Study of Dynamic Stability Analysis in the Sigura-gura Hydro Power Plant using the Power Stabilizer System as Compensation

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Abstract. To maintain the stability of the power plant system, effort are needed to keep the generator in sync. This study was conducted to determine the performance of each power plant in the Sigura-gura power system when interference with the transmission network. By reviewing the response curve through simulations with the EDSA software, it can be seen the changes in rotor angle, voltage oscillation and power for each generating system when a disturbance occurs. The application of PSS as a compensation to improve the character of the power system's stability against interference by observing changes in rotor angle, voltage and power. The observations show that the installation of PSS controllers in excitation as compensation to the Sigura-gura electric power system can contribute to better system performance by improving the rotor angle oscillation time, voltage and overshoot respectively 7.8%, 66.6% and 37.9%.

Keywords: stability, overshoot, oscillation, stabilizer system, compensation

1. Introduction
Power system stability is the state of the system to respond to disruptions during normal operation by returning to conditions where normal operation returned [1][2]. Interference in the system can cause oscillation of system variables, such as voltage, frequency, and power. While system requirements require that the variable be fixed at a certain operating point. Therefore, the problem in system stability is how to make oscillations that occur due to interference can quickly return to normal conditions. For this reason, large systems that have been built must be reviewed and improved every time there is a development in the system itself. As is the case with the Medium Electricity System in North Sumatra and Nanggroe Aceh Darussalam, now this area is expanding because demand for higher load services causes resources or power plants to service loads or uses that are located far from each other and cover large areas, so the central load center is carried out through a transmission channel with limited capacity. Such operations often cause problems with power system dynamics that cause the steady-state to be disrupted. Real conditions that often occur is a short circuit on the transmission line.
Conditions like this can cause the power system to be disrupted. The worst thing that happens is that the power system becomes unstable either by shifting the angle of the rotor, oscillating the voltage and reducing the electrical power in the system. To anticipate these things, a gradual evaluation needs to be done to find out how the behavior of each interconnection installation in North Sumatra if there is interference in one of the transmission lines and the extent of system reliability and what actions can be taken to overcome the unbalanced system. For this reason, evaluating the stability of Sigura-gura plants is the priority analyzed.

2. Basic Systems in Electric Power Systems

In order to understand the nature of power plant systems and control designs for performance improvement, it is necessary to know the basic components of power generation. [3]

The basic components of a power plant are systematically shown in Figure 1. The picture shows the turbine and governor with feedback speed, SG generator, VR voltage regulator excitation with voltage feedback, transformer and transmission network.

![Figure 1. The basic components of a power plant](image)

2.1. Turbine

Conversion of mechanical energy with a steam turbine is a thermodynamic process, where steam is normally expanded through low, medium and high pressure turbines all on one shaft. The high pressure steam energy and high temperature of the boiler are converted to mechanical energy through the turbine fins and diverted to the shaft connected to the generator.

2.2. Governor

The function of the governor is to maintain a constant speed, which is the synchronous speed of the turbine-generator set. When the speed decreases, in order to increase the output of electric power it will send a signal to the governor to increase the mechanical power input to the turbine and when the speed rises then the mechanical input power is reduced to maintain a constant speed. In large generators the governor provides power and frequency control functions, from areas that are in large interconnections.

2.3. Swing Equations

Under normal operating conditions the relative position of the rotor axis and the magnetic field axis are fixed. The angle between the two is called the power angle or torque angle. During disruption, the rotor will slow down or accelerate the synchronous rotation of the
magnetomotive force (mmf) air gap, and start relative motion [4]. The equation that describes the relative motion is the swing equation. If after the oscillation period, the rotor returns to synchronous speed, the generator will maintain stability. If interference is not followed by a change in power, the rotor returns to its original position. If the disturbance is followed by changes in generation, load or network conditions, the rotor will move to a new operating angle relative to the rotating field that is synchronized again. Two-cylinder cylindrical generator illustrative diagram in Figure 2.

Figure 2. Diagram of single-phase phasor cylindrical rotor generators

The power angle is the angle between the mmf rotor and the resultant air gap mmf, both rotating at synchronous speed. Also the angle between the emf generated without load and the resultant stator voltage. If the leakage flux and generator anchor resistance is ignored, the angle between E and terminal voltage V is the power angle.

Synchronous generator that generates electromagnetic torque and rotates with speed and mechanical torque on the rotor, so the steady state operation by ignoring losses is

\[ T_m = T_e \]  

(1)

If is a combination of the moment of inertia of the prime mover and the generator, ignoring the friction and torque of the dampers, the rotation law is obtained as

\[ J \frac{d^2 \theta}{dt^2} = T_e = T_m - T_f \]  

(2)

Swing equation with the inertia constant

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

(3)

In the form of perunit

\[ \frac{H}{180} \frac{d^2 \delta}{dt^2} = P_m - P_e \]  

(4)

\[ P_e = \frac{|E||V|}{X_{12}} \sin \delta \]  

(5)

With the transient voltage behind the transient reactance (bus-1), the voltage at infinity (bus 2), the reactance between bus 1 and bus 2, this is a simple form of the power flow
equation and a basis for understanding stability problems. The relationship of the power transferred depends on the transfer reactance and the angle between the two voltages [5].

Increased generator power output possible until maximum electrical power is transferred. This maximum power is expressed as a steady state stability limit, and occurs during the shrinkage of 90\(^\circ\).

\[ P_{\text{max}} = \frac{|E||V|}{X_{12}} \]  \hspace{1cm} (6)

2.4. Equation of the excitation system

Excitation control systems generally consist of several components, namely rectifiers, voltage regulators and comparators, amplifiers and exciter.

The excitation system reviewed for generators from the electric power system in North Sumatra is as follows:

\[ V_R = \frac{1}{1+\tau_R s} V_T - \frac{1}{\tau_R} V_R \]
\[ V_F = \frac{K_F}{\tau_F} E_{fd} - \frac{1}{\tau_F} V_F \]
\[ V_A = \frac{K_A}{\tau_A} (V_{ref} - V_F) - \frac{1}{\tau_A} V_A \]
\[ E_{fd} = \frac{1}{\tau_E} V_A - \frac{K_E}{\tau_E} E_{fd} \]  \hspace{1cm} (7)

for:
- \( \tau_R \): regulator input time constant
- \( K_F \): strengthening the regulator stabilizer circuit
- \( \tau_F \): time constant of the regulator stabilizer circuit
- \( K_A \): regulator strengthening
- \( E_{fd} \): Field voltage
- \( \tau_A \): regulator time constant
$K_q$: exciter self-excitation at full load field voltage

2.5. Power Sistem Stabilizer (PSS)

The basic function of the Power Stabilizer system (PSS) is to provide damping oscillation of the rotor generator by controlling the excitation signal [1] To get a good damping the stabilizer converts the rotor speed to electric torque. An overview of the Power Stabilizer System (PSS) is shown in Figure 4.

![Block diagram with AVR and PSS](image)

From above figure, if the transfer function and generator transfer function is the basic gain, the feedback will add up the damping torque as compensation for the Power System Stabilizer (PSS).

By illustrating the principle of using the Power System Stabilizer (PSS) by following the parameters exemplified to determine the effect of the excitation system in Figure 3.

From the block diagram 4 if ignored, the PSS can be written

$$\frac{\Delta \psi_{sd}}{\Delta v_i} = \frac{K_sK_A}{sT_3 + 1 + K_sK_AK_s'}$$  \hspace{1cm} (8)

3. Sigura-gura parameter

| Gen | $X_q$ (PU) | $X'_q$ (PU) | $X_d$ (PU) | $X'_d$ (PU) | $T'_d$ | $T'_{q0}$ |
|-----|------------|-------------|------------|------------|--------|-----------|
| 18  | 0.67       | 0.67        | 1          | 0.16       | 4      | 0.33      |
| 19  | 0.67       | 0.67        | 1          | 0.16       | 4      | 0.33      |
| 20  | 0.67       | 0.67        | 1          | 0.16       | 4      | 0.33      |
| 21  | 0.67       | 0.67        | 1          | 0.16       | 4      | 0.33      |
4. Results and Discussion

4.1. The response of the rotor angle
The expected rotor angle before and after Power System Stabilizer (PSS) installation is shown in Figure 5(a) and 5(b).

![Figure 5(a). Rotor angle before using PSS](image1)

![Figure 5(b). Rotor angle after using PSS](image2)

4.2. Voltage response
Voltage responses before and after the installation of the Power System Stabilizer (PSS) are shown in Figures 6(a) and 6(b).

Before installing the Power System Stabilizer (PSS) in Figure 6(a) shows that when the load was released on the Langsa bus. The voltage at the Paya Pasir generator was oscillated for 9.1 seconds with an overshoot of 0.003 pu. After the PSS installation in Figure 6(b) shows that the system experienced an oscillation time reduction from 9.1 seconds (Figure
6(a) to 4.65 seconds (Figure 6(b), resulting in an improvement of 6.05 seconds or 37.6%. 0.003 pu to 0.001 pu, or improved by 0.002 pu. This shows that installing PSS can make time for oscillations and damping oscillations in the Sigura-gura generator.

![Figure 6(a). The voltage response of the Sigura-gura generator before using PSS](image1)

![Figure 6(b). Responses to the Sigura-gura power plant after using PSS](image2)

| Generator   | Response rotor angle | Voltage response |
|-------------|----------------------|------------------|
|             | Rotor angle          | Time oscillation (sec) | Overshoot (pu) | Time oscillation (sec) |
| Sigura-gura | 1, 2⁰                | 7.3              | 0.003          | 9.1                  |
Table 3. Response of generator systems after PSS installation

| Generator  | Response rotor angle | Voltage response |
|------------|----------------------|------------------|
|            | Rotor angle         | Time oscillation | Overshoot (pu) | Time oscillation (sec) |
| Sigura-gura| 1.12°                | 6                | 0.001          | 5.65                  |

From Table 2 shows the rotor angle shift 1.120, oscillation time 7.3 / sec, voltage overshoot 0.0022 and voltage oscillation time 8.56 in the Sigura-gura hydropower plant system due to interference on the transmission network but after installing PSS as compensation in Table 3, they can reduce each: rotor angle oscillation 7.8%, Overshoot 66.6%. 37.9% oscillation time

5. Conclusion
The performance of each hydropower plant in Sigura-gura against one phase ground disturbance is currently quite good, in terms of the response of the rotor angle and the voltage of the plant when the disturbance occurs. Changes in the rotor angle for the whole plant range from 1.120 and the oscillation time to 7.3 sec and the length of the oscillation time of the voltage ranges between 8.36 sec. rotor angle, voltage and overshoot respectively 7.8%, 66.6% and 37.9%.

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