Performance and security enhancement using generalized optimal unified power flow controller under contingency conditions and renewable energy penetrations

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Abstract
In this paper, a novel flexible AC transmission system (FACTS) device named generalized optimal unified power flow controller (GOUPFC) is introduced to control the power flows in multi transmission lines and to regulate the voltages and angles at the load buses. The detailed power injection modeling of GOUPFC is presented in this paper. The optimal location of GOUPFC is determined based on line collapse proximity indicator (LCPI). A multi-objective function is framed in terms of average voltage deviation (AVDI), real power loss ($P_{loss}$) and average line collapse proximity indicator ($LCPI_{avg}$) to test the effectiveness of the proposed device. The simulation studies are performed on standard IEEE 57-bus test system under single line contingency and considering various renewable energy source (RES) penetrations. The control parameters of GOUPFC are optimized by using whale optimization (WO-BAT) algorithm, by hybridizing WOA and BAT algorithms, and the superiority of WO-BAT is observed in minimizing the proposed objective function and enhancing the voltage profile.

Keywords: Average voltage deviation (AVDI), Generalized unified power flow controller (GUPFC), Phase shifting transformer (PST), Optimal power flow (OPF), Whale optimization-BAT (WO-BAT)

Introduction
The growing threat of global warming has spurred the integration of various renewable energy (RE) technologies into various power systems. In addition to its advantages for the environment, intermittent sources of energy can cause a lot of problems with power quality [1]. The development of novel AC-DC hybrid systems with energy storage and the deployment of power quality controllers like FACTS devices can help resolve these problems [2]. In the literature, numerous researchers have concentrated on the application of FACTS devices on enhancing steady-state stability and power system performance under varied probable situations. However, a few studies are only concerned with their efficient management of RE uncertainties. To tackle line contingencies and RE uncertainties, this research introduces an innovative and sophisticated FACTS device.
The evolution of FACTS technology in the power system industry is employed in demand control, voltage stability and control, active and reactive power flow control, improving quality and conditioning of power in transmission system, power factor correction, voltage regulation, minimizing the real and reactive power losses, reactive power compensation; enhances the transmission system security, enhancement of transient and steady-state voltages; and finally reduces the installation cost of the transmission system due to expansion demanded by the load [3–5]. Also, the progressions in the technology advancement new concepts and strategies are introduced in the FACTS devices in the last two decades. The detailed literature review on the existing FACTS devices is found in [6]. UPFC is the basic second-generation FACTS device which regulates the bus voltages and phase angles and control the power flow in all the lines of the power system. The reformed version of UPFC is GUPFC, which can do the same function of UPFC but in multiple lines. The detailed mathematical modeling of GUPFC with three converters in nonlinear interior optimal power flow is implemented in [7]. A hybrid approach for GUPFC optimal location is implemented to damp out inter-area oscillations which is proposed in [8]. Transient stability margin is improved with neuro-fuzzy controller for GUPFC device by damping out transient oscillations and is implemented in [9]. The superiority of GUPFC over M-UPFC for enhancing voltage profile and improving power flow is observed in [10]. The power quality improvement in terms of reducing total harmonic distortion level with a 72-pulse VSC based GUPFC is presented in [10]. The demand-side congestion cost is increased if more number of lines in a transmission system are congested and this cost estimated with and without GUPFC device and observed the cost reduction with GUPFC optimal placement [11]. The stability of a multi-machine system is determined with GUPFC device. The parameters of GUPFC are provided by flower pollination algorithm and controlled by two-stage lead-lag controller [12]. The on-load tap changer (OLTC) cannot be applicable for long radial feeders in distribution network toward voltage regulation. This problem is solved with a hybrid power compensation method D-GUPFC and is presented in [13]. The optimal reactive power dispatch (ORPD), the available transfer capacity, is enhanced by controlling the parameters of GUPFC using PSO algorithm [14]. The GUPFC optimal location is determined based on voltage variations to minimize total transmission loss and is presented in [15].

A similar device, PST, is the series-connected FACTS device used to control the power flow in the line. It consists of an exciting transformer, an injecting transformer and mechanical switches. The switches are used to change the turn's ratio of the transformer [16]. The combination of UPFC and a conventional PST is called as OUPFC which is the more cost-effective device in comparison with the standalone UPFC of same rating. An OPF with fuel cost and real power loss is formulated, and it is solved in MATLAB and General Algebraic Modeling System (GAMS) software environment by using OUPFC is proposed in [17]. A multi-objective function in terms of real power loss and voltage stability limit is solved by UPFC and OUPFC with firefly algorithm, and the superiority of OUPFC is observed [18]. The generation cost and transmission loss cost are reduced with OUPFC in [19] whose parameters are optimized by using genetic algorithm [20]. Voltage stability is improved in [21] under contingency conditions with OUPFC and HICA-PS algorithm. \((n−1)\) Line contingency analysis is performed to increase the
loadability with OUPFC device and is presented in [22]. The economic operation is performed in power systems to analyze the effect of OUPFC under weather changing conditions as well as variable loading conditions [23]. Transmission system security is enhanced under single line contingency conditions with OUPFC device under different renewable energy generations and is proposed in [24].

In light of the reviewed works, we claim that the following are the major contributions of this paper.

1. For the first time, a novel and advanced FACTS device, namely GOUPFC and its steady-state modeling, is introduced.
2. Besides, the optimal location and sizing of GOUPFC are determined using a novel hybrid approach WO-BAT.
3. In order to improve the exploitation features of WOA, a predefined search space for locations is defined using line collapse proximity indicator (LCPI) and its convergence features are improved using BAT algorithm.
4. The impact of GOUPFC is analyzed on IEEE 57-bus system considering line contingencies and renewable energy uncertainty.

Methods

It is possible to extend the voltage and power flow control beyond what can be achievable with the OUPFC by using a new configuration called as generalized optimal unified power flow controller (GOUPFC). To the best of our knowledge, no research work has been developed in the area of GOUPFC power injection modeling and its application to achieve the optimal operation of the power system. Firstly, the power injection modeling of GOUPFC device is presented by considering switching losses, and then, the optimal location is determined based on LCPI index. The control parameters of GOUPFC device are optimized with WO-BAT, WOA and BAT algorithms. Besides, the performance of GOUPFC is investigated under single line contingencies and with support of various renewable penetrations for standard IEEE-57 test system to minimize the objective function formulated in terms of AVDI, P\text{loss}, and LCPI\text{avg} and to enhance voltage profile.

This paper is organized in the following sections. Section 3 describes the operating principle of GOUPFC. Section 4 presents the mathematical modeling of GOUPFC. Section 5 presents the overall objective function formulation. Section 6 presents WO-BAT algorithm description, and Sect. 7 presents the determination of GOUPFC optimal location and the analytical results evaluated from different case studies.

Operating principle of GOUPFC

The transmission system security in the multi-lines can be enhanced by including another OUPFC in different line is not a cost-effective solution instead going for the new device named GOUPFC which is the best choice. The single line diagram of GOUPFC is shown in Fig. 1. It consists of one exciting transformer with four windings such as one primary winding and three secondary windings named as secondary, tertiary and quaternary and two triple winding injecting transformers each with one primary and two secondaries named as secondary and tertiary. The PST in one line is coupled to the two
secondary windings of the exciting and injecting transformers, and the PST in the other line is connected to the quaternary and secondary windings of the exciting and injecting transformer, respectively. One of the three converters is connected in shunt with a bus, and the remaining two converters are connected in series with two different transmission lines through the tertiary winding of the exciting and injecting transformers. The overall configuration of GOUPFC can control the total six control parameters which includes the controllable voltage magnitude and phase angles at bus-\(i\) and \(j\)-independent real and reactive power flows in the two lines. Figure 1 shows the two transmission lines \(i-j\) and \(i-k\) is connected with GOUPFC at buses \(j\) and \(k\), respectively.

The series converter and PST will inject a controllable voltage magnitude and phase in series into the lines through injecting transformers. The shunt converter can control (1) supply or absorb the real power needed by the series converter; (2) exchange the controllable reactive power with line; and (3) regulate the dc link voltage.

**Mathematical modeling of GOUPFC**

A GOUPFC can be represented by three controllable voltage source converters, and two-phase shifting transformers connected in two transmission lines is shown in Fig. 2.
The series converter controllable voltages and PST voltages are given by,

\[
\begin{align*}
V_{\text{seq}} &= r_1 V_i e^{j\gamma_1}; \quad V_{\sigma_1} = k_1 V_i e^{j\sigma_1}; \\
V_{\text{seq}} &= r_2 V_i e^{j\gamma_2}; \quad V_{\sigma_2} = k_2 V_i e^{j\sigma_2}
\end{align*}
\]

where \(r_1, r_2\) and \(k_1, k_2\) are the per unit voltage magnitudes of two series converters and two PSTs, respectively; \(\gamma_1\) and \(\gamma_2\) are the phase angles of series converters; \(\sigma_1\) and \(\sigma_2\) are the PST phase angles; and \(V_i\) is the bus-\(i\) voltage. The voltages and phase angles are operating in the limits specified as follows.

\[
\begin{align*}
& r_{\text{min}} \leq r \leq r_{\text{max}}, \quad k_{\text{min}} \leq k \leq k_{\text{max}} \\
& \gamma_{\text{min}} \leq \gamma \leq \gamma_{\text{max}}, \quad \sigma_{\text{min}} \leq \sigma \leq \sigma_{\text{max}}
\end{align*}
\]

GOUPFC having three voltage source converters among those one is shunt converter, and the remaining two are series converters. Shunt converter is placed at bus-\(I\), and the two series converters are placed in the lines \(i-j\) and \(i-k\), respectively. In addition to the voltage source converters, GOUPFC employing two separate PSTs which are incorporated in the two separate lines where the two series converters are placed. The total voltages injected in the two lines are the phasor sum of the voltages obtained from the series converters and PSTs, and these are given by,

\[
\begin{align*}
V_{\text{inj}_1} &= V_{\text{seq}} + V_{\sigma_1}; \quad V_{\text{inj}_2} = V_{\text{seq}} + V_{\sigma_2}
\end{align*}
\]

The GOUPFC is modeled in series-connected and shunt-connected voltage source models. The voltages in the two transmission lines behind the line reactance can be written mathematically as,

\[
\begin{align*}
\overline{V}_{ij} &= \overline{V}_{\text{inj}_1} + \overline{V}_i; \quad \overline{V}_{ik} = \overline{V}_{\text{inj}_2} + \overline{V}_i
\end{align*}
\]

**Series-connected voltage source model**

The series-connected voltage source model of GOUPFC with three buses \(i, j,\) and \(k\) is shown in Fig. 2a, and the corresponding Norton’s equivalent current source model is shown in Fig. 2b. Let the currents flowing in the two lines \(i-j\) and \(i-k\) are \(I_{\text{seq}_1}\) and \(I_{\text{seq}_2}\), respectively, are given by

\[
\begin{align*}
I_{\text{seq}_1} &= \frac{V_{\text{inj}_1}}{jX_{\text{seq}_1}} = -jB_{\text{seq}_1} V_{\text{inj}_1} = -B_{\text{seq}_1} V_i (r_1 e^{(90+\gamma_1+i\theta_i)} + k_1 e^{(90+\sigma_1+i\theta_i)}) \\
I_{\text{seq}_2} &= \frac{V_{\text{inj}_2}}{jX_{\text{seq}_2}} = -jB_{\text{seq}_2} V_{\text{inj}_2} = -B_{\text{seq}_2} V_i (r_2 e^{(90+\gamma_2+i\theta_i)} + k_2 e^{(90+\sigma_2+i\theta_i)})
\end{align*}
\]

where \(X_{\text{seq}_1}\) and \(X_{\text{seq}_2}\) are the line reactances of the two lines and their corresponding susceptances, respectively, given by, \(B_{\text{seq}_1} = 1/X_{\text{seq}_1}\) and \(B_{\text{seq}_2} = 1/X_{\text{seq}_2}\).

The independent complex power injections of GOUPFC at buses \(i, j,\) and \(k\) are given as,

\[
\begin{align*}
\overline{S}_{\text{seq}_1} &= -V_i (I_{\text{seq}_1})^* - V_i (I_{\text{seq}_1})^* \\
\overline{S}_{\text{seq}_2} &= -V_i^2 B_{\text{seq}_1} (r_1 e^{-(90+\gamma_1)} + k_1 e^{-(90+\sigma_1)}) - V_i^2 B_{\text{seq}_2} (r_2 e^{-(90+\gamma_2)} + k_2 e^{-(90+\sigma_2)})
\end{align*}
\]
Let $\theta_{ij} = \theta_i - \theta_j$; $\theta_{ik} = \theta_i - \theta_k$. By using Euler's and trigonometric identities, the real and reactive power injections at the buses $i$, $j$ and $k$ are calculated as follows.

\begin{align*}
P_{i\text{se}} &= -V_i^2 B_{se1}(r_1 \sin(\gamma_1) + k_1 \sin(\sigma_1)) - V_i^2 B_{se2}(r_2 \sin(\gamma_2) + k_2 \sin(\sigma_2)) \\
Q_{i\text{se}} &= -V_i^2 B_{se1}(r_1 \cos(\gamma_1) + k_1 \cos(\sigma_1)) - V_i^2 B_{se2}(r_2 \cos(\gamma_2) + k_2 \cos(\sigma_2)) \\
P_{j\text{se}} &= V_i V_j B_{se1}(r_1 \sin(\gamma_1 + \theta_{ij}) + k_1 \sin(\sigma_1 + \theta_{ij})) \\
Q_{j\text{se}} &= V_i V_j B_{se1}(r_1 \cos(\gamma_1 + \theta_{ij}) + k_1 \cos(\sigma_1 + \theta_{ij})) \\
P_{k\text{se}} &= V_i V_k B_{se2}(r_2 \sin(\gamma_2 + \theta_{ik}) + k_2 \sin(\sigma_2 + \theta_{ik})) \\
Q_{k\text{se}} &= V_i V_k B_{se2}(r_2 \cos(\gamma_2 + \theta_{ik}) + k_2 \cos(\sigma_2 + \theta_{ik}))
\end{align*}

The equivalent power injection modeling for the series-connected voltage source model is shown in Fig. 3a. The amount of complex power supplied by the combination of series converter and PST in the individual lines is derived as follows

\begin{align*}
\bar{S}_{se1} &= P_{se1} + j Q_{se1} = V_{i\text{ij}} (I_{ij})^* \\
\bar{S}_{se1} &= j B_{se1} V_i \left( r_1 e^{j(\gamma_1 + \theta_i)} + k_1 e^{j(\sigma_1 + \theta_i)} \right) \left( V'_{ij} - V_j \right)^* \\
\bar{S}_{se2} &= P_{se2} + j Q_{se2} = V_{i\text{ik}} (I_{ik})^* \\
\bar{S}_{se2} &= j B_{se2} V_i \left( r_2 e^{j(\gamma_2 + \theta_i)} + k_2 e^{j(\sigma_2 + \theta_i)} \right) \left( V'_{ik} - V_k \right)^* 
\end{align*}

The real and reactive powers supplied by the two converters in the two transmission lines are given by,
\[ P_{se1} = -r_1 B_{se1} V_i^2 \sin (\gamma_1) - k_1 B_{se1} V_i^2 \sin (\sigma_1) + r_1 B_{se1} V_i V_j \sin (\gamma_1 + \theta_{ij}) + k_1 B_{se1} V_i V_j \sin (\sigma_1 + \theta_{ij}) \] (14)
\[ Q_{se1} = B_{se1} V_i^2 \left( r_1^2 + k_1^2 \right) + 2r_1 k_1 B_{se1} V_i^2 \cos (\sigma_1 - \gamma_1) + r_1 B_{se1} V_i^2 \cos (\gamma_1) + k_1 B_{se1} V_i^2 \cos (\sigma_1) - r_1 B_{se1} V_i V_j \cos (\gamma_1 + \theta_{ij}) - k_1 B_{se1} V_i V_j \cos (\sigma_1 + \theta_{ij}) \] (15)
\[ P_{se2} = -r_2 B_{se2} V_i^2 \sin (\gamma_2) - k_2 B_{se2} V_i^2 \sin (\sigma_2) + r_2 B_{se2} V_i V_k \sin (\gamma_2 + \theta_{ik}) + k_2 B_{se2} V_i V_k \sin (\sigma_2 + \theta_{ik}) \] (16)
\[ Q_{se2} = B_{se2} V_i^2 \left( r_2^2 + k_2^2 \right) + 2r_2 k_2 B_{se2} V_i^2 \cos (\sigma_2 - \gamma_2) + r_2 B_{se2} V_i^2 \cos (\gamma_2) + k_2 B_{se2} V_i^2 \cos (\sigma_2) - r_2 B_{se2} V_i V_k \cos (\gamma_2 + \theta_{ik}) - k_2 B_{se2} V_i V_k \cos (\sigma_2 + \theta_{ik}) \] (17)

**Shunt-connected voltage source model**

The equivalent circuit for the shunt-connected voltage source model is shown in Fig. 3b. This model provides the equivalent power injections at the GOUPFC shunt bus to the two series branches through the converter and PST combination. The voltage at the sending end is controlled by the reactive power injection at the GOUPFC shunt converter. The amount of real power supplied by the shunt converter is equal to the real power consumed by the two series converters. Therefore, the real power inserted at the shunt converter is given by:

\[ P_{sh} = -(P_{se1} + P_{se2}) \]

\[ P_{sh} = r_1 B_{se1} V_i^2 \sin (\gamma_1) + k_1 B_{se1} V_i^2 \sin (\sigma_1) + r_2 B_{se2} V_i^2 \sin (\gamma_2) + k_2 B_{se2} V_i^2 \sin (\sigma_2) - r_1 B_{se1} V_i V_j \sin (\gamma_1 + \theta_{ij}) - k_1 B_{se1} V_i V_j \sin (\sigma_1 + \theta_{ij}) - r_2 B_{se2} V_i V_k \sin (\gamma_2 + \theta_{ik}) - k_2 B_{se2} V_i V_k \sin (\sigma_2 + \theta_{ik}) \] (18)

Let assume a constant reactive power injection \( Q_{sh} \) at bus-\( i \) and the apparent power injection at the shunt bus-\( i \) is given as

\[ S_{sh} = P_{sh} + jQ_{sh} \]

**Final GOUPFC modeling**

The final PIM of GOUPFC is achieved by summing up the equations obtained in series- and shunt-connected models. The corresponding equivalent circuit representing GOUPFC power injection is shown in Fig. 4. The resultant real and reactive power equations at the GOUPFC buses are given as

\[ P_{goupfc} = P_{sei} + P_{sh} \]
An OPF-based multi-objective function is formulated to minimize the overall objective function (OOF) is given as,

\[ \text{OOF} = w_1 f_1 + w_2 f_2 + w_3 f_3 \]  

where \( w_1, w_2 \) and \( w_3 \) are the weighing factors considered as one. \( f_1, f_2 \) and \( f_3 \) are the AVDI, \( P_{\text{loss}} \) and average LCPI, respectively.

**Average voltage deviation index (AVDI)**

The voltage profile of the test system subjected to contingency condition is evaluated in terms of stability index called AVDI. It is given as [23],
where $\left| V_{i,ref} \right|$ is the reference voltage at bus-$i$, $\left| V_i \right|$ is the voltage at bus-$i$ under contingencies and nb is the number of load buses.

In specific, AVDI is used to explain the average voltage deviation of the entire network in comparison with the reference bus voltage (i.e., maximum of all bus voltages). Under each contingency, the voltage profile may change, and thus, there is a change in AVDI. The more AVDI means, more voltage imbalance in the network.

**Real power loss ($P_{loss}$)**
The real power loss is given mathematically as,

$$f_2 = P_{loss} = \sum_{k=1}^{nl} I_k^2 r_k$$

$$f_2 = \sum_{i=1}^{nb} \sum_{j=1}^{nb} \left\{ Y_{ii} \cos \theta_{ii} \left[ V_i^2 + V_j^2 - 2V_iV_j \cos (\delta_i - \delta_j) \right] \right\}$$

where nb is no. of buses; nl is no. of lines; $k$ is the line number; $r_k$ and $I_k$ are the resistance of line $k$ and current through it, respectively; $Y_{ii}$ and $\theta_{ij}$ are the shunt admittance at bus $i$ and its angle, respectively; $V_i$ and $\delta_i$ are the voltage magnitude and its angle at bus-$i$, respectively; $V_j$ and $\delta_j$ are the voltage and its angle at bus-$j$, respectively.

**Line collapse proximity index (LCPI)**
The error in evaluating the voltage stability due to neglecting the line charging reactance and the magnitude and relative directions of active and reactive power can be overcome by considering an index called LCPI [25]. LCPI is given as,

$$f_3 = \text{LCPI} = \frac{4A \cos (\alpha) \left( P_j B \cos (\beta) + Q_j B \sin (\beta) \right)}{(V_i \cos (\delta))^2}$$

where $A$ and $B$ are network parameters magnitude; $\alpha$ and $\beta$ are the phases of $A$ and $B$, respectively; and $V_i$ is the sending end voltage.$P_j$ and $Q_j$ are the real and reactive power flow; for a line, LCPI should always less than 1 failing leads to instability.

**Constraints**
The OOF expressed in Eq. (25) is subjected to various equality and inequality constraints [21] as given below.

**Equality constraints**
The active and reactive power balance equations are the equality constraints that can be expressed, for all the buses expect FACTS incident buses, as
The active and reactive power balance equations at the FACTS incident buses are given as,

\[ P_i = P_{gi} - P_{di(t)} = \sum_{k=1}^{nb} |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k), \quad \forall i \in 1, 2, \ldots, nb \] (26)

\[ Q_i = Q_{gi} - Q_{di(t)} = \sum_{k=1}^{nb} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k), \quad \forall i \in 1, 2, \ldots, nb \] (27)

The inequality constraints considered for optimization problem are given as follows.

\[ P_{gi,r} \leq P_{gi,r} \leq P_{gi,r}^{\max} \quad \forall i \in ng, \] (30)

\[ Q_{gi,r}^{\min} \leq Q_{gi,r} \leq Q_{gi,r}^{\max} \quad \forall i \in ng, \] (31)

\[ |V_i^{\min}| \leq |V_i| \leq |V_i^{\max}| \quad \forall i \in nb, \] (32)

\[ \delta_i^{\min} \leq \delta_i \leq \delta_i^{\max} \quad \forall i \in nb, \] (33)

\[ a_i^{\min} \leq a_i \leq a_i^{\max} \quad \forall i = ntcl, \] (34)

\[ Q_{c,inj,i}^{\min} \leq Q_{c,inj,i} \leq Q_{c,inj,i}^{\max} \quad \forall i = nvcb, \] (35)

\[ |S_l| \leq |S_l^{\max}| \quad \forall l = nl, \] (36)

**WO-BAT algorithm**

In this paper, the control parameters of GOUPFC device are optimized with the hybrid algorithm WO-BAT. The detailed description about WO-BAT is described as follows.
Whale optimization algorithm

The exploitation and exploration are the two stages involved in WOA [26]. In exploitation stage, surrounding prey and spiral updation of the position vector are modeled. This method is called bubble net attacking (BNA) method [27]. Random searching of prey is performed in exploitation stage. After identifying the position of prey, humpback whales surround them. Initially, the optimal location of prey in the search space is not defined. Therefore, this algorithm considers the present solution which is the optimal prey and the other search delegates (agents) will drifted toward the best search delegates. This can be expressed mathematically as,

\[
\overrightarrow{P}(t+1) = \overrightarrow{P}^*(t) - \overrightarrow{C_1} \cdot \overrightarrow{D}
\]

(37)

where \(\overrightarrow{P}^*(t)\) is the best location of whale at \(t\)th iteration; \(\overrightarrow{P}(t + 1)\) is the present position of whale; \(\overrightarrow{D}\) is a vector indicates the distance between whale and prey; the coefficient vectors \(\overrightarrow{C_1}\) and \(\overrightarrow{C_2}\) are calculated as follows,

\[
\overrightarrow{C_1} = 2 \cdot \overrightarrow{i} \cdot \overrightarrow{r} + \overrightarrow{i}; \quad \overrightarrow{C_2} = 2 \cdot \overrightarrow{r}
\]

(39)

The range of vector \(\overrightarrow{C_1}\) is \((-i,i)\) where \(i\) value is shrinking from 2 to 0 through iterations. The new position of search delegate is determined by choosing the random value for \(\overrightarrow{C_1}\) in the interval \((-1,1)\).

Consider whale and prey are located at \((P, Q)\) and \((P^*, Q^*)\). The equation for position between whale and prey gives a helix-shaped movement of whale, and it is given as:

\[
\overrightarrow{P}(t + 1) = e^{ck} \cdot \cos(2\pi k) \cdot \overrightarrow{D}^* + \overrightarrow{P}^*(t);
\]

(40)

\[
\overrightarrow{D}^* = \left| \overrightarrow{P}^*(t) - \overrightarrow{P}(t) \right|
\]

(41)

where \(c\) is a constant which recognize the logarithmic spiral shape and \(k\) is a random number in the range \([-1,1)\).

Therefore, the final position vector equation w.r.t. a reference number \(n (0, 1)\) is represented as,

\[
\overrightarrow{P}(t+1) = \begin{cases} 
\overrightarrow{P}^*(t) - \overrightarrow{C_1} \cdot \overrightarrow{D}, & \text{if } n < 0.5 \\
e^{ck} \cdot \cos(2\pi k) \cdot \overrightarrow{D}^* + \overrightarrow{P}^*(t), & \text{if } n \geq 0.5 
\end{cases}
\]

(42)

In the exploration stage, to compel the search delegates to move far away from the local whale, the coefficient vector \(\overrightarrow{C_1}\) is used to generate random values less or greater than one. The location of delegates is identified based on this random selection rather than the best search delegate. This gives the global solution by overcoming the location solution. This can be given mathematically,

\[
\overrightarrow{P}(t + 1) = \overrightarrow{P}_{\text{rand}} - \overrightarrow{C_1} \cdot \overrightarrow{D}
\]

(43)
where $\vec{P}_{\text{rand}}$ is the random position vector.

**Bat algorithm**

Bats are the creatures with echo-location abilities. They create a loud sound pulse and receive the echo from the neighboring objects. They can guess the position of the neighboring object by using the time delay of echo sound. They measure the shape and the direction of object by sound pulse comparative amplitude analysis received at the ear. They investigate and simplify the data collected and figured out an image in brain to identify the neighboring object. The concept of bat algorithm (BA) and its mathematical modeling is provided in [28].

To determine the location of prey, bats fly randomly in the search space with a velocity $v_i$. Later, they change their positions ($x_i$) with constant frequency ($f_{\text{min}}$), different wavelengths ($\beta$) and loudness $A_0$. The new solutions for position and velocity are given mathematically as,

$$f_i = f_{\text{min}} + (f_{\text{max}} - f_{\text{min}}) \cdot \beta,$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*) \cdot f_i,$$

$$x_i^t = x_i^{t-1} + v_i^t,$$

where $\beta$ is a random number obtained by uniform distribution in the range [0, 1]. $x^*$ is the present global best; the minimum and maximum frequency limits ($f_{\text{min}}$ and $f_{\text{max}}$) are taken 0 and 100, respectively.

**WO-BAT algorithm**

The major limitation of WOA is its convergence speed in obtaining global solution. However, this can be overcome by embedding BAT algorithm partially to WOA to increase the exploration. In this hybrid algorithm, the global position is updated based on condition technique, which means if the present solution is better than the old solution, then the old one can be replaced with the present solution. The detailed flowchart for this hybrid algorithm is shown in Fig. 5.

**Results and discussions**

The performance of GOUPFC device is analyzed under single line contingencies, and an OPF-based objective function is solved by using WO-BAT, WOA and BAT algorithms under the different RES penetrations. The test system data are taken from [29]. In comparison with earlier works [23, 24], this work is focused on the development of mathematical modeling for the novel GOUPFC and its location and parameters.
optimization using novel hybrid approach WO-BAT in this work. The type of RES considered in this work is photovoltaic system, and its mathematical modeling is adapted from Ref. [23]. The simulations are carries under five different cases:
Case 1: Performance of GOUPFC under one line contingency condition and with the support of RES penetrations.
Case 2: One line contingency without GOUPFC as well as RES penetrations.
Case 3: One line contingency only with GOUPFC.
Case 4: One line contingency with GOUPFC and 30% RES penetrations.
Case 5: One line contingency with GOUPFC and 50% RES penetrations.

Optimal location of GOUPFC
Under base case conditions (i.e., no GOUPFC device and no RES), LCPI is calculated for all the lines of IEEE-57 test system and arranged in descending order as shown in Table 1. The top 5 ranked locations are only shown here after excluding the lines incident to generator and tap setting transformer. From Table 1, the two lines 38–49 (#78) and 37–38 (#50) are chosen for the placement of GOUPFC device. The shunt converter is placed at the bus#38 which is the common bus to the two line and the two series converters are placed in the two lines.

IEEE-57 bus description
IEEE-57 bus test system has 7 PV buses (i.e., 1, 2, 3, 6, 8, 9 and 12) and 50 PQ buses interconnected by 80 transmission lines. It has real and reactive power loads, respectively,
1250.8 MW and 336.4 MVAr. To maintain the continuity of supply, the lines 32–33 (#45) and 35–36 (#48) are not considered for contingency analysis. By excluding these two lines from 80 lines, the contingency analysis is performed on the remaining 78 lines and the results are demonstrated here.

In case 1, the GOUPFC is tested under normal conditions considering different RES penetrations. The device parameters are optimized with the three algorithms, and the objective function values are shown in Fig. 6. From this figure, under no contingency conditions, GOUPFC along with 50% RES penetration level gives minimum OOF value for WO-BAT algorithm. In other words, as RES penetration increases the net effective loading on the system decreases. Thus, the OOF is decreased. However, by having GUPUF controls, it is further decreases. The optimal controls derived with WO-BAT are caused to improve the system performance than basic WOA and BAT, significantly.

In case 2, the system is suffering with single line contingency and there is no support from GOUPFC device and RES generation. Under these conditions, the performance indices and OOF for no contingency and one line contingency are presented in Table 2. The system has real power loss and LCPI value with no contingency 27.8638 MW and 0.081, respectively, and the objective function value 27.9448. A contingency analysis is performed on the system without GOUPFC and RES, and the indices for the top ranked line 54–55 (#70) are as follows: $P_{loss} = 29.7828$, ALCPI = 0.0860 and OOF = 29.8688. The individual objective functions and OOF values for the remaining lines are presented in Table 2.

In case 3, the integration of GOUPFC without RES is analysed under one line contingencies. The parameters of the GOUPFC device are optimized WO-BAT, WOA and BAT algorithms, and the results are demonstrated in Table 3. When there is no outage the real power loss is decreased to 22.9129 MW which is 17.77% decrement with reference to case 1. Under single line 54–55 (#70) contingency also GOUPFC has shown its superiority in terms of losses and LCPI value. The indices in one line contingency are $P_{loss} = 25.1792$, ALSI = 0.0467, ALCPI = 0.0747 and OOF = 25.2539. Here, the real power loss and OOF have been reduced to 34.18% and 51.83%, respectively, with reference to case 1. The LCPI and OOF values for other lines are presented in Table 3.

| Line contingency | AVDI | $P_{loss}$ (MW) | LCPIavg | OOF |
|------------------|------|----------------|---------|-----|
| –                | 0.0122 | 27.8638 | 0.0810 | 27.957 |
| 54–55            | 0.0169 | 31.6620 | 0.0936 | 31.773 |
| 30–31            | 0.0135 | 29.7828 | 0.0860 | 29.882 |
| 37–38            | 0.0140 | 28.5135 | 0.0853 | 28.613 |
| 53–54            | 0.0125 | 27.7525 | 0.0825 | 27.848 |
| 50–51            | 0.0134 | 28.1352 | 0.0846 | 28.233 |
| 46–47            | 0.0155 | 30.1610 | 0.0878 | 30.264 |
| 41–42            | 0.0124 | 27.9146 | 0.0820 | 28.009 |
| 18–19            | 0.0127 | 28.6013 | 0.0837 | 28.698 |
| 25–30            | 0.0129 | 28.1856 | 0.0816 | 28.280 |
| 38–48            | 0.0238 | 31.3219 | 0.1093 | 31.455 |
| Line contingency | AVD | PLOSS | LCPI<sub>avg</sub> | OOF |
|------------------|-----|-------|-------------------|-----|
|                  | BAT | WOA   | WO-BAT            | BAT | WOA   | WO-BAT | BAT | WOA   | WO-BAT | BAT | WOA   | WO-BAT |
|                  | 0.0095 | 0.0080 | 0.0037 | 25.7411 | 24.0541 | 22.9129 | 0.0795 | 0.0774 | 0.0656 | 25.8301 | 24.1395 | 22.9822 |
| 38–49            | 0.0091 | 0.0083 | 0.0056 | 25.7131 | 25.5613 | 24.8907 | 0.0783 | 0.0718 | 0.0699 | 25.8005 | 25.6414 | 24.9662 |
| 54–55            | 0.0124 | 0.0094 | 0.0051 | 26.6459 | 25.6800 | 25.1792 | 0.0867 | 0.0761 | 0.0747 | 26.745 | 25.7655 | 25.259 |
| 30–31            | 0.0112 | 0.0101 | 0.0073 | 25.8862 | 25.8124 | 25.4048 | 0.0790 | 0.0767 | 0.0736 | 25.9764 | 25.8992 | 25.4857 |
| 37–38            | 0.0265 | 0.0218 | 0.0200 | 29.8423 | 28.8470 | 28.2986 | 0.1097 | 0.1042 | 0.0997 | 29.9785 | 28.973 | 28.4183 |
| 53–54            | 0.0092 | 0.0087 | 0.0070 | 26.1754 | 25.9726 | 25.9248 | 0.0748 | 0.0743 | 0.0722 | 26.2594 | 26.0556 | 26.004 |
| 50–51            | 0.0093 | 0.0084 | 0.0077 | 25.6284 | 25.5713 | 25.2467 | 0.0770 | 0.0750 | 0.0688 | 25.7147 | 25.6547 | 25.3232 |
| 46–47            | 0.0111 | 0.0097 | 0.0064 | 28.0277 | 26.8253 | 26.1605 | 0.0837 | 0.0812 | 0.0714 | 28.1225 | 26.9162 | 26.2383 |
| 41–42            | 0.0112 | 0.0059 | 0.0059 | 26.6106 | 26.2942 | 25.3860 | 0.0870 | 0.0741 | 0.0690 | 26.7088 | 26.3742 | 25.4609 |
| 18–19            | 0.0128 | 0.0106 | 0.0081 | 25.9255 | 24.9389 | 24.8706 | 0.0776 | 0.0776 | 0.0774 | 26.0159 | 25.0271 | 24.9561 |
| 25–30            | 0.0114 | 0.0101 | 0.0046 | 29.0998 | 28.3871 | 27.1199 | 0.0762 | 0.0747 | 0.0629 | 29.1874 | 28.4719 | 27.1874 |

Table 3 GOUPFC under single line contingency conditions without RES
performance of GOUPFC under one line contingency at without RES for three algorithms is shown in Fig. 7.

In case 4, GOUPFC and 30% power penetration are together considered for the contingency. Here, the RES installed capacity is 30% of the real power load, i.e., $1250.8 \times 0.3 = 375.24$ MW. Therefore, the remaining load on the CE sources is $875.56$ MW. Due to the integration of GOUPFC and RES into the system, the line flows and hence transmission losses are reduced under without and with line contingency conditions. The performance indices are evaluated for the both the conditions, and the losses are reduced by 37.57% and 34.18%, respectively. The optimized OOF values by WO-BAT algorithm are 17.4563 and 19.6639, respectively, for without and with line (54–55) contingency conditions. The individual objective functions and OOF for the remaining line contingencies are presented in Table 4. The performance of GOUPFC under single line contingency with0.3 penetrations is shown in Fig. 8.

In case 5, the RES generation is enhanced to 50% and the support of GOUPFC device is still present. Here the RES installed capacity is 50% of the real power load, i.e., $1250.8 \times 0.5 = 625.4$ MW. Hence the remaining load on the CE sources is to be 625.4 MW. The control variables of GOUPFC device are optimized with three algorithms, and the results of WO-BAT are demonstrated here due to its superiority. Under no contingency condition, the performance indices with WO-BAT algorithm are $P_{loss}=14.1166$, $ALCPI=0.0566$ and the OOF = 14.2489. Here, the power loss and OOF are diminished by 49.34% and 96.90%, respectively, with respect to case 1. Under contingency conditions, the line 54–55 (#70) with performance indices as $P_{loss}=15.2089$, $ALCPI=0.0506$ and the OOF = 15.3261. Here also the combination of GOUPFC and 50% RES penetration level reduces the real power losses and OOF by 48.93% and 95.64%, respectively, with respect to case 1. The $P_{loss}, LCI_{avg}$ Values and the corresponding OOF for the remaining line outages are presented in Table 5. The performance of GOUPFC under single line contingency with0.5 penetrations is shown in Fig. 9.
| Line contingency | AVD | WOA | WO-BAT | PLOSS | AVD | WOA | WO-BAT | LCPI<sub>avg</sub> | AVD | WOA | WO-BAT | OOF | AVD | WOA | WO-BAT |
|------------------|-----|-----|--------|--------|-----|-----|--------|----------------|-----|-----|--------|-----|-----|-----|--------|
|                  | BAT | WOA | WO-BAT | BAT | WOA | WO-BAT | BAT | WOA | WO-BAT | BAT | WOA | WO-BAT | BAT | WOA | WO-BAT |
| –                | 0.0075 | 0.0048 | 0.0028 | 20.8213 | 15.170 | 17.3955 | 0.0630 | 0.0608 | 0.0579 | 20.8918 | 18.9278 | 17.4562 |
| 38–49            | 0.0089 | 0.0079 | 0.0072 | 20.5125 | 14.410 | 18.0192 | 0.0730 | 0.0626 | 0.0583 | 20.5944 | 19.2026 | 18.0847 |
| 54–55            | 0.0099 | 0.0057 | 0.0049 | 20.8914 | 14.741 | 19.6030 | 0.0629 | 0.0614 | 0.0609 | 20.9642 | 20.4793 | 19.6688 |
| 30–31            | 0.0110 | 0.0081 | 0.0056 | 20.3284 | 14.540 | 18.2443 | 0.0755 | 0.0697 | 0.0639 | 20.4149 | 19.8867 | 18.3138 |
| 37–38            | 0.0155 | 0.0118 | 0.0105 | 20.7261 | 14.112 | 18.7019 | 0.0896 | 0.0822 | 0.0789 | 20.8312 | 20.0659 | 18.7913 |
| 53–54            | 0.0056 | 0.0052 | 0.0043 | 21.2083 | 14.404 | 19.7277 | 0.0674 | 0.0602 | 0.0587 | 21.2813 | 20.5989 | 19.7907 |
| 50–51            | 0.0112 | 0.0063 | 0.0047 | 20.5972 | 14.707 | 16.3334 | 0.0723 | 0.0608 | 0.0595 | 20.6807 | 18.2805 | 16.3976 |
| 46–47            | 0.0072 | 0.0047 | 0.0046 | 20.1629 | 14.750 | 19.3329 | 0.0656 | 0.0636 | 0.0546 | 20.2357 | 19.7054 | 19.3921 |
| 41–42            | 0.0108 | 0.0101 | 0.0076 | 20.4827 | 14.829 | 19.2511 | 0.0763 | 0.0757 | 0.0656 | 20.5698 | 19.7114 | 19.3243 |
| 18–19            | 0.0121 | 0.0082 | 0.0034 | 20.5838 | 19.737 | 19.0443 | 0.0659 | 0.0655 | 0.0653 | 20.6618 | 19.0828 | 19.113 |
| 25–30            | 0.0122 | 0.0119 | 0.0081 | 20.9185 | 14.646 | 19.4162 | 0.0838 | 0.0760 | 0.0698 | 21.0145 | 20.1884 | 19.4941 |
The control parameters of GOUPFC device are UPFC voltages \((r_{1upfc}(\text{p.u}), r_{2upfc}(\text{p.u}))\) and UPFC phase angles \((\gamma_{1upfc}(\text{radians}), \gamma_{2upfc}(\text{radians}))\), PST ratios \((k_{1pst}(\text{p.u}), k_{2pst}(\text{p.u}))\) and PST angles \((\sigma_{1pst}(\text{radians}), \sigma_{2pst}(\text{radians}))\) for IEEE-57 bus system is optimized with WO-BAT algorithm and the corresponding parameters in case 5 is presented in Table 6. Furthermore, the comparison of convergence time for the three algorithms is given in Table 7. From this table, it can be observed that the hybrid WO-BAT algorithm is converged much faster than the individual WOA and BAT algorithms in all the case studies.

Figure 10 shows the voltage profile at all the buses of IEEE-57 bus under with and without contingency conditions for base case, only with GOUPFC device and due to the presence of both GOUPFC and 50% RES support. From this figure, it is clear that the voltage profile has been improved much with GOUPFC than base case and GOUPFC with RES support than only GOUPFC device present in the system. From the above, it is concluded that the proposed GOUPFC device can improve the voltage stability not only under normal conditions but also under single line contingencies.

As the methodology is implemented on Standard IEEE 57-bus test system, and a significant improvement is observed in all the cases, we believe that this methodology also works on other networks. However, the computational efficiency of any algorithm may not quantifiable only on limited search space with small test systems. Thus, there is a need for evaluating the performance of proposed methodology on larger test systems, which we can consider as our future research work.

**Conclusion**

The detailed power injection modeling of the proposed FACTS device GOUPFC is presented in this paper. The optimal location of GOUPFC device is determined based on LCPI value. The performance indices and OOF value have been evaluated for different
Table 5  GOUPFC under single line contingency conditions with 0.5 RES

| Line contingency | AVD  | PLOSS | LCPIavg | OOF  |
|------------------|------|-------|---------|------|
|                  | BAT  | WOA   | WO-BAT  | BAT  | WOA   | WO-BAT  | BAT  | WOA   | WO-BAT  |
| –                | 0.0085 | 0.0036 | 0.0031 | 16.1146 | 14.8872 | 14.1166 | 0.0616 | 0.0570 | 0.0566 | 16.1847 | 14.9478 | 14.1763 |
| 38–49            | 0.0095 | 0.0072 | 0.0015 | 16.9983 | 16.1851 | 15.8523 | 0.0613 | 0.0557 | 0.0541 | 17.0691 | 16.248 | 15.9079 |
| 54–55            | 0.0041 | 0.0034 | 0.0009 | 16.2212 | 15.8980 | 15.2089 | 0.0547 | 0.0538 | 0.0506 | 16.28 | 15.9552 | 15.2604 |
| 30–31            | 0.0070 | 0.0069 | 0.0025 | 16.3144 | 16.0271 | 15.8782 | 0.0596 | 0.0554 | 0.0545 | 16.381 | 16.0894 | 15.9352 |
| 37–38            | 0.0105 | 0.0071 | 0.0071 | 17.7621 | 16.3370 | 15.6785 | 0.0762 | 0.0719 | 0.0616 | 17.8488 | 16.416 | 15.7472 |
| 53–54            | 0.0112 | 0.0059 | 0.0025 | 15.8741 | 15.6070 | 15.3534 | 0.0665 | 0.0633 | 0.0504 | 15.9518 | 15.6762 | 15.4063 |
| 50–51            | 0.0111 | 0.0058 | 0.0050 | 16.9428 | 16.6313 | 16.0376 | 0.0589 | 0.0582 | 0.0573 | 17.0128 | 16.6953 | 16.0999 |
| 46–47            | 0.0101 | 0.0075 | 0.0025 | 17.6003 | 17.0271 | 15.4511 | 0.0653 | 0.0600 | 0.0597 | 17.6757 | 17.0946 | 15.5133 |
| 41–42            | 0.0091 | 0.0062 | 0.0021 | 17.7065 | 16.4015 | 15.3100 | 0.0624 | 0.0622 | 0.0533 | 17.778 | 16.4699 | 15.3654 |
| 18–19            | 0.0051 | 0.0028 | 0.0021 | 16.9446 | 15.8796 | 14.6927 | 0.0639 | 0.0499 | 0.0484 | 17.0136 | 15.9323 | 14.7432 |
| 25–30            | 0.0135 | 0.0129 | 0.0090 | 17.5112 | 16.8358 | 16.6044 | 0.0730 | 0.0647 | 0.0616 | 17.5977 | 16.9134 | 16.675 |
Table 6  Control parameters of GOUPFC under single line contingency and 0.5 RES

| Line contingency | WO-BAT | r1upfc (p.u) | r2upfc (p.u) | k1upfc (p.u) | k2upfc (p.u) | γ1upfc (rad) | γ2upfc (rad) | α1pst (rad) | α2pst (rad) |
|------------------|--------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| –                | 0.1510 | 0.1904       | 1.0382       | 0.9500       | –1.6280      | 1.1795       | –0.3053      | –0.3075      |
| 54–55            | 0.1951 | 0.0215       | 0.9962       | 1.0392       | –0.9752      | –2.2172      | 0.2221       | –0.5909      |
| 30–31            | 0.1631 | 0.0223       | 1.0079       | 0.9992       | –0.1561      | 3.1416       | –0.4217      | 0.7306       |
| 37–38            | 0.0339 | 0.0264       | 1.0388       | 1.0313       | –3.1416      | 0.8446       | 0.1943       | –0.2600      |
| 53–54            | 0.1612 | 0.1119       | 0.9833       | 0.9744       | –1.1170      | 0.1753       | –0.4000      | –0.5196      |
| 50–51            | 0.1748 | 0.1077       | 1.0236       | 1.0088       | 3.1416       | 2.1380       | 0.5163       | 0.6649       |
| 46–47            | 0.0450 | 0.0807       | 0.9590       | 1.0500       | 3.0767       | 1.2810       | –0.6290      | 0.3736       |
| 41–42            | 0.1224 | 0.1337       | 0.9802       | 0.9773       | –0.2878      | 1.6027       | 0.0049       | 0.7854       |
| 18–19            | 0.2000 | 0.0122       | 1.0500       | 1.0500       | –2.7006      | 1.4835       | 0.6210       | 0.3872       |
| 25–30            | 0.1520 | 0.0772       | 1.0261       | 1.0142       | –0.1200      | 2.0976       | 0.7243       | –0.4862      |
| 38–48            | 0.0795 | 0.1297       | 0.9630       | 1.0375       | –1.2780      | 1.9343       | –0.3627      | –0.6203      |

Table 7  Comparison convergence time (s) for three algorithms

| Line contingency | Convergence time (s) |
|------------------|----------------------|
|                 | BAT                  | WOA                  | WO-BAT               |
| –                | 16.864               | 14.091               | 11.170               |
| 38–49            | 17.196               | 14.573               | 13.410               |
| 54–55            | 17.471               | 15.884               | 13.741               |
| 30–31            | 18.716               | 16.467               | 12.540               |
| 37–38            | 17.823               | 15.482               | 11.112               |
| 53–54            | 17.485               | 16.214               | 12.404               |
| 50–51            | 17.514               | 16.605               | 10.707               |
| 46–47            | 17.962               | 15.322               | 13.750               |
| 41–42            | 18.921               | 16.529               | 13.829               |
| 18–19            | 18.837               | 17.815               | 12.737               |
| 25–30            | 16.653               | 15.044               | 11.646               |
case studies by considering GOUPFC device at different RES penetrations. The parameters of GOUPFC are optimized by using WO-BAT, WOA and BAT algorithms. With the combination of GOUPFC and increased RES penetrations the AVDI, losses, LCPI\textsubscript{avg} and OOF values are considerably reduced under no contingency conditions is observed in case 1. Under single line contingency conditions, without RES and GOUPFC, there is an increment in losses, LCPI index and reduced voltage profile is observed in case 2. All the performance indices and OOF value are significantly reduced with optimal placement of GOUPFC and additional support of RES penetrations 0%, 30% and 50% in the cases 3, 4 and 5, respectively. In addition, the voltage profile is also improved for the case GOUPFC with 50% RES level when compared to the other cases. From the simulation results, the hybrid algorithm WO-BAT is performed better than the individual algorithms such as WOA-BAT in minimizing AVDI, \( P_{\text{loss}} \), LCPI and OOF value. With the optimal location of GOUPFC, the overall system voltage profile is enhanced in IEEE-57 bus test system. Further, the impact the proposed device can be extended for large-scale systems in the real-time scenario by incorporating two or more GOUPFC devices at optimal locations which is considered as the future scope of the present work.

**Abbreviations**

| Abbreviation | Description                          |
|--------------|--------------------------------------|
| FACTS        | Flexible AC transmission systems     |
| OUPFC        | Optimal unified power flow controller|
| GOUPFC       | Generalized optimal unified power flow controller |
| WO-BAT       | Whale optimization-BAT               |
| LCPI         | Line collapse point indicator        |
| RES          | Renewable energy sources             |

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**Author contributions**

KVKK carried out the literature survey and participated in determining the modeling and optimal location of GOUPFC based on voltage collapse point indicator (LCPI). KVKK and KNVST participated in study on the different nature-inspired algorithms and among those WO-BAT, WOA and BAT algorithms are considered for this paper. KVKK and VJ carried the simulations under single line contingency conditions with the support of different RES penetrations and GOUPFC. KVKK, KNVST and VJ participated in the sequence of alignment and drafted the manuscript. All together read and approved the final manuscript.
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