Khan Aafreen Int. Journal of Engineering Research and Applications www.ijera.com
ISSN : 2248-9622, Vol. 4, Issue 11(Version - 5), November 2014, pp.11-18

RESEARCH ARTICLE OPEN ACCESS

Continuation Power Flow Method based Assessment of Static Voltage Stability considering the Power System Contingencies

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ABSTRACT
Power system security is recognized as one of the major problems in many power systems throughout the world. Power system insecurity such as transmission lines being overloaded causes transmission elements cascade outages, which may lead to complete blackout. In accordance with these reasons, the prediction and recognition of voltage instability in power system has particular importance and it makes the network security stronger. This work, by considering the power system contingencies based on the effects of them on Mega Watt Margin (MWM) and maximum loading point (MLP) is focused to analyse the voltage stability using continuation power flow method. The study has been carried out on IEEE 30-Bus Test System using MATLAB and PSAT softwares and results are presented.

I. INTRODUCTION

In the modern competitive electric energy market, power systems are more heavily loaded than ever before because of the rising demands, maximum economic benefits and efficiency of usage of transmission capacity [1].The more efficient use of transmission network has already led to a condition in which many power systems are operated more often longer and closer to voltage stability limit that results in a higher probability of voltage instability or collapse [2,3].Voltage collapse is a phenomenon that may cause serious consequences for power systems, as observed in many reported occurrences around the world. Therefore, voltage stability analysis has become a major concern in power systems planning and operation, and deals with power system adequacy and security. In order to improve the utilization of generation resources and the transmission capacity, the voltage stability margins and control actions have to be determined in the planning and in the real-time operation phases, not only for normal operating conditions (base case) but also for different operating points and contingency conditions. [4-7]

Contingency analysis is a key characteristic of power system security and plays an important role in real-time power system security assessment. Contingency analysis involves the simulation of a set of contingencies in which the system behaviour is observed. Each post-contingent scenario is assessed in order to detect operational problems and the severity of violations. The process of identifying these critical contingencies is referred to as contingency selection [8]. A number of researches have been carried out in this area in the last few years, which consists of the selection of the worst contingency cases by using ranking methods or screening methods. The majority of methods are based on the evaluation by means of some Performance Index (PI). Ranking methods rank the contingencies in estimated order of severity, based on the value of a performance index, which is the measure of system stress expressed in terms of network variables and are directly evaluated [9]. Ranking all probable contingencies based on their impact on the system voltage profile will assist the operators in choosing the most suitable remedial actions before the system moves toward voltage collapse [10].

In [11], surveying possible contingencies with ranking based on to line FVSI indicator is carried out. A method of ranking the possible contingency based on right eigenvector and branch parameter in [12] is given. A three layer perceptron network with back propagation learning technique has been used for line flow and voltage contingency screening [13].A hybrid Decision Tree (DT) based approach for fast voltage contingency screening and ranking for on-line applications in energy management systems is proposed in [14]. Contingency screening for steady-state security analysis by using Fast Fourier Transform (FFT) and ANN is employed by authors in [15].Fuzzified multilayer perceptron network is developed in [16, 17] for voltage contingency screening and ranking.

This work, by considering the power system contingencies based on the effects of them on Mega

Watt Margin (MWM) and maximum loading point is focused to analyse the voltage stability using continuation power flow method.[18] The applicability and effectiveness of the proposed methodology have been investigated on IEEE 30-Bus Test System using MATLAB and PSAT softwares and results are presented.

II. VOLTAGE STABILITY ANALYSIS ANS CONTINGENCY ANALYSIS

The voltage stability margins are generally defined as the difference between the value of a key system parameter at the current operating condition and at the voltage stability critical point.[19]The V–λ curve presents the variation of load voltage magnitude (V) with the increase of the loading (λ) of an area load or power transfer across an interface. Each event in power system would alter the configuration of network that would results in contraction of $V-\lambda$ curve and so as to decrease of Maximum Loading Point (MLP) and its corresponding MWM. Therefore for an ideal condition when system does not experience a contingency and all components work perfectly, system can prepare MLP and Maximum Mega Watt Margin (MMWM). A number of possible contingencies have been experienced in power system that may results in overload in some of lines and/or bus voltages deviation from their allowed limit so that the position of the weakest bus may change.

Figure. 1 shows $V-\lambda$ curve with MLP and Megawatt margin in pre and post case contingencies. The electric power system may have been operating at a stable equilibrium point however, a contingency at maximum loading point may cause system to be unstable or position where there is no solution to the system equations. The main reason, for low voltage profile in case of some contingency and therefore smaller MWM, is the insufficient reactive power in the vicinity of the low voltage buses [3, 20-21]. There may have been some severe contingencies with very low loading that are a small function of maximum loading, while for some other contingencies, the loading margin is near to its maximum.

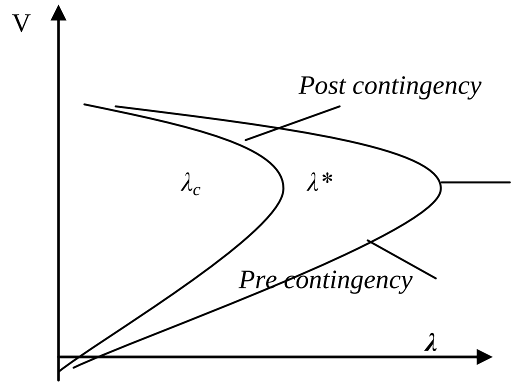

Fig. 1 Voltage Collapse Point at Pre-Contingency and Post-Contingency.

Contingency analysis is a software application run in an energy management system to give the operators an signal of what might take place to the power system in the occurrence of an unplanned (or unscheduled) equipment outage [22]. Contingency analysis is carried out to consider the effect of specified contingencies on the system security and to alert the system operators in relation to the critical contingencies that violate the equipment operating limits and/or make the system to voltage and angle instability or excessive frequency deviations. The most common limit violations include transmission line and/or transformer thermal overloads and inadequate voltage levels at system buses. System operator based on this information may judge the relative severity of each contingency and decide if preventive actions should be initiated to mitigate the potential problems [13].

The process of identifying these critical contingencies is referred to as contingency Selection and it proposes the utmost potential for computational saving, and has received most development effort. Contingency selection identifies the critical contingencies among them and ranks them in order of their severity. The ranking of insecure contingencies in terms of their severity is known as contingency ranking [23]. Contingency analysis is an important aspect of power system security assessment. As various probable outages compose a contingency set, some cases in the contingency set may lead to transmission line over loads or bus voltage limit violations during power system operations. Such critical contingencies should be quickly identified for further detailed evaluation or, where possible, corrective measures taken.’’.

III. Contingencies Ranking With Continuation Power Flow Method

Contingencies ranking are considered as key attribute in analysing contingencies in power system. In order to rank the severity of contingencies, first we determine the variables of power system using analytical method for each event and afterwards the severity are determined based on performance indicator that is function of these variables. Figure 2 shows the flowchart of ranking for contingencies. Consideration to figure, appearing each contingency (like line outages and/or generation unit outages), the MLP and its consequent MWM decrease percent would be estimated by continuation power flow method. Arranging MLP as ascending and its corresponding MWM decrease percent as descending, contingencies with lower MLP and higher MWM decrease percent set in higher ranks. MMWM and MWM calculate for system as:

$$MMWM = P_{imax} - P_{base}$$
$$MWM = P_{i+1max} - P_{base}$$

Where, P_{max} is maximum load active power corresponding with MLP and P_{base} is base load active power. The MWM decrease percent is also calculated based on this:

$$\text{MWM decrease percent} = 100 \times [1-(\frac{MWM}{MMWM})]$$

In power systems, the numbers of contingencies is dependent the number the elements exposed to failure in the system. For event numbers of L level with NCL: L=0, 1, 2,…, N we have

$$NCL=\frac{N!}{L!(N-L)!}$$

The zero level contingency, NC_0, means no element in the system is subject to failure. Contingency of first level, NC_1 is equal with unique element numbers exposed to failure In power system the total number of all possible contingencies is extensive, so usually the first level or sometimes the second level contingencies are considered. In this paper contingencies of zero level and first level are considered so we have: $NC_L = 1+N$

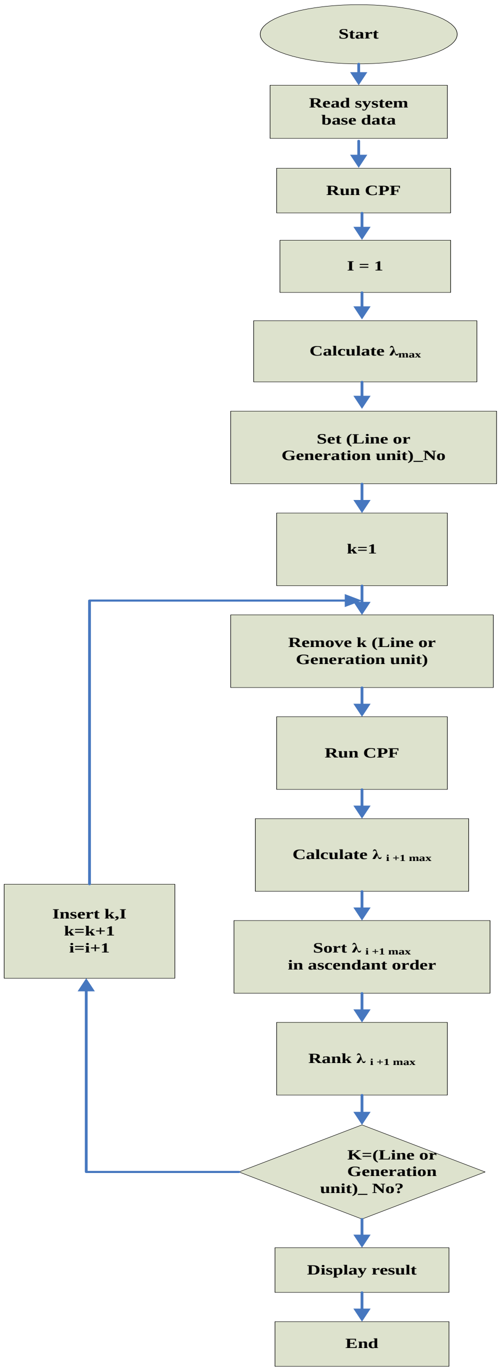

Fig. 2 The flowchart for contingencies ranking of first level.

IV. CASE STUDY AND SIMULATION RESULTS

Case Study

To demonstrate the effectiveness of the proposed methodology, numerical tests have been conducted on the IEEE 30 Bus test systems. In this work, a 30 bus power system is simulated to carry out Continuation Power Flow, results of which are used in Voltage

Stability Assessment. Simulation model are developed in PSAT SOFTWARE and its tool SIMULINK. The IEEE 30 bus system has 6 generation units and bus 1 is considered as slack bus. Also it has 34 transmission lines. In this system generation unit are modelled as standard PV buses and loads are represented as constant PQ loads. The P and Q load powers are not voltage dependent and are assumed to change as follows:

$$P_L = P_{LO}(1 + \lambda)$$
$$Q_L = Q_{LO}(1 + \lambda)$$

Where, P_{L0} and Q_{L0} are the active and reactive base loads, whereas P_L , and Q_L , are the active and reactive loads at bus L for the current operating point as defined by λ .The block diagram of simulated IEEE 30 bus power system is shown in APPENDIX (Fig.3) . The performance characteristics obtained from the simulation have been presented in next section.

V. Simulation Results

The continuation power flow for normal system is done, in a manner that all generation units and lines are connected in the network and no contingencies has occurred in the system. Maximum Loading Point is λ_{max} = 3.9947 *p.u.* Also load active powers are in base and maximum cases are P_{base} = 2.834 *p.u.* and P max = 11.24 *p.u.* respectively. Table 1 shows the results of single generation unit outages applying continuation power flow.

As shown in table 1, in case generation unit outage connected to bus 13, voltage magnitude in MLP at bus 30 that is known as the weakest bus is 0.5226 p.u. Note that in simulation, the generation unit connected to bus 1 that is known as slack bus does not exit from network.

Genera-tion unit outage	**Bus No. with lowest vol-tage magnitude**	**Lowest voltage magnitude in MLP (p.u.)**	**λ_{max} (p.u.)**	**P_{load} (p.u.)**	**Q_{load} (p.u.)**
Bus 2	30	0.7873	3.4675	0.3675	0.06588
Bus 5	5	0.5801	3.2813	3.091	0.62345
Bus 8	30	0.5527	3.873	0.4101	0.07352
Bus 11	30	0.5403	3.7272	0.3944	0.0707
Bus 13	30	0.5226	3.2022	0.3394	0.06084

Table 1 The Results Of Single Generation Unit Outages.

The results of calculation of MWM for contingencies of generation unit outages in zero and one levels are shown in table 2. There are 6 contingencies in zero and first levels. In zero level contingency, all system components are working correctly and system MWM is 8.4058*p.u.*

Contingencies ranking of first level based on their effects in continuum of generation unit outages, we calculate system MWM in each case. In generation unit outage connected to bus 13, MWM and its percent are 6.2409 and 74.24% respectively that is lower than other generation unit outages.

Table 2 The Results Of MWM For Generation Unit Outages In Zero And First Levels.

level	**line Outage**	**Pmax (p.u.)**	**Pbase (p.u.)**	**MWM (p.u.)**	**MWM (%)**
0	No	11.2398	2.834	8.4058	100
1	Bus 2	9.8268	2.834	6.9928	83.190
1	Bus 5	9.2993	2.834	6.4653	76.914
1	Bus 8	10.9655	2.834	8.1315	96.736
1	Bus 11	10.5448	2.834	7.7108	91.731
1	Bus 13	9.0749	2.834	6.2409	74.245

MLP and MWM decrease percent is provided in table 3. This table presents contingencies ranking according to their severity and MLP and MWM decrease percent for single generation unit outages in first level respectively.

Rank	**Generation unit outage**	**λ_{max} (p.u.)**	**MWM decrease (%)**
1	Bus 13	3.2022	25.75484
2	Bus 5	3.2813	23.08525
3	Bus 2	3.4675	16.80982
4	Bus 11	3.7272	8.268101
5	Bus 8	3.873	3.263223

Table 3 Contingency Ranking Of First Level In Single Generation Unit Outages.

Contingencies with lowest MLP and highest MWM decrease percent are at higher rank in table 3. In fact, these severe contingencies can cause to loose system stability. Consideration to table 3, the generation unit outage connected to bus 13 with λ_{max} =3.2022 p.u. and MWM decrease percent 25.75484% are identified as the most critical contingency between contingencies of other generation unit outages.

VI. Simulation results of single line outages with CPF method

Results of single line outages applying continuation power flow are shown in table 4.It is observed that in most line outages cases Bus 30 appears as the weakest bus with lowest voltage magnitude.

The results of calculated MWM for contingencies of line outages in zero and first levels are shown in table 5. Attention to table 5, there are 35 contingencies in zero and first levels.

line Outage	**Bus_No with lowest voltage magnitude**	**lowest voltage magnitude in MLP (p.u.)**	**λ_{max}(p.u.)**
Line 1	30	0.99078	1.5259
Line 2	30	0.66824	3.7387
Line 3	30	0.56852	3.9987
Line 4	7	0.82177	2.9352
Line 5	30	0.70751	3.9684
Line 6	30	0.65557	3.7708
Line 7	30	0.53646	3.4359
Line 8	30	0.57473	3.989
Line 9	30	0.77844	3.4012
Line 10	30	0.54829	3.9337
Line 11	30	0.55518	3.4046
Line 12	30	0.57598	3.988
Line 13	30	0.56551	3.9634
Line 14	30	0.56476	3.9694
Line 15	30	0.56164	3.7562
Line 16	30	0.56606	3.9051
Line 17	30	0.56151	3.9637
Line 18	30	0.5381	3.706
Line 19	30	0.56035	3.971
Line 20	30	0.55092	3.984
Line 21	30	0.56121	3.9589
Line 22	30	0.53441	3.5515
Line 23	30	0.55092	3.978
Line 24	30	0.55156	3.917
Line 25	30	0.56439	3.974
Line 26	30	0.56062	3.981
Line 27	30	0.55193	3.5043
Line 28	30	0.55692	3.6544
Line 29	30	0.57455	3.1486
Line 30	30	0	3e-005
Line 31	30	0.59104	3.7029
Line 32	29	0.53441	2.5634
Line 33	30	0.54368	2.2729
Line 34	30	0.54298	3.1358

Table 4 Results of Single Line Outage

line Outage	**P_{max}(p.u.)**	**P_{base}(p.u.)**	**MWM(p.u.)**	**MWM(%)**
No contingency	11.239	2.834	8.4058	100
Line 1	4.324	2.834	1.4904	17.730
Line 2	10.590	2.834	7.7563	92.273
Line 3	11.199	2.834	8.3653	99.518
Line 4	8.3137	2.834	5.4797	65.189
Line 5	11.148	2.834	8.3142	98.910
Line 6	10.667	2.834	7.8331	93.186
Line 7	9.7373	2.834	6.9033	82.125
Line 8	11.224	2.834	8.3908	99.821
Line 9	9.6364	2.834	6.8024	80.925
Line 10	11.124	2.834	8.2905	98.628
Line 11	9.6488	2.834	6.8148	81.072
Line 12	11.205	2.834	8.3712	99.588
Line 13	11.146	2.834	8.3124	98.888
Line 14	11.149	2.834	8.3151	98.920
Line 15	10.645	2.834	7.8111	92.925
Line 16	11.067	2.834	8.2331	97.945
Line 17	11.147	2.834	8.3134	98.900
Line 18	10.487	2.834	7.6536	91.051
Line 19	11.157	2.834	8.3236	99.022
Line 20	11.183	2.834	8.3491	99.325
Line 21	11.132	2.834	8.2989	98.728
Line 22	10.050	2.834	7.2168	85.855
Line 23	11.166	2.834	8.3325	99.127
Line 24	11.102	2.834	8.4683	100.74
Line 25	11.164	2.834	8.3304	99.103
Line 26	11.268	2.834	8.3342	99.148
Line 27	9.919	2.834	7.085	84.287
Line 28	10.356	2.834	7.5227	89.494
Line 29	8.9116	2.834	6.0776	72.302
Line 30	4.0001	2.834	1.117	13.28
Line 31	10.487	2.834	7.6535	91.050
Line 32	7.2645	2.834	4.4305	52.707
Line 33	6.4231	2.834	3.5891	42.697
Line 34	8.8499	2.834	6.0159	71.568

Table 5 Results Of Calculation Of MWM For Line Outage In Zero And First Levels

rank	**line Outage**	**λ_{max}(p.u.)**	**MWM decrease (%)**
1	Line 30	3e-005	86.72
2	Line 1	1.5259	82.269
3	Line 33	2.2729	57.30
4	Line 32	2.5634	47.292
5	Line 4	2.9352	34.810
6	Line 34	3.1358	28.431
7	Line 29	3.1486	27.697
8	Line 9	3.4012	19.074
9	Line 11	3.4046	18.927
10	Line 7	3.4359	17.874
11	Line 27	3.5043	15.712
12	Line 22	3.5515	14.145
13	Line 28	3.6544	10.505
14	Line 31	3.7029	8.9497
15	Line 18	3.706	8.9485
16	Line 2	3.7387	7.7268
17	Line 15	3.7562	7.0748
18	Line 6	3.7708	6.8131
19	Line 16	3.9051	2.0545
20	Line 24	3.917	1.6357
21	Line 10	3.9337	1.3716
22	Line 21	3.9589	1.2717
23	Line 13	3.9634	1.1111
24	Line 17	3.9637	1.0992
25	Line 5	3.9684	1.0897
26	Line 14	3.9694	1.0790
27	Line 19	3.971	0.9778
28	Line 25	3.974	0.897
29	Line 23	3.978	0.8720
30	Line 26	3.981	0.8517
31	Line 20	3.984	0.6745
32	Line 3	3.987	0.4818
33	Line 12	3.988	0.4116
34	Line 8	3.989	0.1784

Table 6 Contingencies Ranking Of First Level In Lines Outages.

Table 6 shows contingencies ranking of first level in line outages. Attention to table6, outages of lines 30,1, 33 and 32 are considered as critical lines and are in higher ranks in table. The outage of Line 30 with MWM decrease percent 86.72% is identified as the most critical line outage compared to all other line outages. Lines 8, 12, 3, 20, with higher loading point and lower MWM decrease percent are in lower ranks in table.

VII. CONCLUSION

This work, by considering of power system contingencies based on the effects of them on Mega Watt Margin (MWM) and maximum loading point is focused in order to analyse the voltage stability using continuation power flow method. The presented approach has been tested on the IEEE- 30 bus, considering different operating scenarios. The contingency analysis results indicates ability of the methodology to screen all the critical contingencies concerning static security and at the same time ability to rank them accurately according to their severity, except for the cases having marginal values of MWM. Therefore system operator can determine the set of conditions under which a line outage is critical along with its severity from the test results.

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APPENDIX

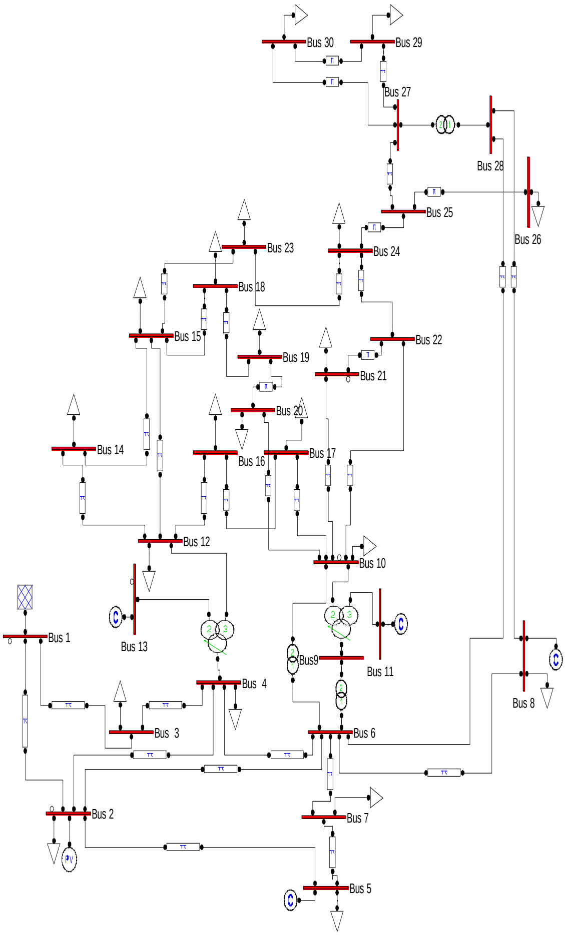

Fig. 3 Block diagram of simulated IEEE 30 bus power system