Dynamic Economic Dispatch of Power System Network Having Thermal Units and Electric Vehicles using IGWO

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ABSTRACT:
Grey Wolf optimizer is a well-known metaheuristic technique but it faces the problem of premature convergence, trapping in local optima and poor balance between exploration and exploitation. Hence, various modifications have been proposed over past few years. One such modification is modelling the prey position as dynamic in nature as shown in GWOLF. However, still it has been observed that to get better solution, GWOLF needs to be modified too, hence an improved version of GWO (IGWO) is proposed. IGWO has the advantage of both GWO and GWOLF. In this paper, IGWO is used to solve Dynamic Economic Dispatch (DED) problem. IGWO is having a better balance between exploitation and exploration for the complex problem such as Dynamic Economic Dispatch (DED) taking into account of valve-point effect, transmission losses and ramp-rate limits with and without Electric Vehicles (EVs). The efficiency of the algorithm is demonstrated on solving different DED problems for 5 generator and 15 generator test systems with and without losses along with different charging profile distribution of electric vehicles. The results showcased by IGWO is compared with the other algorithm. The results obtained by IGWO algorithm adopted in solving dynamic economic dispatch problem is giving competitive results as compared to the results given by other algorithm present in literature.

KEYWORDS: Non-Linear Constrained Optimization, Non-Convex Optimization, Evolutionary Algorithm, Ramp Rate Limits, Valve Point Effects, GWOLF, Levy Flight.

1. INTRODUCTION

Static economic dispatch is a well-known power system problem to determine the power output of committed units at a specified time interval, but static economic dispatch does not consider ramp-rate constraints of generating units. Hence, Dynamic Economic Dispatch (DED) of generating units is used wherein ramp-rate constraints are considered along with other constraints to meet the total load demand. Hence it becomes a significant research problem to optimize DED of the generating units. The objective of DED is to decide the ideal dispatch solution with the minimization of fuel costs in a specific time range while fulfilling various operational constraints, for example, power demand balance, prohibited operating zone, maximum and minimum limit of power generation and ramp rate constraints.

Dynamic Economic dispatch is considered as a dynamic problem because of the dynamic behavior of power system as well as the variation in load demand by the consumers. To simplify the problem, DED is discretized into small intervals wherein the load is assumed to be constant and hence the system is acting as in temporary steady state. Moreover, the addition of ramping constraint complicates the problem further [1]. Hence various methods have been proposed in past by different researchers to solve this problem. Some of the conventional techniques available in literature are dynamic programming[2], successive approximation [3], quadratic programming [4], linear programming method [5], non-linear programming [6], slope projection method [7], Lagrange's method [8] etc. These methods are not applicable to non-smooth, non-convex problems. Moreover, these methods use

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approximations to find solution for DED problem and hence considered to be not very accurate. Also, the convergence by the above-mentioned methods is also dependent on initial solution and if initial solution is improper, it may diverge the result from optimum result.

The limitations of the conventional methods are overcome by metaheuristic techniques. Reference [9] discussed about various AI techniques to solve DED problems such as Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Evolutionary Programming (EP) and differential evolution (DE). Salp-Swarm algorithm (SSA) is used to solve DED problem incorporating electric vehicles to minimize fuel cost and network power loss [10] Then improved Salp-Swarm algorithm is proposed in which a mutation process is added to SSA to improve the exploitation of search space in order to have better population for getting optimum solution [11]. Mojtaba Ghasemi et.al proposed a novel version of PSO with time varying acceleration coefficients to solve DED problems [12]. Reference [13] presented Overlapped Decomposition Optimizer [ODO] to solve DED problem by converting a complex problem in smaller easily solvable problems. This method can be clubbed with ordinary heuristic methods to get high quality solution. Jethmalani et.al employed real coded genetic algorithm to evaluate losses in a dynamic economic dispatch problem [14]. Reference [15] discussed about the employment of Dragonfly algorithm to solve DED problem for just IEEE 5 unit test case. Aamir Nawaz et.al discussed about the constrained globalized Nelder-Mead algorithm to solve DED test cases for both convex and non-convex problems [16]. Reference [17] discussed about Memory-based Global Differential Evolution (MGDE) algorithm to solve DED problem. Apart from this, repair technique and penalty function constraint handling techniques are also discussed in detail and concluded that performance of repair method is more efficient in reduction of violations due to constraints. Reference [18] recommended improved version of Real Coded Genetic Algorithm (IRCGA) to solve DED. There are many others algorithm to solve DED problems such as Enhanced Particle Swarm Optimization [19], Tabu Search [20], Artificial Bee Colony [21], Buzzard Optimisation Algorithm [22] Ant Colony [23], self-learning TLBO [24], Education Search [25] etc. These metaheuristic techniques are more efficient than conventional techniques to solve dynamic economic dispatch problems and do have better accuracy than conventional methods computationally but still these algorithms suffer from trapping in local optima, premature convergence and balance between exploration and exploitation.

To overcome the limitations of single heuristic, hybrid heuristics were also proposed to solve DED problems. In hybrid method, two or more than two techniques are clubbed to get better solution wherein two techniques complement each other to overcome the limitation of one another. Reference [26] discussed about a hybrid method-based biogeography-based optimization (BBO) with brain storm optimization (BSO) in order to have better exploration and exploitation capabilities. Dipankar Santra et.al had also presented a hybrid version with Particle Swarm Optimization (PSO) and Termite Colony Optimization (TCO) to solve small and medium sized DED problems [27]. Anum Abid et.al proposed a hybrid algorithm based on Flower Pollination Algorithm (FPA) and Sequential Quadratic Programming (SQP) to solve DED problem which is also incorporating stochastic and probabilistic behavior of wind and solar plants [28]. In [29], DED is solved by hybrid version of Adaptive Differential Evolution and Simulated Annealing algorithms to solve large scale problems. Hybrid algorithm provides better results but the computational time increases and hence at times not recommended.

There is also literature available wherein DED problems are clubbed with other issues such as demand side management [30]. Not only this, Qing-Guo Wang et.al proposed an effective solution for demand management along with DED, advanced metering system, and bidding strategy as well [31]. LiDai et.al proposed solution to DED problem along with effective control of load shedding and wind curtailment with the help of conditional value at risk recourse function [32]. Reference [33] is using improved firework algorithm for solving DED problems incorporating stochastic behavior of wind and solar. Literature is also available for optimal scheduling of thermal generators along with hydro units along with wind production considering their probabilistic behavior [34]. Reference [35] utilized Moth Flame Optimization to find optimum power flow.

Also, the improved version of Firework algorithm has been utilized to solve DED along with reserve constraints [36]. Amongst various variants for the solution of DED, Zexing Chen et.al proposed stochastic dynamic economic dispatch considering security risk constraints along with integration wind energy and natural gas [37].

Grey wolf optimizer [GWO] was first proposed by Mirjalili et.al [38]. After that its simplicity motivated many researchers from time to time to use GWO to solve complex problems. But because of premature convergence, trapping in local optima and poor balance between exploitation and exploration, various variants of Grey wolf optimizer are proposed. Bishwajit Dey and Parama Das had done hybridization of GWO with various other state of the art algorithm and showcased the performance of GWO with different other variants of GWO to solve DED problems. In this work, GWO algorithm is modified by making omega wolves contribute in the hunting process and incorporating the exploratory benefits of the other algorithm in the performance of GWO [39]. Moreover, [40] proposed utilization of Binary Gray Wolf optimization to solve unit commitment problem for the minimization of total cost. Reference [41] discusses about ramp rate handling techniques using GWO to solve DED problems. Also there is literature available on Levy flight which shows it is used to improve exploration performance of the algorithm [42-43]. In GWOLF algorithm, the prey position is modelled as dynamic rather considering it to be static in nature and hence modelling the hunting process more realistically [44].

Although, there have been numerous methods available in literature but still the dispatch obtained by any algorithm is not best suited for all the different test problem. Hence with the motivation of 'No Free Lunch Theorem' [45] that no optimization theorem work well for all optimization problem, therefore, an algorithm is proposed which is based GWO by Mirjajlili et.al. [38] and GWOLF [44]. Moreover, in this proposed algorithm, the benefit of both the algorithms are incorporated. Here, the proposed algorithm works in two loops wherein for half the iteration it works as GWO with increased hierarchal level and other half it works as GWOLF. In this modification, kappa wolves are added which improves the exploitation capabilities. Moreover, modelling prey position with the help of levy distribution will add to improved exploration capabilities. This not only improves the exploration capabilities but also model the hunting process of grey wolves in a more realistic way.

The proposed algorithm is used to solve dynamic economic dispatch problem for 5 unit and 15 unit cases. Along with the solution to the DED problem, inclusion of different profiles of electric vehicles is also highlighted in the paper.

Contributions of this research work are as under:

- An improved version of GWO (IGWO) to solve DED Problem has been proposed.
- Repair method for handling the constraints is showcased.
- Search space has been reduced by modifying the box limit.

In this paper section 1 talks about the introduction about the work. Section 2 discusses the DED problem with various constraints and electric vehicles profiles. Section 3 demonstrates the usage of IGWO to solve DED problem. Repair method to solve DED is shown in Section 4. Section 5 is about experimental setup. Results and discussion are in section 6 and the paper is concluded in section 7. Finally, the reference and appendix are given for the paper.

2. DYNAMIC ECONOMIC DISPATCH FORMULATION

Dynamic economic dispatch for power is defined as optimal generation of power by different generating units to meet the demand while satisfying all the constraints including ramp-rate limits in the most economical way. The mathematical modelling for the formulation of dynamic economic dispatch is as follows with objective function and different associated constraint. The constraints handled in this study are equality constraints along with capacity limits and ramp-rate limits of generator.

2.1. Optimization Function

The cost for the generation of power has to be minimized and hence can be modelled as a minimization problem as:

$$min\ TC = \sum_{t=1}^{T}\sum_{i=1}^{Ng} Fc_i^t(P_i^t) \quad (1)$$

Here, TC represents the total cost of generation for the said power requirements. Total number of time intervals and the number of generating units are represented by T and Ng , respectively. P_i^t and Fc_i^t are the power generated by i^{th} unit in t^{th} time interval and fuel cost of i^{th} generating unit encountered in t^{th} time interval, respectively. The total fuel cost of i^{th} unit is defined as

$$Fc_i^t(P_i^t) = a_{gi}(P_i^t)^2 + b_{gi}(P_i^t) + c_{gi} + \left|e_{gi}.\sin\left(f_{gi}.(P_i^{min} - P_i^t)\right)\right| \quad (2)$$

Where, P_i^{min} is the lower limit of P_i. a_{gi}, b_{gi} and c_{gi} are the cost coefficients for i^{th} unit and f_{gi} and e_{gi} represent the valve-point coefficients of the i^{th} unit.

2.2. Operational Constraints

The operational constraints to be fulfilled are as follows:

1) Equality Constraint

The generated power by different generating units must be equal to power demand by the load and losses encountered because of power transmission.

$$\sum_{i=1}^{N} P_i^t = PD^t + PL^t + L_{pev}^t \quad (3)$$

Where, PD^t is the power demand of the system at t^{th} interval, PL^t is the losses because of power transmission during t^{th} interval. L_{pev}^t is the power demand because of electric vehicles in t^{th} interval. Here, transmission losses are calculated with Kron's formula

$$PL^t = \sum_{i=1}^{Ng}\sum_{j=1}^{Ng} P_i^t B_{ij} P_j^t + \sum_{j=1}^{Ng} B_{i0} P_i^t + B_{00} \quad (4)$$

Where, B_{ij}, B_{i0}, B_{00} represent loss coefficients.

If no losses are considered, (3) maybe written as

$$\sum_{i=1}^{N} P_i^t = PD^t + L_{pev}^t \quad (5)$$

2) Inequality constraints

Power in each interval can be generated within their minimum and maximum generation capacity. It cannot be increased below or above that minima and maxima limits. Hence for each time interval, generation of power must lies between its minima and maxima power constraints and can be written as:

$$P_i^{min} \leq P_i^t \leq P_i^{max} \quad (6)$$

$P_i^{min}$and P_i^{max} are the maximum power output and minimum power output by i^{th}generator in any time interval.

3) Ramp-rate limits

The change in power output by different generating units cannot be changed abruptly as there will be excessive stress on the boiler and combustion equipment. Hence to avoid this stress, generating units are imposed with ramp-rate limits. For any reference time interval (say rt) where $rt \in [1,2, \ldots\ldots, T]$, P_i^t should satisfy the ramp-rate limit as:

$$P_i^{t+1} - DR_i \leq P_i^t \leq P_i^{t+1} + UR^i \ if\ t < rt \quad (7)$$

$$P_i^{t-1} - DR_i \leq P_i^t \leq P_i^{t-1} + UR^i \ if\ t > rt \quad (8)$$

Where, UR^i and DR^i are defined as upper limits of the ramp-up rate and upper limit of ramp-down-rate of the i^{th} generating unit, respectively. After considering all the inequality constraints under study, power generation by i^{th} unit in time t interval can be defined as

$$\boldsymbol{P_i^t} = \begin{cases} [\boldsymbol{P_i^{min}}, \boldsymbol{P_i^{max}}] & \boldsymbol{if\ t = rt} \\ [\mathbf{max}(\boldsymbol{P_i^{min}}, \boldsymbol{P_i^{t+1}} - \boldsymbol{DR_i}), \mathbf{min}(\boldsymbol{P_i^{min}}, \boldsymbol{P_i^{t+1}} + \boldsymbol{UR_i})] & \boldsymbol{if\ t < rt} \\ [\mathbf{max}(\boldsymbol{P_i^{min}}, \boldsymbol{P_i^{t-1}} - \boldsymbol{DR_i}), \mathbf{min}(\boldsymbol{P_i^{min}}, \boldsymbol{P_i^{t-1}} + \boldsymbol{UR_i})] & \boldsymbol{if\ t > rt} \end{cases} \quad (9)$$

2.3. Electric Vehicle

The detrimental increment in green-house gas discharges propels the consumers to utilize electric vehicles. Apart from the advantages of electric vehicles in reducing green-house gas discharges, electric vehicles pose an uncertain demand on the power system network. Moreover, the inclusion of electric vehicles leads to decrease in green-house gas emissions but on the other hand some planning is also required for charging of these electric vehicles so that the negative impact on power grid may be reduced. For analyzing the effect of electric vehicles on grid, four scenarios of charging probability are considered as per the data available in literature viz EPRI profile, off-peak profile, peak profile and stochastic profile. These profiles are incorporated in such a way which will force additional load $L_{pev,t}$ in the power demand requirements. For 5 gen data and 15 generator data, 375 MW and 1125 MW are the total load connected to the network. To find the charging load by different electric vehicles, total load is multiplied by probability distribution to find the load in each time interval [26].

3. PROPOSED METHODOLOGY

3.1. Overview of GWO

Grey Wolf Optimizer (GWO) is a popular algorithm which is inspired by the hunting process of Canis lupus wolves or grey wolves [38]. The main objective of the algorithm is to reach the prey. As per this algorithm, wolves are arranged in hierarchy based on their position in the pack. The hierarchy is decided by the dominance of the wolves. The wolf which is most dominant is at the top and the wolf which is least dominant is at the bottom in the hierarchy. The wolf at the top is said to be alpha wolf, next level position is given to beta wolves and then delta wolves. At the bottom are placed the omega wolves. According to GWO [38], the characteristics possessed by different wolves in the hierarchy are as under:

1. Alpha wolves: Alpha wolves are responsible of taking all major decisions. They lead and manage the pack and they are the first to approach the prey.
2. Beta wolves: The next category of the wolves is beta wolves. Beta wolves obey alpha wolves. They convey and ensure that the decision by alpha wolves is followed by rest of the wolves.
3. Delta wolves: Wolves on the third hierarchal level are delta wolves. These wolves are hunters, caretakers as well as sentinels. They contribute in hunting process; caretaker wolves take care of those wolves which are hurt while hunting wherein sentinels wolves protect the pack from enemies.
4. Omega wolves: The last level belongs to omega wolves. They are permitted to eat the hunt at the last. Apart from this, this level is important as in the absence of this level, the pack may face many internal issues.

The behavior of the Canis lupus wolves is modelled as per following equation [45],

$$\vec{X}(t+1) = \overrightarrow{X_p}(t) - \vec{A}.|\vec{C}.\left(\overrightarrow{X_p}(t) - \vec{X}(t)\right)| \quad (10)$$

$$\vec{A} = 2\vec{a}.\overrightarrow{r_1} - \vec{a}, \quad (11)$$

$$\vec{C} = 2.\overrightarrow{r_2} \quad (12)$$

$$a(t) = 2 - \frac{2t}{MaxIter} \quad (13)$$

$$\vec{X}_1 = \overrightarrow{X_\alpha}(t) - \overrightarrow{A_1}.\overrightarrow{C_1}.\left(\overrightarrow{X_\alpha}(t) - \vec{X}(t)\right) \quad (14)$$

$$\vec{X}_2 = \overrightarrow{X_\beta}(t) - \overrightarrow{A_2}.\overrightarrow{C_2}.\left(\overrightarrow{X_\beta}(t) - \vec{X}(t)\right) \quad (15)$$

$$\vec{X}_3 = \overrightarrow{X_\delta}(t) - \overrightarrow{A_3}.\overrightarrow{C_3}.\left(\overrightarrow{X_\delta}(t) - \vec{X}(t)\right) \quad (16)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1+\vec{X}_2+\vec{X}_3}{3} \quad (17)$$

Where, $\vec{X}(t+1)$ is the position of wolves in $(t+1)^{th}$ iteration, $\vec{X}(t)$ and $\overrightarrow{X_p}(t)$ are the position vector of Canis lupus wolves and prey in t^{th}, respectively, $\vec{A}$ and $\vec{C}$ are coefficient vectors and are used to define exploration and exploitation [8]. $\vec{r}_1$ and $\overrightarrow{r_2}$ are random vectors and lie in [0, 1], $\vec{a}$ is varying from 2 to 0, $MaxIter$ indicates the total number of iterations, $\overrightarrow{X_\alpha}$, $\overrightarrow{X_\beta}$ and $\overrightarrow{X_\delta}$ are the position vectors of α, β, and δ wolves, respectively, $\overrightarrow{X_1}$, $\overrightarrow{X_2}$ and $\overrightarrow{X_3}$ are helpful in generating new generation.

GWO [38] is a well-known algorithm and has been utilized by many researchers to solve complex problems, but the shortcoming with GWO is poor exploration and hence to improve the exploration capabilities of the algorithm, Improved Grey Wolf Optimizer is proposed which is discussed in next sub-section.

3.2. Improved Grey Wolf Optimizer

Undoubtedly GWO [38] is good in exploitation but it is not giving better solution because of its poor exploration capabilities, premature convergence whereas the modification done in GWOLF [44,46] has improved the exploration capabilities but exploitation is a concern. Hence IGWO is proposed which picks the benefit of GWO and GWOLF and gives a better balance between exploration and exploitation. IGWO works in two loops

(1) Loop 1: IGWO works as original GWO for half the maximum number of iteration so that the merits of good exploiter can be utilized and to further enhance exploitation new level has been added as under:

A new hierarchal level is added. Delta wolves are further divided into two levels wherein first division is called as delta modified level and other level is called kappa level. The work of delta wolves in the grey wolf organizer has been split in two levels. Delta modified wolves are helping alpha and beta wolves in chasing the prey whereas kappa wolves will take care of wounded wolves. The position vector of Kappa wolves is updated as:

$$\vec{X}_4 = \overrightarrow{X_\kappa}(t) - \overrightarrow{A_4}.\overrightarrow{C_4}.\left(\overrightarrow{X_\kappa}(t) - \vec{X}(t)\right) \quad (18)$$

$$a(t) = \left(1 - \frac{\mathrm{t}}{\mathrm{Maxiter}}\right) * \left(1 - \frac{\mathrm{t}}{\mathrm{Maxiter}}\right) \quad (19)$$

The value of $a(t)$ is given as (4) for large system and as per (10) for small system.

(2) Loop2: For getting better exploration, following are the changes which have been introduced.

GWO is improvised by modelling it as per the realistic mimicking of hunting process wherein the real time prey position is considered to be dynamic in nature [46]. The best position achieved by the algorithm is designated to the position of alpha wolves whereas beta , delta modified, kappa wolves will be designated with second, third and fourth best position given by the algorithm. Hence to model the dynamic behavior of prey position, levy flight distribution is considered [43]. The prey position is modelled with the help of levy distribution [43] as,

$$\overrightarrow{X_p} = \overrightarrow{X_\alpha}(t) + a' \oplus Levi(b) \quad (20)$$

Where step size is defined by a' and range is between 0 and 1, power law index lies between 0 and 2 and is defined as b.

In loop 2 alpha and beta positions are updated as per (12-13)

$$\vec{X}_1 = \overrightarrow{X_\alpha}(t) - \overrightarrow{A_1}.\overrightarrow{C_1}.\left(\overrightarrow{X_p}(t) - \vec{X}(t)\right) \quad (21)$$

$$\vec{X}_2 = \overrightarrow{X_\beta}(t) - \overrightarrow{A_2}.\overrightarrow{C_2}.\left(\overrightarrow{X_p}(t) - \vec{X}(t)\right) \quad (22)$$

The delta modified and kappa wolves update their position with the help of (7) and (9), respectively. The weighted sum is taken for finding new position of the wolves. Alpha wolves are considered to be at best position and hence the multiplying factor given to alpha wolves is highest and reduces with the descending order moving from alpha, beta, delta modified and kappa wolves. The new position vectors are given as

$$\vec{X}(t+1) = 0.4 * \vec{X}_1 + 0.3 * \vec{X}_2 + 0.2 * \vec{X}_3 + 0.1 * \vec{X}_4 \quad (23)$$

The social hierarchy for the improved grey wolf optimizer is shown in Fig.1 and the pseudo code and flowchart for the algorithm is shown in Fig. 2 and Fig. 3, respectively.

3 REPAIR METHOD

Repair method used to solve dynamic economic dispatch is discussed in this subsection.

Step 1: Input data for N generating units, B-coefficients, power demand, L_{pev}^t, along with charging probability distribution

Step 2: For $t = 1\ to\ T$, initialize random population

$$P_i = rand\left(P_i^{max} - P_I^{min}\right) + P_i^{min} \quad (24)$$

After initializing the population, check ramp rate constraints as in Step 3

Step 3: For $i = 1\ to\ N$

For t=1:T

$if\ t = 1$

Upper bound and Lower Bound are defined as:

$$\begin{Bmatrix} UB \\ LB \end{Bmatrix} = \begin{cases} P_i^{max}\ if\ P_i > P_i^{max} \\ P_i^{min}\ if\ P_i < P_i^{min} \end{cases} \quad (26)$$

Generate population for $\boldsymbol{t} = 1$ as per the above bounds.

elseif $t \neq 1$

Modify bounds as per ramp rate constraints as:

$$\begin{Bmatrix} UB \\ LB \end{Bmatrix} = \begin{cases} \min\,(P_i^{max}, P_i^{t-1} + UR^i \\ \max\,(P_i^{min}, P_i^{t-1} - DR^i \end{cases} \quad (27)$$

Generate population for $t \neq 1$ as per above equation considering new bounds wherein bounds are modified as per ramp rate constraints.

Check population for bounds as shown in next step

Step 4: For $i = 1\ to\ N$

If $P_i > P_i^{max}$,

Set $P_i = UB - rand\ (UB - LB)$ (28)

If $P_i > P_i^{max}$,

Set $P_i = rand\ (UB - LB) + LB$ (29)

After checking bounds, check demand constraint as follows:

Step 5: For $i = 1\ to\ N$

For t=1 to T

Update population as per modified bounds

Find sum of power of each generating unit in t^{th} time interval

$$sum = \sum_{i=1}^{Ng} P_i \quad (30)$$

Calculate Power Loss, PL is using Kron's Formula

Calculate error, ε

$$\varepsilon = sum - PD - PL \quad (31)$$

If $\varepsilon > 0.001$

$$P_i = P_i - abs(\frac{\varepsilon}{Ng}) \quad (32)$$

If $\varepsilon < -0.001$

$$P_i = P_i + abs(\frac{\varepsilon}{Ng}) \quad (33)$$

End

Generate population with updated bounds

Check bounds again as per Step 3 and 4.

Step 6: Termination Rule: If $|\varepsilon| < 0.001$, Stop

Otherwise go to Step 3 and continue till feasible solution is achieved or maximum number of iterations are reached.

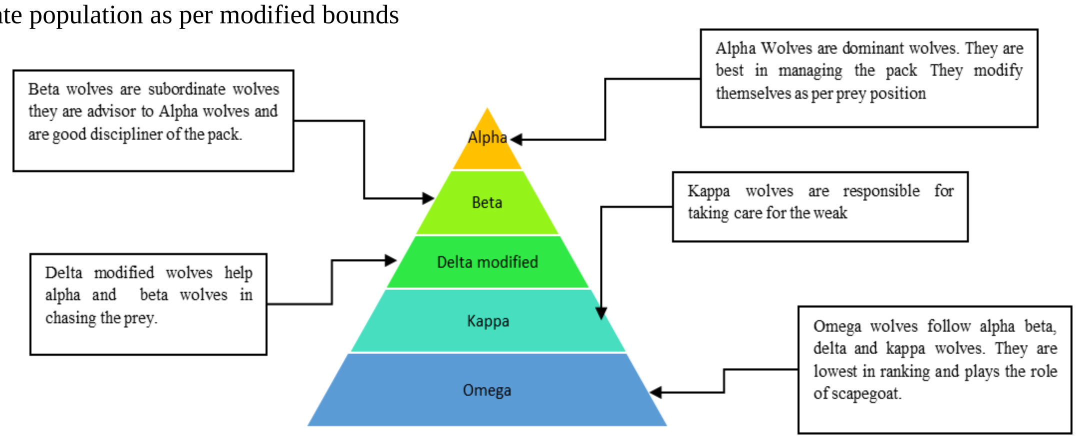

Fig. 1. Social Hierarchy of wolves and their characteristics in IGWO.

```
Set population size and no. of generation, a' and b
Initialize the canin lupus population
Calculate a using (12) and (18) depending on the size of population
Initialize A⃗,C⃗ using (10,11)
Calculate position vector for alpha, beta, delta and kappa wolves
Find prey position with the help of levy operator using (19)
If 1≤ Maxiter/2
       For each search agent
       Update the position of search agent using (13-16)
       End for
Elseif If l > Maxiter/2
       For each search agent
       Update the position of search agent using (20-21,15, 17 and 22)
       End for
Calculate objective function
Update A⃗,C⃗,and prey position
Calculate fitness of all search agent
update position vector for alpha, beta, delta and kappa wolves
Check stop criteria
       If yes, stop
       Otherwise t = t + 1
       Check for condition of t
       End if
End if
```

Fig. 2. Pseudo code for IGWO.

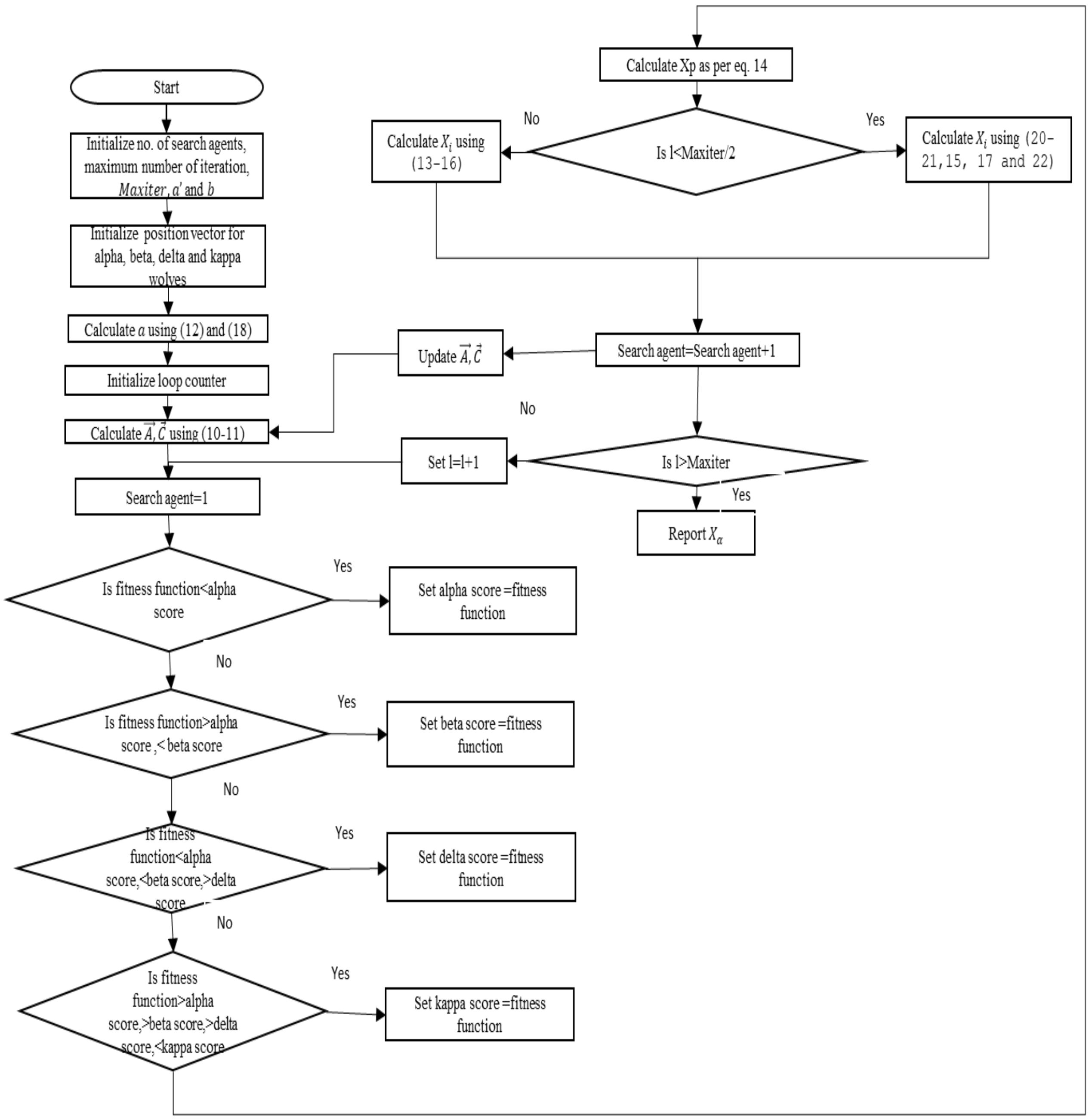

Fig. 3. Flowchart for IGWO.

4 EXPERIMENTAL SET-UP AND RESULTS

The performance of IGWO is assessed for 5-unit test case and 15-unit test case. The data for the 5-unit test case and 15-unit test case system has been taken from [20] and [26] and has been provided in Appendix as well. The platform used for doing simulation is MATLAB 2017b with x64-based processor. The specification of the system on which simulations were run on Lenovo machine with windows10 using Intel® Core™ i5 CPU speed of 1.60GHz and RAM installed of 8GB. So as to survey the productivity of proposed improved GWO for treating different DED problems, following cases are considered.

5.1 Case 1: 5-unit Test System

The test system with 5-units is considered for checking the performance of the proposed algorithm. The generator characteristics, load data and B-coefficient data are given in Appendix A, B and C respectively. The total load considered by electric vehicle in the system is 375 MW [26]. The total demand for the said test case is varying from 410 to 740 MW along with electric vehicle load varying as per charging probability of different profiles. Further, power generation are found for different cases with losses, without losses and with different electric vehicle profile. The following cases are considered for 5-unit test case for checking the performance of algorithm in solving dynamic economic dispatch problem.

1) Dynamic Economic Dispatch with 5-unit without losses.

The power generated by 5-unit test case without losses by different generating units have been shown in Table 1. The comparative convergence curve of IGWO and STLBO has been shown in Fig 4.

2) Dynamic Economic Dispatch with 5 Generator with losses and different EV profiles

The power generated by 5-unit test case with losses has also been discussed. Dynamic economic dispatch is found for 5 generating unit with losses when no electric vehicle is connected and with electric vehicles connected with different profiles. Table 2 shows the power generation by different units with losses and when no electric vehicle is connected. Tables 3-6 show the power generation by different units with losses and electric vehicles having EPRI load profile, off-peak load profile, peak load profile and stochastic load profile, respectively. The comparative convergence curve for IGWO and STLBO for 5-unit test cases with losses and without electric vehicles and with losses with different electric vehicles profile has been shown in Figs. 5-9. The comparison of the algorithm has been shown in Table 7 and Table 8. Table 7 shows the comparative result for 5-unit test case with losses but no electric vehicles whereas Table 8 shows the comparative summary for different algorithm for different charging distribution of electric vehicles.

5.2. Case 2:15-unit Test System

The test system with 15-units is also considered for checking the performance of the proposed algorithm. The generator characteristics, load data and B-coefficient data are given in Appendix D, E and F respectively. The total load considered by electric vehicle in the system is 1125 MW [26]. The total demand for the said test case is varying from 2226 to 2970 MW along with electric vehicle load varying as per charging probability of different profiles. Further, power generation are found for different cases with losses, without losses and with different electric vehicle profile. The following cases are considered for 15-unit test case for checking the performance of algorithm in solving dynamic economic dispatch problem.

3) Dynamic Economic Dispatch with 15 Generator without losses

The power generated by 15-unit test case without losses by different generating units have been shown in Table 9. The comparative convergence curve of IGWO and STLBO has been shown in Fig 10.

4) Dynamic Economic Dispatch with 5 Generator with losses and different EV profiles

The power generated by 15 unit test case with losses has also been discussed. Dynamic economic dispatch is found for 15 generating unit with losses when no electric vehicle is connected and with electric vehicles connected with different profiles. Table 10 shows the power generation by different units with losses and when no electric vehicle is connected. Tables 11-14 show the power generation by different units with losses and electric vehicles having EPRI load profile, off-peak load profile, peak load profile and stochastic load profile, respectively. The comparative convergence curve for IGWO and STLBO for 15 unit test cases without losses and with losses and different electric vehicles profile has been shown in Figs. 11-15. The fuel cost comparison of the algorithm has been shown in Table 15 and Table 16. Table 15 shows the comparative result for 15 unit test case with losses but no electric vehicles whereas Table 16 shows the comparative summary for different algorithm for different charging distribution of electric vehicles.

Table 1. 24-hour Power Generation by 5 generating units with out Losses.

T(h)	Power Generation (MW)				
	P_1	P_2	P_3	P_4	P_5
1	32.4928	97.9889	111.8939	116.0561	51.5682
2	24.2601	107.2436	114.046	125.4824	63.9679
3	33.4229	93.0638	111.2646	124.8924	112.3562
4	55.7876	98.2989	112.6562	123.7767	139.4807
5	59.8727	98.5687	112.7194	146.998	139.8412
6	65.0158	95.8931	112.6335	195.0093	139.4482
7	49.888	112.6351	113.6029	211.9533	157.1242
8	69.8662	99.152	113.0723	210.2238	161.6857
9	64.2128	97.5813	111.8226	208.9695	207.4139
10	63.7412	93.3521	108.9424	209.2749	228.6893
11	51.4987	108.8448	118.8547	210.0055	230.7963
12	74.991	110.0884	115.226	210.1568	229.5377
13	56.1912	98.4264	112.2928	209.578	227.5117
14	36.4665	100.6518	113.5244	209.8215	229.5357
15	49.0368	98.5512	112.6781	164.216	229.518

16	19.791	96.7774	109.8103	124.1947	229.4266
17	10.5571	86.3973	108.0939	123.4759	229.4758
18	40.5066	99.3711	113.2798	125.2584	229.584
19	47.5608	98.5396	111.91	166.4732	229.5164
20	48.6854	101.6054	113.5046	210.6838	229.5208
21	46.0957	98.1892	112.6665	193.5662	229.4824
22	20.9221	98.1034	112.5788	143.8751	229.5206
23	11.0337	72.0767	110.4961	103.8787	229.5148
24	11.3852	64.3198	111.3703	58.8698	217.0549

Table 2. 24-hour Power Generation by 5 generating units with Losses without Electric Vehicle.

T(h)	Power Generation (MW)				
	P_1	P_2	P_3	P_4	P_5
1	12.3625	97.5932	38.1206	126.1605	139.5566
2	26.1244	95.6842	48.8733	127.3578	141.1167
3	12.4834	97.1426	86.3262	132.9298	150.9537
4	33.6304	100.3902	107.0593	131.41	163.411
5	11.0268	109.5495	111.8031	133.4005	198.8882
6	33.1628	124.3305	113.855	120.0825	224.508
7	40.5542	94.5035	121.9732	211.9533	157.1242
8	31.2484	100.5163	106.8655	198.6594	225.9002
9	51.4116	92.2361	121.1401	207.5461	227.7658
10	56.3724	97.8336	116.3699	215.0475	228.9371
11	63.9668	103.3792	126.2509	207.093	230.2859
12	64.1933	99.628	132.5939	214.8682	240.3051
13	64.3659	101.2122	109.1761	209.1743	230.6566
14	49.2201	100.1005	111.509	217.5343	221.8237
15	29.0956	103.4206	109.7	210.4249	210.5567
16	13.0901	90.8943	112.4712	200.6971	170.0692
17	16.1603	76.8963	82.3632	186.8921	202.4653
18	12.3433	64.5182	102.8821	206.153	230.1142
19	26.6453	87.7106	106.6951	212.681	229.4893
20	47.5753	103.6347	124.2659	210.5434	228.5183
21	25.6984	104.3108	129.1817	207.6487	223.0225
22	11.1916	95.7613	108.1622	171.9982	225.7682
23	11.989	91.0694	75.9749	125.0091	229.0747
24	14.3584	81.1474	37.2818	126.2603	208.8358

Table 3.24-hour Power Generation by 5 generating units with Losses and EPRI Load Profile of Electric Vehicle.

T(h)	Generated Power(MW)				
	P_1	P_2	P_3	P_4	P_5
1	45.5525	92.1419	77.7932	92.5523	143.689
2	42.2253	102.333	98.4234	98.1204	136.0811
3	21.042	103.4609	120.1762	127.493	143.9301
4	40.8972	91.2409	110.2902	135.1575	185.1465
5	28.1889	94.6185	114.739	122.1866	224.0921
6	34.883	98.122	110.3445	149.2435	234.8353
7	64.007	99.3968	114.8352	211.9533	157.1242
8	64.6661	101.4554	105.0305	159.1657	233.944
9	68.7719	92.8771	109.9603	204.626	225.0484
10	67.452	95.3525	105.3263	215.3505	236.1596
11	74.31	104.3009	117.5068	213.6849	229.3413
12	65.0568	111.5152	127.9374	210.8847	244.3666
13	70.7308	97.0811	109.1668	219.1183	226.6041

14	71.1726	94.596	110.2402	204.7497	227.4787
15	64.806	95.9607	116.9353	165.1724	228.247
16	42.0719	92.5267	112.5138	121.6567	222.1993
17	16.7905	94.9452	110.1192	121.6934	223.0404
18	18.266	100.4241	100.2084	170.7149	228.2956
19	30.0958	94.8492	111.0779	209.7147	224.3846
20	57.9159	111.7124	118.2769	211.061	229.5119
21	34.1325	101.413	111.7405	227.8661	234.9111
22	12.6697	97.0925	105.5315	208.0493	226.195
23	10.9858	85.3052	73.5166	174.9548	226.7763
24	14.3753	95.5168	38.0122	130.7913	227.559

Table 4. 24-hour Power Generation by 5 generating units with Losses and Off-Peak Load Profile of Electric Vehicle.

T(h)	Power Generation (MW)				
	Pg1	Pg2	Pg3	Pg4	Pg5
1	22.8385	100.3873	109.8184	114.6687	136.4884
2	45.9074	89.7893	113.6095	120.4028	139.9334
3	62.824	97.5074	116.8652	126.6112	110.3129
4	68.82	106.278	116.7093	133.3041	145.2599
5	69.4619	101.62	102.6233	169.181	137.0291
6	74.5311	95.6972	117.0887	207.0673	136.8226
7	55.4149	114.597	107.8238	211.9533	157.1242
8	64.9397	104.1303	108.6459	201.7162	183.6469
9	61.9381	92.9734	106.4015	206.7214	232.1363
10	66.6472	97.2303	111.5634	209.9942	229.125
11	70.5468	94.5442	115.7542	220.4784	229.7156
12	74.1302	115.4081	116.2161	209.5613	236.3686
13	67.1396	94.6511	112.6602	205.1888	234.9095
14	43.254	92.7611	114.7564	209.1283	240.2789
15	31.7455	96.2735	102.6539	206.3969	226.1515
16	12.4379	89.8971	70.4144	190.9743	223.7492
17	10.8237	87.4688	37.0578	202.9148	226.9612
18	16.4842	103.0615	69.7424	194.8153	232.1341
19	13.5158	94.4175	105.4483	218.2502	231.681
20	38.5167	102.0751	111.0061	207.5501	255.53
21	30.6173	92.1124	129.5748	207.0561	230.4647
22	23.4299	99.6017	104.8269	163.6543	221.3303
23	31.278	96.2337	112.1367	132.1322	232.177
24	24.1634	73.8418	95.8836	117.2785	227.2943

Table 5. 24-hour Power Generation by 5 generating units with Losses and Peak Load Profile of Electric Vehicle.

T(h)	Power Generation (MW)				
	P_1	P_2	P_3	P_4	P_5
1	10.0179	97.5683	110.9049	56.3462	138.777
2	17.6615	97.6797	103.1024	104.3221	116.2226
3	12.5632	94.0486	116.5563	121.6995	134.8735
4	12.086	102.1919	123.0582	163.7487	134.8838
5	11.5967	95.9662	111.0593	210.1779	135.969
6	32.6576	96.12	117.7289	225.9491	143.5007
7	56.5305	96.9242	111.7982	211.9533	157.1242
8	67.9788	100.7165	110.9207	202.7516	180.6909
9	62.5593	88.0426	115.2691	210.048	224.1874
10	63.8357	98.4053	122.1142	204.8023	225.3334
11	63.0424	98.2454	122.633	211.9064	235.177

12	67.2918	99.6086	132.1507	215.7599	236.7714
13	74.5591	108.2659	163.2061	213.8002	226.0516
14	51.769	101.3426	164.4725	225.7452	228.1459
15	40.9938	106.765	140.029	213.1798	233.4949
16	18.0325	93.8676	107.597	212.51	226.4941
17	10.2885	98.7846	74.8165	207.268	208.3849
18	12.4107	94.1671	109.9496	202.6045	231.5276
19	12.3004	103.234	119.5116	211.4201	232.2016
20	34.3316	107.784	132.2324	208.9783	246.7005
21	40.5907	106.3036	112.2206	201.6918	229.0924
22	17.6151	93.1878	111.8475	159.5019	230.6817
23	14.6256	92.8947	105.4749	120.708	199.2157
24	18.2534	99.3216	73.4638	124.1851	152.3997

Table 6. 24-hour Power Generation by 5 generating units with Losses and Stochastic Load Profile of Electric Vehicle.

T(h)	Power Generation (MW)				
	P_1	P_2	P_3	P_4	P_5
1	25.5611	22.3848	115.7211	131.437	140.097
2	30.5501	44.9517	110.4862	129.4619	142.1476
3	55.965	72.6374	111.4475	122.0065	135.9401
4	66.7334	94.3776	113.8752	128.8366	141.2018
5	69.0147	94.6612	114.1194	124.7233	171.945
6	63.1005	98.6151	110.2766	171.5136	209.6364
7	43.4398	98.806	112.611	195.6953	217.3046
8	57.241	87.985	100.7926	203.5323	232.1222
9	58.646	96.5167	115.755	201.8695	231.5768
10	66.5014	92.9041	112.0294	224.4545	231.0643
11	74.0315	97.5887	124.3132	207.8896	235.2693
12	64.2524	107.4788	155.7738	217.2503	228.7873
13	66.5813	100.7879	116.3895	214.736	230.7397
14	38.5184	105.3678	112.2748	210.8846	241.6872
15	20.3423	100.0176	110.379	213.0517	227.553
16	11.0176	81.3789	91.3252	213.2269	213.8893
17	11.6998	97.5353	104.0955	184.5919	179.0683
18	13.47	94.1872	114.774	210.1474	191.8459
19	28.1506	95.4126	113.9151	205.2267	231.2655
20	57.863	104.5481	116.683	206.3671	237.6028
21	34.7456	102.0204	127.9164	212.6213	233.7847
22	23.8094	99.0301	107.5889	163.9373	228.0953
23	21.0512	80.8569	98.2099	122.136	224.1297
24	16.4032	57.8983	104.5137	103.4676	216.672

Table 7. Comparison of total fuel cost for 5-unit test case with losses without PEV ($/day).

METHOD	SA[26]	PS[26]	EP[26]	PSO[26]	SLTLBO[26]	RCGA [18]	IRCGA[18]	CGNM[16]	IGWO
Fuel Cost	47356	46530	46777	46402.52	46458	47564	47185	47286	46205

Table 8. Comparative Results for 5-unit test case with different loading of EV with different algorithm ($/day).

Type of Load	Algorithm							
	wPSO [26]	PSO-CF[26]	DE [26]	TLBO [26]	eTLBO [26]	Mtlbo [26]	SL-TLBO [26]	IGWO
EPRI Load	49004.13	51482.18	51457.32	49649.47	49049.49	48974.99	46770.71	47030
Off-peak Load	48587.97	51231.77	51238.97	48884.45	49306.12	47656.89	46508.86	46804
Peak	50875.78	51682.02	51310.22	48775.31	49270.68	48459.7	47367.17	46904
Stochastic Load	49333.11	51292.57	51283.18	49292.38	49549.59	48970.59	47158.86	47209

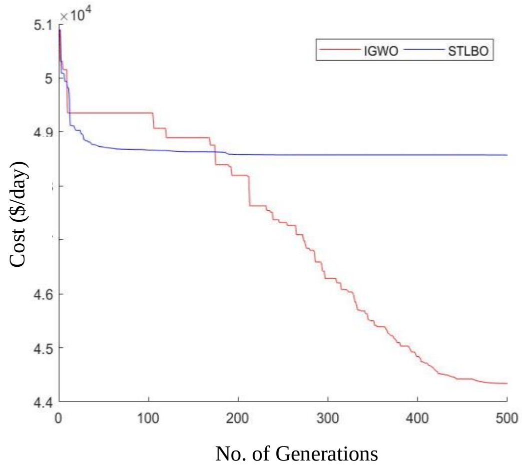

Fig. 4. Comparative convergence curve for IGWO and STLBO for 5 generator case without losses.

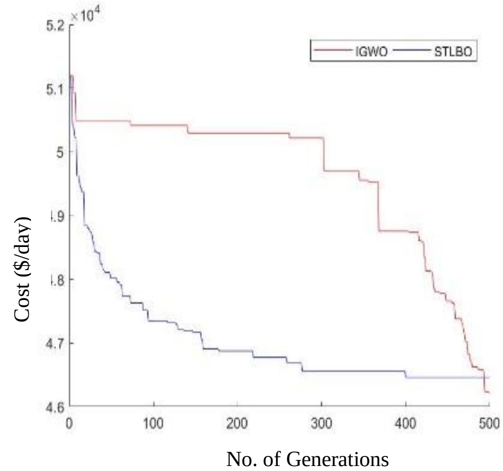

Fig. 5. Comparative convergence curve for IGWO and STLBO for 5 generator case with losses.

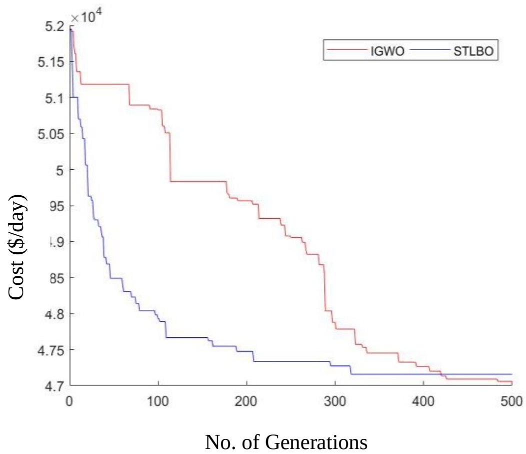

Fig. 6. Convergence curve for Case 3 for 5 generator case with losses and EPRI load profile of Electric Vehicles.

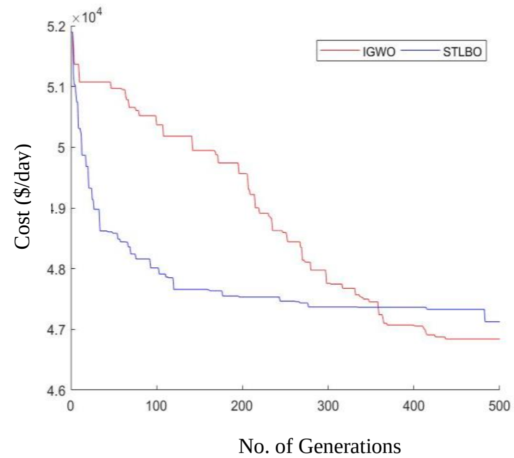

Fig. 7. Convergence curve for Case 4 for 5 generator case with losses and Off-Peak load profile of Electric Vehicles.

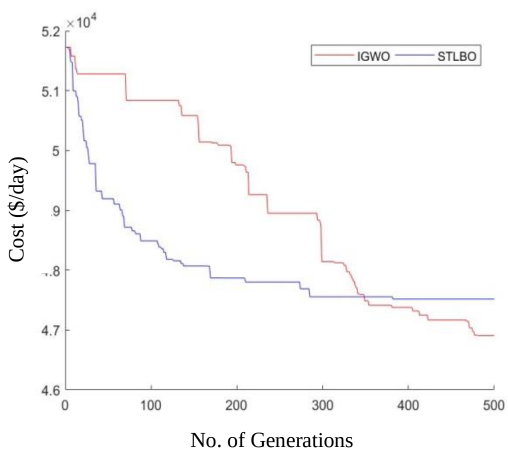

Fig. 8. Convergence curve for Case 5 for 5 generator case with losses and Peak load profile of Electric Vehicles.

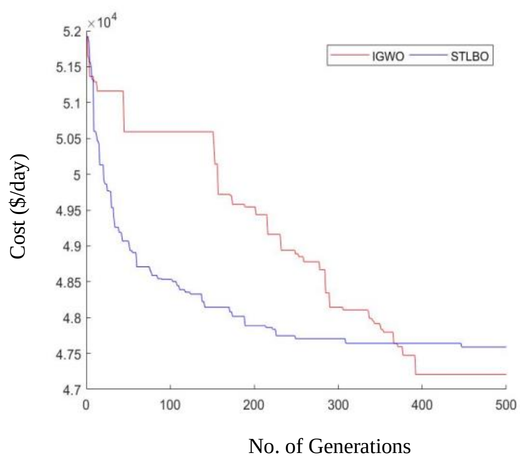

Fig. 9. Convergence curve for Case 6 for 5 generator case with losses and Stochastic load profile of Electric Vehicles.

Table 9. 24-hour Power Generation by 15 generating units with out Losses.

T(h)	Power Generation (MW)														
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
1	438.9137	391.3927	74.8983	94.7644	240.2603	310.6863	461.9032	60.0198	29.3408	27.6829	29.4947	20.5204	25.2434	15.8664	15.0125
2	338.5158	381.4834	128.7211	29.7691	315.544	326.8058	464.2417	61.9936	27.9543	28.1378	25.6266	42.8226	25.8813	23.0846	19.4182
3	358.5278	433.2658	121.3638	64.1814	269.4945	271.0252	448.2066	68.2	43.9718	34.6958	23.7712	33.0154	25.2671	16.0064	15.0073
4	416.5705	399.8973	35.7874	81.7392	194.8575	336.869	464.8371	83.1109	47.1548	49.5261	31.2053	27.4573	28.9406	16.6463	21.4006
5	382.789	385.8936	88.1792	123.617	206.5302	337.4091	450.7301	72.8501	84.6682	27.9985	42.5746	39.3601	25.2376	15.0204	15.1422
6	372.5968	453.9996	117.6073	68.4658	247.3898	366.9548	450.2959	61.4199	32.5758	27.8264	28.7222	28.7881	26.3811	16.2583	16.7183
7	402.9635	391.0526	122.6042	88.9508	254.3029	356.1307	453.3027	61.4604	51.4721	27.5606	22.4442	34.5178	33.9283	15.162	15.1473
8	323.8445	436.7915	126.2819	74.1408	311.9974	422.7223	456.6898	89.6724	28.1782	35.8291	28.0753	34.6235	35.1148	21.3778	17.6607
9	321.9823	426.2748	124.1377	124.7218	330.731	435.6302	459.6721	90.7824	71.6515	80.8288	64.2106	33.7955	25.0115	17.791	22.7789
10	385.5065	452.7812	85.4801	82.9856	376.7342	458.3075	457.4811	102.5757	65.0039	107.0885	42.3881	46.0512	27.6301	22.7274	15.2591
11	418.7071	442.65	97.6894	126.1896	386.9118	439.0027	464.756	90.9415	55.2555	92.4898	54.5999	32.6252	44.4602	18.8308	17.8906
12	417.9385	402.2706	111.0016	128.5671	404.6743	390.784	456.2203	95.4156	89.4305	126.2207	37.6417	53.5604	27.2934	25.2298	18.7516
13	422.0366	436.0146	94.6581	108.2637	445.4725	374.5049	461.9017	100.8005	114.6339	77.598	27.4288	41.648	35.4687	15.0661	24.5037
14	434.2944	453.1824	102.0491	90.0677	356.1337	439.8895	464.0751	112.6462	109.8898	113.4106	47.0306	38.3808	32.0114	19.924	17.0146
15	427.2462	454.1256	126.4307	119.6558	379.6989	457.7465	463.4503	126.4786	115.5618	98.6536	62.1325	44.6677	30.3364	27.5347	36.2809
16	448.331	450.7778	121.827	129.6797	389.044	446.4958	464.8664	119.5347	69.7233	121.6539	45.2298	48.1248	53.7731	15.7261	25.2129
17	420.0824	420.5174	99.6792	119.979	384.897	458.7202	451.4995	131.3808	81.9629	103.6719	58.54	55.1064	44.5567	35.0991	36.3076
18	453.815	359.8113	119.8031	117.6709	376.485	436.3249	464.595	96.9792	82.839	121.5993	41.7021	44.3955	54.8436	15.1456	16.9902
19	348.1557	394.7557	125.6737	127.6231	399.7815	435.9155	463.4708	76.7165	32.5479	103.6769	31.7319	40.0552	25.0012	24.6417	21.2527
20	346.3034	445.3763	124.4515	80.9067	359.0988	419.5378	464.24	67.667	52.5217	93.1712	40.8276	24.1792	25.0532	21.8504	18.8153
21	337.5536	385.6364	106.8848	53.745	316.7581	434.3379	463.3436	106.1936	62.2647	53.5685	22.6331	25.2977	29.2682	16.983	17.5319
22	362.4163	320.6221	99.5271	68.9256	262.2918	431.1563	450.4441	75.4858	94.6485	36.2058	22.2751	26.5291	25.6825	18.8364	16.9535
23	344.8677	334.654	38.0647	120.7276	285.919	335.235	464.4911	84.3319	90.0751	32.9424	37.2941	28.6703	26.506	20.2929	16.9281
24	366.649	313.1598	77.8539	50.4448	294.768	368.4262	464.5982	114.0129	38.1968	40.9859	45.2696	21.9604	25.3856	15.3457	16.9429

Table 10. 24-hour Power Generation by 15 generating units with Losses.

T(h)	Power Generation (MW)														
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
1	266.9516	314.6822	100.1965	88.2797	269.8362	337.0537	436.0417	102.8002	57.3768	122.6753	22.4998	52.1492	27.5861	43.3463	21.4336
2	289.0166	339.8084	126.589	100.6032	246.9926	366.4579	399.854	109.0814	58.0951	58.9983	45.5992	60.7854	26.0061	18.4649	16.7793
3	299.7782	270.2218	70.9867	103.2404	241.4597	365.2339	443.3775	108.0769	61.0718	68.687	56.0548	67.6672	36.7138	35.8184	20.6817
4	363.6698	241.8479	104.7015	102.6067	283.6991	343.9415	337.1123	99.5647	88.8837	86.4071	44.3505	72.887	32.9683	19.9894	38.4625
5	351.4354	307.4967	115.8551	122.1841	206.1357	395.9833	369.6943	65.6449	100.9216	98.8867	70.0225	52.5852	28.8793	19.1004	17.1828
6	322.9689	221.9018	98.8839	112.1387	250.1819	441.5715	413.3579	96.9439	42.1054	109.593	68.7727	70.1541	27.208	25.0378	40.1916
7	400.1433	249.2803	105.1737	71.165	287.652	438.84	436.0006	62.3201	27.2265	99.6085	50.5983	50.2309	29.8937	28.4271	18.3187
8	434.8373	322.1856	101.9124	107.1478	291.0204	416.0379	446.4923	67.4879	51.4738	70.5301	53.8699	28.0204	26.7356	35.7498	16.0786
9	418.4613	369.833	123.9407	104.7408	341.7438	411.3751	439.6923	87.6668	78.3193	55.9746	64.4647	63.8279	41.7566	36.2379	23.336
10	421.5972	386.1344	96.694	115.126	395.9334	426.9948	429.2934	84.972	105.8106	88.7475	42.2166	62.8085	65.1501	20.642	23.0017
11	417.7592	420.0212	102.1094	114.4547	372.3469	422.2114	417.1719	131.6614	107.6198	66.8097	49.2148	49.4367	79.6728	35.7225	35.545
12	437.4431	410.4414	109.8785	110.6182	374.0767	397.1508	445.0129	124.2632	126.6708	79.0063	49.6188	57.6298	61.3769	23.9152	17.8794
13	411.0659	385.845	116.9035	120.492	421.2276	409.5231	425.1833	116.0256	96.7368	87.8017	58.4541	63.2251	46.3793	30.6651	30.7006
14	395.4937	437.5285	111.2431	115.8468	416.669	419.8218	428.179	116.9462	109.9156	95.8317	48.5678	66.6953	46.4217	29.2144	33.517
15	407.9257	433.9785	117.4379	127.626	456.1707	429.0325	434.6891	136.5029	124.3272	107.6638	45.7146	67.9764	55.1011	38.1974	36.5475
16	428.784	437.9583	117.9075	109.8391	444.5692	438.1991	435.1544	144.395	85.2922	119.8189	61.4011	57.7799	41.9889	35.6106	38.4705
17	425.9124	443.5762	117.996	101.4239	389.8687	426.2441	448.6285	93.4085	109.5521	112.0637	67.8893	65.6806	67.8045	35.5825	37.3596
18	451.0855	416.2444	100.8183	104.9477	377.6546	422.1307	420.8389	120.7085	95.256	105.3303	68.7962	54.4067	41.9677	37.6343	24.9244
19	420.6045	416.8669	102.8283	112.9179	319.6233	410.5208	445.9819	70.5978	80.3816	112.4056	38.1102	46.5225	42.901	29.0614	34.6114
20	375.0453	430.2226	92.9546	109.3568	316.3264	452.6042	427.5215	70.9695	87.6293	86.776	31.1875	40.4358	41.3378	27.5647	25.1182
21	376.461	356.0351	109.5369	113.6334	297.9323	399.7886	435.3807	84.1715	62.4331	54.5468	45.2738	40.0571	25.3723	15.926	42.8308
22	363.9917	357.3917	120.7931	92.0824	272.4516	377.5116	400.3427	91.1926	35.1364	61.9563	27.8945	63.9438	29.486	25.5615	16.0256
23	269.5183	315.7877	126.6081	65.6623	260.7936	433.6284	386.201	78.3034	51.92	92.0887	31.3455	70.038	44.6176	32.1933	24.9672
24	338.5838	373.8007	87.1536	107.8559	188.5965	355.8567	434.0976	78.263	45.0046	62.0823	42.5973	55.6867	53.9342	22.7455	28.5864

Table 11. 24-hour Power Generation by 15 generating units with Losses and EPRI Load Profile of Electric Vehicle.

T(h)	Power Generation (MW)														
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
1	249.0404	373.6806	98.1568	106.871	259.2268	426.6244	452.0908	89.34	48.1696	95.7444	43.9538	47.5739	35.9823	16.3575	31.0507
2	282.8024	414.9999	93.7769	116.5679	281.3969	370.135	407.6609	82.984	65.2565	87.1793	46.4938	50.5563	39.5891	17.135	21.8169
3	318.2351	319.0155	112.4005	108.7744	181.1359	404.929	447.3317	91.0603	78.2875	109.4454	56.85	47.6335	37.9681	16.5399	28.5372
4	317.9128	374.4076	104.1712	102.3986	230.4449	421.2502	442.9153	67.1526	59.326	77.8701	27.193	42.4463	25.808	21.5845	23.1306
5	334.7863	367.0866	124.3359	97.1868	183.5347	437.9755	419.8063	90.8942	70.9115	105.8866	43.0956	25.8179	36.7903	16.9169	24.6695

6	366.5185	345.2752	111.5911	117.9171	197.9174	440.5187	431.1323	69.72	73.1706	57.8472	40.7178	49.4767	25.6393	24.4434	20.7318
7	385.8329	302.3962	98.6697	95.2864	259.828	358.1779	434.3189	98.2023	46.8757	76.5947	44.8356	62.3447	32.1105	18.2366	54.2396
8	440.8372	347.6774	94.4876	110.3217	271.0592	400.5418	417.4066	65.2457	36.641	113.4675	46.1933	56.297	25.3146	19.809	27.2825
9	389.6379	407.4948	105.375	104.8813	327.6177	441.7058	438.7441	86.5067	65.3588	100.0535	39.2756	52.4222	30.5261	40.7643	35.57
10	380.5386	429.0411	103.5773	94.2332	357.6294	428.7053	442.8292	136.6518	73.3311	116.6243	55.9308	72.0374	25.8838	21.2608	42.7449
11	432.4013	422.4142	111.291	105.0356	340.7037	435.6692	422.4238	132.7557	80.2358	112.2525	62.7593	65.8182	52.8284	37.3774	30.9464
12	432.6244	413.0677	108.2991	112.853	375.0829	415.7811	447.0119	119.4165	129.653	99.2009	53.9244	53.3003	46.8523	18.8867	24.0688
13	443.3716	394.5929	76.8509	111.262	413.0464	425.3065	426.4336	116.3712	118.1734	104.3394	57.0855	51.9872	43.9495	34.2552	29.02
14	427.3882	447.0147	71.227	116.0093	386.4002	423.6549	449.8373	120.598	121.1909	101.4526	79.9129	64.3633	29.6018	37.2564	20.0558
15	404.5206	441.8686	127.6187	94.1192	436.3852	445.145	446.2059	148.8632	115.1207	133.5693	49.8313	63.0456	58.9562	32.5771	45.5865
16	411.8973	442.1123	113.5744	121.564	398.8558	445.1083	431.5133	160.5384	106.071	102.3896	65.4814	63.4468	63.4583	37.1506	44.2936
17	414.7414	415.5906	110.8032	112.7977	423.1815	420.9994	423.4117	172.6471	93.2592	124.05	53.5316	56.6322	56.9502	36.3138	40.6223
18	405.9367	409.2441	103.2685	93.7467	408.3463	456.6531	437.1076	137.4649	87.427	111.9794	61.3461	50.5117	38.1659	17.5705	32.1525
19	422.6002	446.9668	107.4488	96.745	371.61	408.3359	439.6486	138.8608	42.0964	56.0252	43.7826	56.1265	27.9438	25.0494	23.2075
20	428.3656	404.8155	96.5001	87.5097	371.0773	436.6115	414.504	63.4249	63.1549	95.2956	44.7647	76.3528	26.5862	27.2814	20.5131
21	412.644	360.8009	109.8734	114.3032	332.8618	442.6244	400.6538	67.886	69.7222	58.4477	53.262	22.5218	28.2457	19.0386	26.563
22	334.7023	391.6142	122.1055	98.9408	316.9622	428.686	446.3085	86.7976	34.2722	36.0282	39.1915	40.4318	37.5696	15.402	16.3386
23	403.5277	356.8031	124.07	95.6556	294.6364	361.0477	402.0836	68.6651	38.1381	58.3461	40.5172	48.5402	57.3675	25.1783	23.3447
24	388.2909	372.1141	113.7948	100.2831	310.5107	324.4851	437.3668	60.1937	30.3255	49.0544	49.6839	62.5465	41.2017	26.8384	24.312

Table 12. 24-hour Power Generation by 15 generating units with Losses and Off-Peak Load Profile of ElectricVehicle.

	Power Generation (MW)														
T(h)	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
1	401.4631	361.3456	102.4144	120.2321	264.3094	407.5035	459.9338	68.5182	80.1552	28.3341	28.8553	58.2333	43.3874	22.6569	22.0235
2	391.0781	395.1941	117.4096	99.1318	268.9047	402.1476	429.9164	95.1411	43.693	53.7075	65.8889	42.6438	25.6096	17.5554	26.1979
3	422.8877	302.1563	120.3513	89.9175	209.5895	419.9326	422.7354	88.2013	38.9461	78.3201	49.0738	50.0448	25.3232	17.4556	15.0036
4	380.0425	348.0842	86.26	95.6221	228.4491	436.5034	434.4239	76.4222	37.725	58.0686	49.7192	54.6753	27.6278	24.657	21.2483
5	378.2983	313.8465	109.2257	108.2491	251.9882	401.0677	364.8015	139.0431	73.7808	63.2347	41.0573	56.992	27.862	21.7676	18.5846
6	403.8152	361.1217	114.1269	75.6027	244.0388	413.105	369.9222	99.8399	38.3392	80.1271	42.7465	35.871	40.1898	41.6331	25.3736
7	391.6364	370.3945	113.3901	104.7662	264.7234	348.7686	381.4351	69.7167	71.068	41.2113	48.4896	71.426	26.6407	33.7364	17.101
8	398.7538	389.1465	103.8408	99.9315	217.9253	406.984	415.667	103.3806	84.1797	56.1025	58.4124	55.1501	43.0929	16.8675	19.3973
9	427.61	422.6973	100.6468	107.3878	263.809	398.1352	430.979	99.2224	106.3159	102.5653	54.4571	53.5466	29.7606	30.5119	35.2985
10	431.09	445.0815	98.0328	109.2097	321.4633	437.3383	442.642	104.999	70.209	104.5137	60.1394	54.7585	28.4318	37.2149	17.9254
11	436.7547	418.4381	105.9366	108.3841	354.3	419.5081	448.8422	106.0681	71.9553	104.2332	65.3728	64.9439	33.8463	34.6755	46.939
12	412.0065	425.2472	116.5691	112.3798	387.439	424.6451	448.1429	103.07	72.5603	114.2605	69.9805	45.5337	43.8781	24.965	22.9612
13	417.6587	409.83	89.7542	118.5282	443.0071	429.1755	428.0493	138.8374	61.6245	94.1483	62.577	48.5794	32.8572	26.4979	21.1202
14	452.6075	416.5795	87.7545	92.3431	430.2747	419.5766	421.6699	174.593	73.0948	118.0851	42.287	59.5785	43.6116	22.5953	21.2037
15	416.3573	414.8479	129.6009	116.166	406.3929	455.99	437.4468	178.1754	105.5919	123.9231	71.7449	42.8179	50.4108	36.0816	34.1175
16	411.1722	430.7846	117.0344	116.0306	456.7169	423.9691	435.843	163.361	76.4183	122.8821	69.7765	63.7792	53.5219	15.6265	41.8071
17	408.1189	416.4781	112.9345	111.2475	412.4486	429.111	434.4652	199.2087	88.733	102.7796	64.6279	78.2745	31.6648	41.1856	18.5129
18	414.5094	413.4346	92.8854	128.7569	420.5648	416.2631	434.4231	141.3607	70.2123	126.2602	51.6653	37.7279	38.4973	34.2765	26.1398
19	431.7055	427.4283	106.2427	94.9425	328.1779	412.9882	416.7851	105.1093	54.5762	111.4061	53.7339	52.5618	54.9724	15.711	17.834
20	387.6134	409.5699	101.7829	119.4538	295.6167	443.0002	440.0366	71.8071	38.5785	81.0891	47.0379	53.4955	71.1992	19.1245	32.8836
21	424.7603	405.3112	86.6877	59.2536	300.442	398.293	440.1907	79.9744	31.1991	74.6945	43.3149	32.4839	36.6962	22.1768	23.0311
22	369.0115	352.9788	106.6959	101.3128	268.0546	372.9994	409.3985	99.5959	41.0942	52.5454	36.3408	58.5972	31.0053	20.7682	15.4211
23	380.8842	409.416	81.1113	93.8395	317.8949	395.4061	439.3396	67.1789	45.4143	80.1837	73.9615	41.4611	25.7656	16.2203	28.7702
24	434.7536	423.0486	97.9335	108.0834	273.7255	318.3925	447.0481	66.9829	52.9256	77.5694	52.4305	67.0758	27.6955	24.2002	16.6474

Table 13. 24-hour Power Generation by 15 generating units with Losses and Peak Load Profile of Electric Vehicle.

	Power Generation (MW)														
T(h)	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
1	413.522	339.0179	98.0275	42.4937	235.6963	414.6675	304.1051	106.4274	55.275	86.8342	34.4497	52.8385	37.9459	20.0675	17.4386
2	379.431	314.1956	106.7494	109.9672	188.5827	368.3268	365.5743	81.768	99.6168	93.5787	34.6799	24.9847	45.6879	29.9277	21.2814
3	360.198	271.1779	122.1843	106.2063	220.0004	362.314	352.0066	80.2529	99.3086	89.2399	39.5985	63.943	43.405	17.0237	22.1891
4	418.983	301.0093	105.8938	116.9058	168.1564	374.5833	346.4855	110.3125	97.7203	43.7521	50.2958	48.2386	38.3593	22.8878	15.1402
5	437.632	350.3007	117.3056	85.8431	177.2071	345.9596	350.6644	126.6157	92.9504	101.7374	42.2691	27.72	25.2738	29.5819	15.1532
6	428.48	321.9751	111.9776	95.9996	197.7893	364.7478	372.6479	119.0782	69.8668	87.5054	58.7798	52.4802	26.0935	18.6203	15.1242
7	408.888	364.2791	107.8932	114.3348	255.2982	298.7533	430.5823	104.1176	55.4766	53.1148	40.5249	47.0943	27.0149	16.7329	32.1033
8	433.467	392.7122	96.8057	115.349	279.978	286.1485	377.8569	94.6291	86.4136	79.3723	58.5449	61.8811	52.3307	26.4886	29.1327
9	426.501	433.5602	105.1742	113.6546	305.681	356.1042	404.8864	128.778	102.1475	96.2502	53.1338	45.9453	43.5844	21.9975	27.9985
10	424.884	421.5699	101.4441	104.9185	350.0775	395.1449	418.3285	112.1277	106.2931	95.6678	55.268	53.4444	58.4363	47.7785	19.8899
11	437.495	424.2558	98.2875	104.9741	356.1344	438.2343	426.2118	84.0969	116.3346	100.7275	69.2371	64.0299	51.5456	31.364	17.102
12	431.082	417.9468	94.9142	99.0113	418.1844	403.802	432.735	88.83	111.3898	124.0233	46.6324	44.1711	54.498	26.6447	32.7552

13	437.054	419.0138	110.2046	123.5822	397.2591	443.713	452.0385	104.2376	126.0385	147.9425	59.8808	71.4149	66.0955	43.4857	32.5878
14	449.305	448.4611	121.0112	105.916	442.9051	423.1616	446.9393	130.9106	112.3357	115.3948	78.5733	60.4093	63.29	41.6435	46.6003
15	454.677	441.2727	128.6077	115.5011	460.0774	423.6183	458.1255	184.1106	158.6064	150.7871	63.8118	67.8426	50.0855	45.9186	36.7369
16	443.759	442.6632	120.1787	118.0274	456.3988	455.1868	447.0597	191.7557	136.2522	149.9981	75.3799	65.7065	44.9478	36.5862	34.0868
17	426.07	430.159	96.1554	102.052	443.1716	450.7625	417.9014	170.4318	112.3889	137.2512	65.0096	57.3874	73.1929	47.6813	25.6051
18	414.669	427.0692	129.601	110.6873	416.5406	420.1154	430.7892	142.4955	124.124	103.8798	60.6859	66.9493	46.0261	17.8706	38.3976
19	396.579	404.2036	98.5561	103.0776	327.7689	459.4831	423.3865	126.4496	122.06	85.7466	49.9466	52.989	42.2554	25.1864	15.3623
20	433.377	397.2516	95.7287	90.4239	363.6835	440.4434	381.1023	132.9664	98.7734	48.5848	41.717	45.3767	47.0206	30.6983	17.0121
21	407.964	423.3478	104.1166	113.272	277.2251	413.2828	358.1918	85.6518	42.852	56.2573	56.5868	53.911	33.3085	15.6003	15.9932
22	398.279	346.4606	119.7178	85.6269	225.5816	418.3664	397.9509	79.1746	35.5234	71.6228	44.7729	40.7195	32.4647	16.2284	21.8105
23	353.706	309.9851	100.6388	87.669	231.1699	442.0415	445.318	74.4563	50.7744	30.4085	31.6475	48.7302	28.6677	24.7187	22.2516
24	309.243	344.3183	100.8073	118.5573	302.6573	415.0985	365.1302	118.5524	25.961	29.7929	36.3157	35.9763	37.3951	16.4392	22.1313

Table 14. 24-hour Power Generaon by 15 generating units with Losses and Stochastic Load Profile of ElectricVehicle.

	Power Generation (MW)														
T(h)	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
1	432.4339	356.4065	97.6424	114.4567	218.3918	385.5971	389.774	68.9595	47.7271	58.5439	23.1343	33.8127	51.6195	16.1383	27.6787
2	434.1306	291.9737	93.3415	99.2941	166.9946	425.1913	404.157	70.9829	70.7329	66.67	57.9211	53.6478	29.81	26.1852	25.3797
3	408.9386	314.0869	126.3166	94.0675	202.6089	374.4364	366.6203	109.6568	46.8188	52.5433	53.0981	60.628	38.8673	17.027	36.5554
4	425.1046	338.6045	118.7525	100.7708	198.9737	359.9611	372.1471	64.5504	44.2167	66.8104	76.4916	39.6382	25.8024	30.3969	21.9285
5	409.0142	309.2398	123.4334	110.995	200.7166	375.7419	432.3386	62.3065	40.7304	78.6803	53.0344	60.3001	30.0463	25.2269	37.6151
6	393.3085	366.3908	105.4324	104.8334	252.5689	385.8953	438.2767	89.8509	76.4163	60.5856	29.1525	55.4824	26.2083	43.7689	23.6327
7	406.8216	357.5598	128.5468	109.5854	205.1964	437.8376	434.6459	87.5664	45.1084	58.8639	54.5666	46.274	26.5799	36.2157	18.0141
8	416.7733	398.2079	123.5076	75.7955	233.2044	444.1022	429.388	104.9144	69.8479	58.3073	56.0571	51.0428	26.0824	17.607	18.9887
9	433.6842	425.8993	120.8443	98.6913	256.8604	418.9515	461.3815	109.0124	68.5233	88.8957	52.7293	54.5684	46.5161	16.6319	20.2019
10	430.4581	427.6633	114.749	115.3177	330.6584	436.1236	438.8696	107.3916	79.4958	100.9617	56.0425	57.5576	46.0678	28.1508	30.2822
11	430.493	437.1078	128.7199	102.8635	371.4056	449.5495	389.2674	136.5551	102.5248	62.9502	55.1145	66.8738	58.6822	24.6702	28.2651
12	435.5911	397.9965	112.4972	96.5593	379.0306	448.0029	436.8039	178.3352	84.8113	91.9	47.5942	68.5346	47.033	27.567	39.5838
13	429.9386	439.5254	95.7265	109.2146	380.1334	427.3998	444.3296	112.59	71.8774	111.891	44.2	72.0676	66.7729	30.0117	25.7862
14	427.0514	420.6365	104.6531	100.0568	435.2609	418.4397	436.8239	145.269	95.2196	106.3038	52.6191	58.9215	31.9586	47.7932	19.1538
15	433.1698	435.3195	117.1865	94.9587	432.1706	445.9797	455.7963	161.2328	43.5592	141.1734	74.8993	58.9121	59.7564	42.8082	43.9703
16	445.5334	454.0983	121.0157	120.9827	404.0161	455.3923	438.5449	184.8701	84.9454	110.4488	63.3636	61.5572	51.1139	35.9107	35.4806
17	436.8074	386.0453	108.8959	116.5498	433.498	440.2055	426.6316	164.1952	91.0034	136.5891	49.8321	67.8728	57.7559	38.7086	32.0021
18	429.0516	440.1007	110.4804	124.9209	444.6959	412.0883	421.516	129.5757	93.0047	72.7129	58.0738	38.8565	42.3862	37.2108	16.5125
19	417.9427	409.9079	89.1694	122.6157	413.5864	427.985	413.0253	87.7951	64.6612	111.28	39.2346	45.7726	34.8969	16.4187	25.8258
20	391.9308	420.9616	100.8132	100.5129	321.8701	408.4318	428.2561	103.4298	104.8558	58.3856	67.1116	41.9786	27.1961	48.2396	17.7633
21	405.9499	430.049	95.5226	77.948	306.282	419.9689	425.0376	109.5186	70.4035	72.8627	24.4332	25.4246	29.4261	15.7036	15.925
22	398.825	377.941	102.9501	84.7626	289.0445	353.908	414.2549	113.3456	50.8769	28.6515	26.4801	57.1526	32.2979	15.9304	19.0788
23	347.8458	358.5919	122.8193	100.2611	320.1458	300.6508	423.4705	78.788	48.2414	57.8494	41.4273	60.8205	26.1297	21.798	16.5577
24	389.0685	360.7158	115.5879	103.2672	292.3967	340.6083	410.9844	80.7655	38.3596	65.9131	52.182	31.4688	49.5731	20.4237	19.7064

Table 15. Comparison of total fuel cost for 15-unit test case with losses without PEV ($/day).

METHOD	IFEP[7]	FEP[47]	SFEP[47]	PSO[48]	GHS[49]	SLTLBO[26]	IGWO
Fuel Cost	798403	797084	783411	774131	770428	767800	767220

Table 16. Comparison Results for 15-unit test case with different loading with different algorithm ($/day).

Type of Load	Algorithm								
	wPSO [29]	PSO-CF [29]	DE [29]	TLBO [29]	eTLBO [29]	mTLBO[29]	SL-TLBO [29]	GWOLF [46]	IGWO
EPRI Load	783004.14	784391.24	784354.55	781644.49	782323.93	781562.91	781001.23	780828.88	778850
Off-peak Load	783650.51	784532.96	784313.52	783002.47	782320.70	781179.19	780862.82	780784.83	778390
Peak Load	783863.93	785851.62	785512.3	784004.33	783383.72	782922.74	781961.91	-	780440
Stochastic Load	784610.33	785491.74	785273.31	783962.29	783280.51	782138.87	781459.24	780681.29	778580

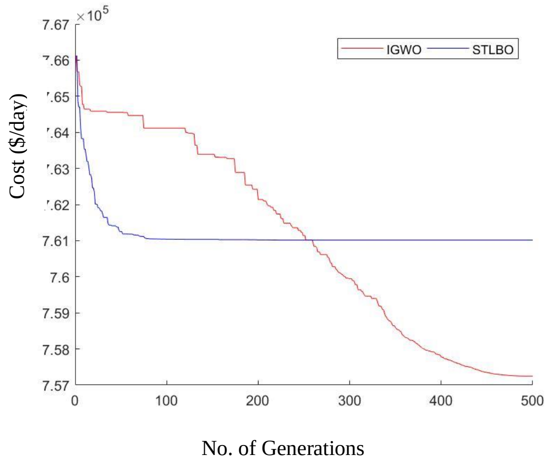

Fig. 10. Comparative convergence curve for IGWO and STLBO for 15 generator case without losses.

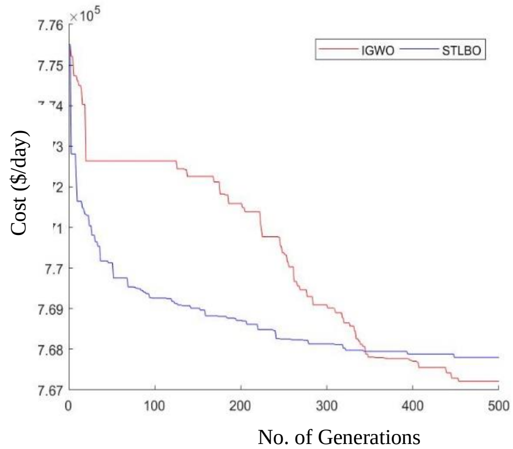

Fig. 11. Comparative convergence curve for IGWO and STLBO for 15 generator case with losses.

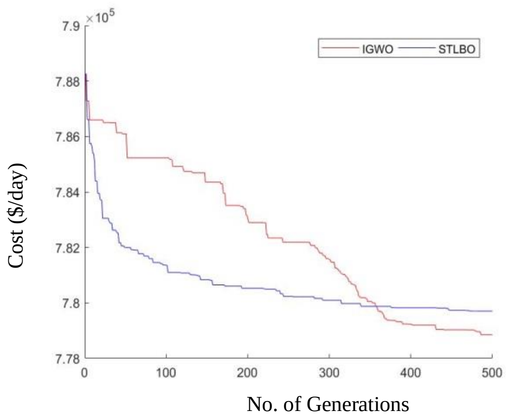

Fig. 12. Comparative convergence curve for IGWO and STLBO for 15 generator case with losses and EPRI load profile of Electric Vehicles.

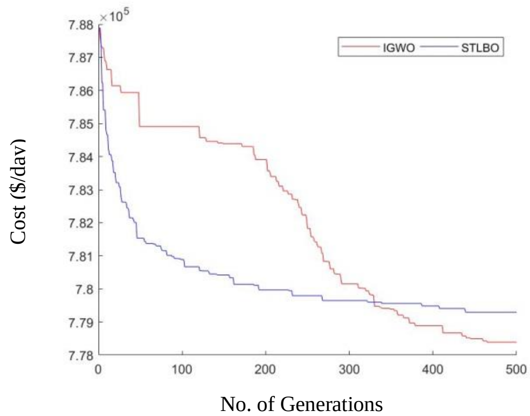

Fig. 13. Comparative convergence curve for IGWO and STLBO for 15 generator case with losses and Off-Peak load profile of Electric Vehicles.

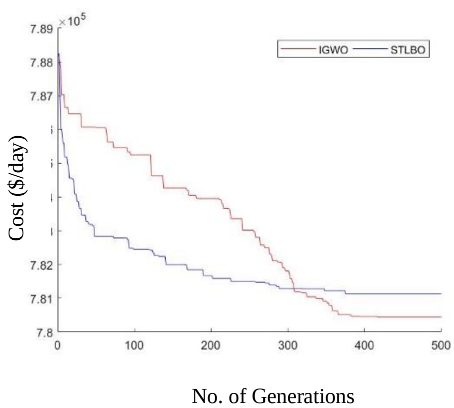

Fig. 14. Comparative convergence curve for IGWO and STLBO for 15 generator case with losses and off-peak load profile of Electric Vehicles.

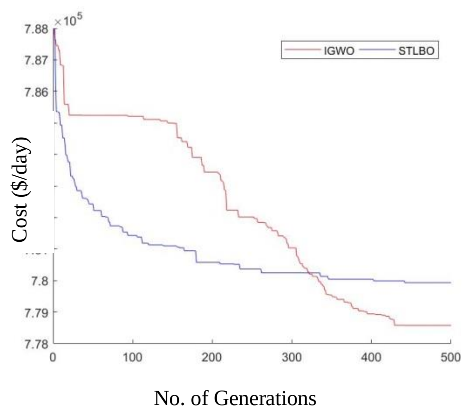

Fig. 15. Comparative convergence curve for IGWO and STLBO for 15 generator case with losses and Stochastic load profile of Electric Vehicles.

6. RESULTS AND DISCUSSION

Dynamic economic dispatch problem is complex problem to optimize the cost of power generation as it has to meet equality and inequality constraints along with ramp rate limits of generators. Here in this paper, two broad cases for 5 thermal units and 15 thermal units are considered. Moreover, the problem is aggravated by the inclusion of electric vehicles as the load in the total demand. Total load of 375 MW is increased for 5 unit case and 1125MW for 15 unit case. The load increased due to inclusion of electric vehicles are checked using different probability distributions such as EPRI, off-peak, peak and stochastic profile. Tables 1-6 show the power generated by 5 units for 24 hours for different cases. Tables 9-14 show the power generated by 15 units for 24 hours for different cases.

It has been observed that cost reduced by using IGWO algorithm for solving dynamic economic dispatch for 5 unit generator without losses and with no electric vehicles is 8% lesser with improved grey wolf optimizer as compared to self-learning teaching learning based algorithm whereas 1.2% for peak load profile and less than 0.5 % for rest of the cases whereas it is less than 0.5 % less than SLTLBO cases in all the 15 unit cases.

Table 8 shows the comparison of the total cost encountered by different algorithms for different test cases for 5 generators with losses and without electric vehicles. The total cost reduced in a year by using IGWO is 1545410$ in 5unit case without loss and with no electric vehicle and 92345$ in 5unit case with loss with no electric vehicle as compared to STLBO [29]. Table 9 summarize the comparison of different algorithm for 5 generator cases with different charging profile and it has been found that annual saving is 46720$, 117165$, 223745$ and 139430$ in 5unit case with loss with EPRI, off-peak, peak and stochastic electric vehicle profile respectively as compared to STLBO[29].

Table 15 shows the comparison of the total cost encountered by different algorithms for different test cases for 15 generators with losses and without electric vehicles. The total cost reduction by employing IGWO is 1376050$ per year for the case without losses and no electric vehicles wherein it is 211700$ per year for case with losses and no electric vehicles as compared to STLBO[29]. Table 16 summarizes the comparison of different algorithm for 15 generator cases with different charging profile and it has been found that annual saving per year calculated for EPRI , off-peak, peak and stochastic electric vehicle load profile with losses for 15 unit test case is 785199$, 902579.3$, 555497.2$, 1050923$, respectively as compared to STLBO[29].

The convergence curve obtained for different cases for 5 unit as well 15 unit test cases shows that SLTLBO stagnates after 50th iteration for the case with no loss and with no electric vehicles wherein stagnates for other cases in between 100th- 300th iterations. It shows that SLTLBO is not able to balance between exploitation and exploration capabilities whereas for IGWO, the cost is decreasing with number of iteration and hence IGWO showcased balanced characteristics.

7. CONCLUSION

This paper proposes an implementation of improved version of grey wolf optimizer. This algorithm is solving dynamic economic dispatch problem for 5-generator and 15-generator test cases. The proposed study finds the optimum solution while meeting equality and inequality constraints using a repair method to repair infeasible solution. The experimental results obtained for different cases show that the results obtained by the Improved Grey Wolf Optimizer (IGWO) are better as compared to result obtained by different state of art algorithm available in literature. It has also been noticed that by incorporating levy flight in prey position, exploration capabilities have been improved and by adding one more level to hierarchy of grey wolves, exploitation capability of original GWO has been improved. Hence, the proposed algorithm is recommended for solving dynamic economic dispatch problem with various constraints for different other test cases.

The scope of the work includes implementation of proposed algorithm for solving different non-linear, non-convex engineering problem. Also, the future scope includes the framing of multi-objective version of proposed algorithm for optimization.

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Appendix A: Data for 5-Unit Test Case

i	P_i^{max}(MW)	P_i^{min}(MW)	a_i($/MWh^2)	b_i ($/MWh)	c_i($/h)	e_i($/h)	f_i(rad/MW)	UR(MW/hr)	DR(MW/hr)
1	10	75	0.008	2	25	100	0.042	30	30
2	20	125	0.003	1.8	60	140	0.04	30	30
3	30	175	0.0012	2.1	100	160	0.038	40	40
4	40	250	0.001	2	120	180	0.037	50	50
5	50	300	0.0015	1.8	40	200	0.035	50	50

Appendix B: Load for 5-Unit Test Case

Time (hr)	Load (MW)	Time (hr)	Load (MW)	Time (hr)	Load (MW)	Time (hr)	Load (MW)
1	410	7	626	13	704	19	654
2	435	8	654	14	690	20	704
3	475	9	690	15	654	21	680
4	530	10	704	16	580	22	605
5	558	11	720	17	558	23	527
6	608	12	740	18	608	24	463

Appendix C: B-Coefficient per MW for 5-Unit Test Case

0.000049	0.000014	0.000015	0.000015	0.000020
0.000014	0.000045	0.000016	0.000020	0.000018

0.000015	0.000016	0.000039	0.000010	0.000012
0.000015	0.000020	0.000010	0.000040	0.000014
0.000020	0.000018	0.000012	0.000014	0.000035

Appendix D: Data for 15-Unit Test Case

i	P_i^{max}(MW)	P_i^{min}(MW)	a_i($/MWh^2)	b_i ($/MWh)	c_i($/h)	e_i($/h)	f_i(rad/MW)	UR(MW/hr)	DR(MW/hr)
1	150	455	0.0003	10.1	671	0	0	80	120
2	150	455	0.00018	10.2	574	0	0	80	120
3	20	130	0.00113	8.8	374	0	0	130	130
4	20	130	0.00113	8.8	374	0	0	130	130
5	150	470	0.00021	10.4	461	0	0	80	120
6	135	460	0.0003	10.1	630	0	0	80	120
7	135	465	0.00036	9.8	548	0	0	80	120
8	60	300	0.00034	11.2	227	0	0	65	100
9	25	162	0.00081	11.2	173	0	0	60	100
10	25	160	0.0012	10.7	175	0	0	60	100
11	20	80	0.00359	10.2	186	0	0	80	80
12	20	80	0.00551	9.9	230	0	0	80	80
13	25	85	0.00037	13.1	225	0	0	80	80
14	15	55	0.00193	12.1	309	0	0	55	55
15	15	55	0.00445	12.4	323	0	0	55	55

Appendix E: Load for 15-Unit Test Case

Time (hr)	Load (MW)	Time (hr)	Load (MW)	Time (hr)	Load (MW)	Time (hr)	Load (MW)
1	2236	7	2331	13	2780	19	2651
2	2240	8	2443	14	2830	20	2584
3	2226	9	2630	15	2970	21	2432
4	2236	10	2728	16	2950	22	2312
5	2298	11	2783	17	2902	23	2261
6	2316	12	2785	18	2803	24	2254

Appendix F: B-Coefficient per MW for 15-Unit Test Case = 1e-05*

1.40	1.20	0.70	-0.10	-0.30	-0.10	-0.10	-0.10	-0.30	-0.50	-0.30	-0.20	0.40	0.30	-0.10
1.20	1.50	1.30	0.00	-0.50	-0.20	0.00	0.10	-0.20	-0.40	-0.40	0.00	0.40	1.00	-0.20
0.70	1.30	7.60	-0.10	-1.30	-0.90	-0.10	0.00	-0.80	-1.20	-1.70	0.00	-2.60	11.10	-2.80
-0.10	0.00	-0.10	3.40	-0.70	-0.40	1.10	5.00	2.90	3.20	-1.10	0.00	0.10	0.10	-2.60
-0.30	-0.50	-1.30	-0.70	9.00	1.40	-0.30	-1.20	-1.00	-1.30	0.70	-0.20	-0.20	-2.40	-0.30
-0.10	-0.20	-0.90	-0.40	1.40	1.60	0.00	-0.60	-0.50	-0.80	1.10	-0.10	-0.20	-1.70	0.30
-0.10	0.00	-0.10	1.10	-0.30	0.00	1.50	1.70	1.50	0.90	-0.50	0.70	0.00	-0.20	-0.80
-0.10	0.10	0.00	5.00	-1.20	-0.60	1.70	16.80	8.20	7.90	-2.30	-3.60	0.10	0.50	-7.80
-0.30	-0.20	-0.80	2.90	-1.00	-0.50	1.50	8.20	12.90	11.60	-2.10	-2.50	0.70	-1.20	-7.20
-0.50	-0.40	-1.20	3.20	-1.30	-0.80	0.90	7.90	11.60	20.00	-2.70	-3.40	0.90	-1.10	-8.80
-0.30	-0.40	-1.70	-1.10	0.70	1.10	-0.50	-2.30	-2.10	-2.70	14.00	0.10	0.40	-3.80	16.80
-0.20	0.00	0.00	0.00	-0.20	-0.10	0.70	-3.60	-2.50	-3.40	0.10	5.40	-0.10	-0.40	2.80
0.40	0.40	-2.60	0.10	-0.20	-0.20	0.00	0.10	0.70	0.90	0.40	-0.10	10.30	-10.10	2.80
0.30	1.00	11.10	0.10	-2.40	-1.70	-0.20	0.50	-1.20	-1.10	-3.80	-0.40	10.10	57.80	-9.40
0.10	-0.20	-2.80	-2.60	-0.30	0.30	-0.80	-7.80	-7.20	-8.80	16.80	2.80	-2.80	9.40	128.30