Journal of Informatics
Electrical and Electronics Engineering, 2020,
Vol. 01, Iss. 02, S. No. 001, pp. 1-26
ISSN (Online): 2582-7006

Operational Cost Minimization of Grid Connected Microgrid System Using Fire Fly Technique

[1]Shubhanshee Jain, [2]Eknath Borkar

[1,2]SCOPE College of Engineering, Bhopal, India
[1]jainshubhanshi13@gmail.com

How to cite this paper: S Jain, E Borkar (2020) Operational Cost Minimization of Grid Connected Microgrid System Using Fire Fly Technique. Journal of Informatics Electrical and Electronics Engineering, Vol. 01, Iss. 02, S. No. 001, pp. 1-26, 2020.

http://doi.org/10.54060/JIEEE/001.02.001

Received: 13/10/2020
Accepted: 10/11/2020
Published: 18/11/2020

Abstract

Present time, green energy sources interfacing to the utility grid by utilizing microgrid system is very vital to satisfy the ever increasing energy demand. Optimal operation of the microgrid system improved the generation from the distributed renewable energy sources at the lowest operational cost. Large amount of constraints and variables are associated with the microgrid economic operation problem. Thus, this problem is very complex and required efficient technique for handing the problem adequately. Therefore, this research utilized the efficient fire fly optimization technique for solving the formulated microgrid operation control problem. Fire fly algorithm is based on the behaviour and nature of the fire flies. A microgrid system modelling which incorporated various distributed energy sources such as solar photo voltaic, wind turbine, micro turbine, fuel cell, diesel generator, electric vehicle technology, battery energy storage system and demands. Energy storage system is utilized in this research for supporting renewable energy sources' integration in more reliable and qualitative way. Further, the electric vehicle technology i.e. battery electric vehicle, plug-in hybrid electric vehicle and fuel cell electric vehicle are utilized to support the microgrid and utility grid systems with respect to variable demands. Optimal operational cost minimization problem of the developed microgrid system is solved by fire fly algorithm and compared with the grey wolf optimization and particle swarm optimization techniques. By comparative analysis it is clear that the fire fly algorithm provides the minimum operational cost of microgrid system as compared to the GWO and PSO. MATLAB software is utilized to model the microgrid system and implementation of the optimization techniques.

Keywords

Microgrid system; energy storage system; Fire Fly algorithm

1. Introduction

The energy demand around the world is continuously increasing. Along with that the green house gas emission, energy efficiency reductions and appropriate renewable energy generation became main issues in the power system. The most suitable remedy for all of these above discussed problems is the construction of the microgrid system with green energy generators like solar photovoltaic, wind turbine, fuel cells, micro turbine, electric vehicle, and energy storage systems. There are two modes of operation in which the microgrid can be operated i.e. standalone micro grid system and grid integrated microgrid system. In the standalone operation mode microgrid can be operated as self sufficient energy grid. Further in the grid tied mode, energy is exported and imported from the grid. Other than t provide the green energy, micro grid system reduced the green house gases from the environment, generated from the thermal power plant with reduction in the power price [1, 2]. Though there are numerous advantages of the micro grid system, but due to intermittent nature of the renewable energy sources such as solar photo voltaic and wind turbine, reliability of the micro grid system is affected. With the utilization of the energy storage systems, reliability issues of the micro grid system can be managed [3]. The main functions of the energy storage system are the supplying energy at the time of energy shortage in the micro grid. Further energy storage system stored surplus energy generated from renewable energy sources of micro grid system energy at the time of off peak load time. Integration of the energy storage devices' in the microgrid system is important for balancing the power in the system. Determination of the energy storage system capacity is very important for the economical operation of the microgrid system. Too much capacity of energy storage system will raise the total cost of the microgrid system while less capacity of energy storage system minimize the reliability of the system and increase the cost of energy generation from the traditional sources of generation.

Hence the determination of the optimal generation of various renewable energy generation sources with the optimal capacity of the energy storage system are the important issues for the economical operation and minimization of the operational cost of the microgrid system [4-6].

The optimized energy management techniques are utilized to find the optimal generation capacity of the various generation components of the microgrid system as well as the capacity of the energy storage system. Further, these techniques minimized the complete operational cost of the system.

The main issue with the some of the Meta heuristic algorithm is that these techniques search the best solution in their local space without incorporating the global solution space. These techniques may mislead the process of searching and due to that the optimization technique stuck into the local optimum value only. On the other hand some of the Meta heuristic techniques provide adequate global search capabilities but their local searching capacity is limited. Both the limitation affected the performance of the Meta heuristic techniques. Therefore, more efficient Meta heuristic techniques are required for good convergence and enhancement of the exploration process. For that purpose, an advanced Meta heuristic technique namely fire fly optimization approach provides the good equilibrium between the global and local search solution spaces, is applied in this research work. The main objective of this research work is the minimization of the operational cost of the grid connected microgrid system. Further optimal output of various generation components of the microgrid system is also computed. The applied technique is based on the food searching capabilities of Fire Flies with the high equilibrium between exploitation and exploration capabilities [7]. At last for verifying the stability and the performance of the applied technique it is executed on the representative low voltage microgrid network. Various case studies have been performed and a comparative analysis with the two renowned techniques i.e. particle swam optimization (PSO) [8] and grey wolf optimization (GWO) [9] is utilized. By comparative analysis it is concluded that the applied fire fly technique provides better results as compare to the other techniques. The fire fly results proved that the ability of the applied technique to obtain the global best solution in the optimization difficulty by means of computation efficacy and solution quality is better as compare to the PSO and GWO.

In [10], Bridier (2016), utilized a meta-heuristic technique to describe the comparison of economical and technical sizing of energy storage system with microgrid generation components such as PV, wind and wave. In [11], Aghamohammadi and Abdolahinia (2014), depending on the primary frequency control of micro grid system, optimal capacity of battery energy storage system is computed. In [12-17], for addressing the optimal dispatch energy flow in the microgrid system, mixed integer linear programming technique is utilized. Further, the same technique is utilized to find the optimal capacity of the energy storage system. In [18-23], for finding the optimum capacity of the energy storage device in the microgrid system, various meta-heuristic techniques are implemented in the hybrid microgrid system. In [24, 25], for computing the optimum scheduling issue of the standalone and grid connected microgrid system, dynamic programming is utilized. For the problem formulation, efficiency and the operation characterises of the energy storage system in the microgrid is considered. In [26, 27], for calculating the optimal capacity of the different generation components such as PV, full cell and energy storage devices along with the distributed generation under the electricity hybrid market structure of the microgrid system, a GA based technique is utilized. This method is useful for enhancing the life cycle cost of microgrid system as well as minimizing the green house gases. In [28-30], researchers are utilized the PSO technique to compute the optimal capacity of the battery energy storage system at minimum cost. In [31], Sukumar et al. (2018) utilized the Grey Wolf optimization technique is utilized for finding the optimal capacity of battery energy storage system by solving the economic operation problem of microgrid system. This work utilized the batteries as the energy storage system but not included the electric vehicles technology for the energy storage purpose. In [32], Nimma et al. (2018) utilized the grey wolf optimization-technique dependent optimal energy-management system is developed for microgrid system. Further, this work computed the optimal capacity of the battery for grid connected microgrid system. This work utilized the batteries as the energy storage system but not included the electric vehicles technology for the energy storage purpose. The main contributions of the manuscript are as follows:

1. Applied a advanced optimization technique i.e. fire fly algorithm for the intelligent energy management which enhances the integration of the renewable energy generators and minimize the reliance on the conventional energy sources such as diesel generator in microgrid system.

2. As compare to the existing system in [32], different types of electric vehicles and diesel generator are incorporated and then optimized the system. Three different types of electric vehicles are modelled in the system those are battery electric vehicles, plug in electric vehicles and fuel cell electric vehicles.

3. Minimized the overall operational cost of the grid connected microgrid system

4. Optimal generation outputs of various microgrid generators components is calculated in this work.

5. Optimal capacities of the batteries are computed in this work by fire fly algorithm.

6. A comparative analysis with GWO and PSO techniques presented the superiority of the fire fly algorithm. As compare to [32], in this work the operation cost of the system calculated with the fire fly algorithm and compared with the grey wolf optimization technique utilized in the base paper. By comparative analysis it is clear that fire fly algorithm has more improved performance as compare to the gray wolf optimization. Further, fire fly algorithm also provided better results as compare to the particle swam optimization [33].

2. Problem Formulation

Based on the above discussed literature review, the proposed microgrid optimal operational problem can be formulated as follows:

2.1 Development of objective function

The objective of optimal operation problem of micro grid system is to minimize the total operational cost of the system [34]. This problem is solved by utilizing the Firefly optimization method for solving the cost minimization problem of microgrid system,

The developed problem is formulated as follows:

The formulation of the optimal operation problem of microgrid is illustrated as follows: Minimization of the total cost of microgrid system is given by:

$$Min\ C_{op}(X) = \sum_{t=1}^{NT} c\,(t) + OM_{DRG} + STCPD_{All\ type\ Battery} + C_f \sum_{i=1}^{N} \left(aP_{DeG(i)}^2 + bP_{DeG(i)} + c\right) \quad (1)$$

where, collective total cost per day for all types of batteries utilized in this research is the summation of total cost per day of:

1. Battery energy storage system
2. Battery of Battery electric vehicle
3. Battery of Plug in Hybrid electric vehicle

$$STCPD_{All\ type\ Battery} = BES\ TCPD + BEV\ TCPD + PHEV\ TCPD \quad (2)$$

$c\,(t)$ is the addition of the energy cost of utility grid, fuel and operational cost of distributed renewable generation (DRG) i.e. solar photo voltaic, wind generation, battery energy storage system (BES), battery electric vehicle (BEV), plug in hybrid electric vehicle (PHEV), as well as start up cost (SUC) of fuel cell (FC), micro turbine (MT) and fuel cell electric vehicle (FCEV), as shown by

$$c\,(t) = Grid\ Cost\ (t) + DRG\ Cost\ (t) + BES\ Cost(t) + BEV\ Cost(t) + PHEV\ Cost(t) + FC\ SUC(t) + MT\ SUC(t) + FCEV\ SUC(t) \quad (3)$$

Cost of supply from the grid is presented by

$$\boldsymbol{Grid\ Cost\ (t)} = \begin{cases} \boldsymbol{Grid\ Bid(t) * Grid\ Power(t)} & \boldsymbol{if\ Grid\ Power(t) > 0} \\ \boldsymbol{(1 - tax) Grid\ Bid(t) * Grid\ Power(t)} & \boldsymbol{if Grid\ Power(t) < 0} \\ \boldsymbol{0} & \boldsymbol{if\ Grid\ Power(t) = 0} \end{cases} \quad (4)$$

The fuel and operational cost of the DRG are given by.

$$DRG\ Cost(t) = MT\ Bid(t) * MT\ Power(t) * MT\ u(t) + FC\ Bid(t) * FC\ Power(t) * FC\ u(t) + FCEV\ Bid(t) * FCEV\ Power(t) * FCEV\ u(t) + PV_i\ Bid(t)\ PV_i\ Power(t) + +WT_i\ Bid(t)\ WT_i\ Power(t) \quad (5)$$

The cost of start up of FC, FCEV and MT are provided in the following equations, respectively.

$$FC\ SUC(t) = FC\ Start * \max(0, FC\ u(t) - FC\ u(t-1)) \quad (6)$$

$$FCEV\ SUC(t) = FCEV\ Start * \max(0, FCEV\ u(t) - FCEV\ u(t-1)) \quad (7)$$

$$MT\ SUC(t) = MT\ Start * \max(0, MT\ u(t) - MT\ u(t-1)) \quad (8)$$

The regular operational and repair cost of DRG are presented by

$$DRG\ OM = (MT\ OM + FC\ OM + FCEV\ OM + PV_i\ OM + WT_i\ OM) * NT \quad (9)$$

In the micro grid system, operational charges of the utility grid, FCEV, PHEV, BEV and BES, operation and maintenance charges and fuel charges of DRGs and DEG, FC, MT and FCEV star up charges with summarized per day total charges of BES, BEV and PHEV batteries (STCPD) provided the total cost of microgrid system. The total cost per day of battery consists of two parts; first part one time single fixed cost (FX) and yearly basis repair cost (MC). The complete charge of the battery is the summation of the above discussed two charges i.e. $(MC + FX) * C_{max}$ with C_{max} represents the maximum size of any battery. The operational time frame selected in this work is 24 hours, therefore TCPD is calculated in Rs./day. By utilizing the following equations TCPDs of various batteries utilized in this work can be calculated [35].

$$BES\ TCPD = \frac{BES\ C_{max}}{365}\left(\frac{IR(1+IR)^{LT}}{(1+IR)^{LT}-1}BES\ FX + BES\ MC\right) \quad (10)$$

$$BEV\ TCPD = \frac{BEV\ C_{max}}{365}\left(\frac{IR(1+IR)^{LT}}{(1+IR)^{LT}-1}BEV\ FX + BEV\ MC\right) \quad (11)$$

$$PHEV\ TCPD = \frac{PHEV\ C_{max}}{365}\left(\frac{IR(1+IR)^{LT}}{(1+IR)^{LT}-1}PHEV\ FX + PHEV\ MC\right) \quad (12)$$

The developed operational cost reduction problem is optimized over the following constraint conditions

2.2 Constraint conditions

2.2.1 Power Balance Condition

The generated power must always be equal to the demand and losses in the system. In this work, the system losses ignore, therefore, the power balance equation can be modified as follows

$$Grid\ Power(t) + MT\ P(t) * MT\ u(t) + FC\ P(t) * FC\ u(t) + PV\ P_i(t) + WT\ P_i(t) + BES\ P(t)\ BES\ u(t) + BEV\ P(t)\ BEV\ u(t) + PHEV\ P(t)\ PHEV\ u(t) + FCEV\ P(t)\ FCEV\ u(t) + DEG\ P_i = Demand\ P(t) \quad , t = 1, \ldots\ldots, NT \quad (13)$$

2.2.2 Dispatchable DRGs constraints

The energy output limits of the various distributed renewable energy sources must be satisfied by the microgrid generation:

$$FC\ P_{min} \leq FC\ P(t) \leq FC\ P_{max} \quad , t = 1, \ldots\ldots, NT \quad (14)$$

$$MT\ P_{min} \leq MT\ P(t)_t \leq MT\ P_{max} \quad , t = 1, \ldots\ldots, NT \quad (15)$$

$$FCEV\ P_{min} \leq FCEV\ P(t) \leq FCEV\ P_{max} \quad , t = 1, \ldots\ldots, NT \quad (16)$$

2.2.3 BES constraints

The minimum and maximum, charging and discharging rates of BES are presented as follows

Discharging mode [35]:

$$BES\ C(t+1) = max\left\{\left(BESC(t) - \frac{\Delta t BESP(t)}{DISCHARGE\ \eta}\right), BES\ C_{min}\right\}, t = 1, \ldots\ldots, NT \quad (17)$$

$$\underline{BES\ P(t)} \leq BES\ P(t) \leq \overline{BES\ P(t)} \quad , t = 1, \ldots\ldots, NT \quad (18)$$

Charging mode:

$$BES\ C(t+1) = min\{(BES\ C(t) - \Delta t BES\ P(t)\ CHARGE\ \eta), BES\ C_{max}\}, t = 1, \ldots\ldots, NT \quad (19)$$

$$\underline{BES\ P(t)} \leq BES\ P(t) \leq \overline{BES\ P(t)} \quad , t = 1, \ldots\ldots, NT \quad (20)$$

Where

$$\overline{BES\ P(t)} = min\left\{\frac{BES\ P_{max}(BES\ C(T) - BES\ C_{min})DISCHARGE\ \eta}{\Delta t}\right\}, t = 1, \ldots\ldots, NT \quad (21)$$

$$\underline{BES\ P(t)} = max\{BES\ P_{min}(BES\ C(t) - BES\ C_{max})/CHARGE\ \eta\ \Delta t\}, t = 1, \ldots\ldots, NT \quad (22)$$

2.2.4 Grid Constraints

Utility grid should provides within the mentioned generation limits represented by the following equation

$$GRID\ P_{min} \leq GRID\ P_t \leq GRID\ P_{max} \quad (23)$$

2.2.5 Diesel Generator Constraints

Diesel generator should generated energy within the mentioned limits represented by the following equation

$$0 \leq P_{DEG(i)} \leq P_{DEG(i)}^{max} \quad (24)$$

2.2.6 BEV Constraints

The minimum and maximum, charging and discharging rates of BEV are presented as follows

Discharging mode:

$$BEV\ C(t+1) = max\left\{\left(BEV C(t) - \frac{\Delta t BEV P(t)}{DISCHARGE\ \eta}\right), BEV\ C_{min}\right\}, t = 1, \ldots.., NT \tag{25}$$

$$\underline{BEV\ P(t)} \leq BEV\ P(t) \leq \overline{BEV\ P(t)} \quad , t = 1, \ldots.., NT \tag{26}$$

Charging mode:

$$BEV\ C(t+1) = min\{(BEV\ C(t) - \Delta t BEV\ P(t)\ CHARGE\ \eta), BEV\ C_{max}\}, t = 1, \ldots.., NT \tag{27}$$

$$\underline{BEV\ P(t)} \leq BEV\ P(t) \leq \overline{BEV\ P(t)} \quad , t = 1, \ldots.., NT \tag{28}$$

Where

$$\overline{BEV\ P(t)} = min\left\{\frac{BEV\ P_{max}(BEV\ C(T) - BEV\ C_{min})DISCHARGE\ \eta}{\Delta t}\right\}, t = 1, \ldots \ldots, NT \tag{29}$$

$$\underline{BEV\ P(t)} = max\{BEV\ P_{min}(BEV\ C(t) - BEV\ C_{max})/CHARGE\ \eta\ \Delta t\}, t = 1, \ldots \ldots, NT \tag{30}$$

2.2.7 PHEV Constraints

The minimum and maximum, charging and discharging rates of PHEV are presented as follows

Discharging mode:

$$PHEV\ C(t+1) = max\left\{\left(PHEV\ C(t) - \frac{\Delta t PHEV\ P(t)}{DISCHARGE\ \eta}\right), PHEV\ C_{min}\right\}, t = 1, \ldots.., NT \tag{31}$$

$$\underline{PHEV\ P(t)} \leq PHEV\ P(t) \leq \overline{PHEV\ P(t)} \quad , t = 1, \ldots.., NT \tag{32}$$

Charging mode:

$$PHEV\ C(t+1) = min\{(PHEV\ C(t) - \Delta t PHEV\ P(t)\ CHARGE\ \eta), PHEV\ C_{max}\}, t = 1, \ldots.., NT \tag{33}$$

$$\underline{PHEV\ P(t)} \leq PHEV\ P(t) \leq \overline{PHEV\ P(t)} \quad , t = 1, \ldots.., NT \tag{34}$$

where

$$\overline{PHEV\ P(t)} = min\left\{\frac{PHEV\ P_{max}(PHEV\ C(T) - PHEV\ C_{min})DISCHARGE\ \eta}{\Delta t}\right\}, t = 1, \ldots \ldots, NT \tag{35}$$

$$\underline{PHEV\ P(t)} = max\{PHEV\ P_{min}(PHEV\ C(t) - PHEV\ C_{max})/CHARGE\ \eta\ \Delta t\}, t = 1, \ldots \ldots, NT \tag{36}$$

2.2.8 Operating Reserve Constraints

Integration of the energy storage systems such as BES, EVTs and operational reserve, increased the reliability of the microgrid system. Operational reserve (ORE) capacity is the summation of the reserve generation capacity of the active BES, electric vehicle technologies, FC, MT, DEG and utility grid, in the each time duration. The ORE can supply to the microgrid system within 10 minutes and presented by the following equations:

$$FC\ P_{max} FC\ u(t) + MT\ P_{max}\ MTu(t) + GRID\ P_{max} + \overline{BES\ P_{BES,t}} BES\ u(t) + \overline{BEV\ P(t)}\ BEVu(t) + \overline{PHEV\ P(t)}\ PHEV\ u(t) + \overline{FCEV\ P(t)}\ FCEV\ u(t) + DEG\ P_{(i)} \geq ORE(t) + Demand\ P(t), \quad t = 1, \ldots.., NT \tag{37}$$

where, ORE(t) is the 10-min ORE requirement at time t.

3. Methodology

For obtaining the above mentioned objectives, this work utilized the methodology presented in figure 1. The basic concepts related to the microgrid system and detailed review of various literatures related to the optimal operation of grid connected microgrid system is performed. The modeling of the grid integrated microgrid system integrated with solar photovoltaic, wind turbine, fuel cell, micro turbine, battery energy storage system, battery electric vehicle, plug in hybrid electric vehicle, fuel cell electric vehicle, diesel generator and demands are carried out both mathematically and in MATLAB coding. Optimal economic operation problem of microgrid system is formulated under various constraint conditions and solved by utilizing the Fire fly optimization technique. Results are calculated and critically discussed in detailed. To show the superiority of the applied algorithm, a comparative analysis with other existing algorithms such as GWO and PSO is carried out.

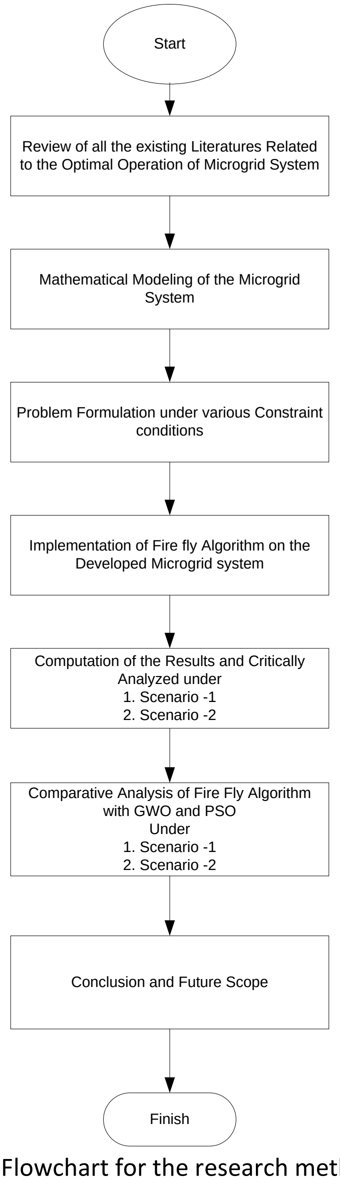

Figure 1: Flowchart for the research methodology

3.1 Fire Fly Algorithm

This technique is a Meta heuristic optimization algorithm, which is based on the natural inspired phenomenon. It is based on the nature and behavior of the fire files. There are three basic rules on which this algorithm is dependent [7].

1. Without related to the gender of the FF, all are attracted to each other

2. Brightness (light emission) is directly related to the attractiveness in such a way that bright flies attracted to less bright flies while in the unavailability of the brighter flies they randomly moved.
3. The objective function is directly proportional to the brightness.
The movement of a firefly *i* is attracted to another more attractive (brighter) firefly *j* is determined by

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha\epsilon_i \quad (48)$$

where, β_0 represents the attraction at distance 0, $r_{ij} = ||x_i - x_j||$ is the space between any two fireflies *i* and *j* at x_i and x_j, respectively, ϵ_i is a random numbers vector computed from a Gaussian or uniform distribution function and α represents the randomization parameter. Table 1 presented the various parameters utilized to model the fire fly algorithm in the developed micro grid optimization problem.

3.1.1 Pseudo code of the Fire Fly Optimization Algorithm

Start

Step 1. Initialize max number of iteration, α, β_0, γ

Step 2. Generate initial population

Step 3. Formulate the Objective function $C_{op}(X)$,

Step 4. Determine Intensity (I) at cost (x) of each individual determined by $C_{op}(X)$

Step 5. While (t < Iter max)

```
            For i=1 to n
                For j=1 to n
                    if (Ij > Ii)
                            Move firefly i towards j in K dimension
                        end if
                    Estimate new solutions and update light intensity
                end for j
            end for i
        Rank the fireflies and find the current best
    end while
```

6. Post process results and visualization

Terminate

Table 1 Parameters Utilized for Firefly Algorithm

Description	Parameter	Typical Value
Highest value of Attractiveness	β_0	2
Parameters Initial value of time varying technique	α	0.2
Coefficient of absorption	γ	0.98
Population size	-	50
Number of iterations	-	500

4. Result and Discussion

4.1 Introduction

In this paper, first the developed system is described. Further, the Fire Fly optimization technique is applied on the developed micro grid system and validated. For validation the purpose, the performance of the Fire fly optimization technique is compared with PSO and GWO methods. Two different operational scenarios are considered to show the effectiveness of the Fire fly algorithm. In the first scenario, it is considers that, all the batteries are integrated to the system with no charge or minimum charging condition. The second scenario considered all connected batteries in charged situation. Figure 2 presented the proposed grid connected microgrid system.

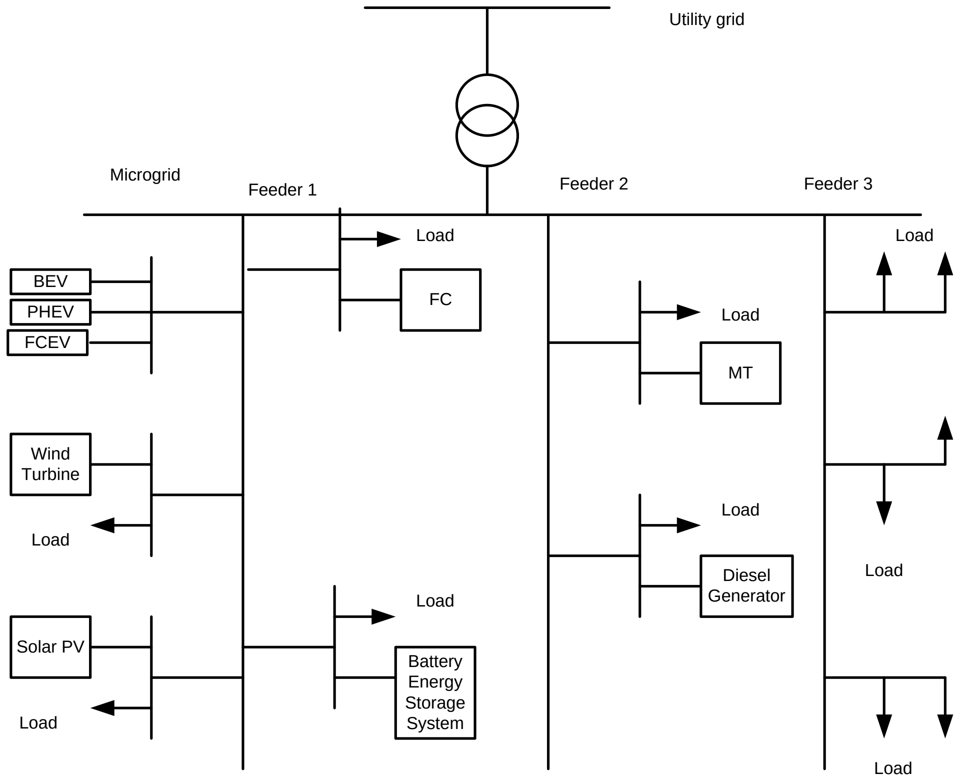

Figure 2: Proposed grid-connected microgrid configuration

4.2 System Description

The proposed microgrid system is shown in Figure 2. Various distributed renewable energy sources such as MT, FC, solar PV, WT, energy storage systems like Li-ion BES and conventional energy sources such as diesel generator (DEG) are integrated in the microgrid system. Further, electrical vehicle technology is also integrated in to this system. Three different types of electric vehicles such as battery electric vehicle (BEV), plug in hybrid vehicle (PHEV) and fuel cell electric vehicle (FCEV) are utilized in this system. Table 2 presents the description of the coefficients and generation limits utilized in this research.

Table 2: Constraints limit and Rates of the DGs, Utility, BES, Dig and EVTs

type	Min. Power (kW)	Max. Power (kW)	Rate (Rs/kW h)	OM (Rs/kW h)	Start-up Cost (Rs)
MT	6	30	39.57	3.86	83.13
FC	3	30	25.46	7.46	142.88
FCEV	3	30	25.46	7.46	142.88
PV	0	25	223.76	18.03	0
WT	0	15	92.91	45.46	0
BES	-30	30	32.91	-	0
BEV	-30	30	32.91	-	0

PHEV	-30	30	32.91	-	0
Grid	-30	30	-	-	-

So microgrid has MT, FC, FCEV, solar PV, WT, BES, BEV, PHEV, DEG and Grid then the place of m^{th} search agent X_m can be defined as:

$$X_m = [x_{m,1} x_{m,2} \dots \dots x_{m,D}]$$

$$\begin{bmatrix} BES\ C_{max,1}, BES\ C_{max,2}, \cdots, BES\ C_{max,s1}, BEV\ C_{max,1}, BEV\ C_{max,2} \\ , \cdots, BEV\ C_{max,s2} \\ PHEV\ C_{max,1}, PHEV\ C_{max,2}, \cdots, PHEV\ C_{max,s3}, MT\ P_1^m, MT\ P_2^m, \dots, \\ MT\ P_T^m, \\ FC\ P_1^m, FC\ P_2^m, \dots, FC\ P_T^m, FCEV\ P_1^m, FCEV\ P_2^m, \dots, FCEV\ P_T^m \\ PV\ P_1^m, PV\ P_2^m, \dots, PV\ P_T^m, WT\ P_1^m, WT\ P_2^m, \dots, WT\ P_T^m \\ BES\ P_1^m, BES\ P_2^m, \dots, BES\ P_T^m, BEV\ P_1^m, BEV\ P_2^m, \dots, BEV\ P_T^m \\ PHEV\ P_1^m, PHEV\ P_2^m, \dots, PHEV\ P_T^m, GRID\ P_1^m, GRID\ P_2^m, \dots, GRID\ P_T^m \\ DEG\ P_1^m, DEG\ P_2^m, \dots, DEG\ P_T^m, MT\ u_1^m, MT\ u_2^m, \dots, MT\ u_T^m, \\ FC\ u_1^m, FC\ u_2^m, \dots, FC\ u_T^m \\ FCEV\ u_1^m, FCEV\ u_2^m, \dots, FCEV\ u_T^m, PV\ u_1^m, PV\ u_2^m, \dots, PV\ u_T^m \\ WT\ u_1^m, WT\ u_2^m, \dots, WT\ u_T^m, BES\ u_1^m, BES\ u_2^m, \dots, BES\ u_T^m \\ BEV\ u_1^m, BEV\ u_2^m, \dots, BEV\ u_T^m, PHEV\ u_1^m, PHEV\ u_2^m, \dots, PHEV\ u_T^m \\ GRID\ u_1^m, GRID\ u_2^m, \dots, GRID\ u_T^m, DEG\ u_1^m, DEG\ u_2^m, \dots, DEG\ u_T^m \end{bmatrix}$$

More information related to the developed microgrid system can be found from [66]. It is assumed that the all distributed renewable generation sources produced the real power at the unity power factor. To mount and operated the batteries utilized in PHEV, BEV and BES, the FX and MT costs are assumed to be 40572.18 (Rs/kWh) and 1308.78 (Rs/ kWh) [71]. The values of IR and LT for the batteries utilized in PHEV, BEV and BES are 0.06 and 3, respectively. The value of tax consider in this work is 10%. Further both the charging and discharging rates of the batteries are considered 90%. For batteries, 10% of the maximum capacities are considered as the minimum capacities. In this research the maximum capacities for all the batteries utilized are selected as 500kWh. Further, the cost minimization problem is performed for the time duration of the 24 hours. Table 3 presented the forecasted demand values and operation reserves for 24 hours utilized in this work. These loads are satisfied by supplying the various generation elements of the microgrid system. The reason behind the selection of the variable loads is the fact that energy utilization trends in the domestic, commercial and industrial customers are varying in nature. The requirement of the operation reserve with standby reserve is also presented by the table 2. It is utilized at the time of energy disconnection from the utility grid.

Table 3: Forecasted load demand and operating reserve

Time (hour)	Total load demand (kW)	Operating reserve capacity (kW)
1	104	67
2	100	69
3	100	69
4	102	68
5	112	62
6	126	55

7	140	49
8	150	42
9	150	45
10	160	47
11	156	58
12	148	65
13	144	72
14	144	68
15	152	50
16	160	41
17	172	33
18	196	30
19	180	28
20	174	31
21	156	40
22	142	47
23	130	52
24	112	61

For verifying the performance of the Fire fly algorithm, the optimal operation problem of microgrid system is solved with 30 trials. The values of the parameters, population size and number of iterations are presented in the table 1.

For the comparative purpose FF results are compared with the GWO and PSO techniques. Various parameters utilized in PSO technique are global and local learning coefficients, which are 2 and 1.5, respectively. Further the damping ration of inertia weight is 0.99.

To find the effectiveness of the firefly algorithm, optimal operation problem of microgrid system is solved under two operational scenarios. In the first scenario, it is considered that all types of batteries utilized in this work are utilized with no charge or minimum charging situation. In the second scenario, all batteries are integrated into the system with full charging condition and considered as generation sources.

4.2.1 Scenario 1: Batteries Charging Mode

In this scenario, various Li-ion batteries are integrated into the microgrid system in the form of PHEV, BEV and BES systems. These are the fundamental elements of the microgrid system. There are numerous advantages of the batteries in the microgrid system such as improved reliability, enhanced power quality and incorporation of intermittent renewable energy sources. At the time of no charge in the batteries, Li-ion batteries are committed into the system, hence the discharging of the batteries are restricted to the charging in the preceding hours. The maximum sizes of the batteries $\mathrm{BES}\ \mathrm{C_{max}}, \mathrm{BEV}\ \mathrm{C_{max}}, \mathrm{PHEV}\ \mathrm{C_{max}}$ are cosndered as the control parameters for observing the effectiveness of the batteries with adequate and effective capacities. The developed microgrid system incorporated the diesel generator. The diesel fuel cost considered in this work is $\mathrm{C_f}$ is 86.96 (Rs/l). The values of various cost parameters a, b, c considered in this work are 0.246, 0.0815, and 0.4333, respectively.

In this particular scenario the optimal operational problem of microgrid system is minimized the operational cost of the system and compute the optimal capacity of the batteries with the optimal generation output of the various microgrid generation element such as utility grid, DEG, PHEV, BEV, FCEV, WT, PV, FC and MT. In this work the compute optimal capacities of the batteries utilized is 50kWh each for the PHEV, BEV and BES.

4.2.2 Scenario 2: Batteries Discharging Mode

This scenario considered that all the batteries integrated with the micro grid system are fully charged. The outputs of the utility grid, DEG, Solar PV, WT, PGEV, FCEV, BES, BEV, MT and FC are computed optimally with the help of fire fly algorithm. In this case it is beneficent to import power form the battery energy storage system and electric vehicles. This case, also considered the optimum battery size of 50 kWh.

4.3 Results Analysis

Fire fly optimization technique is utilized to solve the optimal operation problem of microgrid system. MATLAB software is utilized to model the microgrid system and implementation of the fire fly optimization technique. Further, a detailed comparative analysis is presented to show the effectiveness of the fire fly technique over GWO and PSO technique.

4.3.1 Scenario 1: Batteries Charging Mode

In this operational scenario, all interfaced batteries are considered at no charging or at the minimum charging condition.

4.3.1.1 Optimal Operation Cost Minimization using Fire Fly Algorithm

For scenario one, the results obtained from the fire fly algorithm are presented in the table 4.

Table 4: Charging: Operation cost comparison for Case 1, Rs/day

Methodology	**Average solution**	**Best solution**	**Worst solution**	**Standard deviation**	**Number of trials**	**Population size**	**Iterations**
FF	115219.47	109157.02	119922.14	4251.62	30	50	500

Table 4 presented the results obtained in the scenario one using the fire fly algorithm. The numbers of trials performed are 30. The population size of the fire flies are 50. Total numbers of itation performed are 500. The average cost obtained from the firefly algorithm is 115219.47 Rs/day. The worst solution obtained from the firefly algorithm is 119922.14Rs/day. The best solution i.e. the minimum cost obtained from the firefly algorithm is 109157.02 Rs/day. The standard deviation of the implemented method is 4251.62.

4.3.1.2 Optimal output of microgrid elements using Fire Fly algorithm

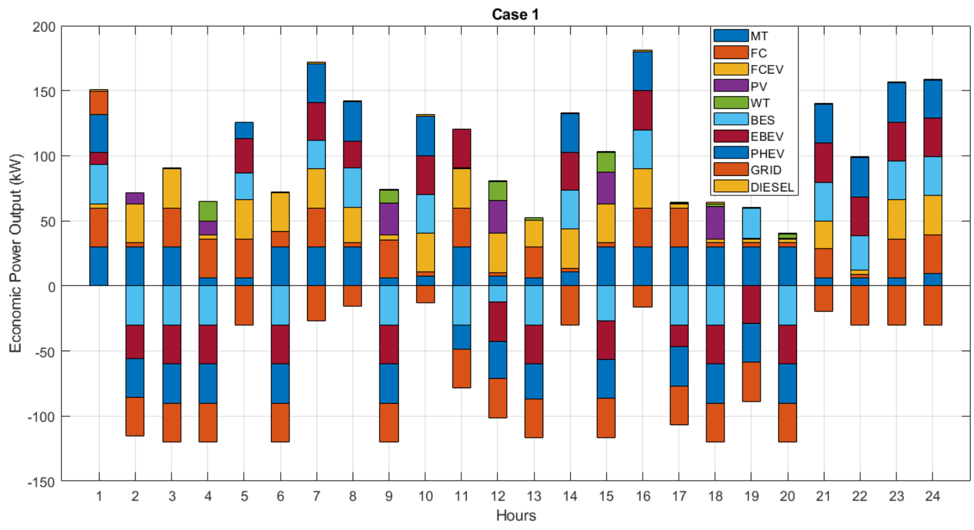

Figure 3: Scenario 1 Output of the various microgrid components using fire fly algorithm for 24 hour operation duration

Figure 3 presented the optimal outputs computed from the firefly algorithm obtained from the various generation elements of the microgrid system. Table 5 presented the optimal power output with the status of the various microgrid generation elements.

Table 5: Optimal power output and the status of the various microgrid generation elements in the scenario one

	Power output of Microgrid Generation Components (kW)										Status of Microgrid Generation Components									
Hours	MT	FC	FCEV	PV	WT	BES	BEV	PHEV	GRID	DIESEL	MT	FC	FCEV	PV	WT	BES	BEV	PHEV	GRID	DIESEL
1	30	29.98602	3.006495	9.36E-05	0.088835	29.99941	9.805939	28.77093	17.82079	1.089826	1	1	1	1	1	1	1	1	1	1
2	29.99998	3.018824	29.94927	8.343124	1.76E-06	-30	-25.6474	-29.6538	-30	0.454174	1	1	1	1	1	1	1	1	1	1
3	29.99985	29.91974	29.99425	0.007056	4.57E-05	-29.9981	-30	-29.9998	-30	0.461547	1	1	1	1	1	1	1	1	1	1
4	6.00001	29.99947	3.002753	10.75492	15	-29.9999	-29.9999	-30	-30	0.4068	1	1	1	1	1	1	1	1	1	1
5	6.001065	29.99754	30	0.00015	1.88E-06	20.42521	26.62639	12.40445	-30	0.532394	1	1	1	1	1	1	1	1	1	1
6	29.9631	11.66797	29.99755	0	0.001577	-29.9999	-29.9999	-29.9991	-29.9998	0.417301	1	1	1	1	1	1	1	1	1	1
7	29.99994	29.97668	29.99943	0.000282	0.000264	21.97344	28.83831	29.99987	-26.7875	0.977333	1	1	1	1	1	1	1	1	1	1
8	29.99857	3.001403	27.3796	2.61E-05	6.81E-06	29.99963	20.87878	29.99769	-15.5853	1.164734	1	1	1	1	1	1	1	1	1	1
9	6	29.09942	3.847468	24.99952	9.808671	-29.9938	-29.9999	-29.9954	-29.9995	0.410836	1	1	1	1	1	1	1	1	1	1
10	7.755	3.001	29.48	2.21E-	7.32E-	29.99	29.99	30	-13.09	1.103	1	1	1	1	1	1	1	1	1	1

	731	9	165	05	05	911	976		17	303										
11	29.85797	29.99986	29.99978	0.001956	0.529091	-29.9978	29.75251	-18.3931	-30	0.427171	1	1	1	1	1	1	1	1	1	1
12	7.309447	3.000164	29.97472	24.99931	14.99997	-12.5968	-29.927	-28.7779	-29.9999	0.429678	1	1	1	1	1	1	1	1	1	1
13	6.000166	24.25378	19.90675	0	2.021598	-29.9232	-29.9818	-26.9807	-29.9993	0.432626	1	1	1	1	1	1	1	1	1	1
14	10.63272	3.068609	29.97721	2.26E-05	8.29E-05	29.94038	28.92772	29.72125	-30	0.412123	1	1	1	1	1	1	1	1	1	1
15	29.99996	3.046329	30	24.57847	14.98763	-26.8993	-29.6115	-29.9999	-29.9999	0.425924	1	1	1	1	1	1	1	1	1	1
16	29.97193	29.99758	30	2.25E-06	0.000337	30	29.99991	29.99999	-16.0777	1.093628	1	1	1	1	1	1	1	1	1	1
17	29.99874	29.99481	3.163664	0.454392	0.02979	-29.9156	-16.915	-29.9999	-29.9999	0.428164	1	1	1	1	1	1	1	1	1	1
18	29.97506	3.000022	3.006045	24.99905	2.036906	-29.9984	-29.9915	-29.9997	-30	1.224929	1	1	1	1	1	1	1	1	1	1
19	29.99739	3.002436	3.006367	0.637565	0	23.16207	-28.6094	-29.9945	-29.9997	0.476362	1	1	1	1	1	1	1	1	1	1
20	29.99987	3.102399	3.000005	0.133087	3.682681	-29.994	-30	-30	-30	0.422514	1	1	1	1	1	1	1	1	1	1
21	6.175715	22.42484	21.03238	1.02E-05	0.000156	29.99932	29.99959	29.99989	-19.8498	0.851631	1	1	1	1	1	1	1	1	1	1
22	6.001781	3.005281	3	7.37E-05	5.05E-05	26.32277	29.99686	29.99801	-30	0.680731	1	1	1	1	1	1	1	1	1	1
23	6.003872	29.99999	29.99996	0.000149	0.000211	29.9998	30	29.99995	-30	0.568508	1	1	1	1	1	1	1	1	1	1
24	9.327409	29.99992	29.99951	4.33E-05	0.000653	29.99446	29.91688	28.85723	-30	0.416024	1	1	1	1	1	1	1	1	1	1

4.3.1.3 Comparative Analysis in Scenario-1

Figure 4 presents the comparative analysis of convergence characteristic of Fire fly algorithm with PSO and GWO.

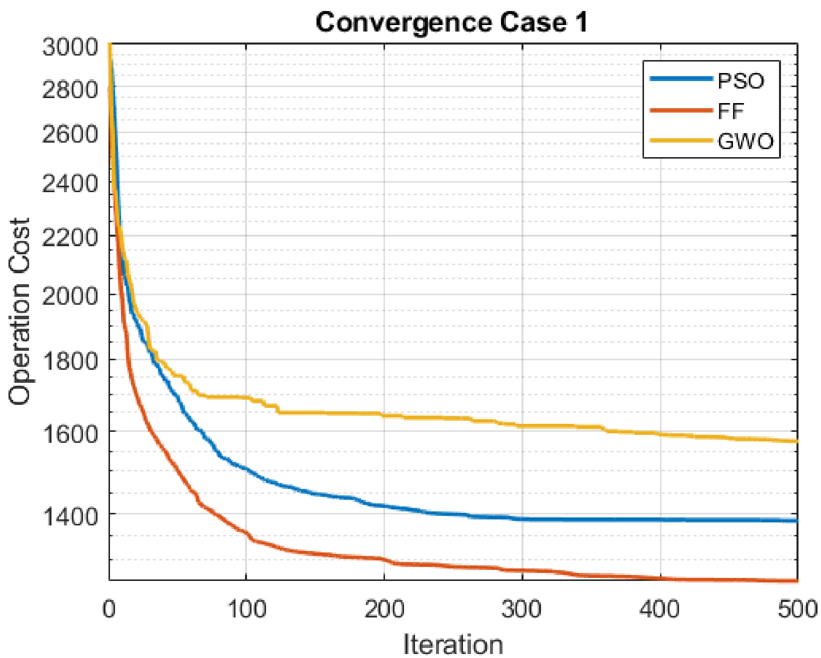

Figure 4: Scenario 1 convergence characteristic of firefly algorithm compare with other techniques

From the figure 4 it is clear that FF algorithm obtained the minimum cost initially and reached to its final value very fast as compare to the GWO and PSO techniques in the scenario one. Table 6 presented the comparative analysis of the different operational costs of microgrid system computed form the fire fly, GWO and PSO techniques.

Table 6: Scenario 1 Operation cost comparison in Rs/day

Methodology	Average solution	Best solution	Worst solution	Standard deviation	Number of trials	Population size	Iterations
FF	**114734.74**	**108697.79**	**119417.62**	**4233.74**	**30**	**50**	**500**
GWO	139693.99	136382.06	146599.47	3624.43	30	50	500
PSO	128864.45	119901.85	144088.00	6050.79	30	50	500

From the table 6, it is clear that the operation cost of the microgrid system calculated with the firefly algorithm is lowest as compared to the grey wolf optimization and particle swarm optimization techniques.

Table 7: Percentage Reduction in the various operational costs as compare to the GWO and PSO in scenario 1

Methodology	Average solution	% reduction	Best solution	% reduction	Worst solution	% reduction
FF	**114734.74**	**-**	**108697.79**	**-**	**119417.62**	**-**
GWO	139693.99	17.86709	136382.06	20.29905	146599.47	18.54157
PSO	128864.45	10.96479	119901.85	9.344363	144088.00	17.12175

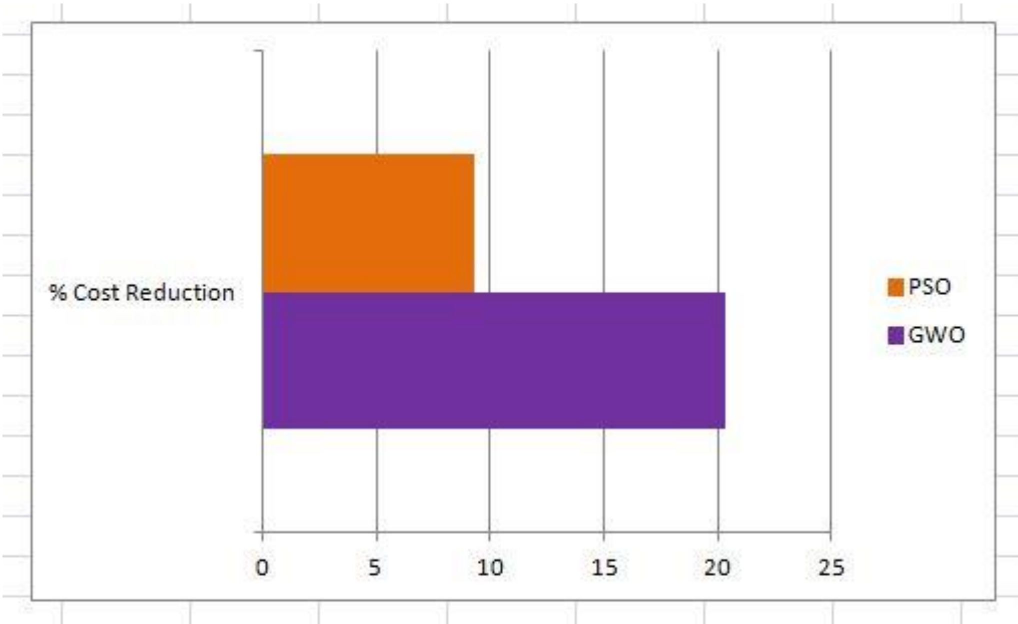

Figure 5: Percentage Reduction in the best operational cost as compare to the GWO and PSO

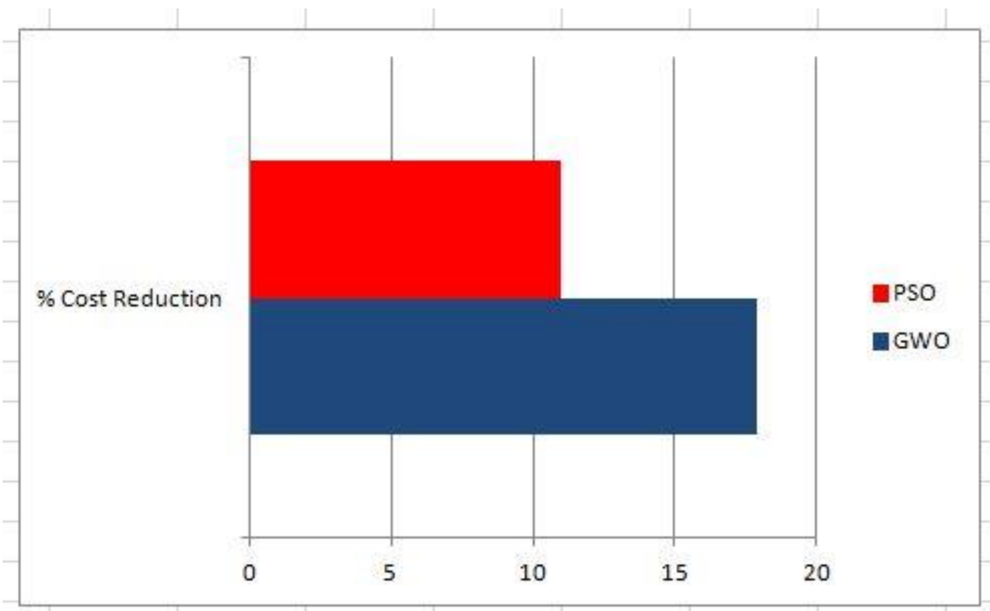

Figure 6: Percentage Reduction in the average operational cost as compare to the GWO and PSO

By comparative analysis, presented in the table 7 it is clear that firefly algorithm has more improved performance as compare to the gray wolf optimisation. A 17.87% average cost reduction is obtained with the help of firefly algorithm as compare to the grey wolf optimization algorithm in the case of scenario 1. Similarly, a 20.3% best cost reduction is obtained with the help of firefly algorithm as compare to the grey wolf optimization algorithm in the case of scenario 1. Further, an 18.54157% worst cost reduction is obtained with the help of firefly algorithm as compare to the grey wolf optimization algorithm in the case of scenario 1. Figure 5 presented the comparative best cost reduction percentage of the PSO and GWO.

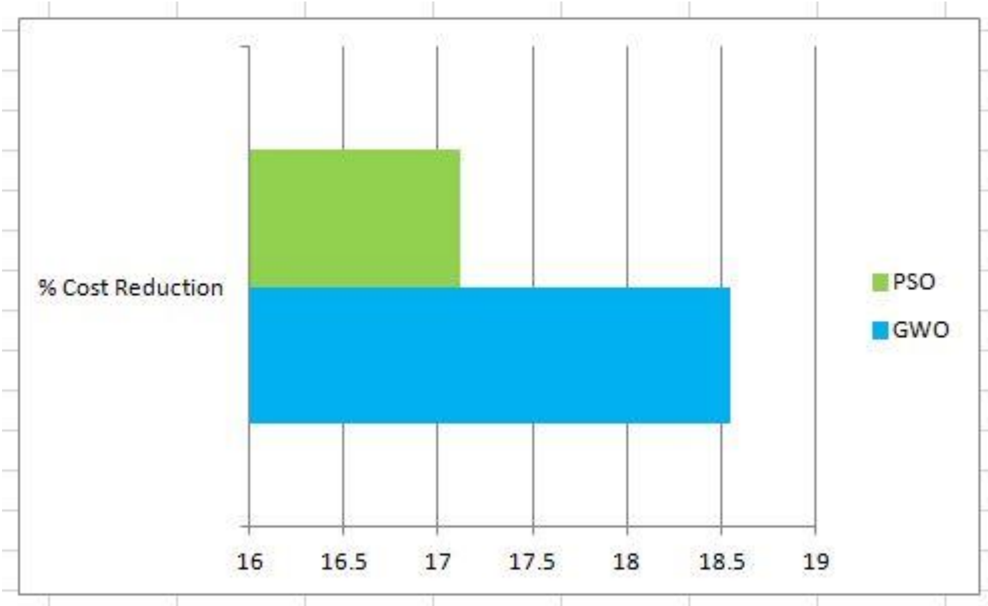

Figure 7: Percentage Reduction in the worst operational cost as compare to the GWO and PSO

Further, it is clear from the table 7 that a 10.96479% average cost reduction is obtained with the help of firefly algorithm as compare to the PSO in the case of scenario 1. Similarly, a 9.344363% best cost reduction is obtained with the help of firefly algorithm as compare to the PSO in the case of scenario 1. Further, a 17.12175% worst cost reduction is obtained with the help of firefly algorithm as compare to the PSO in the case of scenario 1. Figure 6 presented the percentage Reduction in the average operational cost as compare to the GWO and PSO. Figure 7 presented the percentage reduction in the microgrid worst operational cost computed from fire fly algorithm as compare to the GWO and PSO techniques.

4.3.1.4 Comparative analysis of the output of microgrid components

In this research work, fire fly algorithm is utilized to compute the output of various microgrid generation components in scenario 1. A comparative analysis of the power output in (kW) of various microgrid generation components with GWO and PSO techniques is presented by the table 8.

Table 8: Optimal power output for Scenario 1

Scenario 1		
Algorithm Name	Result Criteria	Power Generated (kW)
GWO	MT	335.9989052
	FC	187.3104905
	FCEV	234.2203045

	PV	80.47335551
	WT	84.67019008
	BES	-27.606588
	EBEV	59.03828531
	PHEV	23.40939028
	GRID	-214.89358
	DIESEL	4.460317057
FF	**MT**	**466.9702851**
	FC	**417.56498**
	FCEV	**482.7248558**
	PV	**119.9093351**
	WT	**63.18864062**
	BES	**-7.5010898**
	EBEV	**-15.9405532**
	PHEV	**-64.0443816**
	GRID	**-613.56917**
	DIESEL	**15.30826173**
PSO	MT	414.167348
	FC	382.11836
	FCEV	443.5672794
	PV	157.3263864
	WT	101.7710205
	BES	22.38783989
	EBEV	26.35115574
	PHEV	63.98927284
	GRID	-448.374113
	DIESEL	20.86102467

4.3.2 Scenario 2: Batteries Discharging Mode

In this operational scenario, all interfaced batteries are considered at fully charging or at the maximum charging condition.

4.3.2.1 Optimal Operation Cost Minimization using Fire Fly Algorithm

For scenario two, the results obtained from the fire fly algorithm are presented in the table 9.

Table 9: Operation cost comparison for scenario 2, Rs/day

Methodology	Average solution	Best solution	Worst solution	Standard deviation	Number of trials	Population size	Iterations
FF	**139543.67**	**137734.30**	**143544.72**	**2029.39**	**30**	**50**	**500**

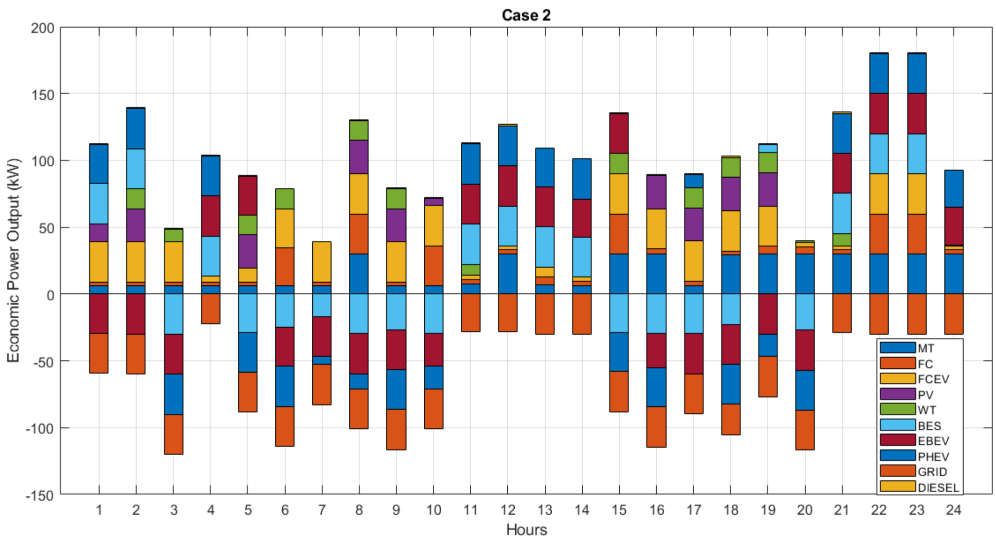

Figure 8: Scenario 2 Output of the various microgrid components using fire fly algorithm for 24 hour operation duration

Table 1 presented the results obtained in the scenario two using the fire fly algorithm. The numbers of trials performed are 30. The population size of the fire flies are 50. Total numbers of iterations performed are 500. The average cost obtained from the firefly algorithm is 139543.67Rs/day. The worst solution obtained from the firefly algorithm is 143544.72Rs/day. The best solution i.e. the minimum cost obtained from the firefly algorithm is 137734.30Rs/day. The standard deviation of the implemented method is 2029.39.

4.3.2.2 Optimal output of microgrid elements using Fire Fly algorithm

Figure 8 presented the optimal outputs in kW computed from the firefly algorithm obtained from the various generation elements of the microgrid system. Table 10 presented the optimal power output with the status of the various microgrid generation elements.

Table 10: Optimal power output and the status of the various microgrid generation elements in the scenario two

	Power output of Microgrid Generation Components (kW)										**Status of Microgrid Generation Components**									
Hours	MT	FC	FCEV	PV	WT	BES	EBEV	PHEV	GRID	DIESEL	MT	FC	FCEV	PV	WT	BES	EBEV	PHEV	GRID	DIESEL
1	6.000018	3.000038	29.99999	13.58599	0.017154	29.99897	-29.3746	29.54785	-30	0.415304	0	0	1	1	1	1	1	1	1	1
2	6.000111	3.000087	29.93141	24.99986	14.99997	29.89979	-30	29.99522	-30	0.43882	0	0	1	1	1	1	1	1	1	1
3	6.000025	3.000033	30	0.0141	9.425953	-30	-30	-30	-30	0.4096	0	0	1	1	1	1	1	1	1	1
4	6.000075	3	4.428639	2.13E-07	2.9E-06	29.99344	29.99922	30	-22.0185	0.768644	0	0	1	1	1	1	1	1	1	1
5	6.000011	3.000272	10.22825	24.95066	14.72802	-28.7544	29.0755	-29.6395	-30	0.414493	0	0	1	1	1	1	1	1	1	1
6	6.000	28.68	28.71	0.302	14.85	-24.7	-29.4	-29.8	-30	0.448	0	1	1	1	1	1	1	1	1	1

	038	042	738	07	149	991	337	947		908										
7	6.00001	3.005334	29.99852	1.48E-05	0.000634	-17.0166	-29.9608	-5.67085	-30	0.414069	0	1	1	1	1	1	1	1	1	1
8	29.87791	29.99872	29.99986	24.99943	14.96968	-29.7604	-29.9998	-11.283	-30	0.419106	1	1	1	1	1	1	1	1	1	1
9	6.000084	3	29.95359	25	14.98732	-27.0402	-29.4739	-29.9995	-30	0.418255	1	1	1	1	1	1	1	1	1	1
10	6.000477	29.99921	29.99999	5.528262	0.137064	-29.5174	-24.533	-16.8863	-30	0.417115	1	1	1	1	1	1	1	1	1	1
11	7.606356	3.265441	3.076866	1.9E-05	8.249697	29.99999	30	30	-28.3929	1.1432	1	1	1	1	1	1	1	1	1	1
12	29.94288	3.000066	3	9.6E-06	2.34E-05	29.99991	30	29.99998	-27.9987	0.998721	1	1	1	1	1	1	1	1	1	1
13	6.951727	6.03421	7.379514	0	1.23E-05	29.96274	29.87297	28.77239	-30	0.392003	1	1	1	1	1	1	1	1	1	1
14	6.27999	3.046712	3.160743	0	1.3E-05	29.97254	28.70106	29.98144	-30	0.345053	1	1	1	1	1	1	1	1	1	1
15	29.98083	29.99957	29.99994	0.290364	15	-28.5141	29.75202	-29.6481	-30	0.41837	1	1	1	1	1	1	1	1	1	1
16	30	3.908657	29.99083	24.65927	0.126206	-29.7996	-25.1155	-29.5104	-30	0.415412	1	1	1	1	1	1	1	1	1	1
17	6.027853	3.536236	29.99903	24.80684	14.9978	-29.548	-29.9923	10.17079	-30	0.392215	1	1	1	1	1	1	1	1	1	1
18	29.1086	3.015878	29.97953	24.99483	14.87761	-22.7269	-29.9985	-29.7095	-23.3063	1.214249	1	1	1	1	1	1	1	1	1	1
19	29.99998	5.663473	29.97837	24.99937	14.9998	6.275623	-29.9579	-16.9214	-30	0.42707	1	1	1	1	1	1	1	1	1	1
20	29.99722	5.432644	3.206785	0.036528	0.97624	-27.0352	-29.999	-29.8952	-30	0.426019	1	1	1	1	1	1	1	1	1	1
21	30	3.189453	3.000118	0	9.074583	30	29.99998	29.99999	-29.1049	1.030347	1	1	1	1	1	1	1	1	1	1
22	29.9678	29.99999	29.99998	0	4.29E-05	29.9999	29.99948	29.99983	-30	0.538425	1	1	1	1	1	1	1	1	1	1
23	29.85821	30	29.9999	8.74E-06	8.95E-07	29.99978	29.99994	29.99991	-30	0.546985	1	1	1	1	1	1	1	1	1	1
24	29.99998	3.000036	3.000245	6.18E-06	0	0.479948	28.7125	27.43542	-30	0.372364	1	1	1	1	1	1	1	1	1	1

4.3.2.3 Comparative Analysis in Scenario-2

Figure 9 presents the comparative analysis of convergence characteristic of Fire fly algorithm with PSO and GWO.

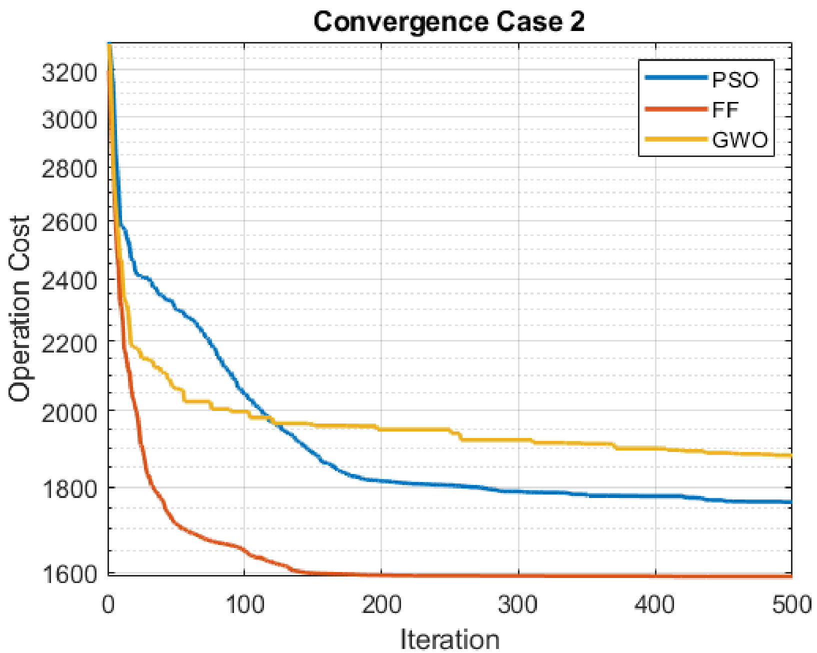

Figure 9: Scenario 2 convergence characteristic of firefly algorithm compare with other techniques

From the figure 9 it is clear that FF algorithm obtained the minimum cost initially and reached to its final value very fast as compare to the GWO and PSO techniques in the scenario one.

Table 11: Scenario 2 Operation cost comparison in Rs/day

Methodology	Average solution	Best solution	Worst solution	Standard deviation	Number of trials	Population size	Iterations
FF	**139543.67**	**137734.30**	**143544.72**	**2029.39**	**30**	**50**	**500**
GWO	175731.84	162791.15	172963.62	3155.15	30	50	500
PSO	157213.75	152662.49	165959.69	3871.52	30	50	500

From the table 11, it is clear that the operation cost of the microgrid system calculated with the firefly algorithm is the lowest as compared with the grey wolf optimization and particle swam optimization techniques.

Table 12: Percentage Reduction in the various operational costs as compare to the GWO and PSO in scenario 2

Methodology	Best solution	% reduction	Average Solution	% reduction	Worst Solution	% reduction
FF	**137734.30**	-	**139543.67**	**-**	**143544.72**	-
GWO	162791.15	15.39202	175731.84	17.48415	172963.62	17.00872
PSO	152662.49	9.778557	157213.75	11.23953	165959.69	13.50627

By comparative analysis, presented in the table 12 it is clear that firefly algorithm has more improved performance as compare to the gray wolf optimization. A 17.48415% average cost reduction is obtained with the help of firefly algorithm as compare to the grey wolf optimization algorithm in the case of scenario 2. Similarly, a 15.39202% best cost reduction is obtained with the help of firefly algorithm as compare to the grey wolf optimization algorithm in the case of scenario 2. Further, a 17.00872% worst cost reduction is obtained with the help of firefly algorithm as compare to the grey wolf optimization algorithm in the case of scenario 2. Figure presented the comparative best cost reduction percentage of the PSO and GWO. Figure 10 presented the percentage reduction in the microgrid best operational cost computed from fire fly algorithm as compare to the GWO and PSO techniques.

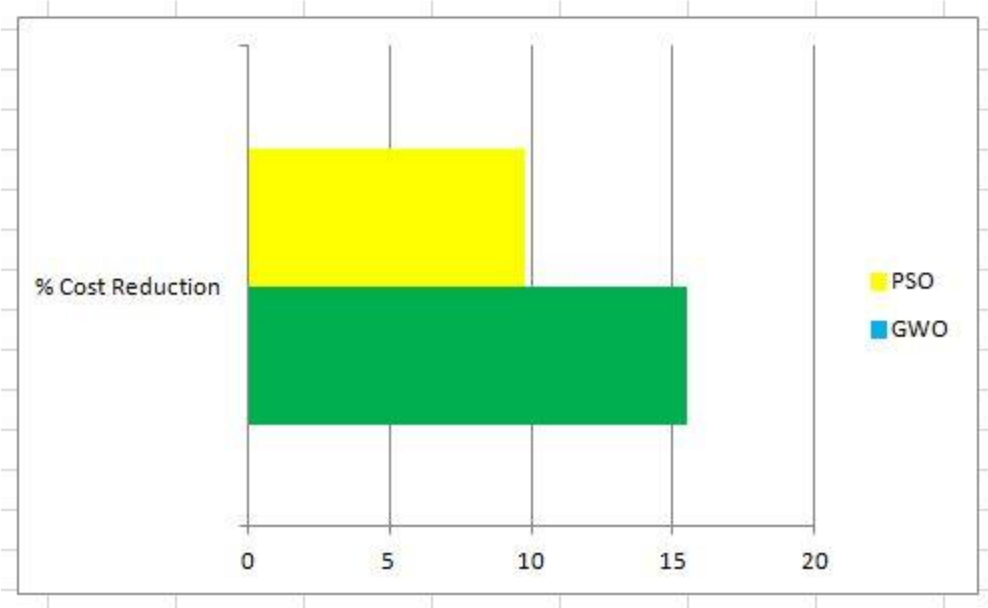

Figure 10: Percentage Reduction in the best operational cost as compare to the GWO and PSO

Further, it is clear from the table 12 that an 11.23953% average cost reduction is obtained with the help of firefly algorithm as compare to the PSO in the case of scenario 2. Similarly, a 9.778557% best cost reduction is obtained with the help of firefly algorithm as compare to the PSO in the case of scenario 2. Further, a 13.50627% worst cost reduction is obtained with the help of firefly algorithm as compare to the PSO in the case of scenario 2.

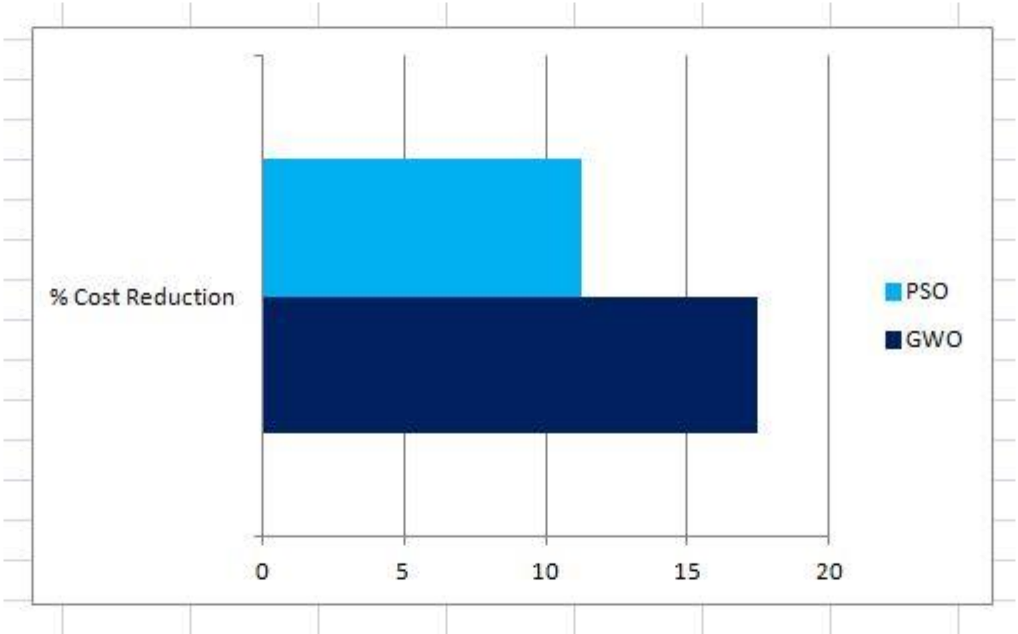

Figure 11: Percentage Reduction in the average operational cost as compare to the GWO and PSO

Figure 11 presented the percentage reduction in the microgrid average operational cost computed from fire fly algorithm as compare to the GWO and PSO techniques.

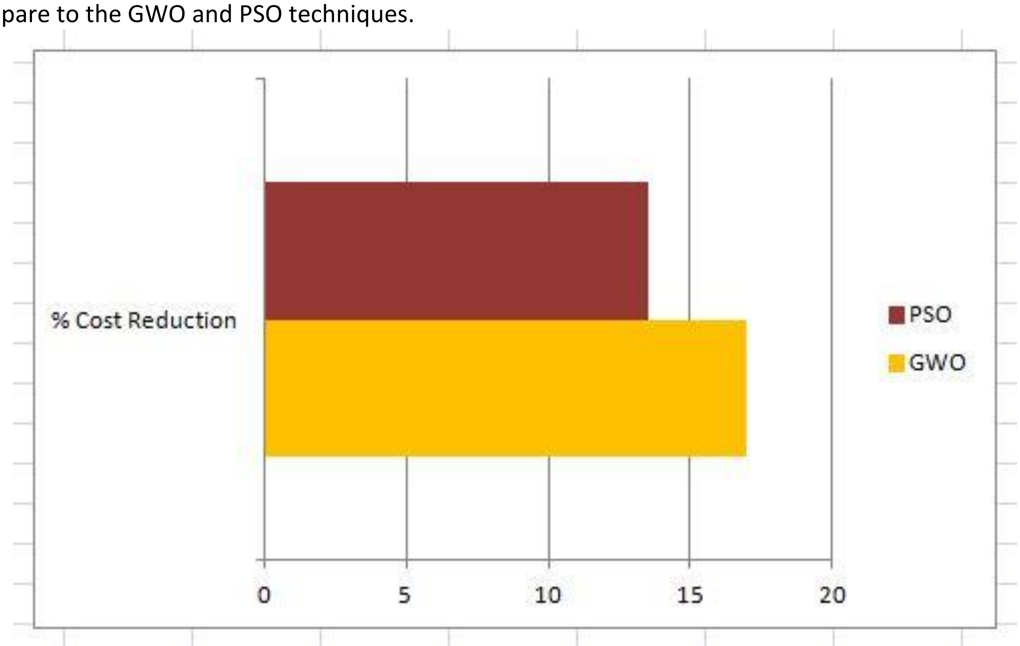

Figure 12: Percentage Reduction in the worst operational cost as compare to the GWO and PSO

Figure 12 presented the percentage reduction in the microgrid worst operational cost computed from fire fly algorithm as compare to the GWO and PSO techniques.

4.3.2.4 Comparative analysis of the output of microgrid components

In this research work, fire fly algorithm is utilized to compute the output of various microgrid generation components in scenario 2. A comparative analysis of the power output in (kW) of various microgrid generation components with GWO and PSO techniques is presented by the table 13.

Table 13: Optimal power output for Scenario 2

Scenario 2		
Algorithm Name	**Result Criteria**	**Power Output in (kW)**
GWO	MT	241.5899786
	FC	171.1541481
	FCEV	190.2919994
	PV	45.63112751
	WT	25.92169052
	BES	9.427490664
	EBEV	-10.2471878
	PHEV	-1.48248939
	GRID	-301.507949
	DIESEL	8.898536746
FF	**MT**	**409.6002007**
	FC	**242.7764903**
	FCEV	**489.0294982**
	PV	**219.1676284**
	WT	**162.4193098**
	BES	**-17.9291653**
	EBEV	**-51.7265048**
	PHEV	**46.84416972**
	GRID	**-700.821003**
	DIESEL	**13.22474574**
PSO	MT	354.0966291
	FC	302.6935642
	FCEV	409.9912975
	PV	245.1726234
	WT	158.3105852
	BES	4.185270072
	EBEV	-54.1308942
	PHEV	-12.5516488
	GRID	-646.08283
	DIESEL	10.08318607

5. Conclusion

The energy demand around the world is continuously increasing. Thus, distributed renewable energy sources should be integrated to the utility grid along with traditional energy sources in the form of microgrid for satisfying the energy demand. Microgrid system integrated various renewable and conventional sources of energy in a single platform. In this work, microgrid system is integrated with MT, FC, PV, WT, BES, EVTs, Diesel Generator and demand. For the efficient working of the microgrid system, operation of microgrid system should be effacingly optimized. Therefore, in this research work efficient fire fly optimization algorithm is utilized and the operation of the microgrid system is optimized. The operational cost of the microgrid system is minimized under two different operational scenarios. First scenario considered that all the integrated batteries are in charging mode while in scenario second discharging modes of all the batteries utilized in this work. Operational cost for scenario one is minimized to 109157.02 Rs/Day and operational cost for scenario two is minimized to 137734.30 Rs/Day. A comparative analysis with the GWO and PSO techniques is also presented. By the comparative analysis it is clear that the fire fly algorithm provided the most optimal solutions i.e. average, best and worst solutions, in both the operational scenarios.

The results of this research work will help the scientists and researchers to optimize the performance of the microgrid system by minimizing the operational cost of the various microgrid generation components under different constraint conditions. This work may also be helpful for the economic operation of microgrid. The futuristic enrichment of this research work can be developed a technique that will generate more minimized operation cost results for the practical micro grid system. Further, hardware implementation of the developed microgrid system with applied fire fly techniques can also do as futuristic enhancement.

References

[1] S. M. Nosratabadi, R.A. Hooshmand, and E. Gholipour, “A comprehensive review on microgrid and virtual power plant concepts employed for distributed energy resources scheduling in power systems,” Renew. Sustain. Energy Rev., vol. 67, pp. 341–363, Jan 2017.

[2] M. D. A. Al-falahi, S. D. G. Jayasinghe, and H. Enshaei, “A review on recent size optimization methodologies for standalone solar and wind hybrid renewable energy system,” Energy Convers. Manag., vol. 143, pp. 252–274, July 2017.

[3] B. B. Firouzi and R. A. Abarghooee, “Optimal sizing of battery energy storage for micro-grid operation management using a new improved bat algorithm,” Int. j. electr. power energy syst., vol. 56, pp. 42–54, March 2014.

[4] M. D. A. Al-Falahi and M. Z. C. Wanik, “Modeling and performance analysis of hybrid power system for residential application,” in Australasian Universities Power Engineering Conference (AUPEC), pp. 1–6, 2015.

[5] M. D. A. Al-Falahi, K. S. Nimma, S. D. G. Jayasinghe, et al, “Sizing and modeling of a standalone hybrid renewable energy system,” in IEEE 2nd Annual Southern Power Electronics Conference (SPEC), pp. 1–6, 2016.

[6] Z. W. Geem and Y. Yoon, “Harmony search optimization of renewable energy charging with energy storage system,” Int. j. electr. power energy syst., vol. 86, pp. 120–126, 2017.

[7] X.-S. Yang, “Firefly algorithms for multimodal optimization,” in Stochastic Algorithms: Foundations and Applications, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 169–178, 2009.

[8] J. Kennedy and R. Eberhart, “Particle swarm optimization,” in Proceedings of ICNN’95 - International Conference on Neural Networks, pp. 1942–1948, 2002.

[9] S. Mirjalili, S. M. Mirjalili, and A. Lewis, “Grey wolf optimizer,” Adv. Eng. Softw., vol. 69, pp. 46–61, 2014 pp. March 2014.

[10] L. Bridier, D. H.Torres, M. David, et al, “A heuristic approach for optimal sizing of ESS coupled with intermittent renewable sources systems,” Renew. Energy, vol. 91, pp. 155–165, June 2016.

[11] M. R. Aghamohammadi and H. Abdolahinia, “A new approach for optimal sizing of battery energy storage system for primary frequency control of islanded Microgrid,” Int. j. electr. power energy syst., vol. 54, pp. 325–333, 2014.

[12] R. R.Mariani, B. Sareni, and X. Roboam, “Fast power flow scheduling and sensitivity analysis for sizing a microgrid with storage,” Math. Comput. Simul., vol. 131, pp. 114–127, Jan 2017.

[13] A. Malheiro, P. M. Castro, R. M. Lima, et al “Integrated sizing and scheduling of wind/PV/diesel/battery isolated systems,” Renew. Energy, vol. 83, pp. 646–657, Nov 2015.

[14] A. Billionnet, M.C. Costa, and P.L. Poirion, “Robust optimal sizing of a hybrid energy stand-alone system,” Eur. J. Oper. Res., vol. 254, no. 2, pp. 565–575, 2016.

[15] S. X. Chen, H. B. Gooi, and M. Q. Wang, “Sizing of energy storage for microgrids,” IEEE Trans. Smart Grid, vol. 3, no. 1, pp. 142–151,

March 2012.

[16] A. C. R.Medina, J. F. Franco, M. J. Rider, et al, "A mixed-integer linear programming approach for optimal type, size and allocation of distributed generation in radial distribution systems," Electric Power Syst. Res., vol. 97, pp. 133–143, April 2013.

[17] Z. L. Wu, J. Y. Ding, Q. H. Wu, et al, "Two-phase mixed integer programming for non-convex economic dispatch problem with spinning reserve constraints," Electric Power Syst. Res., vol. 140, pp. 653–662, Nov 2016.

[18] C. Brandoni and M. Renzi, "Optimal sizing of hybrid solar micro-CHP systems for the household sector," Appl. Therm. Eng., vol. 75, pp. 896–907, Jan 2015.

[19] S. Sanajaoba and E. Fernandez, "Maiden application of Cuckoo Search algorithm for optimal sizing of a remote hybrid renewable energy System," Renew. Energy, vol. 96, pp. 1–10, oct 2016.

[20] M. Schneider, K. Biel, S. Pfaller, et al, "Optimal sizing of electrical energy storage systems using inventory models," Energy Procedia, vol. 73, pp. 48–58, June 2015.

[21] S. Mohammadi and A. Mohammadi, "Stochastic scenario-based model and investigating size of battery energy storage and thermal energy storage for micro-grid," Int. j. electr. power energy syst., vol. 61, pp. 531–546, oct 2014.

[22] X. Zhang, J. Bao, R. Wang, et al "Dissipativity based distributed economic model predictive control for residential microgrids with renewable energy generation and battery energy storage," Renew. Energy, vol. 100, pp. 18–34, Jan 2017.

[23] M. H. M. Camillo, R.Z Fanucchi, M.E.V Romero et al., "Combining exhaustive search and multi-objective evolutionary algorithm for service restoration in large-scale distribution systems," Electric Power Syst. Res., vol. 134, pp. 1–8, May 2016.

[24] T. A. Nguyen, M. L. Crow, and A. C. Elmore, "Optimal sizing of a vanadium redox battery system for microgrid systems," IEEE Trans. Sustain. Energy, vol. 6, no. 3, pp. 729–737, July 2015.

[25] R. R. Mariani, B. Sareni, X. Roboam, et al, "Optimal power dispatching strategies in smart-microgrids with storage," Renew. Sustain. Energy Rev., vol. 40, pp. 649–658, Dec 2014.

[26] M. Mohammadi, S. H. Hosseinian, and G. B. Gharehpetian, "GA-based optimal sizing of microgrid and DG units under pool and hybrid electricity markets," Int. j. electr. power energy syst., vol. 35, no. 1, pp. 83–92, Feb 2012.

[27] B. Zhao, X. Zhang, P. Li, et al, "Optimal sizing, operating strategy and operational experience of a stand-alone microgrid on Dongfushan Island," Appl. Energy, vol. 113, pp. 1656–1666, Jan 2014.

[28] T. Kerdphol, K. Fuji, Y. Mitani, et al, "Optimization of a battery energy storage system using particle swarm optimization for stand-alone microgrids," Int. j. electr. power energy syst., vol. 81, pp. 32–39, oct 2016.

[29] T. Kerdphol, Y. Qudaih, and Y. Mitani, "Optimum battery energy storage system using PSO considering dynamic demand response for microgrids," Int. j. electr. power energy syst., vol. 83, pp. 58–66, Dec 2016.

[30] T. Mesbahi, F. Khenfri, N. Rizoug, et al, "Dynamical modeling of Li-ion batteries for electric vehicle applications based on hybrid Particle Swarm–Nelder–Mead (PSO–NM) optimization algorithm," Electric Power Syst. Res., vol. 131, pp. 195–204, Feb 2016 .

[31] S. Sukumar, M. Marsadek, A. Ramasamy, et al, "Grey wolf optimizer based battery energy storage system sizing for economic operation of microgrid," in IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), pp. 1-5 June 2018,

[32] K. Nimma, M. A. Falahi, H. D. Nguyen, et al, "Grey wolf optimization-based optimum energy-management and battery-sizing method for grid-connected microgrids," Energies, vol. 11, no. 4, p. 847, 2018.

[33] A. Y. Saber and G. K. Venayagamoorthy, "Smart micro-grid optimization with controllable loads using particle swarm optimization," in IEEE Power & Energy Society General Meeting, pp.1-5, July 2013.

[34] F. Laureri, L. Puliga, M. Robba, et al, "An optimization model for the integration of electric vehicles and smart grids: Problem definition and experimental validation," in IEEE International Smart Cities Conference (ISC2), pp. 1-6, Sep 2016.

[35] M. Patterson, N. F. Macia, and A. M. Kannan, "Hybrid microgrid model based on solar photovoltaic battery fuel cell system for intermittent load applications," IEEE trans. energy convers., vol. 30, no.1, pp. 359–366, 2015.