IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 6 Ver. I (Nov – Dec. 2015), PP 21-26
www.iosrjournals.org

Voltage Stability Assessment Using the Concept of GVSM

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Abstract: *To assessment of voltage stability of multi bus power system, the main requirement is equivalent two-bus network models, which is fulfilled by lumping all the series impedances and shunt admittances of transmission lines within a series equivalent impedance. This paper shows the development of an equivalent pi network model using a new technology or methodology called generalized global voltage stability margin (GVSM). This is used to assess the overall voltage stability status of the system accurately. Simulation results for IEEE 14 Test bus system, IEEE 30 Test bus system , IEEE 118 Test bus system are establish that the pi-equivalent model obtained by the proposed method is highly accurate for assessing voltage stability of any power system at any operating point in a better way as compared to series equivalent model.*
Keywords: *GVSM, Critical voltage, Global receiving end voltage.*

I. Introduction

The voltage stability is increasingly becoming a limiting factor in the modern power systems due to the various changes that are continuously introduced to meet ever-increasing load demand without sufficient transmission and generation enhancement. This has necessitated to employment the techniques for analyzed and determined the critical point of voltage stability. Voltage stability is defined as the ability of the power system to maintain acceptable & constant voltage level at all buses in the system under normal conditions and after being subjected to the disturbance. Therefore, voltage stability analysis is necessary to identify the critical buses in a power system i.e., buses which are closed to their voltage instability (near to voltage collapse point) and to help the planning engineers and operators to take appropriate actions to avoid voltage collapse [1, 3]. The common techniques available for the assessment of voltage stability of any power system as well as for identifying the point of critical voltage stability are based on the load flow solution feasibility, singularity of Jacobian, bifurcation technique, optimal power flow, etc. Mostly used techniques are, the conventional P–V, Q–V curves and P–Q plane for assessing the voltage stability of critical bus in a power system. In this paper, the efforts have been made to assess the voltage stability in terms of network equivalencing to obtain a global scenario of voltage stability. In this, the actual system is reduced into an equivalent two-bus system, i.e., methodology applied at line only, by using all parameters in regarding of line and then the global voltage stability indices are used for indicating the state of the actual system. The technique for reducing the given power system to its equivalent two-bus model is described in this dissertation. All the parameters of the equivalent system are obtained from the load flow solution of the original system. This equivalent system is nothing more than a power line having series equivalent impedance with a load at the receiving end, but the sending end voltage is kept at the reference voltage. The concept of single line equivalent is used to determine the voltage collapse proximity. Determination of accurate global voltage stability indices is possible if the power system is accurately and faithfully represented by an equivalent two-bus system. And this equivalent model used to assess voltage stability of a power system is obtained by lumping series impedances and shunt admittances of transmission lines altogether within the series equivalent impedance obtained from any load flow study performed on the actual size system [4-8].

II. Evaluation Of Equivalent Two-Bus Pi-Network Model

The proposed methodology to evaluate the equivalent two-bus pi-network model is developed as follows: Let us assume a two-bus equivalent network in which a generator bus is assumed as sending end bus and a load bus is assumed as receiving end bus as shown in Fig.1. The behavior and properties of the proposed two-bus equivalent model should be the same as the multi-bus network and make possible the evaluation of voltage stability [4-6]. Therefore, the power equation for the two-bus equivalent network can be written as:

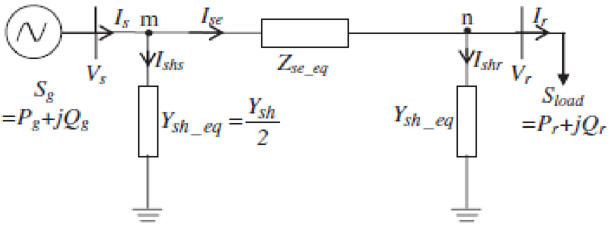

Fig.1. Two bus pi-equivalent network

$$S_g = P_g + jQ_g = \vec{V}_s \vec{I}_s^* = (S_{se} + S_{sh}) + S_{load} \quad (1)$$

Where

$$S_{se} = (\vec{V}_s - \vec{V}_r)\vec{I}_{se}^* \quad (2)$$

$$S_{sh} = \vec{V}_s \vec{I}_{shs}^* + \vec{V}_r \vec{I}_{shr}^* \quad (3)$$

Applying KCL at node m and we get:

$$\vec{I}_{se}^* = \frac{S_g}{\vec{V}_s} - S_{sh}\left(\frac{\vec{V}_s^*}{|\vec{V}_s|^2 + |\vec{V}_r|^2}\right) \quad (4)$$

Similarly at node n

$$\vec{I}_{se}^* = S_{sh}\left(\frac{\vec{V}_s^*}{|\vec{V}_s|^2 + |\vec{V}_r|^2}\right) + \frac{S_{load}}{\vec{V}_r} \quad (5)$$

Where V_s, V_r and I_s, I_r are the sending and receiving-end voltages and currents; Ise is the current through series equivalent impedance; I_{shs}, I_{shr} are the shunt branch currents at sending and receiving end respectively.
After the calculations, we get the equivalent series impedance and equivalent shunt admittance.

$$Z_{se_{eq}} = \frac{(\vec{V}_s - \vec{V}_r)}{\vec{I}_{se}} \quad (6)$$

$$Y_{sh\_eq} = \frac{\vec{I}_{shr}}{\vec{V}_r} = \frac{\vec{I}_{shs}}{\vec{V}_s} \quad (7)$$

Thus the equivalent two-bus pi-network is obtained using the proposed mathematical analysis and this equivalent network can be used to assess the behavior of the actual system in global scenario.

III. Global Voltage Stability Analysis Of Multi-Bus Power System

When the two-bus network equivalent of a multi bus power system is obtained, the global voltage stability indices could be formulated in a straight forward manner from the parameters of the global network as follows:
Here the voltage-current relation in the terms of ABCD parameters for pi-equivalent two-bus circuit of the transmission line, is given by as-

$$\begin{bmatrix} Vs \\ Is \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} Vr \\ Ir \end{bmatrix}$$

Where

$A = D = 1 + \frac{YZ}{2}$; $B = Z$; $C = Y\left(1 + \frac{YZ}{4}\right)$

$\left[Assuming\ Z = Z_{se\_eq}\ and\ \frac{Y}{2} = Y_{sh\_eq}\right]$

Let us assume, $A = |A|\angle\alpha$; $B = |B|\angle\beta$; $\vec{V}_s = |\vec{V}_s|\angle\theta$; $\vec{V}_r = |\vec{V}_r|\angle\delta$ $and\ \delta < \theta.$

Solving for the receiving end current:

$$I_r = \frac{|\vec{V}_s|}{|B|}\angle\theta - \beta - \frac{|A||\vec{V}_r|}{|B|}\angle\alpha - \beta + \delta$$

Complex power of receiving end given by:

$$S_r = \overrightarrow{V_r I_r^*} = |\vec{V}_r|\angle\delta\left[\frac{|\vec{V}_s|}{|B|}\angle(-\theta + \beta) - \frac{|A||\vec{V}_r|}{|B|}\angle(-\alpha + \beta - \delta)\right]$$

Sending end voltage is constant then the active and reactive power at the receiving end is given by:

$$P_r = \frac{|\vec{V}_r|}{|B|}\cos(\beta + \delta) - \frac{|A||\vec{V}_r|^2}{|B|}\cos(\beta - \alpha)$$

$Q_r = \frac{|\vec{V}_r|}{|B|}\sin(\beta+\delta) - \frac{|A||\vec{V}_r|^2}{|B|}\sin(\beta-\alpha)$

The Jacobian matrix is given by:

$$J = \begin{bmatrix} \frac{\partial P_r}{\partial \delta} & \frac{\partial P_r}{\partial V_r} \\ \frac{\partial Q_r}{\partial \delta} & \frac{\partial Q_r}{\partial V_r} \end{bmatrix} = \frac{1}{|B|}\begin{bmatrix} -|\vec{V}_r|\sin(\beta+\delta)\cos(\beta+\delta) - 2|A||\vec{V}_r|\cos(\beta-\alpha) \\ |\vec{V}_r|\cos(\beta+\delta)\sin(\beta+\delta) - 2|A||\vec{V}_r|\sin(\beta-\alpha) \end{bmatrix}$$

The determinant of Jacobian matrix is:

$$\Delta[J] = \frac{1}{|B|^2}\left[2|A||\vec{V}_r|^2\cos(\delta+\alpha) - |\vec{V}_r|\right]$$

At the critical point of voltage stability, $\Delta[J] = 0$

$$|\vec{V}_r| = V_{cr} = \frac{1}{2|A|\cos(\delta+\alpha)}$$

Here Vcr is the critical value of the receiving-end voltage at voltage stability limit. Low value of Vcr indicates the system will have better voltage profile along with higher load catering capability resultant better voltage stability. To maintain global voltage stability, $\Delta[J] > 0$. Therefore to secure global voltage stability, the global voltage stability margin can be defined as $GVSM = \Delta[J]$. It indicates how far the present operating condition is from global system voltage collapse i.e., GVSM points on the global voltage security status of the present operating condition [1].

IV. The Proposed Algorithm For Gvsm, Vcr And Vr :-

The algorithm of the proposed methodology for equivalencing the multi-bus system to a two-bus pi-equivalent system and compute GVSM and Vcr in steps below:

1. Increase active and reactive load in small steps with keeping the power factor constant.
2. Run the load flow solution algorithm for given multi bus system. Go to the step -8 if load flow solution algorithm does not converge.
3. Calculate the total load, generation and transmission line losses of the system.
4. Find the equivalent impedance (Z_{se_eq}) and admittance (Y_{sh_eq}) for the pi-equivalent two-bus model.
5. Find the A, B, C, D parameters for pi-equivalent circuit.
6. Calculate GVSM (global voltage stability margin), Vcr (Critical voltage correspond to voltage collapse point-For series & also for pi-equivalent circuit) and Vr (Receiving end voltage of equivalent system).
7. Go to step-1.
8. Stop.

V. Simulation Results

To demonstrate the effectiveness of the proposed technique, IEEE 14 test bus system, IEEE 30 test bus system, IEEE 118 test bus system have been used.

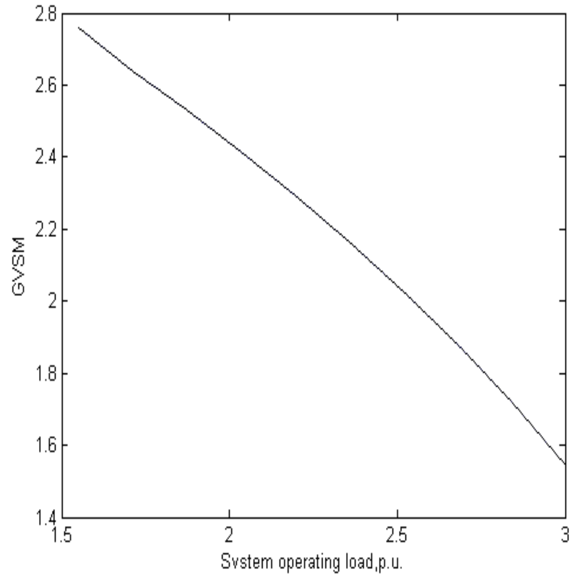

Fig.2. GVSM for 14 Test Bus System

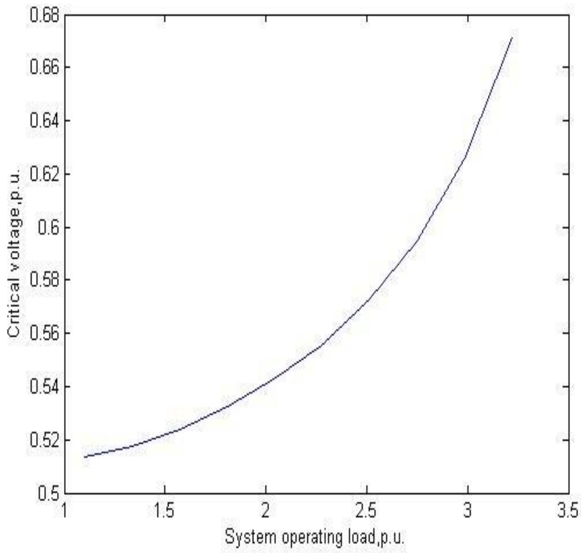

Fig.3 Critical voltage for 14 Test bus pi-equivalant system

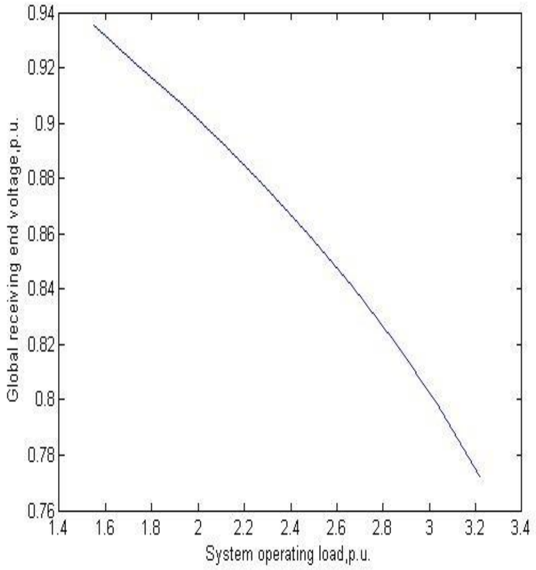

Fig.4. Global Vr For 14 Test Bus System

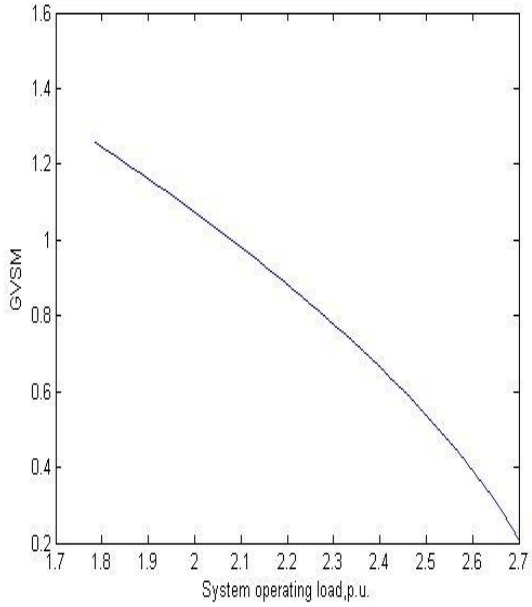

Fig.5 GVSM for 30 Test bus system

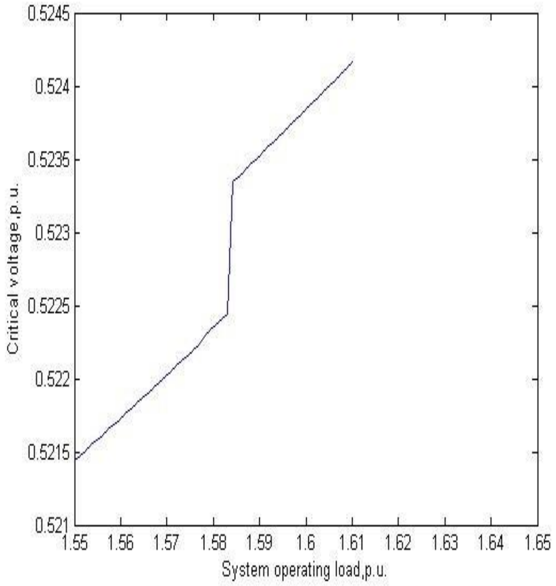

Fig.6 Critical voltage for pi-equivalant 30 Test bus system

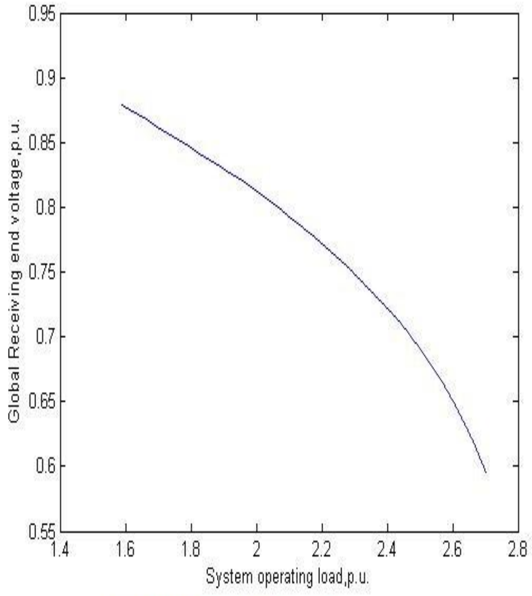

Fig.7 Global Vr for 30 Test bus system

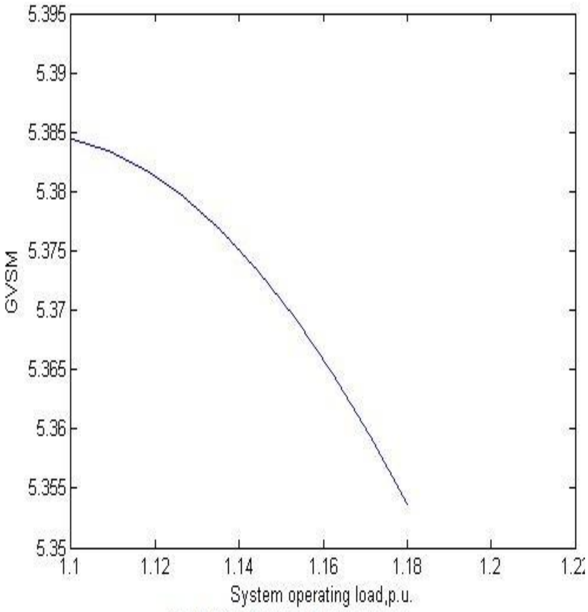

Fig. 8 GVSM for 118 Test bus system

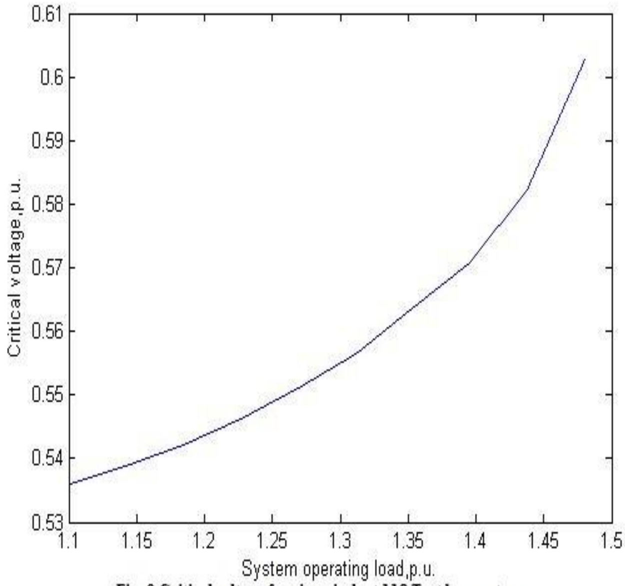

Fig. 9 Critical voltage for pi-equivalant 118 Test bus system

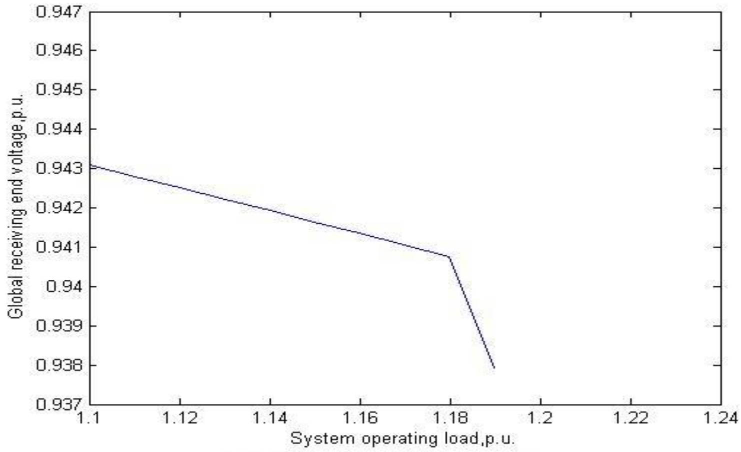

Fig.10 Global Vr for 118 Test bus system

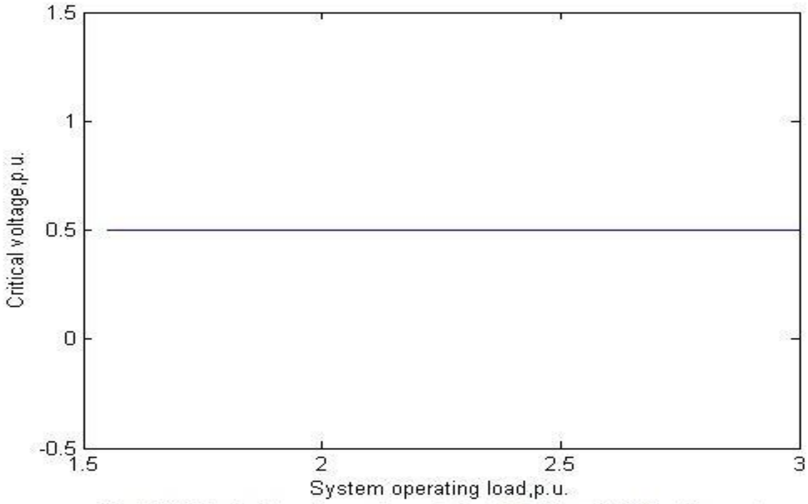

Fig. 11 Critical voltage for series equivalant 14, 30 and 118 Test bus system

VI. Conclusion

In this paper a new methodology is proposed to evaluate an equivalent two bus pi-network model for a multi bus power system where series and shunt parameters of transmission lines are lumped separately in the form of series and shunt equivalent. The equivalent network parameters like GVSM, critical voltage, global receiving end voltage etc., are able to sense any type of change in system in accurate and efficient way as compared to two bus series equivalent methodology. An innovative technique named GVSM is used to assess the voltage instability or in other words to assess the proximity of the existing system state from voltage collapse. This proposed technique is implemented on IEEE-14 test bus system, IEEE-30 test bus system and IEEE-118 test bus system and get the simulation results. In the Fig.2, Fig.5 , Fig.8 , when increases the system operating load then decreases the limit of global voltage stability margin and system goes towards instability. At point of voltage collapse the GVSM becomes zero. The effect of local voltage collapse phenomena in global scenario is quite reliable due to GVSM profile. Fig.3, Fig.6, Fig.9 represented the global critical voltage (V_{cr}) for pi-equivalent network and Fig.11 represented the Vcr for series equivalent network. As the series impedances and shunt admittances of given system are lumped within the series impedance for the series equivalent two bus model, the profile of this model indicate voltage collapse at higher level. In series equivalent network, no appreciable changes in V_{cr} with increase in system load. But in the case of pi-equivalent network V_{cr} is much susceptible to change in system operating load. In pi-equivalent model V_{cr} is increase with increase in system operating load indicating more critical operating condition and at last voltage collapse occur at higher load. Fig.4, Fig.7 and Fig.10 represented the global receiving end voltage. The profile of global receiving end voltage is decreasing when increasing the system operating load. The receiving end voltage for series equivalent is high that show the better voltage stability limit, but when increase the load then its value reached at near to voltage collapse. Actually in case of series model the critical voltage values only depend on power factor of the load, there is no effect of system parameters on this model. The simulation results of the voltage stability analysis using proposed technique give the better accuracy and reliability.

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