Journal Of Economics, Technology And Business (JETBIS)
Volume 2, Number 7 July 2023
p-ISSN 2964-903X; e-ISSN 2962-9330

ANALYSIS OF IMPROVEMENTS TO THE AUTOMATIC GENERATION CONTROL (AGC) FREQUENCY REGULATION SYSTEM IN THE JAVA MADURA BALI SYSTEM FOR INTERMITTENT NEW AND RENEWABLE ENERGY (EBT) INTERCONNECTION

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KEYWORDS :
Auto Frequency Setting; AGC; Error Control Area; PID Control; Intermittent EBT.

ABSTRACT

This study aims to propose improvements to the AGC system by designing a new control design, namely the Proportional Integral Derivative, and adding Intermittent EBT factors in the simulation. The increasing penetration of Intermittent New and Renewable Energy will have the potential to disrupt system stability, especially system frequency settings. This is due to the unique characteristics, namely power intermittency, output variability, and reduction of inertia. The secondary frequency control system, Automatic Generator Control, which is installed on the Java-Madura-Bali electrical system requires a design development as a measure to mitigate the frequency response to the Intermittent EBT phenomenon. This research aims To propose improvements to the system AGC with a design control design new that is Proportional Integral Derivative and adds an Intermittent EBT factor in simulation. This results in an increase in AGC dynamic performance so that an increase in system response speed is obtained towards the nominal frequency which is of 9,257 seconds more fast and muffled undershoot of 0.72 Hz than using the control design existing. Increasing the dynamic performance of AGC is very important to get the energy management of the JAMALI Electrical system according to the operating criteria, namely reliability, quality, and economy.

INTRODUCTION

In the process of energy transition towards the utilization of clean energy sources, the encouragement of Intermittent EBT integration into Indonesia's modern electricity system cannot be avoided. This was triggered by several main factors including the abundant potential throughout the year (Kabir et al., 2018) , the government's target to utilize EBT is 23% in 2025 and 31% in 2050 (Tambunan et al., 2021) , support for government regulations through ministries, developments in PV technology around the world, until *grid parity begins to be reached* where the rupiah electricity price per kWh of PV will be the same as PLO's Basic Cost of Production (Breyer & Gerlach, 2013)

Increased Intermittent EBT penetration provides environmental benefits and energy security. However, on the other hand, it will pose challenges in the operation of the electric power system due to the inability of the generator to produce power continuously *(intermittent)*, variations in the output power of the generator at different time scales based on the energy source *(variability)*, and decreased system inertia due to the generator being connected to the network via a power electronics converter. Systems with an ever-increasing percentage of Intermittent EBT mix require more flexibility to balance frequencies across all timeframes. This condition will change the behavior of the electric power system so it needs to be properly mitigated by the load manager to avoid *blackouts*. (Mohammed Nour et al., 2022).

One of the reliability parameters in the power network is the stability of the system frequency. A comparison of the instantaneous balance between the power required by consumers and the power supplied by the power plant can be seen from the frequency. If the system has more power supply than needed, the frequency will increase/increase, whereas if the system has less power supply than demand, then the frequency will drop and require increased supply from other sources in the network. If the frequency drops further below a threshold, then emergency unloading action can be activated to prevent equipment damage and further outages.

Automatic Generation Control (AGC) is a secondary frequency setting control whose job is to manage the frequency balance by adjusting the variations in the rise and fall of the generator power output automatically so that the system frequency is stable at the nominal reference value. In general, fossil fuel generators are still the main provider of system frequency regulation. However, as the generation of Intermittent EBT increases, it is important to consider how these generators can contribute to the reliability of the power system. Several incidents such as blackout in the UK and in Australia (Operator, 2016) proves that conventional AGC has difficulties in dealing with random disturbances from Intermittent EBT. The main failure of the blackout was caused by the disconnection of the wind turbine network which resulted in a drastic decrease in frequency, while the AGC was unable to respond quickly so the frequency setting capacity was limited. As a result, the system is unable to maintain its stability and a blackout occurs. Therefore it is very important to increase the response speed and control performance of AGC in complex power grid systems (Li & Yu, 2020).

Several studies on AGC have been developed before, such as conventional AGC designs with integral controllers, PI controllers, and PID controllers. (Sahu et al., 2014); which is equipped with ramp rate constraints, dead band constraints, and network constraints (Rositawati & Mulyana, 2022), (Sahu et al., 2016), (Patel et al., 2019);single-areaarea systems or multi-area systems (Shaker et al., 2019), (Kumar et al., 2015); with energy sources from fossil, hydro, diesel and intermittent EBT generators such as wind energy sources, solar energy sources, and others (Mohammed Nour et al., 2022), (Sahu et al., 2016), (Ramesh et al., 2021).

The Java Madura Bali (Jamali) system is the largest electrical interconnection system in Indonesia with a peak load of 29,689 MW in 2023 and a total generating capacity of 43,244 *Mega Watt* (MW). Sources of supply for power plants come from various types of primary energy with the majority of fuel from coal. Currently, the Jamali electrical system uses a conventional AGC control design, namely *the Integrator Controller* with a control area burden single (Rositawati & Mulyana, 2022). As one of the systems projected for intermittent EBT interconnection, it is necessary to prepare an AGC frequency control system with a reliable design so that it can increase the response speed of generators that can accommodate intermittent EBT factors. Based on this, research was conducted to model AGC system with PID controller so that obtained performance response arrangement frequency ready secondary For face intermittent EBT penetration .

RESEARCH METHODS

Research Design

A studwas done with modeling the existing AGC system on the network power electricity Jamali and propose scheme arrangement new to consider Intermittent EBT factor with using PID controlleThe simulationtion scheme done on the Application Matlab Simulink R2023a use scenario change random loads and changes Intermittent EBT factor so Can analyto zed How design reliability against response frequency system . Flow design study Can seen in Figure 1.

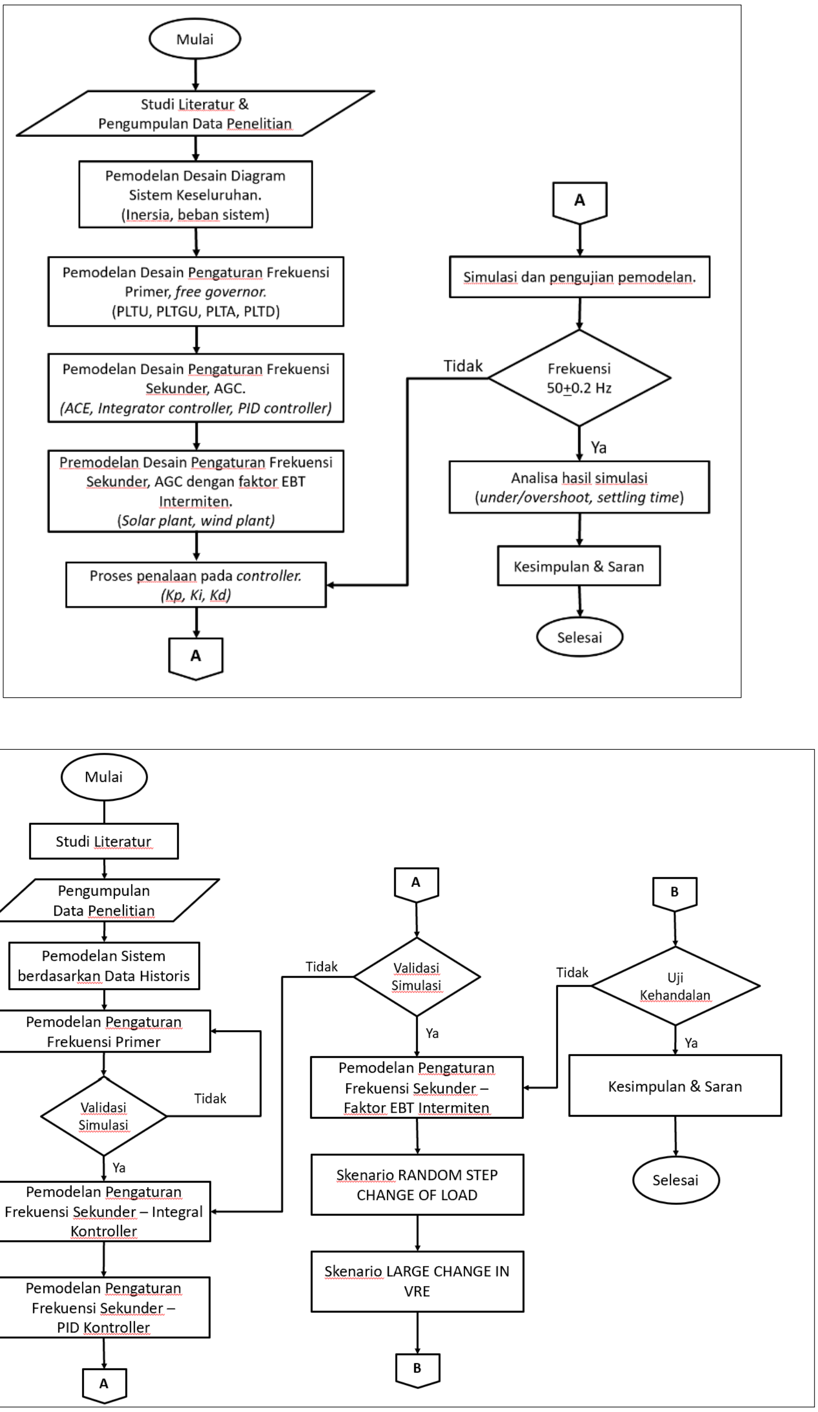

Figure 1

Flowchart Study

Stability Frequency System Electricity

Frequency is indicator quality in system power electricity . System frequency is generally not in a balanced condition, this is because the power requirements change continuously . Stability frequency defined as ability system For maintain frequency still stable moment after happen disturbance big yield _ imbalance between Power generation and load consumer . Imbalance the will produce acceleration and influence speed rotor angle so impact to frequency system .

Frequency will experience increase moment Power generation exceed amount burden . Conversely , frequency will decrease moment Power generation more A little compared to amount burden . Characteristics This described in the equation swing (*swing equation)* as follows:

$$\frac{2H}{\omega}\frac{df}{dt} = Pm - Pe\ (per\ unit) \qquad (1)$$

where H is constant inertia , f is frequency , t is time , $\omega$is the nominal angular velocity, Pm is the mechanical power generated, and Pe is the electrical load.

Based on Arrangement frequency can shared become a number of the stages illustrated in Figure 2 , namely :

a. Primary frequency setting (*free governor, FG*), namely the main setting of the generating unit *governor* , motor load, and other devices that provide direct response based on the local control system according to changes in system frequency. FG works on the order of 0 – 20 seconds. The main goal of *primary regulation* is to obtain a stable frequency.

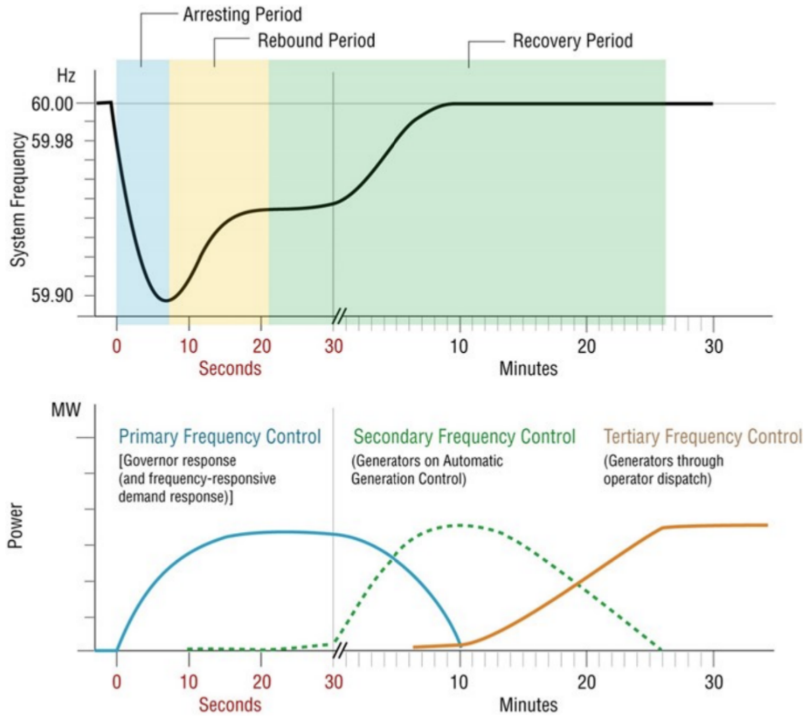

Figure 2
Illustration of Frequency Settings in Electric Power Systems

b. Secondary frequency regulation (automatic generation control, AGC), namely automatic regulation of the increase/decrease of the output power of the generating unit which corrects the imbalance so that the frequency remains at the nominal reference value. AGC works centrally from the center of load control on the order of seconds to minutes. Its main purpose is to return the working frequency to its nominal value.

c. Tertiary frequency settings, namely frequency settings that are carried out manually by the dispatcher, such as re-dispatch due to less than optimal generator response, economic dispatch , dispatch due to transfer factors, and so on. The purpose of tertiary regulation is to return the system's operation to a point the optimum .

According to (Tapada, 2022) about Rule Network System power electricity System Java - Madura-Bali mentioned that :

(1) Point CC 3.3 Generator Unit Rapid Reaction Governor That the generating unit must operate with a quick reaction governor provided that:
  - For thermal generation, the maximum deadband is +0.05 Hz, the maximum speed droop is 5%, the ramp rate is at least 3 MW/minute .
  - For hydro generators, the maximum deadband is +0.05 Hz, the maximum speed droop is 2%, the ramp rate is at least 20 MW/minute;

(2) Point OC 3.4 Generators that have Automatic Generation Control (AGC) That the total control range of the generator with AGC must be maintained at least 2.5% of the system load.

System controller

In something system control , there a number of type action controller among them action controller proportional (P), action integral controller (I), and action derivative controller (D). all three own characteristics of each. Action P has superiority fast rise *time* , action I have superiority For zoom out *error* , and action D has superiority reduce overshot/undershot (Sulaiman et al., 2016) . These three components complement each other, so that weaknesses in one component can be covered by other components.

The PID controller consists of three components, namely the Proportional component (P), the Integral component (I) and the Derivative component (D). Objective merger third type control the is For cover lacking and highlighting excess of each type control . The PID controller will issue a control action by comparing the error or error which is the difference between the process variable and the setpoint, which will be used as input for the controller to issue a control signal , so as a whole aims to speed up the reaction of a system, eliminate *offsets* and produce large initial changes.

The PID controller output is the sum of the proportional controller outputs, integral controller outputs. Arrangement constant Kp , Ti , and Td will resulted protrusion characteristic of each element . One or two of third constant the can arranged more stand out compared to the others. Prominent constant _ that's will give contribution influence on the overall system response. In general, the form of the PID controller equation can be expressed as in equation (2).

$$m(t) = K_p \left(e(t) + \frac{1}{T_i} \int e(t) \partial t + T_d \frac{\partial e(t)}{\partial t} \right) \qquad (2)$$

Where mv(t) = manipulated variable, Kp = reinforcement proportional , Ti = integral time, Td = time derivative and e(t) = error = setpoint – output. Figure 3 shows the relationship.

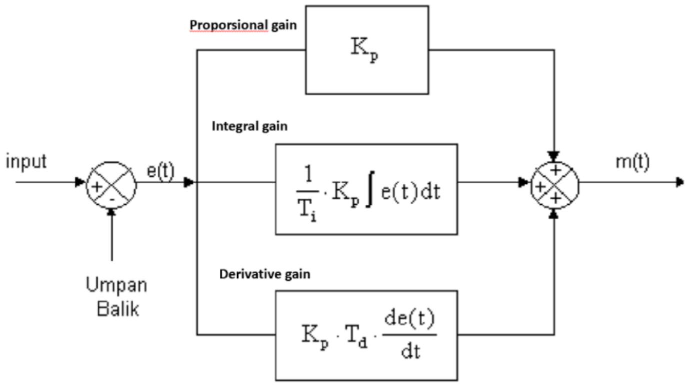

Figure 3
PID Controller Block Diagram

Modelling Control Power Plant

Electricity is generated of the conversion process primary energy (material burn) be Power next kinetic _ changed become Power generator mechanics _ power electricity . Energy mechanic that drives a synchronous generator got from round axis machine so- called mover turbine or mover start (*prime mover*).

The generator is driven from the rotation of two opposite torques, namely the mechanical torque *T* m from *the prime mover Pm* whose job is to increase the rotational speed, while the electric torque coupling *Te from* changes in the load *Pe* whose duty is to slow down the rotational speed. The rotational speed ω becomes constant when the magnitudes *T* m and *T* e are balanced. Changes in rotational speed will affect the frequency, so to achieve a *steady state frequency* , *Pm* and *Pe* must be the same. Therefore, the *governor* scheme necessary to adjust the frequency generated by the generator with the rotational speed of the turbine shaft through *valve position adjustment* so that the mechanical coupling of the turbine can be controlled (Pata & Manglili, Nd) . The working principle of the generator uses a closed system control cycle which can be illustrated in Figure 4 .

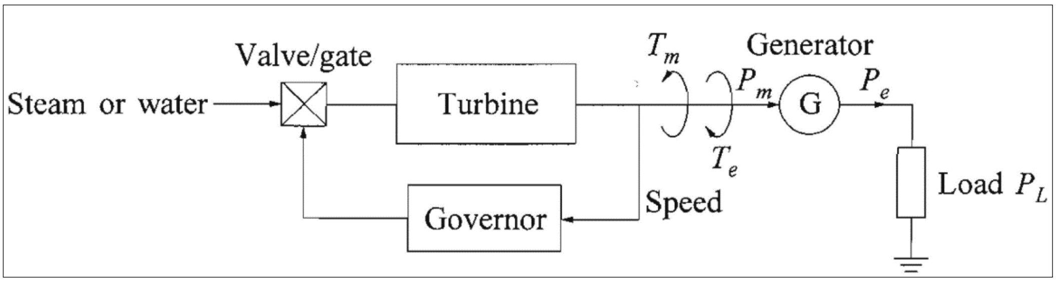

Figure 4
Arrangement Block Diagram governors.

When the electric load increases which causes *T* e > *T* m, the rotating system slows down, the governor speed becomes a feedback signal which determines the adjustment of valve position changes to add input to the turbine so that the rotating speed *T* m increases towards balance. The process is repeated according to changes in system load . The rotational speed ω becomes constant when the magnitudes *T* m and *T* e are balanced. When the electric load increases which causes *T* e > *T* m, the rotating system slows down, the governor speed becomes a feedback signal which determines the adjustment of valve position changes to add input to the turbine so that the rotating speed *T* m increases towards balance. The process is repeated according to changes in system load.

Nilai speed governor disebut juga dengan droop yang dirumuskan dalam persamaan (3) berikut:

$$R(\%) = \frac{Perubahan\ kecepatan\ atau\ frekuensi(\%)}{Perubahan\ daya\ output(\%)}\ x\ 100 \qquad (3)$$

Existence control *governor* on the generator system delivers reduction of torque rotation error. it in accordance with objective system control that is get constant actual signal The same with setting signal. The transfer function can illustrated in the block diagram Figure 5.

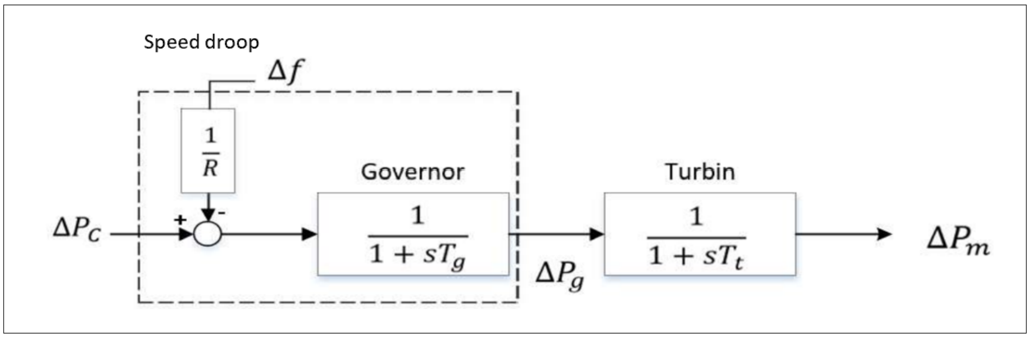

Figure 5
System Block Diagram Arrangement *governors*

Modelling AGC System

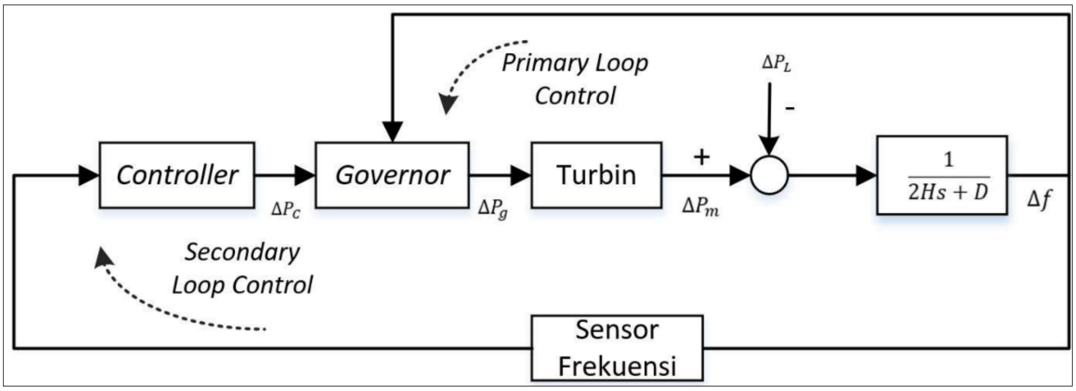

Figure 6
System Block Diagram Arrangement frequency

Besides primary settings, for make the *steady state* frequency at a value nominal frequency, is required A arrangement secondary that is *Automatic Generation Control* (AGC). AGC is an automatic regulation of the generating unit from the control center whose job is to adjust the variation of the power up/down of the generating unit in response to changes in frequency so that the System Frequency is stable at the system reference value of 50 Hz. AGC works centrally in the control center on the basis of detecting accumulated frequency deviations on the order of seconds to minutes.

Objective from AGC system is For restore frequency system to face value and ensure exchange Power between fixed tie - lines stable. The AGC system is at the center regulator load, every change the frequency caused by the change system load ($\Delta\ P$) will be become base Area Control Error (ACE) calculations for set up and down Power generation ($\Delta\ MW$) as compensation in return

frequency deviation (Δ f) to mark zero (Lackner et al., 2020) .
ACE in a one-area AGC system is written in equation (4).

$$ACE = \Delta Ptie + \beta \Delta f \qquad (4)$$

Where Δ $Ptie$ is the exchange power between areas (MW), β is the bias area frequency (MW/Hz) and Δ f is the system frequency deviation (Hz).

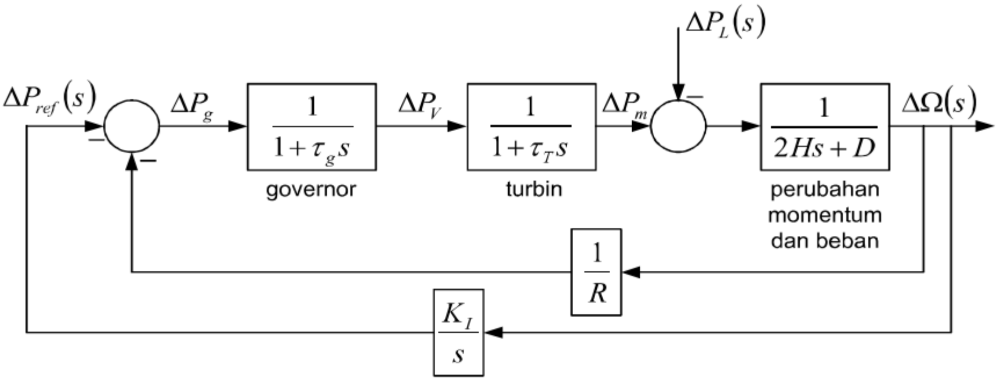

Figure 7
AGC Regulatory System Block Diagram

modelling System Control Generator

Modeling of generator control systems both conventional and Intermittent EBT can be modeled as follows :

a. Sistem Pembangkit *Hydro.*

$$\Delta Pm = \frac{1}{T_{gh}S+1} * \left(\frac{T_{rs}S+1}{T_{rh}S+1}\right) * \left(\frac{-T_W S+1}{0.5*T_W S+1}\right) * \left(\frac{-1}{R} * \Delta f - \Delta P_c\right) \qquad (5)$$

$Pm, T_{gh}, T_{rs}, T_{rh}, T_w, R, f, P_c,$

are generator mechanical power, time constant governor, hydro turbine reset time, hydro turbine transient droop time constant t, Starting time of water, speed droop, frequency and signal from secondary controller.

b. *Thermal* Generation System

Non-reheat Thermal

$$\Delta Pm = \frac{1}{T_g S+1} * \left(\frac{1}{T_t S+1}\right) * \left(\frac{-1}{R} * \Delta f - \Delta P_c\right) \qquad (6)$$

$Pm, T_g, T_t, f, R, P_c,$

are generator mechanical power, time constant governor, time constant turbine, frequency, speed droop and signal from the secondary controller.

Reheat Thermal

$$\Delta Pm = \frac{1}{T_g S+1} * \left(\frac{1}{T_t S+1}\right) * \left(\frac{K_r*T_r S+1}{T_r S+1}\right) * \left(\frac{-1}{R} * \Delta f - \Delta P_c\right) \qquad (7)$$

$Pm, T_g, T_t, K_r, T_r, f, R, P_c,$

are generator mechanical power, time constant governor, time constant turbine, reheater gain, time constant reheater, frequency, speed drop and signal from the secondary controller.

c. *Diesel* Generator System

$$\Delta Pm = \left(\frac{K_{di}*(S+1)}{\left(\frac{1}{40}\right)S^2+S}\right) * \left(\frac{-1}{R} * \Delta f - \Delta P_c\right) \qquad (8)$$

$Pm, K_{di}, f, R, P_c,$

are generator mechanical power, diesel gain, frequency, speed drop and signal from the secondary controller.

d. Generation System .

$$\Delta P_{WG} = \left(\frac{K_{WG}}{T_{WG}S+1}\right) * \Delta P_{Wind} \quad (9)$$

K_{WG} and T_{WG} is the gain wind generation and time constant. ΔP_{Wind} shows the change in power in the wind and ΔP_{WG} describes the change in the load on the wind generator.

e. Generation System

$$\Delta P_{PV} = \left(\frac{K_{PV}}{T_{PV}S+1}\right) * \Delta P_{Solar} \quad (10)$$

Kpv PV generation gain, Tpv time constant PV, delta-Psolar change in power for solar irradiance, delta Ppv change in power for PV generation.

RESULTS AND DISCUSSION

In this simulation, there are three models that are compared, namely the design of the primary frequency control control (*free governor*), the design of the secondary AGC control control with the Integral Controller. AGC secondary control design with PID controller, and AGC secondary control design with intermittent EBT factor.

The research uses data from the Jamali electrical system , the system operates with a load of 26,000 MW, a DMP of 35,000 MW, so an operating reserve of 9,000 MW, and *a base power* of 26,000 MW. The average of the system's refractive index is 1300 MW/Hz as *the base case* to get the *damping D calculation.* Data can be seen in Table 1 below:

Table 1
Power System Parameter Data

Power system parameters	Mark
Frequency, f (Hz)	50
Base Power (MVA)	26,000
System Load (MW)	26,000
Supply Power (MW)	35,000
System Bias, β (MW/Hz)	1,300
System Inertia, H (MW-s/MVA)	5
Droop System, R (%)	4

Table 2
Research Input Parameter Data Condition Existing

Power plate parameters	symbol	power plant	PLTGU	PLTA	PLTD
base power (MVA)		26000	26000	26000	26000
DMP (MW)		26000	6000	2500	500
Mixed energy (MWh)		20100	3750	1940	201

Speed Regulation (%)	R	5	3	2,4	4
Speed Regulation (pu)	R	0.05	0.13	0.2496	2.08
	1/R	20	7.9623	4.01	0.48077
Governor time constant (s)	Tg	0.08	0.3	2	
Turbine Time Constant (s)	Tt	0.4	0.36	-	
Turbine Hydraulic Time Constant (s)	Tw	-	-	4	
Reheater Gain	cr	0.5			
Reheater Time Constant(s)	tr	10			
Fuel Cost (Rp./kWh)		289	750	7	

Based on the table, the simulation uses the following assumptions:

(1)The system operates at a nominal frequency of 50 Hz.

(2)System is at in one single area with load data of 26,000 MW and power capable supply of 35,000 MW so backup operation of 9,000 MW. *Base power* 26,000 MVA.

(3)Generator unit parameter data consists of *thermal, hydro* and *diesel* with a mix of 77.73% PLTU, 14.42% PLTGU, 7.46% PLTA and 0.81% PLTD.

(4)The intermittent EBT factor uses PLTS penetration projection data on the Jamali electricity system until 2030 worth 12 MWp, 149 MWp, and 277 MWp in accumulation.

(5)Simulation response frequency system using the AGC *integrator* controller design (existing Jamali system) and AGC PID controller (proposal repair).

Simulation modelling Arrangement Primary Frequency , *free governor.*

The free governor simulation in this study uses 4 types of generators according to the modeling data and generator parameters of the Jamali System. The generator energy mix consists of 77.31% PLTU, 14.42% PLTGU, 7.46% PLTA, and 0.81% PLTD.

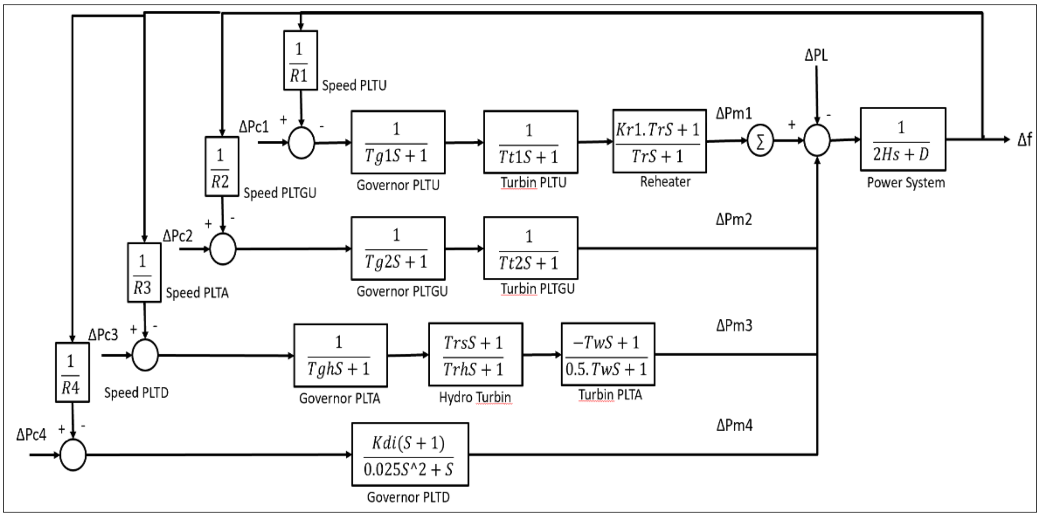

Figure 8
***Transfer Function* Arrangement Block Diagram Primary Frequency**

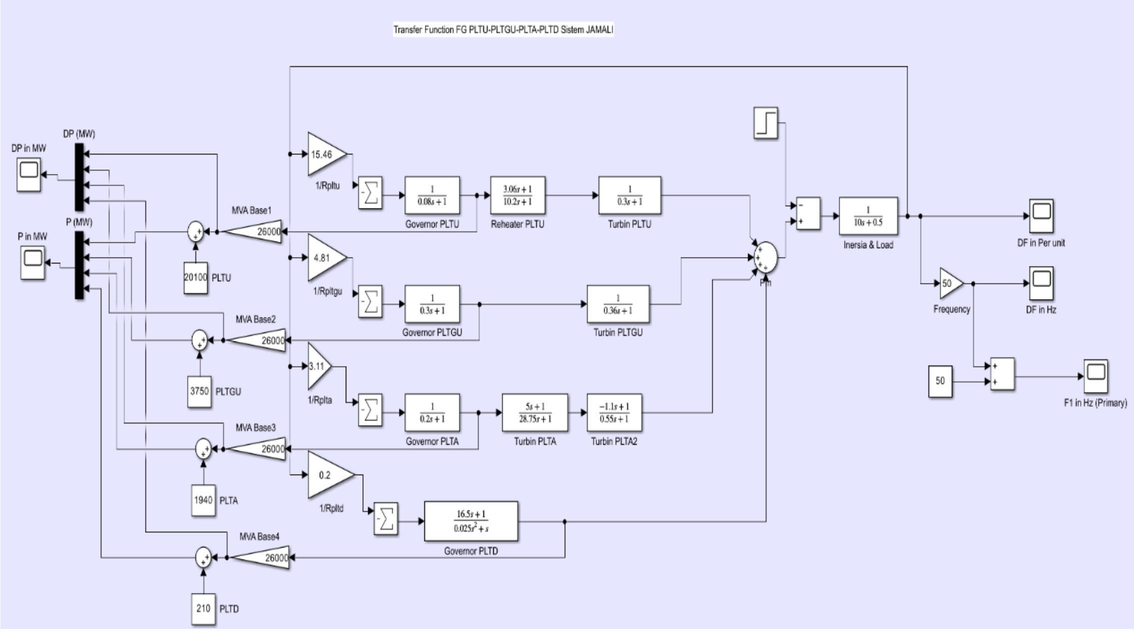

Figure 9
Free Governor **System Block Diagram on Matlab Simulink**

For a 20% change in ΔPD load, there will be a change in frequency Δf of:

$$\Delta = -\left[\frac{1}{\mathrm{D}+\left(\frac{1}{\mathrm{R1}}+\frac{1}{\mathrm{R2}}+\frac{1}{\mathrm{R3}}+\frac{1}{\mathrm{R4}}\right)}\right]\Delta PD\ pu\Delta f = -\left[\frac{1}{0.5+(15.46+4.81+3.11+0.20)}\right]x0.2$$

$$= -0.00831\,pu\Delta f = -0.00831\ x\ 50\ Hz = -0.41528\ Hz$$

The frequency for the *steady state* when there is a 20% load increase is:

$f = fo + \Delta f = 50 + (-0.41528) = 49.584\ Hz$

So according to calculations, the frequency of 49,584 Hz is the stable state value of the system when there is an increase in load of 20% or 5,200 MW .

The simulation results in Figure 10 show that the final *steady state frequency* is 49.63 Hz at 7.991 seconds. This is still in line with manual calculations.

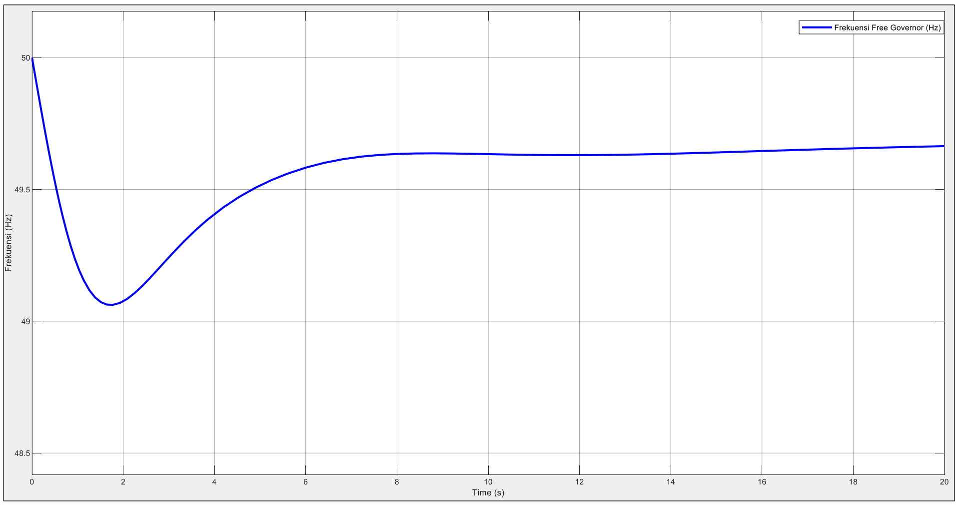

Figure 10
System *steady state* Frequency Response (ΔPd=20%)

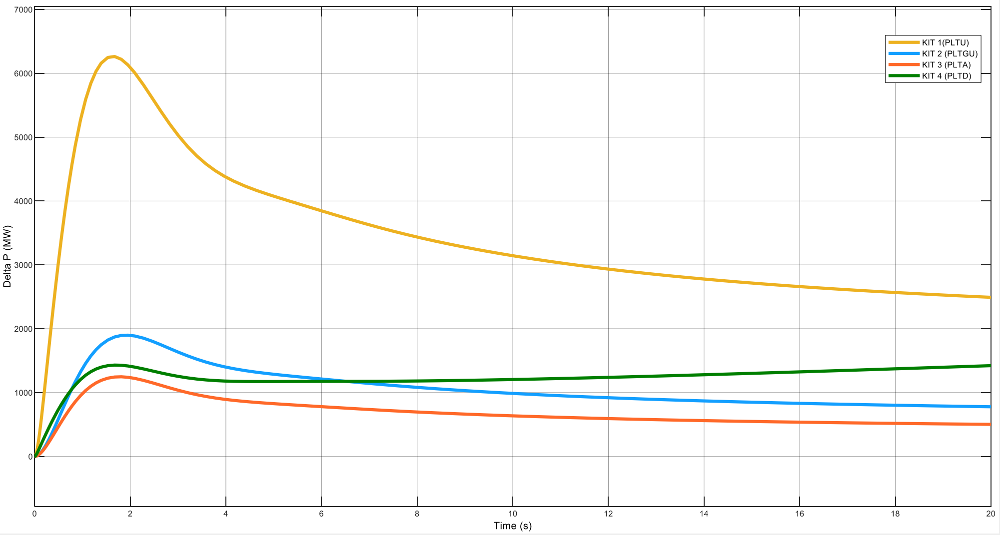

Figure 11
Change Loading Generation ΔP (MW)

The power of each simulated generating unit with an increase in load of 5200 MW (the total system becomes 31,200 MW) causes a change in the energy mix where the PLTU decreases. This is caused by the droop speed of the PLTU governor which is slower compared to the governors of other generators so that the PLTGU, PLTA, and PLTD generators respond more quickly to reach the system frequency balance point.

From the free governor simulation described above, it can be seen that the frequency is going to the equilibrium point but has not yet reached the nominal frequency point of 50 Hz, so there is a need for a secondary frequency control design control that makes the frequency return to the nominal value, namely the Automatic Generation Control system.

Simulation AGC modeling with Integral Controller.

To return the system frequency to the nominal value, it is not enough to just adjust the frequency with the free governor primary regulator, it requires an additional AGC secondary regulator. The control function is as feedback to the governor to improve response during transients and errors during steady state. The AGC system simulation uses an integrator control design according to the system operating in the Jamali System.

The AGC system design with *Integral* Controller is shown in the following Figure block:

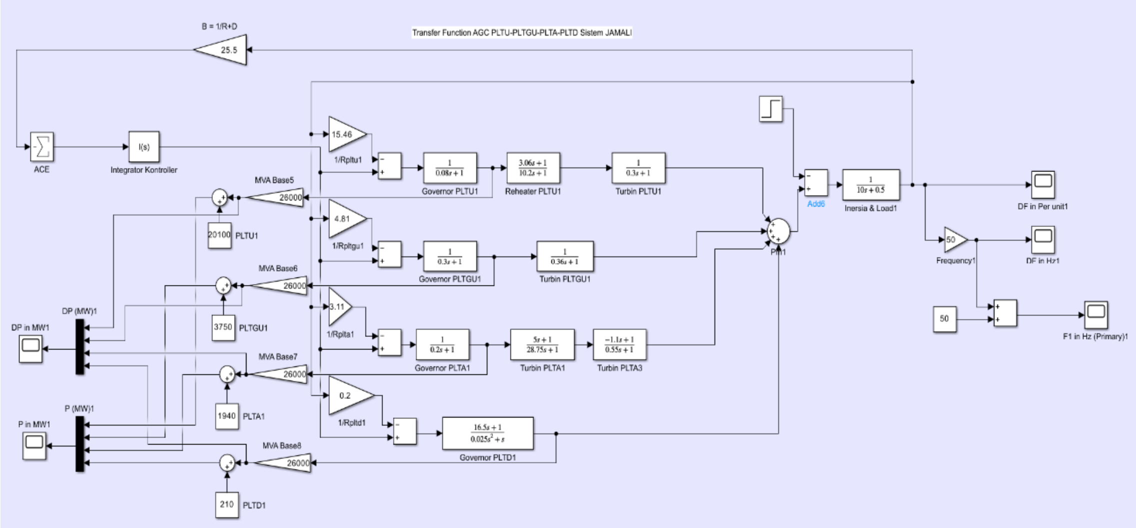

Figure 12
Integral Controller AGC System Block

The integral constant Ki is obtained randomly by taking the best simulation results, worth 0.0384. The following is a detailed table of the observed controller integral parameters:

Table 3
Integral Controller Parameters

Parameter, Ki	Rise Time, Tp	Overshoot	Settling Time, Ts	Error Steady State
0.0303	0.93 s	49.45 Hz	9.02 s	0.02 Hz
0.0384	**0.89 s**	**49.48 Hz**	**7.92 s**	**0 Hz**
0.0403	0.86 s	49.48 Hz	8.14 s	0 Hz

Figure 13 shows that the AGC system with Integral Controller succeeded in making the frequency steady state at the nominal frequency point of 50 Hz in 7.92 seconds. In Bye integral characteristics, namely action I have the advantage of minimizing the steady state error, but integral feedback tends to make the system experience overshoot spikes that lead to oscillations. Overshoot occurs up to 49.48 Hz with a rise time of 0.89 seconds.

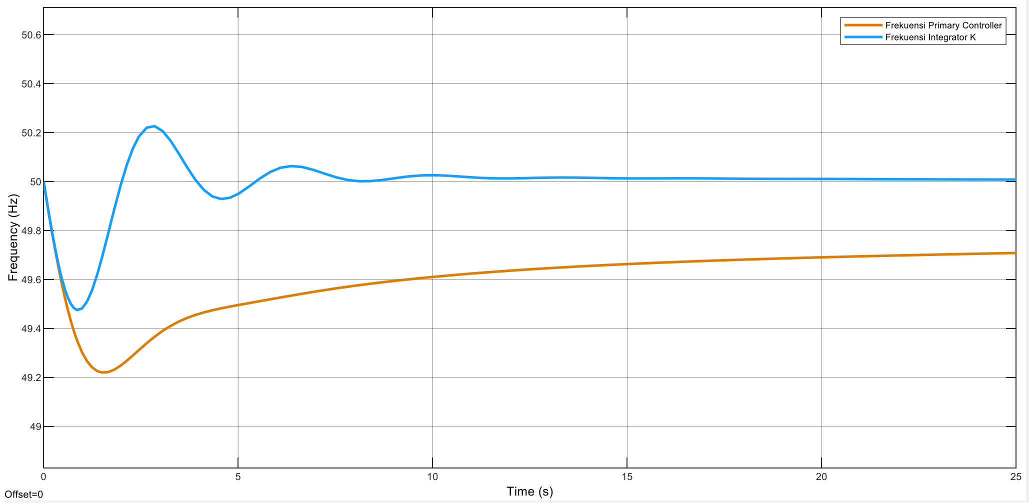

Figure 13
System *steady state* Frequency Response (AGC Integral Controller)

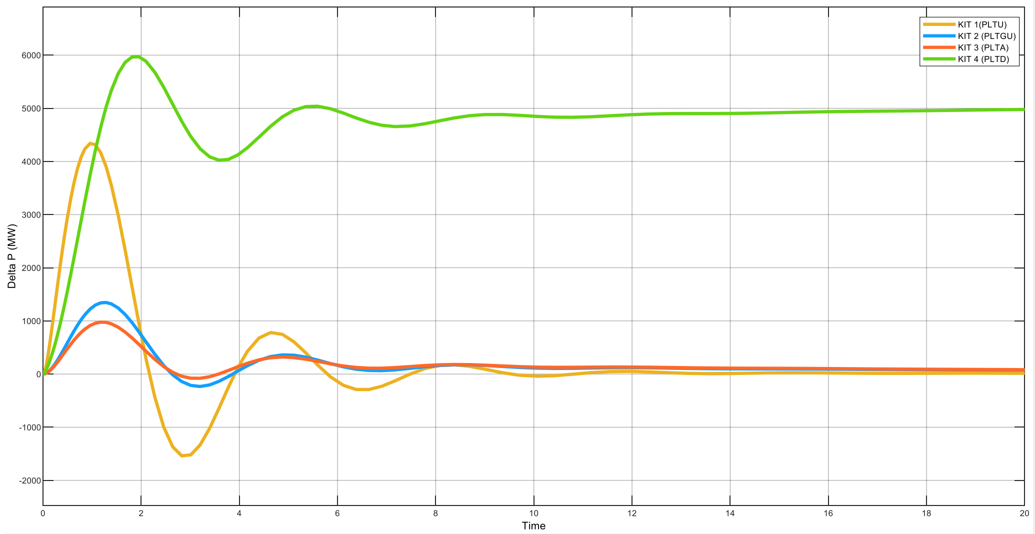

Figure 14
Change Loading Generation ΔP (MW)

Simulation AGC modeling with PID controller

To improve the performance of the existing AGC system which tends to oscillate in the process towards a *steady state, a new control design is proposed using a PID controller, so it is expected that the response from the frequency setting will be more optimal compared to the existing control.* The design of the AGC system with a PID controller is shown in block Figure 15.

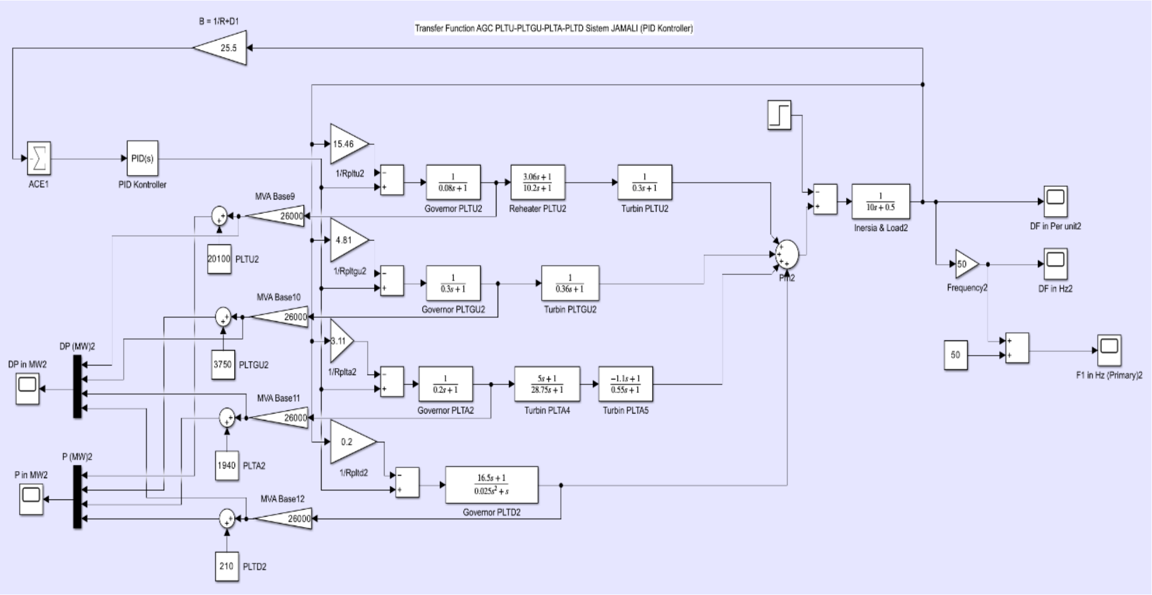

Figure 15
Blok Sistem AGC PID Kontroller

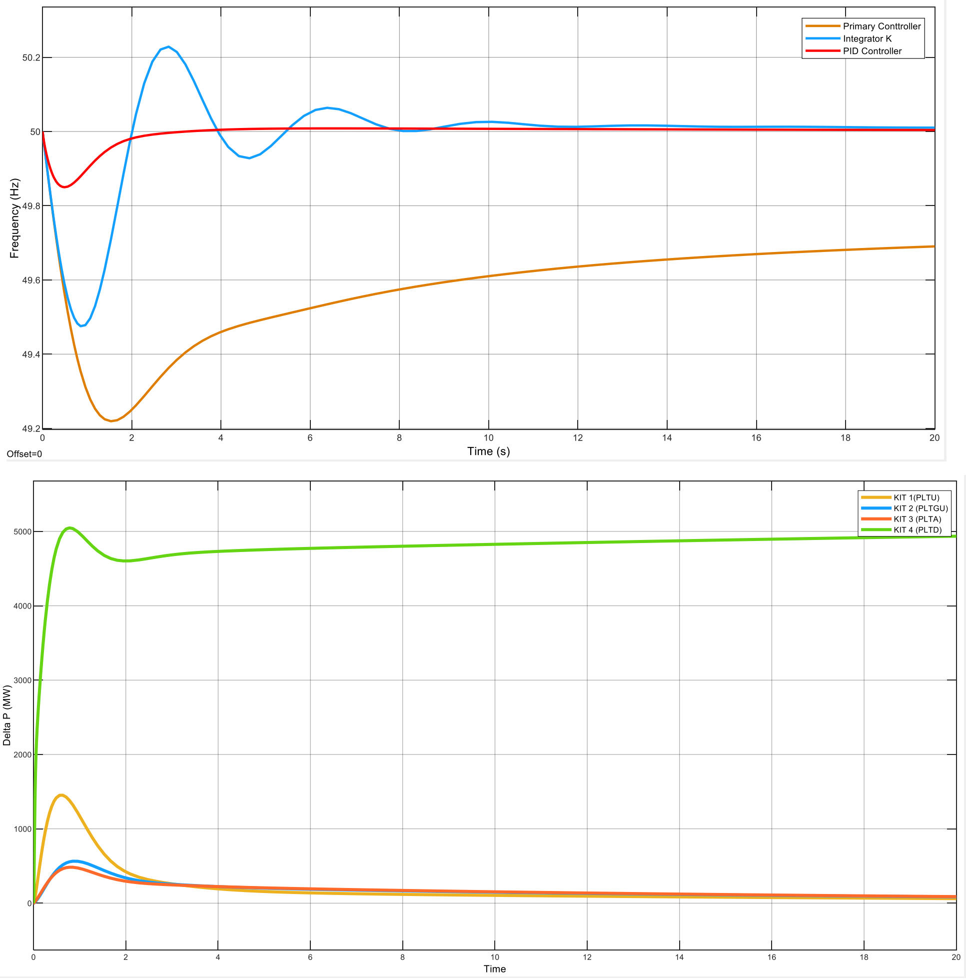

Figure 16

Frequency Response *steady-state* system (AGC PID Controller)

Figure 16 shows the system frequency response to load changes using the AGC PID controller system. That frequency response performance has increased very significantly. The problem of *overshoot spikes* which tend to oscillate is handled by derivative constraints, where its function is to dampen the spikes of the controlled variable and slow down the movement of the variable just before it reaches a *steady state point.* The system experienced *a steady state* in a relatively fast time of 3.406 seconds with a decreasing *overshoot from an error of* 0.52 Hz (with a point of 49.48 Hz) to *an error* of 0.15 Hz (with a point of 49.85 Hz).

Simulation Scenario Intermittent EBT Power Change

The intermittent NRE simulation is modeled by the inclusion of *a solar plant* in the Jamali system. The PV *array* is modeled using blocks using the parameters in Table 9 as shown in Figure 17 below:

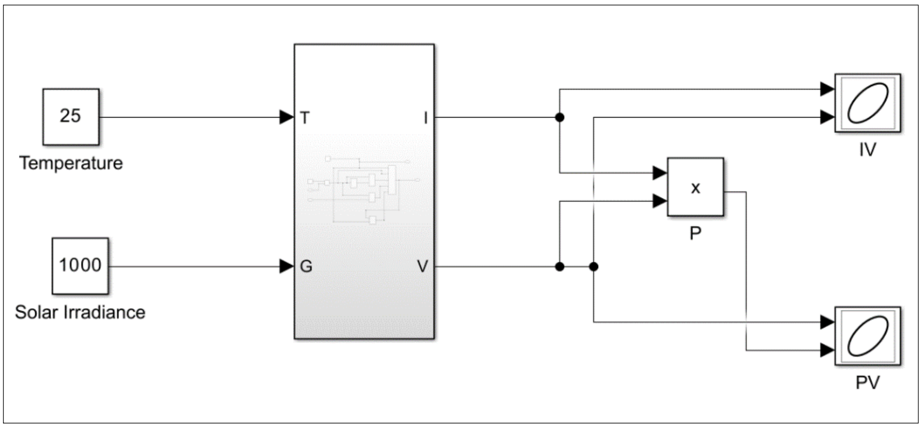

Figure 17
PV Array Models

Table 4
PV Array Parameters

Parameter	Deskripsi	Nilai
P	Rated Power	200 W
Voc	Open circuit voltage	32.9 V
Is	Short Circuit Current	8.21 A
Ns	Total Cells Series	54
Np	Total Cells Parallel	1
Vmax	Voltage Maximum point	26.4 V
Imax	Current Maximum point	7.58 A
Ki	Short circuit current pada STC	0.0032
Q	Electron Charge	1.6e-19
K	Boltzmann Constant	1.38e-23
N	Faktor ideal diode	1.3
Eg0	Band Gap Energy Semi-Conductor	1.1
Rs	Series Resistansi	0.221
Rsh	Paralel Resistansi	415.405
Tn	Nominal Temperatur	298

T	Operating Temperatur	25
G	Solar Irradiance	1000

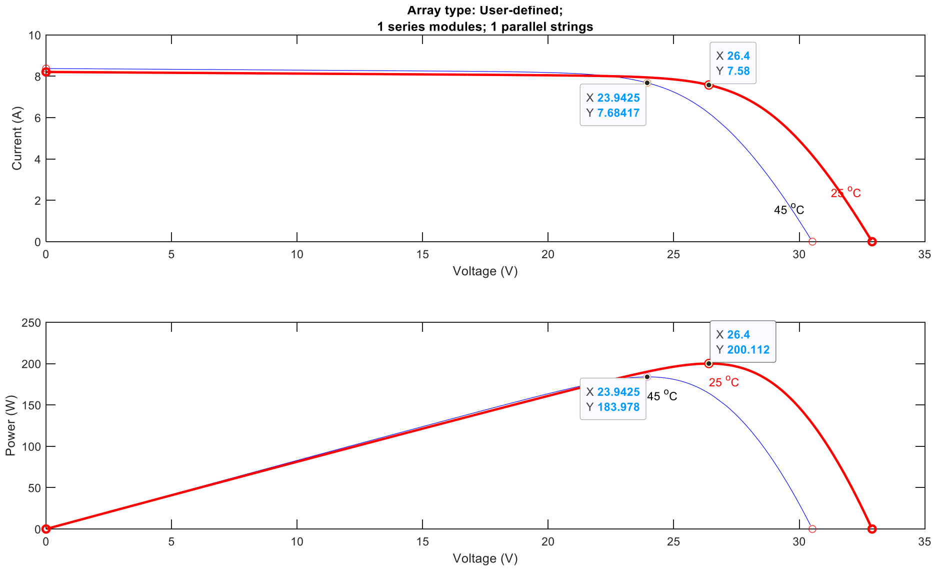

Figure 18

Characteristics of PV and IV on the PV Model (irradiance variation) At a temperature of 25 degrees and irradiance of 1000W/m2, *solar plant* own Power maximum by 200 W at the moment voltage 26.4 V and current 7.58 A. AGC system design with *solar plant* displayed in block Figure 32.

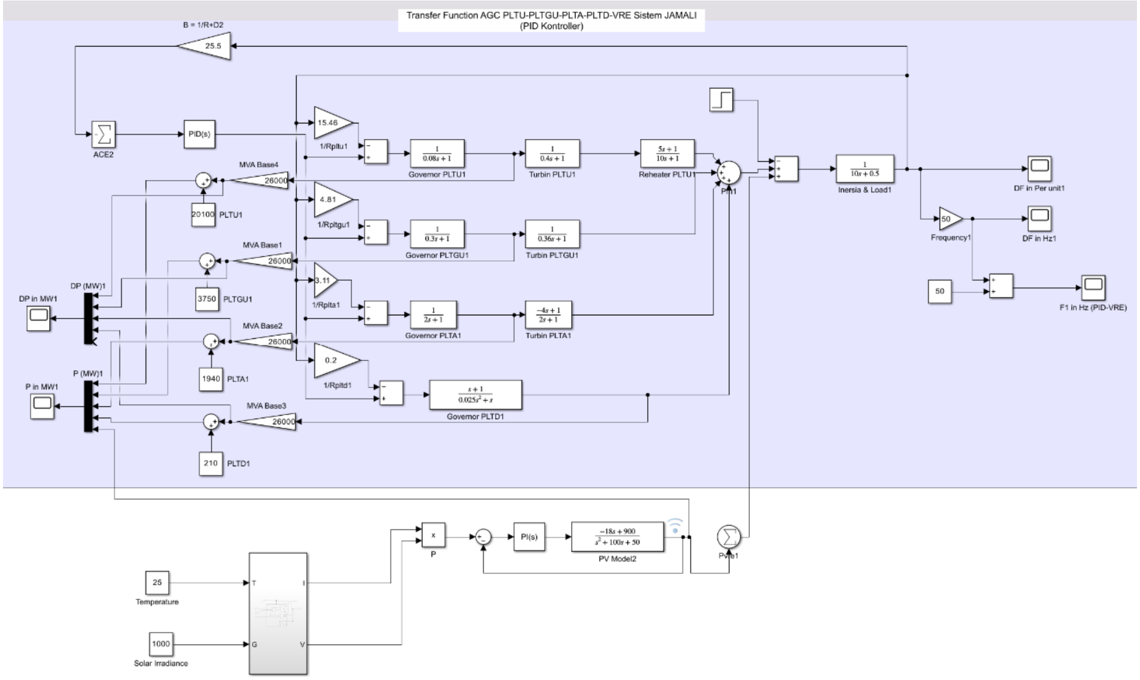

Figure 19
AGC system design with solar plant

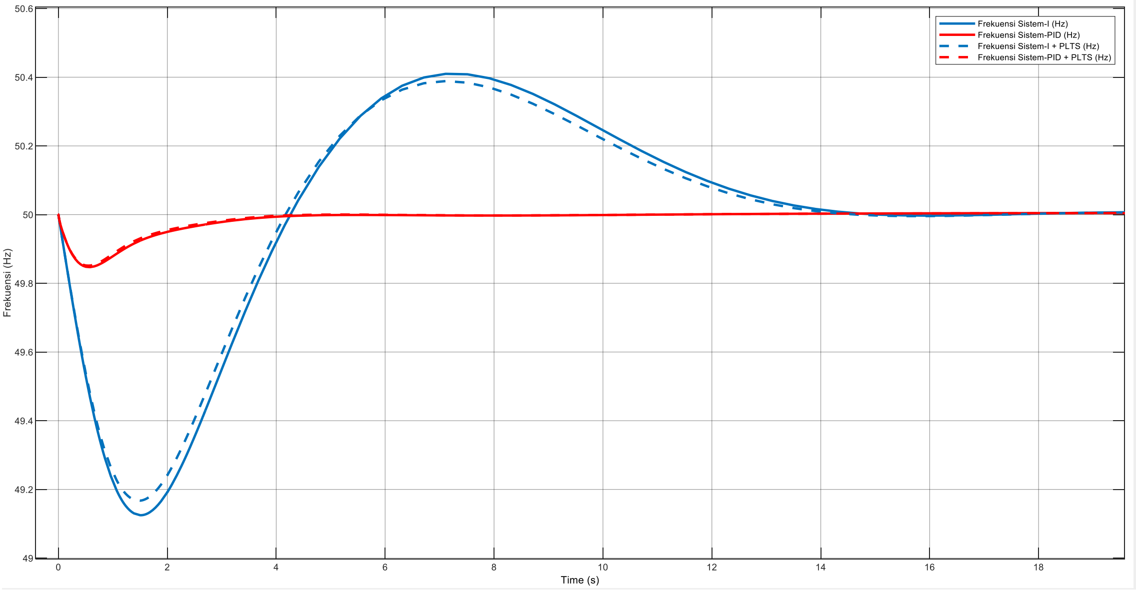

Figure 20
AGC System Frequency with Solar plant

Based on Figure 20, the simulation with *solar plant* penetration, when compared with the AGC Integral Controller control system, it can be seen that the PID controller produces a faster frequency *settling time response and* significantly reduces *undershoot/overshoot.* In addition, the impact of the entry of *the solar plant* into the system causes changes to the system frequency and the amount of composition of each conventional generator.

CONCLUSION

Based on the results of the analysis and discussion that has been carried out, it can be concluded that the frequency response performance analysis is getting better by using the proposed new control design PID controller (Kp 1, Ki 0.03, Kd 0.3, N 100) which provides a faster recovery response of 9,257 seconds than existing control. In addition, the new control design also eliminates *overshoot* and reduces *undershoot* by 0.719 Hz better than the existing control. To improve performance even better, you can use *artificial intelligent algorithms* and add *economic dispatch factors* so that optimal results are obtained.

Frequency response performance analysis with the inclusion of PLTS is accommodated by PLTD where the generator has the fastest ramp rate and characteristics, but economically it will increase BPP because diesel fuel costs are more expensive than other primary energy prices. Battery storage, PLTA pump storage, and flywheel can also be used as an alternative for adequate energy balance.

BIBLIOGRAPHY

Breyer, C., & Gerlach, A. (2013). Global Overview On Grid-Parity. *Progress In Photovoltaics: Research And Applications*, *21*(1), 121–136. Google Scholar

Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K.-H. (2018). Solar Energy: Potential And Prospects. *Renewable And Sustainable Energy Reviews*, *82*, 894–900. Google Scholar

Kumar, S., Nath, A., Kumar Singh, S., Das, P., & Bhattacharya, A. (2015). Automatic Generation Control For A Two-Area Power System Using A Backtracking Search Algorithm. *2015 International Conference On Energy, Power, And Environment: Towards Sustainable Growth (Icepe)*, 1–6. Google Scholar

Lackner, C., Osipov, D., Cui, H., & Chow, J. H. (2020). A Privacy-Preserving Distributed Wide-Area Automatic Generation Control Scheme. *Ieee Access*, *8*, 212699–212708. Google Scholar

Li, J., & Yu, T. (2020). Virtual Generation Alliance Automatic Generation Control Based On Deep Reinforcement Learning. *Ieee Access*, *8*, 182204–182217. Google Scholar

Mohammed Nour, M. A. M., Magdy, G., Chaves Ávila, J. P., Sánchez Miralles, A., & Petlenkov, E. (2022). *Automatic Generation Control Of A Future Multi-Source Power System Considering High Renewables Penetration And Electric Vehicles: Egyptian Power System In 2035*. Google Scholar

Operator, A. E. M. (2016). *Preliminary Report: Black System Event In South Australia On 28 September 2016*. Google Scholar

Pata, A. M., & Manglili, L. (N.D.). *Studi Pengendalian Frekuensi Pada Pembangkit Listrik Tenaga Air (Plta) Bili–Bili Sektor Bakaru Pt Pln (Persero) Wilayah Sulawesi Selatan, Tenggara, Dan Barat*. Google Scholar

Patel, R., Meegahapola, L., Wang, L., Yu, X., & Mcgrath, B. (2019). Automatic Generation Control Of Multi-Area Power Systems With Network Constraints And Communication Delays. *Journal Of Modern Power Systems And Clean Energy*, *8*(3), 454–463. Google Scholar

Ramesh, M., Yadav, A. K., & Pathak, P. K. (2021). An Extensive Review On Load Frequency Control Of Solar-Wind-Based Hybrid Renewable Energy Systems. *Energy Sources, Part A: Recovery, Utilization, And Environmental Effects*, 1–25. Google Scholar

Rositawati, S., & Mulyana, I. G. (2022). Dampak Variasi Beban Dan Keterbatasan Pembangkit Terhadap Kontrol Frekuensi Sistem Menggunakan Automatic Generation Control. *Sutet*, *12*(1), 1–11. Google Scholar

Sahu, R. K., Gorripotu, T. S., & Panda, S. (2016). Automatic Generation Control Of Multi-Area Power Systems With Diverse Energy Sources Using Teaching Learning-Based Optimization Algorithm. *Engineering Science And Technology, An International Journal*, *19*(1), 113–134. Google Scholar

Sahu, R. K., Panda, S., & Yegireddy, N. K. (2014). A Novel Hybrid Deps Optimized Fuzzy Pi/Pid Controller For Load Frequency Control Of Multi-Area Interconnected Power Systems. *Journal Of Process Control*, *24*(10), 1596–1608. Google Scholar

Shaker, H. K., El Zoghby, H., Bahgat, M. E., & Abdel-Ghany, A. M. (2019). Advanced Control Techniques For An Interconnected Multi-Area Power System For Load Frequency Control. *2019 21st International Middle East Power Systems Conference (Mepcon)*, 710–715. Google Scholar

Sulaiman, M., Zulfatman, Z., & Hakim, E. A. (2016). *Modul Sistem Pengaturan Kecepatan Motor Dc Secara Real-Time Berbasis Labview*. Google Scholar

Tambunan, H. B., Surya, A. S., Jintaka, D. R., Harsono, B. B. S., Sinaga, D. H., Sidik, A., & Pramurti, A. R. (2021). Review Proses Perencanaan Jangka Panjang Sistem Tenaga Listrik. *Epic (Journal Of Electrical Power, Instrumentation And Control)*, *4*(1). Google Scholar

Tapada, R. (2022). Akibat Hukum Penerapan Undang-Undang Nomor 3 Tahun 2020 Tentang Perubahan Atas Undang-Undang Nomor 4 Tahun 2009 Tentang Pertambangan Mineral Dan Batubara Terhadap Peningkatan Nilai Tambah Pertambangan. *Lex Privatum*, *10*(4). Google Scholar