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Location Optimization and Tuning of IPFC for Enhancing Power System Performance

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Abstract: This paper presents a new scheme for reducing the transmission line congestion based on optimized cuckoo search algorithm (OCSA). The performance of interline power flow controller (IPFC) can be increased in a great extent under multiline transmission system.An objective function is defined with bus voltage limit violation, active power loss reduction, security margin and maximizes the voltage stability margin.The multi objective function is tuned by OCSA for optimal placement of IPFC and enhances the power system performance. The simulationis carried out using MATLAB for two case studies using an IEEE 27-bus and IEEE57-bus test systems. The performance of OCSA hasbeen compared with two other optimization techniques such as particle swarm optimization (PSO) and genetic algorithm (GA) under different loading conditions. The result shows that theproposed OCSA outperforms the other two optimization techniques and it best suits for enhancing the performance of power system.

Key words: Optimizedcuckoo search algorithm · Interline power flow controller (IPFC) · Optimal location · Power system · Optimal tuning

INTRODUCTION

There is a huge increase in power transaction due to power system renovation and different factors such as environment, right-of-way and high cost, which forms hurdle in the expansion of power transmission network. With the advancement in flexible AC transmission system (FACTS), several innovative concepts are turning the system into more flexible and are having control over power flow without altering the generation schedule. Optimal location identification and allocation of FACT devices improve various parameters of the system [1, 2]. FACT is based on power electronics and other stationary tools which control one or more parameters of AC transmission system thereby increasing the power transfer capability and controllability [3]. IPFCis an extended version of unified power flow controller (UPFC) used to control multiline transmission system. The steady state performance of more than two AC systems is studied by Ceraand Vasquez [4]. The simulation result of IPFC shows that the power flow controlling is better than compensated transmission lines. IPFC is a voltage-sourced converter (VSC) based multiline transmission system which has a unique power flow management and controls technique among them. Three operating modes of IPFC with 12- pulse three-level converters using D-Q model has been studied by Padiyarand Nagesh[5]. A novel power injection model is introduced for IPFC and the control strategy can be achieved by adjusting the state variable of the network through IPFC state variable. The performance of the system has been verified using IEEE 57-bus and IEEE 300-bus test systems [6].

A particle swarm optimization (PSO) based algorithm is used to estimate exact location and sizing of unified power flow controller to perform congestion management. The impact of load variations, system

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reliability and congestion cost of the system has been studied [7]. Automatic human motion tracking based on PSO technique is proposed bySanjay *et al*. [8]. DC link voltage regulation in the IPFC configuration is an important issue and it affects the system performance. To regulate DC link voltage,the GA-based regulation method is presented by Fekri *et al.* [9]. An objective function is defined and the parameters are adaptively chosen tocontrolthe DC link of IPFC. A genetic algorithm approachbased multi-objective function is defined for multi-type FACTS devices for improving the performance of power system [10]. OCSA algorithm is the nature-inspired algorithm for optimization heuristics to solve difficult optimization problems. The obligatory brood parasitism with levy flight is a unique behavior of OCSA algorithm [11]. Comparison of several FACT devices using OCSAalgorithm for three unequal areas of thermal systems has been studied in [12]. Distributed network reconfiguration for power loss minimization, load frequency control, voltage profile improvement for the nonlinear interconnected power system using OCSAalgorithm has been studied [13, 14].

Optimal tuning is done to reduce power loss and which in turn leads to increase the performance of transmission line. The PSO requires large amounts of memory, which may limit its implementation in some applications and it may provide premature convergence. On the other hand, OCSA generates two solution sets through Levy flights and alignment of eggs. So we have chosen OCSA for location optimization and sizing of IPFC. The performance of OCSA has been compared with two other optimization techniques such as PSO and GA under IEEE 27-bus and IEEE 57-bus test system. The performance of proposed method is tested under three different loading conditions (80%, 100% and 110%). The remainder of this paper is organized as follows: section 2 describes the modeling of IPFC; section 3 describes the optimal location and sizing of IPFC, section 4 describes the proposed OCSA algorithm; section 5 explains the simulation results and discussion; and finally, the conclusion is discussed in section 6.

Model of IPFC: In this section, power injection model of IPFC is presented with a mathematical derivation. The multi-objective function is defined and tuned using OCSA for optimal location of IPFC and enhances the power system performance. The basic schematic of IPFC is shown in Fig. 1. It consists of at least two back-to-back DC-AC converters connected through a common DC link and the DC link between each VSC can be represented by

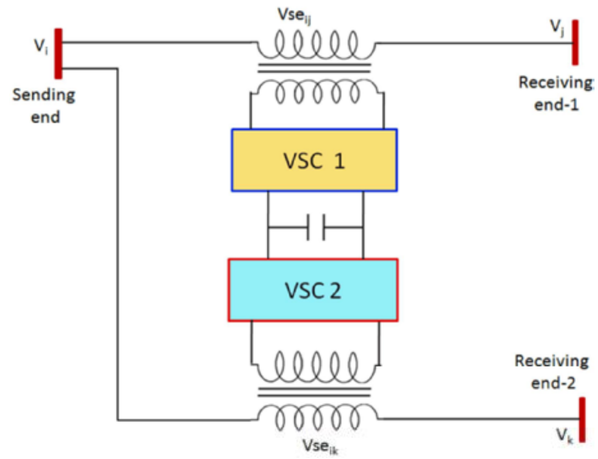

Fig. 1: Basic schematic of IPFC.

a bidirectional link, for exchanging active power between them [15, 16]. The bus i,j and k has the complex voltages V_i, V_j and V_k and the series compensation of series converter voltage, Vse_{in} is the controllable series injected voltage source which can be defined as $V_{se_{in}} = V_{se_{in}} \angle \theta_{se_{in}}$ (n=j, k). Fig. 1 consists of three buses i, j and k and two transmission lines are connected with a commoni^{th} bus. The equivalent circuit of IPFC using voltage source representation is shown in Fig. 2. It has two series injected voltages (Vse) and series with the transfer impedance Zse_{in} with controllable phase angle. From fig.2 the complex bus voltage magnitude and the complex voltage injected by the series converter can be expressed as:

$$\overline{V_m} = |V_m| \angle \beta_m; \quad \forall\ m = i,j,k \tag{1}$$

$$\overline{V_{se,\,in}} = CV_{in} \overline{V_i} e^{j\delta in}; \quad \forall\ n = j,k \tag{2}$$

where CV_{in} is the voltage magnitude of series connected transformer with the range $0 \le CV_{in} \le CV_{in}^{max}$ and the maximum value, CV_{in}^{max} is taken from 0.1° to 360°. δ_{in} is the phase angle of the series connected transformer with the range $0 \le \delta_{in} \le \delta_{in}^{max}$ and δ_{in}^{max} is also taken from 0.1° to 360°.

The complex power injected at the IPFC sending end $\left(\overline{C}_i^{IPFC}\right)$ and receiving end bus $\left(\overline{C}_n^{IPFC}\right)$ can be expressed as:

$$\overline{C}_i^{IPFC} = V_i^2 \left(T_{ij} B_{se,\,ij}\, e^{-j\left(90^o + \delta_{ij}\right)} + T_{ik} B_{se,\,ik}\, e^{-j\left(90^o + \delta_{ik}\right)} \right) \tag{3}$$

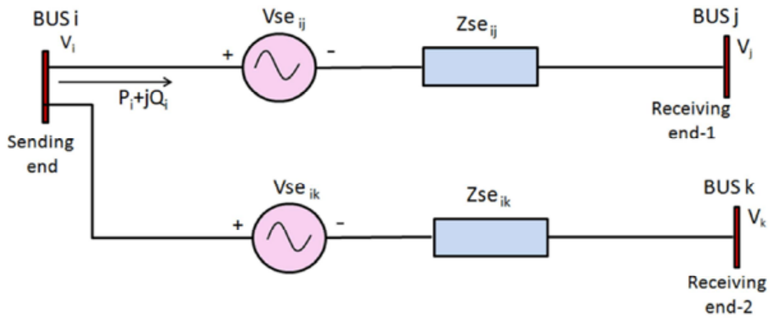

Fig. 2: Equivalent circuit model of IPFC.

$$\overline{C}_{\mathrm{n}}^{\mathrm{IPFC}} = -\mathrm{V_i}\left(\mathrm{V_n} T_{in} B_{se,\,\mathrm{in}}\, e^{-j\left(90^o+\delta_i-\right)} + T_{ik} B_{se,\,\mathrm{ik}}\, e^{-j\left(90^o+\beta_i-\beta_n+\delta_{in}\right)}\right) \quad (4)$$

Using the above equations, the real and reactive power injection at the relevant IPFC buses can be expressed as:

$$\mathrm{P_i^{IPFC}} = -\mathrm{V_i^2}\left(CV_{ij}B_{se,\,\mathrm{ij}}\ \sin\delta_{ij} + CV_{ik}B_{se,\,\mathrm{ik}}\ \sin\delta_{ik}\right) \quad (5)$$

$$\mathrm{Q_i^{IPFC}} = -\mathrm{V_i^2}\left(CV_{ij}B_{se,\,\mathrm{ij}}\ \cos\delta_{ij} + CV_{ik}B_{se,\,\mathrm{ik}}\ \cos\delta_{ik}\right) \quad (6)$$

$$\mathrm{P_n^{IPFC}} = \mathrm{V_j V_n} CV_{in}B_{se,\,\mathrm{in}}\ \sin(\beta_i-\beta_n-\delta_{in});\ \ \forall\ \mathrm{n = j, k} \quad (7)$$

$$\mathrm{Q_n^{IPFC}} = \mathrm{V_j V_n} CV_{in}B_{se,\,\mathrm{in}}\ \cos(\beta_i-\beta_n-\delta_{in});\ \ \forall\ \mathrm{n = j, k} \quad (8)$$

Optimal Sizing and Location of IPFC: The optimal sizing of IPFC minimizes load voltage variation (LVV), active power loss reduction and maximization of voltage stability margin (VSM).Identification of optimal location is essential to obtain maximum benefit from IPFC. Most of the power flow controlling techniques used in the transmission lines is varying the compensation using voltage source converter and they will not provide the balanced output. Optimal sizing is determined by formulating a multi-objective function.

Multi-Objective Function: This work focuses the main three objective functions that can be combined to form a multi-objective function. The multi-objective function can be described as:

$$\min F(x) = \min \sum_{a=1}^{3} f_a(x)\ w_a \quad (9)$$

where w_a is the weight factor of individual objective function, a=1,...,3. The weighting factor is used in the objective function to replicate its relative importance and all the individual weighting factors are considered equally.So that $w_1 + w_2 + w_3 = 1$.

Minimization of Load Voltage Variation: The first objective function is the reduction of load voltage variation (LVV). The LVV at each bus should be as small as possible and the deviation in each bus can be expressed as [16]:

$$\mathrm{f_1}(x) = \min\left(\sum_{\mathrm{a=1}}^{\mathrm{n\ bus}}\left|V_a - V_a^{ref}\right|^2\right) \quad (10)$$

where V_a represents the magnitude of the voltage at the a-th bus.

Active power loss reduction: The second objective function is reduction of active power loss and it can be applied based on [12] as:

$$\min \mathrm{f_2}(x) = \sum_{a=1}^{m} P_{Ga} - \sum_{a=1}^{n} P_{La} \quad (11)$$

where P_{Ga} is the active power generated by the a-th generator with the constraint $P_{Ga\ \min} \le P_{Ga} \le P_{Ga\ \max}$ and $P_{La}$is the active power consumed by the a-th load bus with the constraint $P_{La\ \min} \le P_{La} \le P_{La\ \max}$.

Maximization of VSM: The Maximum Loadability Index (MLI) defines the voltage stability margin. The risk of voltage collapse can be reduced by increasing the value of MLI and it leads to increase the voltage stability margin. The MLI can be determined based on [17] and it can be expressed as:

$$MLI_k = \frac{V_j^2}{2\left(\left[P_{jk}R_{jk} + X_{jk}Q_{jk}\right] + \sqrt{\left[R_{jk}^2 + X_{jk}^2\right]\left[P_{jk}^2 + X_{jk}^2\right]}\right)} \quad (12)$$

where R_{jk} is the resistance and X_{jk} is the reactance between the bus j and k. P_{jk} and Q_{jk} are the real and reactive power flow between the bus j and k respectively. When the load increases, the value of MLI decreases and the third objective function can be expressed as:

$$f_3(x) = \max\left(\sum_{a=1}^{N} MLI(a)\right) \quad (13)$$

In-equality Constraints: Contingency event occurs if the outage of a transmission line or a generator and it leads to unstability. Thisinsecure state can be avoided by taking preventive and/or corrective actions. Contingency analysis is one of the important functions to solve this state. In this work, the standard test systems such as an IEEE 27-bus and IEEE 57-bus are considered under multiline outage contingencies. The constraints are:

Voltage constraints: $V_k^{min} \le V_k \le V_k^{max}$; $k \in N_N$

Line flow limit: $F_k^{min} \le F_k \le F_k^{max}$; $k \in N_F$

Tap position constraints: $T_k^{min} \le T_k \le T_k^{max}$; $k \in N_T$

Power generation limit: $P_k^{min} \le P_k \le P_k^{max}$; $k \in N_P$

After determining the violation, the severity order is allotted for the lines. The OCSA is applied for the critical contingency and to find out the optimized location and other parameters of IPFC. Installing IPFC in the optimized location by OCSA which leads to eliminating or minimize the overloading and bus voltage violation limits. The real and reactive power flow constraints can be taken from (5) and (6).

IPFC Limits: The IPFC control parameters are considered as:

$$0 \le CV_{i,j}, CV_{i,k} \le CV^{\max}\left(0.1p.u\right)$$
$$0 \le CV_{i,j}, CV_{i,k} \le CV^{\max}\left(360^o\right)$$
$$0 \le X_{se,\,ij}, X_{se,\,ik} \le X_{se}^{\max}\left(0.1p.u\right)$$

Optimal location of IPFC: The conventional methods, which are used to identify the optimal location, are not suitable for IPFC because it requires two transmission lines. Optimal location identification is necessary to obtain maximum benefit from IPFC. Most of the power flow controlling techniques used in the transmission lines is varying the compensation using voltage source converter and they will not provide a balanced output. The power flow in a few lines gets decreased and some other lines get increased. The severity line index and ranking of the line are determined based on [18]. The line stability index represents the stability according to the loading of the line. The stability of the line connected between buses i and j can be calculated based on [19] as:

$$LSM_{ij} = \frac{4XP_r}{\left[V_i \sin\left(\theta\text{-}\beta_s + \beta_r\right)\right]^2} \quad (14)$$

where X represents the reactance of the transmission line, P_r represents the receiving end reactive power, V_i is the voltage magnitude of the i-th bus, ? is the angle of the impedance of the line and $â_s$, $â_r$ are the angle of the voltage at the sending and receiving end respectively. For installing IPFC, two transmission lines are required with a common bus and to increase the effectiveness and decrease the computation the following conditions has been included.

- The IPFC must not be connected to the line where the transformer is connected.
- The IPFC must be connected between the buses where shunt compensators are not connected.

Overview of OCSA: OCSA obliges brood parasitism of cuckoo species by laying their eggs in the host birds' nests. OCSA is a stochastic global search meta-heuristics with random walk based on population. This algorithm is a mixture with the Levy flight behavior of some birds [20] and motivated us to calculate the location and other parameters such as overloaded lines, voltage violation limit and congestion management of IPFC. OCSA follows three important rules which are: 1) each cuckoo can choose the location randomly and lay their eggs one at a time. 2) The highest quality eggs present in their nest are found by Elitist selection process and carry over to next generation. 3) The host nest number cannot be adjustable and the egg laid by the cuckoo can be found by the probability P_dε [0,1] proposed in [21, 22].

At first, the objective function value $F_i(x)$ for the i-th population is $F_i(k) = f(k_{1i}, k_{2i}, k_{3i},...., k_{ni}),\ \forall_i = 1,2,..., n$. where n is the number of control variables and m is the total number of populations. It can be expressed as:

$$\begin{bmatrix} F_1(k) \\ F_2(k) \\ : \\ F_n(k) \end{bmatrix} = \begin{bmatrix} f(k_{11}, k_{21},..., k_{n1}) \\ f(k_{12}, k_{22},..., k_{n2}) \\ : \\ f(k_{1m}, k_{2m},..., k_{mn}) \end{bmatrix} \quad (15)$$

Based on the three rules of OCSA method, the IEEE 27-bus and IEEE 57-bus test cases taken from [23] and implementation is as follows:

- In this study radial topology of the network is considered, the number of tie-lines (TL) is equal to the number of open branches of the network.
- Every member present in the initial population is a radial structure of the network and it is considered as a host nest.
- A population of N host nests is, $k_i = \left[k_1^i, k_2^i, ..., k_{d-1}^i, k_d^i)\right]$, i=1,2,…,N.
- Initialization process of OCSA, the eggs are randomly generated and the population of each nest i can be randomly initialized as: $K_i = round\left[TL_{min,n}^i, rand(TL_{max,n}^i - TL_{min,n1}^i)\right]$, where n=1,2,…,$N_{LS}$, TL_n^i is the tie-lines corresponding to nest n. The fitness of each nest is calculated according to the objective function given in (8) and the load flow can be calculated.
- The best value of each nest is set $Kbest_i$ (i=1,2,…,N) and based on the best fitness function set the best nest M_{best} among all nests in the population.
- For calculating the location and other parameters of IPFC, new cuckoo eggs are replaced based on the quality to all the nest except the best one which is produced by Levy flights as: $k_i^{new} = round\left[kbest_i + \gamma \text{ x rand x } \Delta k_i^{new}\right]$ where rand is a normally distributed random number [0,1], the step size γ>0, ΔK_i^{new} is the increased value and it can be determined as:

$$k_i^{new} = \frac{rand_p}{\left|rand_q\right|^{1/\gamma}} \frac{\sigma_p(\gamma)}{\sigma_q(\gamma)} \left(kbest_i - Mbest_i\right) \quad (16)$$

where $rand_p$ and $rand_q$ are the two normally distributed stochastic random variables which has standard deviation $\sigma_q(\gamma)$=1 and $\sigma_p(\gamma)$ is given by:

$$\sigma_p(\beta) = \left[\frac{\left(\Gamma(1+\gamma)\sin(\pi.\gamma/2)\right)}{\Gamma\left(\left(\frac{1+\gamma}{2}\right)\gamma.2^{\gamma-1/2}\right)}\right]^{1/\gamma} \quad (17)$$

where γ represents the distribution factor with the range $0.3 \le \gamma \le 1.99$ according to [24] and Γ is the gamma distribution function. The fitness value of the radial topology can be calculated using eq.(8)

- Alignment of eggs in the nest of host bird similar to Levy flight with probability P_A and the eggs replacement from their current positions through the random walk with step size is, $K_i^{new} = round\left[Kbest_i + L \text{ x } \Delta K_i^{new}\right]$, where L is updated based on the probability, L =1 for rand<P_A and L=0 for all other values, the increased value, $\Delta K_i^{new} = rand\left[randp_1(Kbest_i) - randp_2(Kbest_i)\right]$. Where rand is the random number [0,1] and $randp_1(Kbest_i)$, $randp_2(Kbest_i)$ are the random perturbation for the position of the nests in $Kbest_i$.

The fitness value of the radial topology can be calculated using eq. (8).In the experiments, the common control parameters such as maximum function evaluation number and pattern matrix size are considered as 1,00,000 and 20 respectively. The minimum values less than 10^{-6} are not included in the experiments and assumed to be zero. On the other hand, the algorithmic control of PSO is set according to [25] and the values C_1=C_2=1.8 and ω=0.6 have been used. The generating cuckoos and alignment steps are alternatively performed until it reaches the maximum iteration (It_{max}).

RESULTS AND DISCUSSION

To demonstrate the performance and effectiveness of the proposed technique, the standard IEEE 27-bus,and IEEE 57-bus test systems are considered and the result is compared with two optimization techniques such as PSO and GA. The simulation was developed using MATLAB R2014a in Intel core i5, 3.2 GHz with 8 GB RAM personal computer. The lower voltage limit (V_{min}=0.95 p.u), the upper voltage limit (V_{max}=1 p.u) and the threshold value of power flow analysis is 0.006 has been set. The voltage magnitude and angle of two converters of IPFC is taken in the range $0 \le V_{se} \le 1$ and $-\pi \le \theta_{se} \le \pi$ respectively.

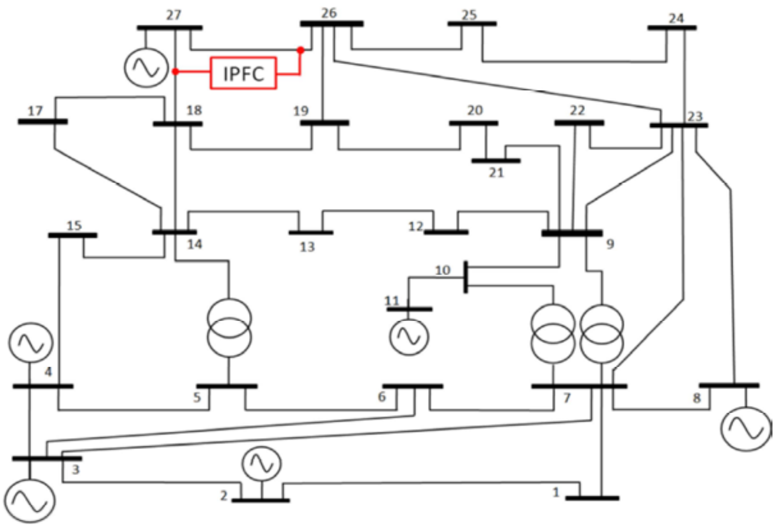

Fig. 3: IPFC placed between buses 18-27 and 27-26 inaIEEE 27-bus test system.

Table 1: Initialization parameters used for implementing OCSA, PSO and GA techniques.

OCSA Technique	Value	PSO Technique	Value	GA Technique	Value
Number of cuckoos	50	Number of swam	50	Number of initial chromosome	50
Maximum number of generations	400	Maximum number of flights	400	Mutation Rate	0.25
Minimum number of eggs for each cuckoo	25	W_{max}	0.92	Fraction of population kept	0.5
Maximum number of eggs for each cuckoo	45	W_{min}	0.45	Number of variables	15
Motion coefficient	8	Termination criteria	1.exp-6		
Number of cluster	1	Weighting factors	c_1=2, c_2=1.5		
Termination criteria	1.exp-6	Deviation			

IEEE 27-bus Test System: In IEEE 27-bus system, bus number 4 is a slack bus, bus numbers 2, 3, 6, 8 and 13 are considered as PV buses and all other buses are considered as load buses. The single line diagram of IEEE 27-bus system with IPFC between buses 18-27 and 27-26 is shown in Fig. 3. The network topology and data for simulating above systems are taken from the University of Washington [23]. The performances of OCSA, PSO and GA algorithms are studied together for comparison. Different initial parameters have been used for implementing OCSA, PSO and GA to find the optimal values of IPFC are presented in Table 1.

To demonstrate the performance of the proposed OCSA technique, a large scale of distributed network with 27 nodes are considered. The initial minimum bus voltage was 0.94p.u and total load power is 22854.4W. The series inductive reactance is 2.78% p.u,the coupled pi-section inductive reactance is 5.79% p.u, the susceptance is 5.62% p.u and resistance is 1.89% p.u is considered. The series coupling transformer has 30.32 MVA with leakage reactance is 1.0% p.u and has a winding ratio of 22.73 kV/9.21 kV.

The voltage limit range of 0.94-1.1 P.U is considered for (easy calculation) determining voltage violation and 100% loading is considered for determining overloaded lines. The total overloaded lines (TOL), total violation buses (TVB) and the priority of the line is presented in Table 2. Based on these considerations fifteen lines comes under severe contingency scenarios. From Table 2 one can easily understand that the line connected between 18and27 is most congested lines between the load buses. Hence, the first and second converter of IPFC can be inserted between the lines 18-27 and the line has a bus common with line 27-26 respectively.

The voltage profile before and after utilizing IPFC for IEEE 27-bus system is shown in Fig. 4. It is observed that after the placement of IPFC the bus voltage of the system has improved significantly.

The multi-objective function F(x) is used to tune the IPFC and the values are shown in Fig. 5. From Fig. 5 one can easily understand that the number of cuckoos and number of generation increases, the value of objective function decreases. Hence, to minimize computation time, the number of cuckoos can be chosen 50 and number of generation in the range 100 to 400. Comparison of Vse and

Table 2: Contingency analysis and priority fixing used in IEEE 27-bus system

Tripped Lines						
Line Number	From bus	To bus	Total overloaded lines (TOL)	Total voltage violation buses (TVB)	TOL + TVB	Priority
2	1	2	7	3	10	6
4	2	4	6	6	13	3
5	2	5	4	1	5	12
7	6	9	1	4	5	11
9	3	7	2	4	6	10
10	2	8	8	5	13	2
11	7	13	3	1	4	14
13	11	16	7	3	10	5
15	17	19	3	2	5	13
19	18	27	6	8	14	1
21	21	25	2	4	6	9
22	20	22	1	7	8	7
24	16	26	2	1	3	15
25	25	27	6	6	12	4
27	24	26	5	3	8	8

Table 3: Comparison of Vseand èsefor un-tuned, tuned IPFC using PSO, GA and OCSA under different loading condition

	Normal loading				100% loading				110% loading			
IPFC Parameters	Untuned IPFC	Tuned IPFC using PSO	Tuned IPFC using GA	Tuned IPFC using OCSA	Untuned IPFC	Tuned IPFC using PSO	Tuned IPFC using GA	Tuned IPFC using OCSA	Untuned IPFC	Tuned IPFC using PSO	Tuned IPFC using GA	Tuned IPFC using OCSA
V_{se1}, pu	0.0059	0.0076	0.0076	0.0018	0.0056	0.0079	0.0029	0.0022	0.0061	0.0045	0.0025	0.0014
V_{se2}, pu	0.0131	0.0206	0.0206	0.00239	0.0140	0.0605	0.0604	0.0997	0.0129	0.0063	0.026	0.0098
O_{se1}, degree	-145.83	-128.85	-129.63	-170.47	-158.27	158.48	168.23	180	-164.36	162	164	180
O_{se1}, degree	180	180	180	180	180	-180	-180	-180	180	-21.283	-22.184	-25.734

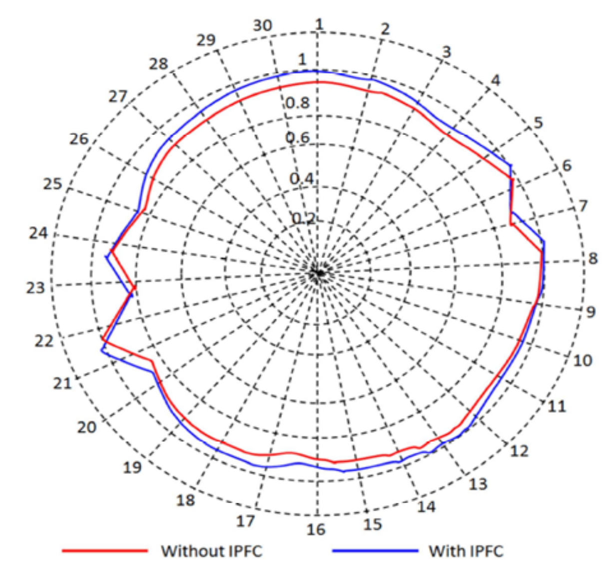

Fig. 4: Comparison of voltage profile before and after inserting IPFC.

èse of IPFC has been performed for different cases such as un-tuned IPFC, IPFC with PSO-tuned, IPFC with GA-tuned and IPFC with OCSA-tuned under different loading condition are presented in Table 3.

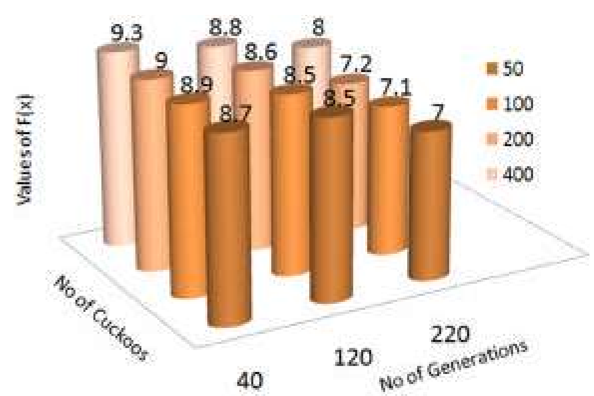

Fig. 5: Objective function values for various parameters setting of OCSA.

The voltage deviation is reduced from 2.51 to 2.3pu after inserting the IPFC at the optimal location. It is noted that after placing IPFC at the optimal location, the congestion in line 4 and 5 has been reduced from 0.8496 to 0.8149. The real and reactive power loss of the system with and without IPFC and optimally tuned IPFC with PSO, GA and OCSA under different loading conditions is presented in Table 4. It is observed from Table 4 that the real and reactive power loss is very less using OCSA compared with PSO and GA for all the loading conditions.

Table 4: Real and reactive power loss with and without IPFC, tuned IPFC using PSO, GA and OCSA for IEEE 30-bus test system under different loading condition.

	Normal loading		100% loading		110% loading	
Condition	Real power losses, MW	Reactive power losses, MVAR	Real power losses, MW	Reactive power losses, MVAR	Real power losses, MW	Reactive power losses, MVAR
Without IPFC	31.127	107.754	32.549	126.264	36.046	159.589
Un-tuned IPFC	25.273	101.467	28.493	117.435	34.285	147.486
Tuned IPFC using PSO	24.4722	101.164	28.374	118.592	33.476	146.094
Tuned IPFC using GA	24.6925	100.535	27.952	118.376	32.528	145.593
Tunes IPFC using CSA	24.1205	98.275	23.893	114.826	29.742	144.738

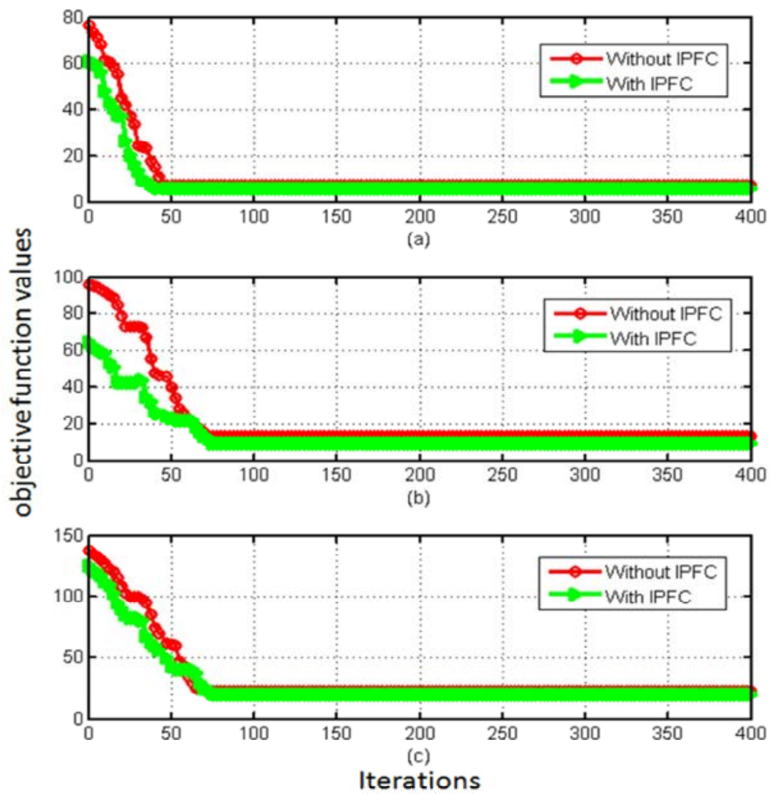

Fig. 6: Convergence characteristicsof the proposed system with and without IPFC for IEEE 27-bus system. (a) normal loading condition (b) 100% loading (c) 110% loading.

The convergence characteristicsof the proposed system with and without IPFC under various loading conditions such as normal loading,100% loading and 110% loading conditions are shown in Fig. 6. Even the initial population set of all the algorithms are equal, the OCSA initiate the best solution with the fitness value of 1.031 at the first iteration because OCSA generates two solution sets through Levy flights and alignment of eggs. On the other hand, PSO and GA have the fitness value of 1.091 and 1.106respectively. Fig. 6(a) shows thatthe minimum fitness value under normal loading condition attains at 50 and38 iterationsbefore and after inserting IPFC respectively.

The load is increased to 100% and the simulation is carried out on IEEE 27-bus system. Fig. 6(b) shows that the minimum fitness value reaches at 62 and 66 iterationsbefore and after inserting IPFC respectively. It is noted that when load increases the real and reactive power losses increases. From Table 4 one can easily understand that optimal placement of IPFC with tuning reduces the real and reactive power loss.The convergence characteristicsbefore and after placing IPFC at 110% loading condition are shown in Fig. 6(c) and it reaches the minimum fitness value at77 and 83 iterations respectively. The simulation is carried out on IEEE 27-bus system under 110% loading is shown in Fig. 6(c). It is observed from

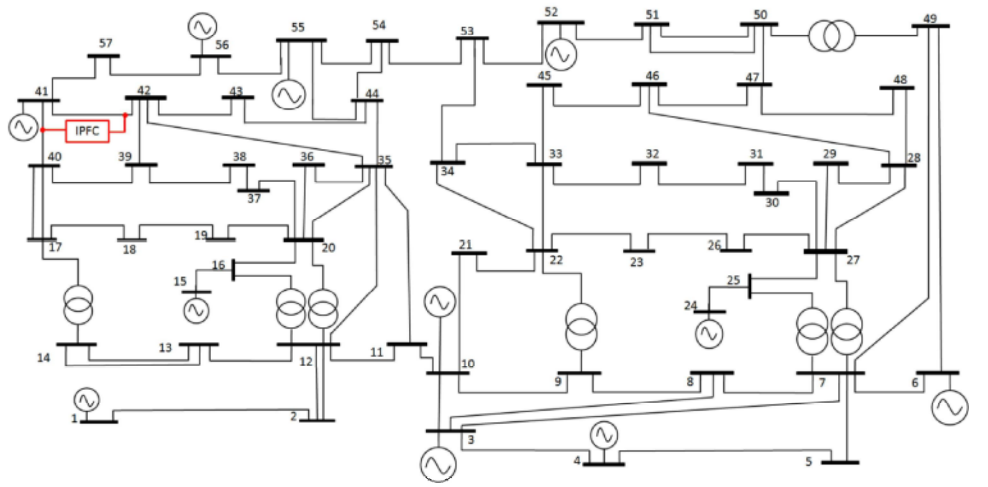

Fig. 7: IPFC placed between buses 40-41 and 41-42 inaIEEE 57-bus test system.

Table 5: TVB, TOL and priority of IEEE 57-bus test system

Tripped Lines						
Line Number	From bus	To bus	Total overloaded lines (TOL)	Total voltage violation buses (TVB)	TOL + TVB	Priority
2	2	4	5	8	13	10
3	4	8	8	4	12	16
5	7	9	2	8	10	20
6	4	10	5	3	8	21
8	9	12	9	8	17	5
10	9	14	10	3	13	11
14	10	16	3	10	13	13
17	15	18	7	6	13	12
19	14	17	2	8	10	19
22	20	22	8	2	10	18
25	21	25	3	12	15	8
28	25	30	8	8	16	6
32	15	18	11	4	15	7
34	19	21	4	9	13	14
36	25	26	9	3	12	15
40	15	19	11	7	18	3
45	11	18	5	9	14	9
47	23	26	3	8	11	17
50	40	41	9	10	19	1
53	16	20	10	8	18	2
57	19	23	6	11	17	4

Fig. 6(a),(b),(c) and Table 3, that optimally tuned IPFC performs better than without IPFC.On comparing OCSA with PSO and GA, the OCSA method performs better than other two methods.

IEEE 57-bus Test System: In this work, IEEE 57-bus system is taken as the second example. Here we are considering the bus number 17 is a slack bus, the bus numbers 2, 3, 5, 9, 17, 19, 23, 34, 46 and 55are considered as PV buses and all other buses are considered as load buses. The single line diagram of IEEE 57-bus system with IPFC between buses 40-41 and 41-42is shown in Fig. 7. The data required for simulating above systems are taken from the University of Washington [23].

The voltage limit is considered in the range of 0.94-1.1 P.U for easy calculation. The total violation buses (TVB), total overloaded lines (TOL) and the priority of the line is presented in Table 5. Based on these considerations twenty-onelines come under severe contingency scenarios. From Table 5 one can easily understand that the line connected between 40 and 41 is most congested lines between the load buses. Hence, the first and second

Table 6: Comparison of Vse and èsefor un-tuned, tuned IPFC using PSO, GA and OCSA under different loading condition

IPFC Parameters	Normal loading Untuned IPFC	Tuned IPFC using PSO	Tuned IPFC using GA	Tuned IPFC using OCSA	100% loading Untuned IPFC	Tuned IPFC using PSO	Tuned IPFC using GA	Tuned IPFC using OCSA	110% loading Untuned IPFC	Tuned IPFC using PSO	Tuned IPFC using GA	Tuned IPFC using OCSA
Vse1, pu	0.0103	0.0125	0.0113	0.0037	0.0157	0.0103	0.0116	0.0094	0.0194	0.0116	0.0102	0.0099
Vse2, pu	0.0178	0.0372	0.0304	0.0193	0.0252	0.0842	0.0794	0.0426	0.0932	0.081	0.0584	0.0517
⊖se1, degree	-157.73	-136.72	-142.27	-163.73	-127.36	149.73	173.62	180	-173.36	178	172	180
⊖se1, degree	180	180	180	180	180	-180	-180	-180	180	-18.463	-25.262	-22.574

Table 7: Real and reactive power loss with and without IPFC, tuned IPFC using PSO, GA and OCSA for IEEE 57-bus test system under different loading condition.

Condition	Normal loading Real power losses, MW	Reactive power losses, MVAR	100% loading Real power losses, MW	Reactive power losses, MVAR	110% loading Real power losses, MW	Reactive power losses, MVAR
Without IPFC	32.164	109.931	34.734	129.743	39.378	161.389
Untuned IPFC	26.734	104.783	30.853	120.735	37.379	149.844
Tuned IPFC using PSO	25.6842	101.063	29.794	119.733	34.842	148.275
Tuned IPFC using GA	25.6973	101.683	29.993	119.489	33.593	147.745
Tunes IPFC using CSA	25.1047	99.836	24.943	115.589	28.936	145.738

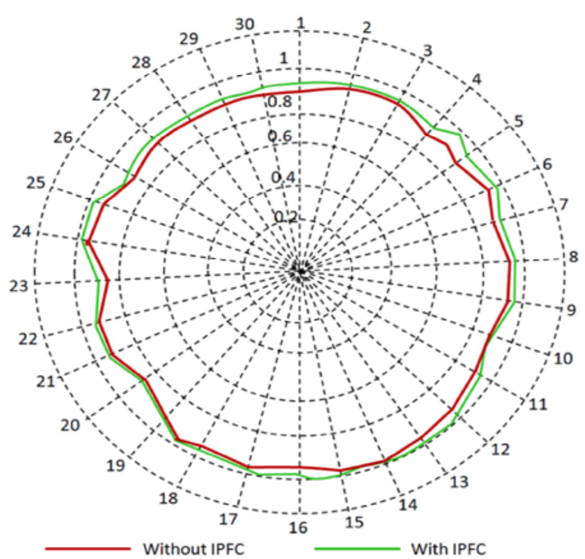

Fig. 8: Comparison of voltage profile before and after inserting IPFC.

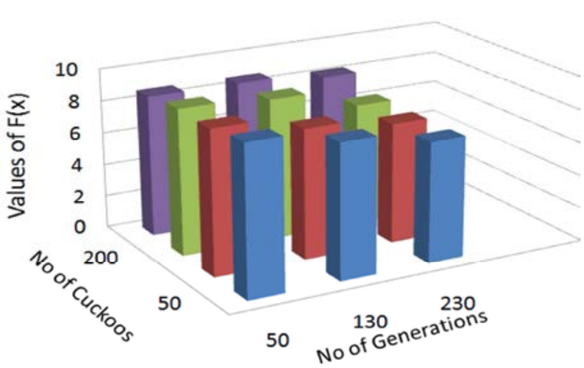

Fig. 9: Objective function values for various parameters setting of the OCSA.

converter of IPFC can be inserted between the lines 40-41and the line has a bus common with line 41-42respectively.

The voltage profile before and after utilizing IPFC for IEEE 57-bus system is shown in Fig. 8. It is observed that after the placement of IPFC the bus voltage of the system has improved significantly.The multi-objective function F(x) is used to tune the IPFC and the values are shown in Fig. 9. From Fig. 9 one can easily understand that the number of cuckoo and number of generation increases, the value of objective function decreases. Hence, to minimize computation time, the number of cuckoos can be chosen 50 and number of generation in the range 100 to 400. Comparison of Vse and èse of IPFC has been performed for different cases such as un-tuned IPFC, tuned IPFC with PSO, GA and OCSA under different loading condition are presented in Table 6.

The voltage deviation is reduced from 2.95 to 2.63pu after inserting the IPFC at the optimal location. The real and reactive power loss of the system with and without IPFC and optimally tuned IPFC with PSO, GA and OCSA under different loading conditions is presented in Table 7. It is observed from Table 7 that the real and reactive power loss is very less using OCSA compared with PSO and GA for all the loading conditions.

The convergence characteristicsof the proposed system with and without IPFC under various loading conditions such as normal loading, 100% loading and 110% loading conditions are shown in Fig. 10. The OCSA initiates the best solution because it generates two solutions through levy flight and alignment of eggs. The fitness values of PSO, GA and OCSA are 1.071, 1.29

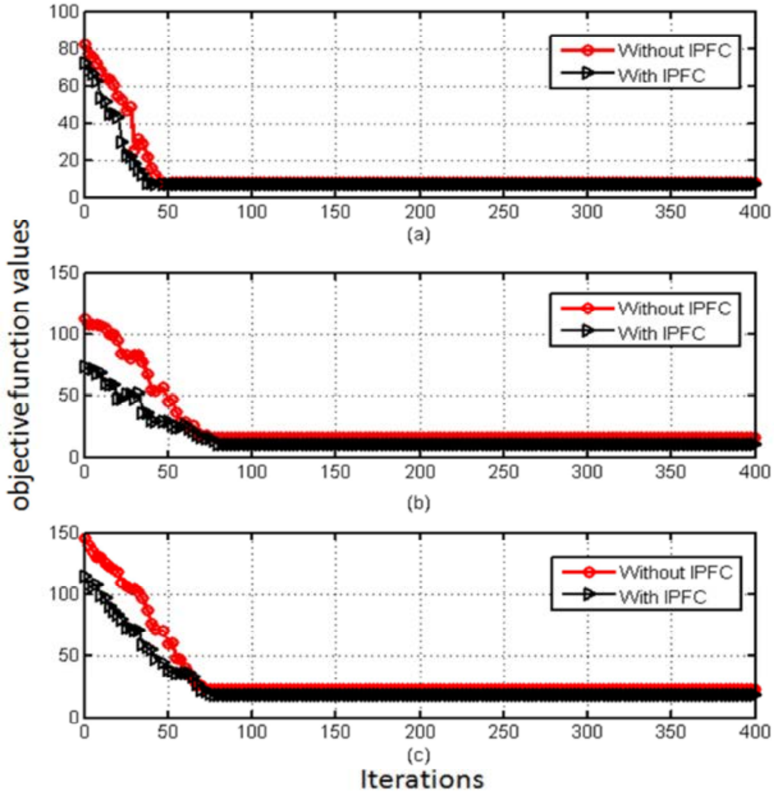

Fig. 10: Convergence characteristicsof the proposed system with and without IPFC for IEEE 57-bus system (a) normal loading condition (b) 100% loading (c) 110% loading.

and 1.12 respectively. The minimum fitness values before and after inserting IPFC reaches at 42 and 49 iterations under normal loading condition is shown in fig. 10(a).

The load is increased to 100% and the simulation is carried out on IEEE 57-bus system. Fig. 10(b) shows that the minimum fitness value attains at 72 and 76 iterations before and after inserting IPFC. It is also noted that after 74 and 77 iterations the minimum fitness value reaches under 110% loading. The simulation is carried out on IEEE 27-bus system under 110% loading is shown in fig. 10(c). It is observed from Fig 10(a),(b),(c) that optimally tuned IPFC performs better than without IPFC.On comparing OCSA with PSO and GA, the OCSA method performs better than other two methods.

CONCLUSION

In this paper, a new method is proposed for proper placement of IPFC based on OCSA. Before inserting the IPFC in the optimal location, the percentage of overloading of some lines is very high which leads to trip the line and continuous failure in the system and nearby system as well. After utilizing IPFC in the optimal locations, voltage violations are eliminated and overloading is reduced with the considerable amount. The performance of OCSA is done using IEEE 27-bus and IEEE 57-bus test systems and is compared with two other optimization techniques such as PSO and GA and the results show that the effectiveness of OCSA for tuning of IPFC. The multi-objective function is formulated and tuned using OCSA and the performance shows that tuning of IPFC reduces the real and reactive power loss and load voltage variation of transmission lines. It is also noted that the performance of the system improved significantly with IPFC.

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