Voltage Stability Analysis Using GVSM

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Abstract

Voltage stability is currently causing a lot of concern. This research presents the evaluation of voltage stability using the global voltage stability margin (GVSM).The system's overall state with regard to voltage stability is evaluated using it. This approach is assessed using the IEEE 14-bus test system. In terms of voltage stability, GVSM is an effective system health indicator. An algorithm to compute GVSM, (V_{crm}) is used. To analyse the voltage stability of any system at any operating point, the π-equivalent model generated by the recommended technique is more accurate than the series equivalent model, according to simulation findings for the IEEE 14-bus system.

Keywords

Global Voltage Stability Margin (GVSM), Voltage Collapse, Critical Voltage.

1. INTRODUCTION

Modern electricity systems have developed in recent years into a sophisticated, linked network. With a variety of utilities of various types at the generating, transmission, and distribution ends. Issues with voltage stability are well-known and significant given the market's dynamic demand pattern. Stability is referred to as perturbation. Stability of voltage is the capacity of a system to sustain adequate voltages at each bus both during standard functioning conditions and after a disruption. After a disturbance, the level of voltage at various points somewhat fluctuates, which is a common characteristic of voltage instability. It could be close to the brink of collapse. As a result, the voltage level alone is not a reliable indication of the system's health. The mismatch between the supply and demand for reactive power is what leads to voltage instability. Voltage collapse results from repeated episodes of voltage instability. Voltage stability research is crucial for locating crucial buses in a power system.

The feasibility of power flow solutions, the singularity of the Jacobian, the bifurcation method, the optimal flow of power, etc. are some of the ways for assessing the voltage stability of power systems along with for recognizing the point of critical voltage stability. For evaluating the voltage stability of key buses in power systems, researchers mostly employed the traditional PV, QV curves, and PQ plane [1, 2]. V-I characteristics were employed by MH Haque et al. [1] to evaluate the voltage stability limit. In this technique, current and recent operating point bus voltage and current data were used. The least squares approach was used to analyse these data and create the V-I characteristics. P. Nagendra et al. [3] In their discussion of the equivalent pi-network construction utilising series and shunt the line in certain places. Separate data on power losses were acquired from operational characteristics of the original OPF solution multiple bus power network. The state of the voltage stability was evaluated by GVSM. A method to simplify the provided power system to a two bus equivalent model is described in [4, 5]. The notion of single line equivalent is used in the references [6–8] to determine the vicinity of voltage collapse. References [4–11] equivalent models that are used for the assessment voltage stability of the system and are created by grouping together all transmission line shunt admittances and series impedances into a single equivalent are reviewed. Voltage stability indices comparison is provided in [12]. This work presents the simulation for weak load bus detection and credentials of global voltage stability based on the magnitude of the Global Voltage Stability Margin Analysis (GVSM) assessed via IEEE-14 bus system. The rest part of the paper is organized as follows: In section 2, technique to evaluate equivalent two-bus pi-network is described. Section 3 formulates the mathematical analysis of GVSM. Algorithm is provided in section 4. The simulation results are given in section 5. Section 6 presents the whole work's conclusion.

2. A TECHNIQUE FOR EVALUATING THE EQUIVALENT TWO-BUS π-NETWORK MODEL

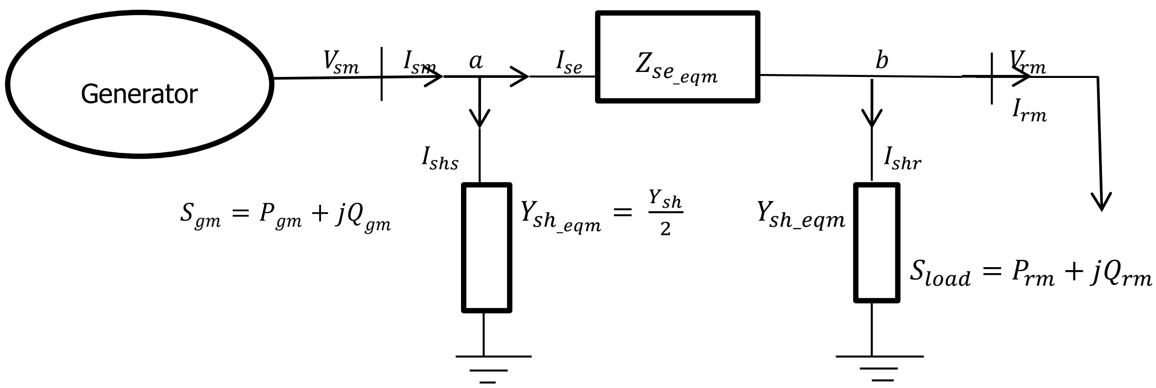

Figure 2.1 Model of the equivalent two-bus π network

$$S_{gm} = P_{gm} + jQ_{gm} = \vec{V}_{sm}\,\vec{I}_{sm^*} = (S_{se} + S_{sh}) + S_{load} \quad (1)$$

Where

$$S_{se} = \left(\overrightarrow{V_{sm}} - \overrightarrow{V_{rm}}\right)\ \vec{I}_{se^*} \quad (2)$$

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

At nodes a and b, apply Kirchoff's current law (KCL).

$$\vec{I}_{se^*} = \frac{S_{gm}}{\overrightarrow{V_{sm}}} - S_{sh}\left(\frac{\vec{V}_{sm^*}}{\left|\vec{V}_{sm}\right|^2 + \left|\vec{V}_{rm}\right|^2}\right) \quad (4)$$

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

where the voltages and currents at the sending and receiving ends are $V_{sm}, V_{rm}, I_{sm}, I_{rm}$. The current flowing via the equivalent series impedance I_{se}, and at the transmitting and receiving end sides, the shunt branch currents, are denoted by I_{shs}, I_{shr}.

$$S_g\left|\vec{V}_{sm}\right|^2\overrightarrow{V_{rm}} + S_g\left|\vec{V}_{rm}\right|^2\overrightarrow{V_{rm}} - S_{sh}\left|\vec{V}_{sm}\right|^2\vec{V}_{rm} - S_{sh}\left|\vec{V}_{rm}\right|^2\vec{V}_{sm} - S_{load}\left|\vec{V}_{sm}\right|^2\vec{V}_{sm}$$
$$-S_{load}\left|\vec{V}_{rm}\right|^2\vec{V}_{sm} = 0 \quad (6)$$

By assuming transmitting end voltage, eq. (6) equation may be split into real and imaginary portions. $\vec{V}_{sm} = 1\angle 0°$ and receiving end voltage $\vec{V}_{rm} = \left|\vec{V}_{rm}\right|\angle\delta$ and the two equations obtained are as follows:

$$\left|\vec{V}_{rm}\right|^3\left(P_{gm}\cos\delta - Q_{gm}\sin\delta\right) - \left|\vec{V}_{rm}\right|^2(P_{sh} + P_{load}) + \left|\vec{V}_{rm}\right|\left(P_{gm}\cos\delta - Q_{gm}\sin\delta - P_{sh}\cos\delta + Q_{sh}\sin\delta\right) - P_{load} = 0 \quad (7)$$

$$\left|\vec{V}_{rm}\right|^3\left(P_{gm}\sin\delta + Q_{gm}\cos\delta\right) - \left|\vec{V}_{rm}\right|^2(Q_{sh} + Q_{load}) + \left|\vec{V}_{rm}\right|\left(P_{gm}\sin\delta + Q_{gm}\cos\delta - P_{sh}\sin\delta - Q_{sh}\cos\delta\right) - Q_{load} = 0 \quad (8)$$

On solving Eq. (7) & (8) by using Newton – Raphson method.

$$Z_{se\_eqm} = \frac{\left(\vec{V}_{sm} - \vec{V}_{rm}\right)}{\vec{I}_{se}} \ \ and\ \ Y_{sh\_eqm} = \frac{\vec{I}_{shr}}{\vec{V}_{rm}} = \frac{\vec{I}_{shs}}{\vec{V}_{sm}}$$

Where, Z_{se_eqm} and Y_{sh_eqm} are the equivalent series impedance and equivalent shunt admittance respectively. To assess how the actual system behaves, the equivalent two-bus π-network model is obtained.

3. GLOBAL VOLTAGE STABILITY MARGIN (GVSM)

The global network's parameters can be used to create global voltage stability indices. For the two-bus network that corresponds to the transmission line's π-equivalent, the V-I relation is calculated using ABCD parameters and is given by

$$\begin{bmatrix} V_{sm} \\ I_{sm} \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_{rm} \\ I_{rm} \end{bmatrix} \qquad A = D = 1 + \frac{YZ}{2}; B = Z; C = Y\left(1 + \frac{YZ}{4}\right)$$

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

Suppose $A = |A|\angle\alpha;\ B = |B|\angle\beta;\ \vec{V}_{sm=}\left|\vec{V}_{sm}\right|\angle 0;\ \vec{V}_{rm} = \left|\vec{V}_{rm}\right|\angle\delta;\ \delta < \theta$

Receiving end current will be obtained as

$$I_{rm} = \frac{\left|\vec{V}_{sm}\right|}{|B|}\angle(\theta - \beta) - \frac{|A|\left|\vec{V}_{rm}\right|}{|B|}\angle(\alpha - \beta + \delta) \tag{9}$$

Receiving end complex power is given by,

$$S_{rm} = \vec{V}_{rm}\,\vec{I}_{rm^*} = \left|\vec{V}_{rm}\right|\angle\delta\left[\frac{\left|\vec{V}_{sm}\right|}{|B|}\angle(-\theta + \beta) - \frac{|A|\left|\vec{V}_{rm}\right|}{|B|}\angle(-\alpha + \beta - \delta)\right] \tag{10}$$

At the receiving end Active power (P_{rm}) and Reactive power (Q_{rm}) are:-

$$P_{rm} = \frac{\left|\vec{V}_{rm}\right|}{|B|}\cos(\beta + \delta) - \frac{|A|\left|\vec{V}_{rm}\right|^2}{|B|}\cos(\beta - \alpha) \tag{11}$$

$$Q_{rm} = \frac{\left|\vec{V}_{rm}\right|}{|B|}\sin(\beta + \delta) - \frac{|A|\left|\vec{V}_{rm}\right|^2}{|B|}\sin(\beta - \alpha) \tag{12}$$

$$J = \begin{bmatrix} \frac{\partial P_{rm}}{\partial \delta} & \frac{\partial P_{rm}}{\partial V_{rm}} \\ \frac{\partial Q_{rm}}{\partial \delta} & \frac{\partial Q_{rm}}{\partial V_{rm}} \end{bmatrix}$$

$$= \frac{1}{|B|}\begin{bmatrix} -\left|\vec{V}_{rm}\right|\sin(\beta + \delta) & \cos(\beta + \delta) - 2|A|\left|\vec{V}_{rm}\right|\cos(\beta - \alpha) \\ \left|\vec{V}_{rm}\right|\cos(\beta + \delta) & \sin(\beta + \delta) - 2|A|\left|\vec{V}_{rm}\right|\sin(\beta - \alpha) \end{bmatrix}$$

The Jacobian matrix's determinant is:

$$\Delta[J] = \frac{1}{|B|^2}\left[2|A|\left|\vec{V}_{rm}\right|^2 \cos(\delta + \alpha) - \left|\vec{V}_{rm}\right|\right] \tag{13}$$

$\Delta[J] = 0$, when voltage stability reaches its critical point.

$$\left|\vec{V}_{rm}\right| = V_{crm} = \frac{1}{2|A|\cos(\delta + \alpha)} \tag{14}$$

Where, V_{crm} stands for the receiving-end voltage stability limits' critical value. A low value for V_{crm} indicates that the system will be able to handle more load while also having a better voltage profile. For maintaining, global voltage stability $\Delta[J]$ should be greater than 0. For achieving the global voltage stability, it can be written as $GVSM\ equals\ to\ \Delta[J]$.On the operating condition's global voltage security status, it shows the GVSM points.

4. ALGORITHM

The following steps describe how to compute GVSM and V_{crm} using the suggested methodology:

a) Execute optimal flow of power, trace the weakest bus, and stipulate the power factor.
b) Maintaining the power factor constant, increase active load, and change reactive load.
c) Execute the optimal power flow algorithm. Stop, the algorithm if it does not converge.
d) Determine the overall generation, load, and losses of the system.
e) Find Z_{se_eq} & Y_{sh_eq}
f) Determine the ABCD parameters of the system.
g) Compute the $GVSM, V_{crm}, V_{rm}$, & Go to step (b)
h) Stop.

5. RESULTS OF SIMULATION

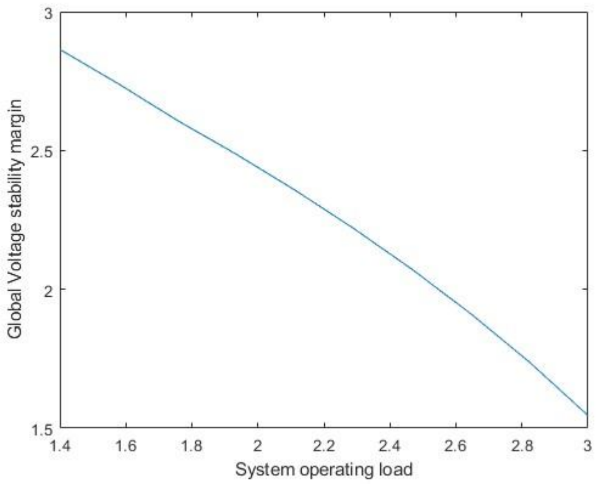

Figure 5.1 GVSM Profile for the IEEE 14-bus system.

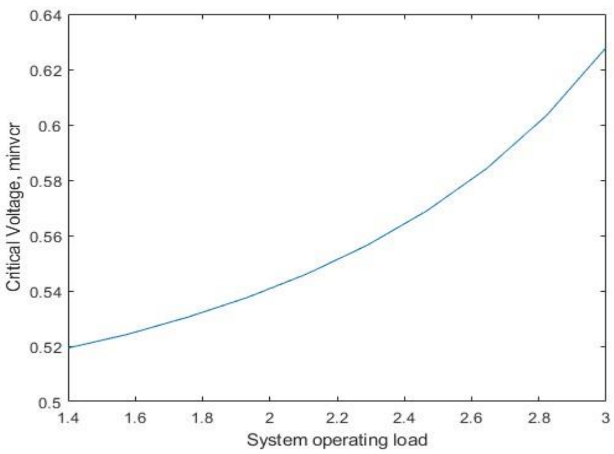

Figure 5.2 Critical Voltage Profile for the IEEE 14-bus system

Using a test system for the IEEE 14-bus, the efficacy of the suggested approach has been shown. There are 14 buses, 5 generators, and 11 loads in the IEEE 14-bus system. A computer programme made in the MATLAB 2022a environment runs the simulations. The parameters of the overall voltage stability margin for the IEEE 14-bus test system with increasing load are displayed in Fig.5.1. As seen in Fig. 5.1, the system is moving closer to voltage instability as the GVSM profile declines.

The parameters of critical voltage with variations in operational load are shown in Fig. 5.2. The V_{crm} is particularly vulnerable to variations in system operating load, it should be highlighted. Voltage collapse can happen even at high voltage magnitudes, V_{crm} increases with load, suggesting a more hazardous operating condition.

6. CONCLUSION

In this study, a novel approach is provided to assess a two-bus equivalent π-network model for a series and shunt characteristics of transmission lines are combined independently into series and shunt equivalents in a multi-bus power system. As opposed to the two-bus series equivalent technique, equivalent network metrics such as GVSM,V_{crm} , global receiving end voltage, etc., are able to sense any form of change in the system with accuracy and efficiency. To evaluate voltage instability, or, to put it another way, to evaluate how far the current system state is from voltage collapse, a novel approach known as GVSM is applied. The IEEE-14 test bus system is used to accomplish the suggested approach. GVSM technique is developed by using the proposed equivalent two-bus π-network model which helps to analyse the proximity of the present system state from global voltage collapse. In Fig. 5.1, when the operational load rises, the global voltage stability margin also declines, causing the system to become unstable. The GVSM is zero at the point of voltage breakdown. The GVSM profile makes the impact of local voltage collapse occurrences in a global context highly dependable. The global critical voltage V_{crm} for a π-equivalent network is shown in Figure 5.2. In the π-equivalent model, V_{crm} increases as system operating load increases, signifying a more critical operating situation.

7. ACKNOWLEDGMENT

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