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Dynamic stability improvement with integrated power plant scheduling method based on moment of inertia

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Abstract. Dynamic stability is one of the important aspects of maintaining the stability of an electrical power system as a whole. Dynamic stability study is the ability of the electric power system to return to the equilibrium point after a relatively small disturbance suddenly occurs for a long time. In this paper, we offer a method of rescheduling the generator to improve system stability by looking at the critical clearing time (CCT). Changes in the CCT value are due to changes in the load on each bus. The modelling of the IEEE 14 bus system is carried out with the help of the Simulink Power System Analysis Toolbox (PSAT) 2.1.10, which is integrated with the MATLAB R.2016a program. The simulation results show that the CCT value decreases as the fault location gets closer to the main generator.

1. Introduction

In this modern era, the human need for electrical energy is very important and cannot be separated from daily life, it is necessary to maintain the stability of a system [1-3]. Power system stability shows the ability of an electric power system at a given initial operating condition to restore operating conditions to balance again after getting physical disturbances in almost all interdependent system variables so that system integrity cannot be maintained. [4-6]. Disturbances in the system in the form of load changes that occur continuously and the system adapts to changing conditions and short circuits on the transmission line [7]. To maintain the stability of a system, it is necessary to strive for synchronous machines to be in synchronous conditions. The system must be able to respond quickly to a temporary disturbance of the level of stability. Instability occurs when a disturbance causes a persistent imbalance between these opposing forces. [8-9]. This research is focused on critical clearing time analysis studies to improve dynamic stability in the IEEE 14 bus system by looking at the rotor angle parameters at each generator with disturbances that occur on a bus with the H index generator rescheduling method.

1.1. System Stability

System stability is defined as the property of the system that allows the generator to move synchronously in the system and react to disturbances in normal working conditions and return to its original working condition (balance) when conditions return to normal [10-12]. Excess mechanical power over electrical power results in an acceleration of the generator rotor rotation or vice versa, if the disturbance is not removed quickly, the acceleration and deceleration of the generator rotor rotation will result in loss of synchronization in the system [13-14]. Stability studies are needed to ensure the ability of the system to reach a point of balance/synchronization after experiencing a large disturbance because the system loses stability when the disturbance occurs above the system's capability [15-17].

1.2. Generator Scheduling

The Rescheduling decision represents the final step in the production cycle. The production process begins with capacity planning (step 1), is followed by aggregate planning (step 2), and ends with operations scheduling (step 3). The main function of scheduling is to organize time. The basic goal of the rescheduling process is to design an optimal work sequence i.e. a plan that shows the best trade-off among conflicting goals. The time sequence of work is often formulated using a priority decision rule. Specifically, the priority decision rule is used to determine which jobs are processed when some jobs are pending. The relative effectiveness of each rule can be determined by observing the performance of the system [18-20].

1.3. Rotor Dynamics and Swing Equations

The basic principle in dynamics is that the rotational moment of acceleration is the product of the rotor moment of slack and its angular acceleration. This equation can be written in the form:

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

Where: J: Moment of inertia of the rotor mass (kg.m^2); θ_m: Rotor angle shift about a stationary axis (mechanical radians); t: Time (seconds); T_m: Mechanical or shaft turning moment (N.m); T_e: Electric turning moment (N.m); T_a: Net acceleration torque (N.m).

For the swing equation is

$$\frac{2H}{\omega_R}\frac{d^2\delta}{dt^2} = T_{m(PU)} - T_{e(PU)} \tag{2}$$

The power equation for each generator can be expressed by:

$$P_{Generator} = \frac{H_{Generator}}{Total\ H_{Generator}}\ x\ P_{Total} \tag{3}$$

2. Proposed Method

The method used in this study is the method of rescheduling the generator operation to improve the stability of the system based on the moment of inertia (H) of each generator. The IEEE 14 bus system was used as the test case in the study shown in Figures 1 and 2.

Table 1. Generating rescheduling results based on a moment of inertia.

No	Total of Load (MW)	Generator	Moment Inertia (H)	Active Power (MW)
1	392	Generator 1	5.148	2.324
		Generator 3	6.54	0.4
2	381	Generator 1	5.148	1.7
		Generator 3	6.54	2.19

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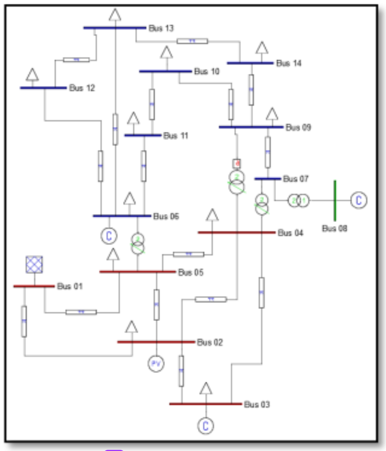

Figure 1. IEEE-14 bus system normal condition.

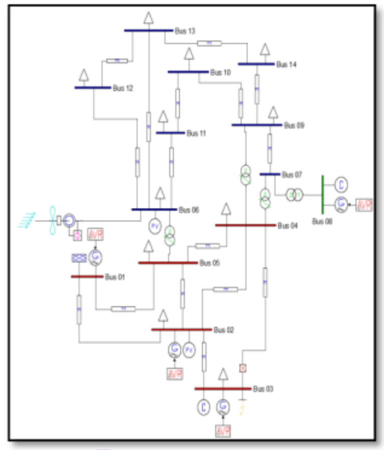

Figure 2. IEEE-14 bus system with fault and wind turbine.

The procedures for this research are:
1. Bus, generator, transmission, and load data collection
2. Making single line diagram of IEEE 14 bus system on PSAT 2.1.10
3. Simulation and data processing on PSAT 2.1.10
4. Added interference and wind turbine
5. Power flow study
6. Rotor angle stability analysis
7. Recording Critical Clearing Time (CCT)
8. Reschedule with index value H
9. Changing the active power of the power plant
10. Comparing CCT values before and after rescheduling

Table 2. IEEE-14 bus system data.

No Bus	P Generated (p.u)	P Generated (p.u)	P Load (p.u.)	Q Load (p.u.)	Bus Type*	Q Generated Max. (p.u.)	Q Generated Min. (p.u.)
1	2.324	0.0	0.00	0.00	2	9.9	-9.9
2	0.4	-0.424	0.2170	0.2170	1	0.5	-0.4
3	0.0	0.0	0.9420	0.1900	2	0.4	0.0
4	0.0	0.0	0.4780	0.0400	3	0.0	0.0
5	0.0	0.0	0.0760	0.0160	3	0.0	0.0
6	0.0	0.0	0.1120	0.0750	2	0.24	-0.06
7	0.0	0.0	0.00	0.00	3	0.0	0.0
8	0.0	0.0	0.00	0.00	2	0.24	-0.06
9	0.0	0.0	0.2950	0.1660	3	0.0	0.0
10	0.0	0.0	0.0900	0.0580	3	0.0	0.0
11	0.0	0.0	0.0350	0.0180	3	0.0	0.0
12	0.0	0.0	0.0610	0.0160	3	0.0	0.0
13	0.0	0.0	0.1350	0.0580	3	0.0	0.0
14	0.0	0.0	0.1490	0.0500	3	0.0	0.0

Table 3. Moment of inertia generator.

No	Generator	Xd'	H (Moment Inertia)
1	Generator 1	0.6	5.148
2	Generator 3	0.185	6.54

Table 4. IEEE-14 bus system transmission line data.

From Bus	To Bus	Resistance (p.u)	Reactance (p.u)	Line Charging (p.u)
1	2	0.01938	0.05917	0.0528
1	5	0.05403	0.22304	0.0492
2	3	0.04699	0.19797	0.0438
2	4	0.05811	0.17632	0.0374
2	5	0.05695	0.17388	0.034
3	4	0.06701	0.17103	0.0346
4	5	0.01335	0.04211	0.0128
4	7	0.00	0.20912	0.00
4	9	0.00	0.55618	0.00
5	6	0.00	0.25202	0.00
6	11	0.09498	0.1989	0.00
6	12	0.12291	0.25581	0.00
6	13	0.06615	0.13027	0.00
7	8	0.00	0.17615	0.00
7	9	0.00	0.11001	0.00
9	10	0.03181	0.0845	0.00
9	14	0.12711	0.27038	0.00
10	11	0.08205	0.19207	0.00
12	13	0.22092	0.19988	0.00
13	14	0.17093	0.34802	0.00

3. Simulation Results

In this simulation, dynamic stability analysis is carried out on the IEEE-14 bus test system using the generator rescheduling method. After describing the modeling of the IEEE-14 bus system in the form of a single line diagram on PSAT 2.1.10, then a stability simulation will be carried out covering several cases such as simulation of rotor angle stability during normal conditions, when the wind turbine is integrated when a disturbance occurs, and when a disturbance occurs. After rescheduling the generator based on the moment of inertia. To see the value of the IEEE-14 bus system muscle angle before and after the wind turbine integration is shown in Figures 3 and 4.

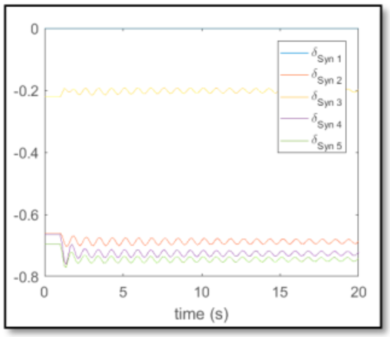

Figure 3. rotor angle response under normal conditions

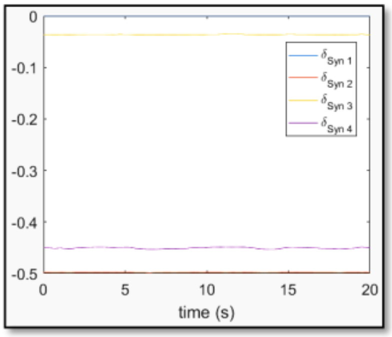

Figure 4. rotor angle response when the wind turbine integrated condition

In the simulation of Figure 3, the stability of the rotor angle when under normal conditions has not been obtained the critical clearing time value, because at this time there has not been a disturbance. Under normal conditions, the graph of the rotor angle is still synchronous or stable (there are no generators that are out of sync). While in Figure 4 when the wind turbine is integrated, the rotor angle value is different from normal conditions, but the rotor angle value is still in synchronous or stable condition.

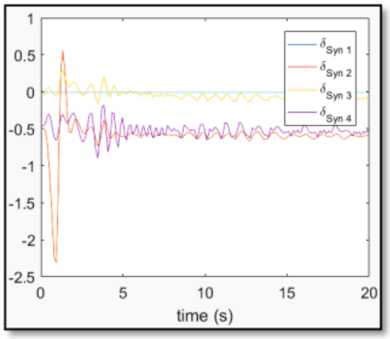

Figure 5. the response of the rotor angle when there is a disturbance during synchronous conditions

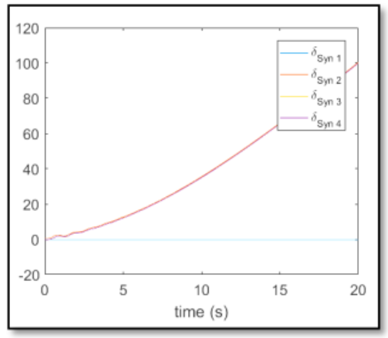

Figure 6. the response of the rotor angle when there is a disturbance when the condition is out of sync

In Figure 5 it can be seen that the system remains stable even though it is transiently stable where the generator is isolated when a disturbance occurs which results in a change in the rotor angle between the generators but it is not too significant because, with a disturbance duration of 0.6 seconds, the system is stable again. The system is said to be stable because no generator loses synchronization during the disturbance until it reaches a critical disconnection time. However, if the disturbance is decided by the CB which exceeds the critical time for disconnecting the CB, which is 0.61 seconds, it can be seen through the second graph in Figure 6 that the system becomes unstable (out of sync). This instability is characterized by a very significant change in the rotor angle which causes the generator to lose its synchronization, especially the generator which is located closest to the fault location. The generator that experienced out-of-sync is Generator 2 (syn 2) so that the system looks unstable at 0.61 seconds and the CCT value is 0.8 seconds.

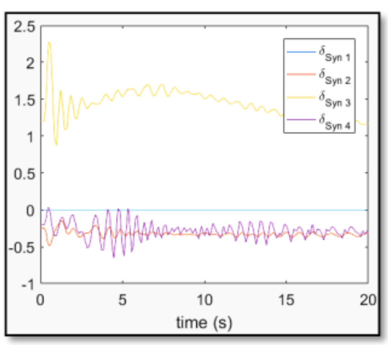

Figure 7. rotor angle response after rescheduling Synchronous condition.

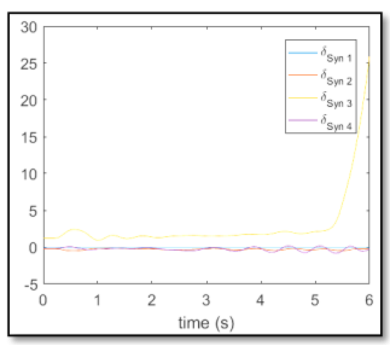

Figure 8. rotor angle response after rescheduling Synchronous release condition.

4 Figure 7 shows a graph of the response of the rotor angle when a short circuit occurs after rescheduling the generator based on the magnitude of the moment of inertia. Disruption time has given 0.18 seconds. It can be seen in the graph that the generation experiencing conditions leading to unstable or out of sync is Generator 3 (syn 3). Then in Figure 8, it can be seen that the system is out of sync with a disturbance duration of 0.19 seconds, and the critical clearing time value is 0.38 seconds.

Table 5. Comparison of CCT

No	Fault	CCT (second) Base Case	CCT (second) Proposed Method
1	Bus 1	0.421	0.29
2	Bus 2	0.57365	0.268
3	Bus 3	0.8	0.38
4	Bus 4	0.913	0.34
5	Bus 5	0.9813	0.34
6	Bus 6	Stable	Stable
7	Bus 7	0.76	0.6
8	Bus 8	Unstable	Unstable
9	Bus 9	0.77	0.553
10	Bus 10	0.91	0.54
11	Bus 11	Stable	Stable
12	Bus 12	Stable	Stable
13	Bus 13	Stable	0.54
14	Bus 14	Stable	Stable

Based on the simulation results, it turns out that not all buses in the system have or can be searched for a critical breaker time. Buses 6, 11, 12, 13, and 14 have no critical disconnection times. This indicates that the breakdown of the fault, including the critical time of disconnection from the CB to the fault on the five buses, will not affect the stability of the system. But for bus 8 which is also a bus of one of the generators whose rotor angle is also a reference for stability, it turns out that it does not have a disconnection time because as soon as there is a disturbance and the CB immediately trips, the system immediately becomes unstable.

4. Conclusion

From several fault points that are simulated in the IEEE-14 bus system, there is a Critical Clearing Time that is not found, which means the system remains stable up to 5 seconds of CB opening. The duration of the disturbance affects the stability of the rotor angle of all generators. The longer the disturbance it will make the rotor angle an unstable condition and this has an impact on the system imbalance.

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