

Identification of Weakest Node in Radial Distribution System Using Fast Voltage Stability Index

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ABSTRACT: Now-a-days, the electrical energy suppliers cannot cope up with the increasing demand of end users. The restructuring of the existing network and addition of active support are the viable solutions to balance the energy supply-demand. The voltage instability is the major issue faced by the ill-conditioned radial distribution system. Traditional power flow analysis might be unstable and diverge, due to the peculiarities of radial systems such as high R/X ratio. This paper focussed on a BIBC-BCBV algorithm based load flow analysis to find the voltage stability and power loss. The voltage instability causes voltage collapse which starts at weakest node first. The weakest node identified based on stability index method. The effectiveness of the algorithms tested on IEEE 33 bus radial distribution system.

KEYWORDS: Radial distribution system, BIBC-BCBV algorithm, Fast Voltage Stability Index (FVSI)

I. INTRODUCTION

The load demands in distribution networks are increasing with a high rate due to the development of economy. Voltage instability is the major issue faced by the designers and engineers in power system operation, planning and control. The instability in voltage leads to voltage collapse [1]. The system experiences a voltage instability problem when there is an uncontrollable voltage drop after a disturbance and increase in load demand [2]. The inability of power system to meet the reactive power demand is the main reason for the voltage instability, which is a localized problem but it would lead to the system collapse [3]. So it is important to identify the locations where the voltage instability is initiated. Identification of the weakest buses is the effective way to locate the origin of voltage instability. Weakest bus is most vulnerable to voltage collapse due to lack of reactive power support. Stability index based method is commonly used for the identification of weakest node. Load flow analysis is a tool for identifying the location at which active/reactive support needs. Many researchers proposed various algorithms to compute the voltage stability and power losses. Since the distribution network have high R/X ratio, traditional load flow methods such as Newton-Raphson (N-R) and Gauss-Seidel (G-S) methods failed to converge and hence these methods are not used in radial distribution networks [4].

With its high R/X ratio, the radial system possesses poor voltage regulation and high power loss. For ill-conditioned radial system, an algorithm based on Bus Injection to Branch Current (BIBC) matrix and the Branch Current to Bus Voltage (BCBV) matrix used for load flow analysis [5]-[7]. In this method, one matrix used for finding the angle and magnitude of bus voltage and other matrix used for computing power loss. This method requires less computer memory and less computation time.

This paper presents an index named Fast Voltage Stability Index (FVSI), to identify the location of weakest node. The voltage collapse starts from the weakest node first [8]-[12]. In order to protect the radial system from voltage instability, active/reactive support has to be given at the weakest node. The proper assigning of active/reactive supports helps in improving voltage profile with a considerable decrease in power loss [13][14].

II. BIBC-BCBV METHOD

In a radial distribution network, an iterative algorithm named BIBC-BCBV used for the load-flow computation, to find bus voltages and power loss. There are two sets of equations used for load flow of a single source network. The first set of equations for the calculation of the power flow through the branches and second set for the calculation of angle and magnitude of bus voltage. The two matrices used in this algorithm are Bus Injection to Branch Current (BIBC) matrix and the Branch Current to Bus Voltage (BCBV) matrix [4].

A. Equivalent current injection

For i^{th} node, the complex load S_i can be expressed as

$$S_i = P_i + jQ_i, \quad i=1, \dots, N \quad (1)$$

The corresponding equivalent current injection at the k^{th} iteration of the solution is computed as

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{P_i + jQ_i}{V_i^k} \right)^* \quad (2)$$

Where,

S_i is the complex power at the i^{th} node.

P_i is the real power at the i^{th} node.

Q_i is the reactive power at the i^{th} node

V_i^k is the node voltage at the k^{th} iteration for i^{th} node.

I_i^k is the equivalent current injection at the k^{th} iteration for i^{th} node.

I_i^r and I_i^i are the real and imaginary parts of the equivalent current injection at the k^{th} iteration for i^{th} node.

B. BIBC matrix formation.

The formulation of Bus-injection to Branch-current (BIBC) matrix is explained with the help of simple distribution system shown in Fig. 1

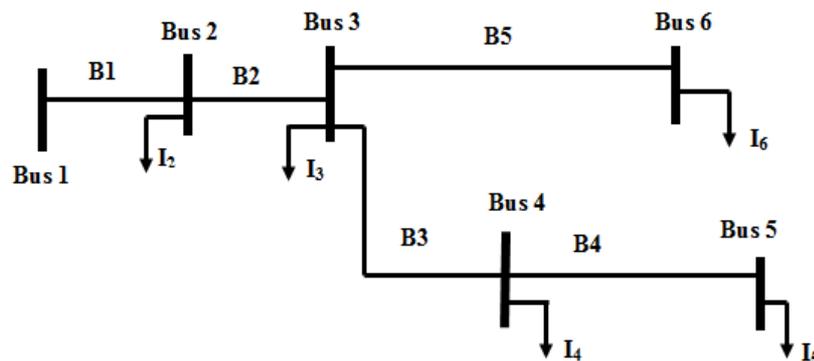


Fig.1. Simple distribution system

The power injections at each bus can be converted to the equivalent current injections using eqn. (2) and a set of equations can be written by applying KCL at each node. As shown in Fig. 1, the branch currents can be expressed as:

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix}$$

The general form as of eqn. (3) can be expressed as:

$$[B] = [BIBC][I] \quad (4)$$

C. BCBV matrix formation.

The Branch-Current to Bus voltage (BCBV) matrix summarizes the relation between branch current and bus voltages.

The relationship between the branch currents and bus voltages is,

$$V_2 = V_1 - B_1 Z_{12} \quad (5)$$

$$V_3 = V_2 - B_2 Z_{23} \quad (6)$$

$$V_4 = V_3 - B_3 Z_{34} \quad (7)$$

$$V_5 = V_4 - B_4 Z_{45} \quad (8)$$

$$V_6 = V_3 - B_5 Z_{36} \quad (9)$$

As shown in Fig. 1, according to KVL the voltage of bus 4 is,

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \quad (10)$$

Similar procedures can be utilized for other buses, and the BCBV matrix can be derived as:

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (11)$$

The general form of eq. (11) can be expressed as:

$$\text{Or, } [\Delta V] = [BCBV][B] \quad (12)$$

Combining eqns. (4) and eqn. (12) will get,

$$[\Delta V] = [BCBV]. [BIBC]. [I] \quad (13)$$

$$[\Delta V] = [BIBC]^T. [ZD]. [BIBC]. [I] \quad (14)$$

$$[DLF] = [BIBC]^T . [ZD]. [BIBC] \quad (15)$$

$$\text{So, } [\Delta V] = [DLF]. [I] \quad (16)$$

The solution for the load flow can be obtained by solving eqns. (17) and (18) iteratively which are given below:

$$I_i^k = I_i^k(V_i^k) + jI_i^k(V_i^k) = \left(\frac{P_i + jQ_i}{V_i^k} \right)^* \quad (17)$$

$$[\Delta V^{k+1}] = [DLF] . [I^k] \quad (18)$$

$$[V^{k+1}] = [V^0] - [\Delta V^{k+1}] \quad (19)$$

The total power loss can be expressed as a function of the bus current injections

$$P_{\text{loss}} = \sum_{k=1}^{nb} |B_k|^2 . R_k = [R]^T |[BIBC]. [I]|^2 \quad (20)$$

Where R_k is the k^{th} branch resistance.

III.FAST VOLTAGE STABILITY INDEX (FVSI)

Fast Voltage Stability Index (FVSI) generally derived from the voltage quadratic equation at the receiving end bus on a two-bus system [10][11]. The single line diagram of a two bus system is shown in Fig.2.

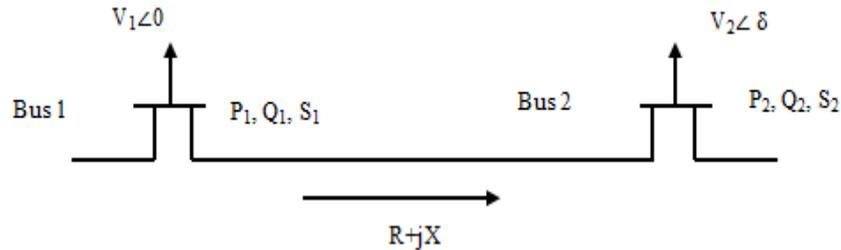


Fig.2. Single line diagram of 2-bus distribution system

The voltage equation at the receiving end bus is given as

$$V_2^2 - \left[\frac{R}{X} \sin \delta + \cos \delta \right] V_1 V_2 + \left[X + \frac{R^2}{X} \right] Q_2 = 0 \tag{21}$$

Set the discriminant be greater than or equal to zero.

$$\left(\left[\frac{R}{X} \sin \delta + \cos \delta \right] V_1 \right)^2 + 4 \left(X + \frac{R^2}{X} \right) Q_2 \geq 0 \tag{22}$$

Rearranging (22), then

$$\frac{4Z^2 Q_2 X}{V_1^2 (R \sin \delta + X \cos \delta)^2} < 1 \tag{23}$$

Since δ is too small, $R \sin \delta \approx 0$ and $X \cos \delta \approx X$. FVSI can be defined as:

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \tag{24}$$

Where Z and X are line impedance and line reactance, Q_j is the reactive power at the receiving end, and V_i is the sending end voltage. FVSI is a stability indicator to identify the weakest bus from which the voltage collapse starts first. The bus with highest value of FVSI is treated as unstable and weakest bus [12]-[14].

IV. RESULTS AND DISCUSSIONS

The proposed BIBC-BCBV Algorithm applied to the test system for finding total power loss and voltage at each bus. Fig.3 shows that the voltage profile of IEEE 33 bus test system. The base voltage of the test system is 12.66 KV. Total connected active and reactive loads are 3715KW and 2300KVAR respectively. It is found that the number of buses with under voltages are 21, out of which bus 18 having minimum voltage.

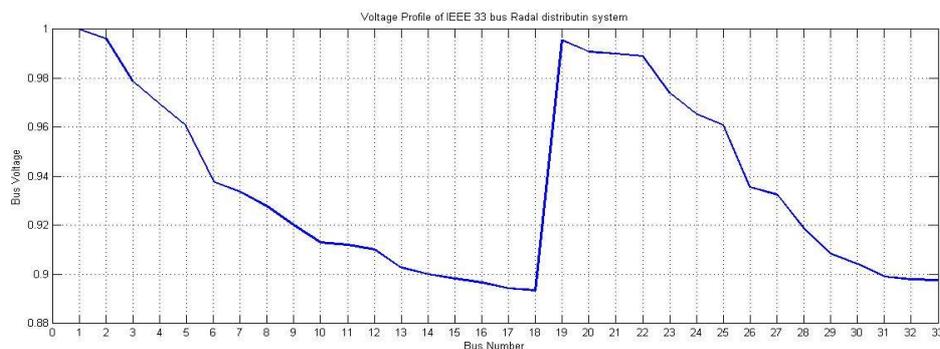


Fig.3. Voltage profile of IEEE 33bus Radial power distribution system

Fig.3. clearly shows that buses 6 to 18 and buses 26 to 33 suffer from under voltage. All these buses are far from the substation. A minimum voltage of 0.8935 pu (11.3117KV) is obtained at bus 18 with a drop of 10.65%. The maximum voltage which is obtained at bus 2 is 0.9963pu (12.613KV) with a drop of 0.37%. The permissible limit of voltage is in the range of $\pm 5\%$ (12.027 KV/13.293KV). From Fig. 3, it is observed that the buses near to the substation have voltage approximately equal to 1pu and far end buses suffering from under voltages. Since it is a radial distribution system, the feeder far away from the slack bus or substation suffers from high voltage regulation.

Fig.4 and Fig.5 show the real power loss and reactive power loss in each branch of the test system. It is observed that the losses are very high in the branch connecting buses 2 to 3 and 5 to 6. It is because of the heavy load connected at these buses. The active power loss in the branch 2 to 3 founded as 60.79 KW and reactive power loss, 30.96 KVAR respectively. Similarly, active and reactive power losses in branch 5 to 6 are observed as 43.41 KW and 37.1 KVAR respectively.

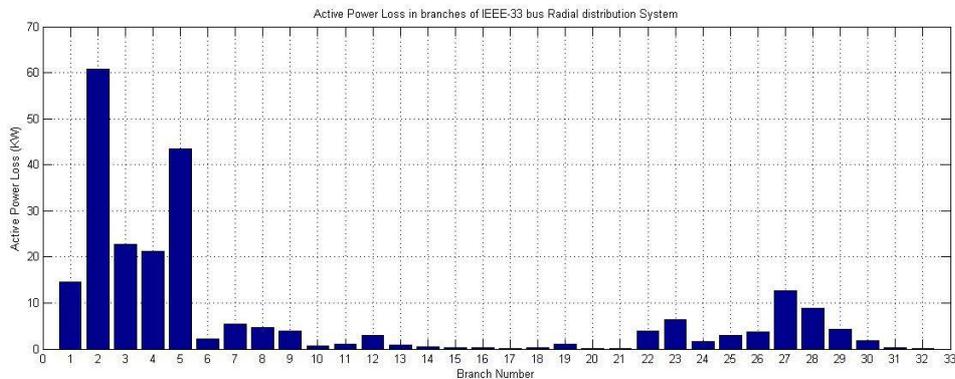


Fig.4. Active power loss in branches of IEEE 33 bus system

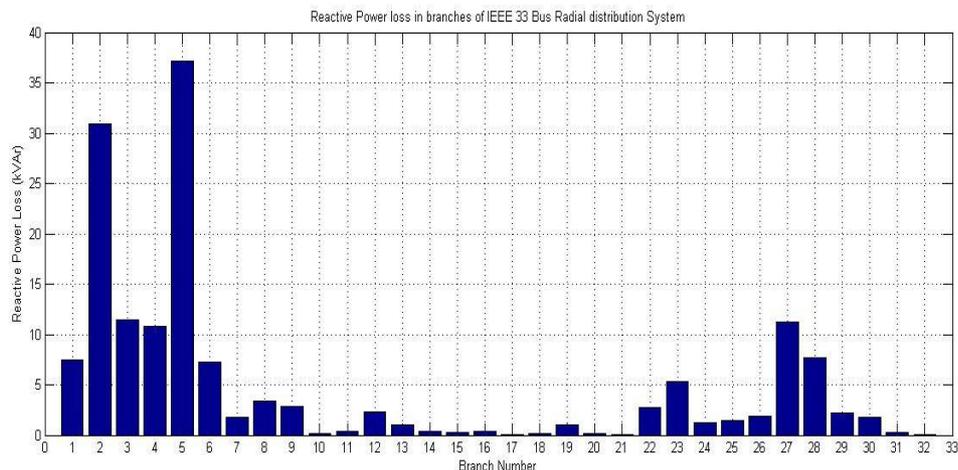


Fig.5. Reactive power loss in branches of IEEE 33 bus system

From Fig.4 and Fig.5, it is clear that the active and reactive power losses are very high near to the substation. Fig.6 shows the total active and reactive power loss of IEEE 33 bus test system. It is computed as 230 KW and 160 KVAR respectively.

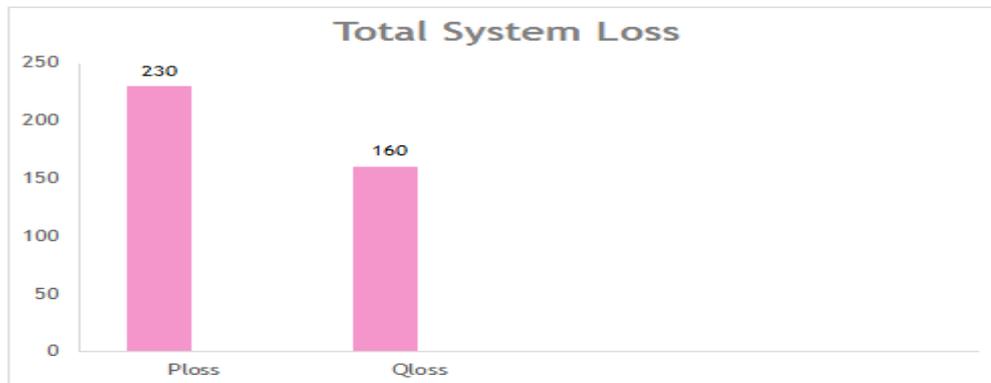


Fig.6. Total system loss in branches of IEEE 33 bus system

The FVSI of each bus is computed and found that bus 30 have the highest FVSI shown in Fig.7. It reveals that the most unstable and affected bus is 30 and any disturbance in the system affects this bus first. The comparison between FVSI analysis and BIBC-BCBV analysis showed that bus 18 is suffering from voltage instability, but, bus 30 is the weakest bus.

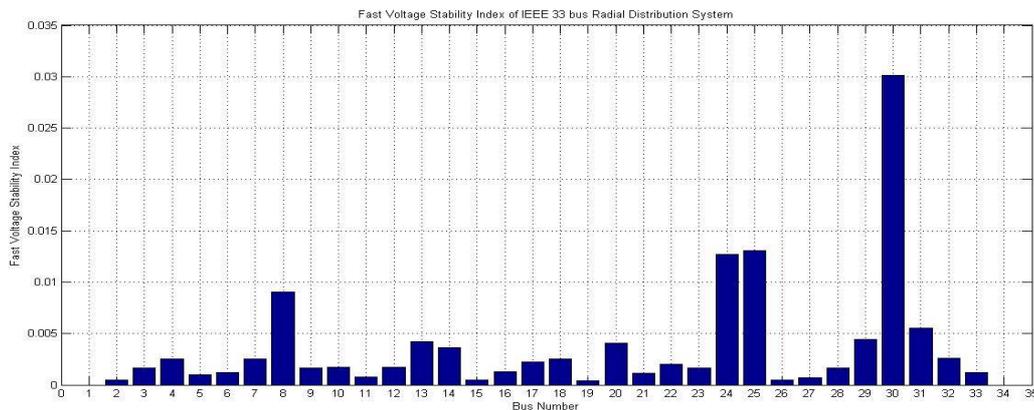


Fig.7. Fast Voltage Stability Index of IEEE 33 bus system

Table I shows the overall result of the IEEE-33 bus test radial distribution. From this, it is observed that the bus with minimum voltage might not be a weakest bus.

TABLE I
OVERALL RESULTS OF IEEE 33 BUS TEST SYSTEM

System Parameters	33-bus
Total connected Active Load, P _{LOAD} (kW)	3715
Active Power Loss, P _{LOSS} (kW)	230
% of P _{LOSS} wrt P _{LOAD}	6.191
Total connected Reactive Load, Q _{LOAD} (kVAr)	2300
Reactive Power Loss, Q _{LOSS} (kVAr)	160
% of Q _{LOSS} wrt Q _{LOAD}	6.956
Minimum Voltage (pu)	0.8935
Location at minimum voltage	18
Bus with high FVSI	30

V. CONCLUSION

This paper focussed on IEEE-33 bus, to find the voltage and angle of each bus using a proposed algorithm named BIBC-BCBV. In connection with this algorithm, an index named FVSI used to identify the weakest node at which voltage collapse starts first. This method uses only two matrices so that the convergence is very easy for any large system. The computer memory required is less. The time of computation is measured as 0.662970 seconds. The algorithm helps in finding the location needs active/reactive support. It is concluded that the voltage stability can be improved with the help of active or reactive support at this bus.

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