SOFT COMPUTING LINE OUTAGE CONTINGENCY RANKING FOR VOLTAGE STABILITY STUDIES

[1]C.Subramani, [1]Subhransu Sekhar Dash, [2]M.Arun Bhaskar, [2]M.Jagadeeshkumar*
[1]Faculty of Electrical and Electronics Engg. SRM University, Chennai, India
[2]Research Scholar, Department of EEE, S.R.M. University, Chennai

ABSTRACT: Voltage stability is currently one of the most important research areas in the field of electrical power systems. With the increased loading and exploitation of the power transmission system being also due to improved optimized operation the problem of voltage stability and voltage collapse attracts more and more attention. Voltage collapse can take place in systems or subsystems and can appear quite abruptly which requires the improved continuous monitoring of the system state. Researchers have been trying to find out the most effective way for online system status monitoring, so that necessary precautions can be taken prior to voltage collapse. Suitable preventive control actions can be implemented considering contingencies that are likely to affect the power system performance. An effective method for contingency ranking is proposed in this paper. This method calculates the voltage stability margin considering branch outages. The basic methodology implied in this technique is the investigation of each line of the system through calculating line stability indices. The point at which VSI close to unity indicates the maximum possible connected load termed as maximum loadability at the point of bifurcation. This technique is tested on the IEEE system and results proved that the contingency ranking indicates the severity of the voltage stability condition in a power system due to line outage.

I. INTRODUCTION

Voltage stability has recently become a challenging problem for many power systems. Voltage instability is one phenomenon that could happen in power system due to its stressed condition. The result would be the occurrence of voltage collapse which leads to total blackout to the whole system Investigation and online monitoring of power system stability have become vital factors to electric utility suppliers. The problem of voltage collapse may be simply explained by an inability of the power system to supply the reactive power or by an excessive absorption of reactive power by the system itself. It is to be understood as a reactive problem and it is strongly affected by the load behavior (i.e. constant Q for varying voltages).

Voltage collapse occurs when a system is heavily loaded and unable to maintain its generation and transmission schedule, observed by a sudden decline or 'sag' in system-wide voltages. This change in voltage is so rapid that voltage control devices may riot take corrective actions rapidly enough to prevent cascading blackouts. The continual increase in demand for electric power has forced utility companies to operate their systems closer to the limits of instability. This has increased the importance of implementing suitable and efficient techniques for analysing, monitoring and prediction of possible voltage collapses in the system prior to their occurrence.

In this paper voltage stability analysis and maximum loadability are conducted using new line stability index indicated by VSI. The new line stability index and contingency analysis techniques are tested on a standard IEEE 9- bus system. The reactive power at a particular bus is increased until it reaches the instability point at bifurcation. At the instability point, the connected load at the particular bus is determined as the maximum loadability. The line stability indices are evaluated for each loading condition and line outage. The values of line stability index would indicate the voltage stability condition in a power system for a particular load demand. Line stability indices values which approach 1.00 imply that the power system approaches its voltage stability limit. A contingency table was developed from the results obtained from the simulation of each transmission line outage. The outage which resulted in a severe stability condition will be ranked high. From the contingency ranking table, the effect of breakdown at a line on voltage stability condition of a system could be determined.

II. PROPOSED TECHNOLOGY

The voltage stability index or proximity is the device used to indicate the voltage stability condition formulated based on a line or a bus. The maximum threshold is set at unity as the maximum value beyond which this limit system bifurcation will be experienced.

The VSI is derived from the voltage quadratic equation at the receiving bus on a two-bus system. The general two-bus representation is illustrated in Figure 1. The symbols are explained as follows

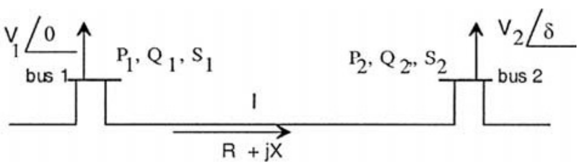

Fig. 1.Two-bus power system model

The line impedance is noted as Z=R+jX with the current that flows in the line is given by;

$$I = \frac{V_1\angle 0 - V_2\angle \delta I}{R + jX} \qquad (1)$$

V_1 is taken as the references, and therefore the angle is shifted into 0. The apparent power at bus 2 can be written as;

$$S_2 = V_2 j^* \qquad (2)$$

Rearranging (2) yields;

$$I = \left(\frac{S_1}{V_2}\right)^* \qquad (3)$$

$$= \frac{P_2 - jQ_2}{V_2\angle -\delta} \qquad (4)$$

Equating (1) and (4) we obtained;

$$V_1V_2\angle -\delta - V_2^2\angle 0 = (R + jX)(P_2 - jQ_2) \qquad (5)$$

Separating the real and imaginary parts yields;

$$V_1V_2\cos\delta - V_2^2 = RP_2 + XQ_2 \qquad (6)$$

and,

$$V_2^2 - \left(\frac{R}{X_{ij}}\sin\delta + \cos\delta\right)V_1V_2 + \left(X_{ij} + \frac{R^2}{X_{ij}}\right)Q_2 = 0$$

$$-V_1V_2\sin\delta = X_{ij}P_2 - RQ_2 \qquad (7)$$

Rearranging (7) for P_2 and substituting into (6) yields a quadratic equation of V_2;

$$V_2^2 - \left(\frac{R}{X_{ij}}\sin\delta + \cos\delta\right)V_1V_2\left(X_{ij} + \frac{R^2}{X_{ij}}\right)Q_2 = 0 \qquad (8)$$

To obtain the real roots for V_2, the discriminant is set greater than or equal to '0'; i.e.

$$\left[\left(\frac{R}{X_{ij}}\sin\delta + \cos\delta\right)V_1\right]^2 - 4\left(X_{ij} + \frac{R^2}{X_{ij}}\right)Q_2 \geq 0$$

$$\frac{4Z^2Q_2}{(V_1)^2\left(R\sin\delta + X_{ij}\cos\delta\right)^2} \leq 1 \qquad (9)$$

Since δ is normally very small then,

$$\delta \approx 0, R\sin\delta \approx 0, and, X\cos\delta \approx X$$

Taking the symbols 'i' as the sending bus and 'j' as the receiving bus. Hence, the fast voltage stability index, VSI can be defined by;

$$VSI_{ij} = \frac{4Z_{ij}^2 Q_J}{V_1^2 X_{ij}} \qquad (10)$$

The value of VSI that is evaluated close to 1.00 indicates that the particular line is closed to its instability point. Therefore, VSI has to be maintained less than 1.00 in order to maintain a stable system.

III. WEAK BUS IDENTIFICATION

The proposed algorithm was implemented in MATLAB 7 and executed on Pentium 4 machine. The flow chart is given below

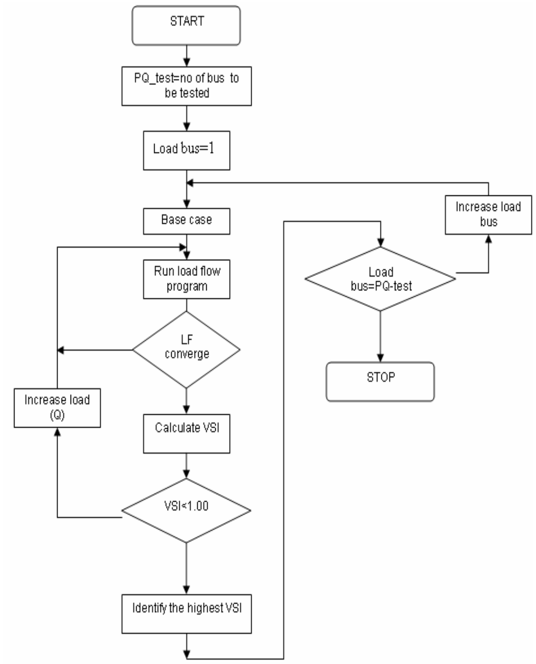

Fig 2 Flow chart for weak bus identification

To validate the performance of the indicator, an IEEE 9 bus reliability test system is used.

This system has3 generator buses and 6 load buses. In order to investigate the effectiveness of the VSI 6 load buses were selected. The reactive power at these buses increased gradually one at a time.

IV. RESULTS AND DISCUSSION

For finding the maximum load and weak bus 6 load buses are investigate one by one. The results are tabulated below. From table 1 we can find the maximum load, critical voltage and critical line .For example consider Bus no.9, it has the rank 1. From the base case increase the reactive power till the index value closes to 1. The maximum computable value of VSI obtained is 0.9999 for the line connected between buses 2 and 9 i.e. L3. The VSI (L3) value (0.9999) at this point is close to unity indicating that the system has reached its stability limit. At this point L3 is the most critical line with respect to bus 9. The critical voltage of particular bus is 0.7458 p.u. At the same time maximum reactive power loading for the maximum computable value of VSI (Bus No.9) is 9.5458 Mvar (Qmax), beyond this limit violation will be experienced.

Table 1

Rank	**Bus**	**Line From, To**	**Q max. (p.u)**	**Voltage**	**VSI max.**
1	**9**	**2-9**	**9.545**	**0.7458**	**0.9999**
2	**8**	**1-8**	**6.717**	**0.7879**	**0.9999**
3	**3**	**2-3**	**5.250**	**0.7588**	**0.9999**
4	**6**	**6-7**	**5.230**	**0.7706**	**0.9999**
5	**4**	**3-4**	**3.688**	**0.6262**	**0.9999**
6	**5**	**5-6**	**3.112**	**0.6949**	**0.9998**

From this result we can also found that Bus No. 9 has the maximum reactive power (9.5455 P.U.) and Bus No. 5 has the minimum reactive power (3.1126 P.U.).This means that Bus No.9 is the healthy bus and Bus No. 5 is the weakest bus in this system.

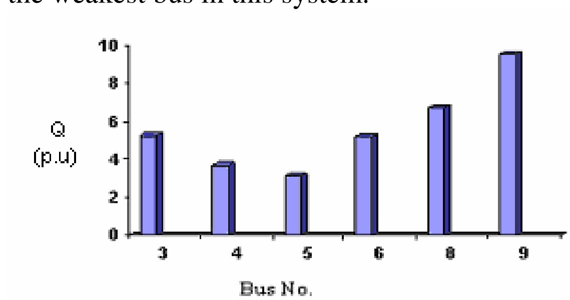

Fig 2 Maximum reactive power of load buses

V. CONTINGENCY SCREENING AND RANKING

In power system operation unpredictable events is termed as contingency. It may be caused by line outage in the system which could lead to entire system instability. Voltage stability analysis could be performed in a power system by evaluating the derived voltage stability index. The values of the voltage stability index would indicate the distance to voltage collapse for a given loading condition. These indices are taken as an instrument that will measure the stability condition and used to rank the contingencies in a power system. A high contingency ranking implies the severe effect of a particular contingency to the system. A load flow analysis is carried out prior to the computation of the voltage stability index and ranking of contingencies. The results obtained from the load flow analysis will be utilized for computed the voltage stability index and ranking of the contingencies.

Using the line stability index (VSI) contingency analysis was carried out and a contingency table was developed from the results obtained from the simulation of each transmission line outage. The outage which resulted in a severe stability condition will be ranked high. From the contingency ranking table, the effect of breakdown at a line on voltage stability condition of a system could be determined. The contingencies tested were based on transmission line outage. Several cases are simulated in order to determine the contingency ranking.

VI. CONTINGENCY SCREENING

The contingency ranking for different cases randomly selected were based on line stability values evaluated for each loading condition. The computation was performed by taking line outage 1 through 11consecutively for each different case. The line stability indices were computed and the results are tabulated in Table 2**.**The values of line stability indices highlighted in the table demonstrate the highest indices after being sorted in descending order.

a. Single load change with reactive power

Case1: increase Q at bus 3
Case 2: increase Q at bus 4
Case 3: increase Q at bus 5
Case 4: increase Q at bus 6
Case 5: increase Q at bus 8
Case 6: increase Q at bus 9

Referring to table 2 when line 1 is outage, the proposed line stability index is evaluated for each line in the system and the result yields the line stability index value for line 3 is the highest which is 0.4930.It shows that line 3 is approaching its voltage stability limit .However, it can be seen that outage in line 4 gives the index value 257.9233 indicates voltage collapse has occurred in this line. Similar analysis was conducted for all other cases in order to determine which line outage would cause voltage collapse to occur in the system

From the table we can also analyses that the line which has the index value close to 1.00 which is the most critical line in that case. And the line which has the index value greater than 1 means due to the outage of that line voltage collapse was occurred. For example consider the outage of L4 we can say that in case 4,5 and 6 the index value is less than 1 (0.5084, 0.4576and0.4924) .But in case 1,2 and 3 the index value is greater than 1. (257.9233, 7.8829 and 1.0154). From this we can conclude that the line outage L4 is not a severe in case 4, 5 and 6. But in case 1, 2 and 3 it is the most severe case.

From this result we can found which the critical line is when the outages occur. For example consider case1. Here when outage of L1 occurs then Line 4 is the most critical line. From this result we can also found that in case1 most of the outages line 4 is the severe one. We can conclude that line 4 is the critical line.

b. Single load change with real power

Case 7: increase P at bus 3
Case 8: increase P at bus 4
Case 9: increase P at bus 5
Case 10: increase P at bus 6
Case 11: increase P at bus 8
Case 12: increase P at bus 9

Referring to table3 when line 1 is outage, the proposed line stability index is evaluated for each line in the system and the result yields the line stability index value for line 10 is the highest which is 5.2389.It shows that line 3 is beyond its voltage stability limit .However, it can be seen that outage in line 4 gives the index value 34.7386 indicates voltage collapse has occurred in this line. Similar analysis was conducted for all other cases in order to determine which line outage would cause voltage collapse to occur in the system

From the table we can also analyses that the line which has the index value close to 1.00 which is the most critical line in that case. And the line which has the index value greater than 1 means due to the outage of that line voltage collapse was occurred. For example consider the outage of L4 we can say that in case 9, 10, 11 and 12, the index value is less than 1 (0.4039, 0.3236, 0.2218 and 0.2742) .But in case7 and 8the index value is greater than 1. (34.7386 and 10.4718).From this we can conclude that the line outage L4 is not a severe in case 9,10,11 and 12. But in case 7 and 8 it is the most severe case.

From this result we can found which the critical line is when the outages occur. For example consider case 7. Here when outage of L1 occurs then Line 10 is the most critical line. From this result we can also found that in case 2 most of the outages line 4 is the severe one. We can conclude that line 4 is the critical line.

VII. CONTINGENCY RANKING

Table 4. Gives the contingency ranking for the system based on line outage. The line outage which caused the system to violate or resulted in system to be closest to its voltage stability limit is ranked the highest. For case 1 for example, it can be seen that line outage at line 4 is at the top of the list. Since it has caused voltage collapse in the system .Line outage in line10 is ranked the lowest since the maximum line stability indices evaluated for this contingency is less than 1.00 (i.e. 0.4363), indicating that the system is far from its stability limit.

VIII CONCLUSION

A rigorous investigation was carried out to see the effectiveness of reactive load variation on the line stability index (VSI).The VSI determines the maximum load that is possible to be connected to a bus in order to maintain stability before the system reaches its bifurcation point. This point is determined as the maximum loadability of a particular bus which beyond this limit system violation will be experienced.

The individual maximum loadability obtained from the load buses will be sorted in ascending order. The highest rank implies the weak bus in the system with low sustainable load and the bus which ranked highest may sustain higher load with broader stability margin. From this information, proper monitoring of a weak node can be conducted in maintaining a secure electric utility so that the load connected to the respective bus will not exceed the maximum allowable load to maintain a stable system.

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Table 2 Results for contingency analysis

Outage	Case1		Case2		Case3		Case4		Case5		Case6	
	L	Index	L	Index	L	Index	L	Index	L	Index	L	Index
L1	4	0.4573	5	0.3765	7	0.3032	8	0.3722	10	0.4480	3	0.4930
L2	4	0.4535	5	0.3608	7	0.3168	8	0.3860	10	4.1826	3	0.4507
L3	4	0.4731	5	0.4042	6	0.2929	8	0.5299	2	0.4580	11	1.3929
L4	7	257.9233	5	7.8829	7	1.0154	8	0.5084	2	0.4576	3	0.4924
L5	4	0.4878	7	0.5888	7	0.7920	8	0.4583	2	0.4461	3	0.4850
L6	4	0.4993	5	0.5553	7	0.7455	8	0.4446	2	0.4476	3	0.4832
L7	4	0.5563	5	0.6925	6	1.0499	8	0.4138	2	0.4376	3	0.4780
L8	4	0.4816	5	0.4274	9	0.4125	9	0.9847	2	0.4315	3	0.5611
L9	4	0.4517	5	0.3915	8	0.2790	8	0.5967	2	0.4345	3	0.5250
L10	4	0.4363	5	0.3541	7	0.3020	8	0.3462	2	0.6086	3	0.4691
L11	4	0.4385	5	0.3557	7	0.2930	8	0.3653	2	0.4421	3	0.5908

Table 3 Results for contingency analysis

Outage	Case7		Case8		Case9		Case10		Case11		Case12	
	L	Index	L	Index	L	Index	L	Index	L	Index	L	Index
L1	10	5.2389	10	1.4209	10	1.0446	10	1.1630	10	0.4963	10	1.7257
L2	10	0.2713	10	0.2713	10	0.2713	11	0.2814	1	7.7334	10	0.2713
L3	4	0.2383	11	0.2254	10	0.2569	10	0.7325	2	0.2504	10	1.2275
L4	6	34.7386	9	10.4718	8	0.4039	10	0.3236	2	0.2218	10	0.2742
L5	4	0.2223	9	10.3994	9	0.2977	10	0.2989	2	0.2078	10	0.2547
L6	4	0.2411	4	0.2378	9	0.2696	10	0.2902	2	0.2081	10	20.2470
L7	4	0.3292	4	0.3830	8	18.3386	10	0.2622	10	0.2094	10	0.2212
L8	4	0.2408	4	0.1922	9	0.2199	3	0.3478	10	0.2275	3	0.2323
L9	4	0.2265	4	0.1761	4	0.1524	10	0.3198	2	0.2086	10	0.2310
L10	4	0.1896	10	0.1591	11	0.1388	11	0.2043	2	0.3679	8	0.1469
L11	4	0.2165	4	0.1527	3	0.1495	10	0.2195	10	0.2166	3	0.2051

Table 4 Contingency ranking

CASES												
Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	**L4**	**L4**	**L7**	**L8**	**L2**	**L3**	**L4**	**L4**	**L7**	**L1**	**L2**	**L6**
2	**L7**	**L7**	**L4**	**L9**	**L10**	**L11**	**L1**	**L5**	**L1**	**L3**	**L1**	**L1**
3	**L6**	**L5**	**L5**	**L3**	**L3**	**L8**	**L7**	**L1**	**L4**	**L8**	**L10**	**L3**
4	**L5**	**L6**	**L6**	**L4**	**L4**	**L9**	**L2**	**L7**	**L5**	**L4**	**L3**	**L4**
5	**L8**	**L8**	**L8**	**L5**	**L1**	**L1**	**L6**	**L2**	**L2**	**L9**	**L8**	**L2**
6	**L3**	**L3**	**L2**	**L6**	**L6**	**L4**	**L8**	**L6**	**L6**	**L5**	**L4**	**L5**
7	**L1**	**L9**	**L1**	**L7**	**L5**	**L5**	**L3**	**L3**	**L3**	**L6**	**L11**	**L8**
8	**L2**	**L1**	**L10**	**L2**	**L11**	**L6**	**L9**	**L8**	**L8**	**L2**	**L7**	**L9**
9	**L9**	**L2**	**L11**	**L1**	**L7**	**L7**	**L5**	**L9**	**L9**	**L7**	**L9**	**L7**
10	**L11**	**L11**	**L3**	**L11**	**L9**	**L10**	**L11**	**L10**	**L11**	**L11**	**L6**	**L11**
11	**L10**	**L10**	**L9**	**L10**	**L8**	**L2**	**L10**	**L11**	**L10**	**L10**	**L5**	**L10**

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AUTHOR BIOGRAPHIES

C.Subramani is working as Assistant Professor in the Department of EEE, SRM University, Chennai, India. He is also a research scholar in SRM University, Chennai, India. His areas of interest are Voltage stability, Intelligent Techniques and Power System Control.
Email: csmsrm@gmail.com

Dr.S.S.Dash is working as Professor and Head in the Department of EEE, SRM University, India. His areas of interest are Power system Operation & Control, Stability, FACTS, Drives, and AI Techniques.
Email: munu_dash_2k@yahoo.com

M.Arun Bhaskar is working as a Senior Lecturer in the Department of EEE, Velammal Engineering College, Chennai, India. He is currently a research scholar in SRM University, Chennai, India. His areas of interest are power system stability, Modelling of FACTS devices, Intelligent Techniques.
Email: m.arunbhasakar@gmail.com

M.Jagadeesh Kuamr is working as Asst. Professor in the Department of EEE, Velammal Engineering College, Chennai, India. He is currently a research scholar in SRM University, Chennai, India. His areas of interest are Power Electronics in Power Systems, Intelligent Techniques and Power System Stability.
Email: mpjagadeesh@yahoo.com