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Simulation technique for voltage stability Analysis and contingency ranking in power systems

C.Subramani[1], Subhransu Sekhar Dash[2] M Arun Bhaskar[3], M.Jagdeshkumar[4]
[1] Velammal Engineering College/EEE, Chennai, India
Email: csmsrm@gmail.com
[2] SRM university/EEE, Chennai, India, [3, 4] Velammal Engineering College/EEE, Chennai, India,
Email:(munu_dash_2k@yahoo.com, m.arunbhaskar@gmail.com, mpjagadeesh@yahoo.com,)

***Abstract*— 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. Therefore voltage collapse prediction is important in power system planning and operation. Line outage in power system could also lead to the event of voltage collapse which implies the contingency in the system. Line outage contingencies are ranked so that the line which highly affects the system when there is an outage occurs in this line in terms of voltage instability could be identified. The contingency ranking process can be conducted by computing the line stability index of each line for a particular line outage and sort them in descending order. The contingency which is ranked the highest implies that it contributed to system instability. This paper demonstrates a new voltage stability index referred to a line used to rank the line outage contingency. 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.**

***Index Terms*— contingency ranking, voltage collapse prediction, Line outage contingencies, voltage stability index**

I. INTRODUCTION

The continuing increase in demand for electric power has resulted in an increasingly complex interconnected system, forced to operate closer to the limits of stability. This has necessitated the implementation of techniques for analyzing and detecting voltage collapse in bus bar or lines prior to its occurrence. Voltage collapse occurs when a system is heavily loaded and is not able to maintain its generation and transmission schedule [1,2]. 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 [3]. 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 [4,5]. The results obtained from the load flow analysis will be utilized for computed the voltage stability index and ranking of the contingencies [7].

In this paper voltage stability analysis is conducted using new line stability index indicated by VSI. The new line stability index and contingency analysis techniques are tested on a standard IEEE 6- bus system. 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. VOLTAGE STABILITY INDEX AND METHODOLOGY

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.

A. proposed VSI Formulation

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

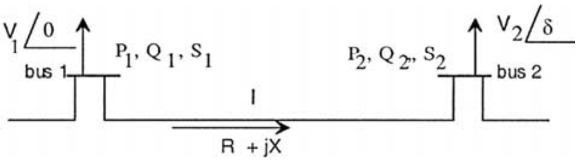

Fig. 1.Two-bus power system model

V_1, V2 =*Voltage on sending and receiving buses.*
P_1, Q_1 = active and reactive power on the sending bus
P_2, Q2 = active and reactive power on the receiving bus
S_1, S_2 = apparent power on the sending and receiving buses

δ = $\delta_1-\delta_2$ (angle difference between sending and receiving buses)

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;

$$S_2=V_2j^* \qquad (2)$$

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;

$$V_1V_2\angle -\delta - V_2^{\,2}\angle 0 = \left(R + jX\right)\left(P_2 - jQ_2\right) \quad (5)$$

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;

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

To obtain the real roots for $V_{2,}$ the discriminant is set greater than or equal to ‘0’; i.e.

$$\left[\left(\frac{R}{X_{ij}}\sin\delta + \cos\delta\right)V_1\right]^2 - 4\left(X_{ij} + \frac{R^2}{X_{ij}}\right)Q_2 \geq 0 \quad (9)$$

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

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;

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

Where: Z = line impedance
X_{ij} = line reactance
Qj = reactive power at the receiving end
Vi = sending end voltage

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.

B. Test system

To validate the performance of the indicator, an IEEE 6 bus reliability test system is used. This system has3 generator buses and 3 load buses. In order to investigate the effectiveness of the VSI 3 load buses were selected. The reactive power at these buses increased gradually one at a time.

III. LINE OUTAGE CONTINGENCY RANKING

The following steps are implemented.

1. Run the load flow program using Newton-Raphson method for the base case.
2. Simulate all selected transmission line outage on all cases.
3. Evaluate the VSI value for every line outage in the system.
4. Rank the value of L in descending order.
5. Extract the line index that has the highest value; this line is to be closest to its voltage stability limits and leads to voltage collapse

The proposed algorithm was implemented in MATLAB 7 and executed on Pentium 4 machine.

The contingencies tested were based on transmission line outage. Several cases are simulated. In order to determine the contingency ranking, namely:

Case 1: Base case
Case 2: increase Q at bus 4
Case 3: increase Q at bus 5
Case 4: increase Q at bus 6

Table 1 Contingency Analysis

Outage	Case1		Case2		Case3		Case4		Case5	
	L	Index	L	Index	L	Index	L	Index	L	Index
L1	3	0.4055	3	0.6593	3	0.6257	3	0.4642	3	0.7334
L2	3	0.4186	3	0.6712	3	0.6507	3	0.4784	2	1.0018
L3	7	0.4473	7	0.7662	2	0.643	7	0.6047	1	1.2041
L4	1	0.8160	1	3.7263	1	1.0105	1	0.8875	1	12.433
L5		NR		NR		NR		NR		NR
L6	3	0.6685	1	0.7154	3	1.0042	3	0.7917	1	0.9834
L7	3	0.5995	3	0.9560	2	0.6173	3	0.7477	6	50.987

Outage	Case6		Case7		Case8		Case 9		Case10	
	L	Index	L	Index	L	Index	L	Index	L	Index
L1	3	0.5586	3	0.3775	3	0.9653	3	0.7436	3	0.6159
L2	6	45.972	3	2.2511	3	0.8081	3	1.2301	3	0.6235
L3	2	1.1126	6	9.6441	7	0.8700	2	0.7410	7	0.8753
L4	3	1.4248	7	430.15	6	4.3050	3	1.1750	3	1.1391
L5		NR		NR		NR		NR		NR
L6	3	1.6092	7	15.798	3	0.6685	3	1.2440	3	1.2486
L7	2	1.0003	6	20.003	3	1.1219	2	0.6278	3	1.0975

Table 2. Contingency Ranking

	Cases									
Rank	1	2	3	4	5	6	7	8	9	10
1	L5	L5	L5	L5	L5	L5	L5	L5	L5	L5
2	L4	L4	L4	L4	L7	L2	L4	L4	L6	L6
3	L6	L7	L6	L6	L4	L6	L7	L7	L2	L4
4	L7	L3	L2	L7	L3	L4	L6	L1	L4	L7
5	L3	L6	L3	L3	L2	L3	L3	L3	L1	L3
6	L2	L2	L1	L2	L6	L7	L2	L2	L3	L2
7	L1	L1	L7	L1	L1	L1	L1	L6	L7	L1

Case 5: increase P at bus 4
Case 6: increase P at bus 5
Case 7: increase P at bus 6
Case 8: increase P and Q at bus 4
Case 9: increase P and Q at bus 5
Case10: increase P and Q at bus 6

IV. RESULTS AND DISCUSSION

The contingency ranking for the 10 cases mentioned above were based on line stability values evaluated for each loading condition. The computation was performed by taking line outage 1 through 7 consecutively for each different case. The line stability indices were computed and the results are tabulated in Table 1.The values of line stability indices highlighted in the table demonstrate the highest indices after being sorted in descending order.

Referring to table 1 and taking case 1 for example; 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 0.9653.It shows that line 3 is approaching its voltage stability limit .However, it can be seen that outage in line 5 gives non convergence result 'NR' (no result) 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. The highlighted values are retabulated in descending order in table 2. This table 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 5 is at the top of the list. Since it has caused voltage collapse in the system .Line outage in line 1 is ranked the lowest since the maximum line stability indices evaluated for this contingency is less than 1.00 (i.e. 0.5995, indicating that the system is far from its stability limit. Contingency ranking for other cases are also shown in Table 2.

V. 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 critical line in a system. A line is considered to be critical if the voltage stability index referred to this line closes to 1.00.This index is then further used in determining the contingency ranking which is based on the line outage in the system. Line outage which resulted in voltage instability is ranked the highest. The contingency ranking could assist the operating engineer to take necessary actions in order to avoid the occurrence of voltage collapse in the system.

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AUTHOR BIOGRAPHIES

C.Subramani 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 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, AI Techniques. Email: munu_dash_2k@yahoo.com

M.Jagdeesh Kumar 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

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.arunbhaskar@gmail.com