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Firefly Algorithm Based Generator Contingency Management Using an Interline Power Flow Controller

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ABSTRACT

In the competitive electric market of recent times, continuous supply of electricity in normal and contingency condition is mandatory. Hence, post-contingency management of the transmission system is a task to be done most accurately. Generator contingencies have been take into consideration in this study. In this paper, the Interline Power Flow Converter (IPFC) has been placed using Fused Index (FI).The IPFC has been further tuned using most recent Firefly algorithm for a multi-objective function. The multi-objective function consists of Active power loss, voltage deviation, security margin and size of IPFC. The proposed strategy has been implemented on an IEEE 30 and 57 bus system for verification and illustration purposes.

Keywords: Contingency; Interline Power Flow Controller; Fused Index; Optimal Placement; Optimal tuning.

1. INTRODUCTION

Blackouts have become a very common event throughout the world. Proper steps need to be taken to avoid the occurrence of this alarming situation. Hence, contingency assessment and secured operation reinforcement have become vital aspects of power system operation.

Contingency screening is the first step for the security evaluation of the power system. Several steady state and dynamic contingency ranking methods are used for contingency screening [1-7]. But the traditional method for contingency analysis is still considered to be the most accurate method of severity assessment.

During system disturbances, system stability becomes vulnerable and there is a high risk of moving towards global instability or total collapse or blackout if preventive actions are not taken quickly. Facts devices provide good solution to various power system issues including congestion and contingency provided the devices have been optimally placed and tuned in the system. Many computational intelligence methods have been applied for optimal placement and tuning of UPFC[8-11]. Moazzami et al. [12] have offered a strategy for blackout prevention in a power system using parallel FACTS devices and a combination of corrective actions. Jayasankar et al.[13] have used artificial neural network for the optimal placement of TCSC based on Voltage stability index. Tiwari has used mixed integer programming for optimal allocation of VAR compensators. Varshney et al. [14] have used PSO-TVAC for optimal placement and sizing of STATCOM for improvement of voltage security. IPFC is one of the most recently invented FACTS device with the capability to regulate multiple transmission lines [15, 16]. Optimal placement and sizing of IPFC for contingency management is expected to provide good solution to the post-contingency issues.

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In this paper, two separate indices have been united to formulate a Fused Index (FI) to estimate line overloads and bus voltage deviation of the system for correct assessment of severity. Line Utilization Factor (LUF) is used for the measurement of line overloads in terms of both real and reactive power. Voltage Stability Index (Lmn) has been used for voltage contingency ranking. Two approaches for the placement of IPFC have been chosen, namely, deterministic and probability approach. In the deterministic approach, IPFC is placed on the severe-most line in the power system, while, in the probability approach the IPFC is placed on the line with maximum probability of severity. One of the most recent and successful metaheuristic method- FA has been used for the tuning of IPFC for a multi-objective function. The multi-objective function consists of minimization of active power loss, voltage deviation, security margin and capacity of installed IPFC. The method discussed above is applied to an IEEE 30 and 57 bus system.

2. FUSED INDEX

2.1. Line Utilization Factor

LUF uses apparent power for the calculation of line loading as given by the expression (3)

$$LUF_{ij} = \frac{MVA_{ij}}{MVA_{ij\max}} \tag{3}$$

where, LUF_{ij}-LUF of line ij.

$MVA_{ij(max)}$–Rated apparent power in line i-j.

MVA_{ij}- Actual apparent power flow in line i-j.

The overall LUF of the system is given by equation (4)

$$OverallLUF = \sum_{\forall L} LUF \tag{4}$$

Where, L is the no. of lines in the system

2.2. Line Stability Index

The expression for Line Stability index has been given in equation (5)

$$L_{ij} = \frac{4xQ_j}{[V_i \ \sin(\theta - \delta)]^2} \tag{5}$$

Where,

$\delta = \delta_i - \delta_j$,

$\theta = \tan^{-1}(X / R)$

where,

x Line i-j reactance,

R Line mn resistance

δ_i, δj Phase angle of bus i and bus j respectively,

Q_n Reactive power at bus j,

V_i, V_j is the voltage magnitude at bus i and bus j respectively.

The overall L_{mn} of the system is given by equation (6)-

$$OverallL_{mn} = \sum_{\forall L} L_{mn} \tag{6}$$

2.3. Fused Indices

A Fused Index is formulated by taking one index of each category in equation (9).

$$FI_{ij} = a \times LUF_{ij} + b \times L_{ij} \tag{9}$$

Where,

$$a + b = 1 \tag{10}$$

a and b are the weighting factors for each line. In this study, a = b = 0.5

$$OverallFI = \sum_{\forall L} FI \tag{11}$$

4. PROPOSEDMULTI-OBJECTIVE FUNCTION FOR IPFC TUNING

A multi objective function is expressed as given in equation (12)

$$MinF = Min \sum_{i=1 to 4} w_i f_i \tag{12}$$

Where, w_i is the weighting factor.

$$\sum w_i = 1 \tag{13}$$

All the weights are equal in this study.

4.1. Active loss

The expression for active power loss is given in equation (14)

$$f_1(x) = \min(P_{loss}) = \begin{pmatrix} |V_i|^2 G_{ik} - |V_i||V_k|[G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}] \\ -|V_i||V_{sik}|[G_{ik}\cos\theta_{isik} + B_{ik}\sin\theta_{isik}] \end{pmatrix}$$
$$+\begin{pmatrix} |V_k|^2 G_{ik} - |V_i||V_k|[G_{ik}\cos\theta_{ki} + B_{ik}\sin\theta_{ki}] \\ -|V_k||V_{sik}|[G_{ik}\cos\theta_{ksik} + B_{ik}\sin\theta_{ksik}] \end{pmatrix} \tag{14}$$

Where, lk is the number of transmission lines,

$V_L = V_L \angle \theta_l$ and $V_k = V_k \angle \theta_k$ are the voltages at the end buses l and k (k = m, n).

$V_{slk} = V_{slk} \angle \theta_{slk}$ (k = m, n) is the series injected voltage source of k^{th} line, s stands for series,

G_{lk} and B_{lk} are the transfer conductance and susceptance between bus l and k (k = m, n) respectively.

4.2. Voltage Deviation

The Voltage Deviation (VD) can be expressed by equation (15):

$$f_2(x) = \min(VD) = \min(\sum_{k=1}^{Nbus} |V_k - V_k^{ref}|^2) \tag{15}$$

V_k is the voltage magnitude at bus k

4.3. Security Margin

Since, it is required to minimize the multi-objective function, the expression is as given in equation (16).

$$f_3(x,u,z) = 1 - SM = \frac{\sum_{j \in J_L} S_j initial}{\sum_{j \in J_L} S_j \lim} \tag{16}$$

Where, J_L = set of load bus in the system

4.4. Size of Installed IPFC

The expression is mentioned in equations (17) and (18) given below:

$$f_4(x) = \min(PQ_1^2 + PQ_2^2) \tag{17}$$

where, PQ: capacity of each VSCs of IPFC

$$PQ_1^2 + PQ_2^2 = \left(Vse_{ij} \left(\frac{\overline{V_i - Vse_{ij} - V_j}}{Z_{ij}} \right) \right)^2 + \left(Vse_{ik} \left(\frac{\overline{V_i - Vse_{ik} - V_k}}{Z_{ik}} \right) \right)^2 \tag{18}$$

5. FIREFLY ALGORITHM

Firefly Algorithm (FA) was developed by Dr. Xin-She in 2007. Firefly algorithm is based on the typicalblinkingcharacteristic of the fireflies. The parameters of the firefly algorithm are population size, attractiveness, absorption coefficient and maximum number of iterations.

6. RESULTS AND DISCUSSION

6.1. IEEE 30 bus system

An IEEE 30 bus system consists of 5 generators, namely 2, 5, 8, 11, 13 and 41 transmission lines. Each of the 5 generators have been removed from the system sequentially for contingency analysis. The result of the analysis has been presented in Table 1. It is observed that for generator 13 contingency, line 4-12, with highest FI value, is the severe-most line of the system. But another important observation is that for all other generator outages line 3-4 is the severe-most line. Thus, although line 4-12 is the severe-most line of the system by deterministic approach, the probability of severity for line 3-4 is highest.

By deterministic approach line 4-12 is chosen for the placement of IPFC, and 4-12 have been presented in Table 1. It is observed from Table 2 that line 12-16 has the least FI [16], hence is the fittest line linked to line 4-12. Thus, line 4-12 and 12-16 are chosen for the placement of IPFC.

Table 1
Generator Contingency analysis of IEEE 30 Bus System.

S. No.	*Gen No.*	*From Bus*	*To Bus*	*FI*
1	2	3	4	0.4689
2	5	3	4	0.4656
3	8	3	4	0.4761
4	11	3	4	0.4382
5	13	4	12	0.869

Table 2
Generator Contingency analysis of IEEE 30 Bus System.

S. No.	*Line*	*FI*
1.	3-4	0.4574
2.	4-6	0.4581
3.	4-12	0.869
4.	12-14	0.1636
5.	12-15	0.1818
6.	12-16	0.0681

For Firefly algorithm, the values of the objective function vs number of generations and number of fireflies has been shown in Fig.1. Accordingly the values of the parameters of the objective function has been set as given in Table 3.The IPFC has been tuned using FA and all the results have been presented in Table 4. It is observed that due to outage of generator 13 the total active and reactive power loss increases from 22.286 MW and 102.334 MVAR to 26.676 MW and 146.618 MVAR respectively. After the placement of IPFC the losses reduce to 25.385 MW and 123.439 MVAR respectively. Tuning of IPFC using FA further reduces the loss to 23.7 MW and 122.043 MVAR respectively. Similarly other parameters of the system also show minimum values when FA has been implemented for tuning the IPFC.

Fig. 2 shows the voltage profile of the transmission system. A good improvement is noticed in the voltage profile of the system after tuning the parameters of the IPFC with FA.Fig. 3 shows the FI values of the transmission lines. The FI values of the lines reduces effectively after tuning the IPFC with FA.

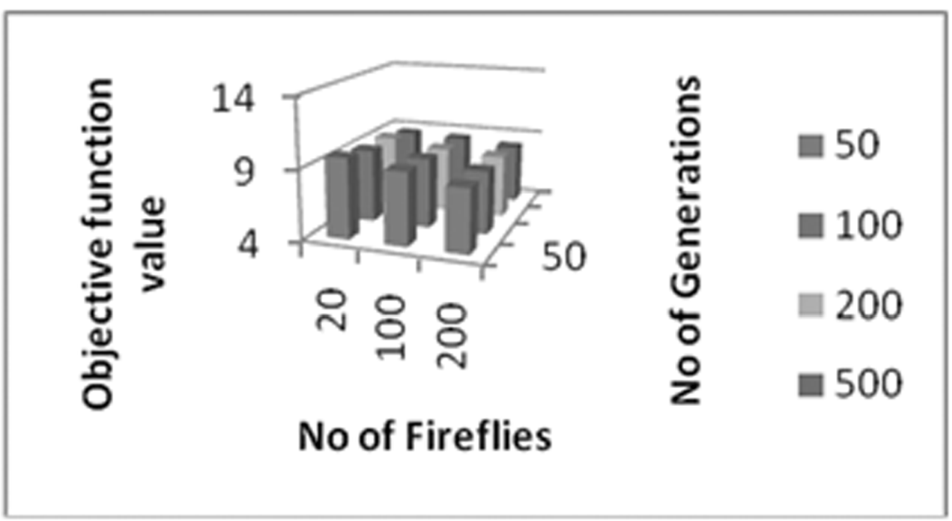

Figure 1: Obj. Func. Vs Parameter values of FA

Table 3
Values of the parameters of FA

S. No.	*Parameter*	*Value*
1.	No. Of Fireflies	20
2.	Max.no. generations	50
3.	α	0.5
4.	β	0.5
5.	γ	1

Table 4
Comparison of system parameters for various system conditions

Sl. No.	*Parameters*	*Without Cont*	*With Cont in Gen 13*	*IPFC Placement*	*FA tuned IPFC*
1	Act. Power Loss (MW)	22.288	26.676	25.385	23.700
2	React. Power Loss (MVAR)	102.334	146.618	123.439	122.043
3	LUF of Sev. Line (p.u.)	0.5157	0.8436	0.7577	0.5319
4	Lmn of Sev. Line (p.u.)	0.0171	0.0408	0.0091	0.0076
5	FISev. Line (p.u.)	0.3754	0.8690	0.7331	0.5254
6	VoltageDev. (p.u.)	3.1435	5.7579	4.004	3.7523
7	Cap. of Inst. IPFC (p.u.)	——-	——	0.0014	5.8085E-6
8	Overall FI (p.u.)		11.6592	10.8805	10.6272
9	Sec. Margin (p.u.)	12.962	14.7207	14.6587	14.3659

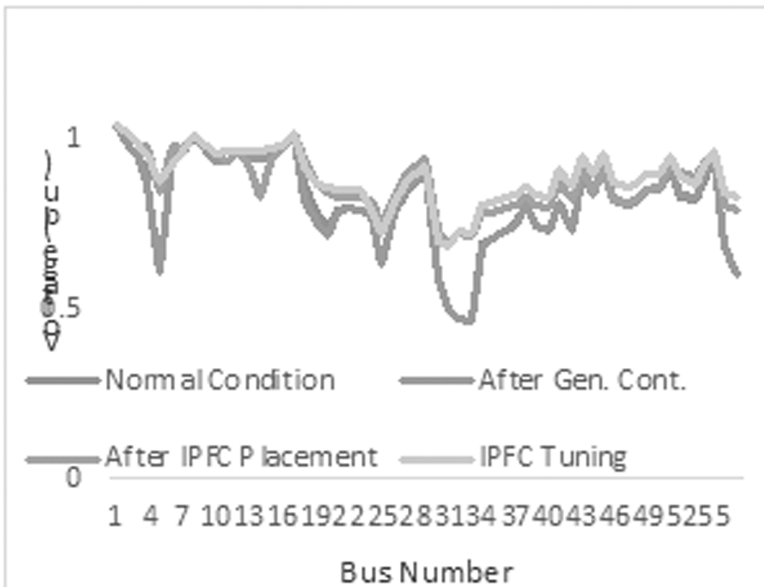

Figure 2: Comparison of Voltage profile for different system conditions

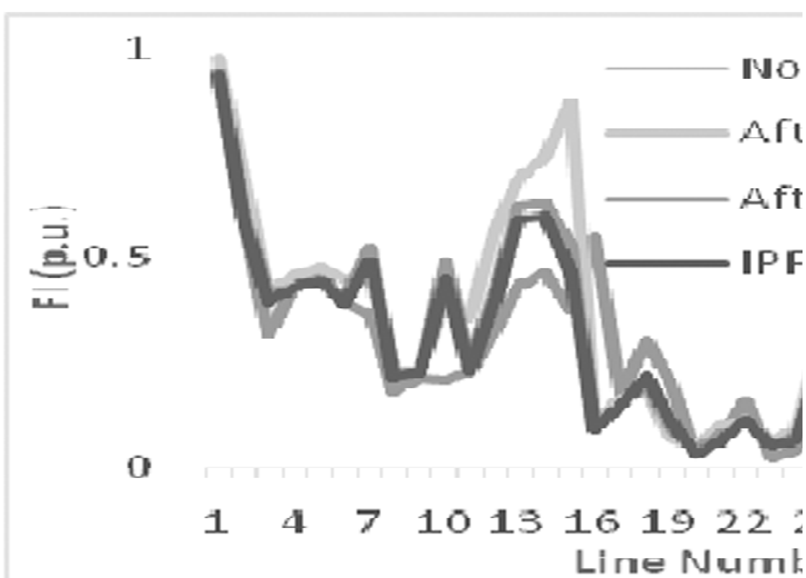

Figure 3: Comparison of FI of transmission lines of 30 bus system

6.2. IEEE 57 Bus system

An IEEE 57 bus system consists of 6 generator buses, namely, 2, 3, 6, 8, 9, 12 and 81 transmission lines. The results of generator contingency of the 57 bus system is shown in Table 5. It is observed that for outage of all generators line 24-25 is the severe-most line. Hence IPFC is placed on line 24-25 both by deterministic approach and probability approach. Line 24-26 is the healthiest line connected to line 24-25 with FI value of 0.234p.u. Thus the IPFC is placed on line 24-25 and line 24-26. The IPFC is then tuned using FA and the results have been presented in Table 6. It is observed that the active and reactive power loss without contingency are 58.7084MW and 226.751MVAR. After contingency in gen 6 the losses increase to 59.848MW and 232.526MVAR. After the IPFC has been placed in optimal location the losses are reduced to 44.466MW and 156.508MVAR. When the IPFC is tuned using FA the active and reactive losses of the system drop further to 42.964MW and 164.946MVAR respectively.

Table 5
Generator Contingency Analysis of IEEE 57 Bus system

S. No.	*Gen. No.*	*From Bus*	*To Bus*	*FI(p.u.)*
1	2	24	25	0.9204
2	3	24	25	1.0492
3	6	24	25	1.0671
4	9	24	25	0.9204
5	12	24	25	0.9844

Table 6
Comparison of system parameters under various system conditions

S. No.	*Parameters*	*W/T Cont*	*WithGen 6 Cont*	*IPFC Placment*	*FA Tuned IPFC*
1	Active Power Loss (MW)	58.7084	59.5848	44.466	42.964
2	Reac. Power Loss (MVAR)	226.0751	232.5258	156.508	164.946
3	LUF of Sev. Line (p.u.)	0.2464	0.2639	0.1118	0.0801
4	L_{mn} of Sev. Line (p.u.)	1.5943	1.8703	0.3132	0.2720
5	FI of Sev. Line (p.u.)	0.9204	1.0671	0.2125	0.1760
6	Volt. Dev.(p.u.)	10.1691	11.0154	6.8924	6.6362
7	Cap. of Inst. IPFC (p.u.)	—	—-	0.0243	6.1965e-6
8	Overall FI(p.u.)	24.51985	25.6876	16.9184	16.8853
9	Overall LUF (p.u.)	29.3497	29.4408	25.8650	25.0233
10	Overall Lmn (p.u.)	19.69	21.9344	9.2937	8.7473

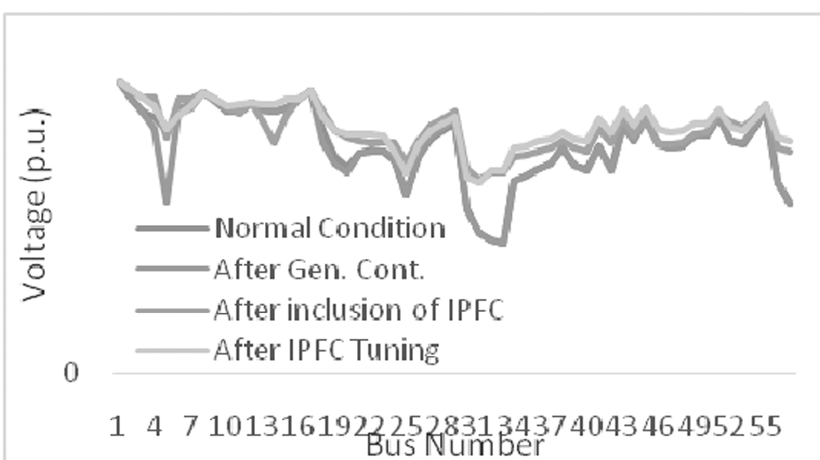

Figure 4: Comparison of voltage profile of 57 bus system

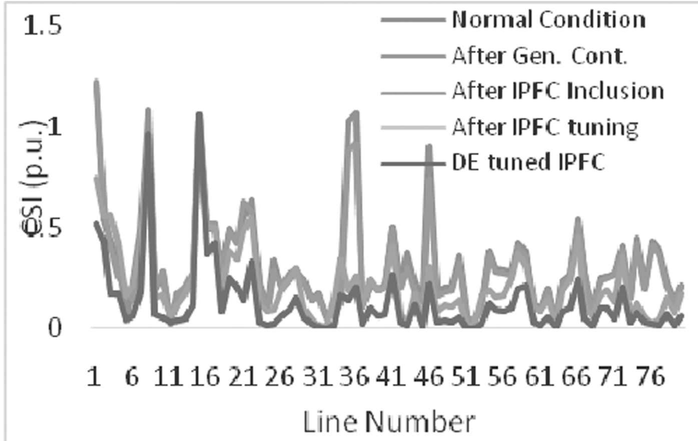

Figure 5: Comparison of FI of transmission lines of 57 bus system

The voltage profile of the 57 bus system has been presented in Fig. 4. Tuning of IPFC with FA shows an effective reduction in voltage profile. The FI values of the transmission lines is compared in Fig. 5. FA is found to reduce the severity of the lines most effectively.

6. CONCLUSION

Contingency assessment and appropriate control methodologies of the system post-contingency condition is a mandatory requirement. In this paper-

- Generator Contingency analysis of 30 and 57 bus system has been performed.
- An appropriate location for the IPFC converters both by severity approach is set up to reduce the system severity.
- The IPFC parameters have successfully been tuned using FA for the multi-objective function. Improvement in security margin reduces congestion in the line. Reduction in losses progresses the power transfer capability of the system. Thus, the overall system condition is improved post-contingency with the application of IPFC.

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