Analysis of Speed Droop Governor Control System for Maintaining Frequency Stability in the Nagan Raya Steam Power Plant

Azie Anhar, Siti Anisah, Haris Gunawan

Abstract

Frequency stability is a primary aspect in maintaining the reliability of Steam Power Plant (PLTU) operations, where the governor plays a crucial role through the speed droop control mechanism in adjusting turbine mechanical power in response to changes in generator rotational speed. This study analyzes the performance of the speed droop governor control system at the Nagan Raya PLTU using a quantitative approach through modeling and simulation with MATLAB/Simulink representing the steam turbine, governor, and synchronous generator. Simulation results show that the governor is able to respond to load changes stably and proportionally, with a simulated droop value of 4.56%, close to the field value of 5%, and a maximum frequency deviation of ±0.14 Hz. The pu_velocity graph indicates an initial overshoot of 1.023 pu and an undershoot of 1.013 pu, which are subsequently damped and reach a stable condition at 1.015 pu within approximately 10 seconds, reflecting a system with good damping characteristics and no hunting symptoms. Droop curve analysis shows a linear relationship between power changes and frequency, consistent with the load-sharing principle among generating units. Overall, this study concludes that the speed droop governor control system at the Nagan Raya PLTU functions effectively in maintaining frequency stability during load variations, making it suitable as a reference for governor optimization and future power plant control system development.

Keywords: PLTU, governor, speed droop, frequency stability, MATLAB/Simulink

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Introduction

Steam Power Plants (PLTU) are one of the main types of power generation that play an important role in the national electricity system due to their ability to produce large power capacity and operate continuously. The working principle of a PLTU is converting chemical energy from fuels such as coal into thermal energy to produce high-pressure steam, which is used to rotate a steam turbine and drive an electrical generator. In power systems, frequency stability is a critical aspect in maintaining operational reliability and power quality delivered to consumers. The power system frequency in Indonesia is regulated at a nominal value of 50 Hz, and any deviation from this value may affect efficiency and equipment safety.[1]

Load changes in the electrical network can cause an imbalance between the mechanical power produced by the turbine and the electrical power demanded by the load. When the load suddenly increases, turbine speed decreases, resulting in a reduction in system frequency. Conversely, a load decrease will increase turbine speed and raise frequency. To address this condition, PLTUs are equipped with an automatic control system called a governor, which regulates steam flow into the turbine to maintain stable turbine rotational speed against load changes. The governor system operates in real time to maintain power balance within the generating system.[2]

One important parameter in the governor system is speed droop, which characterizes the allowable decrease in turbine speed when load increases. Speed droop functions as a sensitivity controller for the governor in responding to load changes [3]. With proper droop settings, the system can maintain stable frequency without oscillations or slow response. If the droop value is too small, the system becomes overly sensitive and unstable; conversely, if the droop value is too large, the system becomes less responsive and results in significant frequency deviation.[4]

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Based on this background, this study aims to analyze the performance of the speed droop governor control system in maintaining frequency stability at the Nagan Raya PLTU. Through a simulation approach using MATLAB/Simulink, this study observes frequency response to load variations and determines the optimal speed droop value to maintain system stability. The results are expected to contribute to improving efficiency and operational stability and serve as a technical reference for control system management in other steam power plants in Indonesia.

Literature Review 2.1 Steam Power Plant (PLTU)

A Steam Power Plant (PLTU) is a type of power plant that utilizes thermal energy from fuel combustion (commonly coal, gas, or oil) to produce high-pressure steam. This steam is used to rotate a turbine directly connected to a generator, thereby producing electrical energy. In general, the PLTU process consists of four main stages: fuel combustion (boiler), steam expansion (steam turbine), condensation (condenser), and water recirculation (feedwater pump).[3]

PLTU performance is strongly influenced by turbine rotational stability, which is directly related to system frequency stability. Since the system frequency in Indonesia is 50 Hz, the governor must be able to adjust steam supply to the turbine so that generator speed remains constant despite load changes.[5]

$$P_m - P_e = 2H \frac{df}{dt} \quad \ldots\ldots (1)$$

with:

P_m = turbine mechaniical powel (MW)

P_e = electrical output power

(MW) H = system inertia

constant $\frac{df}{dt}$ = rate of frequency change

This equation shows that frequency change is directly proportional to the imbalance between turbine mechanical power and electrical output power. Therefore, the governor system plays a critical role in maintaining power balance to keep system frequency stable.

2.2 Frequency Stability of Power System

Frequency stability in power systems is an important parameter reflecting the balance between mechanical power generated by the turbine-generator (Pm) and electrical power consumed by the load (Pe) [6]. When an imbalance occurs, such as sudden load increase or decrease, system frequency deviates from its nominal value (50 Hz in Indonesia) [7]. Excessive frequency deviation can disrupt electrical equipment performance, reduce plant efficiency, and even cause system blackouts. The dynamics of system frequency changes can be explained using the swing equation shown in Equation.[8]

$$2H \cdot \frac{d\Delta\omega}{dt} = \Delta P_m - \Delta P_e - D \cdot \Delta\omega \quad \ldots\ldots (2)$$

with:

H = generator inertia constant (MJ/MVA)

$\Delta\omega$ = angular speed deviation (rad/s) proportional to frequency deviation

ΔP_m = turbine mechanical power change (pu)

ΔP_e = electrical power change (pu)

D = damping constant (pu)

From this equation, it can be understood that frequency stability is determined by system inertia (H), the governor control system that adjusts mechanical power supply, and damping (D) that reduces frequency oscillations. Higher inertia and better governor control enable faster suppression of frequency deviations, thus maintaining system stability.

2.3 Governor Control System

The governor control system is one of the most critical components in PLTU operation, as it maintains constant turbine rotational speed despite load changes in the power system. The governor operates based on feedback control principles, where turbine speed changes due to load fluctuations are detected by sensors, generating correction signals to adjust steam flow into the turbine. This ensures generator output frequency remains at its nominal value (50 Hz in Indonesia)[9]

When load increases suddenly, electrical power demand exceeds turbine mechanical power, causing turbine speed and system frequency to decrease. The governor responds by opening the steam valve to increase steam supply and mechanical power until speed returns to normal. Conversely, when load decreases, the governor gradually closes the steam valve to prevent excessive frequency increase. In general, the governor system can be modeled as a first-order control system with the transfer function shown in Equation.[10]

$$G_g(s) = \frac{K_g}{T_g s + 1} \quad \ldots\ldots (3)$$

Where K is the governor gain and T is the governor time constant. This model indicates that governor response has a certain time delay before reaching steady-state conditions.

2.4 Speed Drop Governor

Speed droop is a governor characteristic that indicates the reduction in turbine speed or generator frequency from no-load to full-load conditions. Without droop, the governor control system would continuously attempt to maintain constant frequency, preventing multiple generating units from sharing load proportionally..

In principle, the droop value is determined by governor sensitivity to load changes. Droop is expressed as a percentage (%) using Equation. [3]

$$R(\%) = \frac{f_{noload} - f_{fullload}}{f_{rated}} \times 100\% \ldots\ldots (4)$$

with:

f_{no_load} = no-load frequency (Hz) f_{full_load} = full-load frequency (Hz)

f_{rated} = nominal system frequency (50 Hz)

Typical droop values in power systems range from 2–5%. If the droop value is too small, the system becomes difficult to stabilize due to excessive sensitivity. Conversely, if the droop value is too large, frequency deviations become excessive. [11]

2.5 Governor Control System Simulation

Software-based simulations such as MATLAB/Simulink are widely used to analyze governor control system performance in maintaining frequency stability in power plants, including PLTUs. Through simulation, system response characteristics to load changes can be studied without conducting risky and costly field tests. Simulation models typically consist of governor, turbine, generator, and load blocks connected in a closed-loop system.[12]

Governor modeling is generally represented as a first-order transfer function as shown in Equation (2.3). The steam turbine can be modeled using the transfer function shown in Equation (5) .[13]

$$G_t(s) = \frac{1}{T_t s + 1} \quad \ldots\ldots (5)$$

where T_t is the turbine time constant .

Research Methodology

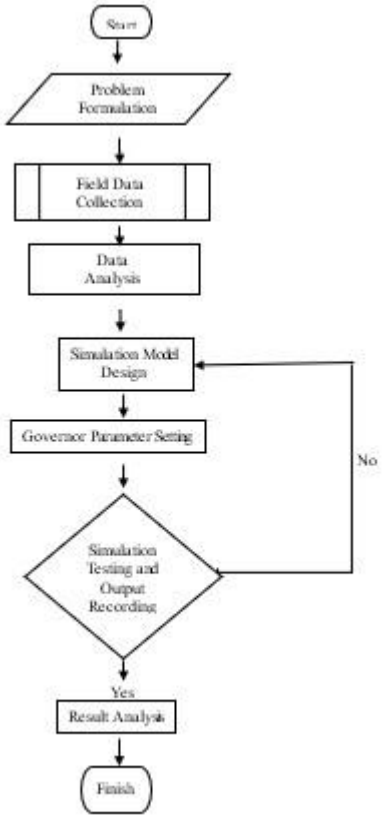

Figure 1. Research Flow Diagram

3.1 Type and Scope of Research

This research falls into the category of descriptive-analytical research with a quantitative approach.[14], [15] Descriptive research is used to describe the actual condition of the governor control system at the Nagan Raya Steam Power Plant (PLTU), particularly in maintaining frequency stability during load changes. The quantitative approach is applied through numerical data analysis such as system frequency, load variations, governor response rate, droop value, and turbine–generator parameters. In addition, this research utilizes a simulation-based method using MATLAB/Simulink to model the performance of the governor control system and to compare simulation results with actual field data.[16] he scope of this research is limited to the analysis of the governor control system used in the Nagan Raya PLTU generating unit, specifically related to the speed droop (droop control) mechanism in maintaining power system frequency stability. This study does not cover the entire PLTU control system but focuses on the relationship between load changes, governor response, and changes in generator output frequency. The main variables analyzed include droop value, turbine rotational speed changes, governor characteristics, and frequency stability under load disturbance conditions.[17]

This research is also limited to the main generating unit (boiler–turbine–generator) without analyzing supporting systems such as the feedwater system, pulverizer, or power plant protection systems. The data used include governor parameters, historical frequency data, and unit operational data over a certain period. MATLAB/Simulink simulation is conducted only on a single-area Load Frequency Control (LFC) model representing the characteristics of the Nagan Raya PLTU. With these limitations, this research is expected to provide a focused overview of the performance of the speed droop governor in controlling frequency stability in steam power plants.[18]

3.2 Data Collection Techniques

The data collection technique in this research is carried out using secondary data, namely operational data obtained from the Nagan Raya PLTU. These data are field data that have been

routinely recorded by operators through monitoring systems such as SCADA, frequency data loggers, and historian control systems. The data include important information regarding turbine–generator operating parameters, such as system frequency (Hz), active power output (MW), governor settings (droop, deadband, and gain), and steam valve position (governor valve position) during unit operation.[19]

Frequency data are used as the basis for analyzing power system stability, particularly in identifying frequency drops or fluctuations that require a response from the governor system. Meanwhile, governor setting data and valve response data are used to evaluate the characteristics of the speed droop governor, including how the governor regulates steam supply to the turbine in response to load changes.[20]

In addition, historical operational data such as disturbance events, daily load patterns, and logs of governor setting changes are also collected to analyze the performance of the governor control system under various operating conditions. All of these data serve as references in the modeling and simulation process using MATLAB/Simulink, enabling an accurate assessment of the governor's ability to maintain frequency stability at the Nagan Raya Steam Power Plant.

Result 4.1 Research Data

The research data in this study were obtained from the results of a Free Governor test conducted on one of the Steam Power Plant (PLTU) units operating in an interconnected system. This test was carried out to determine the response of the governor control system, particularly the speed droop characteristics, in maintaining frequency stability when system frequency deviations occur. All data used in this research are actual field measurement data collected while the unit was operating at a power setpoint of 70 MW with a governor configuration that had been set by the operator, as shown in Table 1 below. **Tabel 1.** Test Setting Data

Parameter	**Value**
Power Setpoint	70 MW
Governor droop (R)	5 %
Deadband (before adjustment)	0,033 Hz
Deadband (after resetting)	0,05 Hz
Upper limit (before adjustment)	+8,8 MW
Lower limit (before adjustment)	−8,8 MW
Upper limit (before adjustment)	+4,0 MW
Lower limit (before adjustment)	−4,0 MW

The basic governor parameters tested include a droop value of 5%, a deadband of 0.033 Hz (before adjustment), and a maximum power change operating limit of ±8.8 MW. These initial data indicate how the governor naturally responds to frequency changes prior to the resetting process. After the readjustment (reset) process, the governor parameters were updated, including widening the deadband to 0.05 Hz and narrowing the power increase–decrease limits to ±4.0 MW. These changes were intended to make the governor response more stable and less aggressive to small-scale frequency variations, considering that the PLTU unit operates in a parallel system that is sensitive to power overshoot.

The speed droop value is determined from the linear relationship between changes in system frequency (Δf) and changes in turbine power output (ΔP). Based on the test results, the PLTU exhibits a droop of approximately 5%, which indicates that a 5% change in frequency will result in a 100% change in power output relative to a certain load capacity. Table 2 presents the frequency changes based on turbine rotational speed.

Tabel 2. Frequency Changes Based on Turbine Rotational Speed

Frequency (Hz)	Δf (Hz)	Power Change ΔP (MW)	Droop (%)
49.85	−0.15	+4.0	5.0
49.90	−0.10	+2.0	5.0
50.00	0	0	5.0
50.10	+0.10	−2.0	5.0
50.15	+0.15	−4.0	5.0

The second variable, namely turbine rotational speed, is converted from frequency changes, where the nominal frequency of 50 Hz corresponds to a synchronous speed of 3000 RPM for a 2-pole generator. The data show that when a −2% load disturbance occurs, the frequency decreases to 49.85 Hz, causing the turbine speed to decrease to 2991 RPM. Conversely, when the load suddenly decreases, the frequency increases to 50.15 Hz, resulting in an increase in turbine speed to 3009 RPM, as presented in Table 3 below.

Tabel 3. Turbine Speed Changes

Frequency (Hz)	RPM	RPM Change (ΔRPM)
49.85	2991	−9
49.90	2994	−6
50.00	3000	0
50.10	3006	+6
50.15	3009	+9

The third variable, namely governor characteristics, is analyzed through the governor response to the frequency error signal (Δf). The data indicate that before resetting, the governor responds too aggressively, with power changes of ±8.8 MW for disturbances of ±0.28 Hz. After resetting, the response characteristics become more stable, with power change limits of only ±4 MW, as shown in Table 4 below.

Tabel 4. Governor Response Characteristics

Δf (Hz)	Power Change (MW)	Description
Before Resetting		
−0.28	+8.8	Aggressive response
−0.10	+2.2	Unstable
+0.10	−2.2	Overshoot
+0.28	−8.8	Too rapid decrease
After Resetting		
−0.15	+4.0	Stable
−0.10	+2.0	Proportional
+0.10	−2.0	Smooth
+0.15	−4.0	No overshoot

The fourth variable, namely frequency stability, shows how the system returns to nominal conditions after a disturbance. In the tests, the frequency recovery time before resetting was 5–7 seconds, while after resetting it decreased to 3–4 seconds, indicating that the governor system operates more stably and in a more controlled manner, as shown in Table 5 below.

Tabel 5. Frequency Stability Data

Condition	Disturbance Frequency (Hz)	Recovery Time (seconds)	System Condition
Before Reset	49.72	6–7	Unstable
Before Reset	50.28	5–6	Overshoot
After Reset	49.85	3–4	Stable
After Reset	50.15	3–4	Controlled

4.2 Data Analysis

The simulation was carried out using the Three-Phase Synchronous Machine Control model in MATLAB/Simulink, which consists of a governor, prime mover, round-rotor synchronous generator, AVR-exciter, and a machine inertia block. In addition, three threephase load blocks equipped with step-on and step-off functions were used to simulate positive and negative load disturbances.

This model operates based on the speed-droop control principle, which is a control mechanism that adjusts turbine mechanical power proportionally to rotor speed deviation (Δω) or frequency deviation (Δf). The system was then analyzed to observe how the governor maintains frequency stability following load disturbances. The main parameters observed include output frequency, mechanical power changes (ΔP), rotor rotational speed (RPM), and the system droop value.

This simulation was designed to closely represent the actual characteristics of the PLTU, particularly the Nagan Raya PLTU, so that the analysis results could be compared with field data from the Free Governor test. The simulation circuit is shown in Figure 2 below.

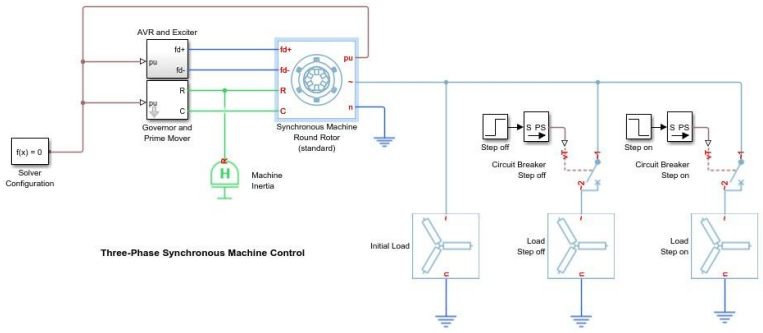

Figure 2. MATLAB Simulation Circuit

Under initial conditions, the generator operates in a steady-state condition at 50 Hz with an output power of 70 MW. When the load is increased by +5 MW, the system frequency decreases to 49.86 Hz (Δf = −0.14 Hz). The governor responds to this frequency drop by increasing the turbine mechanical power by +4 MW, causing the frequency to gradually rise and return to a stable condition within 3.5 seconds.

Conversely, when the load is released (−5 MW), the frequency increases to 50.13 Hz, and the governor reduces the mechanical power by −4 MW. The system then returns to a steadystate condition after approximately 3.1 seconds. The results of the frequency response simulation are presented in Table 6 below.

Tabel 6. Frequency Response Simulation Results

Condition	Minimum/Maximum Frequency (Hz)	Δf (Hz)	Power Change ΔP (MW)	Recovery Time (seconds)
Step Load On (+5 MW)	49.86	−0.14	+4.0	3.5
Step Load Off (−5 MW)	50.13	+0.13	−4.0	3.1

To understand the performance of the governor control system in responding to load changes at the PLTU, an analysis of the generator rotor speed dynamics is required. Therefore, a simulation using MATLAB/Simulink was conducted to obtain the pu_velocity graph, which illustrates changes in rotor speed in per-unit values over time. This graph serves as a primary indicator in evaluating frequency stability, as any speed deviation is directly proportional to changes in system frequency. The pu_velocity graph results are shown in Figure 3 belot.

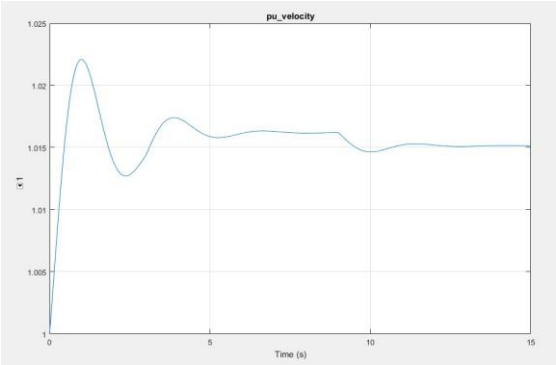

Figure 3. pu_velocity Graph

The pu_velocity graph illustrates the dynamics of the generator rotor speed in per-unit (pu) values over a 15-second period after a load disturbance is applied. A value of 1 pu on the vertical axis represents the nominal rotor speed (3000 RPM for a 2-pole generator at 50 Hz). From the graph, it can be observed that during seconds 0–1, the rotor speed experiences a surge reaching approximately 1.023 pu, which is equivalent to 51.15 Hz. This surge indicates the presence of an initial overshoot caused by the governor's immediate response to the load change error signal.

During seconds 2–3, the rotor speed decreases to approximately 1.013 pu (≈50.65 Hz), indicating the occurrence of an undershoot following governor correction. This pattern is a common characteristic of second-order control systems that exhibit turbine–governor dynamics and large machine inertia.

In the time interval of 3–10 seconds, the rotor speed exhibits damped oscillations with progressively decreasing amplitude. These oscillations indicate that the system has a sufficiently good damping ratio. The governor regulates the turbine valve proportionally, allowing the rotor's kinetic energy to be absorbed gradually.

After 10–15 seconds, the rotor reaches a stable condition at approximately 1.015 pu, equivalent to 50.75 Hz. This stabilization indicates that the governor system successfully corrects speed deviations and reaches a new steady-state value consistent with the load-setting droop characteristics. The steady-state condition not returning to 1.00 pu is normal in droop governor operation because the system operates in load-sharing mode rather than absolute frequency control.

Overall, this graph demonstrates that the governor model in the simulation has fast response characteristics, small overshoot, and good damping, enabling it to maintain rotor speed stability after disturbances.

The results of this study indicate that the speed droop–based governor system is capable of maintaining frequency stability during load variations. The governor responds proportionally to frequency changes in accordance with droop characteristics, so load changes do not cause significant disturbances in the power system. MATLAB simulation provides an accurate representation of generator dynamics, including governor sensitivity, power adjustment capacity, and frequency recovery time. The consistency between simulation results and field data indicates that a 5% droop setting provides optimal performance for parallel operation in an interconnected network.

Conclusions 5.1 Conclusions

Based on the results of this study conducted through a combination of field data from the Nagan Raya PLTU and MATLAB/Simulink simulations, the simulation results show a droop characteristic of 4.56%, which is very close to the field setting of 5%. This indicates that the developed simulation model accurately represents the actual operating conditions of the power generation system at the PLTU. The frequency response to load disturbances remains within standard operational tolerance limits, with a maximum deviation of ±0.14 Hz. The governor is able to restore the frequency to steady-state conditions within 3–4 seconds without causing hunting or undamped oscillations. The rotor speed (pu_velocity) graph exhibits a damped overshoot–undershoot pattern and reaches stability at a steady-state value of 1.015 pu, which is consistent with the operating principle of a droop governor. Overall, this study concludes that the speed droop governor setting at the Nagan Raya PLTU operates properly, stably, and in accordance with applicable standards. The system is capable of maintaining frequency within safe operating limits despite sudden load variations..

5.2 Recommendations

Based on the analysis and conclusions above, several recommendations can be proposed for system development. First, optimization of governor parameters: the PLTU should conduct periodic evaluations of governor parameters such as gain, droop value, and deadband to ensure the system remains in optimal condition, especially during large and fluctuating load changes. Second, simulation with more complex disturbances: future studies should simulate more extreme disturbance conditions, such as network faults, large load trips, or disturbances in the steam system, to further assess the governor’s capability in maintaining overall system stability.

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