge while EB is negative, and the battery starts to discharge if EB is positive. From the test analysis, GWO effectively minimizes total operating cost of the MG system as well optimize the power dispatch in the MG system.

AUTHORS' CONTRIBUTIONS

Salem Aljribi: Perofrmed the experiments and analyse the results and wrote the paper.

Ziyodulla Yusupov: Perofrmed the experiments and analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this stud

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