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Power-Voltage Characteristics of Power System with the Medium Transmission Line

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Abstract: Problem statement: Power-Voltage curve provides very important information for voltage stability analysis. The exact medium transmission line model consists of the resistance and the reactance. The resistance causes in the active line loss. It is not easy task to achieve the power-voltage curve characteristics of power system with the exact medium line model. **Approach:** This study applies the concept of the Newton-Raphson method to iteratively solve the nonlinear power flow equations. The Power-Voltage (P-V) curve charateristic of the system without line loss and with line loss are plotted and compared on various cases. **Results:** It is found from the study that the resistance of the line obviously provides the negative effects on the voltage stability. The line loss causes in the decrement of the critical point. In addition, it is found that the leading power factor can increase the critical point of P-V curve. **Conclusion:** The exact medium line model should be considered for voltage stability analysis of the system with the medium transmission line.

Key words: Voltage stability, voltage collapse, critical voltage, critical power, power-voltage curve, newton-raphson, reactive power, active power

INTRODUCTION

Power system stability is classified as rotor angle stability and voltage stability. Voltage stability is a stability in power systems which are heavily loaded, distubeanced or have a mediumage of reactive power. Nowadays, the demand of electricity has dramatically increased and a modern power system becomes a complex network of transmission lines interconnecting the generating stations to the major loads points in the overall power system in order to support the high demand of consumers. It is becoming increasingly important to fully utilize the existing transmission system assets due to environmental legislation, rights-of-way issues and costs of construction and deregulation policies that introduced in recent years. A number of Flexible AC Transmission System (FACTS) controllers, based on the rapid development of power electronics technology, have been proposed for better utilization of the existing transmission systems (Subramani *et al*., 2012; Omar *et al*., 2010; Osuwa and Igwiro, 2010; Marimuthu and Thangaraj, 2010; Zarate-Minano *et al*., 2010).

The evaluation of the power-votage (P-V) curve of the power system is one of the most important research areas for power engineers because it indicates the maximum power load. If the load is increased beyond the maximu value, the voltage will be collapsed and then the system is considered as unstable.

The transmission line is one of the most important parts in power system components. Most of the fault occurs at the transmission line. It is generally divided into three major categories; medium, medium and long model whose distance are about 80 km, above 80-250 and above 250 km, respectively. Many previous researches used simple transmission line model by neglecting its resistance or capacitance. To fully utilization the existing system, the exact transmission line should be further investigated.

This study investigated the effects of line losss in medium transmission line on voltage stability. The mathematical model of the power flow is systematically derived. The concept of the Newton-Raphson method is applied to iteratively solve the nonlinear power flow equations. The Power-Voltage (P-V) curve charateristic of the system without line loss and with line loss are plotted, discussed and compared on various cases.

MATERIALS AND METHODS

Mathematical model: Consider the simple system as shown in Fig. 1. The generator supplies the active power and reactive power, which is transferred through a transmission line to the load. The voltage at generator bus (V_S) is considered as constant value. The exact medium transmission line model is represented by the series impedance (Z) consisting of a resistance (R) and reactance (X) and shunt admittance (Y) or susceptance line charging (B). The load is represented by the active (P_R) and reactive power (Q_R).

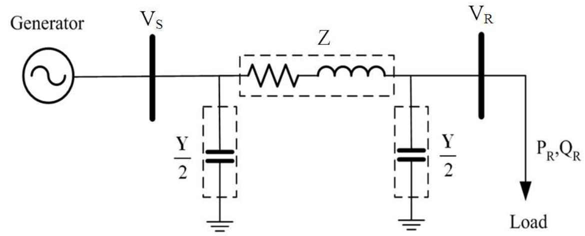

Fig. 1: Configuration of a power system with the medium transmission line model for illustration of voltage instability

This study applies the concepts of the two ports network to simplify the equivalent in Fig. 1:

$$\mathbf{A}_1 = (1 + \mathbf{YZ}/2) \quad (1)$$

$$\mathbf{B} = \mathbf{Z} \quad (2)$$

$$\mathbf{C} = \mathbf{Y}(1 + \mathbf{YZ}/4) \quad (3)$$

$$\mathbf{D}_1 = \mathbf{A}_1 \quad (4)$$

From Eq. 1-4, the voltage and the current at load bus (V_R,I_R) can be expressed in terms of matrix by:

$$\begin{bmatrix} \mathbf{V}_R \\ \mathbf{I}_R \end{bmatrix} = \begin{bmatrix} \mathbf{D} & -\mathbf{B} \\ -\mathbf{C} & \mathbf{A} \end{bmatrix} \begin{bmatrix} \mathbf{V}_S \\ \mathbf{I}_S \end{bmatrix} \quad (5)$$

From Eq. 5, the line current at load bus is given by Eq. 6:

$$\mathbf{I}_R = \frac{\mathbf{V}_S - \mathbf{A}\mathbf{V}_B}{\mathbf{B}} = \frac{V_S\angle(\delta-\theta_B)}{B} - \frac{AV_R}{B}\angle(\theta_A - \theta_B) \quad (6)$$

The complex power load is written by Eq. 7:

$$\begin{aligned} \mathbf{S}_R &= P_R + jQ_R = \mathbf{V}_R\mathbf{I}_R^{*} \\ &= \frac{V_R V_S}{B}\angle(\theta_B - \delta) - \frac{AV_R^2}{B}\angle(\theta_B - \theta_A) \end{aligned} \quad (7)$$

Then the active and reactive power load are given by Eq. 8 and 9:

$$P_R = \frac{V_R V_S}{B}\cos(\theta_B - \delta) - \frac{AV_R^2}{B}\cos(\theta_B - \theta_A) \quad (8)$$

And:

$$Q_R = \frac{V_R V_S}{B}\sin(\theta_B - \delta) - \frac{AV_R^2}{B}\sin(\theta_B - \theta_A) \quad (9)$$

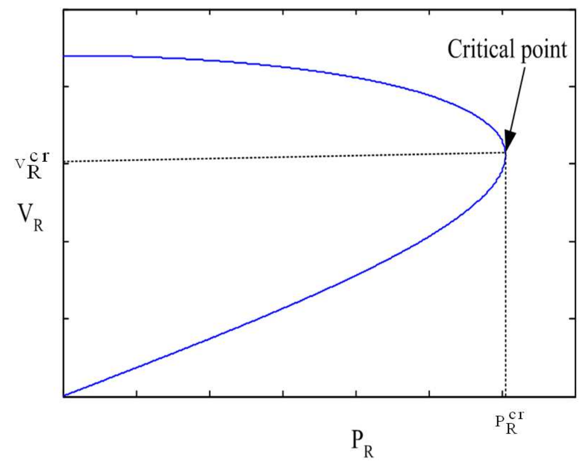

Fig. 2: P-V curve

The objective of this study is to evaluate the voltage at load bus (V_R) with various cases of load. This study applies the Newton-Raphson method to iteratively solve the nonlinear Eq. of 3 and 4 given by Eq. 10:

$$\begin{bmatrix} \Delta P_R \\ \Delta Q_R \end{bmatrix} = \begin{bmatrix} \frac{\partial P_R}{\partial \delta} & \frac{\partial P_R}{\partial V_R} \\ \frac{\partial Q_R}{\partial \delta} & \frac{\partial Q_R}{\partial V_R} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \quad (10)$$

The general form of (5) is given by Eq. 11:

$$\begin{bmatrix} \Delta P_R \\ \Delta Q_R \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \quad (11)$$

This study will investigate the effect of line loss on voltage stability of the system and be compared that of without line loss. Without line loss, the active and reactive powers are given by Eq. 12 and 13:

$$P_R = \frac{V_R V_S}{X}\sin\delta \quad (12)$$

And:

$$Q_R = \frac{V_R}{X}\left[V_R - V_S\cos\delta\right] \quad (13)$$

The characteristic of the P-V curve for neglecting line loss is shown in Fig. 2. The power system are operated in upper part of the P-V curve. The head of the

P-V curve is called the critical point (V_R^{cr} , P_R^{cr}). The critical point provides very important information to power system engineers. If the system supplies load beyond P_R^{cr} , it causes in voltage collapse.

RESULTS

The proposed method is tested on the sample system consider the diagram of sample system is shown in Fig. 1. The system supplies power which is transferred through a 130 km transmission line to the load. The system voltage at the generator bus is 345 kV. Fig. 3 shows the P-V curve of the system with various parameters of the medium transmission line.

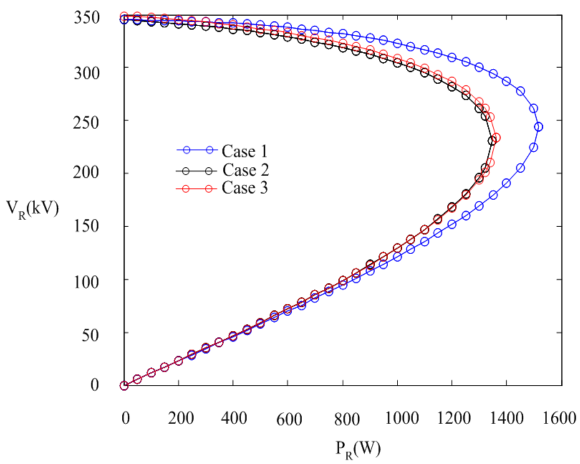

Fig. 3: P-V curve of the sample system with various parameters of the medium transmission line

Table 1: The critical point of the system with various parameters of the medium transmission line.

Case	Transmission line	Critical point P_R^{cr} (W)	V_R^{cr} (kV)
1	X	1517.91	244.014
2	R and X	1347.49	230.779
3	R, X and B	1360.57	233.476

Table 2: The critical point of the system without and with line loss for various power factors

Case	tan ϕ	Critical point P_R^{cr} (W)	V_R^{cr} (kV)
1	0.4	955.85	202.469
2	0.2	1138.55	215.793
3	0.0	1360.57	233.476
4	-0.2	1619.10	256.924
5	-0.4	1905.14	286.271

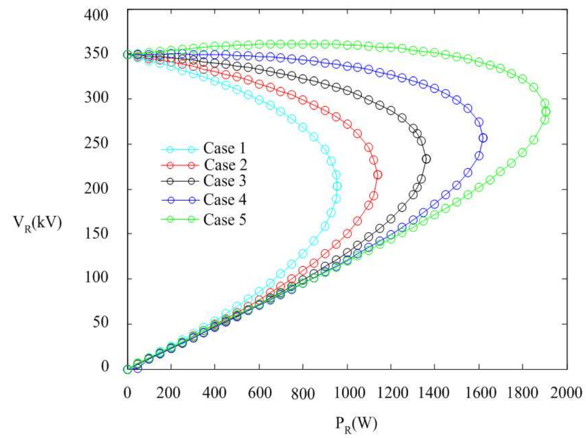

Fig. 4: P-V curve of the sample system with medium transmission line for various power factors

Table 1 summarizes the critical point (V_R^{cr} , P_R^{cr}) of Fig. 3. The effect of power factor on the P-V curve of the system with the exact medium transmission line model is shown in Fig. 4. Table 2 sunnarizes the critical point of Fig. 4.

DISCUSSION

It can be seen from the Fig. 3 and Table 1 that with a reactance the critical power is around 1517 W and coresponse to the critical voltage at 244 kV. It can be seen from the Figure that the resistance of the line significantly affects on the P-V curve whereas the susceptance line charging slightly affects on the P-V curve. With the resistance and line charging, the critical power is decreased around to 1300 W. It was found in this study that the power factor affects on the critical point of the system. The increment of the leading power factor makes it possible to supply more power to the load. With tan ϕ = -0.4, the capability of the system for sending the active power to the load is around 1900 W. In contrast, with lagging power factor the critical point of the system is decreased. It can be observed from Fig. 4 and Table 2 that with tan ϕ = 0.4the critical power is decresed around to 950 W.

CONCLUSION

This study investigated the effects of line loss in medium transmission line on voltage stability. The mathematical model of the power flow is systematically derived. The concept of the Newton-Raphson method is applied to iteratively solve the nonlinear power flow equations. The power-voltage (P-V) curve characteristic of the system without line loss and with line loss are plotted, discussed and compared on various cases.

It was found from the study that the resistance of the line obviously provides significantly negative effects on the voltage stability whereas the susceptance line charging improve slightly critical point. In addition, it was found that the leading power factor can significantly increase the critical point of P-V curve. Thus to achieve the actual capability of the system, the exact medium line model is needed to be considered.

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