Contingency Assessment of Electric Power System by Calculation of Unequal Priority Factors for Static Severity Indices using Analytic Hierarchy Process

Samrat Malakar[1], M. K. Maharana[2]

[1]M. Tech, Power & Energy Systems, School of Electrical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, India

[2]Associate Professor, School of Electrical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, India

Abstract: ***Contingency analysis of electric power system operation, is considered as the most vital concern of its security appraisal. Present days, on-line security assessment is carried out by contingency ranking, with the help of various computing techniques. One of the iterative methods is Newton Raphson power flow method for obtaining the magnitudes of different parameters. The intention of contingency ranking is to create a short list of possible potential threats quickly and rank them according to their severity in an accurate manner. In this paper a static security assessment based approach is presented for contingency ranking, incorporating analytic hierarchy process as an improvement to the conventional power flow based ranking techniques. The proposed method is employed to choose proper unequal priority factors for the weighted severity index. The usefulness of the technique has been verified on IEEE 14 bus system and the results are presented with a detailed comparison, with the help of Network Graphical Overlays for pre and post-contingent states of power system.***

Keywords: Contingency ranking, Static security assessment, Severity index, Priority factor, Analytic hierarchy process

1. Introduction

Contingencies are expressed as a specified set of events occurring within a short duration of time, which actually indicates loss or failure of one or more components on power system [1]. In the experience of an unintended (or spontaneous) apparatus outage, contingency analysis gives the operators a clue, of what might ensue to the power system [2]. It is basically a computational software continuously run in an energy management system, simulating a hypothetical test on a list of conjectural cases, which would generate line flow, voltage or reactive power violations. These cases are recognized and graded according to their level of severity using contingency ranking algorithm [3].

Usually the procedure of contingency analysis can be classified as, contingency definition, selection and evaluation [4], but in present days the selection and the evaluation both steps are done in same segment. For more than three decades many work has been done on contingency selection, aiming at reducing the primary extensive list of contingencies, by choosing the cases with severe limit violations only [5]–[8]. This selection is accomplished by mainly two methods, i.e., contingency ranking and contingency screening. The screening methods are local solution based analysis, which basically gives top priority to the most severe cases for detailed ac analysis, at the same time the non-critical cases are removed from the list [6]. Another method is ranking method, which uses a system performance index as a scalar function to illustrate the effects of an outage on the whole system [9]–[13].

In the present work, the effort has been made towards contingency ranking incorporating Analytic Hierarchy Process, for calculating the unequal weights for the weighted severity index. At first the contingency list is processed, which contains the cases whose chance of arising is estimated amply high. Then the large list is routinely rendered into electrical network transformations: usually generator and/or line outages. Detailed AC power flow is then carried out on the consecutive distinctive cases in declining order of severity for contingency evaluation. Then up to the spot where no post-contingency infringement are met, or until a precise time has been elapsed, the process is continued. The proposed technique has been verified on IEEE 14 bus system and the network graphical overlays are depicted in order to express its effectiveness for contingency ranking.

2. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criterion decision making approach which was introduced by Saaty (1977 and 1994) [14]. Due to its simplified mathematical properties and the fact that the required input data are somewhat effortless to achieve it has engrossed the concern of many researchers. The AHP is applicable as a decision support tool, as it is used for selecting one alternative from a set of alternatives and for determining the relative merit of a set of alternatives. It provides a way of decomposing the problem into a pecking order of sub problems which can more easily be realized and intuitively evaluated. These individual assessments are then transformed into numerical values and processed to rank each alternative on a numerical scale.

During power system operation, the assignment of priority factors to individual buses and transmission lines is influenced by the significance of the particular bus and transmission line respectively. Therefore, power system operation has noteworthy impact on the judgment of experts for suitable priority factor assortment to be imposed on severity index. The application of AHP for priority factor selection is based on inquiries requested from experts.

The inquiries can be just categorized as:
(a) What is the priority of *i*th bus compared to *j*th bus?
(b) What is the priority of *i*th line compared to *j*th line?

The exact predilection values based on the above two inquiries given in Table 1, should be selected by each expert, based on their previous experience or may be from the results of conventional contingency ranking scenario. A numerical value is allocated to each answer from Table 1. Then, the priority factors are calculated in accordance with numerical average value for the solutions contributed by experts, from decision matrix (DM) by AHP [15], [16].

Table1: Range of prefference values

Numerical Values of priority	Definition
1	Two options have equal priority
3	One has week priority over another
5	One of the options have strong priority
7	One of the options have significant priority
9	Supreme priority of one option over another
2, 4, 6, 8	Intermediate values between two adjacent judgments
Reciprocals of above nonzero	If option *i* has one of the above nonzero numbers allotted to it when compared with option *j*, then j has the reciprocal value when compared with *i*

Assume the decision matrix of a four bus power system shown in Figure 1, based on proficient views associated to voltage security (i.e. $|V_i|-|V_i^{SP}|$) for all buses of this sample system is:

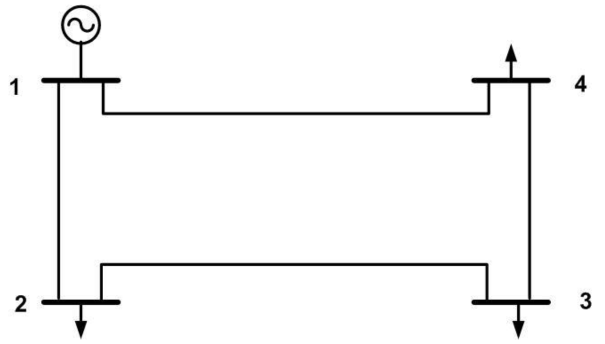


Figure 1: Four bus power system

$$W_{DM}=\begin{array}{c|cccc} & \text{Bus 1} & \text{Bus 2} & \text{Bus 3} & \text{Bus 4} \\ \hline \text{Bus 1} & 1 & 2 & 4 & 2 \\ \text{Bus 2} & \frac{1}{2} & 1 & 2 & 3 \\ \text{Bus 3} & \frac{1}{4} & \frac{1}{2} & 1 & 2 \\ \text{Bus 4} & \frac{1}{2} & \frac{1}{3} & \frac{1}{2} & 1 \end{array} \quad (1)$$

In W_{DM} it is clear that, from the experts' point of view the priority of voltage security in bus 1 is twice compared to voltage security in bus 2. Likewise, the priority (importance) of voltage security in bus 2 is half of the priority of voltage security in bus 1. Also, it can be understood that the diagonal elements of decision matrix (W_{DM}) is equal to unity all the times. Now for the formulation of the AHP technique, we will go after these steps:

- *Step 1*: The columns of W_{DM} are added, thus:

$$W_{DM}^{1}=\begin{array}{c|cccc} & \text{Bus 1} & \text{Bus 2} & \text{Bus 3} & \text{Bus 4} \\ \hline \text{Bus 1} & 1 & 2 & 4 & 2 \\ \text{Bus 2} & \frac{1}{2} & 1 & 2 & 3 \\ \text{Bus 3} & \frac{1}{4} & \frac{1}{2} & 1 & 2 \\ \text{Bus 4} & \frac{1}{2} & \frac{1}{3} & \frac{1}{2} & 1 \\ \text{Sum} & \frac{9}{4} & \frac{23}{6} & \frac{15}{2} & 8 \end{array} \quad (2)$$

- *Step 2*: Each elements of the decision matrix (W_{DM}) are divided in specific columns to sum of its own column given in W_{DM}^{1}, thus:

$$W_{DM}^{2}=\begin{array}{c|cccc} & \text{Bus 1} & \text{Bus 2} & \text{Bus 3} & \text{Bus 4} \\ \hline \text{Bus 1} & \frac{4}{9} & \frac{12}{23} & \frac{8}{15} & \frac{1}{4} \\ \text{Bus 2} & \frac{2}{9} & \frac{6}{23} & \frac{4}{15} & \frac{3}{8} \\ \text{Bus 3} & \frac{1}{9} & \frac{3}{23} & \frac{2}{15} & \frac{1}{4} \\ \text{Bus 4} & \frac{2}{9} & \frac{2}{23} & \frac{1}{15} & \frac{1}{8} \end{array} \quad (3)$$

- *Step 3: The mean value of each row in* W_{DM}^{2} *are calculated, thus:*

$$W_{DM}^{3}=\begin{array}{c|ccccc} & \text{Bus 1} & \text{Bus 2} & \text{Bus 3} & \text{Bus 4} & \text{mean} \\ \hline \text{Bus 1} & 0.444 & 0.522 & 0.533 & 0.25 & 0.437 \\ \text{Bus 2} & 0.222 & 0.261 & 0.267 & 0.375 & 0.281 \\ \text{Bus 3} & 0.111 & 0.130 & 0.133 & 0.25 & 0.156 \\ \text{Bus 4} & 0.222 & 0.087 & 0.067 & 0.125 & 0.125 \\ \text{sum} & 1 & 1 & 1 & 1 & 1 \end{array} \quad (4)$$

This column matrix expressing the mean values is called the right eigenvector of the comparison matrix. These elements of the normalized eigenvectors are termed importance or priorities with respect to the criteria and ratings with respect to the alternatives, are also used to derive the principal eigenvalue. This principle eigenvalue is used to evaluate the consistency ratio (CR) of the previously calculated decision matrix, which according to Saaty (1994) should be less than 0.1 [16]–[19]. In our case we have the CR of 0.0872 for the four bus system. Therefore for the specified power system the calculated priority factors are:

$$W_1 = 0.437,\ W_2 = 0.281,\ W_3 = 0.156,\ W_4 = 0.125$$

These results indicate that bus 1 is the most important bus from the AHP method based on hypothesis experts' viewpoint, on the topic of voltage security importance in the power system shown in Fig. 1. It can be made obvious that the same procedure could be implemented in order to calculate priority factors for line flow security (i.e. $\frac{P_l}{P_l^{lim}}$).

3. System Severity Index

The deviation of system variables such as line flows, bus voltages, from its rated value is measured by the system severity index. It is also used to evaluate the relative stability of a contingency [2], [20].

3.1 Voltage Severity Index "SI_V"

The system deficiency due to out-of limit bus voltages is defined by the voltage severity index [2], [20].

$$SI_V=\sum_{i=1}^{NB}\left(\frac{W_{vi}}{2n}\right)\left(\frac{(|V_i|-|V_i^{SP}|)}{\Delta V_i^{lim}}\right)^{2n} \quad (5)$$

Where $|V_i|$ is the voltage magnitude at bus i, $|V_i^{sp}|$ the specified (rated) voltage magnitude at bus i, $|\Delta V_i^{lim}|$ is the voltage deviation limit, $|\Delta V_i^{lim}|$ is the average of V_{imax} and V_{imin} which are the maximum and minimum voltage limits of the ith bus respectively, higher than which voltage variations are intolerable. n is the exponent of penalty factor (n= 1), NB is the total number of buses in the system, W_{vi} the real non-negative weighting factor (W_{vi}=1). The voltage variation ΔV_i^{lim} symbolize the verge, higher than which the voltage level difference are outside their restrictions. The harshness of the voltage profile on buses with out-of limit voltages and the relative severity of the contingencies for different outages are measured by this severity index.

3.2 Real Power Severity Index "SI$_P$"

A manifestation for measuring the degree of overloads of lines can be expressed in terms of real power severity index [2], [20].

$$SI_P = \sum_{i=1}^{NL} \left(\frac{W_{li}}{2n}\right)\left(\frac{P_l}{P_l^{lim}}\right)^{2n} \quad (6)$$

Where, P_l the real power flow of line l, P_l^{lim} the maximum endurance of active power flow e of line l, NL the number of lines of the system, W_{li} real nonnegative weighting factor (W_{li}=1), n is the exponent of penalty factor (n=1). The severity index SI$_P$ contains all normalized line flows, elevated to an even power setting (by selecting n = 1, 2...n), thus the use of absolute magnitude of flows is avoided. The value of maximum power flow in each line is calculated using the formula:

$$P_l^{lim} = \frac{V_i * V_j}{x_l} \quad (7)$$

Where, V_i = Voltage at bus i obtained from NRPF solution, V_j = Voltage at bus j obtained from NRPF solution, x_l = Reactance of the line linking bus i and bus j. For calculation of SI$_V$ it is required to know the maximum and minimum voltage limits, generally a margin of 5 percent is kept for assigning the limits. The boundary is normally 1.05 P.U. for maximum and 0.95 P.U. for minimum limits respectively . To obtain the value of SI for each contingency the lines in the bus system are being numbered as per convenience, then a particular transmission line and/or a generator at a time is simulated for outage condition and the individual power flows and the bus voltages are being calculated with the help of Newton-Raphson power flow solution.

Apparently, there is no clear suggestion on how to choose the weighting factors and hence, are usually considered to be equal. In the present paper we use the mentioned severity index widely for contingency ranking in static security appraisal. So we apply the Analytic Hierarchy Process (AHP) to correct the proper unequal weighting factor values in the given equations, to offer more precise and practical contingency ranking. These factors are termed as the priority factors. This approach corrects the errors in ranking due to the assumption of the weighting factors as unity in the conventional methods.

4. Contingency Assessment

The priority factors for the respective lines and buses are first calculated using AHP in MATLAB coding environment following by a consistency check of its calculated weights, from the decision matrix. Then the data are fed into the contingency ranking algorithm while calculating severity index for the bus voltages and line flows. Further the power system analysis toolbox (PSAT) is used to develop the Network Graphical Overlays, which is a MATLAB-based Open Source software (OSS), certified by IEEE for electric power system simulation and analysis [20].

In the present work the active power flows and magnitude of bus voltages are obtained from Newton Raphson power flow, which is achieved using MATLAB coding and followed by a detailed comparison via Network Graphical Overlays, for pre-contingency and post-contingency state of the system using PSAT (ver.2.2). The Figure 2 shows the flow chart for the simplified severity index based power system contingency ranking, incorporating AHP for calculation of priority factors.

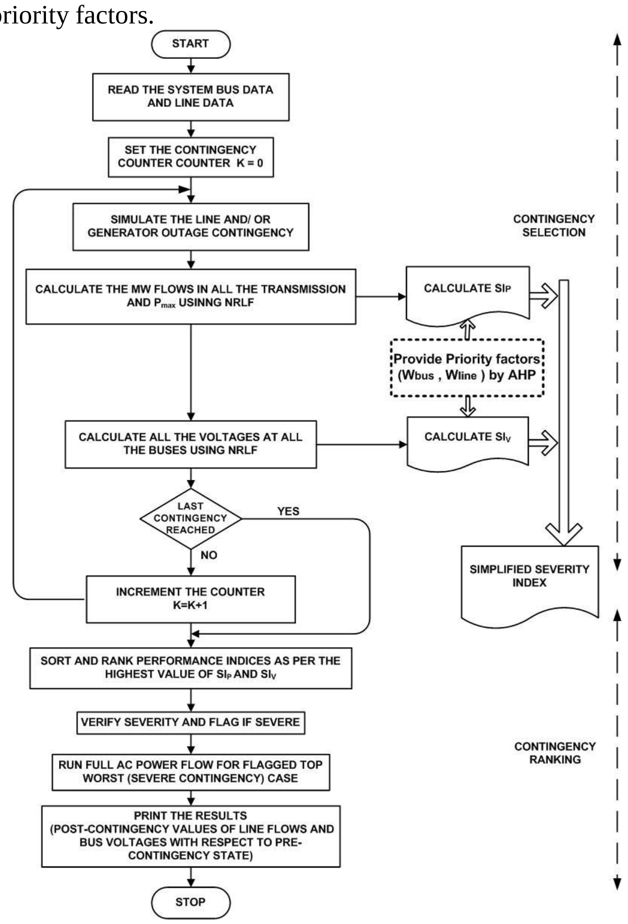


Figure 2: Flowchart for contingency ranking using Analytic Hierarchy Process

5. Results and Discussion

To demonstrate the effectiveness of the proposed analytic hierarchy approach, contingency ranking is performed on IEEE 14 bus system which is shown in Figure 3. The system consists of 5 synchronous generators including 3 synchronous condensers, 14 buses, 20 lines and 1 shunt capacitor.

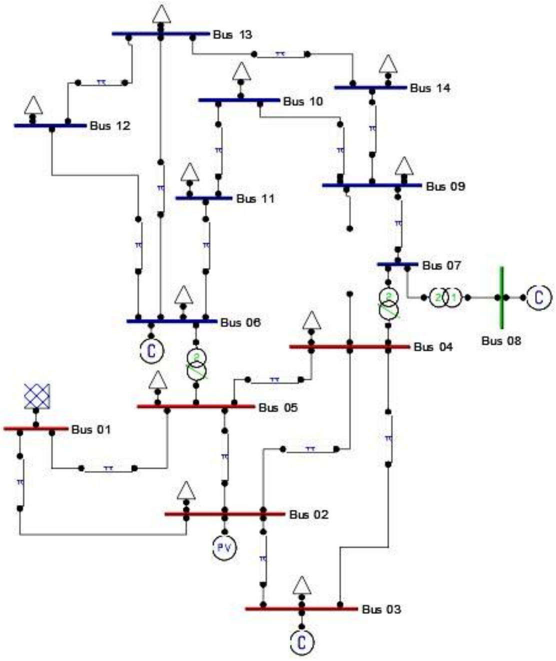


Figure 3: Equivalent simulation diagram of IEEE 14 bus system

The priority factors of the 14 buses are evaluated before demonstrating the simulation result, which is tabulated in Table 2.

Table 2: Priority factors for buses obtained by AHP

Bus	Priority Factor
1	0.13320000
2	0.10910000
3	0.11620000
4	0.11110000
5	0.08400000
6	0.07700000
7	0.07550000
8	0.06900000
9	0.05670000
10	0.04720000
11	0.03550000
12	0.02690000
13	0.03570000
14	0.02290000

Similarly the priority factors of 20 lines of the test power system are presented are presented in Table 3.

Table 3: Priority factors for lines obtained by AHP

Line Number	From Bus	To Bus	Priority Factor
1	1	2	0.06644446
2	2	3	0.05125154
3	2	4	0.03943731
4	1	5	0.04740199
5	2	5	0.06037220
6	3	4	0.06139875
7	4	5	0.05985670
8	5	6	0.04410364
9	4	7	0.05211741
10	7	8	0.04625939
11	4	9	0.05620352
12	7	9	0.05171349
13	9	10	0.00428919
14	6	11	0.05919837
15	6	12	0.05608748
16	6	13	0.00417537
17	9	14	0.05671457
18	10	11	0.06199013
19	12	13	0.05628163
20	13	14	0.05557197

The consistency ratios of the decision matrices are 0.0994 and 0.091 respectively. The pre-contingency state and base case power flow of the IEEE 14 bus system is shown in Figure 4.

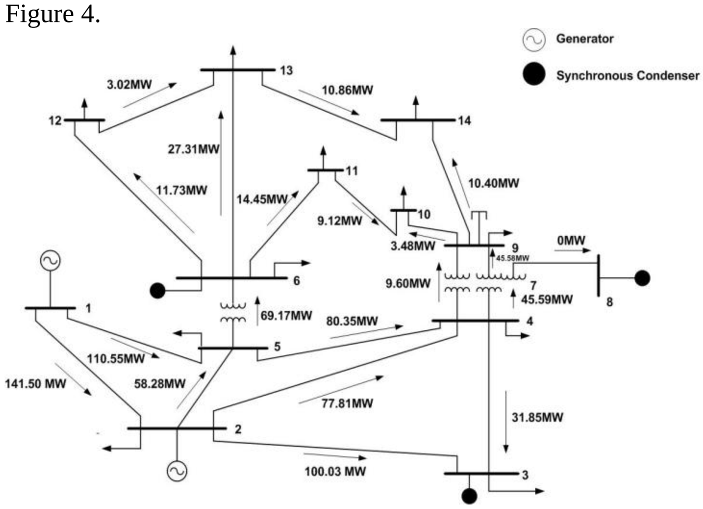


Figure 4: Pre-contingency state of IEEE 14 system

The ranking of the contingency cases incorporating line and/or generator outage has been detailed in Table 4.

Table 4: AHP based contingency ranking of IEEE 14 bus system

Contingency No.	*Type Of Outage*	*From Bus*	*To Bus*	*SI_P*	*SI_V*	*SSI*	*Rank*
1	Line	1	2	71.8200	2.7520	74.570	1
2	Line	2	3	1.2940	2.0870	3.3812	9
3	Line	2	4	0.4901	1.9646	2.4546	12
4	Line	1	5	0.6026	1.0923	1.6949	21
5	Line	2	5	0.5339	1.1699	1.7038	20
6	Line	3	4	0.8024	1.2368	2.0390	17
7	Line	4	5	0.5496	6.1611	6.7108	5
8	Line	5	6	2.9795	5.7691	8.7486	4
9	Line	4	7	0.4043	5.1387	5.5430	7
10	Line	7	8	35.371	3.3923	38.763	2
11	Line	4	9	0.5664	2.6689	3.2350	10
12	Line	7	9	0.8570	5.7732	6.6300	6
13	Line	9	10	0.6849	0.5243	1.2092	23
14	Line	6	11	0.6158	3.1795	3.7953	8

15	Line	6	12	0.6470	0.9152	1.5622	22
16	Line	6	13	0.7676	0.0280	0.7956	24
17	Line	9	14	0.8649	10.344	11.208	3
18	Line	10	11	0.6739	2.2230	2.8969	11
19	Line	12	13	0.6769	1.2923	1.9692	19
20	Line	13	14	0.6941	0.0074	0.7015	25
21	Generator	G1	G1	0.6712	1.3972	2.0684	16
22	Generator	G2	G2	0.5701	1.4467	2.0168	18
23	Generator	G3	G3	0.6712	1.3972	2.0685	13
24	Generator	G6	G6	0.6712	1.3972	2.0685	14
25	Generator	G8	G8	0.6712	1.3972	2.0685	15

From the contingency ranking list it can be seen that, the first contingency case was identified as most severe as it forces the power systems to make its transition into the emergency state, upon its occurrence. So this contingency due to the outage of the line between bus 1 and bus 2 is elaborated and parameters of the post contingent states are also explained. The post-contingency state of the system after the occurrence of the outage is shown in Figure 5.

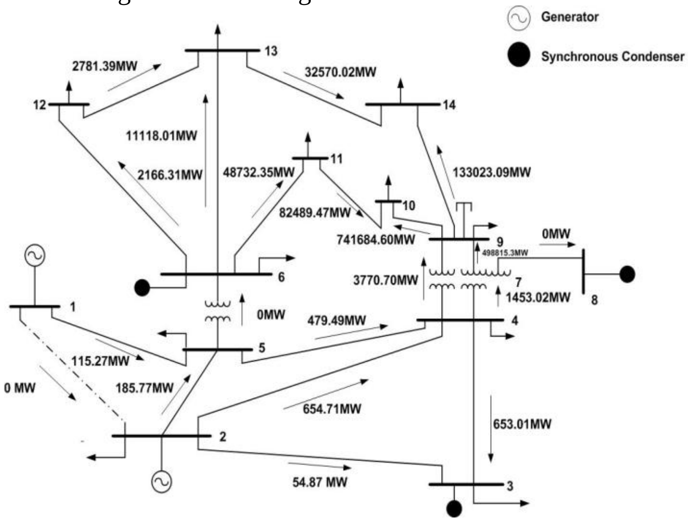


Figure 5: Post-contingency state of the IEEE 14 bus system after the outage of the line between bus 1 and bus 2

The pre and post-contingency values of the bus voltage magnitudes are presented in Table 5 along with the limit violations.

Table 5: Bus voltage magnitudes of pre-contingency and post-contingency state

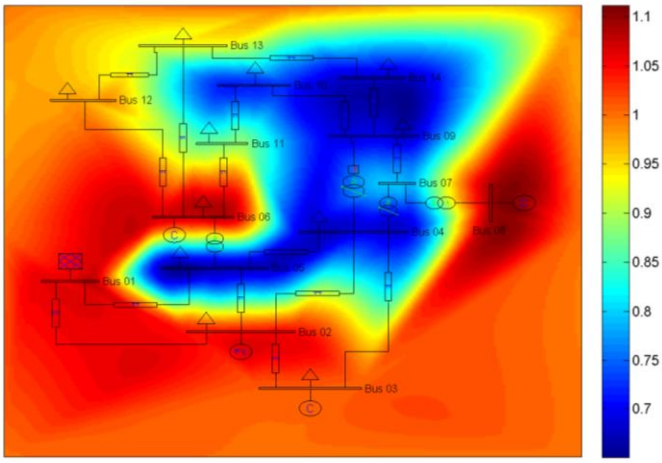
Bus No.	Pre-contingency Voltage (p.u)	Post-contingency Voltage (p.u)	Limit Violation
1	1.06	1.06	No
2	1.045	1.045	No
3	1.01	1.01	No
4	0.99772	0.83721	Yes
5	1.0024	0	Yes
6	1.07	1.07	No
7	1.0347	2.35873	Yes
8	1.09	1.09	No
9	1.0111	2.99623	Yes
10	1.0105	2.65655	Yes
11	1.0346	1.45976	Yes
12	1.0461	3.517	Yes
13	1.0362	6.1084	Yes
14	0.99568	2.18274	Yes

Similarly, the pre and post-contingency values of the line flows are detailed in Table 6 along with the limit violations.

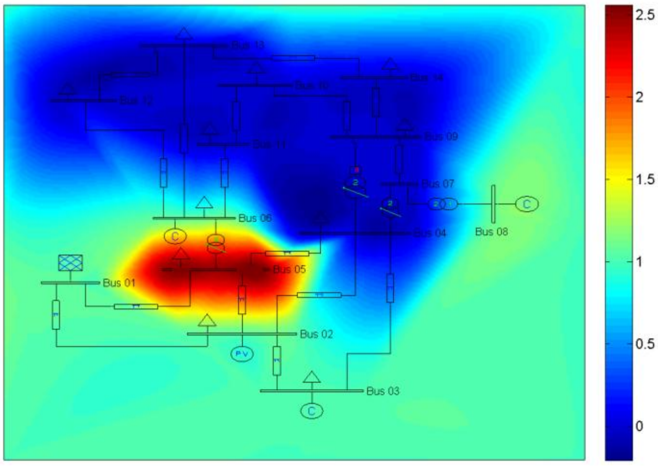
Table 6: Line flows for pre-contingency and post-contingency state

From Bus	To Bus	Pre-contingency MW Flow	Post-contingency MW Flow	Limit Violation
1	2	141.4974	0	Outage
2	3	100.0314	54.8678	No
2	4	77.8081	654.7052	Yes
1	5	110.5549	115.27	No
2	5	58.2781	185.7687	Yes
3	4	31.8486	653.0107	Yes
4	5	80.3531	479.4949	Yes
5	6	69.1681	0.0003	No
4	7	45.5864	1453.0238	Yes
7	8	0	0	No
4	9	9.5983	3770.2954	Yes
7	9	45.5864	498815.3077	Yes
9	10	3.4796	741684.6092	Yes
6	11	14.4494	48732.353	Yes
6	12	11.7258	2166.3097	Yes
6	13	27.3128	11118.0123	Yes
9	14	10.4001	133023.0877	Yes
10	11	9.1243	82489.4662	Yes
12	13	3.0168	2781.3947	Yes
13	14	10.8573	32570.0206	Yes

From the comparisons of Table 5 and 6 it is evident that the specified contingency has made severe limit violations, thus it cannot be taken care of and it will result in complete loss of load or voltage collapse. The scenario is better understood with the network graphical overlays of the bus voltages comparison, for the pre-contingency and post-contingency state of the power system given in Figure 6.



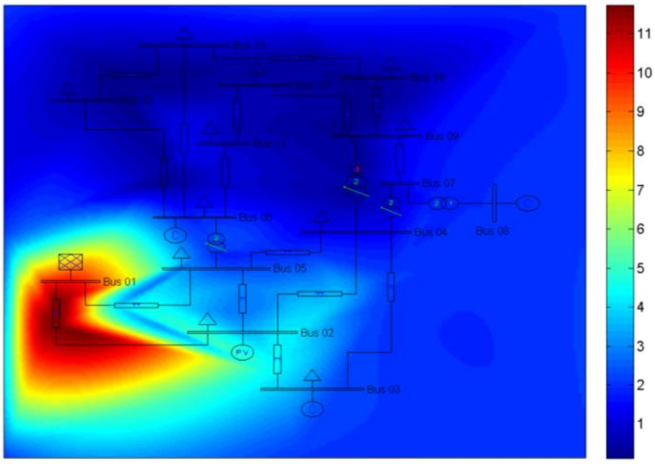
(a) Pre-contingency bus voltage magnitudes



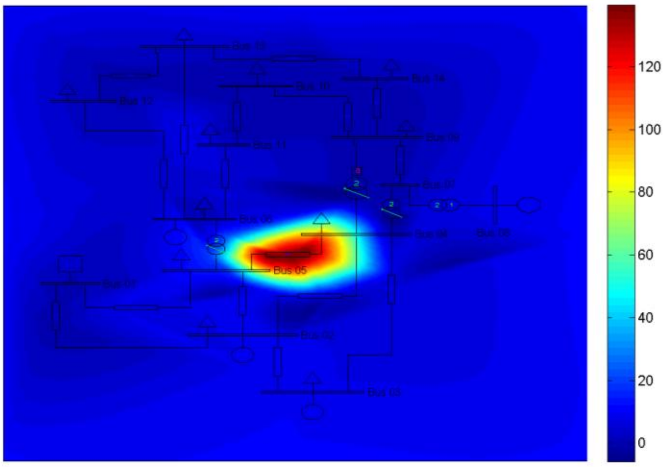
(b) Post-contingency bus voltage magnitudes

Figure 6: Network graphical overlays of the bus voltage for IEEE 14 bus system

Similarly the network graphical overlays for the line flows for the pre-contingency and post-contingency state of the power system are given in Figure 7.



(a) Pre-contingency line flows



(b) Post-contingency line flows

Figure 7: Network graphical overlays of the line flows for IEEE 14 bus system

6. Conclusion

In this paper, an Analytic Hierarchy Process based approach has been developed for contingency ranking. The present approach incorporates severity index, related to the priority factors adjustment of the bus bars and transmission lines. The usefulness of the proposed approach has been demonstrated on IEEE 14 bus power system and detailed comparison is portrayed with the help of network graphical overlays. A more accurate and realistic ranking can be obtained by the proposed method. Thus, it is expected that the proposed approach can serve as an on-line operational aid to operators.

References

[1] L. H. Fink and K. Carlsen, "Operating under stress and strain.", IEEE spectrum, vol. 15, pp. 48-53, Mar. 1978.

[2] K. S. Swarup and G. Sudhakar, "Neural network approach to contingency screening and ranking in power system." Neurocomputing 70, vol. 1, pp. 105-118, June 2006.

[3] G. C. Ejebe, and B. F. Wollenberg "Automatic contingency selection.", IEEE Transactions on Power Apparatus and Systems, vol. 1, pp. 97-109, Feb. 1979.

[4] Brian Stott O. Alsac, and A. J. Monticelli, "Security analysis and optimization.", Proceedings of the IEEE 75, vol. 12, pp. 1623-1644, 1987.

[5] A. J. Wood and B. F. Wollenberg, "Power generation, operation, and control.", John Wiley & Sons, 2012.

[6] J Zaborszky, K. Whang and K. Prasad, "Fast contingency evaluation using concentric relaxation.", IEEE Transactions on Power Apparatus and Systems, vol. 1, pp. 28-36, 1980.

[7] V. Brandwajn and M. G. Lauby, "Complete bounding method for AC contingency screening.", IEEE Transactions on Power Systems, vol. 4, pp. 724-729, 1989.

[8] N. M. Peterson, W. F. Tinney and D. W. Bree, "Iterative linear AC power flow solution for fast approximate outage studies.", IEEE Transactions on Power Apparatus and Systems, vol. 5, pp. 2048-2056, 1972.

[9] C. Y. Lee,, and N. Chen, "Distribution factors of reactive power flow in transmission line and transformer outage studies.", IEEE Transactions on Power Systems, vol. 1, pp. 194-200, 1992.

[10] S. N. Singh and S. C. Srivastava, "Improved voltage and reactive power distribution factors for outage studies.", IEEE Transactions on Power Systems, vol. 3, pp. 1085-1093, 1993.

[11] F. Albuyeh, A. Bose, and B. Heath, "Reactive power considerations in automatic contingency selection.", IEEE Transactions on Power Apparatus and Systems, vol. 1, pp. 107-112, 1982.

[12] M. K. Maharana, and K. Shanti Swarup. "Identification of Operating States of Power System Using Transient Stability Analysis.", In Power System Technology and IEEE Power India Conference, 2008. POWERCON 2008. Joint International Conference on, pp. 1-6. IEEE, 2008.

[13] M. K. Maharana, and K. Shanti Swarup. "A corrective strategy to alleviate overloading in transmission lines based on particle swarm optimization method.", The Journal of Engineering Research, Vol. 7, No. 1, pp. 31-41, 2010.

[14] Thomas L. Saaty, What is the analytic hierarchy process?. Springer Berlin Heidelberg, 1988.

[15] N. Bhushan and Kanwal Rai, "Strategic decision making: applying the analytic hierarchy process", Springer Science & Business Media, 2004.
[16] H. R. Baghaee. and M. Abedi. "Calculation of weighting factors of static security indices used in contingency ranking of power systems based on fuzzy logic and analytical hierarchy process.", International Journal of Electrical Power & Energy Systems, vol. 33, no. 4 pp. 855-860, 2011.
[17] E. Triantaphyllou, and Stuart H. Mann. "Using the analytic hierarchy process for decision making in engineering applications: some challenges.", International Journal of Industrial Engineering: Applications and Practice, Vol. 2, no. 1, pp. 35-44, 1995.
[18] Saaty, Thomas L. "How to make a decision: the analytic hierarchy process.", European journal of operational research, vol. 48, no. 1, pp. 9-26, 1990.
[19] M. K. Maharana and Samrat Malakar, "Sensitivity Based Network Contingency Ranking Using Newton Raphson Power Flow Method", International Journal of Scientific Engineering and Technology, Volume No.4, Issue No.2, pp. 45-49, 2015.
[20] L. Vanfretti, F. Milano, "Application of the PSAT, an Open Source Software for Educational and Research Purposes", pp. 7803-6672, IEEE 2001.
[21] V. Terzija, G. Valverde, D. Cai, P. Regulski, V. Madani, J. Fitch, S. Skok, M. M. Begovic, and A. Phadke. "Wide-area monitoring, protection, and control of future electric power networks.", Proceedings of the IEEE, vol. 99, no. 1, pp. 80-93, 2011

Author Profile

Samrat Malakar completed B. Tech in Electrical Engineering first class in 2013 and pursuing M. Tech in Power Engineering & Energy Systems, from KIIT University, Bhubaneswar, India. His Research interested on Power System Contingency analysis, Power System Voltage Security. He is at KIIT University, Bhubaneswar, India

Dr. M. K. Maharana received M. Tech from NIT-Warangal and PhD from IIT Madras. He is currently working as Associate professor and working in many areas in KIIT University, his area of interest is Power System Security, Power System Operation and Control, contingency analysis, smart grid etc. He presented many research papers in National and International conferences.