Transient Stability Improvement Using Allocation Power Generation Methods Based on Moment Inertia

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***Abstract*— Stability issues are a matter of great concern in the operation of electrical power systems. Transient stability is a study that discusses the state of the power system after a major and rapid disturbance. In this paper will be offered method to improve the condition of transient system stability. By rescheduling the generation based on the value of the inertia moment, the critical clearing time (CCT) of the system will be increased. Changes in CCT values due to load changes on each bus are also observed. In this research used WSCC 9 bus system as test case. From the simulation it can be seen that by doing rescheduling active power at the generator spacing allocation of moment value of inertia hence value of CCT can be significantly improved**

Keywords—transient stability; critical clearing time; rescheduling; moment inertia

I. Introduction

Nowadays, power systems are becoming heavily stressed due to the increased loading of the transmission lines. These problems lead to the steady state stability problem in the system. There are many of incidents in power system diagnosed as steady state stability problems caused by the increased loading and decreased stability margin. The stability margin may be defined as the distance between the loading of the system and the maximum loading limit of the system [1-3].

The problem in voltage instability has been the major cause for blackout cases all over the world recently [2]. Voltage stability is closely related with the steady state stability margin. If it has over limited to the maximum of power transfer, it leads to loss of operations of system and the voltage collapse will happen. The need of power has been changing in every single day since the peak load occurs in early evening. The balance between power demand on power and power on generator must be carefully maintained [3].

The continuity of the service must always be kept never to be extinguished, the voltage and frequency stability must be good, and the total harmonics are close to at least [1]. Large-scale power outages that occur as a result of a major disruption to the electrical power system are undesirable, both in the electrical and consumer companies side. Large-scale power outages will result in huge losses, both material and immaterial in nature [2]. To produce good electrical power quality, good control and stability of the power system are required.

In a large-scale power system consisting of many power plants and interconnected loads, the regulation of system stability is an important and complicated matter. To keep the power system in order to keep operating continuously and stable, a good stability arrangement is required. One of the stability parameters of a power system is the transient stability. Transient stability is the ability of the electric power system to achieve stable conditions of acceptable new operations after major disruption [4-7].

Commonly used conventional computational methods for interpreting transient stability conditions of a power system are time domain methods, transient energy functions, the same broad criteria, and several other methods. Such methods generally do not include the effect of the effect value of the generation scheduling to the interpretation of the transient stability result [8-9].

There are many methods to improve the stability of transient system, including: install FACT device equipment, repair line transmission and others. In this paper we will offer a method to improve transient stability by performing rescheduling of the generation using H index method.

This study aimed to examine the relationship between active power generation to improved the stability of system. System WSCC 9 bus used as a test case in this study.

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II. POWER SYSTEM STABILITY

A. Stability in Power System

The tendency of a power system to return a power equal to or greater than the power of interference to maintain a balanced state is called stability. If the power generated to keep the machine in sync with the other is sufficient to overcome the interference power, the system is said to be stable (synchronous) [10-13].

In a stable operating state of a power system, there is a balance between the mechanical input power of the prime mover generator and the electrical output power (electrical load) on the system. In this state all generators rotate at synchronous speed. Minor or large disturbances in the power system will have an impact on synchronous operations. For example, a sudden increase or decrease in the load, or the consequence of a generation loss, becomes one type of interference that has a significant effect on the system. Another type of potential disturbance is the breaking of the transmission net, overload, or short circuit. With good control, it is expected the stability of the system will lead to a steady state in a short time after the interruption is overcome [14].

Disturbances in electrical power systems can be classified into 2 categories, ie minor disturbances and major disruptions. [1-2] Minor noise is one of the elements of a dynamic system that can be analyzed using linear equations. Minor disturbances that occur in the form of load changes on the load side or generator randomly, slowly, and storied. Trips on the power system's net is considered a minor annoyance if its effect on the power flow before the interruption of the system is insignificant. The disruption that produces a sudden shock to the bus voltage is a major type of disturbance that must be immediately eliminated. If the interference is not immediately removed, then the interference will affect the stability of the system. Large scale disruptions will have a significant effect on the power flow on the system, even allowing for blackouts to occur.

In general, stability studies are classified into 3 categories, namely steady state stability, dynamic stability, and transient stability [16]. Steady state stability is the ability of the electric power system to achieve stable conditions under new operating conditions that are identical or identical to the conditions before interference occurs after the system has minor disturbances. Conceptually, dynamic stability is the same as steady state stability [5]. Figure (1) shown the classification of power system stability. The difference lies in modeling, ie, in dynamic stability, excitation systems, turbines, and generators is modeled by providing flux variation in engine gap water, while steady state generator stability is represented as a constant voltage source [1-2]. While the transient stability is the ability of the power system to achieve stable conditions under new acceptable operating conditions after the system has large-scale disruption in the period during the first 1 swing assuming the AVR and governor have not worked [13].

A study of transient stability is required to ensure the system's ability to withstand transient conditions after major disruption. Often, studies of transient stability are made when transmission and generating facilities are installed

New electrical power and is very helpful in determining the necessary rele system, the breaking time of the circuit breaker, the voltage level, and the transferability between the systems [2].

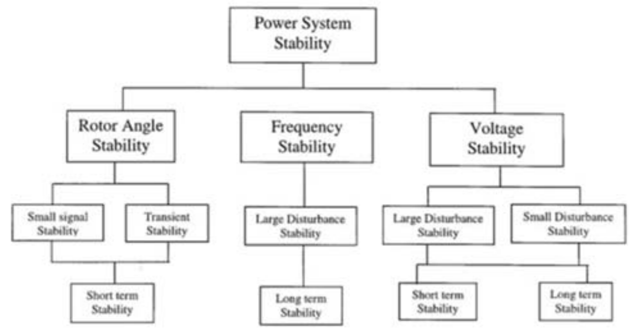

Fig. 1. Classification of Power System Stability

B. Swing Equation

The swing equation expresses the rotor motion of a machine simultaneously, and is the basic principle which states that the acceleration of the acceleration moment is the product of the rotor's inertia moment with its angular acceleration. The equation can be written as follows:

$$J.\frac{d^2\theta}{dt^2} = T_a = T_m - T_e \quad (1)$$

The symbols above have the meaning as follows:

J = Moment of rotor inertia (Kg.m)

θ = Shifting the rotor angle to the stationary axis (Radian)

t = time (second)

T_m= The mechanical turning point of the drive shaft provided by the prime mover is reduced by the loss (N.m)

T_e = Electric swivel moment (N.m)

T_a = Spatial play moments (N.m)

With dot notation writable

$$\ddot{\delta} = \frac{d^2\delta}{dt^2}$$

So that,

$$J\ddot{\delta} = T_m - T_e \quad (2)$$

Several ways are used from the development of equations:

$J\ddot{\delta} = T_m - T_e$

thenωThe first way is the form of power generated by multiplying both sides with ω then;

$$J\omega\ddot{\delta} = P_m - P_e \quad (3)$$

with Jω is the constant of inertia and angular momentum is M, then M can be expressed by:

M = Jω

The power equation is :

$$M\ddot{\delta} = P_m - P_e \tag{4}$$

the second way derived from kinetic energy is

$$W_k = \left(\frac{1}{2}\right) J\omega_R^2 \tag{5}$$

constants H

$$H = \frac{W_k}{P_R}$$

then the equation per unit or swing equation is

$$\left(\frac{2H}{\omega_R}\right)\ddot{\delta} = T_{mpu} - T_{epu} \tag{6}$$

III. Proposed Method

This research offers a method to improve the stability of transient system by performing reschedulling of active power generation based on proportional moment inertia constanta (H) value of each generator. WSCC 9 bus system is the test case of simulation, shown on figure (2).

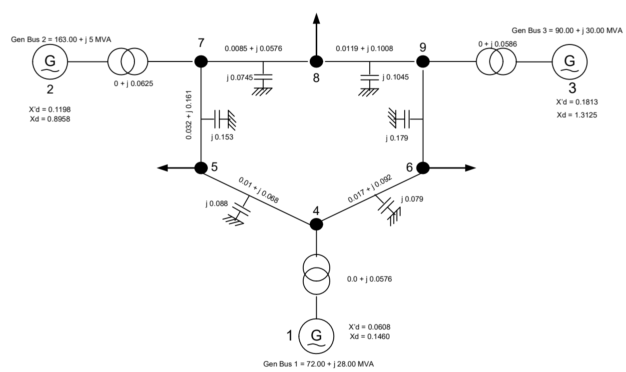

Fig. 2. Single line diagram of WSCC 9 bus system

The steps undertaken in this study are:

1. Generator data collection, transmission and load of system
2. Running transient stability simulation
3. Looking at the critical clearing time (CCT)
4. Change the active power generation
5. Conducting rescheduling with the value of index H
6. Compare the CCT value for each method of generating scheduling

The procedure of this research is complete can be seen on the figure (3).

Table 1. Moment Inertia of Generator

No.	Generator	Xd'	H (Moment Inertia)
1	Generator 1	0.0608	23.64
2	Generator 2	0.1198	6.40
3	Generator 3	0.1813	3.01

Table 2. Load Flow Data

Bus to	Bus	R (p.u)	X(p.u)	1/2B (p.u)
1	4	0.00000	0.05917	0.0000
2	7	0.00000	0.06250	0.0000
3	9	0.00000	0.05860	0.0000
4	5	0.01000	0.06800	0.0880
4	6	0.01700	0.09200	0.0790
5	7	0.03200	0.16100	0.1530
6	9	0.03900	0.17380	0.1790
7	8	0.00850	0.05760	0.0745
8	9	0.01190	0.10080	0.1045

The method offered to improve the stability of the system in this paper is rescheduling of the plant based on the value of the generator inertia moment. Each power generator will generate power according to the value of its inertial moment. The great equation for explaining the power value of each generator can be seen in equation (7).

$$P_{Generation} = \frac{H_{Generator}}{Total\ H_{Generator}}\ x\ P_{Total} \tag{7}$$

Using equation (7), we obtain the power of each generator based on the moment inertia value. At the time of total power at 315 MW load using equation (7), the power of generator 1 (G1) is 225 MW, then 61 MW and 29 MW, respectively for G2 and G3. For more details can be seen in table (3)

Table 3. Result of Power Rescheduling Based on Inertia Value

Proportional Power Rescheduling Based on Momen Inertia Value				
No.	Total of Load (MW)	Generator	Moment Inertia (H)	Active Power (MW)
1	315	G1	23,64	225
		G2	6,4	61
		G3	3,01	29
		Total moment inertia	33,05	
2	325	G1	23,64	232
		G2	6,4	63
		G3	3,01	30
		Total moment inertia	33,05	

In this paper, we will show the relation between the change of load on the other bus to the value of CCT on the bus that has interference. Suppose that on bus 9 fault occurs, it is simulated when load on bus 5, bus 6 and bus 8 are changed for fixed slack bus. The purpose of the simulation is to see the effect when a generator becomes slack bus with the moment value to the existing CCT value. Is there any connection between slack bus selection to CCT value is the purpose of this simulation.

In this study also examined the relationship between the value of CCT to economical scheduling by using lagrange method. Then it will be seen large operating costs for each operation pattern. There are 3 operating conditions that will be compared that is base case, economic dispatch using lagrange method and proposed method.

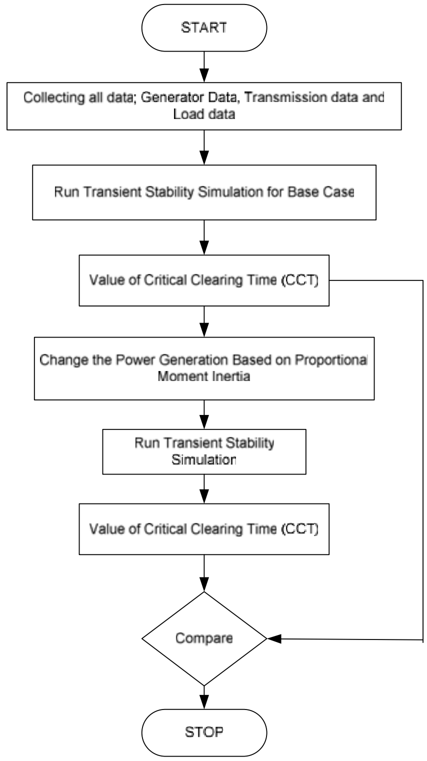

Fig. 3. Research Procedure

IV. SIMULATION RESULT

The first step in this research is to study load flow for WSCC 9 bus system. The value can be seen in table 4.

Table 4. Load Flow Result for Base Case

Bus No.	Gen MW	Gen MVar	Load MW	Load Mvar	V (p.u)	Angle (degree)
1	72	28			1.04	
2	163	5			1.025	9.351
3	85	-11			1.025	5.142
4					1.025	-2.217
5			125	50	0.9997	-3.680
6			90	30	1.012	-3.567
7					1.027	3.796
8			100	35	1.017	1.337
9					1.033	2.445

After the load flow simulation then the next step is to do some scenarios for transient stability simulation. The scenarios are as follows:

- Base Case Scenario: Power allocation is appropriate to the initial conditions
- Economic Dispatch Scenario (ED): Power allocation based on economi dispatch results using lagrange method
- Proposed Method Scenario: The allocation of power generation is determined by the value of the inertia moment of the plant CCT Relationship to Load Demand Changes

A. CCT Relationship to Load Demand Changes

In this simulation shows the relationship between load changes on bus 5, bus 6 and bus 8, in the event of interference at bus 9. The simulation result shows an increase of CCT value when the load on the bus is increased. To see it can be seen in table (5-7).

Table 5. Fault on Bus 9 with Load Change on Bus 5

Fault	Load bus 5 (MW)	CCT (second))
9	125 MW	0.219
9	135 MW	0.224
9	145 MW	0.228
9	175 MW	242

Table 6. Fault on Bus 9 with Load Change on Bus 6

Fault	Load bus 6	CCT
9	100 MW	0.17
9	110 MW	0.18
9	120 MW	0.18
9	130 MW	0.19
9	140 MW	0.19

Table 7. Fault on Bus 9 with Load Change on Bus 8

Fault	Load bus 8	CCT
9	110 MW	0.173
9	120 MW	0.184
9	130 MW	0.195
9	140 MW	0.21
9	150 MW	0.214
9	175 MW	0.226
9	200 MW	0.243

The rotor angle respon of each generator can be seen on figure (4). Fault on bus 9 with total load demand is 145 MW.

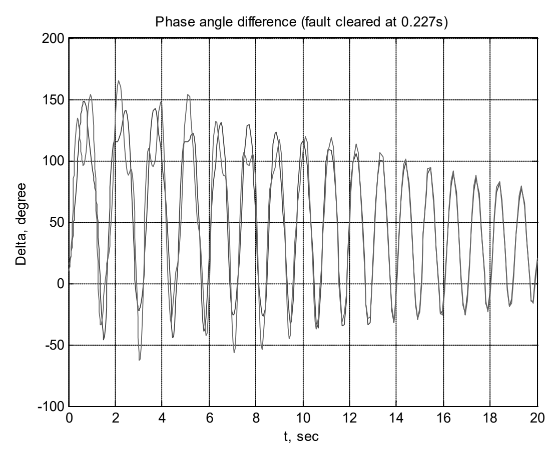

Fig. 4. Rotor Angle Respon when Fault on bus 9 with total load demand on bus 5 is 145 MW

B. CCT Relationship to Allocation Power Generation

In this research, some simulation scenarios are done:

1. There is a short circuit on bus 7 by removing line 5-7
2. There is a short circuit on bus 8 by removing line 7-8
3. There is a short circuit on bus 5 by removing line 4-5
4. There is a short circuit on bus 6 by removing line 4-6
5. There is a short circuit on bus 9 by removing line 6-9

The rotor angle response for base case condition at fault on bus 7 for interruption time for 0.16237 seconds. As shown in figure (5).

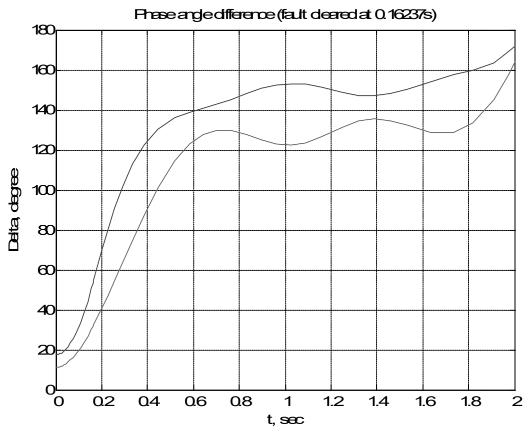

Fig. 5. The rotor angle response for base case condition at fault on bus 7 for interruption time for 0.16237 seconds.

For generating conditions obtained using lagrange method obtained power sharing for each plant as follows:

Active Power Generation G1 (P1) = 90.3845 MW
Active Power Generation G2 (P2) = 134.2522 MW
Active Power Generation G3 (P3) = 94.1720 MW
Operation Cost = 5309,2 $/h

Rotor angle response for discharging economic dispatch result condition at fault on bus 7 for critical clearing time is 0.2285 sec. As shown in figure (6).

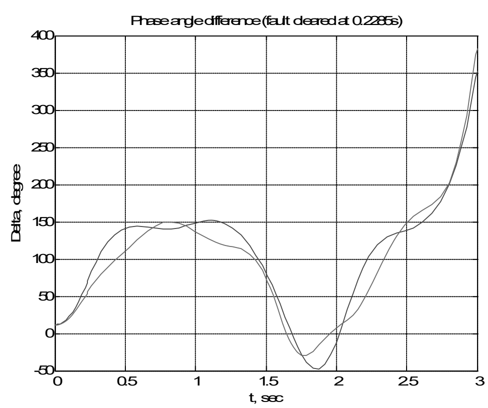

Fig.6 The rotor angle response for economic dispatch method, when fault on bus 7 for interruption time for 0.2285 seconds

Furthermore, by rescheduling the generator based on the value of index H obtained the value of each generator as follows:

Active Power Generation G1 (P1) = 229.169 MW
Active Power Generation G2 (P2) = 60.999 MW
Active Power Generation G3 (P3) = 28.688 MW
Operost = 8526,9 $/h

After generating values are obtained, proceed with determining the critical clearing time value by looking at the rotor angle response of each generator.

From the simulation shows that in the event of fault on bus 7, then the critical clearing time obtained for 0.7 seconds. As shown in the figure (7).

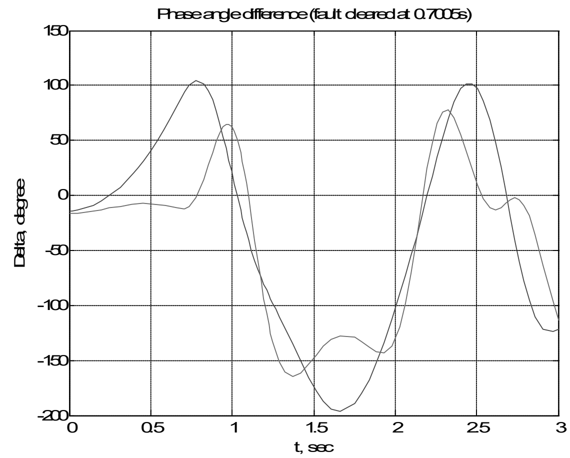

Fig.7 The rotor angle response for proposed method, when fault on bus 7 for interruption time for 0.700 seconds

From the simulation it can be seen that by applying the proposed method, there is an increase of CCT value. This means that the proposed method can improve the transient stability of the system. Comparison of CCT values for the three scenarios can be seen in the table (8).

Table 8. Comparison of CCT for all Scenario

No	Fault	Line Open	CCT (second) Base Case	CCT (second) ED	CCT (Second) Proposed Method
1.	Bus 7	line 5-7 open	0.16237	0.2286	0.7100
2.	Bus 8	line 7-8 open	0.2700	0.3455	stable
3.	Bus 5	line 4-5 open	0.3820	0.4710	stable
4.	Bus 6	line 4-6 open	0.4583	0.5835	stable
5.	Bus 9	line 6-9 open	0.2185	0.2250	0.7500

V. CONCLUTION

From the simulation result, it can be seen that by using scheduling method based on H index value, it is found that *critical clearing time* (CCT) value becomes more stable, so the system is more robust to disturbance. The value of the H index can be a solution to improve the stability of the power system.

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References

[1] Hadi, S., ***Power System Analysis***, McGraw-Hill Book Co., Singapore, 1999.

[2] Allen, J.W. dan Bruce, F.W., ***Power Generation, Operation, and Control***, John Wiley & Sons Inc., Canada, 1996.

[3] Anderson, P. M., and Fouad A. A., *Power System Control and Stability,* **Iowa University Press**, Ames, Iowa, 1990.

[4] Zhenyu Huang, Lixin Bao, and Wilsun Xu, "A Method to measure QV curves and its Application in Power System,," **Electrical Power and Energy Systems**, June 2006, pp. 147-154.

[5] Campeanu, H. S., L'Helguen, E., Assef, Y., Vidal, N., and Savulescu, S. C., "Real-Time Stability Monitoring at Transelectrica," Paper PSCE06-1288, presented at the "Real- Time Stability Applications in Modern SCADA/EMS" **Panel, IEEE PSCE 2006 Atlanta**, GA, October 29–November 2, 2006.

[6] Gunadin, I.C., Abdillah, M., Soeprijanto, A., Penangsang, "Determination of steady state stability margin using extreme learning machine ",**WSEAS Transactions on Power Systems,** 2012

[7] Gunadin, I.C., Soeprijanto, A., Penangsang, O, "Steady state stability assessment using extreme learning machine based on modal analysis ",**International Review of Electrical Engineering,** 2012

[8] Pitono, J., Soeprijanto, A., Purnomo, M.H., Gunadin, I.C. , "Power generation optimization based on steady state stability limit using particle swarm optimization (PSO)", International Review on Modelling and Simulations, 2013

[9] Gunadin, I.C., Soeprijanto, A., Penangsang, O, "Real power generation scheduling to improve steady state stability limit in the Java-Bali 500 kV interconnection power system ",World Academy of Science, Engineering and Technology, 2010

[10] Indar Chaerah Gunadin, Adi Suprijanto, Ontoseno Penangsang,"Study on Effect of STATCOM Installation to Improved Voltage Stability in East Indonesia System", Proceeding of National Seminar on Applied Technology, Science, and Art (APTECS), Surabaya, December 22, 2009.

[11] Indar Chaerah Gunadin, Adi Suprijanto, Ontoseno Penangsang," Effect of VAR Suppor Installation to Improved Voltage Stability in East Indonesia System", **Proceeding of Basic Science National Seminar 7th**, February 20th, 2010

[12] Indar Chaerah Gunadin, Nadjamuddin Harun, Adi Suprijanto, ,"Transient Stability on East Indonesia System", **Proceeding of National Seminar on Applied Technology, Science, and Art (APTECS**), Surabaya, December 22th, 2009.

[13] Indar Chaerah Gunadin, Adi Suprijanto, Ontoseno Penangsang," Effect of VAR Suppor Installation to Improved Voltage Stability in East Indonesia System", **Proceeding of Basic Science National Seminar 7th**, February 20th, 2010.

[14] "A Novel Method for Staedy State Stability Limit Assessment" **Proceeding of The 3rd International Student Conference on Advanced Science and Technology (ICAST)**, Seoul, Korea, 2009.

[15] Indar Chaerah Gunadin, Nadjamuddin Harun, Adi Suprijanto, ,"Transient Stability on East Indonesia System", **Proceeding of National Seminar on Applied Technology, Science, and Art (APTECS**), Surabaya, December 22th, 2009.

[16] Indar Chaerah Gunadin, Adi Suprijanto, Ontoseno Penangsang," Effect of VAR Suppor Installation to Improved Voltage Stability in East Indonesia System", **Proceeding of Basic Science National Seminar 7th**, February 20th, 2010.