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Stability Prediction of Radial Distribution Network

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Abstract—*Distribution networks experience distinct change from a low to high load level every day. Hence, a major concern in power distribution networks is voltage stability issues and reactive power remuneration. It is significantly critical to take both distribution network and loads into consideration to determine reasonable reactive compensation capacity for distribution network. In this paper in the first phase of work an attempt has been made for performing voltage stability analysis of different distribution system based on synthesis load model. Taking example of a typical radial Distribution network, it has been shown that the node having the minimum value of VSI is the most sensitive. In the second phase of work the critical values of total real power load and total reactive power load for various cases is found. The system will collapse beyond the computed values of critical power. The performance of the voltage stability index is tested on different types of loads and different substation voltage levels. Results are obtained on IEEE 33-bus and IEEE 69-bus radial distribution systems.*

1. INTRODUCTION

The deregulated market requires a great deal of attention to satisfy reliability, security and optimization objectives. As is well known, the voltage stability problem may become more and more frequent in this new scenario. Voltage stability has become a critical issue for electrical power transmission and distribution systems because of: (i) continuing increases in demand; (ii) the transfer of high powers between several interconnected areas; (iii) economic and environmental constraints, that have resulted in investment delays; and (iv) high penetration of emerging new and renewable energy sources in both distribution and transmission systems.

Voltage stability of a distribution system is one of the keen interests of industry and research sectors around the world. It concerns stable load operation, and acceptable voltage levels all over the distribution system buses. The distribution system in a power system is loaded more heavily than ever before and operates closer to the limit to avoid the capital cost of building new lines. When a power system approaches the voltage stability limit, the voltage of some buses reduces rapidly for small increments in load and the controls or operators may not be able to prevent the voltage decay. In some cases, the response of controls or operators may aggravate the situation and the ultimate result is voltage collapse. Voltage collapse has become an increasing threat to power system security and reliability. Many incidents of system blackouts because of voltage stability problems have been reported worldwide (India, July 2012; Takahashi K., Nomura Y, 1987). In order to prevent the occurrence of voltage collapse, it is essential to accurately predict the operating condition of a power system. So electrical engineers need a fast and accurate voltage stability index (VSI) to help them monitoring the system condition. Nowadays, a proper analysis of the voltage stability problem has become one of the major concerns in distribution power system operation and planning studies.

Currently, most electrical power systems operate very close to their stability limits and it is crucial to keep both efficiency and security at appropriate levels (S. Sakthivel et al., 2011). The objective in power systems operation is to serve energy with acceptable voltage and frequency to consumers at minimum cost. Thus, an accurate knowledge of how far the current system's operating point is from the voltage instability limit is crucial to system operators, which often need to assess if the system has a secure and feasible operation point following a given disturbance, such as a line outage or sudden change in system loading (L. A. Ll. Zarate, and C. A. Castro, 2006).

A fast method to determine the voltage stability limit of power system was proposed by Haque (M. H. Haque, 1995). Analytical approach to voltage collapse proximity determination is proposed for radial networks by Gubina, et al. (F. Gubina, and B. Strmcnik, 1997). (Moghavvemi, et al., 2001) proposed bus/line stability indices which is obtained from the solution of the line receiving end reactive power equation (Qr) and the line receiving end active power equation (Pr) of the reduced two-bus equivalent network. In (M. Chakravorty, and D. Das, 2001) proposed a new stability index based on well-known bi-quadratic equation relating the voltage magnitudes at the sending and receiving ends and power at the receiving end of the branch. Two simple methods to evaluate two efficient voltage collapse proximity indicators are presented in (A. Augugliaro et al., 2007) to find the weakest node, where voltage instability phenomenon can occur bringing the whole system to the voltage collapse, and evaluate the maximum loading capability of the entire system or of the weakest node, beyond which voltage collapse takes place. A new bus stability index is developed by Chaturvedi, et al. (A. Chaturvedi et al, 2006) from the line receiving bus voltage equation of Kirchhoff's voltage law for a particular branch section. A new static voltage stability index of a RDS is developed (M. M. Hamada et al., 2010] by Hamada et al., to faithfully evaluate the severity of the loading situation, thereby predicting for voltage instability at definite load value. A new VSI for all the buses proposed (G.A. Mahmoud, 2012) for radial distribution networks by Mahmoud using the catastrophe theory. Investigation of different load models on voltage stability of unbalanced radial distribution system is presented by Gunalan, et al. in (S. Gunalan, et al., 2010). A CTP Flow approach for voltage stability analysis of unbalanced three-phase power systems is presented in (X. P. Zhang et al., 2005). A three-phase constrained optimal power flow is proposed to analyse voltage stability in an unbalanced power system (G. Carpinelli, et al., 2006). The voltage stability analysis in unbalanced radial distribution systems using secant predictor is given in by (Mamdouh Abdel-Akher, 2013).

The load on a power system is constantly changing. There is no such thing as a "steady state" load. Seasonal effects, weekly/daily, and legal/religious holidays, play an important role in load patterns. Most electric utilities serve customers of different types such as residential, commercial, and industrial. To study the system more realistic we have to consider these different load models together along with load curve variation. Distribution networks comprise of loads like industrial, commercial, residential and lightning loads are generally weak in nature because of high resistance to reactance ratio. Each of these loads is at its maximum at different times of the day and this may cause feeder overloading which may result in voltage collapse. Voltage stability is one of the important factors that dictate the maximum permissible loading of a distribution system. Using this VSI, the buses of the system which are weak in nature can be identified. Voltage stability of a system depends on load model, the network topology and settings of reactive compensation devices.

In this paper, Load modelling is carried out and MATLAB programs are developed for four different load models constant power, constant current, constant impedance, and composite load for comparison. It is shown that the node, at which the value of voltage stability index is minimum, is more sensitive to voltage collapse. Composite load modeling is considered for voltage stability analysis.

2. MATHEMATICAL MODEL

Distribution networks are assumed to be balanced and can be represented by a single line diagram.

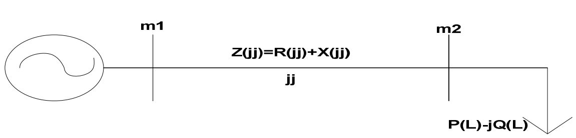

Fig. 1: Two bus power system model

V(m1)= Voltage at sending bus

V(m2)= Voltage at receiving bus

Q(L)= Reactive power at sending bus

P(L)= Active power at sending bus

Z(jj)= Impedance of branch jj

R(jj)= Resistance of branch jj

X(jj)= Reactance of branch jj

I(jj)= Current in branch jj

$$I(jj)= V(m1)-V(m2)/r(jj)+jx(jj) \tag{1}$$

$$P(m2)-jQ(m2)=V^*(m2)\times I(jj) \tag{2}$$

From (1) and (2),

$$|V(m2)|^4=\{|V(m1)|^2-2P(m2)r(jj)-2Q(m2)x(jj)\}|V(m2)|^2+\{P^2(m2)+Q^2(m2)\}\{r^2(jj)+x^2(jj)\}=0 \tag{3}$$

Let,

$$b(jj)=|V(m1)|^2-2P(m2)r(jj)-2Q(m2)x(jj) \tag{4}$$

$$c(jj)=\{P^2(m2)+Q^2(m2)\}\{r^2(jj)+x^2(jj)\} \tag{5}$$

Now from (3),

$$|V(m2)|^4-b(jj)|V(m2)|^2+c(jj)=0 \tag{6}$$

V(m2) has four solutions, but the solution is feasible only when,

$$b^2(jj)-4c(jj)\geq 0 \tag{7}$$

$$|V(m1)|^4-4\{P(m2)x(jj)-Q(m2)r(jj)\}^2-4\{P(m2)r(jj)+Q(m2)x(jj)\}|V(m1)|^2\geq 0 \tag{8}$$

$$VSI(m2)=|V(m1)|^4-4\{P(m2)x(jj)-Q(m2)r(jj)\}^2-4\{P(m2)r(jj)+Q(m2)x(jj)\}|V(m1)|^2\geq 0 \tag{9}$$

Where,

VSI(m2)= Voltage Stability Index of node m2, (m2= 2, 3, 4, ……. NB)

For stable operation of the radial distribution networks,

$VSI(m2)\geq 0$, for m2= 2, 3, …… NB

By using this voltage stability index, one can measure the level of stability of radial distribution networks and there by appropriate action may be taken if the index indicates a poor level of stability

$$V(m2)=V(m1)-I(jj)Z(jj) \quad (10)$$

Load current of any receiving end node m2 of branch j is,

$$IL(m2)= PL(m2)-jQL(m2)/V^*(m2) \quad (11)$$

The real and reactive power loss of branch jj is expressed by,

$$LP=I^2(jj)R(jj), \text{ and } LQ=I(jj)^2X(jj) \quad (12)$$

The current beyond branch jj,

$$I(jj)=\sum_{i=1}^{S(jj)} IL\{IE(jj,i)\} \quad (13)$$

Equation (15) is used for finding out branch current of branch 1,2,3……LN1

Nodes beyond branches are to be found out one by one[18].

3. LOAD MODELING

For the purpose of voltage stability analysis of radial distribution networks, composite load modeling is considered.

The real and reactive power loads of node 'i', is given as:

$$P(m2)=P_n\left[a0+a1V(m2)+a2V^2(m2)\right] \quad (14)$$

$$Q(m2)=Q_n\left[b0+b1V(m2)+b2V^2(m2)\right] \quad (15)$$

Where Pn and Qn are nominal real and reactive power respectively and V(m2) is the voltage at node m2. For all the loads, (14) and (15) are modeled as,

$$a0 + a1 + a2 = 1.0 \quad (16)$$

$$b0 + b1 + b2 = 1.0 \quad (17)$$

For constant power (CP) load a0=b0=1 and ai=bi=0 for i=1, 2.
For constant current (CI) load a1 =b1=1and ai=bi=0 for i=0, 2.
For constant impedance (CZ) load a2 =b2=1and ai=bi=0 for i=0, 1.
For Composite Load, 40% constant power (CP) load, 30% constant current (CI) load, and 30% constant impedance (CZ) load is considered.

4. RESULTS AND DISCUSSION

In this paper the voltage stability index method is applied on IEEE 33-bus and IEEE 69-bus test systems. The total load on 33-bus test radial distribution system is 3.715+j*2.3 MVA (M. A. Kashem *et al.*, 2000) and on 69-bus test radial distribution system is 3.8013+j*2.6936 MVA (M.E.Baran *et al.*, 1989).

Table 1. presents the value of voltage magnitude and the voltage stability index in per unit(p.u.) for 33-bus system and for 69-bus system both for constant current (CI) load. The node which has the least value of voltage stability index is known as critical node, where the chances of voltage collapse is more frequent. Here bus 18 is critical node point for 33-bus system, and bus 65 is for 69-bus system, which has least value of voltage stability index.

The stability index and consequently the voltage are minimum for constant power load and maximum for constant impedance load and that for constant current load is in between these two. The composition of loads governs the position of the voltage stability index and voltage magnitude for the composite load.

Fig.2. shows voltage profile of 33-bus system for different types of loads i.e. constant current (CI), constant power (CP), constant impedance (CZ), and composite load (CZIP).

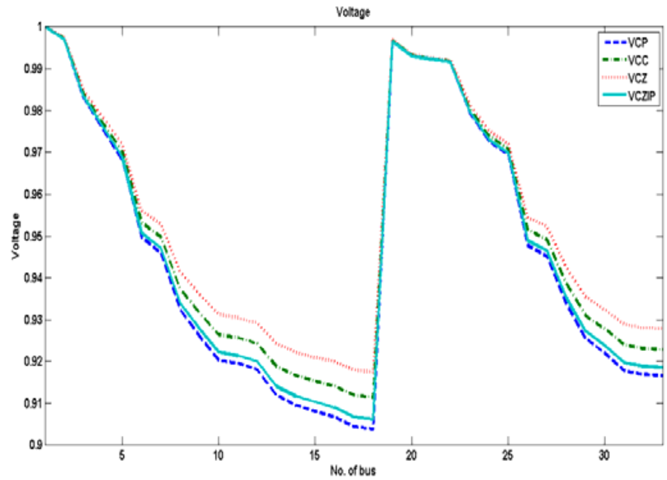

Fig. 2: Voltage profile of 33-bus system

Similarly voltage stability index of 33-bus system is shown in Fig.3.

Table 1: Voltage and Voltage Stability Index for Constant Current Load

Bus No.	33-Bus System		69-Bus System		Bus No.	69-Bus System	
	Voltage(p.u.)	VSI(p.u.)	Voltage(p.u.)	VSI(p.u.)		Voltage(p.u.)	VSI(p.u.)
1	1	1	1	1	36	0.99992	0.99968
2	0.99720	0.98827	0.99996	0.99986	37	0.99975	0.99900
3	0.98399	0.93420	0.99993	0.99973	38	0.99959	0.99836
4	0.97708	0.90951	0.99984	0.99937	39	0.99954	0.99818
5	0.97027	0.88437	0.99908	0.99614	40	0.99954	0.99817
6	0.95323	0.82054	0.99076	0.96133	41	0.99884	0.99539
7	0.94983	0.81296	0.98212	0.92809	42	0.99855	0.99423
8	0.93740	0.76842	0.98006	0.92209	43	0.99851	0.99408
9	0.93167	0.75177	0.97901	0.91838	44	0.99850	0.99405
10	0.92638	0.73491	0.97420	0.90004	45	0.99841	0.99365
11	0.92562	0.73387	0.97314	0.89669	46	0.99841	0.99365
12	0.92432	0.72957	0.97012	0.88527	47	0.99979	0.99918
13	0.91874	0.71082	0.96733	0.87513	48	0.99856	0.99421
14	0.91657	0.70515	0.96457	0.8652	49	0.99474	0.97898
15	0.91527	0.70140	0.96183	0.85542	50	0.99420	0.97700
16	0.91405	0.69769	0.96133	0.85398	51	0.98002	0.92247
17	0.91196	0.69105	0.96048	0.85094	52	0.98002	0.92244
18	***0.91142***	***0.68988***	0.96048	0.85104	53	0.97647	0.90835
19	0.99667	0.98675	0.96003	0.84940	54	0.97351	0.89726
20	0.99312	0.97264	0.95975	0.84842	55	0.96944	0.88195
21	0.99242	0.97003	0.95929	0.84677	56	0.96546	0.86758
22	0.99179	0.96756	0.95928	0.84682	57	0.94507	0.79042
23	0.98050	0.92388	0.95921	0.84657	58	0.93504	0.76114
24	0.97402	0.89931	0.95907	0.84603	59	0.93116	0.75061
25	0.97080	0.88786	0.95890	0.84546	60	0.92661	0.73579
26	0.95146	0.81904	0.95884	0.84524	61	0.91988	0.71403
27	0.94910	0.81078	0.95882	0.84518	62	0.91962	0.71515
28	0.93858	0.77303	0.99992	0.99971	63	0.91927	0.71403
29	0.93103	0.74927	0.99985	0.99943	64	0.91755	0.70829
30	0.92777	0.74000	0.99973	0.99894	65	***0.91703***	***0.70703***
31	0.92394	0.72777	0.99971	0.99886	66	0.97309	0.89663
32	0.92310	0.72590	0.99960	0.99843	67	0.97309	0.89663
33	0.92284	0.72523	0.99935	0.99741	68	0.96980	0.88452
34			0.99901	0.99607	69	0.9698	0.88456
35			0.99895	0.99580			

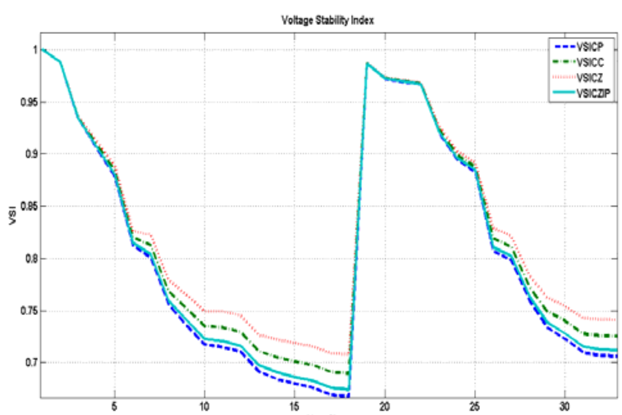

Fig. 3: Voltage stability index profile of 33-bus system

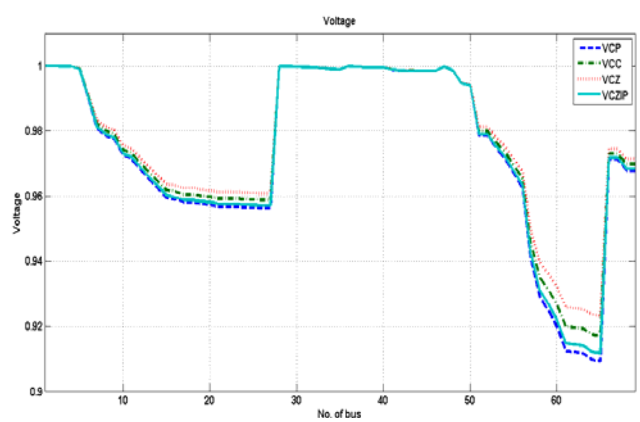

Fig. 4: Voltage profile of 69-bus system

Fig.4. shows voltage profile of 69-bus system for different types of loads i.e. constant current (CI), constant power (CP), constant impedance (CZ), and composite load (CZIP).

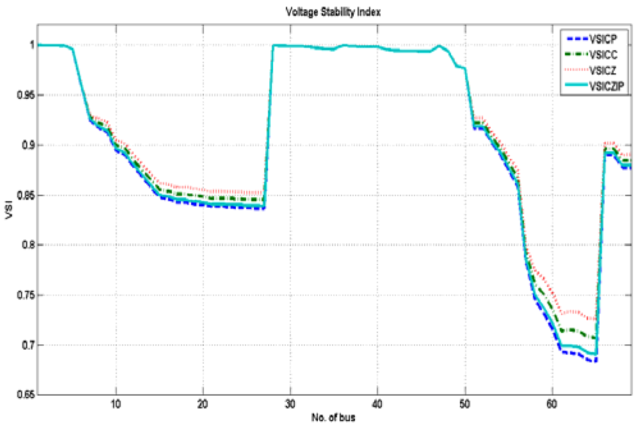

Fig. 5: Voltage stability index profile of 69-bus system

Similarly voltage stability index of 69-bus system is shown in Fig.5.

5. CONCLUSION

In this paper Voltage stability index is used to compute the most sensitive node of radial distribution system. The most sensitive node and the node having the minimum voltage are identical that have been demonstrated by two examples 33-bus system and 69-bus system for constant power (CP), constant current (CI), constant impedance (CZ) and composite load modeling for substation voltage of 1.0 p.u. and results are obtained. The critical loading for constant current load is the maximum and that for constant power load is minimum. The critical loading for constant impedance lies between these two and that for the composite load solely depends on the percentage composition of the three loads.

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