Composite Severity Contingency Distribution Index based Contingency Management of Power System

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***Abstract*—Secured and uninterrupted operation of the power systems has become a great challenge. The load on the practical power systems vary through the day, month and year. Thus making the task of the power system engineers much more complicated. In this paper, a novel index, namely, composite severity contingency distribution index (CSCDI) has been proposed in order to find the severe-most line of the system under contingency condition in real time scenario. Contingency analysis for each hour load of the IEEE 30 bus system has been performed. CSCDI has been calculated for each line of the system and the result obtained indicates the stress on the lines due to contingency for varied load throughout the day. An IPFC has been optimally placed to improve the post-contingency condition. The device has further been tuned for a multi-objective function using differential evolution algorithm. The results obtained have been presented and analyzed to emphasize on the advantages of IPFC for post-contingency management in a real time framework.**

Keywords—Contingency, Interline Power Flow Controller, Differential Evolution, Optimal Placement.

I. INTRODUCTION

There is an increased dependence on electricity in the recent modernized world. Thus, a continuous and uninterrupted electrical supply of electricity has become a mandatory requirement. A total interruption of electric power (blackout) of even a few hours not only cause a heavy financial loss to the industries but can fully collapse even the basic and emergency services of the area. On the contrary, the increased load on the power systems have increased the stress on the transmission lines and hence the chances of its failure is also ever increasing. Hence, there is a primary need for development of an effective technique to manage continuous supply of electricity even in contingency condition.

In the conventional study, the load at a bus is represented by a constant impedance. But in actual practice, the load varies over the day, week and month. Thus, such an assumption may give erroneous result. Therefore, a dynamic model for loads have been developed [1]. But the problem is that different loads have different models and the composition of the loads at a particular bus also varies from time to time and for different seasons of the year [2]. Another approach can be to consider various instances of the system in terms of varying loads, which provides various snapshots of the dynamic load. Thus, the dynamic tendency of the system can be obtained without much complexities. Since, the real time systems replicate the actual power systems very closely, the contingency analysis of real time system can provide a very accurate measure of system severity.Hence, contingency analysis of real time systems is used by the power system engineers for practicalpower system planning and operation issues [3]. Lot of focus is being given recently to improve the speed of computation of real time power system analysis[4-6]. Thus, the scope for more detailed contingency analysis has improved. Contingency analysis can be done based on real-time pricing[7], sensitivity-based methods[8], bounding methods etc. [9]. Sensitivity based methods have been found to be very accurate and at the same time simple and easy to apply.

Line loading and voltage deviation are the two most effected parameters due to outage of a transmission line. Hence, both the factors need to be considered while assessing the severity of the transmission lines. A composite of line loading and voltage stability index has been found very successful in determining the overall severity of the lines [10]. FACTS devices have been found to be very successful in solving various issues related to contingency. IPFC is one of the most recent, flexible and powerful FACTS device [11, 12]. Mishra et al [13] have implemented IPFC on the basis of LUF for overcoming the congestion problem. IPFC has been found to reduce the loading stress on the lines very effectively for static load. Since, LUF measures line loading in terms of MVA, it gives a correct measure of overall line loading for a particular loading condition.For static load condition, a line with maximum LUF is easily classified as the most stressed line. FVSI has been used for the measurement of voltage stability post-contingency by various researchers and has been found to be very successful [14]. Hence, a composite of the above mentioned indices can be used for the measurement of overall stress on the transmission lines in static condition. A real time load can be viewed as a compilation of many static loads. A composite index when applied for the measurement of severity for a real time load may tend to give different values at different loadings. Thus, there is a need to develop a composite index that should consider the loading on the system throughout the day, month or year under normal and contingency condition.It should finally indicate towards one most effected line due to contingency suitable for the placement of a FACTS device for the improvement of post-contingency condition.

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In this paper, a new index, compositeseverity contingency distribution index (CSCDI) has been proposed to measure the percentage increment on the overall stress on the line for real time loading due to contingency. Detailed contingency analysis has been done on an IEEE 30 bus system for real time loading. The severe-most contingency of the system with respect to losses has been determined. Thereafter CSCDI for all the lines has been calculated to obtain the sever-most line of the system. An IPFC has been placed accordingly to reduce the stress on the system post-contingency. The IPFC has been tuned for a multi-objective function using differential evolution algorithm. The multi-objective function comprises of reduction of real power loss, voltage deviation, security margin and reduction of capacity of installed IPFC. Detailed results have been presented and analyzed to prove the effectiveness of the proposed methodology.

II. Proposed Composite Severity contingency distribution index (CSCDI)

Two major indications of severity of a line are voltage deviation and line overloading. Hence, both these factors need to be considered for post contingency assessment and management to avoid further contingencies in the system. Under static conditions composite severity index can be developed as shown in equation 1.

Line utilization factor (LUF) of a line is the ratio of MVA loading on the line to the maximum load. LUF is given by equation (1)

$$LUF_{ij} = \frac{MVA_{ij}}{MVA_{ij\,\max}} \tag{1}$$

For under loaded lines LUF≈0, while for congested (overloaded) lines LUF≥1. For lines with normal loading 0 < LUF < 1.

Fast Voltage Stability Index (FVSI) is a line-based voltage stability indicator given by equation (2)

$$FVSI_{ij} = \frac{4Z^2Q_j}{V_i^2X} \tag{2}$$

A system is considered to be unstable if FVSI ≥ 1.

After obtaining the LUF and FVSI values of all the lines for a particular line outage, the composite severity index is calculated as given in (10).

$$CSI_{ij} = w_1 \times LUF_{ij} + w_2 \times FVSI_{ij} \tag{3}$$

Where w_1, w_2 are the weighting factors

$$w_1 + w_2 = 1 \tag{4}$$

$$w_1 = w_2 = 0.5 \tag{5}$$

CSI if used for the determination of stressed line under contingency condition for real time loading may tend to give different results for each hour. Also, the distribution of severity on the remaining lines due to outage in a given line cannot be determined using CSI alone. CSCDI is an index used to measure the distribution of stress on the lines after contingency for real time loading. The formula is developed as discussed below.Both under loading and overloading of lines can prove to be dangerous to power system. Overloading of lines causes congestion while under loading may lead to Ferranti effect. Similarly, voltage variations have an allowable limit within minimum and maximum values. Hence, the overall stress that the line ij has to endure for different loadings throughout the day can be represented as-

$$Overallstress_{ij} = MaxCSI_{ij} - MinCSI_{ij} \tag{6}$$

For a healthy system, the overall stress on the line may not be alarming. But an outage, may greatly increase the stress on the lines. Let us consider that an outage of line connected between buses k and l occurs. The incremental stress on line ij due to contingency in line kl is termed as CSCDI which is given by-

$$CSCDI_{ij} = \frac{Overallstress_{ij(contingency-kl)}}{Overallstress_{ij(healthy)}} \times \beta \tag{7}$$

i.e.

$$CSCDI_{ij} = \frac{MaxCSI_{ij(Contingency-kl)} - MinCSI_{ij(Contingency-kl)}}{MaxCSI_{ij(Healthy)} - MinCSI_{ij(Healthy)}} \times \beta \tag{8}$$

III. Tuning of IPFC

The IPFC has been tuned for a multi objective function using differential evolution algorithm.

The multi objective function is as given in equation (9)

$$MinF = Min \sum_{i=1\ to\ 4} w_i f_i \tag{9}$$

$$\text{Where } w_1 + w_2 + w_3 + w_4 = 1 \tag{10}$$

$w_1 = w_2 = w_3 = w_4 = 0.25$

w_1, w_2, w_3, w_4 are the weighting factors of the multi-objective function. The objectives chosen for optimization are namely-

A. Minimization of active power loss

$$f_1(x) = \begin{pmatrix} |V_i|^2 G_{ik} - |V_i||V_k|[G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}] \\ -|V_i||V_{sik}|[G_{ik}\cos\theta_{isik} + B_{ik}\sin\theta_{isik}] \end{pmatrix} + \begin{pmatrix} |V_k|^2 G_{ik} - |V_i||V_k|[G_{ik}\cos\theta_{ki} + B_{ik}\sin\theta_{ki}] \\ -|V_k||V_{sik}|[G_{ik}\cos\theta_{ksik} + B_{ik}\sin\theta_{ksik}] \end{pmatrix} \tag{11}$$

B. Minimization of voltage deviation

$$f_2(x) = \left(\sum_{k=1}^{Nbus} |V_k - V_k^{ref}|^2\right) \tag{12}$$

$V_k$is the voltage magnitude at bus k

C. Minimization of security margin

$$f_3(x) = \frac{\sum_{j \in J_L} S_j^{\lim} - \sum_{j \in J_L} S_j^{initial}}{\sum_{j \in J_L} S_j^{\lim}} \quad (13)$$

D. Minimization of total capacity of installed IPFC

$$f_4(x) = \left(Vse_{ij} \left(\frac{\overline{V_i - Vse_{ij} - V_j}}{Z_{ij}} \right) \right)^2 + \left(Vse_{ik} \left(\frac{\overline{V_i - Vse_{ik} - V_k}}{Z_{ik}} \right) \right)^2 \quad (14)$$

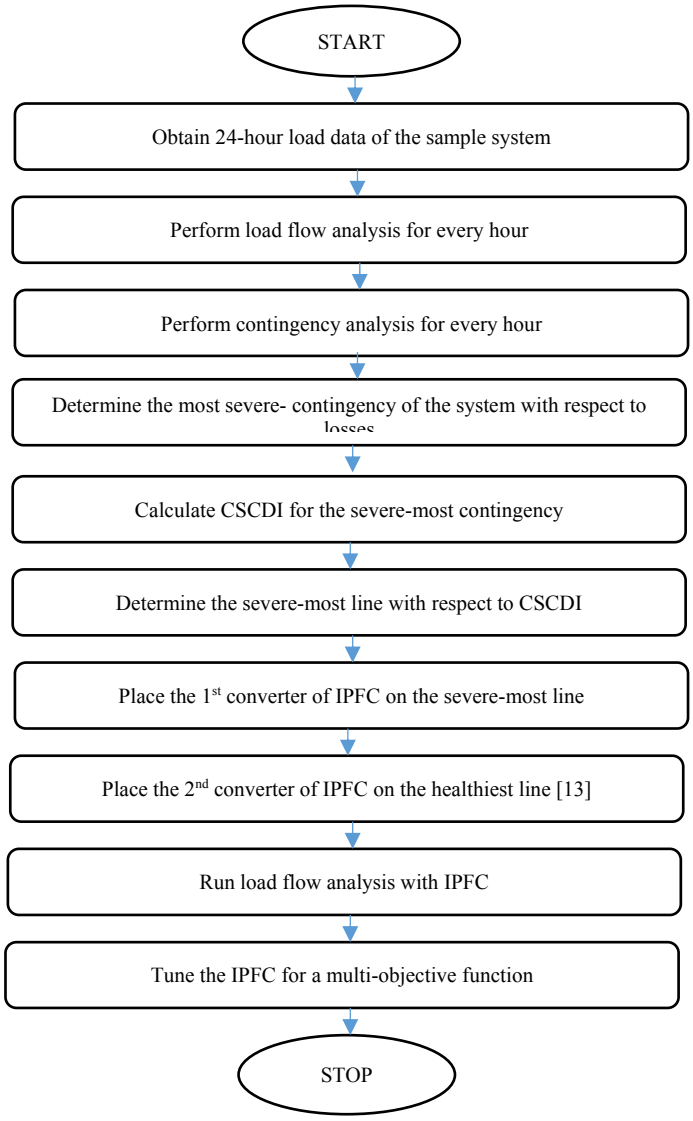

Fig. 1 Flowchart for real-time contingency management

For details regarding the multi-objective optimization please refer[13].The line with highest value of CSCDI for a particular contingency denotes the line under highest stress throughout the day. Thus, CSCDI gives a correct measure of stress on the line due to contingency for real time loading. The steps involved to perform contingency analysis and management using CSCDI has been mentioned in Fig. 1.

IV. Results and Discussion

An IEEE 14 bus system has been considered for analysis. System base MVA is 100. An IPFC with two converters has been considered for the study. The inductivereactance and resistance of the coupling transformers are taken as 0.001 p.u. The voltage magnitude of the two converters of the IPFC is taken in the range $0 \leq Vse \leq 0.1$ and the angle is taken in the range $-\Pi \leq \theta_{se} \leq \Pi$.

The 24 hour active and reactive power demand and loss of the IEEE 14 bus system has been depicted in Fig.2. It is observed that the minimum load of 103.6 MW and 29.4 MVAR occurs on the system at the 4th hour, while, the maximum load of 259 MW and 73.5 MVAR occurs at the 21st hour. The maximum and minimum loss of the system also occur at the 21st and the 4th hour respectively.

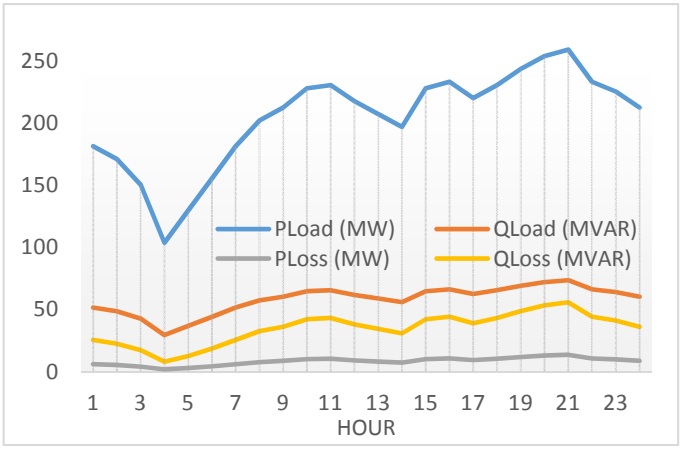

Fig. 2 The 24 hour active and reactive load demand and loss on IEEE 14 bus system

Further, Contingency analysis has been performed and the values of P_{Loss} and Q_{Loss} for each contingency have been mentioned in Table I. From the comparison of the data obtained for each hour, it is observed that outage of line 1-2 causes maximum loss in the system in every hour. Therefore, outage of line 1-2 is considered to be the severe-most contingency of the system. Further, it is observed that the loss in the 21st hour is maximum. The distribution of stress throughout the day due to outage of line 1-2 is calculated for the IEEE 14 bus system. The values of CSCDI of each line has been presented in Table II. It is observed that, on the basis of CSCDI, the line 4-5 is the line under maximum stress throughout the day when a contingency in line 1-2 occurs. Hence, line 4-5 is chosen for the placement of the first converter of IPFC. The second converter of the device is placed on line 4-9, which is the line connected to line 4-5 with least stress as shown from Table II. The tuning of IPFC for the proposed multi-objective function proposed above has been carried out using Firefly algorithm (FA). The value of the FA parameters chosen are mentioned in Table III.

TABLE I. COMPARISON OF ACTIVE AND REACTIVE POWER LOSS AFTER EVERY CONTINGENCY FOR ALL 24 HOUR

Line outage Fb-Tb	21st hour P_{Loss}(MW)	Q_{Loss}(MVAR)
1-2	42.4	178.2
1-5	21.2	78.3
2-3	24.6	86.3
2-4	15.5	65.6
2-5	14.5	61.0

TABLE II. CSCDI OF ALL LINES OF 14 BUS SYSTEM FOR REAL TIME LOADING FOR LINE 1-2 CONTINGENCY

Line connected between buses (from bus –to bus)	Stress in healthy state (p.u.)	Stress under contingency (p.u.)	CSCDI (p.u.)
2-3	0.4463	0.2607	0.58
2-4	0.3129	0.0559	0.18
2-5	0.2132	0.4113	1.93
4-5	**0.3954**	**1.0351**	**2.62**
4-7	0.148	0.1352	0.91
4-9	0.0985	0.078	0.79
5-6	0.2492	0.3201	1.28
6-11	0.0533	0.0882	1.65
6-12	0.0508	0.0556	1.09
6-13	0.1189	0.1373	1.15
7-8	0.0642	0.1396	2.17
7-9	0.2031	0.179	0.88
9-10	0.0325	0.0038	0.12
9-14	0.0585	0.0388	0.66
10-11	0.0284	0.0606	2.13
12-13	0.0114	0.0159	1.39
13-14	0.038	0.0602	1.58

TABLE III. VALUES OF THE PARAMETERS OF FA USED FOR TUNING IPFC

S. No.	Parameter	Value
1.	No. of Fireflies	20
2.	Maximum generations	50
3.	Alpha (Randomness)	0.5
4.	Beta	0.5
5.	Gamma	1

In Fig. 3 the CSCDI of lines without and with IPFC has been depicted. It is observed that the stress on the lines, measured in terms of CSCDI is more evenly distributed after the placement of IPFC. CSCDI of line 4-5 is considerably reduced after the placement of IPFC while the same for line 4-9 has increased. Thus, the capability of IPFC to transfer power from overloaded line to under loaded line has been helpful for the reduction of stress on the overloaded line and its redistribution on the under loaded lines.

Fig. 4, 5, 6 and 7 show the active power loss, reactive power loss, voltage deviation, and security margin respectively of the 14 bus system. It is observed that placement and tuning of IPFC considerably reduces the above parameters, thereby improving the system performance for real time 24 hour loading scenario. Fig. 8 shows that tuning of IPFC considerably reduces the installed capacity of the device, thus reducing installation cost.

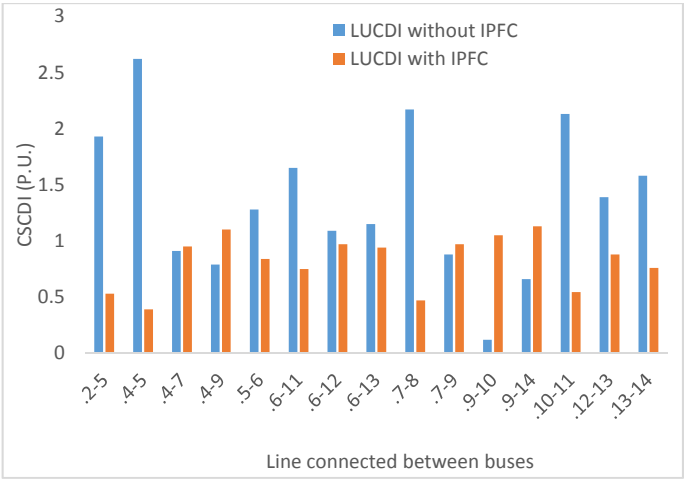

Fig. 3 Comparison of CSCDI of sample lines without and with IPFC for outage of line connected between buses 1-2

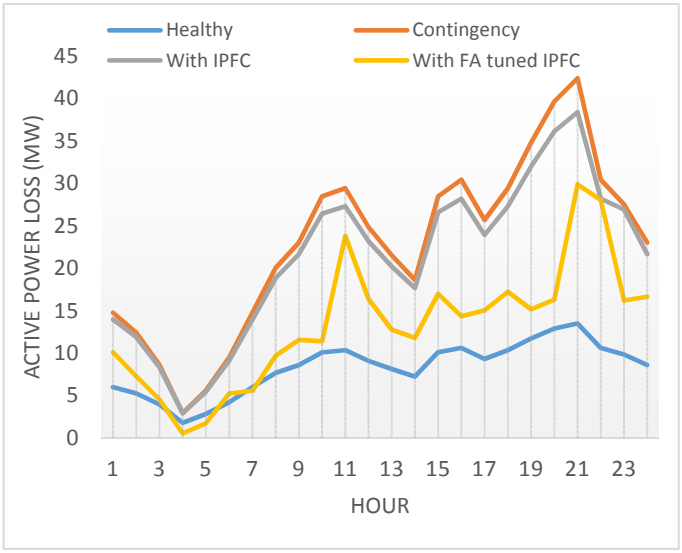

Fig. 4 Active power loss for contingency in line 1-2 for 24 hour real time loading

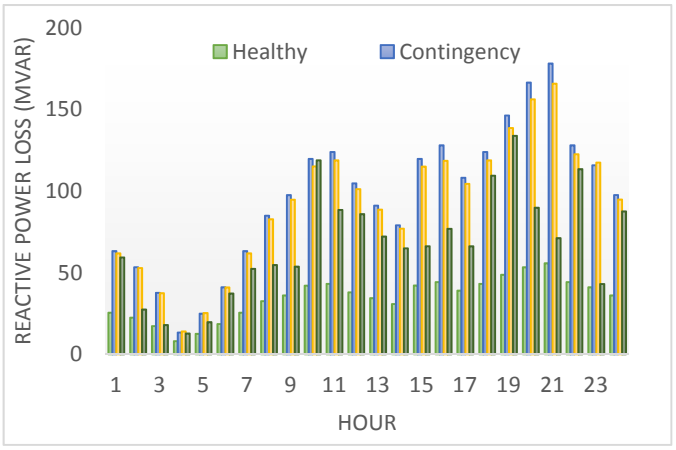

Fig. 5 Reactive power loss for contingency in line 1-2 for 24 hour real time loading

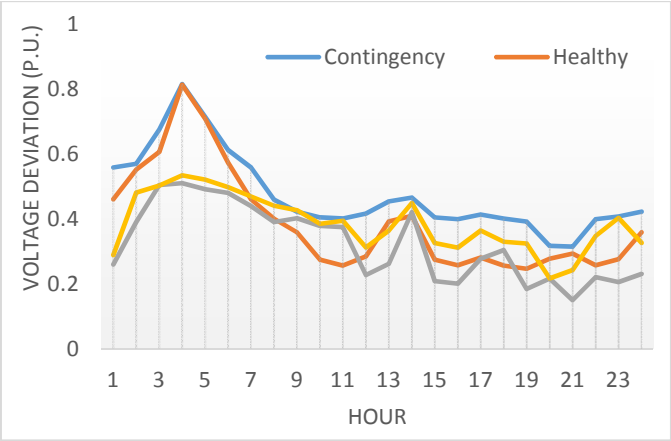

Fig. 6 Voltage deviation for contingency in line 1-2 for 24 hour real time loading

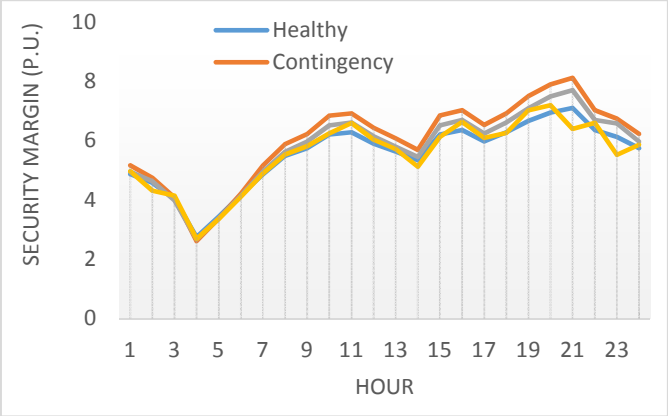

Fig. 7 Security margin for contingency in line 1-2 for 24 hour real time loading

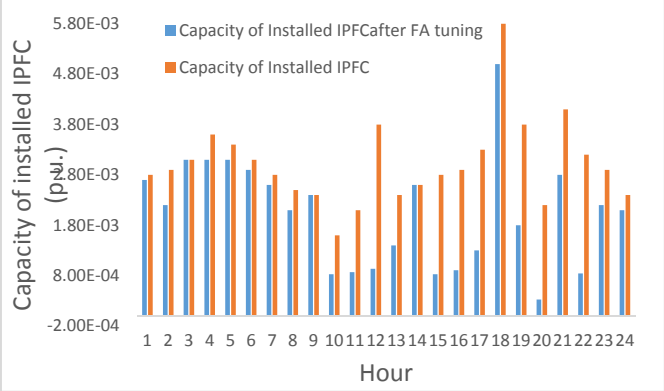

Fig. 8 Capacity of installed IPFC for contingency in line 1-2 for 24 hour real time loading

V. CONCLUSION

This paper deeply analyzes the system performance in healthy and contingency condition and proposes a new index especially suited for a real time loading scenario on power systems. The following are the major contributions of the paper

- Proposal and application of CSCDI for determination of the severe-most line of the system for 24 hour loading on an IEEE 14 bus system.
- Placement of IPFC on the severe-most line on the basis of CSCDI for the improvement of post-contingency conditions. It has been demonstrated that the stress on the transmission lines after the placement of IPFC is more evenly distributed, thus reducing the chances of further contingencies.
- Multi-objective tuning of IPFC using firefly algorithm for further improvement of the performance of the device and reduction of its installed capacity. The multi-objective function consists of reduction of real power loss, voltage deviation, security margin and capacity of installed IPFC. Reduction of real power loss improves the power transfer capability of the system. Reduction of voltage deviation improves the voltage profile of the system. Reduction in security margin reduces congestion in the power system. Thus, the overall performance of the system has been enhanced under normal and contingency condition.

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