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Sensitivity Based Network Contingency Ranking Using Newton Raphson Power Flow Method

M. K. Maharana, Samrat Malakar
School of Electrical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, India

Abstract: In the area of power system planning and operation, contingency analysis plays an important role. In the present days, on-line security assessment is done by contingency ranking, with the help of various computer software, incorporating iterative method like Newton Raphson power flow for obtaining the magnitudes of different parameters. The motive of contingency ranking is to create a short list of potential contingencies quickly and rank them according to their severity in an accurate manner. In this paper sensitivity based wide performance index with respect to outage have been presented. The Newton-Raphson power flow results were used to construct two kinds of performance indices, namely the real power performance index and voltage performance index, which reflect the degree of severity of contingencies. Then full AC load flow was performed for each contingency case, to study the contingency effect. The effectiveness of the proposed method has been demonstrated by contingency screening and ranking on a standard 6-bus and IEEE 14-bus system.

Keywords— Power system security, Contingency assessment, Newton Raphson power flow, Simplified performance index

I. 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 event of an unplanned (or unscheduled) equipment outage, contingency analysis gives the operators an indication, of what might happen to the power system [2]. It is basically a software application run in an energy management system, simulating a hypothetical test on a list of conjectural cases, which would create line flow, voltage or reactive power violations. These cases are identified and ranked in order of their severity using contingency ranking algorithm [3].

Usually contingency analysis is segregated into three parts, 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 specially, whose aim is to reduce the original long list of contingencies by selecting only the cases with severe limit violations [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 describe the effects of an outage on the whole network [9-10].

In the present work, the effort has been given on contingency ranking. At first the contingency list is processed, which contents those cases whose probability of occurrence is estimated sufficiently high. The list, which is normally large, is automatically translated into electrical network changes: normally generator and/or branch outages. Contingency evaluation using full AC load flow is then performed on the successive individual cases in decreasing order of severity. The process is continued up to the point where no post-contingency violations are encountered, or until a specified time has elapsed.

II. SYSTEM PERFORMANCE INDEX

The deviation of system variables such as line flows, bus voltages, from its rated value is measured by the system performance index. It is also used to evaluate the relative stability of a contingency [11].

A. Voltage performance index "PI_V"

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

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

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 i[th] bus respectively, above which voltage deviations are unacceptable. n is the exponent of penalty function (n= 1), NB the number of buses in the system, W_{vi} the real non-negative weighting factor (W_{vi}=1). The voltage deviation ΔV_i^{lim} represents the threshold, above which the voltage level deviations are outside their limits, any contingency power flow with voltage levels outside this limit yields a high value of the index PI_V. When all the voltage level deviations from the rated voltage are within $|\Delta V_i^{lim}|$, the voltage performance index PI_V is small. Thus, this index measures the severity of the bus voltages which are out-of limits and for a set of contingencies, this index provides a direct means of comparing the relative severity of the different outages on the system voltage profile.

B. MW performance index "PI_{MW}"

An index for quantifying the extent of line overloads may be defined in terms of MW performance index [2].

$$PI_{MW} = \sum_{i=1}^{NL} \left(\frac{W_{li}}{2n}\right)\left(\frac{P_l}{P_l^{\lim}}\right)^{2n} \qquad (2)$$

Where P_l the MW flow of line l, P_l^{lim} the MW capacity 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 function (n=1). The performance index PI_{MW} contains all line flows normalized by their limits. These normalized flows are raised to an even power (by setting 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:

$$P_l^{\lim} = \frac{V_i * V_j}{x_l} \qquad (3)$$

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 connecting bus i and bus j. For calculation of PI_V it is required to know the maximum and minimum voltage limits, generally a margin of + 5% is kept for assigning the limits i.e., 1.05 P.U. for maximum and 0.95 P.U. for minimum. To obtain the value of PI 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.

III. CONTINGENCY ASSESSMENT

Power system analysis toolbox (PSAT) is a MATLAB-based Open Source software (OSS) certified by IEEE for electric power system simulation and analysis [12]. In the present work the active, reactive power flows and magnitude of bus voltages are obtained from Newton Raphson power flow, which is achieved using PSAT (ver.2.2), along with associated simulation in MATLAB environment. These values are further used in the performance index, for the evaluation process of contingency analysis.

The *Fig.1* shows the flow chart for the simplified performance index based power system contingency ranking.

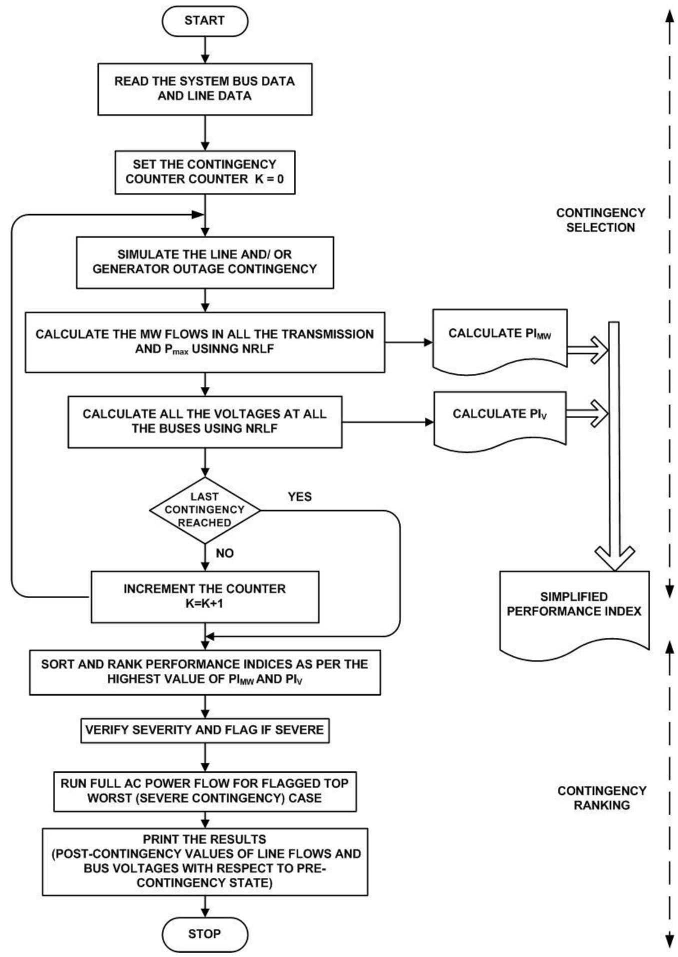

Figure 1 Flow chart for contingency ranking using Newton Raphson power flow

IV. RESULTS AND DISCUSSION

The main focus here is to perform the contingency selection and ranking, by calculating the active power and voltage performance indices i.e. PI_P and PI_V respectively. The contingencies are then ranked where the most severe contingency is the one which is having the highest simplified performance index value. The computation of these indices has been done based on power flow analysis carried out using Newton Raphson power flow (NRPF) under MATLAB environment. The most severe contingency is then chosen from the contingency list and the corresponding power flows and bus voltages are analysed for the entire system. The study has been carried out for the standard 6 bus system and for the IEEE-14 bus system.

A. Standard 6 bus system

The active power flow in each transmission lines for a standard 6 bus test system has been obtained using NRPF corresponding to the base case loading condition is shown in Figure 2. This state of the system corresponds to the pre contingency state. The system has a total eleven numbers of transmission lines and three numbers of generators, hence we evaluate total of fourteen contingency scenarios. The performance indices are summarized in the Table 1. The

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contingencies have been ordered by their ranking where the most severe contingency is being ranked 1 and the least has been ranked 14.

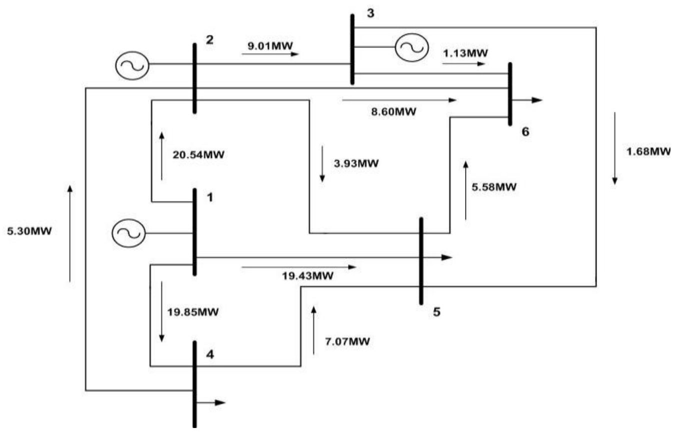

Figure 1 Pre-contingency state of standard 6 bus system

Table 1 Performance Index screening and ranking for standard 6 bus system

From Bus	To Bus	Line No	Type	PI_{MW} (n=1)	Rank	PI_V (n=1)	Rank
1	2	1	Line	0.2136	4	0.9455	7
1	4	2	Line	0.4046	1	0.9307	10
1	5	3	Line	0.3327	2	0.9509	5
2	3	4	Line	0.1312	13	0.9345	9
2	4	5	Line	0.2353	3	0.9355	8
2	5	6	Line	0.1523	9	0.9513	3
2	6	7	Line	0.1380	12	0.9771	2
3	5	8	Line	0.1551	8	0.9043	12
3	6	9	Line	0.1706	7	0.8505	13
4	5	10	Line	0.1430	11	0.9520	4
5	6	11	Line	0.1511	10	0.9474	6
G1	G1	12	Generator	0.0151	14	0.9049	11
G2	G2	13	Generator	0.1906	5	0.9775	1

From the performance index table, it is somewhat confusing to rank the outages as, both the indices flags different contingencies as most severe. Thus the *simplified performance indices* (SPI) are utilized to solve the above difficulties. Table 2 represents the rank of contingencies, based on their SPI. The simulation yields a result that the outage scenario line 2, which is between bus-1 and bus-4, is the most severe one. So it is flagged as severe as per the implemented algorithm, and Newton-Raphson power flow analysis is performed to analyse the post-contingency state of the standard 6 bus systems.

Table 2 Simplified performance indices screening and ranking for standard 6 bus system.

From Bus	To Bus	Line No	Type	SPI	Rank
1	2	1	Line	1.1591	5
1	4	2	Line	1.3353	1
1	5	3	Line	1.2836	2
2	3	4	Line	1.0657	10
2	4	5	Line	1.1708	3
2	5	6	Line	1.1036	7
2	6	7	Line	1.1151	6
3	5	8	Line	1.0594	11
3	6	9	Line	1.0211	12
4	5	10	Line	1.0943	9
5	6	11	Line	1.0985	8
G1	G1	12	Generator	0.9200	13
G2	G2	13	Generator	1.1681	4

For the outage phenomenon of line 2, which is between bus-1 to bus-4, the post-contingency values of bus voltages and line flows, corresponding to the pre contingency state and the post contingency state are represented in the table 3 and table 4 respectively.

Table 3 Bus voltages in the pre and post contingency state.

Bus No.	Pre-contingency voltage (p.u)	Post-contingency voltage (p.u)
1	1.05	1.05
2	1.05	1.05
3	1.07	1.044
4	1.05	1.049
5	1.053	1.044
6	1.06	1.044

Table 4 Active power flows in the lines for pre and post contingency state.

From Bus	To Bus	Pre-contingency MW flow	Post-contingency MW flow
1	2	20.54	30.17
1	4	19.85	0
1	5	19.43	25.71
2	3	9.01	8.38
2	4	5.3	6.3
2	5	3.93	2.82
2	6	8.6	7.9
3	5	1.68	1
3	6	1.13	1.19
4	5	7.07	3.39
5	6	5.58	6.23

The post-contingency state of the system, after the outage of the line connected between bus-1 and bus-4 has been represented in Figure 3.

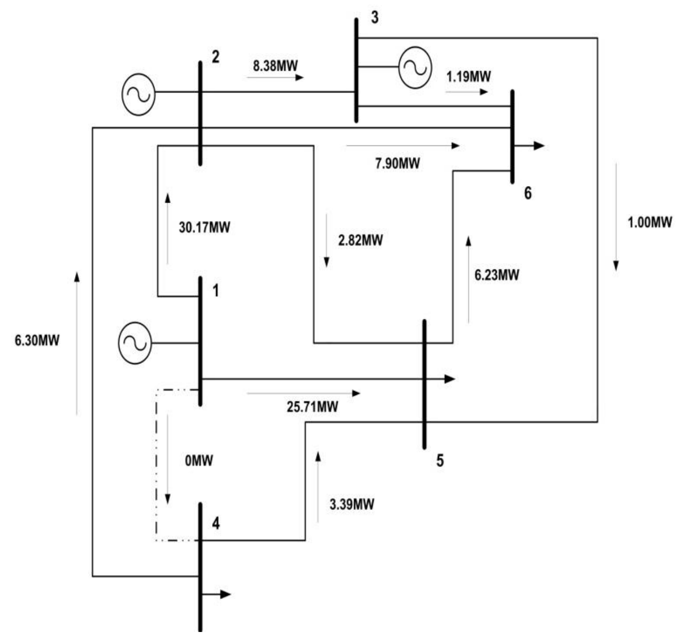

Figure 2 Post-contingency state of standard 6 bus system.

B. IEEE-14 bus system

The active power flow for IEEE-14 bus system is shown in Figure 4. Similarly for IEEE-14 bus system the simulation yields a result that the outage scenario line 4, which is between bus-1 and bus-5, is the most severe one. So it is flagged as severe as per the previously implemented algorithm, and Newton-Raphson power flow analysis is performed to represent the post-contingency state of the IEEE-14 bus power system. The performance indices are summarized in the Table 5 and Table 6 represents the rank of contingencies, based on their SPI.

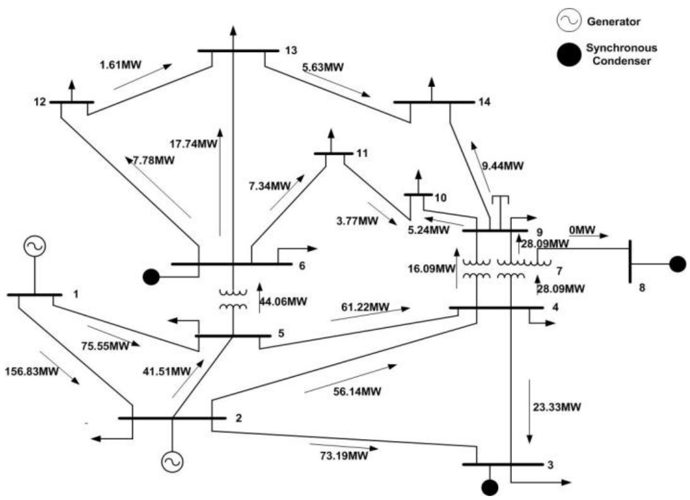

Figure 3 Pre-contingency state of IEEE-14 bus system

Table 5 Performance Index screening and ranking for IEEE-14 bus system

From Bus	To Bus	Line No	Type	PI_{MW}	Rank	PI_V	Rank
1	2	1	Line	1.0851	12	1.9569	5
2	3	2	Line	0.9695	20	1.8264	15
2	4	3	Line	0.8941	21	1.8283	14
1	5	4	Line	2.5424	1	1.7865	17
2	5	5	Line	0.8903	22	1.8865	12
3	4	6	Line	1.1647	4	2.0023	1
4	5	7	Line	1.3978	3	1.7876	16
5	6	8	Line	1.1497	5	1.0498	22
4	7	9	Line	1.0791	18	1.9467	7
7	8	10	Line	1.0812	17	1.9469	6
4	9	11	Line	1.0822	16	1.9072	10
7	9	12	Line	1.0767	19	1.6409	20
9	10	13	Line	1.0830	15	1.9050	11
6	11	14	Line	1.0910	7	1.7088	19
6	12	15	Line	1.0879	9	1.7817	18
6	13	16	Line	1.0973	6	1.5492	21
9	14	17	Line	1.0849	14	1.9697	3
10	11	18	Line	1.0878	10	1.9233	9
12	13	19	Line	1.0854	11	1.9712	2
13	14	20	Line	1.0892	8	1.8813	13
G1	G1	21	Generator	1.0852	13	1.9569	4
G2	G2	22	Generator	1.6309	2	1.9286	8

Table 6 Simplified performance indices screening for IEEE-14 bus system

From Bus	To Bus	Line No	Type	SPI	Rank
1	2	1	Line	3.0420	8
2	3	2	Line	2.7959	17
2	4	3	Line	2.7224	19
1	5	4	Line	4.3289	1
2	5	5	Line	2.7768	18
3	4	6	Line	3.1670	4
4	5	7	Line	3.1854	3
5	6	8	Line	2.1995	22
4	7	9	Line	3.0258	10
7	8	10	Line	3.0281	9
4	9	11	Line	2.9894	12
7	9	12	Line	2.7176	20
9	10	13	Line	2.9880	13
6	11	14	Line	2.7998	16
6	12	15	Line	2.8696	15
6	13	16	Line	2.6465	21
9	14	17	Line	3.0546	6
10	11	18	Line	3.0111	11
12	13	19	Line	3.0566	5
13	14	20	Line	2.9705	14
G1	G1	21	Generator	3.0421	7
G2	G2	22	Generator	3.5595	2

For the outage phenomenon of line 4, which is between bus-1 to bus-5, the post-contingency values of bus voltages and line flows, corresponding to the pre contingency state and the post contingency state are represented in the table 7 and table 8 respectively.

Table 7 Bus voltages in the pre and post contingency state.

Bus No	Pre-contingency voltage (p.u.)	Post-contingency voltage (p.u.)
1	1.06	1.06
2	1.045	1.036
3	1.01	1.01
4	1.019	1.006
5	1.02	1.003
6	1.07	1.07
7	1.062	1.056
8	1.09	1.09
9	1.056	1.052
10	1.051	1.047
11	1.057	1.055
12	1.055	1.055
13	1.05	1.05
14	1.036	1.033

Table 8 Active power flows in the lines for pre and post contingency state.

From Bus	To Bus	Pre-contingency MW flow	Post-contingency MW flow
1	2	156.83	240.06
2	3	73.19	87.1
2	4	56.14	83.31
1	5	75.55	0
2	5	41.51	77.95
3	4	-23.33	-10.42
4	5	-61.22	-24.74
5	6	44.06	42.27
4	7	28.09	29.25
7	8	0	0
4	9	16.09	16.72
7	9	28.09	29.25
9	10	5.24	6.37
6	11	7.34	6.21
6	12	7.78	7.68
6	13	17.74	17.19
9	14	9.44	10.1
10	11	-3.77	-2.64
12	13	1.61	1.51
13	14	5.63	4.98

The post-contingency state of the system, after the outage of the line connected between bus-1 and bus-5 has been represented in Figure 5.

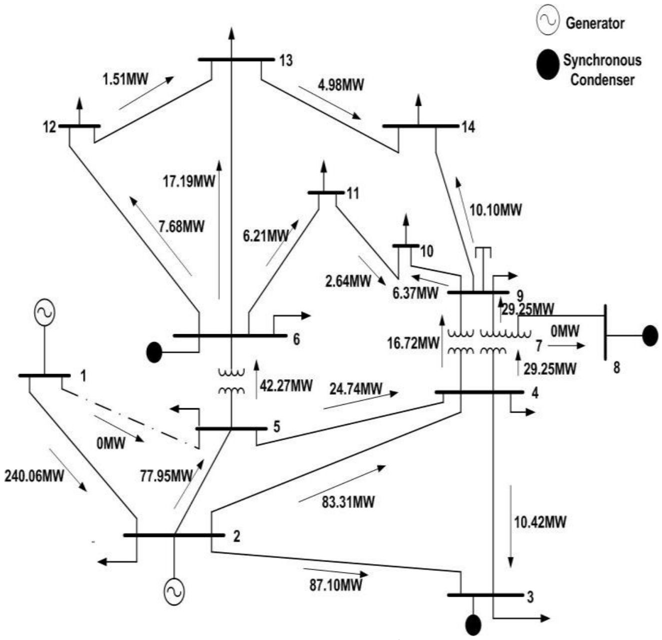

Figure 4 Post-contingency state of IEEE-14-bus system

V. CONCLUSION

The methods of contingency ranking using sensitivity factors have been presented. The analysis with AC power flow using NRPF is found most suitable in the approach of contingency selection, as it played a very important role in eliminating the large number of contingency cases and focused on the most severe contingency case. From the results, it can be concluded, that the calculation of performance indices gives a good measure of the cases, which has the highest potential to make the system parameters to go beyond their limits. Calculation of SPI are also obtained, in order to increase the accuracy of the sorting and ranking technique of the contingency analysis process.

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