AN INDEX FOR DISSECTION OF VOLTAGE STABILITY AND REACTIVE POWER REMUNERATION OF DISTRIBUTION NETWORK BASED ON SYNTHESIS LOAD MODEL

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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

Key Words: Radial Distribution System, Voltage Stability Index, Critical Bus, Reactive Power, Synthesis Load Model.

I 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) 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 (Takahashi K., Nomura Y, 1987). In order to prevent the occurrence of voltagecollapse, 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.Sakthiveleta., 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 theeconomic and environmental constraints, that 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 (Or) 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 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 Kirchoff'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.,

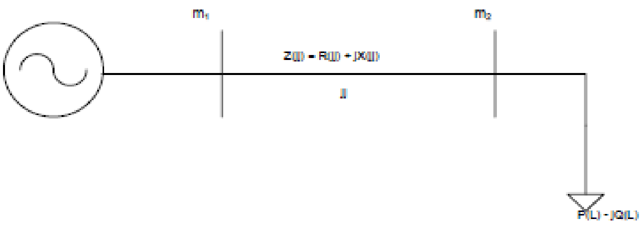
2010) a CTP Flow approach for voltage stability analysis of unbalanced three-phase power systems is presented in (X. P. Zhang et al., 2005).A three-phase constrained optimal power flow is proposed to analyse voltage stability in an unbalanced power system (G. Carpinelli, et al., 2006). The voltage stability 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 three different load models constant power, constant current and constant impedance 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. It is also shown that the load flow solution with feasible voltage magnitude for radial distribution networks is unique.

II MATHEMATICAL MODEL

For a distribution line model in fig 1. Distribution Networks are assumed to be balanced and can be represented by a single line diagram.



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

$$P(m2) - jQ(m2) = V * (m2) \times I(jj)$$
(2)

From equation (1) and (2).

$$\frac{|V(m1)|\angle\delta(m1) - |V(m2)\angle\delta(m2)|}{r(jj) + jx(jj)} = \frac{P(m2) - jQ(m2)}{V * (m2)}$$
(3)

$$|V(m1)| \times |V(m2)| \cos\{\delta(m1) - \delta(m2)\} - |V(m2)|^2 + j\sin\{\delta(m1) - \delta(m2)\} = P(m2)r(jj) + Q(m2)x(jj) + j\{P(m2)r(jj) - Q(m2)x(jj)\}$$
(4)

$$|V(m1)||V(m2)| \cos\{\delta(m1) - \delta(m2)\} - |V(m2)|^2 = \{P(m2)r(jj) + Q(m2)x(jj)\}$$
(5)

$$|V(m1)||V(m2)|\{\sin\{\delta(m1) - \delta(m2)\} = \{P(m2)x(jj) - Q(m2)r(jj)\}$$
(6)

Squaring and adding (5) and (6)

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

Let

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

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

From equation (3), (4), (5) and (6)

$$|V(m2)^4| - b(jj)|V(m2)|^2 + c(jj) = 0$$
(7)

V (m2) has four solutions.

$$\left[\left(\frac{1}{2}\right)[b(jj) - \{b^2(jj) - 4c(jj)\}^{0.5}]\right]^{0.5}$$

$$\left[\left(\frac{1}{2}\right)[b(jj) - \{b^2(jj) - 4c(jj)\}^{0.5}]\right]^{0.5}$$

$$\left[\left(\frac{1}{2}\right)[b(jj)+\{b^2(jj)-4c(jj)\}^{0.5}]\right]^{0.5}$$

$$\left[\left(\frac{1}{2}\right)[b(jj)+\{b^2(jj)-4c(jj)\}^{0.5}]\right]^{0.5}$$

$|V(m2)|=$

$$\left[\left(\frac{1}{2}\right)[b(jj)+\{b^2(jj)-4c(jj)\}^{0.5}]\right]^{0.5} \quad (8)$$

Only feasible solution of load flow when,

$$b^2(jj)-4c(jj)\geq 0$$

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

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

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

$VSI(m2)\geq 0$ for nodes m2=2,3,4…………..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

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

$$V(m2)=V(m1)-I(jj)[R(jj)+X(jj)] \quad (11)$$

m1=IS(jj)

m2=IR(jj)

load current of any receiving end node m2 of branch j is

$$IL(m2)=\frac{PL(m2)-jQL(m2)}{V*(m2)} \quad (12)$$

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

$$LP=I(jj)^2R(jj) \quad (13)$$

$$LQ=I(jj)^2X(jj) \quad (14)$$

The current beyond branch jj

$$I(jj) = \sum_{i=1}^{S(jj)} IL\{IE(jj,i)\} \quad (15)$$

From equation (15) it can be seen that for finding out branch current of branch 1,2,3……LN1

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

III 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:

$$P(m2) = P_n[a_0 + a_1 V(m2) + a_2 V^2(m2)] \quad (16)$$

$$Q(m2) = Q_n[b_0 + b_1 V(m2) + b_2 V^2(m2)] \quad (17)$$

Where Pn and Qn are nominal real and reactive power respectively and V(m2) is the voltage at node m2. For all the loads, Eq.(17) are modeled as

$$a_0 + a_1 + a_2 = 1.0 \quad (18)$$

$$b_0 + b_1 + b_2 = 1.0 \quad (19)$$

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.

IV. SIMULATION RESULTS AND DISCUSSIONS

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). Fig.2. shows Voltage profile of 33-bus system for different types of loads i.e. constant power (CP), constant current (CI) and constant impedance (CZ).. Similarly for 69-bus system is shown in Fig.3.Table 1. Presents the value of index is given for all node and which one have the least value of 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 and bus 65 is for 69 bus system which have least value of voltage stability index.

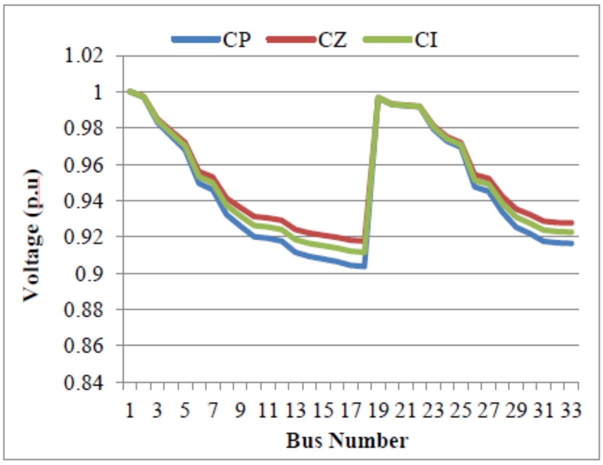


Fig. 2.Voltage profile for 33-bus system

Multiplier power flow analysis in which each node power is multiplied by a factor (λ) as S=λSB and the critical node bus is identified by calculating bus voltage magnitude just before the load flow diverge. This voltage stability index is used for different types of static load models, and constant power, constant current, constant impedance loadmodels is used for different loading conditions.

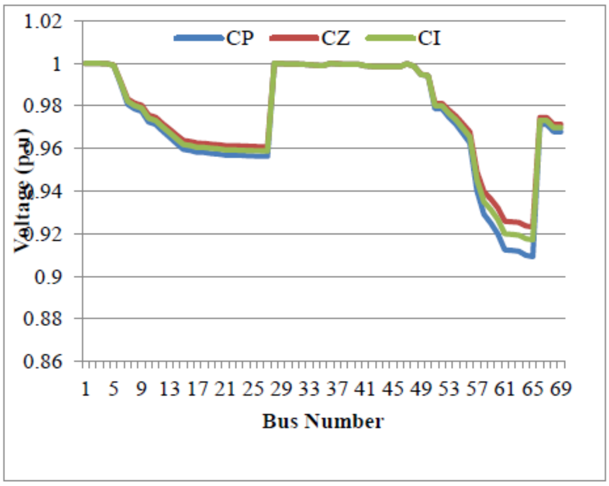


Fig. 3.Voltage profile for 69-bus system

We can observe the variations of index value for four cases constant power, constant current, constant impedance and composite loadfromTable. 2 critical loading conditions for different types of load and different values of substation voltage. It is seen that 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. 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. Similarly, the composition of loads governs the position of the stability index for the composite load.

Table 1: Bus voltage stability indices for the base load of the systems

BusNo.	Radialtestsystems			
	33-Bus	69-Bus	BusNo.	69-Bus
23	0.988136	0.999866	36	0.999677
45	0.932919	0.999732	37	0.99899
67	0.905002	0.999358	38	0.998357
89	0.877756	0.996087	39	0.998174
10	0.812106	0.960781	40	0.998165
11	0.800678	0.925217	41	0.99538
12	0.755146	0.917046	42	0.994216
13	0.735094	0.912813	43	0.994062
14	0.716628	0.894252	44	0.994029
15	0.713985	0.890261	45	0.993637
16	0.709288	0.878729	46	0.993635
17	0.690324	0.868186	47	0.999158
18	0.683469	0.857854	48	0.994183
19	0.679197	0.847687	49	0.978922
20	0.675071	0.845823	50	0.976818
21	0.668984	0.842723	51	0.916923
22	**0.667181**	0.842693	52	0.916887
23	0.98606	0.84106	53	0.902437
24	0.971949	0.840014	54	0.890482
25	0.96922	0.838325	55	0.874174
26	0.966732	0.838301	56	0.858486
27	0.919739	0.838049	57	0.780142
28	0.894867	0.837501	58	0.744773
29	0.882759	0.83691	59	0.731345
30	0.806134	0.836665	60	0.715567

Table 2: critical bus index value and its bus voltage for maximum TPL and TQL of 69 bus system

Loadtype	Substation voltage(pu	Criticalloadingcondition			
		TPL (MW)	TQL(MVAR)	SImin=SI65(pu)	Vmin=V65(pu)
Constant Power(CP)	1	18.410	11.336	0.0639	0.5028
	1.025	20.037	12.476	0.0770	0.5276
Constant Current (CI)	1	20.399	13.155	0.1095	0.5754
	1.025	21.722	13.991	0.1165	0.5843
Constant Impedance	1	19.090	12.706	0.2142	0.6806
	1.025	19.471	12.976	0.2446	0.7035
Composite Load(40%CP, 30%CIand	1	20.6128	13.072	0.0798	0.5315
	1.025	21.877	13.866	0.0858	0.5413
	1.05	23.174	14.683	0.0924	0.5513

V. 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 pu, 1.025 pu and 1.05 pu 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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