TRANSIENT STABILITY ANALYSIS WITH CRITICAL CLEARING TIME METHOD ON TRANSMISSION LINE 150 KV

Rahmaniar*, **Pristisal Wibowo**, **Paulina Magdalena Br Meliala**
Electrical Engineering Department, Universitas Pembangunan Panca Budi, Indonesia
Corresponding author: rahmaniar@dosen.pancabudi.ac.id

ABSTRACT
Transient stability is the ability of the power system to maintain synchronism when subjected to a transient disturbance such as a fault on a transmission line. To obtain the stability condition of the power system after fault, a transient stability study must be done. This research applies to transmission line fault and analyses its effect on Critical Clearing Time. This research will determine Critical Clearing Time in each fault condition and carried out with Runge-Kutta 4th Order Method and applied in computing software Matlab R2015a using 5 Busses and 2 Machines system. This research contains 5 case conditions. The result of the simulation show that 1st case cleared at 0.29 second, 2nd case cleared at 0.38 second, 3rd the case cleared at 0.22 second, however, the 4th and 5th case show that the system remain stable along the fault. The stability condition is affected by the location of the fault, load factor, and influence of reactances in power system lines. Small load factors have a great Critical Clearing Time and the number of line reactances will affect received electric power transfer to become smaller.

Keywords: Transient Stability, Critical Clearing Time, Runge Kutta 4th Order Method

INTRODUCTION
Transient stability (switching) is the ability of a power system to maintain generator synchronization when a switching fault occurs (Agus 2021). The transient stability analysis is based on the first swing of the generator, i.e. as long as the generator experiences a large disturbance in the first swing period of the transition state (Agus 2018). This analysis of the electric power system aims to determine whether the system will remain stable in the event of a disturbance or not. (Abdilla 2018).

The generator can go through a disturbance state without losing synchronization so the system will remain stable. Conversely, if the generator loses synchronization and cannot survive through the first swing then the system becomes unstable. The disturbance causes a change in the rotor position which will eventually cause a large change in the rotor angle if this angle change is allowed, the system will lose its stability, (Rahmaniar, 2022). For the system to remain stable, the disturbance must be disconnected at a certain time, which is called the Critical Clearing Time, which is the longest time allowed to secure the disturbance. (Napitupulu and Hardi 2017).

This study performs transient stability analysis to see the effect of disturbance on the electric power system to determine whether the system is stable or not. The method used to determine stability in this study is the Runge-Kutta Method of Order 4 as a numerical method for plotting the swing curve. This method will be simulated using MATLAB R 2015a software to obtain a curve of the rotor angle swing for time and then the Critical Clearing Time value will be set for each disturbance. The data used is system data 5 Bus 2 Machine.

LITERATURE REVIEW
The electric power system is a collection of centres or power plants and substations (load centres) which are connected by a transmission network so that it is an interconnection unit so that electric power can flow as needed. (James A. Pongtiku, 2014).

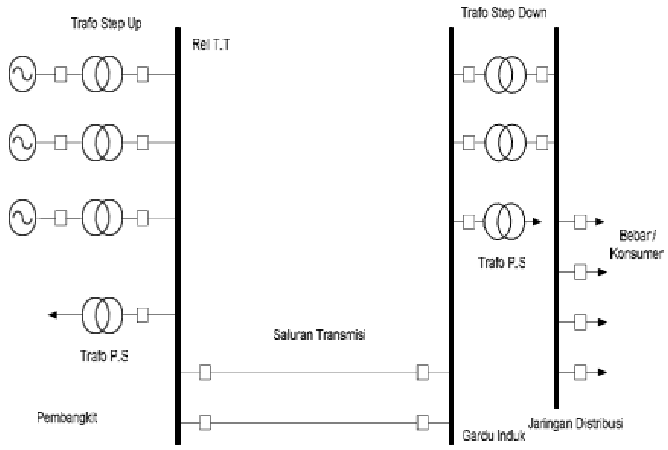

Figure 1. Schematic of the Electric Center Connected Through the Transmission Line to the Load (*James A. Pongtiku, 2014)*

Swing Equation

The equation of rotor dynamics is an equation that regulates the motion of the rotor of a machine in unison. The basic principle of dynamics states that the accelerating torque is the product of the rotor's moment of inertia and its angular acceleration. The synchronous generator equation is written as follows:

$$J\frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e \qquad [1]$$

If the generator synchronously generates electromagnetic torque in a rotating state at synchronous speed then:

$$T_m = T_e \qquad [2]$$

If a disturbance occurs it will produce an acceleration ( ) or a deceleration::

$$T_a = T_m - T_e \qquad [3]$$

In equation 2.1 δ_m measured about the stationary axis, this results in a constant synchronous speed. The swing generator is used to measure the angular position of the rotor for the rotating axis for synchronous speed with the following equation:

$$\theta_m = \omega_m t - \delta_m \qquad [4]$$

where :

If the angular displacement of the rotor is θ_m measured at the angular position of the rotor for the rotating axis at synchronous speed, then the equation is as follows:

$$\omega_m = \frac{d\theta_m}{dt} = \omega_{sm} + \frac{d\delta_m}{dt} \qquad [5]$$

And the acceleration of the rotor is:

$$\frac{d^2\delta_m}{dt^2} = \frac{d^2\delta_n}{dt^2} \qquad [6]$$

From equations (1) and (6), the following new equations:

$$J\frac{d^2\delta_m}{dt^2} = T_m - T_e \quad [7]$$

Equation (7) above is multiplied by ω_m :

$$J\omega_m\frac{d^2\delta_m}{dt^2} = \omega_m T_m - \omega_m T_e \quad [8]$$

If the rotational speed times the torque is the same as the power, then the above equation can be written in the form of the power equation as follows:

$$J\omega_m\frac{d^2\delta_m}{dt^2} = P_m - P_e \quad [9]$$

$J\omega_m$ is the angular moment (angular momentum) of the rotor which is expressed by M. The relationship between kinetic energy and rotating mass is as follows:

$$W_k = \frac{1}{2}J\omega_m{}^2 = \frac{1}{2}M\omega_m \quad [10]$$

If ω_m there is no change before stability is lost, then M is evaluated simultaneously with the following velocity: The relationship between the swing equation and the angular moment is:

$$M\frac{d^2\delta_m}{dt^2} = P_m - P_e \quad [11]$$

If P is the number of poles of the synchronous generator, then the relationship between the electric power angle and the mechanical power angle is:

$$\delta = \frac{P}{2}\ \delta_m \quad [12]$$

Also

$$\omega = \frac{P}{2}\omega_m \quad [13]$$

Then we get the swing equation relationship with the following electric power angle:

$$\frac{2}{P}M\frac{d^2\delta}{dt^2} = P_m - P_e \quad [14]$$

equation (14) is then substituted into equation (8) and then divided by the basic power SB until the following equation is obtained:

$$\frac{2}{P}\frac{2W_k}{\omega_{sm}S_B}\frac{d^2\delta}{dt^2} = \frac{P_m - P_e}{S_B} \quad [15]$$

The constant H is the kinetic energy (MJ) with synchronous speed divided by the motor rating (MVA) which is expressed by the following equation:

$$H = \frac{W_k}{S_B} \quad [16]$$

Then equation (16) is substituted into equation (15) so that the following equation is obtained:

$$\frac{2}{P} x \frac{2H}{\omega_{sm}} x \frac{d^2\delta_m}{dt^2} = P_{m\,(pu)} - P_{e\,(pu)} \qquad [17]$$

To determine the swing equation where the input power P_m is assumed to be constant. When steady-state operation $P_e = P_m$ where the initial power angle is given by:

$$\delta_0 = sin\left(\frac{P_m}{P_{1mak}}\right) \qquad [18]$$

With X_2 is the transfer reactance during the disturbance so the given swing equation is:

$$\frac{d^2\delta}{dt^2} = \frac{\pi f_0}{H}(P_m - P_{2mak} sin\delta) = \frac{\pi f_0}{H} P_0$$

The above equation is transformed into a state variable as follows

$$\frac{d\omega}{dt} = \frac{\pi f_0}{H} P_0 \qquad [19]$$

Runge-Kutta Method Order 4

To determine the price δ and ω with the completion of the Runge-Kutta method of Order 4, first determine the price $k_1, k_2, k_3, k_4,\ l_1, l_2, l_3\ dan\ l_4$ with the following equation:

$$k_1 = f(\delta_1, \omega_1)\Delta t = \omega_1 \Delta t$$
$$l_1 = g(\delta_1, \omega_1)\Delta t = \frac{\pi f}{H}(P_m - P_e)\Delta t$$
$$k_2 = f\left(\delta_1 + \frac{1}{2}k_1, \omega_1 + \frac{1}{2}l_1\right)\Delta t = (\omega_1 + \frac{1}{2}l_1)\Delta t$$
$$l_2 = g\left(\delta_1 + \frac{1}{2}k_1, \omega_1 + \frac{1}{2}l_1\right)\Delta t = \frac{\pi f}{H}\left(P_m - P_e sin\left(\delta_1 + \frac{1}{2}k_1\right)\right)\Delta t$$
$$k_3 = f\left(\delta_1 + \frac{1}{2}k_2, \omega_1 + \frac{1}{2}l_2\right)\Delta t = \left(\omega_1 + \frac{1}{2}l_2\right)\Delta t$$
$$l_3 = g\left(\delta_1 + \frac{1}{2}k_2, \omega_1 + \frac{1}{2}l_2\right)\Delta t = \frac{\pi f}{H}\left(P_m - P_e \sin\left(\delta_1 + \frac{1}{2}k_2\right)\right)\Delta t$$
$$k_4 = f(\delta_1 + k_3, \omega_1 + l_3)\Delta t = (\omega_1 + k_3)\Delta t$$
$$l_4 = g(\delta_1 + k_3, \omega_1 + l_3)\Delta t = \frac{\pi f}{H}(P_m - P_e \sin(\delta_1 + k_3))\Delta t$$

The value $\delta\ dan\ \omega$ can be determined using the following equation:

$$\delta_{i+1} = \delta_1 + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)$$
$$\omega_{i+1} = \omega_1 + \frac{1}{6}(l_1 + 2l_2 + 2l_3 + l_4)$$

METHODS

The study began with data collection, in the form of an inline diagram of the 5 Bus 2 Engine electrical system, generation data, impedance data loading, line charging data and generator data.

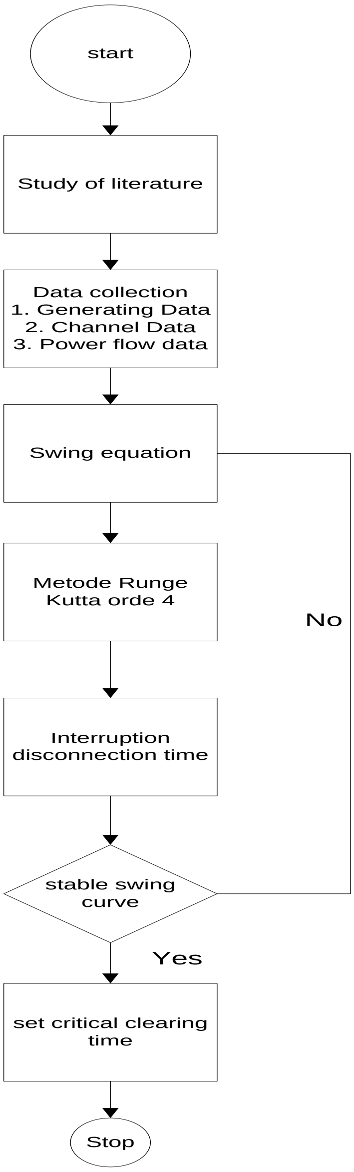

Figure.2 Research Flowchart

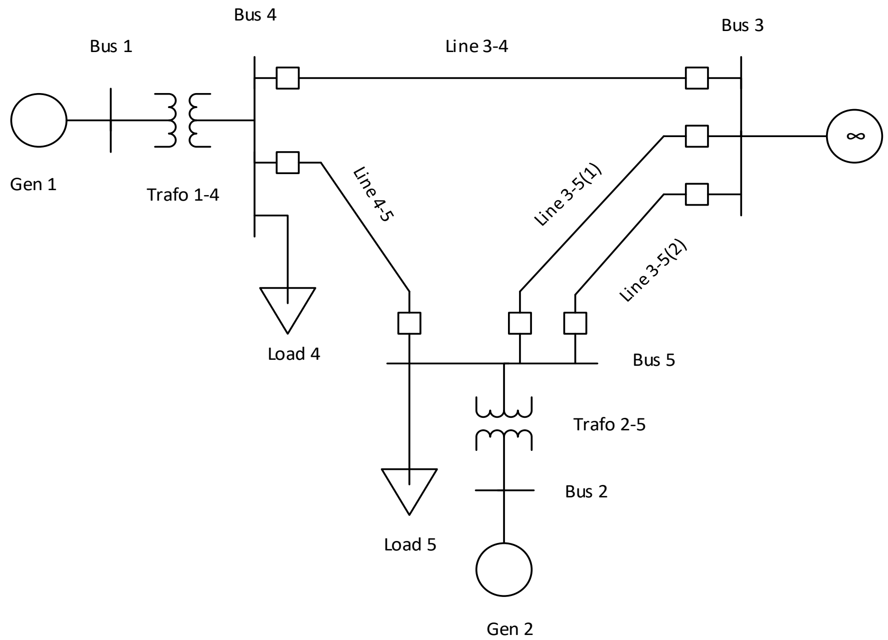

Figure 3. Single Line Diagram of a 5 Bus 2 Generator System

Table 1. Data Channel 5 Bus 3 Generator

Tract		Impedance Z (PU)		Suseptansi B/2 (PU)
From the bus	To the bus	Resistance R (PU)	Reaktansi X (PU)	
1	4		0.022	
2	5		0.04	
3	4	0.007	0.04	0.082
3	5(1)	0.008	0.047	0.098
3	5(2)	0.008	0.047	0.098
4	5	0.018	0.11	0.226

Table 2. Data for System 5 Bus 2 Generator

Parameter	Generator 1	Generator 2
S	400	250
kV	20	18
X'd	0.067	0.1
H	11.2	8

Table 3. System Power Flow Data 5 Bus 2 Generator

Bus	Voltage (PU)	Generator		Load	
		Active Power P (PU)	Reactive Power Q (PU)	Active Power P (PU)	Reactive Power Q (PU)
1	1.03∠8.88	3.5	0.712		
2	1.02∠6.38	1.85	0.298		
3	1.0∠0				
4	1.018 ∠4.68			1	0.44
5	1.011∠2.27			0.5	0.16

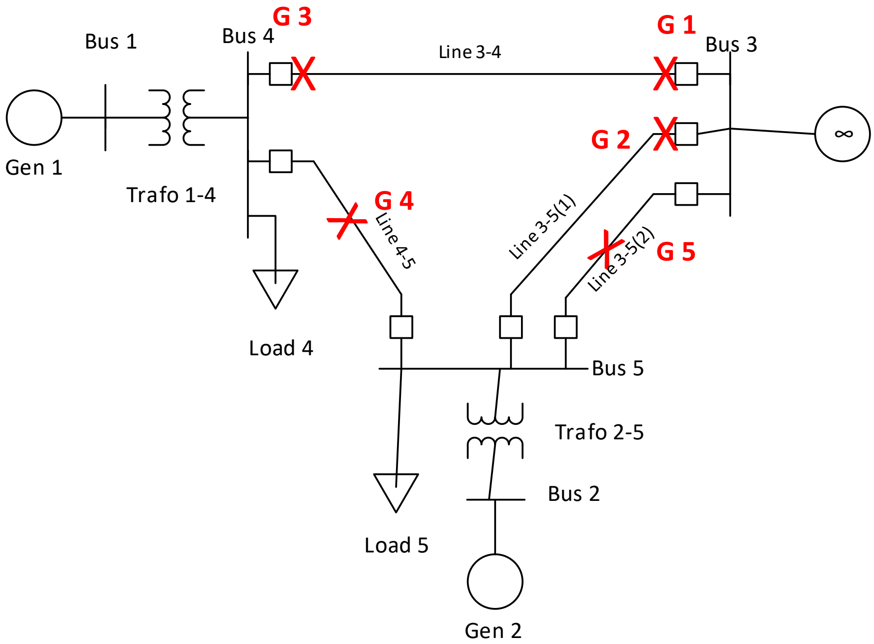

Figure 4. Disturbance Location Scenario

RESULTS AND DISCUSSION

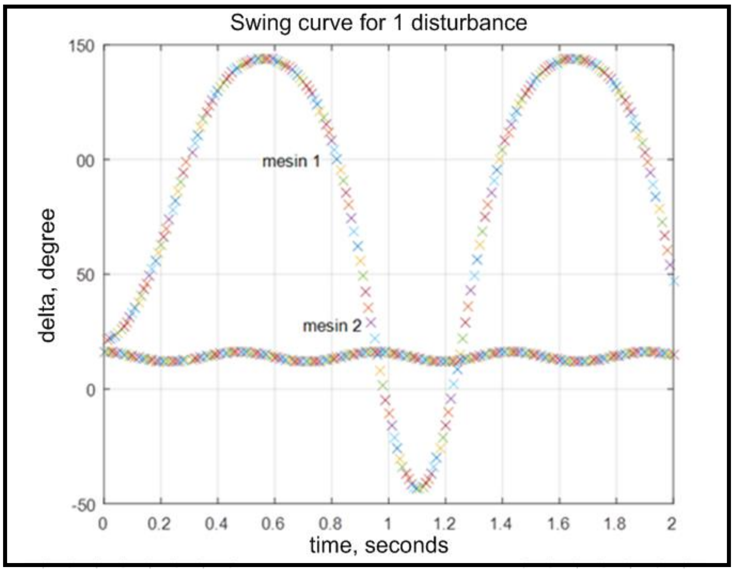

Figure 5. Graph of Delta Simulation Results Against Time on Transmission Lines 3-4 near bus 3, Disconnection Time 0.29 seconds

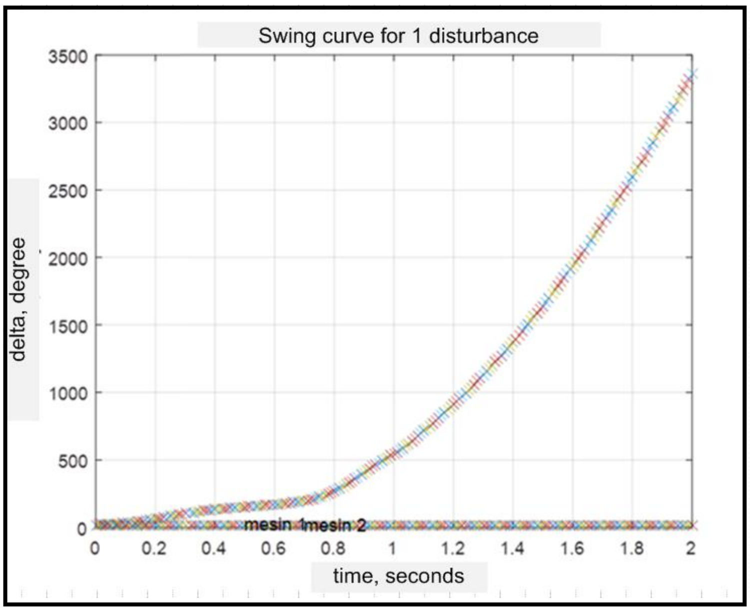

Figure 6. Graph of Delta Simulation Results Against Time on Channel 3-4 Near Bus 3, Disconnection Time of 0.3 Seconds

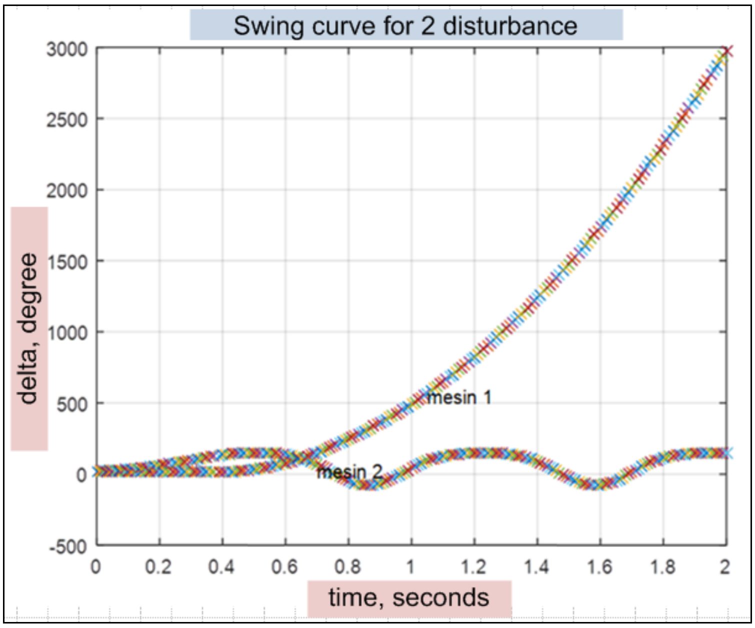

Figure 7. Graph of Delta Simulation Results Against Time on Transmission Lines 3-5(1) Near Bus 3. Disconnection time of 0.38 seconds

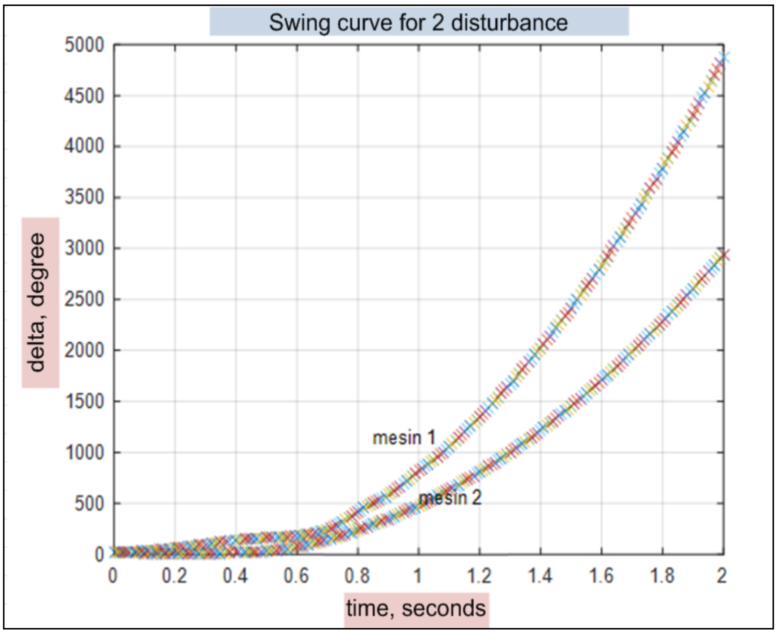

Figure 8. Graph of Delta Simulation Results Against Time in Transmission Line 3-5(1). Disconnection Time 0.39 Seconds

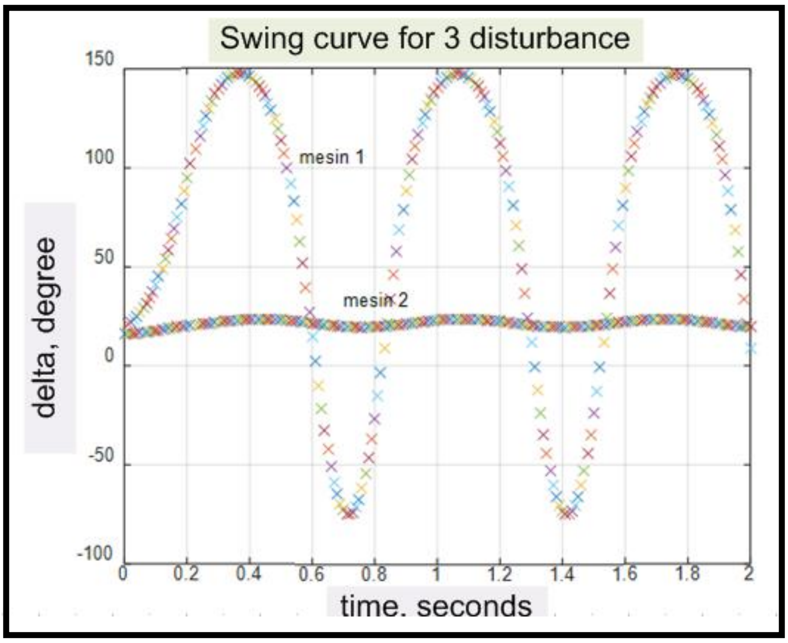

Figure 9. Graph of Delta Simulation Results Against Time on Transmission Lines 3-4 Near Bus 4. Interruption Termination Time 0.22 Seconds

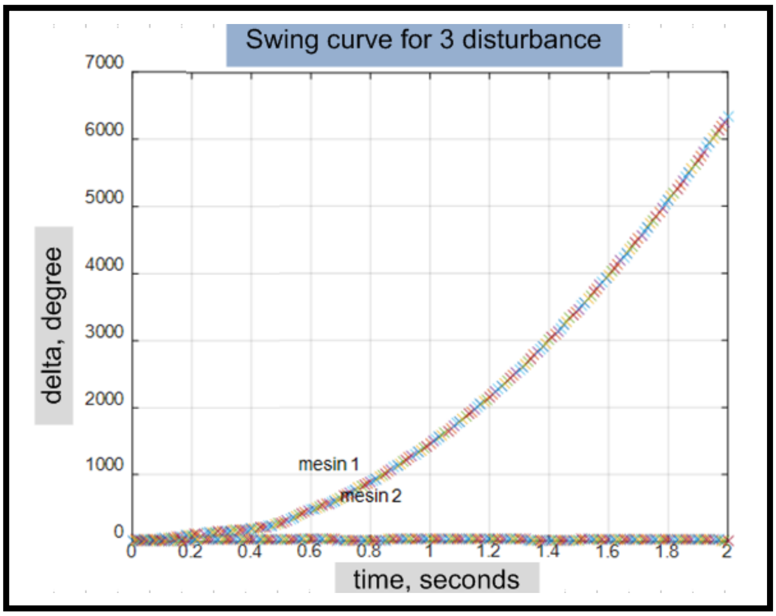

Figure 10. Graph of Delta Simulation Results Against Time on Transmission Lines 3-4 Near Bus 4. Interruption Termination Time 0.23 seconds S

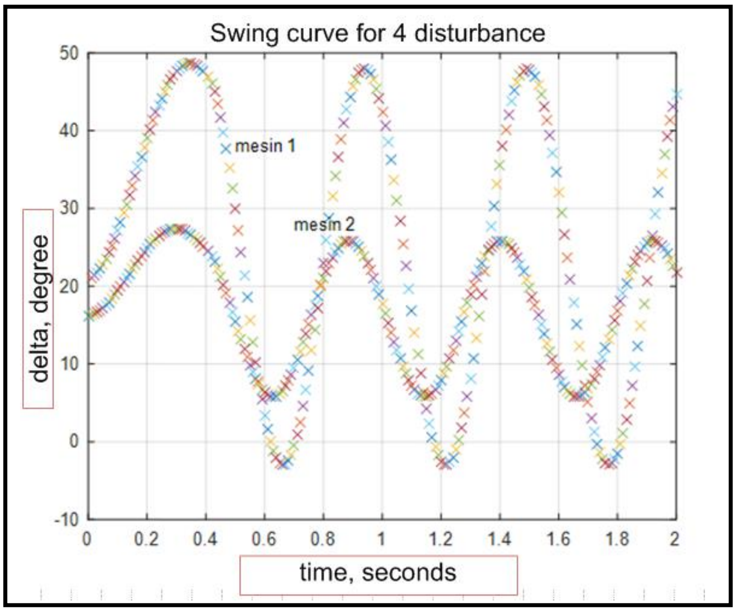

Figure 11. Graph of Delta Simulation Results Against Time in the Middle of Transmission Line 4-5. Disconnection Time 0.4 seconds

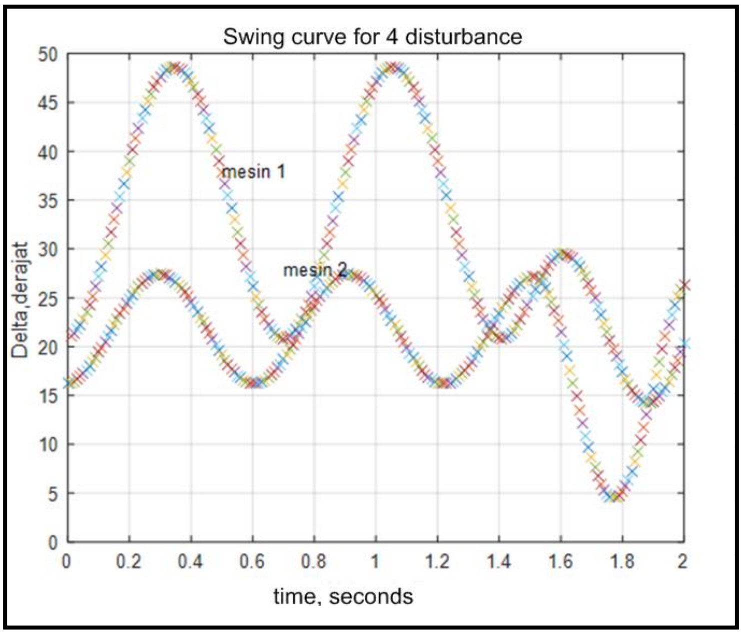

Figure 12. Graph of Delta Simulation Results Against Time in the Middle of Transmission Line 4-5. Interrupt Termination Time 1.5 Seconds

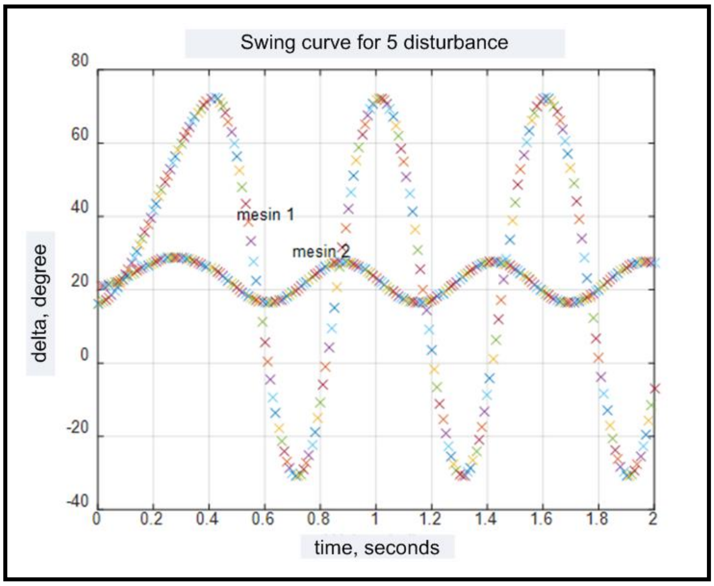

Figure 13. Graph of Delta Simulation Results Against Time in the Middle of Transmission Line 5-3(2). Disconnection Time 0.4 Seconds

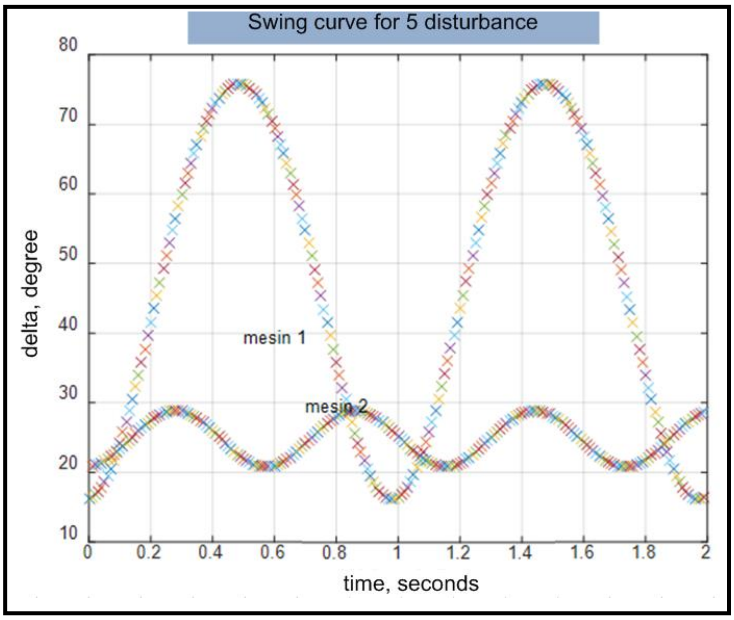

Figure 14. Graph of Delta Simulation Results Against Time in the Middle of Transmission Line 5-3(2). Interrupt Termination Time 2 Seconds

Discussion

Factors affecting CCT include fault location, fault disconnection time, line admittance and load. The length of the CCT is influenced by the location of the fault point, where the simulation results show that the closer the fault occurs to the generator, the faster the critical disconnection time will be.

Table 4. Critical Clearing Time Based on Disturbance Scenarios

No. Disturbance	Disturbance Location	Critical Clearing Time
1	Transmission lines 3-4 (near the bus 3)	0.29 second
2	Transmission lines 3-$5_{(1)}$ (near bus 3)	0.38 second
3	Transmission lines 3-4 (near bus 4)	0.22 second
4	In the middle of the transmission line 4-5	- (stable)
5	In the middle of the transmission line 3-$5_{(2)}$	- (stable)

CONCLUSION

1. Critical Clearing Time obtained from 5 disturbance scenarios is 0.29 seconds for 1st disturbance, 2nd disturbance is 0.38 seconds, and 3rd disturbance is 0.22 seconds. Meanwhile, in disturbances 4 and 5, the system is declared to remain stable until the simulation time for 2 seconds ends.
2. From the simulation results, it is known that the stability of the system is influenced by the location of the fault, the length of time it takes to disconnect the fault, the reactance of the line and the load.

REFERENCES

Abdilla, Reza. 2018. "LISTRIK WILAYAH RIAU Mahasiswa Program Studi Teknik Elektro , 2) Dosen Teknik Elektro Program Studi Teknik Elektro S1 , Fakultas Teknik Universitas Riau

Agus J, Abdul Hamid K, 2018, Design of Simulation Product for Stability of Electric Power System Using Power System Stabilizer and Optimal Control DOI:10.1088/1742-6596/970/1/012013, IOP Conf. Series: Journal of Physics: Conf. Series 970 (2018) 012013

Agus Junaidi, Rahmaniar, Rudi Salman, Joni S. Rambey,Abd. Hamid K, Baharuddin,(2021) Modelling And Simulation Of Symmetrical And Unsymmetrical Faults On 14 Bus Ieee-Power System, Journal of Theoretical and Applied Information Technology

James A. Pongtiku, Maickel Tuegeh, ST., MT., Ir. Hans Tumaliang, MT. 2014. "Analisa Stabilitas Transien Untuk Menentukan Waktu Pemutusan Kritis (Critical Clearing Time) Pada Jaringan Transmisi 70 Kv Plta Tanggari Ii-Gi Sawangan Dengan Menggunakan Program Matlab." *Jurnal Teknik Elektro Dan Komputer* 3(2):53–58.

Napitupulu, Reinhard, and Surya Hardi. 2017. "Analisis Kestabilan Peralihan Pada Sistem Jaringan Transmisi 150 KV PLN Sumatera Bagian Utara." 6(2):72–76.

Rahmaniar, Agus Junaidi, Adi Sastra P. Tarigan, Dicky Lesmana, M. Rizki S., Abd.Hakim Butar-Butar, (2022) Digital Learning: Modeling and Simulation of Three-Phase Short Circuit Fault Currents Using the Case Method for Strengthening MBKM Policy, 10.33258/birci.v5i2.4725, Budapest International Research and Critics Institute-Journal (BIRCI-Journal).