

## Transient Stability of the Power System with the Exact Long Transmission Line Model

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**Abstract: Problem statement:** The exact long transmission line model consists of the lump of the series resistance, reactance and shunt capacitance. With the consideration the actual long transmission line model, it causes in the difficulty of deriving the mathematical model. **Approach:** This study investigates the transient stability of power system with consideration the exact long transmission line model. The concept of two-port network is applied in this study. The generator, transformer and short transmission line are represented by two-port networks. With the combination principles of the series and shunt connection, the mathematical model is achieved in a much simpler way. The proposed method is tested on the sample system and compared on various cases. **Results:** The first swing of rotor angle curve of the faulted system without the resistance is obviously higher than that of with the resistance whereas the second swing of the faulted system without the resistance is slightly less than that of with the resistance. The critical clearing time of the system with the resistance is better than that of with resistance. **Conclusion:** 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 long line, the resistance is very import parameters to determine the critical clearing time of the single machine infinite system whereas shunt capacitance insignificantly affects 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 reactance, transmission line, long transmission line, two-port network

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### 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 and cost 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 (Li *et al.*, 2010; Magaji and Mustafa, 2009; Kumkratug, 2010; Omar *et al.*, 2010; Padma and Rajaram, 2011; Valarmathi and Chilambuchelvan, 2011; 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 dynamic behavior of synchronous generator plays very important role to determine the CCT of power system.

The transmission line is one of the most important parts in power system components. The transmission line 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 the transmission, the exact transmission line is needed to studied.

This study will investigate the critical clearing time of the system with the exact long transmission line model. 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.

**MATERIALS AND METHODS**

**Mathematical model:** The transmission line is considered as long line when its distance is beyond 150 km. The basic model of long transmission line consists of the lump of medium transmission line model with serial  $\pi$  models as shown in Fig. 1a.

Its simpler model is represented by a  $\pi$  model as shown in Fig. 1b Eq. 1 and 2.

The  $Z'$  and  $Y'$  are:

$$Z' = Z_c \sinh(\gamma) \tag{1}$$

$$Y' = 2 / Z_c \tanh(\gamma) \tag{2}$$

Here:

$$\gamma = \sqrt{ZY}$$

And:

$$Z_c = \sqrt{\frac{Z}{Y}}$$

Figure 2a shows the single line diagram of power system consisting of a generator, a transformer and four short transmission lines. Figure 2b shows the equivalent of Fig. 2a. 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.

This study applies the concept of the two-port network to simplify the equivalent in Fig. 2b. Each component of power system can be represented the two-port networks (A, B, C and D) as shown in Fig. 2d and given by Eq. 3-8:

$$A_1 = 1, B_1 = jX'_d, C_1 = 0, D_1 = 1 \tag{3}$$

$$A_2 = 1, B_2 = jX_t, C_2 = 0, D_2 = 1 \tag{4}$$

$$A_3 = A_4 = A_5 = A_6 = \cosh(\gamma) \tag{5}$$

$$B_3 = B_4 = B_5 = B_6 = Z_c \sinh(\gamma) \tag{6}$$

$$C_3 = C_4 = C_5 = C_6 = \frac{1}{Z_c} \sinh(\gamma) \tag{7}$$

$$D_3 = D_4 = D_5 = D_6 = \cosh(\gamma) \tag{8}$$

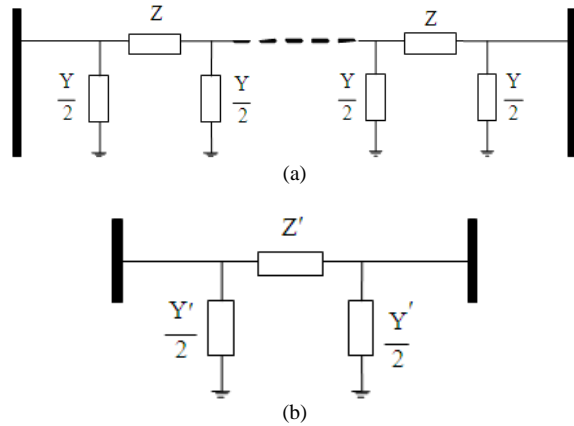


Fig. 1: Long transmission line model (a) Basic model with the serial  $\pi$  models (b) a  $\pi$  model.

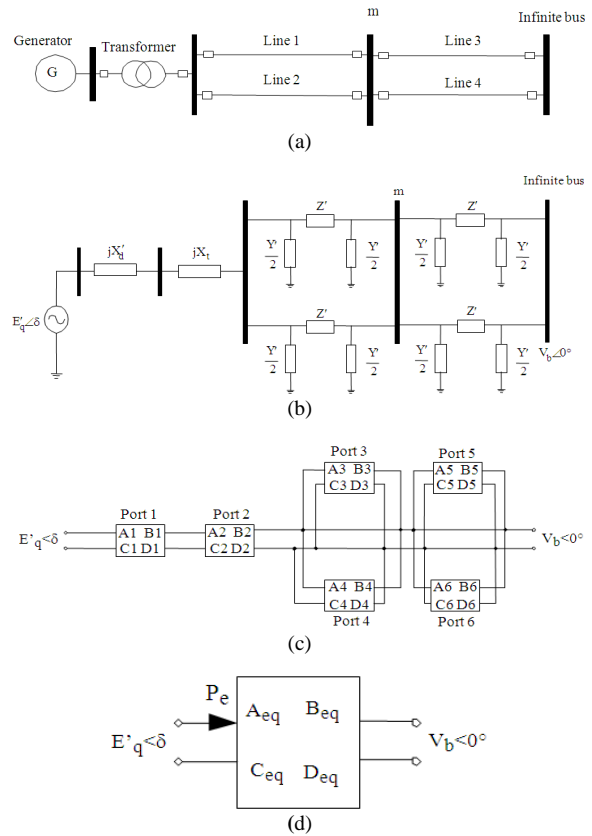


Fig. 2: Single machine infinite bus system with consideration of the exact short line model (a) schematic diagram (b) equivalent circuit (c) two-port networks diagram (d) the net two-port network

It can be seen from the Fig. 2c that some ports are in series and in shunt connection. 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 Eq. 9-12:

$$A_s = A_1B_2 + B_1C_2 \quad (9)$$

$$B_s = A_1B_2 + B_1D_2 \quad (10)$$

$$C_s = A_2C_1 + C_2D_1 \quad (11)$$

$$D_s = B_2C_1 + D_1D_2 \quad (12)$$

Similarly, with the shunt combination of port 3 and port 4, a new port is given by Eq. 13-16:

$$A_{sh} = (A_3B_4 + A_4B_3) / (B_3 + B_4) \quad (13)$$

$$B_{sh} = B_3B_4 / (B_3 + B_4) \quad (14)$$

$$C_{sh} = C_1 + C_2 + (A_1 - A_2)(D_2 - D_1) / (B_1 + B_2) \quad (15)$$

$$D_{sh} = (B_4D_3 + B_3D_4) / (B_3 + B_4) \quad (16)$$

With the above concepts, the net two-port network diagram is shown in Fig. 2d. Here  $A_{eq}$ ,  $B_{eq}$ ,  $C_{eq}$  and  $D_{eq}$  are the element in net matrix of net two-port networks. The output electrical power of synchronous machine ( $P_e$ ) is given by Eq. 17:

$$P_e = \frac{A_{eq}(E'_q)^2}{B_{eq}} \cos(\theta_{Beq} - \theta_{Aeq}) - \frac{V_b E'_q}{B_{eq}} \cos(\theta_{Beq} + \delta) \quad (17)$$

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

The dynamic equation for evaluating critical clearing time of the system in Fig. 2a is given by Eq. 18 and 19:

$$\dot{\delta} = \omega \quad (18)$$

$$\dot{\omega} = \frac{1}{M} [P_m - P_e] \quad (19)$$

Here  $\delta$ ,  $\omega$  and  $P_m$  are the rotor angle, speed, mechanical input power and moment of inertia, respectively of synchronous machine.

### RESULTS

Consider the diagram of sample system is shown in Fig. 2a. The system data are:

Generator:

$$H=5, X_t = 0.1 \text{ pu}, X'_d = 0.20 \text{ pu}, E'_q = 1.22 \angle 31.64 \text{ pu}$$

Transmission line data:

$$\text{Voltage level } 500 \text{ kV}, 300 \text{ km}, f = 50 \text{ Hz}, R = 0.016 \Omega \text{ km}^{-1}, L = 0.97 \text{ mH km}^{-1}, C = 0.0115 \mu\text{F km}^{-1}$$

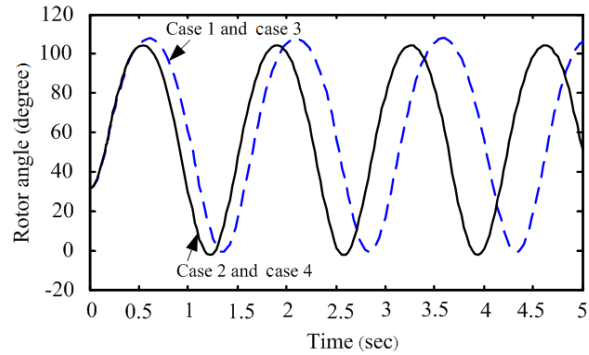


Fig. 3: Rotor angle of the system with various cases of changing long line parameters for  $t_{cl} = 170 \text{ m sec}$

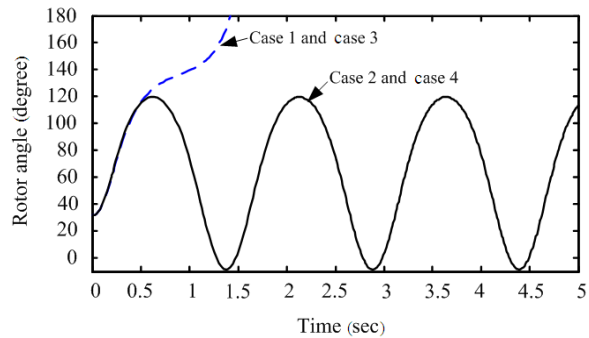


Fig. 4: Rotor angle of the system with various cases of changing long line parameters for  $t_{cl} = 191 \text{ m sec}$

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

Case	R	$B_c$	$\delta_{max}$ (degree)	$\delta_{min}$ (degree)
1	0.0000	0.0000	107.80	-0.63
2	0.0524	0.0000	104.20	-2.40
3	0.0000	0.0020	107.80	-0.63
4	0.0524	0.0020	104.20	-2.40

Thus the impedance ( $Z$ ) and the admittance ( $Y$ ) of the long line at fundamental frequency are  $Z = 19.588 + j187.09 \text{ ohm}$  and  $Y = 0 + j0.0021 \text{ Siemens}$ , respectively. The percentage of  $R/X$  and  $B_c/X$  of the line are = 10.47 % and  $B_c/X = 0.00112 \%$ , respectively.

With the given reactance of the line ( $X$ ) = 0.5 pu, the per unit of  $R$  and  $B_c$  are 0.0524 and 0.002 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 3 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 4 shows the rotor angle of the system with 5percent for  $t_{cl} = 191 \text{ msec}$ . Table 1 summarizes the critical clearing time ( $t_{cr}$ ) of the system with various  $R/X$ .

**DISCUSSION**

It can be seen from the Fig. 3 and Table 1 that resistance of the long line provides the improvement of the first swing stability but not for the second swing.

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

Case	R	B <sub>c</sub>	t <sub>cr</sub> (m sec)
1	0.0000	0.000	190-191
2	0.0524	0.000	204-205
3	0.0000	0.002	190-191
4	0.0524	0.002	204-205

Without the resistance of the long 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 104.20 and 2.40°, respectively. In practical long line, the resistance is very import parameters to determine the critical clearing time of the system whereas shunt capacitance would not affect on critical clearing time of single machine infinite bus as can be seen in Fig. 4 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 204-205 m sec. With t<sub>cl</sub> = 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. 4.

**CONCLUSION**

This study investigated the critical clearing time of the system with consideration various parameters of long 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 long 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 paper that for practical long line, the resistance is very import parameters to determine the critical clearing time of the single machine infinite system whereas shunt capacitance would not affect on critical clearing time of single machine infinite bus system.

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