

VOLTAGE STABILITY INDICATOR AT THE PROXIMITY OF THE VOLTAGE COLLAPSE POINT AND ITS IMPLICATION ON MARGIN

GURPREET SINGH DEOL, SHAILY SAO*, HARMADEEP SINGH AND VIKAS GUPTA

Electrical Engineering Department Punjab Technical University

*Corresponding Author: Email- shailysao@gmail.com

Received: November 30, 2011; Accepted: December 12, 2011

Abstract- Maximum power transfer and optimal reactive power at voltage stability limit is the major problem. In power system, engineers faced with problem of variable load ranging from minimum to maximum at or near a constant value of voltage. A power system must be planned and operated in such a manner so as it gives good quality of reliable supply. Power system must be planned, designed installed and operated in such a manner so as to avoid voltage instability and voltage collapse. When the inductive load is increased the reactive power absorption is increased and hence voltage drop in transmission lines is increased and receiving end voltage is decreased. Voltage drop in transmission line depends upon the reactive power. Power transfer and receiving end voltage can be enhanced by using shunt compensation in order to increase the load. This paper looks in to a power flow program in MATLAB environment. Thus it is a graphical method to find out the magnitude of power transfer and receiving end voltage at steady state voltage stability limit and optimum value of power transfer and receiving voltage when the system is at stable state.

Key words- Power Transfer capability, Receiving End Voltage, Voltage Stability Margin, Voltage Stability

Introduction

Voltage stability problems have received increased attention over the last few years. Since power systems are operated under maximum loading condition the ability to maintain voltage stability has become a major problem and good measures to improve the reactive power and voltage level control are required. If effective control actions are not appropriately implemented, successive load increases may drive a system to an unstable state, at which abnormal operating conditions can be identified. [17], the following formal definitions of terms related to voltage collapse are given in reference [10]:

- Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition.
- *Voltage Collapse* is the process by which voltage instability leads to loss of voltage in a significant part of the system.
- *Large-Disturbance Voltage Stability* refers to the system's ability to maintain steady voltages following large disturbances such as system faults, loss of generation, or circuit contingencies. This ability is determined by the system and load characteristics, and the interactions of both continuous and discrete controls and protections.
- *Small-Disturbance Voltage Stability* refers to the system's ability to maintain steady voltages when subjected to small perturbations such as

incremental changes in system load. This form of stability is influenced by the characteristics of loads, continuous controls, and discrete controls at a given instant of time.

A system becomes unstable when a disturbance (load increase or other system change) voltage to drop quickly or drift downward, and operators and automatic system control fail to improve the voltage level. [17]

Methodology

Firstly the expression of receiving end voltage V_R and complex power S for two bus system is derived

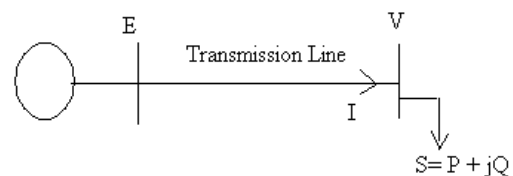


Fig. 1- Two bus system in transmission line

Real Power Flow

$$P = \frac{EV}{B_0} \sin \delta \quad (1)$$

And Reactive Power Flow

$$Q = \frac{EV}{B_0} \cos \delta - \frac{A_0 V^2}{B_0} \quad (2)$$

$$V = \left[\frac{-2QB_0A_0 + E^2 \pm \sqrt{(2QB_0A_0 - E^2)^2 - 4A_0^2S^2B_0^2}}{2A_0^2} \right]^{\frac{1}{2}} \quad (3)$$

The expression (3) shows the magnitude of receiving end voltage in terms of A_0 and B_0 , where $A_0 = A$, $B_0 = B$, the A, B, C, D parameter of the system.

The expression of (3) gives the magnitude of receiving end voltage having two values, upper voltage and lower voltage. For stable operation

$$\sqrt{(2QB_0A_0 - E^2)^2 - 4A_0^2S^2B_0^2}$$

expression (3) is positive. When the system load increases and approaches to voltage collapse point both the higher and lower voltages approaches to same value, and is called critical voltage. For determining the critical value of complex power S

$$\sqrt{(2QB_0A_0 - E^2)^2 - 4A_0^2S^2B_0^2} = 0$$

$$S_{cri} \text{ or } S_{max} = \frac{E^2}{2B_0A_0(1 + \sin \theta)} \quad (4)$$

Now using expressions (1), (2), (3) and (4) three program are built in MATLAB environment.

A Modified A, B, C, D Parameter with Shunt Compensation

A, B, C, D parameter are used to represent transmission line. It depends upon the system parameters. When shunt reactive support is add to the system, the values of A, B, C, D parameter are changed, therefore called modified A, B, C, D parameter and represented by A_m , B_m , C_m and D_m .

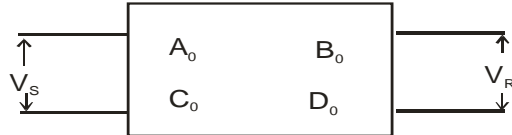


Fig. 2- network of transmission lines in terms of A, B, C D parameter at no load.

At no load condition current at receiving end is zero as given in fig 2.

$$V_s = V_R + 0 I_R$$

$$V_s = V_R$$

$$I' = V_R Y_{cap}$$

$$Y_{cap} = j\omega C$$

$$I' = jV_R \omega C$$

$$I_s = I' + I_R$$

$$I_s = jV_R \omega C + I_R$$

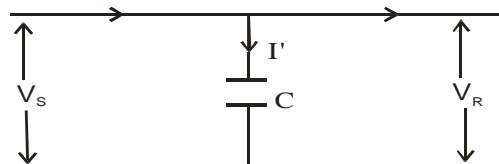


Fig. 3- Equivalent Circuit of figure 2.

In matrix form,

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ j\omega C & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

Now the modified parameter,

$$\begin{bmatrix} A_m & B_m \\ C_m & D_m \end{bmatrix} = \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j\omega C & 1 \end{bmatrix}$$

$$A_m = A_0 + j\omega C B_0 \angle \beta$$

For Phase constant $\beta = 90^\circ$

$$A_m = A_0 + j^2 \omega C B_0$$

$$A_m = A_0 - \omega C B_0$$

$$A_m = A_0 - Y_{cap}$$

Where $Y_{cap} = j\omega C$

$$\text{Similarly, } B_m = B_0$$

$$C_m = C_0 + Y_{cap} A_0$$

$$D_m = A_0$$

Here Y_{cap} is the shunt compensation.

B An Indicator of Voltage Stability and its Implication of Voltage Stability Margin

Considering a generator bus connected to a load bus through a transmission line having series admittance Y_L and shunt admittance Y_S .

Line current is given by

$$[I] = [Y][V] \quad (5)$$

$$\text{Where } [I] = \begin{bmatrix} I_R \\ I_S \end{bmatrix} \text{ and } [V] = \begin{bmatrix} V \\ E \end{bmatrix}$$

And the system admittance matrix

$$[Y] = \begin{bmatrix} Y_{LL} & Y_{LS} \\ Y_{SL} & Y_{SS} \end{bmatrix} = \begin{bmatrix} Y_L + Y_S & -Y_L \\ -Y_L & Y_L + Y_S \end{bmatrix}$$

Where V , I_R , S_R and E , I_S , S_S are complex voltages, current and power at receiving end and sending end respectively.

The load current I_R is given by

$$I_R = \left(\frac{S_R}{V} \right)^* \quad (6)$$

And from (5),

$$I_R = Y_{LL} V + Y_{LS} E \quad (7)$$

A comparison between (6) and (7) gives,

$$\left(\frac{S_R}{Y_{LL}} \right)^* = V^2 + V_0 V^* \quad (8)$$

$$\left(\frac{S_R}{Y_{LL}} \right)^* = V^2 + V_0 V e^{j\delta} \quad (9)$$

Where δ is the angular difference between V and E and

$$V_0 = \left(\frac{Y_{LS}}{Y_{LL}} \right) E$$

$$V_0 = -\frac{Y_L}{Y_L + Y_S} V_s \quad (10)$$

Noting that V_0 is kept constant by keeping the sending end voltage constant,

$$Re \left(\frac{S_R}{Y_{LL}} \right)^* = f_1(V, \delta) = V^2 + V_0 V \cos \delta \quad (11)$$

And

$$Im \left(\frac{S_R}{Y_{LL}} \right)^* = f_2(V, \delta) = V_0 V \sin \delta \quad (12)$$

The Jacobian corresponding to these power flow equation is given by

$$J = \begin{bmatrix} 2V + V \cos \delta & -V_0 V \sin \delta \\ V_0 \sin \delta & V_0 V \cos \delta \end{bmatrix}$$

Where $\Delta[J] = [-V_0^2 V \sin^2 \delta - V_0 V \cos \delta (2V + V_0 \cos \delta)]$

$$\Delta[J] = -V_0^2 V - 2V_0 V^2 \quad (13)$$

Assuming the singularity of Jacobian, at voltage stability limit, $\Delta[J] = 0$, i.e.

$$V_0^2 V + 2V_0 V^2 \cos \delta = 0 \quad (14)$$

Expression (14) determines the voltage stability limit where the point of voltage instability coincides with the singularity of Jacobian matrix of the load flow.

Here from the equation (14)

$$\frac{V}{V_0} \cos \delta = -\left(\frac{1}{2}\right)$$

$$Re\left[\frac{V}{V_0}\right] = -\left(\frac{1}{2}\right) \quad (15)$$

Again from (8)

$$S_R^* = V^2 Y_{LL} + V_0 V^* Y_{LL}$$

The above equation can further be simplified by taking the complex conjugate on both sides, and dividing by $(Y_{LL}^* V^2)$ as

$$\frac{S_R}{Y_{LL}^* V^2} - 1 = \frac{V_0 V^* Y_{LL}}{Y_{LL}^* V^2} = \frac{V_0^*}{V}$$

Where,

$$\left|1 + \frac{V_0^*}{V}\right| = \left|\frac{S_R}{Y_{LL}^* V^2}\right| \quad (16)$$

From (15) and (16)

$$\left|\frac{S_R}{Y_{LL}^* V^2}\right| = \frac{1}{2} \quad (17)$$

The expression (17) gives the criteria of voltage stability of the assumed line model. In other words, for a system as described, to retain its voltage stability, magnitude of expression $\left|\frac{S_R}{Y_{LL}^* V^2}\right|$ must be less than unity.

Thus $\left|\frac{S_R}{Y_{LL}^* V^2}\right|$ is the voltage stability indicator.

Voltage Stability Margin (M_v) is defined as

$$M_v = \left[1 - \left|\frac{S_R}{Y_{LL}^* V^2}\right|\right] \times 100\% \quad (18)$$

M_v represent the margin of voltage collapse for a system.

For the practical analysis to verify the theoretical concept a single circuit of 60-Hz transmission line is 370 Km (230 mi) long is taken. The conductors are Rook with flat horizontal spacing and 7.25 m (23.8 ft) between conductors. The load on the line is 125 MW at 215 KV with 100% power factor.

Result and Discussion

The stable operation is possible when voltage stability margin is positive and lies between 0 and 100%. In fig 4 to 10, gives different curves of load voltage, power transfer verses voltage stability margin. A voltage regulator of -10% is assumed. The dotted line area represents voltage stability margins under this condition. These curves give following result:

It can be observed from fig 4 that a high range of voltage stability margin from 91% to 95% obtain for the proposed range of allowable voltage regulation of -10%. However

power transmission is very low it is only 0.5 p.u. to 0.65 p.u. receiving end voltage is 0.65 p.u. With the increase of power transfer, receiving end voltage drops with decrease in voltage stability margin. In Fig 5, with shunt reactive support, though the voltage stability zone is widened when the magnitude of voltage stability margin is reduced from 87% to 91% whereas the magnitude of power transfer is increased from 0.61 p.u. to 0.72 p.u. and the magnitude of receiving end voltage is improved to 0.7 p.u. Similarly with further increase of shunt compensation as shown in Fig 6, 7, 8 power transfer and receiving end voltage is increased and voltage stability margin is reduced. With further increase in shunt capacitor value as shown in Fig 9 though the terminal voltage increases, voltage stability margin becomes remarkably narrow for the condition of -10% voltage regulations in receiving end voltage. The power transfer increases marginally and the state of operation corresponding to this voltage stability margin is closed to steady state voltage stability limit 1.2 p.u.

Further increase of shunt reactive support at load bus corresponding to Fig 10 enhances the receiving end voltage and operation with positive voltage stability margin is not possible for the proposed range of regulation.

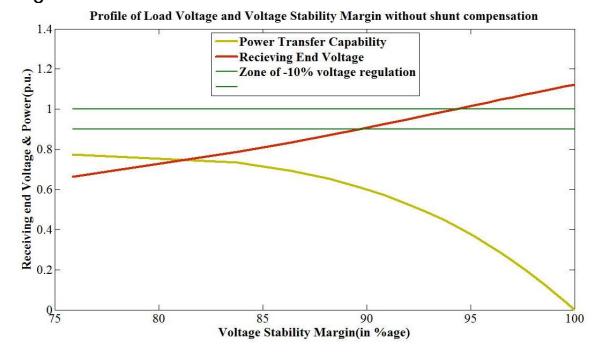


Fig. 4- Load voltage and power transfer versus margin. voltage stability margin without any compensation.

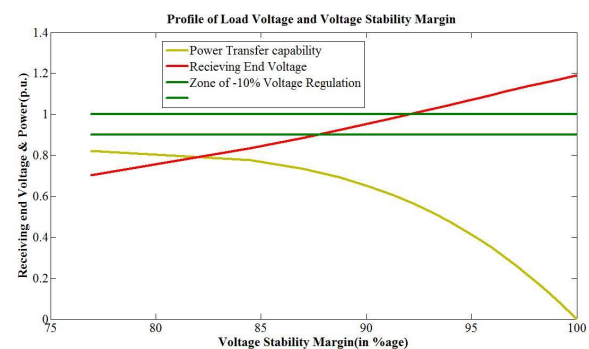


Fig. 5- Load voltage and power transfer versus voltage stability margin with 10% compensation

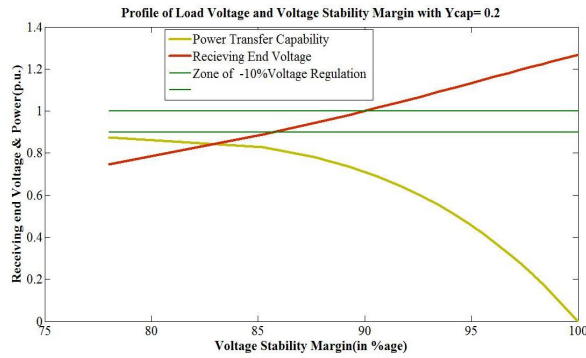


Fig. 6- Load voltage and power transfer versus voltage stability margin with 20% compensation

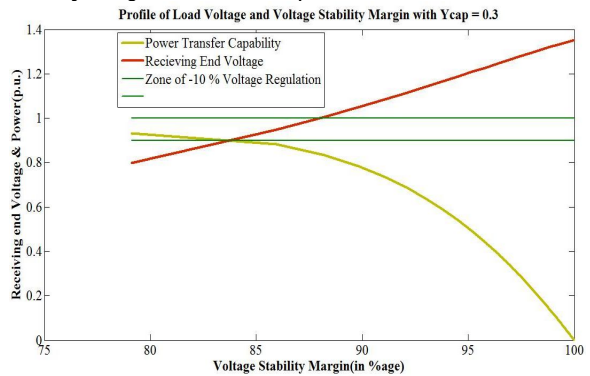


Fig. 7- Load voltage and power transfer versus voltage stability margin with 30% compensation

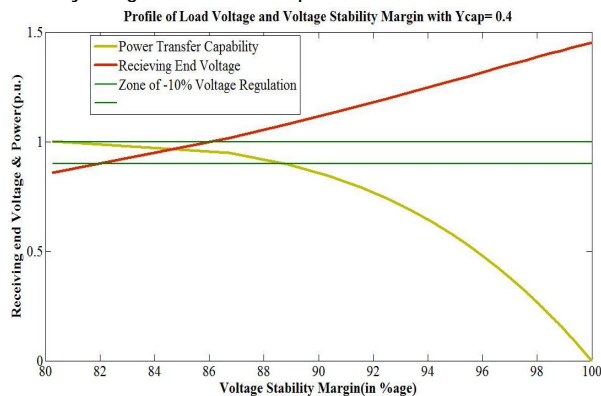


Fig. 8- Load voltage and power transfer versus voltage stability margin with 40% compensation

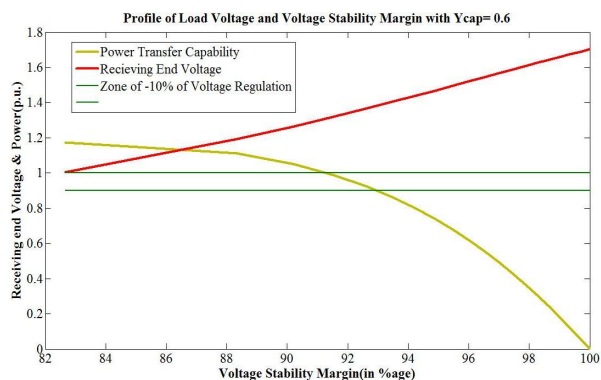


Fig. 9- Load voltage and power transfer versus voltage stability margin with 60% compensation

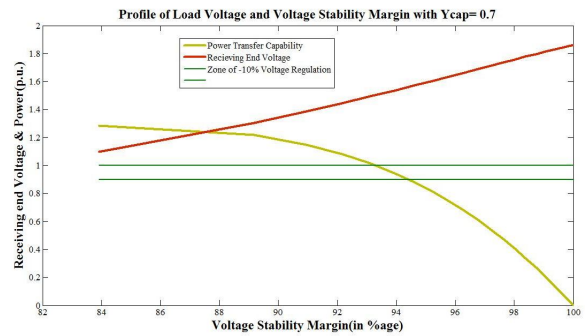


Fig. 10- Load voltage and power transfer versus voltage stability margin with 70% compensation.

A. Comparison of power transfer capability for different values of shunt reactive compensation

Power transfer capability increases as the shunt reactive compensation is added to the system. When there is no shunt compensation power transfer capability is 0.7p.u. and when the value of $Y_{cap} = 0.7$ it becomes 1.3 p.u.

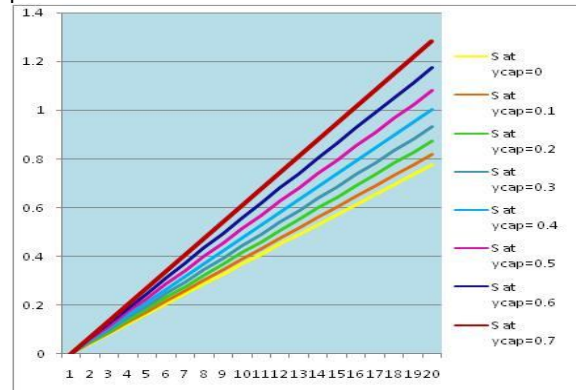


Fig. 11- Comparison of power transfer capability for different value of shunt compensation.

B. Comparison of Receiving End Voltage for Different Values of Shunt Reactive Compensation

Receiving end voltage also increases as the shunt reactive compensation increases at the load bus as describes in Fig 12. It shows how receiving end voltage is increased from no any compensation to high value (70 μF) of shunt compensation.

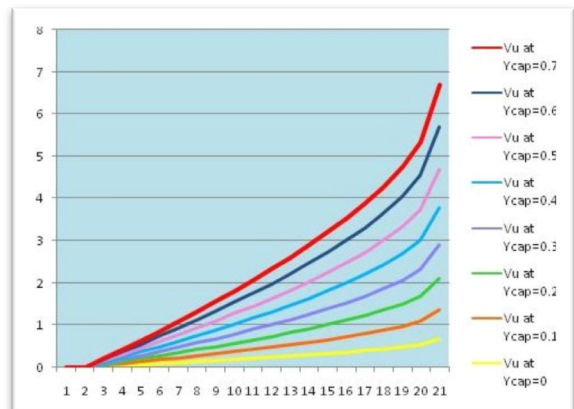


Fig. 12- Comparison of receiving end voltage at different value of shunt reactive compensation

Conclusion

To transmit power to transmission line within stable voltage limits, the magnitude of $\left[\frac{S_R}{Y_{LL}^*V^2}\right]$ is less than unity during maximum power transfer and any overloading of the system beyond this stage leads to voltage instability.

It is further observed that for a longitudinal power transmission system, where the voltage regulation is restricted -10% only, the magnitude of power transfer and receiving end voltage can be enhanced by shunt capacitive support at load end. However the voltage stability margin reduces with the shunt capacitive support for a fixed amount of allowable voltage regulation.

The approximate optimum range of capacitive support can be assessed graphically for a reasonable safe range of voltage regulation and power transfer for this line model. Any lower or higher values of shunt compensation may cause voltage instability violating the condition of $\pm 10\%$ transmission voltage regulation.

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