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Investigating the Critical Clearing Time of Power System with the Exact Medium Transmission Line Model

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Abstract: Problem statement: The exact medium transmission line model consists of the resistance, series reactance and shunt capacitance. Most of previous research studies show the critical clearing time of single machine infinite bus while neglecting the resistance and capacitance of the line. **Approach:** This study investigates the critical clearing time of power system with consideration the exact medium transmission line mode. The concept of two-port network is applied to simplify the mathematical model of the power system. The proposed method is tested on sample system and compared on various cases. **Results:** The first swing of rotor angle curve of the faulted system without resistance is obviously higher than that of with resistance whereas the second swing of the faulted system without resistance is slightly less than that of with resistance. **Conclusion:** It was found from this study that the resistance of the line provides the improvement of the first swing but not for the second swing. The simulation results indicate that for practical medium line, the resistance is very import parameters to determine the critical clearing time of the single machine infinite system whereas shunt capacitance doesn't affect on the critical clearing time of the single machine infinite bus system.

Key words: Power system stability, transient stability, critical clearing time, FACTS devices, resistance, capacitance, transmission line, medium transmission line, two-port network

INTRODUCTION

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, 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 (Magaji and Mustafa, 2009; Prechanon, 2010; Omar *et al*., 2010; Li *et al*., 2010; Padma and Rajaram, 2011; Valarmathi and Chilambuchelvan, 2012; Zarate-Minano *et al*., 2010).

The evaluation of Critical Clearing Time (CCT) of power system is one of the most important research areas for power engineers because it indicates the robustness of the faulted power system. The rotor angle of the synchronous generator determines the stability of power system. Although the stability of the synchronous machine is used to represent the stability of the power system, all of the power system components such as transmission line and transformer affect the stability of the power system.

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; short, medium and long model whose distance are about 80 km, above 80-250 km 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 will investigate the critical clearing time of the system with the exact medium transmission line model. The concept of two-port network is applied to simplify the mathematical model of the power system. The sample system consisting the practical medium transmission line is used to investigate in this study. The proposed method is tested on various cases.

MATERIALS AND METHODS

Mathematical model: Figure 1a shows the single line diagram of a power system consisting of a generator, a transformer and four medium transmission lines.

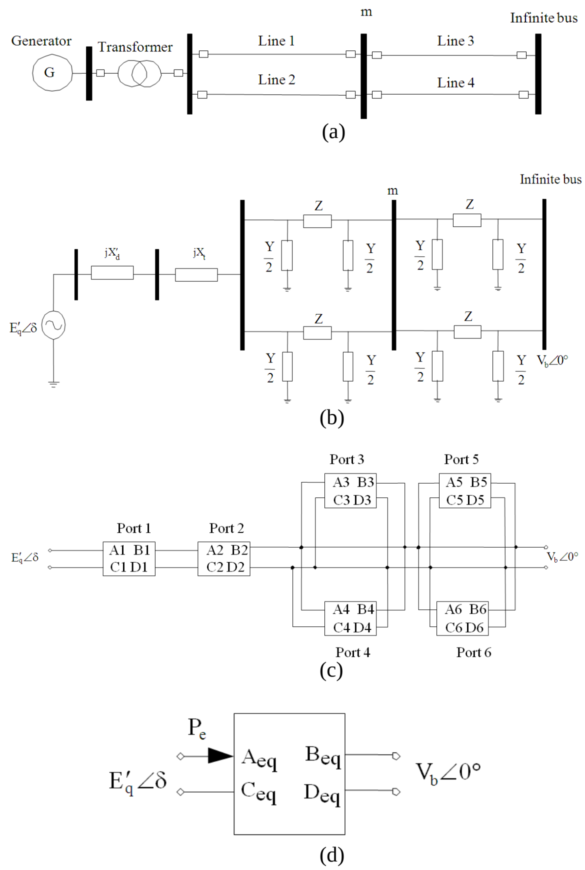

Fig. 1: Single machine infinite bus system with consideration of the exact medium line model (a) schematic diagram (b) equivalent circuit (c) two-port network diagram (d) the net two-port network

Figure 1b shows the equivalent of Fig. 1a. The generator is represented by a synchronous voltage in quadrature axis (E'_q) behind direct transient reactance (X'_d). The V_b is the voltage at infinite bus. The exact medium transmission line model is represented by the series impedance (Z) consisting of a resistance (R) and a reactance (X) and the shunt admittance (Y) or susceptance (B_c). This study applies the concept of the two-port network to simplify the equivalent in Fig. 1b. Each of components in power system can be represented the two- port network (A, B, C and D) as shown in Fig. 1d and given by:

$$A_1 = 1, B_1 = jX'_d, B_1 = jX'_d, D_1 = 1 \tag{1}$$

$$A_2 = 1, B_2 = jX_t, C_2 = 0, D_2 = 1 \tag{2}$$

$$A_3 = A_4 = A_5 = A_6 = (1 + YZ/2) \tag{3}$$

$$B_3 = B_4 = B_5 = B_6 = Z \tag{4}$$

$$C_3 = C_4 = C_5 = C_6 = Y(1 + YZ/4) \tag{5}$$

$$D_3 = D_4 = D_5 = D_6 = (1 + YZ/2) \tag{6}$$

Here Eq. 1-6 are the constant parameters of a generator, a transformer and the transmission lines.

It can be seen from the Fig. 1c that some ports are in series and in shunt connections. For example, a port 1 and port 2 are in series connection whereas port 3 and port 4 are in shunt connection. Thus with the series combination of port 1 and port 2, a new port is given by:

$$A_s = A_1B_2 + B_1C_2 \tag{7}$$

$$B_s = A_1B_2 + B_1D_2 \tag{8}$$

$$C_s = A_2C_1 + C_2D_1 \tag{9}$$

$$D_s = B_2C_1 + D_1D_2 \tag{10}$$

Similarly, with the shunt combination of port 3 and port 4, a new port is given by:

$$A_{sh} = (A_3B_4 + A_4B_3)/(B_3 + B_4) \tag{11}$$

$$B_{sh} = B_3B_4/(B_3 + B_4) \tag{12}$$

$$C_{sh} = C_3 + C_4 + (A_3 - A_4)(D_4 - D_3)/(B_3 + B_4) \tag{13}$$

$$D_{sh} = (B_4D_3 + B_3D_4)/(B_3 + B_4) \tag{14}$$

With the series combination as given in Eq. 7-10 and the shunt combination as given in Eq. 11-14, the net two-port network diagram is shown in Fig. 1d. Here A_{eq}, B_{eq}, C_{eq} and D_{eq} are the element in net matrix of net two-port network.

The output electrical power of synchronous machine (P_e) is given by:

$$P_e = \frac{A_{eq}(E'_q)^2}{B_{eq}}\cos(\theta_{Beq} - \theta_{Aeq}) - \frac{V_bE'_q}{B_{eq}}\cos(\theta_{Beq} + \delta) \tag{15}$$

Here:

$$A_{eq} = A_{eq}\angle\theta_{Aeq} B_{eq} = B_{eq}\angle\theta_{Beq}$$

The dynamic equation for evaluating critical clearing tine of the system in Fig. 1a is given by:

$$\dot{\delta} = \omega \quad (16)$$

$$\dot{\omega} = \frac{1}{M}[P_m - P_e] \quad (17)$$

Here, δ, ω and P_m as shown in Eq. 16-17 are the rotor angle, speed, input mechanical power and moment of inertia, respectively of synchronous machine. The P_e is the output electrical power as given in Eq. 15.

RESULTS

Consider the diagram of sample system is shown in Fig. 1a. The system data are:

Generator:

H = 5, X_t = 0.1 pu, X'_d=0.20 pu,E'_q = 1.22∠31.64pu

Transmission line data: Voltage level 345 kV, 130 km, f = 50 Hz, R = 0.036 Ω km^{-1}, L = 0.8 mH km^{-1}, C = 0.0112 μF km^{-1}. Thus the impedance (Z) and the admittance (Y) of the medium line at fundamental frequency are Z = 4.68 + j 32.6726 ohm and Y = 0 + j 0.000457416 Siemens, respectively. The percentage of R/X and B_c/X of the line are = 14.32 % and B_c/X = 0.0014 %, respectively. With the given reactance of the line (X) = 0.5 pu, the per unit of R and B_c are 0.0716 and 7×10^{-6} pu, respective.

It is considered that three phase fault appears at line 2 near bus m and the fault is cleared by opening circuit breakers at the end of the line. Figure 2 shows the rotor angle of the system with clearing time (t_{cl}) for 170 msec and the detail of the simulation and data is summarized in Table 1.

Figure 3 shows the rotor angle of the system with 5% for t_{cl} = 191 msec. Table 1 summarizes the critical clearing time (t_{cr}) of the system with various R/X ratios.

Table 1: The damping performance of the system with various cases of changing the medium line parameters

Case	R	B_c	δ_{max} (degree)	δ_{min} (degree)
1	0.0000	0	107.80	-0.63
2	0.0716	0	103.74	-2.77
3	0.0000	7×10^{-6}	107.80	-0.63
4	0.0716	7×10^{-6}	103.74	-2.77

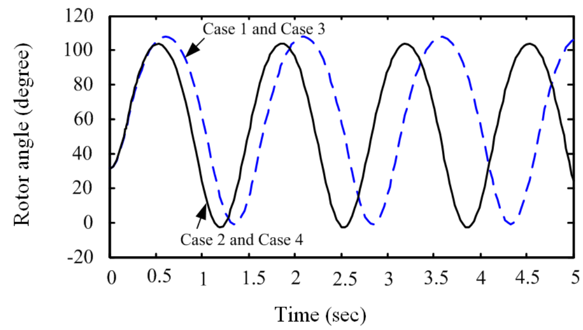

Fig. 2: Rotor angle of the system with various cases of changing medium line parameters for tcl =170 m sec

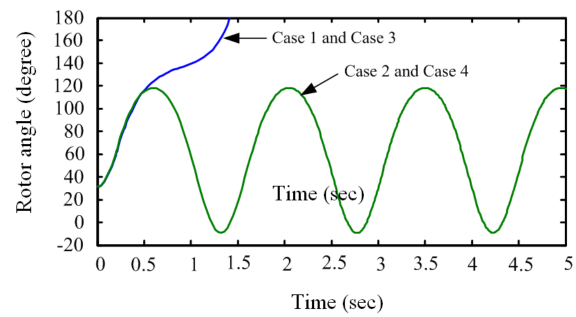

Fig. 3: Rotor angle of the system with various cases of changing medium line parameters for tcl =191 m sec

DISCUSSION

It can be seen from the Fig. 2 and Table 1 that resistance of the medium line provides the improvement of the first swing stability but not for the second swing. Without the resistance of the medium line, the maximum and the minimum rotor angle are 107.80 and -0.63°, respectively whereas with the resistance, the maximum and the minimum rotor angle are 103.74 and -2.77°, respectively. In practical medium line, the resistance is very import parameters to determine the critical clearing time of the system whereas shunt capacitance doesn't affect on critical clearing time of single machine infinite bus as can be seen in Fig. 3 and Table 2. Without resistance, the critical clearing time of the system is 190-191 m sec whereas with resistance the critical clearing is increased to around 209-210 m sec. With t_{cl}=191 m sec, the system without consideration of line resistance can be considered as unstable but for with line resistance is stable as shown in Fig. 3.

Table 2: The critical clear time of the system with various cases of changing medium line parameters

Case (m sec)	R	B_c	t_{cr}(msec)
1	0.0000	0	190-191
2	0.0716	0	209-210
3	0.0000	7×10^{-6}	190-191
4	0.0716	7×10^{-6}	209-210

CONCLUSION

This study investigated the critical clearing time of the system with consideration various parameters of medium transmission line. The concept of two-port network is applied to simplify the mathematical model of the power system. The reactance of generator, transformer and exact medium line model can be represented by a net two-port network.

It was found from the simulation results that the resistance of the line provides the improvement of the first swing but not for the second swing. It was found from this study that for practical medium line, the resistance is very import parameter to determine the critical clearing time of the single machine infinite system whereas the shunt capacitance doesn't affect on critical clearing time of the single machine infinite bus system.

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