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Critical Clearing Time Analysis of the South Sulawesi Interconnection System Due to Injection of the Sidrap & Jeneponto Wind Turbine

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Abstract

The high demand for electricity causes the need to build more power plants for electricity generation. Because the construction of power plant cannot keep up with the rapid growth of existing loads, then the continuity of the distribution of electrical energy to consumers can be disrupted, which causes the stability of the power system to become unbalanced especially in the stability of the rotor angle. One of the efforts to utilize renewable energy is the construction of a Wind Turbine Power Station (WTPS) in South Sulawesi, namely in the districts of Sidrap and Jeneponto. The method used in analyzing the integration of Sidrap & Jeneponto Wind Turbine is the analysis method by providing 3 phase short circuit interference on the transmission line. The research objective is to determine the stability of the rotor angle and critical clearing time before and after the integration of the Sidrap & Jeneponto Wind Turbine on the Sulselrabar interconnection system using Tools PSAT software. When one of the Sidrap & Jeneponto Wind Turbine is integrated into the rotor angle value system it is still in a stable condition because it is still within the limits that are not beyond 90. When a 3 phase short circuit interruption occurs after the integrated Sidrap & Jeneponto Wind Turbine can further slowdown the generator experiencing synchronous loss with Critical Clearing Time (CCT) when there is a disturbance in the Sungguminasa - Maros CCT transmission line before one of the integrated Wind Turbine in the system is obtained CCT = 0.121 seconds after the integrated Jeneponto Wind Turbine is obtained CCT = 0.125 seconds after the Integrated Sidrap Wind Turbine is obtained CCT = 0.123 seconds.

Keywords: BPS Sidrap, WTPS Jeneponto, rotor angle, 3 phase short circuit fault, Critical Clearing Time (CCT)

1. Introduction

An electric power system that is connected interconnected through a transmission network cannot be separated from the disruption that can cause instability in the form of changes in system voltage and frequency [1]. Severe, sudden interruptions to the system that often occur such as short-circuiting, breakage of conductors, and increased loading can cause loss of synchronization. In the operation of an electric power system, at any time there will always be a change in the capacity and location of the load in the system, these changes require that each generator adjust the active power and frequency through governor or Automatic control.

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Voltage Regulator with which serves to regulate the reactive power and voltage magnitude by adjusting the change in load on the system [2]. If this is not done it will cause the balance in the system to be disrupted so that system efficiency will decrease which can cause the system performance to deteriorate. So that requires critical clearing time analysis which helps to determine the setting time on/off the protection relay and circuit breaker. Transient stability is the ability of a power system to maintain synchronization after experiencing sudden major disruptions such as the sudden release of load [3].

This research is focused on the study of critical clearing time analysis in the interconnection system of South Sulawesi by looking at the parameters of the rotor angle at each plant with three-phase to a ground disturbance that occurs on a bus. In this study, critical clearing time values were obtained and compared before and after the entry of one PLTB, and when there was a disturbance in the Sulselrabar interconnection system using MATLAB PSAT 2.1.10 software.

2. Theoretical Basis

2.1. Electric Power System

The Electric Power System is a system consisting of several components in the form of generation, transmission, distribution and load which are interconnected and work together to serve the electricity needs of customers according to their needs. In electric power generation, there is a process of converting primary energy sources into electrical energy [4]. The process of converting both conventional and non-conventional energy sources can be seen in Figure 1. One thing that is common in electric power plants is that they all function to convert mechanical energy into electrical energy by changing the potential for mechanical energy that comes from water, steam, gas, wind, geothermal, nuclear, the combination. Broadly speaking, the Electric Power System can be described with a scheme such as Figure.

Figure 1. Electric Power Distribution System

2.2 Stability of the Rotor Angle

The stability of the rotor angle is the ability of several synchronous machines that are interconnected to a power system to maintain synchronous conditions after a fault occurs. This instability can cause changes in the angular speed of the generator swing so that the generator experiences loss of synchronization with other generators [5].

According to Nadjamuddin (2012) and Hadi Saadat (1999), the equation that regulates the rotor motion of a synchronous machine is based on a basic principle in dynamics which states that the accelerated rotational moment is the product of the moment of inertia of the rotor and its angular acceleration [6]. For a synchronous generator this equation can be written in the form:

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

Where J is the moment of total inertia of the mass of the rotor in kg-m2, θ_m is the angle of shift of the rotor to a resting axis in radians, Ta is the net moment of acceleration in Newton-meters, Tm is the mechanical torque in Newton Meters and Te is the electromagnetic torque in Newton-meters. If a synchronous generator generates electromagnetic torque while rotating at synchronous speed ω_s then:

$$T_m = T_e$$

If a disturbance occurs, it will produce an acceleration (Tm> Te) or a deceleration (Tm <Te) with, [6]

$$Ta = T_m - T_e$$

The stability of the rotor angle itself is classified into two, namely due to small disturbances and due to large disturbances. The stability of the rotor angle due to major disturbances or transient stability is the power system's ability to maintain synchronization when the system experiences severe disturbances, such as a short circuit and sudden load shedding on the transmission line [7]. Transient stability is the ability of an electric power system to maintain synchronization after experiencing a sudden major disruption. The rotor angle is said to be stable if the value of the rotor angle is still within the tolerance limit, that is, does not exceed 90^O which can be known as steady state stability [8].

2.3. Critical Clearing Time (CCT)

CCT or Critical Clearing Time is the critical point in milliseconds which determines an electric power system is in an unstable condition. If a system experiences a disturbance, the area experiencing the disturbance will be isolated by triggering a CB (Circuit Breaker) to immediately release the affected area. CB works with the coordination of the safety relay which requires the fastest time from time operating of CB [9].

In determining the critical breaker time, we must first solve the critical breaker angle equation, where this equation is obtained from the equation of the area criteria equal to the disturbance in the middle of the transmission line. By writing the criteria for the same area: [10]

$$P_m(\delta_c - \delta_0) - \int_{\delta_0}^{\delta_c} P_{2\max} \sin\delta \, d\delta = \int_{\delta_c}^{\delta_{\max}} P_{3\max} \sin d\delta - P_m(\delta_{\max} - \delta_c)$$

By integrating the two sides, we get the critical angle:

$$\cos\delta_c = \frac{P_m(\delta_{\max} - \delta_0) + P_{3\max} Cos\,\delta_{\max} - P_{2\max}\, Cos\delta_0}{P_{3\max} - P_{2\max}}$$

To determine the critical break time tk, it is necessary to solve the swing equation. In this case, where P_e is 0 during the disturbance. From the swing equation given by equation 2.1 it can be determined the critical breaker time, during which the fault occurs $P_e = 0$, so that the critical breaker time can be determined as follows [11-12];

$$\frac{H}{\pi f_0} \frac{d^2\delta}{dt^2} = P_m - P_e$$

where Pe = 0, so:

$$\frac{H}{\pi f_0} \frac{d^2\delta}{dt^2} = P_m$$

$$\frac{d^2\delta}{dt^2} = \frac{\pi f_0}{H} = P_m$$

By integrating equation [3]:

$$\int \frac{d^2\delta}{dt^2} = \int \frac{\pi f_0}{H} = P_m$$

so you get the equation;

$$\frac{d\delta}{dt} = \frac{P_m \omega t}{2H}$$

by integrating again, the following equation is obtained;

$$\delta_c \frac{P_m \omega tc^2}{2H} + \delta_0$$

$$\delta_c - \delta_0 \frac{P_m \omega tc^2}{2H}$$

$$\frac{(\delta_c - \delta_0)2H}{P_m \omega} tc^2$$

by moving equation [3]

$$\sqrt{\frac{2H(\delta_c - \delta_0)}{P_m \omega}} tc$$

Information:

Pm = turbine mechanical power (Watt)
δo = starting rotor angle
Pe = generator electrical power (Watt)
δc = critical break angle
H = synchronous machine moment of inertia (MJ / MVA)
F_0 = frequency

3. Research Methods

3.1 Simulation Modelling

Stability of the angle Simulation modelling carried out is the Sulselrabar interconnection system with the inclusion of PLTB Sidrap and PLTB Jeneponto in the system. Critical clearing time analysis is an analysis of determining the critical time which aims if a system experiences a disturbance, the affected area will be isolated quickly. Critical clearing time analysis that is performed when the system is experiencing problems is by looking at the value and the rotor angle graph. There are several simulation scenarios carried out, starting from the simulation before the entry of the Sidrap & Jeneponto PLTB, after the entry of the Sidrap & Jeneponto PLTB, and when a three-phase short circuit occurs in each condition. This simulation is done using the PSAT 2.1.10 toolbox

3.2 Research Procedure

For this research, there are five stages carried out, namely the first to collect and study literature related to determining the stability of the rotor angle. Then the next step is to determine the data and parameters directly from PT. PLN Persero which is needed to support the calculation and determination of Critical Cleaning Time. The third stage is processing the data that has been obtained based on the existing theories using the PSAT 2.1.10 program. The last stage is to write based on the research that has been done.

4. Simulation & Analysis

4.1 Simulation of Rotor Stability of the Sulselrabar System during Normal Conditions (PLTB Sidrap & Jeneponto has not been integrated)

This simulation aims to determine the effect of the moment of inertia on the value of the rotor angle of the Sulselrabar system when the two PLTB conditions have not been integrated at night peak loads using PSAT 2.1.10.

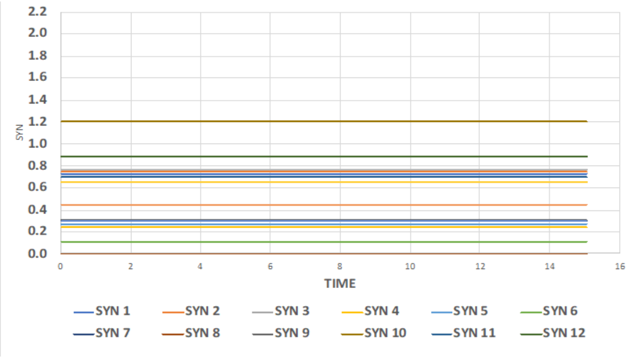

Figure 2. Graph of Rotor Angle when the Sidrap & Jeneponto PLTB has not been integrated.

This simulation uses the Single Line Diagram of the Sulselrabar transmission system to see the condition of the rotor angles in each generator bus. This simulation consists of 3 types of buses, namely the reference bus / slack bus (Pamona bus), the voltage bus (PV) and the load bus (PQ). After simulating the power flow program, the rotor angle value is obtained in Figure 2:

Table 1. Value of Rotor Angle when PLTB Sidrap and Jeneponto have not been integrated into the System

No	Generating Unit	Moment of Inertia MJ / MVA	Active Power (MW)	Reactive Power (MVar)	Rotor angle	
					Radians	Degree
1	PLTGU Sengkang	5.55	200.93	19.07	0.7262	41.627
2	PLTA Tangka Manipi	2.97	135.83	1.79	0.7444	42.671
3	PLTU Jeneponto Expsi	5.00	2	0.22	0.2705	15.509
4	PLTU Jeneponto	5.00	191.15	33.12	0.2432	13.941
5	PLTU Punagaya	5.00	5.28	1.04	0.2726	15.626
6	PLTA Malea	5.00	5.28	1.04	-0.0631	-3.615
7	PLTMH Simbung & Siteba	2.97	3.13	1.25	0.0016	0.089
Slack	PLTA Poso	2.97	206.1	0	0.0000	0.0000
9	PLTU Mamuju	5.00	49.95	18.35	0.3117	17.867
10	PLTA bakaru	2.97	126	-3.5	1.2066	69.166
11	PLTM Sawitto	2.97	0.805	0	0.7014	40.206
12	PLTD Suppa	1.02	0	0	0.8878	50.893
13	PLTU Barru	5.00	51.53	7.63	0.30.00	17.197
14	PLTA Bili-bili	2.97	0	0	0.4489	25.734
15	PLTA Tello	5.00	0	0	0.7739	44.365
16	PLTD Agrekko	1.02	0	0	0.65.15	37.344

4.2. Simulation of Rotor Stability of the Sulselrabar System during Integrated Sidrap PLTB

CCT In this simulation, the condition of the rotor angle at each generator is still in a synchronous state, where the critical clearing time value does not exist, because in this condition there is no three-phase short circuit fault.

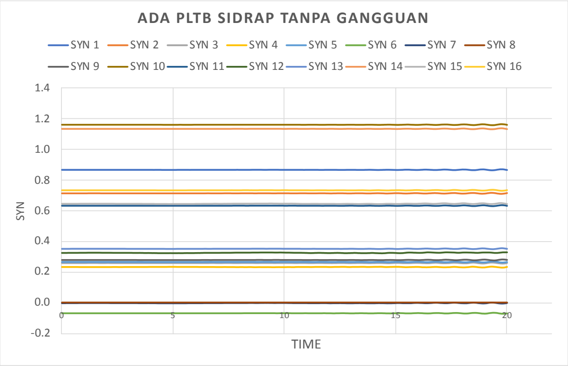

Figure 3. Graph of the Angle of the Rotor when the Sidrap PLTB has been Integrated

When PLTB Sidrap is integrated, the value of the rotor angle is different from normal conditions, but the value of the rotor angle is still in a stable state. To see more clearly the value of the rotor angle between before and after the Sidrap PLTB integrated in the Sulselrabar interconnection system can be seen in the graph and table below:

Table 2. Value of Rotor Angle when PLTB Sidrap is Integrated in the System

No	Generating Unit	Moment of Inertia MJ / MVA	Active Power (MW)	Reactive Power (MVar)	Rotor angle	
					Radians	Degree
1	PLTGU Sengkang	5.56	200.93	19.07	0.8742	50.112
2	PLTA Tangka Manipi	2.97	135.83	1.79	0.7191	41.220
3	PLTU Jeneponto Expsi	5.00	2	0.22	0.2660	15.248
4	PLTU Jeneponto	5.00	191.15	33.12	0.2387	13.683
5	PLTU Punagaya	5.00	113.56	49.47	0.2308	15.521
6	PLTA Malea	5.00	5.28	1.04	0.3628	20.798
7	PLTMH Simbung & Siteba	2.97	3.13	1.25	0.0014	0.077
Slack	PLTA Poso	2.97	206.1	0	0.0000	0.000
9	PLTU Mamuju	5.00	49.95	18.35	0.2862	16.405
10	PLTA bakaru	2.97	126	-3.5	1.1656	66.818
11	PLTM Sawitto	2.97	0.805	0	0.6396	36.665
12	PLTD Suppa	1.02	0	0	0.3276	18.777
13	PLTU Barru	5.00	51.53	7.63	0.3558	20.394
14	PLTA Bili-bili	2.97	0	0	1.1355	65.094
15	PLTA Tello	5.00	0	0	0.6476	37.121
16	PLTD Agrekko	1.02	0	0	0.7412	42.490

4.3 Simulation Simulation of Rotor Stability of the Sulselrabar System when the Integrated Jeneponto PLTB Conditions

In this simulation, it is the same as the previous simulation, but what distinguishes only the PLTB input is the Jeneponto PLTB input.

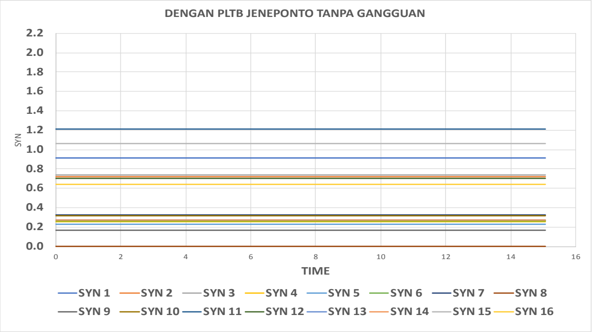

Figure 4. Graph of Rotor Angle when PLTB Jeneponto Has Been Integrated.

The Jeneponto PLTB supplies active power which is not big enough, namely 11.90 MW for active power and -1.8 MVAR for reactive power. For this simulation, the rotor angle value obtained is almost the same as the previous simulation, it's just a different value.

Table 3. Value of Rotor Angle when PLTB Jeneponto is Integrated in the System

No	Generating Unit	Moment of Inertia MJ / MVA	Active Power (MW)	Reactive Power (MVar)	Rotor angle	
					Radians	Degree
1	PLTGU Sengkang	5.56	200.93	19.07	0.9095	52.14
2	PLTA Tangka Manipi	2.97	135.83	1.79	0.7173	41.12
3	PLTU Jeneponto Expsi	5.00	2	0.22	0.7350	42.13
4	PLTU Jeneponto	5.00	191.15	33.12	0.2599	42.90
5	PLTU Punagaya	5.00	113.56	49.47	0.2326	13.33
6	PLTA Malea	5.00	5.28	1.04	0.2672	15.32
7	PLTMH Simbung & Siteba	2.97	3.13	1.25	0.3269	18.74
Slack	PLTA Poso	2.97	206.1	0	0.3269	18.74
9	PLTU Mamuju	5.00	49.95	18.35	0.0000	0.00
10	PLTA bakaru	2.97	126	-3.5	0.1715	9.83
11	PLTM Sawitto	2.97	0.805	0	1.2132	69.55
12	PLTD Suppa	1.02	0	0	0.7055	40.44
13	PLTU Barru	5.00	51.53	7.63	0.2733	15.67
14	PLTA Bili-bili	2.97	0	0	0.2768	15.87
15	PLTA Tello	5.00	0	0	1.0586	60.68
16	PLTD Agrekko	1.02	0	0	0.6415	36.78

4.4 Simulation of rotor angle stability when a 3-phase short circuit occurs in the Sungguminasa-Maros transmission line before the Integrated Sidrap & Jeneponto PLTB.

The simulated fault is a 3 phase short circuit. In this disturbance, it can be seen that the longer the disturbance time occurs, the graph will show the response of the rotor angle which will increasingly lead to an unstable condition.

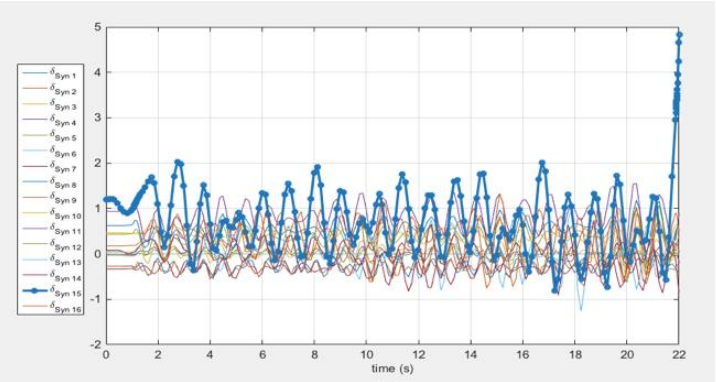

Figure 5.Graphic Angle of the Rotor when there is a disturbance in the Sungguminasa-Maros transmission line and the PLTB is not yet integrated

In the simulation when this disturbance occurs, the author adds a connector that functions as a connector for the Sungguminasa-Maros transmission line in this case. interference occurs in the middle of the transmission line. Also added 1 Fault (3 phase short circuit) on the transmission line Sunggumiasa - Maros and 2 Breakers. To see the value of the rotor angle when there is a disturbance before the two PLTBs are integrated, it can be seen in Figure 5 and Table 4 below:

Table 4. Value of Rotor Angle When Fault Occurs in the Line Sungguminasa - Maros transmission before both PLTB Integrated with CCT = 0.121s

No	Generating Unit	Moment of Inertia MJ / MVA	Active Power (MW)	Reactive Power (MVar)	Rotor angle	
					Radians	Degree
1	PLTGU Sengkang	5.56	200.93	19.07	0.8745	50.128
2	PLTA Tangka Manipi	2.97	135.83	1.79	0.9047	51.862
3	PLTU Jeneponto Expsi	5.00	2	0.22	0.7233	41.463
4	PLTU Jeneponto	5.00	191.15	33.12	0.5312	30.449
5	PLTU Punagaya	5.00	113.56	49.47	0.4852	27.813
6	PLTA Malea	5.00	5.28	1.04	0.2867	16.436
7	PLTMH Simbung & Siteba	2.97	3.13	1.25	-0.3040	-17.427
Slack	PLTA Poso	2.97	206.1	0	0.0000	0.000
9	PLTU Mamuju	5.00	49.95	18.35	-0.1174	-6.727
10	PLTA bakaru	2.97	126	-3.5	0.19.10	10.948
11	PLTM Sawitto	2.97	0.805	0	1.2259	70.277
12	PLTD Suppa	1.02	0	0	0.5640	32.332
13	PLTU Barru	5.00	51.53	7.63	0.8114	46.514
14	PLTA Bili-bili	2.97	0	0	0.8585	49.212
15	PLTA Tello	5.00	0	0	1.4349	82.253
16	PLTD Agrekko	1.02	0	0	0.9967	57.137

4.5 Simulation of the Stability of the Rotor Angle in the event of a 3-phase short circuit in the Sungguminasa-Maros transmission line after integrated Sidrap PLTB.

In this simulation, the disturbance time is 1.077s and the CCT value is 0.123s. In the simulation when a disturbance occurs, the writer gets the CCT value by varying the duration of the disturbance until the generator experiences out of sync. For the simulation of this disturbance, this is the same as before, but the only difference is the Sidrap PLTB input to the system. The Sidrap PLTB has an installed power of 75MW.

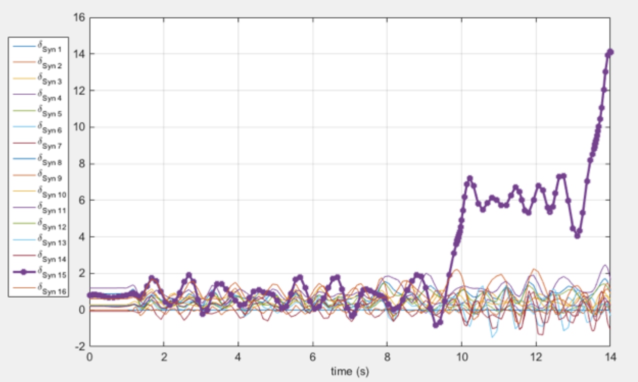

Figure 6. Graph of the Angle of the Rotor after the Integrated Sidrap PLTB when there is a disturbance in the Sungguminasa-Maros transmission line with a value CCT = 0.123 s

Table 5. Value of Rotor Angle When Fault Occurs in the Line Sungguminasa - Maros transmission after Integrated Sidrap PLTB with CCT = 0.123s

No	Generating Unit	Moment of Inertia MJ / MVA	Active Power (MW)	Reactive Power (MVar)	Rotor angle	
					Radians	Degree
1	PLTGU Sengkang	5.56	200.93	19.07	0.9241	52.9761
2	PLTA Tangka Manipi	2.97	135.83	1.79	0.7992	45.8163
3	PLTU Jeneponto Expsi	5.00	2	0.22	0.8831	50.6224
4	PLTU Jeneponto	5.00	191.15	33.12	0.4660	26.7139
5	PLTU Punagaya	5.00	113.56	49.47	0.3387	19.4176
6	PLTA Malea	5.00	5.28	1.04	0.3405	19.5214
7	PLTMH Simbung & Siteba	2.97	3.13	1.25	0.3405	19.5214
Slack	PLTA Poso	2.97	206.1	0	0.5621	32.2228
9	PLTU Mamuju	5.00	49.95	18.35	0.0000	0
10	PLTA bakaru	2.97	126	-3.5	0.4300	24.6519
11	PLTM Sawitto	2.97	0.805	0	1.2194	69.9007
12	PLTD Suppa	1.02	0	0	0.5580	31.9884
13	PLTU Barru	5.00	51.53	7.63	0.6420	36.8025
14	PLTA Bili-bili	2.97	0	0	0.4483	25.6998
15	PLTA Tello	5.00	0	0	0.4483	25.6998
16	PLTD Agrekko	1.02	0	0	1.8122	103.8817

4.6 Simulation of rotor angle stability when a 3-phase short circuit occurs in the Sungguminasa-Maros transmission line after the Jeneponto PLTB is integrated.

The power installed in this generator is 60MW, while the power generated is 11.90 MW. In this simulation, the disturbance time is 1.125s and the CCT value is 0.125s. For this simulation, the CCT value obtained is greater than when there is a Sidrap PLTB input to the system.

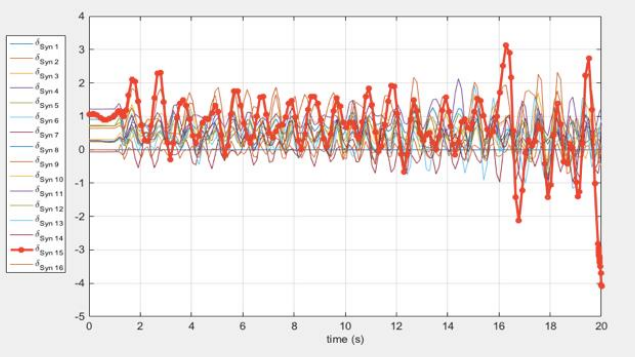

Figure 7. Graph of the Angle of the Rotor after the Jeneponto PLTB is integrated when there is a disturbance on the Sungguminasa-Maros transmission line with a value CCT = 0.125 s

Table 6. Value of Rotor Angle When Fault Occurs in the Line Sungguminasa - Maros transmission after Integrated Jeneponto PLTB with CCT = 0.125s

No	Generating Unit	Moment of Inertia MJ / MVA	Active Power (MW)	Reactive Power (MVar)	Rotor angle	
					Radians	Degree
1	PLTGU Sengkang	5.56	200.93	19.07	0.5811	33.3103
2	PLTA Tangka Manipi	2.97	135.83	1.79	0.7461	42.7695
3	PLTU Jeneponto Expsi	5.00	2	0.22	0.7997	45.8438
4	PLTU Jeneponto	5.00	191.15	33.12	0.4219	24.1854
5	PLTU Punagaya	5.00	113.56	49.47	0.3048	17.4749
6	PLTA Malea	5.00	5.28	1.04	-0.0082	-.04689
7	PLTMH Simbung & Siteba	2.97	3.13	1.25	-0.9859	-56.5160
Slack	PLTA Poso	2.97	206.1	0	0.0000	0.0000
9	PLTU Mamuju	5.00	49.95	18.35	-0.0215	-1.2348
10	PLTA bakaru	2.97	126	-3.5	0.1606	9.2058
11	PLTM Sawitto	2.97	0.805	0	0.6538	37.4784
12	PLTD Suppa	1.02	0	0	0.5277	30.2475
13	PLTU Barru	5.00	51.53	7.63	0.1786	10.2388
14	PLTA Bili-bili	2.97	0	0	0.6514	37.3408
15	PLTA Tello	5.00	0	0	2.2999	131.8391
16	PLTD Agrekko	1.02	0	0	1.7123	98.1579

5. Conclusion

Based on the research that has been done, it can be concluded that :

1. In determining the value of the rotor angle, the moment of inertia does not really affect the resilience of the system before the PLTB is integrated, where even though the value of the moment of inertia is large, if the generator does not supply active power to the system, the rotor angle value will be large and the generator is susceptible to synchronous loss. The value of the rotor angle before the integrated PLTB is in the range 0.151390 rad (8.66^{o}) to 0.796360 rad (45.624^{o}). In this condition, the generator rotor angle is at the tolerance limit, which does not exceed 90^{o}, so the system is still in stable condition.
2. In determining the value of the rotor angle when one of the PLTB has been integrated before there is a disturbance, the moment of inertia is not too influential because the PLTB does not have a moment of inertia, but the PLTB can supply active power to the system so that the rotor angle value is greater than before the PLTB input. The value of

the rotor angle after the integrated Sidrap PLTB is in the range 0.245140 rad (14.043^o) to 1.13716 rad (65.10^o) while the Jeneponto PLTB is in the range 0.354780 rad (20.28^o) to 1.234170 rad (70.702^o) in this condition the interconnection system is at the limit tolerance i.e. does not exceed 90^o so that the system is still in stable condition.

3. The integration of the Sidrap & Jeneponto PLTB in the Sulselrabar interconnection system has not significantly affected the value of the rotor angle, but it can prevent the generator from going out of sync quickly when there is a 3-phase short circuit on the Sungguminasa-Maros transmission line, this is because even though the PLTB does not have a moment of inertia but PLTB supplies active power which is not too large, namely 26.42 MW for Sidrap PLTB and 11.90MW where in determining the CCT value if the Pm value is greater then the CCT value will be smaller (the Pm value is inversely proportional to the CCT value) so that it can be seen that the CCT value is getting bigger. increased in 3 conditions, namely before integrated PLTB (CCT = 0.121s), Integrated Sidrap PLTB (0.123s) and Integrated Jeneponto PLTB (0.125s). In this condition, it can be seen that the CCT value is greater when one of the PLTB is integrated.

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