Voltage Stability Analysis of Rural Distribution Feeder

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ABSTRACT--- ***The objective of this paper is to present two new voltage stability indices have been proposed for identifying the node which is most sensitive to voltage collapse.The useful information given by the new indice with conventional indices is investigated.The proposed approach has been applied to several Indian rural distribution networks and 15-bus test system which demonstrated applicability of the proposed approach.***

Keywords--- Voltage Stability Analysis, Radial Distribution Systems.

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1. INTRODUCTION

Power systems is an interconnected system composed of Generating stations, which convert fuel energy into electricity ,substations that distribute power to loads(consumers) and transmission lines that tie the generating stations and distribution substations together. According to voltage levels an electric power system can be viewed as consisting of a generating system, a transmission system and a distribution system.

The transmission system is distinctly different in both its operation and characteristics from the distribution system. Whereas the latter draws power from a single source and transmit it to individual loads, the Transmission systems not only handle the largest blocks of power but also the system. The main difference between the transmission system and the distribution systems shows up in the network structure. The former tends to be a loop structure and the latter generally a radical structure.

The modern power distribution network is constantly being faced with an ever-growing load demand. Distribution network experience distinct changes from a low to high load level every day. In certain industrial areas, it has been observed that under certain load critical loading conditions, the distribution system experience voltage collapse. Brownell and Clarke [1] have reported the actual recordings of this phenomenon in which system voltage collapses periodically and urgent reactive compensation needs to be supplied to avoid repeated voltage collapse. The transmission of large amounts of power through the lines results in the large voltage drops. Sudden disturbances like line generator outage or faults in the transmission lines may result in conditions that the transmission system may not be able to supply the load demand. This could manifest as ac drop in the system bus voltages which may be sudden or progressive. If the necessary remedial measures are not taken, then this may lead to the blackout or collapse of the whole system. As a result of number of voltages Stability incidents reported from various countries, there is a widespread interest in understanding, characterizing and preventing this phenomenon. This paper is essentially concerned with analyzing the effect of active power on voltage stability.

2. LITERATURE REVIEW

Literature survey shows that a lot of work has been done on the voltage stability analysis of transmission systems [2], but hardly some work has been done on the voltage stability analysis of radial distribution networks. Jasmon [3] and Gubina and Strmcnik [4] have studied the voltage stability analysis of radial networks. They have represented the whole network by a single line equivalent. The single line equivalent derived by these authors [3]and[4] is valid only at the operating point at which it is derived. It can used for small load changes around this point. However since the power flow equations are highly nonlinear, even in a simple radial system, the equivalent would be inadequate for assessing the voltage stability limit. Also their techniques [3]and[4] do not allow for the changing loading pattern of the various nodes which would greatly affect the collapse point.

Voltage Stability analysis is important at assesses the criticality of the existing networks. An in depth assessment of this class of methods is attempted here. In particular, the methods considered are the following.

The line flow index which provides stability measures for the lines in power system is proposed in [5].The L-index method proposed in [6] which attempts to provide a measure of stability of load buses in a system by ranking them according to a parameter(L-index). The Eigen values and Eigen vectors of power flow Jacobin have been used in [7] to characterize the stability margin in a system. Further we are looking at the information provided by the two new indices.

3. VOTAGE STABILITY INDICES

A. Line Flow Index

This method has been proposed in [5] to find the most critical lines in a system from the point of view of voltage stability. In this method the power flow in a transmission line is examined from both directions (i.e. power flowing from the bus at the sending end to the bus at the receiving end).This leads to four indices; two each for the real and reactive power flows. Each of these are utilized to determine whether any lines/buses are critical.
The four line flow indices are calculated as follows.

Line flow index for the sending end real power:

$$LFISP : 4\frac{r_i}{V_i^2}\left(P_r + \frac{r_i}{V_i^2}Q_i^2\right) \text{---(1)}$$

Line flow index for receiving end real power

$$LFIRP : 4\frac{r_i}{V_{i+1}^2}\left(-P_i + \frac{r_i}{V_{i+1}^2}Q_r^2\right) \text{---(2)}$$

Line flow index for sending end reactive power:

$$LFISQ : 4\frac{X_i}{V_i^2}\left(Q_r + \frac{X_i}{V_i^2}P_i^2\right) \text{---(3)}$$

Line flow index for receiving end reactive power:

$$LFIRQ : 4\frac{X_i}{V_{i+1}^2}\left(-Q_i + \frac{X_i}{V_{i+2}^2}P_r^2\right) \text{---(4)}$$

where
V_i :- voltages at the sending end node i
V_{i+1} :- voltages at the receiving end node *i +1*
ri :- resistance of the line joining the nodes *i and i +1*
Xi :- reactance of the line joining the nodes
Pi :- real power flowing from node *i*
Qi :- reactive power flowing from node *i*
P_r :- real power entering from node *i +1*
Q_r :- real power entering from node *i +1*

These line flow indices are calculated for all the lines in the system and the lines with a high value (close to 1) are considered as critical lines. The receiving end bus of the critical line/lines is identified as the weakest bus from the voltage stability perspective.

B. L-Index method

In this method the Ybus matrix of the system is split into rows and columns of generators and load buses.

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{pmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{pmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \text{---(5)}$$

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{pmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{pmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \text{---(6)}$$

$$F_{LG} = -[Y_{LL}]^{-1}[Y_{LG}] \text{---(7)}$$

$$L_j = \left| 1 - \sum_{i=1}^{i=g} F_{ji} \frac{V_i}{V_j} \right| \text{---(8)}$$

where the subscript

"G" :- refers to the generator buses in the system

"L" :- refers to the load buses in the system

A L-index value away from 1 and close to 0 indicates a large voltage stability margin.

C. Participation Factor.

The participation factor is developed as follows. Consider the load flow Jacobin

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{pmatrix} H & N \\ M & L \end{pmatrix} \begin{bmatrix} \Delta \theta \\ \Delta V \end{bmatrix} \text{---(9)}$$

Although both P and Q changes affect system conditions, it is possible to study the effects of reactive power injections on the voltage stability by setting ΔP (P constant) and deriving the Q-V sensitivities at different loads. Thus the 5 can be written as

$$\Delta Q = \left[L - MH^{-1}N \right] \Delta V = J_R \Delta V \text{---(10)}$$

$$J_R = \xi \Lambda \eta \text{---(11)}$$

where

Λ :- left eigen matrix of J_R

η :- right eigen matrix of J_R

ξ :- eigenvalues of J_R

The participation factors for the bus k and the critical mode i are defined as $\xi_{ki}\eta_{ik}$.

D. An Alternate L-index

The original L- index as defined in (5) based on (5) to (7) is actually a function of the network parameters and bus voltage magnitudes. An Alternate L- Index is proposed in [2].and [8] The bus voltages magnitudes seem to capture the impact of load on the criticality of buses from the point of view of voltage stability. The new definition is as follows. Equation (5) is rewritten as below.

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{pmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{pmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \text{---(12)}$$

The only difference between them is that loads at all load buses are considered to be of constant impedance type and their nominal value is included in the diagonal values of Y_{LL}. F_{LG} defined as before and the new L- index, NL_j is defined as:

$$L_j = \left| 1 - \sum_{i=1}^{i=g} F_{ji} \right| \text{---(13)}$$

where g is the number of generators in the system.

E. Pattern of Diagonal of (Inverse of YLL)

While developing the alternate L-index section it was noticed that ΣFij will be equal to 1 for all load buses if loads are not included in the diagonals of YLL matrix. It is easy to see that the values of loads when converted into admittances generally have very small values and therefore do not contribute to significant changes in the YLL values. Hence, it appears logical to expect that the Y_{LL} *matrix contains the information pertaining to the pattern of these indices. In many of the systems it was observed that the most critical buses turned out to be those buses which seem to be away from the generator buses.*

Table 1: Line flow index values for 15 bus radial system.

From	To	LFISP	LFISQ	LFIRP	LFIRQ
1	2	0.1075	-0.1111	0.1048	-0.1082
2	3	0.0495	-0.0505	0.0483	-0.0493
3	4	0.0185	-0.0186	0.0180	-0.0182
4	5	0.0025	-0.0025	0.0017	-0.0017
2	8	0.0081	-0.0081	0.0054	-0.0055
8	9	0.0026	-0.0026	0.0018	-0.0018
2	6	0.0445	-0.0454	0.0299	-0.0305
6	15	0.0055	-0.0055	0.0037	-0.0037
6	7	0.0032	-0.0032	0.0021	-0.0021
3	10	0.0166	-0.0168	0.0112	-0.0113
10	11	0.0103	-0.0103	0.0069	-0.0070
11	12	0.0033	-0.0033	0.0022	-0.0022
4	13	0.0057	-0.0057	0.0039	-0.0039
4	14	0.0061	-0.0062	0.0041	-0.0042

An intuitive way of capturing the distance of load buses from the generator buses would be in terms of Z_{th} that is diagonal terms of inverse of the Y_{LL} matrix. As the loads are taken into consideration this would be a valid index

SIMULATION AND RESULTS

15-bus test system

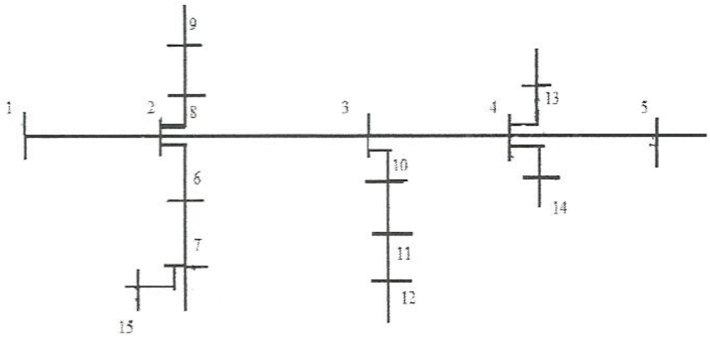

Figure 1 Rural distribution Feeder with 15 nodes

The numbering of nodes is done as in (8). We have assumed that three phase radial networks are balanced and can be represented by their equivalent single line diagrams. This assumption is valid for 11 KV rural distribution feeder shown above. Line shunt capacitance is negligible at the distribution voltage levels as is found in many cases. The bus data is given in the table 1.

L-index plot

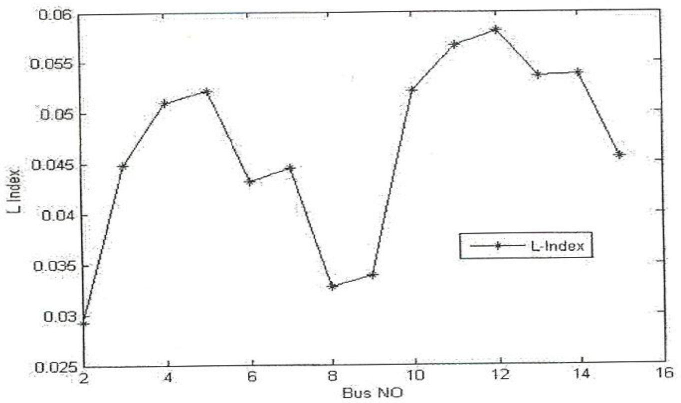

Figure 2: Plot of L-index for 15 bus radial system.

Participation Factor

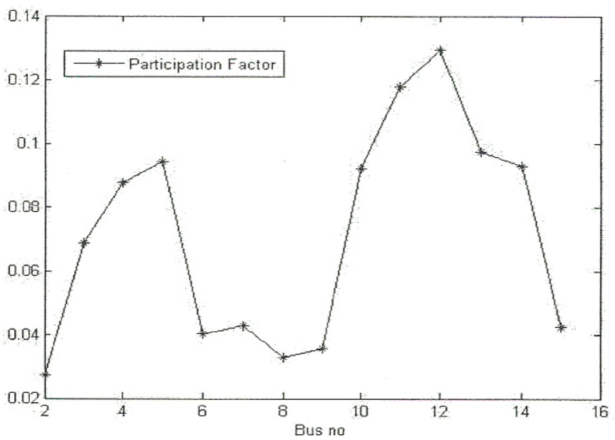

Figure 3: showing Participation Factor for 15 bus .

New L-index

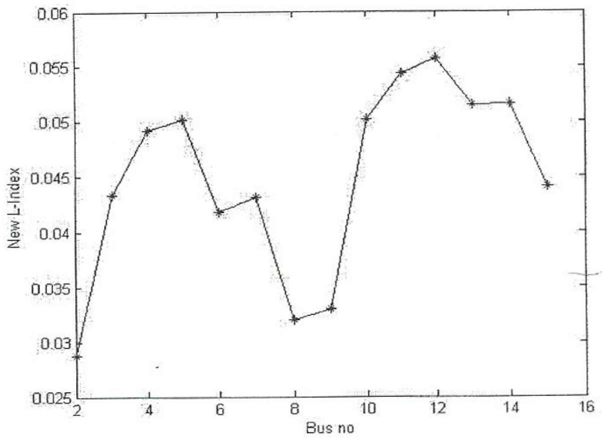

Figure 4: Showing New L-index.

Pattern of diagonal

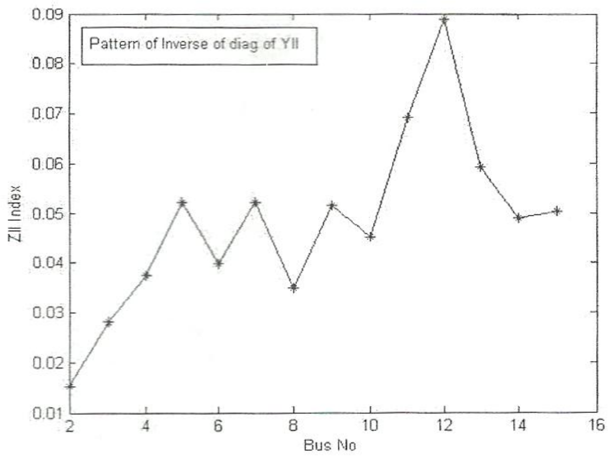

Figure 5: showing Pattern of diagonal of inverse of Y_{LL}.

4. CONCLUSIONS

Indices that have been proposed by the other researchers to assess the voltage stability of a power system have been studied. The advantage with the new L-index is that it does not need power flow solution and so computational effort is less. The second index captures the criticality of buses based on their distance from the generators.

5. REFEERENCES

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