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Adaptive Grey Wolf based on Firefly algorithm technique for optimal reactive power dispatch in unbalanced load conditions

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Abstract

ORPD (Optimal Reactive Power Dispatching) is a subset of optimal power flow. The reduction of an objective function expressing total various other optimization methods of ORPD problems have been utilized, but these methods are not able to select optimal active power losses in power systems was traditionally thought of as ORPD. In literature, control variables of power systems, and in order to overcome the drawbacks, the proposed method is developed. For solving the ORPD problem in power systems, this paper suggested an adaptive Grey Wolf based Firefly Algorithm (GWFA). The adaptive technique is carried out by combining the Grey Wolf Optimization (GWO) and the Firefly Algorithm (FA). The FA is utilized to achieve the updating process of grey wolves in the GWO for enhancing the performance of GWO. The suggested methodology is used to tap change transformers by tap positions, compute optimal control variables of generator voltages, and optimize two different objective functions such as voltage deviation minimization and power loss minimization using shunt capacitors. The proposed adaptive technique is implemented in the standard IEEE 14, IEEE 30 and IEEE 39 bus systems in order to overcome the issue of ORPD within power systems, and it is compared with the already existing methods of ABC, Bat, FA and GWO. Ultimately, the proposed adaptive technique is capable of producing optimal control variables for solving ORPD problems in power systems.

Keywords: *adaptive technique; control variables; generator; power loss; ORPD problem; voltage deviation.*

1. Introduction

ORPD is a hot topic among power system practitioners and researchers in today's modernized power systems (Ghasemi, Taghizadeh, Ghavidel, Aghaei, & Abbasian, 2015). The insufficient reactive power supply should induce voltage instability and voltage collapses in many extreme cases. Thus, appropriate management and distribution of reactive power have become a major concern in power system utilities. The system does not eliminate the reactive power, most of the loads are inductive, and transformer components, as well as the transmission line, also consume reactive power. To manage the reactive power requirements, ORPD is the best contrivance (Shaw, Mukherjee, & Ghoshal, 2014). ORPD is used to achieve a variety of goals, including voltage stability, voltage deviation minimizing, power loss minimization, and energy dispatch, among others (Mohseni-Bonab, Rabiee, Mohammadi-Ivatloo, Jalilzadeh, & Nojavan, 2016). Furthermore, each ORPD solution should adhere to some operational constraints in the power system, such as the need for generators to operate within their capacity limits, voltage control devices to operate within their capacities simultaneously, and bus voltage to remain within the permissible range (Nuaekaew, Artrit, Pholdee, & Bureerat, 2017). The OPF problem can be solved by determining the steady-state functioning of an electrical power system, which aids in the solution of a stated objective function and must satisfy power system limitations. The challenges in ORPD are traditionally addressed using traditional ways. Based on usual mathematical approaches, dissimilar size of ORPD issue and heterogeneous size of ORPD issue are solved (Dutta, Mukhopadhyay, Roy, & Nandi, 2016).

The conventional methods are divided into interior point method linear programming, Newton's method, quadratic programming, gradient method, non-linear programming etc. Unfortunately, traditional approaches suffer from a number of drawbacks, including lack of convergence, failure to satisfy restrictions, and being influenced by optimal local conditions (Mohseni-Bonab, Rabiee, & Mohammadi-Ivatloo, 2016). In recent years, a revised algorithm based on the metaheuristic approach has been created to address the limitations of the traditional method. Some of the algorithms were utilized for overcoming the issue of ORPD within the power system, such as Genetic Algorithm (GA), Differential Evaluation (DE) Approach, Artificial Bee Colony algorithm (ABC) (Sayah, 2018), hybrid Nelder-Mead simplex based Firefly Algorithm (Rajan, & Malakar, 2015), Bat Algorithm (BA) (Latif, Ahmad, Palensky, & Gawlik, 2016), imperialist competitive algorithms and hybrid particle Swarm Optimization, Fuzzy satisfying approach, kill herd algorithm and hybrid particle swarm optimization with multiverse optimizer (Mehdinejad, Mohammadi-Ivatloo, Dadashzadeh-Bonab, & Zare, 2016) etc. The above-mentioned algorithms, on the other hand, will not use differential calculus and thus will not have any limits in their objective functions. The recommended method will be developed in this study to address this issue.

1.1. Contribution and organization of the study

In this paper, the ORPD problem is solved with the help of the Adaptive technique by optimizing the control variables of the power system. The main contribution of the paper is presented as follows,

- The adaptive technique of GWFA based IEEE 14, IEEE 30 and IEEE 39 bus systems were designed and analyzed the performance under unbalanced conditions for solving ORPD problems.
- The adaptive technique is the mixture of FA and GWO algorithm which is used to compute optimal control variables for reducing power loss and voltage deviation. The algorithm FA is utilized to update the grey wolf's position in the GWO algorithm.
- The proposed method is implemented in MATLAB, and performance is analyzed in IEEE 14, IEEE 30 and IEEE 39 bus systems individually. Moreover, the outcome of the proposed approach is compared with existing methods of ABC, Bat, GWO and FA.

The remaining part of the paper is organized into five main sections, which include: Section 2 provides some of the research work related to the issue of ORPD within the distribution system. The objective functions, problem formulation, and constraints of the power system associated with the issue in ORPD were explained in Section 3. Section 4 provides information about the adaptive technique of GWFA related to the ORPD problem. Section 5 of the paper covers the results that were obtained from implementation and performance analysis of the proposed method related to ORPD on IEEE 30, IEEE 14, IEEE 39 and bus system. Finally, Section 6 is concluded with the obtained result from the proposed adaptive technique conclusion of the implementation of the proposed adaptive technique.

2. Literature review

In recent years, various methods have been developed for solving issues in ORPD problems in power systems. Some of the methods are reviewed in this section. Nuaekaew, Artrit, Pholdee, & Bureerat (2017) have developed a Two-Archive Multi-Objective Grey Wolf Optimizer (2ArchMGWO) in order to overcome the issue existing in Multi-Objective Optimal Reactive

Power Dispatch (MORPD). ben oualid Medani, Sayah, & Bekrar (2018) has presented an algorithm named Whale Optimization Algorithm (WOA) for overcoming the issue of ORPD. The main aim of the ORPD was the minimization of voltage deviation and reactive power loss. Mouassa, Bouktir, & Salhi (2017) have presented Ant Lion Optimizer (ALO) algorithm for overcoming the issue of ORPD within the power system in a huge scale manner. The ALO was utilized for obtaining a lot of optimal control variables, which includes a number of switchable capacitor banks, generators terminal voltage and position of tap changers of a transformer. Mei, Sulaiman, Mustaffa, & Daniyal (2017) have developed Moth-Flame Optimization Algorithm (MFO) to address the ORPD problem. Naderi, Narimani, Fathi, & Narimani (2017) have presented an optimization algorithm named Fuzzy Adaptive Heterogeneous Comprehensive-Learning Particle Swarm Optimization (FAHCLPSO) to solve the ORPD in the distribution method. Shaheen, Yousri, Fathy, Hasanien, Alkuhayli, & Muyeen (2020) have suggested an improved Marine Predators Technique and Particle Swarm Optimization (IMPAPSO) was a robust and adaptable optimization algorithm with the fewest configurable parameters for coping with ORPD non-linearity. This approach is validated in IEEE 30 bus, IEEE 57 bus, and IEEE 118 bus systems. Dutta, Paul, & Roy (2018) have presented a flexible AC transmission system (FACTS) device, and an efficient quasi-oppositional chemical reaction optimization (QOCRO) technique was able to identify a feasible optimal solution to the multi-objective optimal reactive power dispatch (RPD) problem. Barakat, El-Sehiemy, Elsayd, & Osman (2019) have suggested an improved Jaya optimization algorithm (IJOA) for resolving the optimal reactive power dispatch (ORPD) problem with a multi-objective function (MOF). Saddique, Bhatti, Haroon, Sattar, Amin, Sajjad, & Rasheed (2020) have suggested a meta-heuristic method to solve the ORPD issues in transmission systems. Moreover, a sine cosine algorithm was also used to mitigate the problem. Mahzouni-Sani, Hamidi, Nazarpour, & Golshannavaz (2019) have presented a multi-objective method to mitigate the problem of ORPD in wind farm coupled power systems. The key importance of introducing this method is given and take among voltage deviation and power loss, in addition to reducing the amount of ULTC operation and tap variation. Reddy, Abhyankar, & Bijwe (2011) have suggested the reactive power price clearing (RPPC) mechanism, which was based on a novel multi-objective for improving voltage stability. The problem of multi-objective was solved by the usage of the Strength Pareto Evolutionary Algorithm (SPEA). The method was implemented and tested in IEEE 30 bus system. Reddy & Bijwe (2019) have suggested the idea of an incremental load flow model based on sensitivity and some heuristics, and we developed a unique, efficient evolutionary-based multi-objective optimization (MOO) strategy for solving the optimal power flow (OPF) problem. The method was implemented and validated in IEEE 30 bus system. Reddy & Bijwe (2017) have presented the optimal power flow (OPF) problem have been solved using a new efficient multi-objective optimization (MOO) technique. Implementation of this method was based on differential evolution (DE) algorithm. Reddy & Panigrahi (2017) have suggested an LBEST PSO, a new swarm-based evolutionary algorithm with dynamically shifting sub-swarms (LPSO DVS). Satisfied the set of system operating limitations, OPF optimizes the power system operating objective function. Reddy (2017) have suggested the Cuckoo Search Algorithm (CSA) was used to solve an optimal reactive power scheduling problem in a deregulated power system. This method was designed and tested in standard Ward Hale 6 bus, IEEE 30 bus, 57 bus, 118 bus and 300 bus test systems.

3. Problem formulation ORPD problem

One of the major problems that are happening in power systems is ORPD. This problem has a significant part in the improvement of the economy as well as security within power systems. The reactive power under power systems should be redistributed onto the stage that offers minimum transmission loss, rated capacity and improved voltage profile in spite of its drawback in network and equipment. This leads to mitigate the issues of ORPD. In this paper, the adaptive technique was utilized for solving the issue of ORPD within power systems. The term ORPD defines as a control vector calculation which has in the voltage control device for optimizing constraints of equality and inequality based on the objective function simultaneously. The proposed adaptive approach is the hybrid form of FA and GWO. FA algorithm helps in improving the process of optimization to achieve the position updating of the grey wolf algorithm. With the utilization of the adaptive technique, the objective functions are attained. The objective function includes voltage deviation and power loss minimize under unbalanced conditions within the power system (Rajan, & Malakar, 2016).

Minimization:

$$\partial(X,U) \tag{1}$$

Subject to:

$$\left.\begin{aligned} EC\ (X,U)=0 \\ IC(X,U)\leq 0 \end{aligned}\right\} \tag{2}$$

Where, $\partial(X,U)$ is denoted as the objective function that needs to be reduced, such as power loss and voltage deviation and of the unbalanced conditions in the power system. The equality constraints of the system are described as $EC\ (X,U)=0$ and inequality constraints of the system are mentioned as the $IC(X,U)\leq 0$. Here, U can be denoted as independent control variables, and X can be denoted as dependent variables.

$$U^T=\left[V_{g1},\dots\dots V_{g\text{-}ng}Tap_1,\dots\dots Tap_{NT}Q_{c1},\dots\dots Q_{c\text{-}nc}\right]$$

Where, $V_{g1},\dots\dots V_{g\text{-}ng}$ can be described as the generators voltages, which are also called continuous variables, $Tap_1,\dots\dots Tap_{NT}$ is described as the tap changers positions, which are considered as the discrete variables and $Q_{c1},\dots\dots Q_{c\text{-}nc}$ is described as the switchable capacitor's output which is considered as the discrete variables. In general, PV buses are generation bus, each and every bus have both real power and voltage individually. Consider the problem of ORPD, the active generator's power is considered as fixed and the reactive power only controlled (which is presented in equation (3)) by adjusting control variables for achieving the objective functions of power loss and voltage deviation. The independent variables of the power system are explained in relation to equation (3), and they are generated at random according to their limits. Additionally, dependent variables within the system are mathematically presented in follows,

$$X^T=\left[P_{g1},V_{l\text{-}1},\dots\dots\dots,V_{l\text{-}npq},Q_{g1},\dots\dots\dots,Q_{g\text{-}npq},S_{l1},\dots\dots\dots S_{l\text{-}ng}\right] \tag{4}$$

Where, P_{g1} is represented as a slack generator that has real generation. For PV generation, the reactive power generation is represented as $Q_{g1},\dots\dots\dots,Q_{g\text{-}npq}$, transmission line flows are represented as $S_{l1},\dots\dots\dots S_{l\text{-}ng}$ and load bus voltage magnitude is represented as $V_{l\text{-}1},\dots\dots\dots,V_{l\text{-}npq}$ which are considered as dependent variables. The PV bus is a load bus in a power system that has fixed active and reactive power in the apiece bus since they are the dependent variables whose values fluctuate according to changes in the independent variables in equation (3). Based on the control variable that is independent and dependent, the objective function of the power system is attained.

3.1. Objective function of the ORPD problem

In this paper, two different kinds of the objective function are taken for enhancing the power system performance under unbalanced load conditions. These two problems are crucial problems in the entire power system, and these cause several problems to the consumer. Stable power is free from power loss and voltage difference, and this system provides a full amount of power to the consumer without lag.

3.1.1 Minimization of power loss

The first goal of the ORPD issue was to reduce power loss in the power system in order to improve the system's performance. The conditions in power loss must satisfy the constraints that were classified into equality and inequality (Sayah, 2018). The consumption rate of energy should be reduced because the consumption rate is increased, the rate of power loss also increased.

$$\partial_1=MIN(P_{Loss})=MIN\left[\sum_{C=1}^{NTL} G_C\left(V_a^2+V_b^2\text{-}2V_aV_b\cos\alpha_{ab}\right)\right] \tag{5}$$

Where, P_{Loss} can be described as the sum of active power loss, NTL may be represented like number of transmission lines, voltage magnitude of the a^{th} and b^{th} bus respectively, G_C can be represented as the conductance of c^{th} branch associated among a^{th} and b^{th} bus, V_a and V_b can be represented like transmission line admittance angle of power system among a^{th} and b^{th} bus correspondingly.

3.1.2 Minimization of voltage deviation

The power system's performance must be improved, and bus voltage is one of the most important service and security quality indicators. Voltage deviation is used as the suggested method's second goal function. To enable the optimal operation in electrical equipments, the nominal voltage should be maintained.

$$\partial_2=MIN(VD)=MIN\left(\sum_{a=1}^{NL}\left|V_{La}\text{-}V_{La}^{Ref}\right|\right) \quad (6)$$

Where, V_{La}^{Ref} can be described as the voltage of reference for a^{th}bus and it contain a value of 1.0p.u. V_{La} will be denoted as voltage within the a^{th}load bus. The adaptive approach can be used to reduce the voltage variation of each bus. Constraints must be met in the power system in order to achieve the voltage deviation and power loss objective functions. The many sorts of limitations are described in the section below.

3.2. Power system constraints

In the power system, the constraints are classified as two different kinds such as inequality constraints and equality constraints and. The constraints are must be satisfied to achieve the voltage deviation and power loss objective function for enhancing the system performance (Bingane, Anjos, & Le Digabel, 2019).

3.2.1 Equality constraints

In the ORPD issue of power system, the reactive and real equation for power balance is taken as the equality constraints.

$$P_{ga}\text{-}P_{da}\text{-}V_a\sum_{b\text{-}1}^{NB}V_b[G_{ab}\cos(\delta_{ab})+B_{ab}\sin(\delta_{ab})]=0,\ \ a=1,\ldots,NB \quad (7)$$

$$Q_{ga}\text{-}Q_{da}\text{-}V_a\sum_{b\text{-}1}^{NB}V_b[G_{ab}\cos(\delta_{ab})\text{-}B_{ab}\sin(\delta_{ab})]=0,\ \ a=1,\ldots,NB \quad (8)$$

Where, G_{ab} can be described as the real part of the bus admittance matrix of the $(a,b)^{th}$ entry, reactive and active power within a^{th} bus was mentioned as $P_{ga}$and Q_{ga}, active and reactive load demand of the a^{th} bus is mentioned as P_{da} and Q_{da}, and B_{ab} can be described as the bus admittance matrix that is considered as the imaginary part of the $(a,b)^{th}$ entry.

3.2.2 Inequality constraints

In the power system, inequality constraints may be represented as operating constraints, which follows,

❖ ***Generator constraints***

In the power system, the generation bus voltage and reactive and real power generation are limited through lower as well as upper confines, which are mathematically formulated below,

$$P_{ga}^{MIN}\leq P_{ga}\leq P_{ga}^{MAX} \quad a=1,\ldots.,NG \quad (9)$$

$$Q_{ga}^{MIN}\leq Q_{ga}\leq Q_{ga}^{MAX} \quad a=1,\ldots.,NG \quad (10)$$

$$V_{ga}^{MIN}\leq V_{ga}\leq V_{ga}^{MAX} \quad a=1,\ldots.,NG \quad (11)$$

Where, NG can be described as the number of generators, minimum and maximum voltage generator of the a^{th}generating unit is represented by V_{ga}^{MIN}andV_{ga}^{MAX}, maximum and minimum reactive power output of the a^{th} generating unit is represented by Q_{ga}^{MIN} and Q_{ga}^{MAX}, maximum and minimum active power output for a^{th} generating unit is represented by P_{ga}^{MIN} and P_{ga}^{MAX},.

❖ ***Transformer constraints***

The upper and lower confines were restricted in the transformer tap settings, which were presented below,

$$T_a^{MIN}\leq T_a\leq T_a^{MAX}, \quad a=1,\ldots,NT \quad (12)$$

Where, maximum and minimum tap settings of the a^{th}transformer can be represented by T_a^{MAX} and T_a^{MIN}

❖ ***Shunt Var constraints***

The upper and lower confines were restricted in the shunt Var compensators, which were presented below,

$$Q_{Va}^{MIN}\leq Q_{Va}\leq Q_{Va}^{MAX}, \quad a=1,\ldots,NC \quad (13)$$

Here, maximum and minimum and Var injection limits for a^{th}shunt compensator can be represented by Q_{Va}^{MAX}andQ_{Va}^{MIN}.

❖ ***Security constraints***

The security confines for the power system is transmission line loading and voltages at load buses which are presented below,

$$V_{La}^{MIN}\leq L_{La}\leq L_{La}^{MAX}, \quad a=1,\ldots,NPQ \quad (14)$$

$$S_{La} \leq S_{La}^{MAX}, \quad a=1,\ldots,NTL \quad (15)$$

Where, the load voltage maximum and minimum at a^{th}unit can be represented by L_{La}^{MAX}, V_{La}^{MIN} and. The obvious flow of power for a^{th} branch is represented byS_{La}. S_{La}^{MAX}Can be represented as apparent power flow limit at the maximum of a^{th} branch. Within the power system, the voltage deviations and power loss objective function are achieved by means of adaptive technique.

4. Adaptive technique for solving ORPD problem

The adaptive technique is utilized to optimize the control variable in the ORPD problem inside the power system in order to reduce power loss and voltage deviation objective function. In addition, the limits that have been described will be met. The proposed adaptive algorithm is the combination of the FA algorithm (Abd-Elazim, & Ali, 2018) and the GWO algorithm (Saxena, Soni, Kumar, & Gupta, 2018). The FA is added along with GWO for enhancing its performance. The update of wolves' position in GWO is achieved by means of the FA algorithm. Figure 1 depicts the suggested method's workflow procedure.

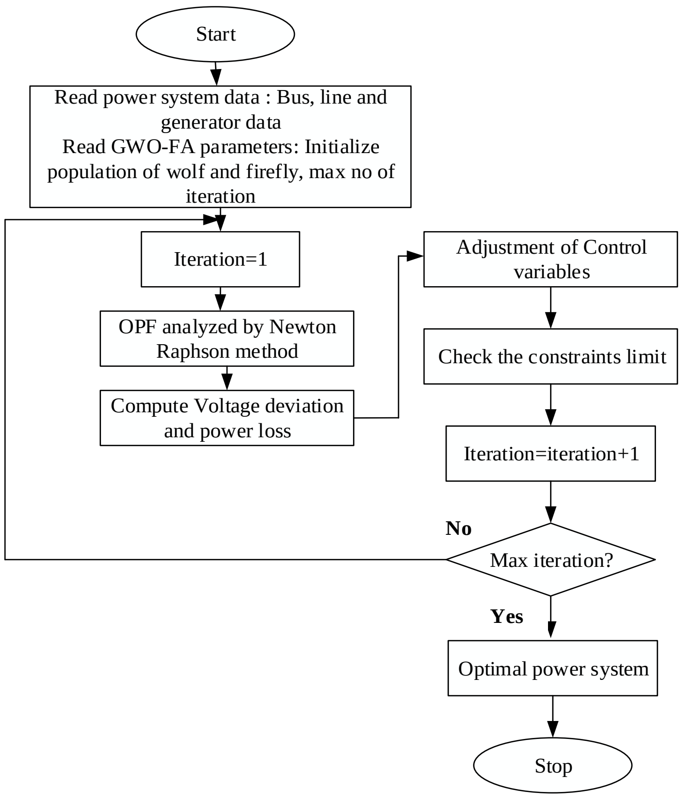


Figure 1 Overall workflow process of ORPD problem

The data from the power system and the adaptive technique settings are set up first. Following that, the N-R technique is used to analyze the typical power flow. The nominal voltage deviation and power loss for the system are calculated using this method. With the use of adaptive techniques, the system's power loss and voltage deviation must be reduced. Adaptive techniques are used to determine the best control variables. It was possible to alter the objective functions as well as the control vector for the system. Additionally, the selection of control vector must be satisfied the inequality and equality and constraints. The optimal control vectors are selected by an adaptive technique which consists of algorithms named FA and GWO. The update of the wolf's current position in GWO is achieved by means of the FA algorithm. At the initial stage, the number of search agents and maximum iteration is set. The population vector is represented below,

$$Y=\begin{bmatrix} y_1^1 & \cdots & y_n^1 \\ \vdots & \ddots & \vdots \\ y_n^p & \cdots & y_n^p \end{bmatrix} \tag{16}$$

Where, control variables of the power systems or position for every wolf n and quantity of grey wolves or quantity of population are described as p. To produce the goal function, each wolf's position is linked to load flow data, and the load flow software is utilized to calculate the loss. The voltage deviation within load buses was computed using a similar technique, and the power loss and voltage deviations are presented in section 3.2. In the adaptive technique, the best solution or minimum power loss with minimum voltage deviation were taken as the alpha solution. The second-best solutions hold back as bets, and the third fitness and placements are saved as the delta solution. The loss and voltage fluctuations in the power system are reduced, and the limits in unbalanced load conditions are fulfilled via the proposed adaptive technique. The proposed GW-FA flowchart is represented in Figure 2.

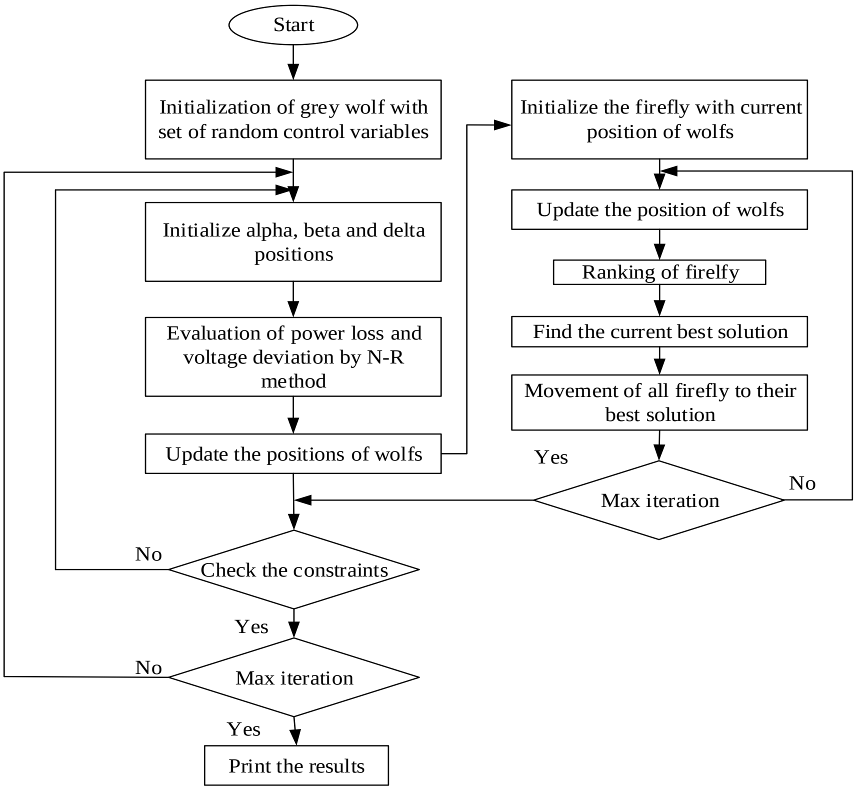


Figure 2 Flowchart of GWFA technique

The following are the steps of the adaptive techniques:

Step 1: Initialization

In the ORPD issue, the control variables are generators, transformers and static VAR compensators. From the control variables, discrete variables are transformer and static VAR compensators; continuous variables are generator voltages. In search space, the grey wolf positions represent control variables. Furthermore, grey wolf placements are produced at random across the ranges at first. The discrete variables are rounded in the population phase to the nearest decimal integer value.

Step 2: Fitness calculation

The fitness function is used to reduce voltage variation and power loss, i.e. in equation (1). The above section discusses the objective functions. To achieve the low power loss and voltage deviation goal functions, the limitations must be met. The constraints limits are generator voltages, transformer and shunt VAR compensators.

Step 3: Update process

In the grey wolf, positions are updated by the FA algorithm. The FA is employed in the updating process of GWO algorithms to improve their performance. The current location of the grey wolves is sent to the FA algorithm's initial population. The FA algorithm updates the grey wolf positions.

Step 4: Checking the limits

After the update of the position of the grey wolf, there is a possibility for the new position to exist outside the limit. So the limits are checked in the step.

Step 5: Checking of maximum iteration

The maximum iteration that is fixed was checked in this stage. If maximum iteration was attained, goes for the next step; otherwise, goes for step 2.

Step 5: Optimal control variables and display the result

The optimal control variables of transformer tap setting, generators, shunt VAR compensators are computed with the use of the adaptive technique. The alpha(α), beta(β), delta (δ) are considered as the finest results for control variables. The best control variables are those that have the least voltage deviation and the least power loss. The effectiveness of the given strategy is evaluated based on the results of its execution. In the section below, the simulation results for the proposed technique are shown.

5. Simulation results and discussion

This section describes the implementation results for the standard IEEE 14 bus system, IEEE 39 bus system, and IEEE 30 bus system that were achieved using adaptive GWFA to solve the issue of ORPD. The ORPD problem is formulated and solved for two main aims, which include power loss as well as voltage deviation. With GEOFA, the objective functions are met while the restrictions are met at the same time. For solving the issue of ORPD using GWFA, the simulation is processed using MATLAB with CPU @ 2.20GHz 6GB RAM and Windows 7 professional core i3-2330M. For solving the issue of ORPD in power systems, the GWFA algorithm tunes the control variables. Generators, transformers, and shunt compensators are considered to control variables. The ORPD problem was solved by utilizing the power system's control variables. To assess the suggested technique's performance, a comparison is made between it and the active technique of artificial bee colony (ABC), Bat, FA and the GWO algorithm. The values acquired through the application of the proposed and existing methods are shown in Table 1.

Table 1 Implementation parameters

S.No	Algorithms	Descriptions	Parameters
1	GWFA	Number of iterations	500
2		Grey wolf population size	50
3		Lower bound	-100
4		Upper bound	100
5		Absorption coefficient	1
6		Alpha	0.25
7		Beta	0.2
8		Gamma	1
9		Damping ratio	0.98
10		Number of firefly population	30

Case study 1: *IEEE 14 bus system*

The control variable must be optimized to obtain the result of solving the problem of ORPD in the power system. The test system contains the different sizes of the initial population. In general, the IEEE 14 bus test system contains five generators at buses 1,2,3,6 and 8; 20 transmission lines and 3 branches, and under load tap setting transformer branches. Shunt reactive power sources are also regarded to be bus 9 and 14. Figure 3 depicts the single line diagram for the IEEE 14 bus system. The line, maximum and minimum limits of real power generations and bus data are taken from the work of Raha & Chakraborty (2012). In Table 2, the limit for the control variable is given. For IEEE 14 bus system, the load system is taken as $P^{LOAD}=259MW$ ***and*** $Q^{LOAD}=73.5MVAr$ correspondingly. The initial entire generations and power loss of the system is taken as $\sum P^{G}=272.39MW$, $\sum Q^{G}=82.44MVAr$, $P^{Loss}=13.3933MW$ ***and*** $Q^{Loss}=-54.54MVAr$ respectively.

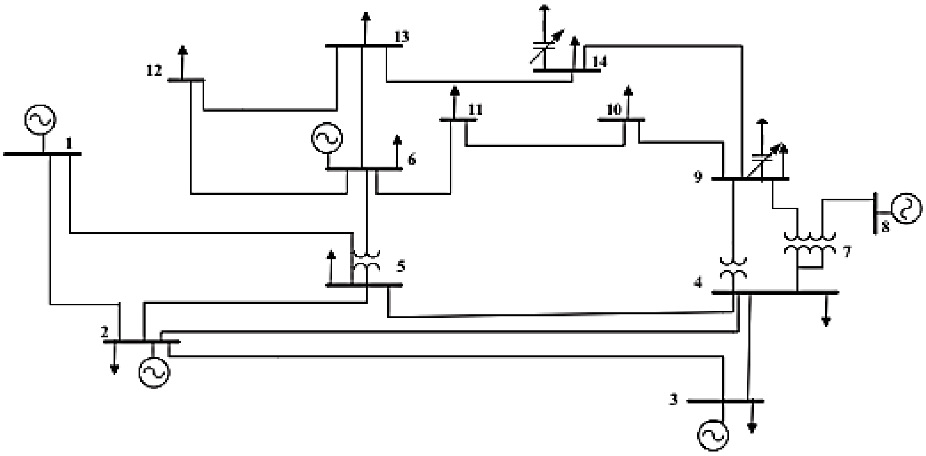


Figure 3 Single Line diagram for IEEE 14 bus system

Table 2 IEEE 14 bus system (a) Generators reactive power limits and (b) voltage, tap setting and reactive power sources

(a)

Bus. No	1	2	3	6	8
Q_{ga}^{MIN}	0.1	0.5	0.4	0.24	0.24
Q_{ga}^{MAX}	0.0	-0.4	0.0	-0.06	-0.06

(b)

S.No	Description	Parameters	Value
1	Voltage	V_{ga}^{MIN}, V_{ga}^{MAX}	0.95-1.05
2	Real and reactive power limits	V_{PQ}^{MIN} ,V_{PQ}^{MAX}	1.05-0.95
3	Tap-setting limits	T_a^{MIN},T_a^{MAX}	1.1-0.9
4	Shunt Var compensators	Q_{Va}^{MIN} ,Q_{Va}^{MAX}	0.3-0.0

Table 3 Optimal control variables of IEEE 14 bus system

S.NO	Variable	Base Case	ABC	BAT	GWO	FA	Proposed
1	V_1	1.06	1.26	1.23	1.07478	1.068	1.1
2	V_2	1.045	1.24	1.24	1.04751	1.053	1.0851
3	V_3	1.01	1.20	1.17	1.0159	1.018	1.055
4	V_6	1.07	1.18	1.20	1.0254	1.045	1.1
5	V_8	1.09	1.13	1.08	1.0385	1.053	1.094
6	T_8	0.978	1.17	1.15	0.92	0.96	0.971
7	T_9	0.969	0.90	1.19	1.08	1.07	0.998
8	T_{10}	0.932	1.07	1.10	1.0	1.0	0.999
9	Q_{va9}	0.18	0.15	0.17	0.17	0.28	0.176
10	Q_{va14}	0.18	0.54	0.15	0.15	0.06	0.19
Power loss	-	***13.3933 MW***	***13.3794 MW***	***13.2015 MW***	***13.1053 MW***	***13.135 MW***	***12.3215 MW***
Voltage Deviation	-	***0.8393 p.u***	***0.6786 p.u***	***0.5216 p.u***	***0.1058 p.u***	***0.1251p.u***	***0.0425 p.u***

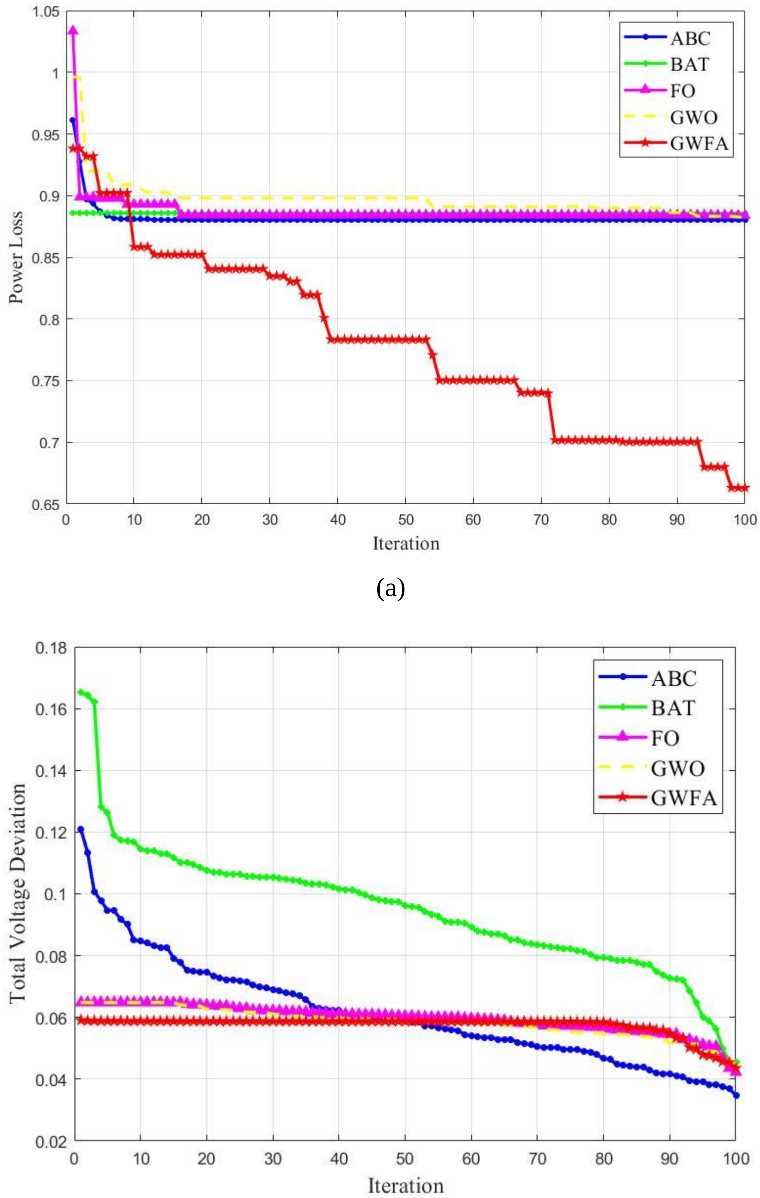


Figure 4 Analysis of IEEE 14 bus system (a) Power loss and (b) Voltage deviation

The objective function is minimized, and the control variable is optimized with the help of the proposed approach GWFA. As objective functions, voltage variation and power loss were used. The base case voltage deviation and power loss for IEEE 14 bus system are ***0.8393 p.u*** and ***13.3933 MW*** correspondingly. Controlling 10 control vectors of shunt compensators, transformers, and generators also reduces voltage deviation and power loss in the system. The best control variable is selected using the GWFA algorithm for reducing the voltage deviation and power loss of the system, which includes ***0.6786 p.u, 0.1058 p.u, 0.0425 p.u.*** and ***12.3215MW.*** A comparison is made between the existing method of ABC, Bat, FA and GWO algorithm and the proposed method for examining the proposed technique performance. The proposed technique and existing methods power loss values are ***12.3215MW, 13.135MW, 13.1053 MW.*** As compared to the optimal solution of the proposed and existing methods, the proposed work has its worst solution at the variables V_1 and V_6, and the existing work of ABC, Bat, FA and GWO has the worst solution at the variable T_9. The average solution of FAGWO, ABC, Bat, GWO and FA is present at the variable T_8, T_8, T_8 , T_8 and T_8 respectively. Finally, the best optimal solutions in FAGWO, GWO and FA is present at the variable Q_{va9}, Q_{va14} and Q_{va14} respectively. The power loss value produced through the proposed strategy is modest, according to the analysis, when compared to the currently active method for ABC, Bat, FA and GWO. Secondly, the voltage deviation value of the proposed method and existing method are ***0.0425 p.u, 0.1251p.u*** and ***0.1058 p.u.*** The better minimization of voltage deviation is achieved by an assist from the proposed technique.

Case study 2: *IEEE 30 bus system*

In this section, the numerical result achieved by utilizing GWFA to solve the problem in OPRD was presented. To evaluate the performance of the suggested technique, it is tested on a standard IEEE 30 bus system. Six generators, four transformers tap ratio, and three shunt compensation devices are among the thirteen control variables of the IEEE 30 bus system. The generator buses are connected to the power system by 1, 2, 5,8,11 and 13. Branch data Load data and bus data of the IEEE 30 bus system is referred from the work of Duman, Sönmez, Güvenç, & Yörükeren (2012). The transformers are connected to the power system by 9, 10, 12 and 27. The shunt compensator devices are connected by 3, 10 and 24, respectively. The system loads of the IEEE 30 bus systems were considered as $\boldsymbol{P^{LOAD} = 283.4MW}$ ***and*** $\boldsymbol{Q^{LOAD} = 126.2MVAr}$ respectively. The initial entire generations and power loss of the system is taken as $\sum \boldsymbol{P^G = 289.3857MW}, \sum \boldsymbol{Q^G = 98.0199MVAr}, \boldsymbol{P^{Loss} = 5.9879MW}$ ***and*** $\boldsymbol{Q^{Loss} = -6.4327MVAr}$ respectively. The major goal was to find the appropriate control variables for achieving the objective functions of power loss and voltage variation. The constraint limits for the IEEE 30 bus system are listed in Table 6.

Table 4 IEEE 30 bus system (a) Generators reactive power limits and (b) voltage, tap setting and (c) reactive power sources

(a)

Bus. No	**1**	**2**	**5**	**8**	**11**	**13**
Q_{ga}^{MIN}	0.596	0.48	0.6	0.53	0.15	0.155
Q_{ga}^{MAX}	-0.298	-0.24	0.3	-0.265	-0.075	-0.078

(b)

S.No	**Description**	**Parameters**	**Value**
1	Voltage	V_{ga}^{MIN}, V_{ga}^{MAX}	0.9-1.1
2	Real and reactive power limits	V_{PQ}^{MIN} ,V_{PQ}^{MAX}	1.05-0.95
3	Tap-setting limits	T_a^{MIN},T_a^{MAX}	0.95-1.05

(c)

Bus. No	**3**	**10**	**24**
Q_{Va}^{MIN}	0.36	0.36	0.36
Q_{Va}^{MAX}	-0.12	-0.12	-0.12

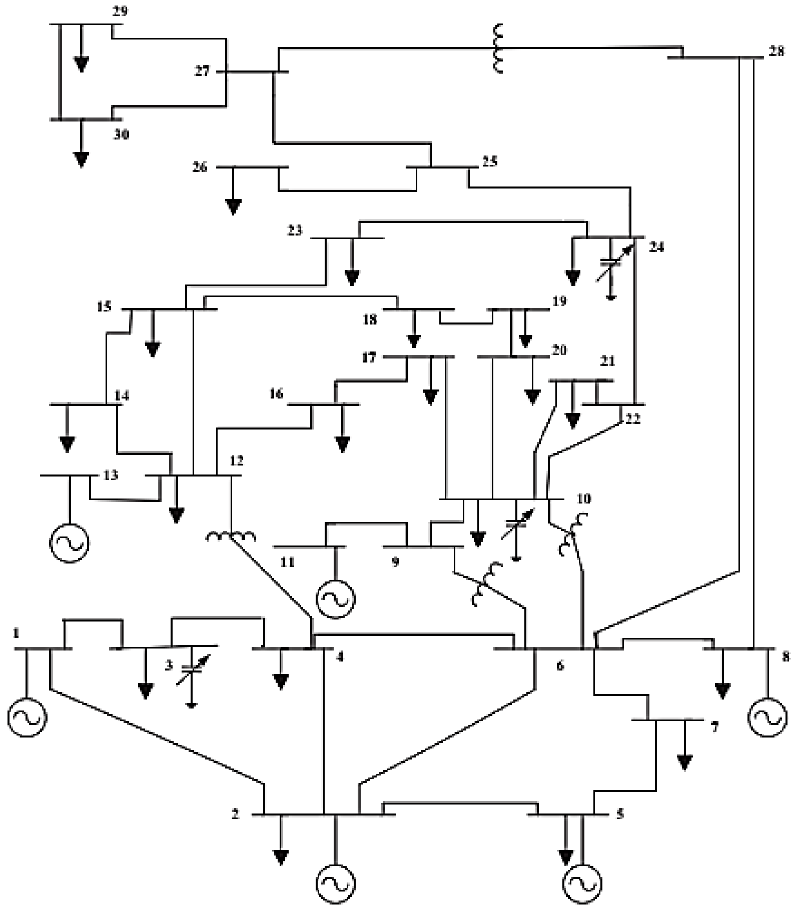
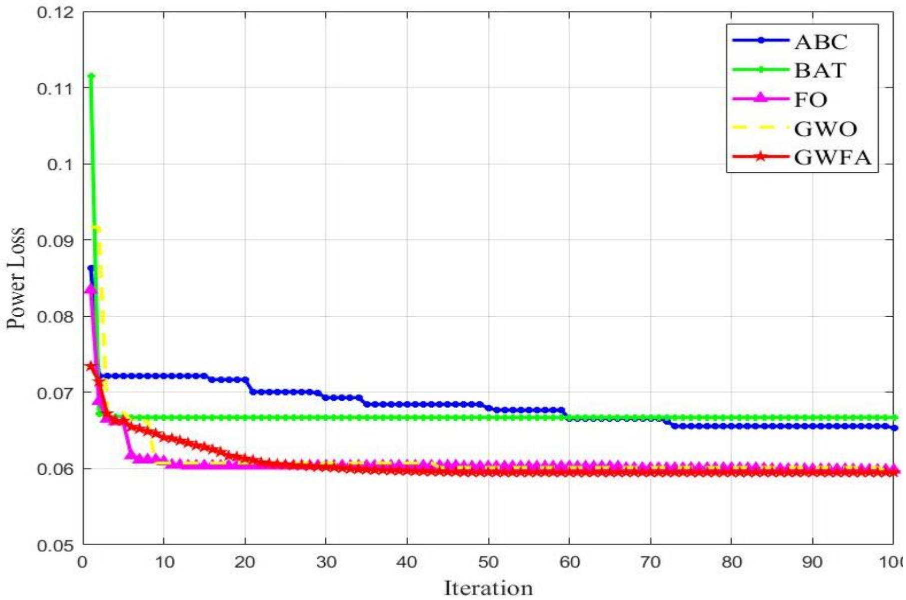


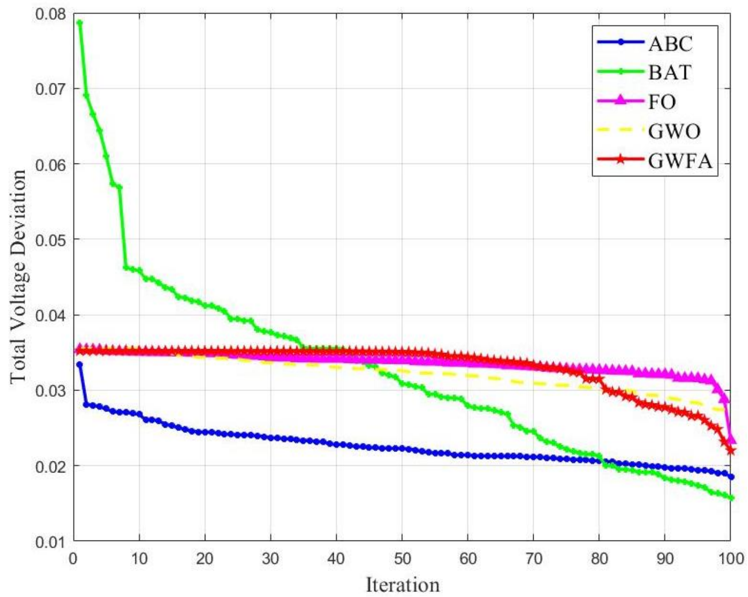
Figure 5 Single Line diagram for IEEE 30 bus system

Table 5 Optimal control variables of IEEE 30 bus system

S.NO	Variable	Base Case	ABC	BAT	GWO	FA	Proposed
1	V_1	1.05	1.04	1.07	1.10	1.10	1.10
2	V_2	1.04	1.03	1.07	1.10	1.10	1.10
3	V_5	1.01	1.02	1.07	1.09	1.09	1.09
4	V_8	1.01	1.03	1.07	1.10	1.10	1.10
5	V_{11}	1.05	1.02	1.07	1.10	1.10	1.10
6	V_{13}	1.05	1.05	1.07	1.10	1.10	1.10
7	T_9	1.078	1.05	1.02	1.03	1.02	1.01
8	T_{10}	1.069	1.03	1.02	1.01	1.02	1.02
9	T_{12}	1.032	1.00	1.02	0.97	0.98	0.97
10	T_{27}	1.068	1.01	1.02	1.02	1.03	1.04
11	Q_{va3}	0	7.08	19.97	16.62	15.00	17.86
12	Q_{va10}	0	38.33	14.97	19.80	20.00	18.72
13	Q_{va24}	0	7.82	14.97	15.00	15.00	15.00
Power loss	-	***5.9878 MW***	***4.8625 MW***	***3.7836 MW***	***3.215 MW***	***3.984MW***	***1.7908MW***
Voltage Deviation	-	***1.054 p.u***	***1.032 pu***	***1.014 pu***	***0.951 p.u***	***1.001p.u***	***0.025 p.u***



(a)



(b)

Figure 6..Analysis of IEEE 30 bus system (a) power loss and (b) Voltage deviation

With the assist of the proposed method GWFA, the minimization of the objective function and optimization of the control variable is achieved. The voltage deviation and power loss were taken as objective functions. The base case voltage deviation and power loss for IEE 14 bus system are ***1.054 p.u*** and ***5.9878 MW*** correspondingly. Further, the voltage deviation and power loss for the system is achieved by controlling 10 control vectors of shunt compensators, transformers and generators. The best control variable is selected using the GWFA algorithm for reducing the voltage deviation and power loss of the system, which includes ***0.025 p.u.*** and ***1.7908MW.*** A comparison is made between the existing method of ABC, Bat, FA and GWO algorithm and the proposed method for examining proposed technique performance. The proposed method and existing methods power loss values are

1.7908MW, 4.8625 MW, 3.7836 MW, 3.215 MW, 3.984MW. Through the analysis, it is confirmed that the power loss value generated by the proposed technique was low when in contrast to an already active method for ABC, Bat, FA as well as GWO. Secondly, the voltage deviation value of the proposed technique, as well as the active method, is ***0.025 p.u, 1.032 pu, 1.014 pu, 1.001p.u*** and ***0.951 p.u.*** As compared to the optimal solution of the proposed and existing methods are, the variable Q_{va10} have the worst optimal solution of proposed work, but the existing work of both FA and GWO has the worst solution at the same variable Q_{va10}. The average solution of FAGWO, ABC, Bat, GWO and FA is present at the variable Q_{va24} ,Q_{va10}, Q_{va3}, Q_{va3} and Q_{va3} respectively. Finally, the best optimal is present at the variable T_{12} for FAGWO, T_{10} and T_{12} for GWO, T_{10} for FA T_{12} for ABC, and T_{27} for Bat. The better minimization of voltage deviation is achieved with the help of the proposed technique.

Case study 3: *analysis of IEEE 39 bus system*

With the use of GWFA algorithms, the control variable inside the power system is improved to tackle the issue of ORPD. 10 generators are contained in the IEEE 39 New England bus system (30, 31, 32,33,34,35,36,37,38 and 39) and transformer settings are 4 such as 35, 36, 38 and 44. Additionally, shunt compensators are three buses such as 3, 10 and 24, respectively. Reference (Pai, 1989) provides branch data, load data, and bus data for the IEEE New England bus system. Figure 5 depicts the single line diagram for the IEEE 39 bus system. Table 4 shows the limits of the control variables. The system loads of the IEEE 39 bus system is taken as $\boldsymbol{P^{LOAD}=6150.55MW}$ ***and*** $\boldsymbol{Q^{LOAD}=1409.5MVAr}$ correspondingly. The initial entire generations and power loss of the system is taken as$\sum \boldsymbol{P^{G}=6186.92MW}$, $\sum \boldsymbol{Q^{G}=866.44MVAr}$, $\boldsymbol{P^{Loss}=13.3933MW}$ ***and*** $\boldsymbol{Q^{Loss}=-54.54MVAr}$ respectively.

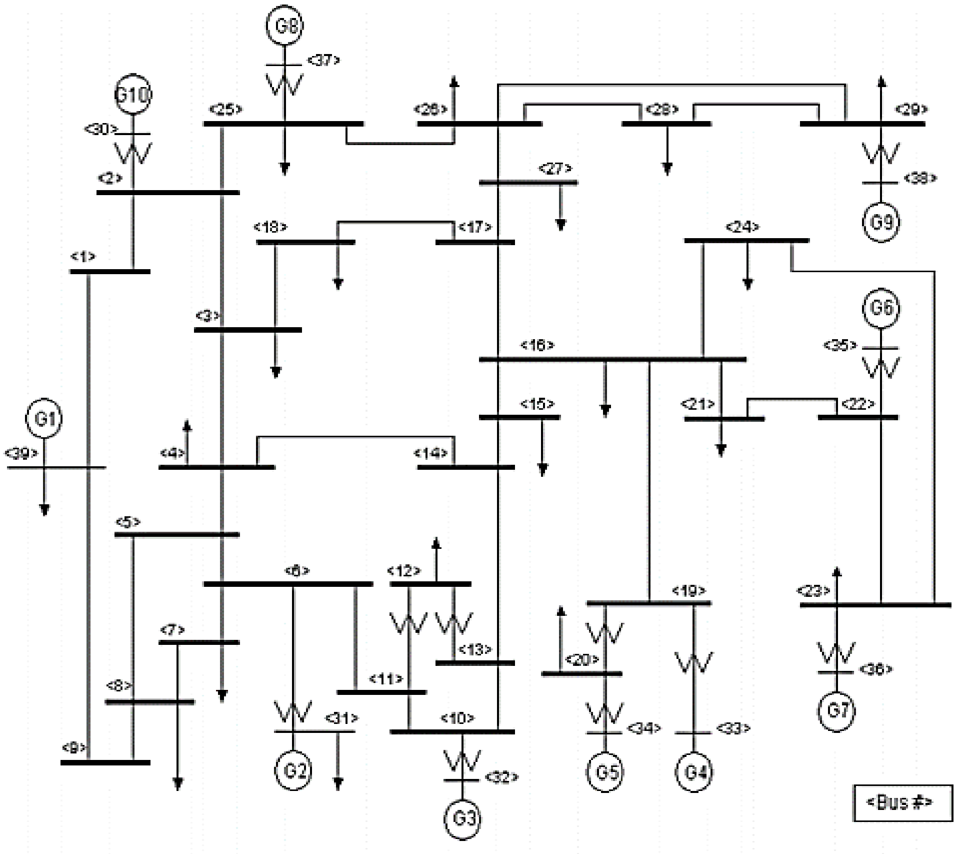


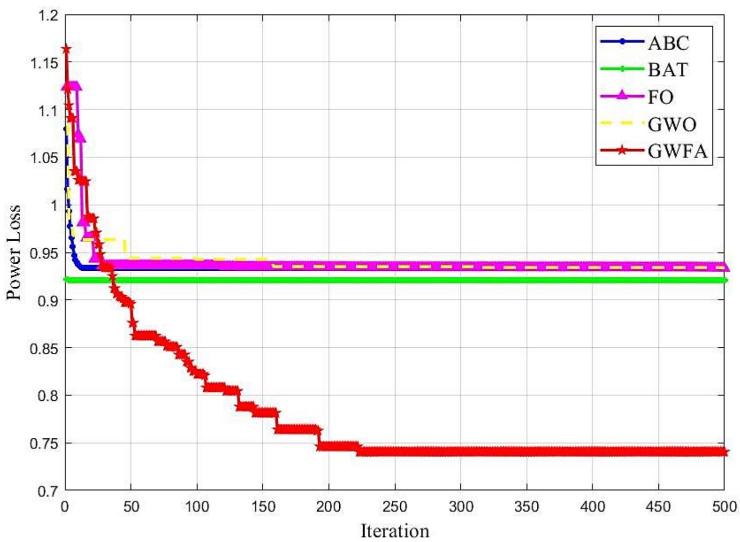
Figure 7 Single Line diagram for IEEE 39 bus system

Table 6 IEEE 39 bus system; Generators reactive power limits, voltage, tap setting and reactive power sources

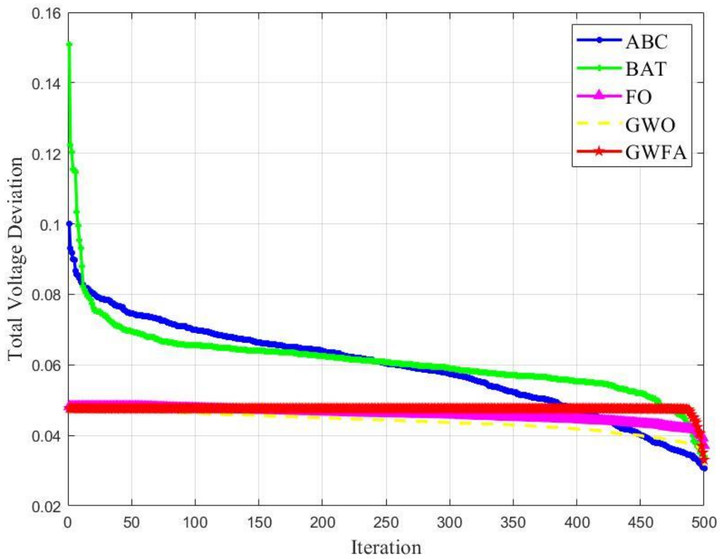
S. No	Description	Parameters	Value
1	Voltage	V_{ga}^{MIN}, V_{ga}^{MAX}	0.95-1.05
2	Real and reactive power limits	V_{PQ}^{MIN},V_{PQ}^{MAX}	1.05-0.95
3	Tap-setting limits	T_{a}^{MIN},T_{a}^{MAX}	1.1-0.9
4	Shunt Var compensators	Q_{Va}^{MIN},Q_{Va}^{MAX}	0.3-0.0
5	Generator reactive power limits	Q_{ga}^{MIN}, Q_{ga}^{MAX}	9999,-9999

Table 7 Optimal control variables of IEEE 39 bus system

S.No	Variable	Base Case	ABC	BAT	GWO	FA	Proposed
1	V_{30}	1.047	1.1	1.2	1.1	1.1	1.1
2	V_{31}	0.98	1.2	1.1	1.1	1.1	1.1
3	V_{32}	0.9831	1.1	1.1	1.1	1.1	1.1
4	V_{33}	0.9972	1.2	1.1	1.1	1.1	1.1
5	V_{34}	1.0123	1.2	1.1	1.1	1.1	1.1
6	V_{35}	1.0493	1.2	1.2	1.1	1.1	1.1
7	V_{36}	1.0635	1.2	1.2	1.1	1.1	1.1
8	V_{37}	1.0278	1.3	1.2	1.1	1.1	1.1
9	V_{38}	1.0265	1.3	1.2	1.1	1.1	1.1
10	V_{39}	1.03	1.2	1.1	1.1	1.1	1.1
11	T_{35}	1.006	1.0	1.1	1.0	1.0	1.0
12	T_{36}	1.006	1.0	1.1	1.0	1.0	1.0
13	T_{38}	1.07	1.0	1.1	1.0	1.1	1.1
14	T_{44}	1.025	1.2	1.1	1.0	1.0	1.0
15	Q_{va3}	0	-0.5	15.9	15.7	20.0	20.0
16	Q_{va10}	0	52.0	17.8	19.7	20.0	20.0
17	Q_{va24}	0	18.6	16.8	18.7	20.0	20.0
Power loss	-	***42.7359 MW***	***39.762 MW***	***38.396 MW***	***38.512MW***	***40.8971MW***	***36.4167MW***
Voltage Deviation	-	***1.8291 p.u***	***1.6431 p.u***	***1.5962 p.u***	***1.4524 p.u***	***1.6524p.u***	***0.0341 p.u***



(a)

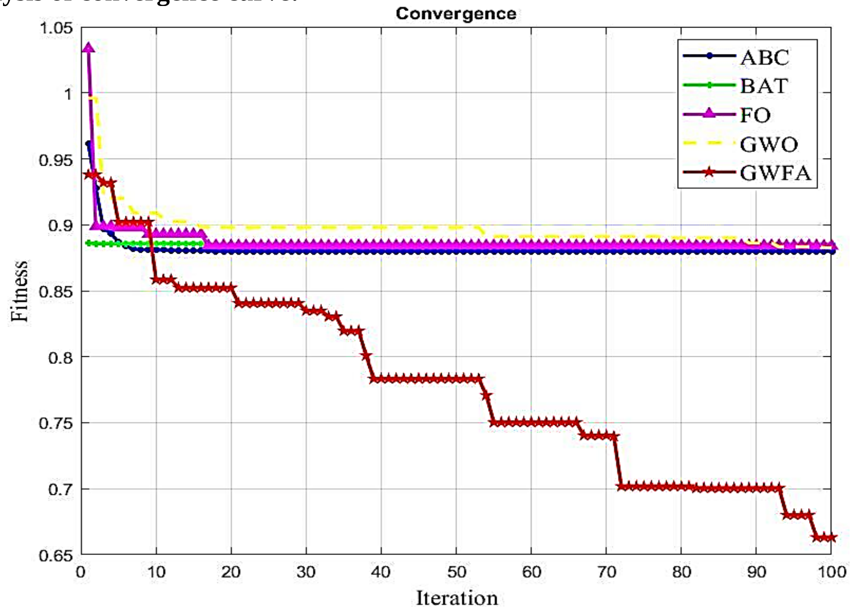


(b)

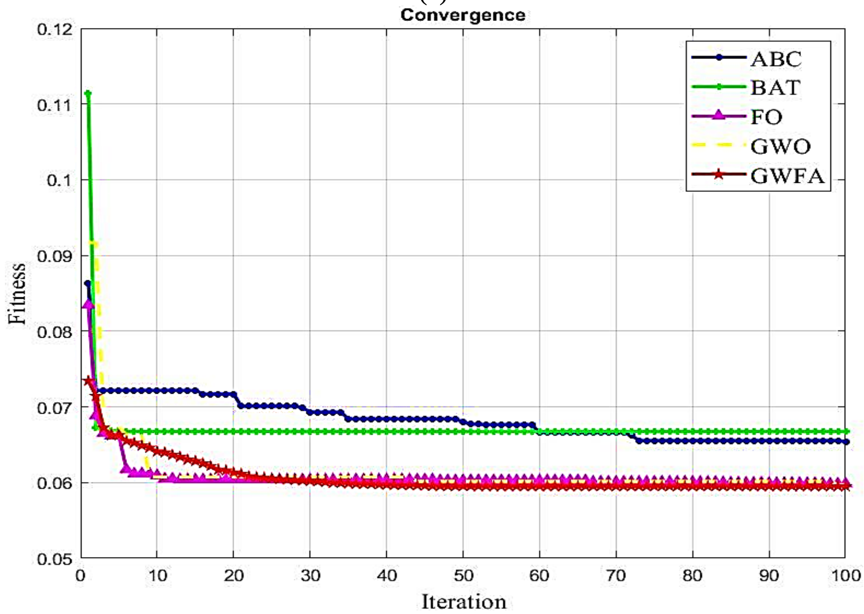
Figure 8 Analysis of IEEE 39 bus system (a) power loss and (b) Voltage deviation

The objective function is reduced, and the control variable is optimized with the assistance of the proposed approach GWFA. As objective functions, voltage variation and power loss were used. The base case voltage deviation and power loss for IEEE 39 bus system are ***1.8291 p.u*** and ***42.7359 MW*** correspondingly. Controlling 10 control vectors of shunt compensators, transformers, and generators are also used to reduce voltage variation and power loss in the system. The best control variable is selected using the GWFA algorithm for reducing the voltage deviation and power loss of the system, which includes ***0.0341 p.u.*** and ***36.4167MW.*** A comparison is made between the existing method of ABC, Bat, FA and GWO algorithm and the proposed method for examining the performance for the proposed technique. The proposed technique and existing methods power loss values are ***36.4167MW, 39.762 MW, 38.396 MW, 38.512MW, 40.8971MW.*** Through the analysis, it is confirmed active method of ABC, Bat, FA and GWO. Secondly, the voltage deviation value of the proposed method and existing method are ***0.0341 p.u, 1.6431 p.u, 1.5962 p.u, 1.4524 p.u*** and ***1.6524 p.u.*** As compared to the optimal solution of the proposed and existing methods are, the variable Q_{va10} have the worst optimal solution of proposed work, but the existing work of both FA and GWO has the worst solution at the same variable Q_{va10}. The average solution of FAGWO, ABC, Bat, GWO and FA is present at the variable Q_{va3}, Q_{va10}, Q_{va10}, Q_{va3} and Q_{va24} respectively. Finally, the best optimal is present at the variable T_{35} for FAGWO, V_{31} for GWO, T_{35} for FA, T_{35} for ABC, and T_{38} for Bat. Better minimization of voltage deviation is achieved with the help of the proposed technique.

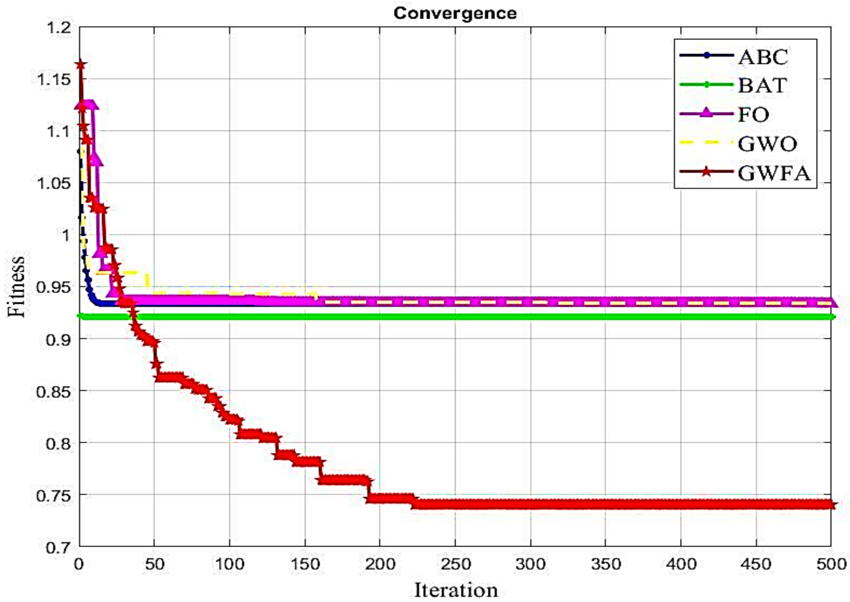
Analysis of convergence curve:



(a)



(b)



(c)

Figure 9 Convergence curve comparison (a) IEEE 14 bus system (c) IEEE 30 bus system (c) IEEE 39 bus system

At last, the convergence curve of proposed and existing methods are evaluated, which is illustrated in Figure 9. Figure 9 (a) shows the convergence curve comparison of the IEEE 14 bus system. The graphical model shows the proposed GWFA give a better convergence value, it reaches 0.66 at the 100th iteration period, but the existing approaches of ABC, Bat, GWO and FA give 0.89 fitness value at the 100th iteration. Similarly, Figure 9 (b) shows the convergence curve comparison of the IEEE 30 bus system, and it contains the comparison convergence curve in both proposed and existing methods like ABC, Bat, GWO and FA. The graphical model shows the proposed GWFA give a better convergence value, it reaches 0.6 at the 100th iteration period, but the existing approaches of ABC, Bat, GWO and FA give 0.075, 0.076, 0.06, and 0.06 fitness value at the 100th iteration. Similarly, the bus structure of the IEEE 39 bus convergence curve is evaluated, which is illustrated in Figure 9 (c). The graphical model shows the proposed GWFA give a better convergence value, it reaches 0.74 at the 100th iteration period, but the existing approaches of ABC, Bat, GWO and FA give 0.93, 0.92, 0.93, and 0.93 fitness value at the 100th iteration. Table 8 shows the computational time of proposed and existing approaches. It shows that the proposed method consumes less time to give a better outcome that is proposed FAGWO take 40.5 seconds to complete the process, but the existing methods of ABC, Bat, GWO and FA take 50.2 seconds, 51 seconds, 45.8 seconds and 44.58 seconds.

Table 8 Comparison of computational time

Methods	Execution time
Proposed FAGWO	40.5 seconds
ABC	50.2 seconds
Bat	51 seconds
GWO	45.8 seconds
FA	44.58 seconds

6 Discussion

This section describes the discussion of obtained results for the standard IEEE 14 bus system, IEEE 39 bus system, and IEEE 30 bus system, which is achieved via the proposed GWFA to resolve the problem of ORPD. The ORPD problem is expressed and resolved by reducing power loss as well as voltage deviation. Table 1 contains the proposed method parameters. In the proposed work number of iteration is 500. GWO population is 50, and the population of FA is 30. In the first case, the bus IEEE 14 is designed. Its single line structure is sketched in Figure 3. IEEE 14 bus system's generator reactive bus limits and reactive power sources and voltage tap settings are presented in Table 2. Moreover, its optimal control variable with proposed and existing methods are presented in Table 3. The proposed FAGWO based system's voltage deviation and power loss for IEEE 14 bus system are 12.3215 MW and 0.0425 p.u, respectively. The graphical model of IEEE 14 bus power loss and voltage deviation in both proposed and existing methods are illustrated in Figure 4. In the second case, the bus of IEEE 30 is designed. Its single line diagram is sketched in Figure 5. Then the generators reactive power limits, voltage, reactive power source and tap setting are given in Table 4. Moreover, its optimal control variable of proposed and existing approaches are provided in Table 5. The proposed FAGWO based system's voltage deviation and power loss for IEEE 30 bus system are 1.7908 MW and 0.025 p.u, respectively. In the third case, the bus of IEEE 39 is designed. Its single line diagram is sketched in Figure 7. Then the generators reactive power limits, voltage, reactive power source and tap setting are given in Table 6. Moreover, its optimal control variable of proposed and existing approaches are provided in Table 7. The proposed FAGWO based system's voltage deviation and power loss for IEEE 30 bus system are 36.4167 MW and 0.0341 p.u, respectively. Moreover, the result is compared to existing approaches like ABC, Bat, GWO, and FA. The proposed method power losses and voltage deviation is sketched in Figure 8. The advanced approach effectively reduces the ORPD problems and minimize the power losses and voltage deviation. Finally, the computational time of the proposed and existing approaches are analyzed and observed that is presented in Table 8. Figure 9 shows the convergence curve comparison of proposed and existing methods for the IEEE 14 bus system, IEEE 30 bus system and IEEE 39 bus system.

7. Conclusion

Adaptive GW-FA is created in this study to solve the ORPD problem in power systems. The adaptive approach is a combination of GWO and FA. The FA algorithm is used to update the positions of grey wolves. Minimization of the voltage difference and power loss are two key objective functions created. The optimal control variables of generators, shunt VAR compensators, and tap changing transformers are estimated using the adaptive approach to achieve the objective functions. The procedure of the adaptive technique is presented in this work. The approach has been implemented in three different bus systems, including the IEEE 14 bus system, IEEE 30 bus system, and IEEE 39 bus system as well as the process is designed and validated in Matlab. The results of the proposed method are contrasted with the oldest methods are GWO and FA algorithms. The proposed method is to produce better results of minimization of voltage deviation and of power loss compared with the existing methods. Ultimately, the proposed adaptive technique is capable of effectively and quickly solving ORPD problems, and it could be measured as a hopeful solution for the forthcoming investigates. In future, the optimal problem will be solved by an enhanced hybrid optimization. Moreover, more problems are taken as an objective function to found an accurate and improved outcome. The high penetration of renewable energy sources, as well as the dynamic approach to the ORPD problem, should be the focus of future study in power systems.

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