

# Noise Tolerable PID Controller for Load Frequency Control (LFC) in Multi Area Power Plant

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**Abstract**—Noise Tolerable PID Controller had been introduced in previous work and notice that it can improve the system performance by reducing the fluctuation on derivative control action of PID controller on Load Frequency Controller (LFC). However, this proposed method was applied to single power plant and located on primary control loop. This scheme was not suitable with the real condition, which it has some interconnections between multi area power plant and LFC was configured on secondary loop that should minimize the fluctuation of the frequency of the grid. In this study, a new configuration of Noise Tolerable PID Controller was proposed to be able to implement on the Multi Area Power Plant and also located on secondary control loop. By adding low pass filter (LPF) and averaged on derivative action of PID controller, two steam power plants were selected to simulate and evaluate the performance of system after applying LFC. The better performance was obtained from the system with averaged derivative PID controller. After simulated, the frequency drop from this controller was the smallest one.

**Keywords**—LFC, Noise Tolerable PID Controller, PID LPF, PID averaged derivative.

## I. INTRODUCTION

MULTI area power plant, that contains many unit and power generation types, was successfully interconnected each other to handle the load demand. For example in Indonesia, especially in Java and Bali island, there are many of such types of power plant, such as steam or natural gas combined with steam (cogeneration), diesel, hydro power plant, etc. All of them was interconnected to supply load demand for both islands that managed by national company called PT. Pembangkit Jawa Bali (PJB). Each generated power of each power plant also varies depends on its power source that caused more complexity of interconnection challenges.

One of advanced and important challenges was occurred on Load Frequency Control (LFC) which was designed to perform balancing mechanism between supply and load demand power. Unbalance between supply and load causes changing of the system frequency [1]. While load increase, the generator speed will decrease and also the frequency. The load changing characteristic was well known as quite noisy environment. This characteristic occurred because the numerous on/off switching in the load side produces frequency noise tremendously. LFC

generally regarded as a part of Automatic Generation Control (AGC), which is located on secondary control loop [3]. The secondary control regulates frequency to its nominal value and maintains the power interchange among areas by adjusting the output of selected generators.

Many works have been contributed to address the LFC problems. The basic design rule of advanced LFC was introduced by Glover [4]. The PID controller method was also developed to obtain desired system response specification [5, 6]. According to the noisy characteristic of frequency, noise tolerable PID controller was developed by adopting filtering technique [7]. A low pass filter was combined with derivative gain to reduce the noise and compared with modify to averaged derivative. This scheme seemed plausible and was proven to reduce noise effect on derivative action. However, the PID feedback control was added to primary control loop which was totally different from the loop position of LFC on AGC system. Furthermore, the system was tested on a single power plant.

Building up on previous work, this study proposes a new configuration of noise tolerable PID controller that is applied on the secondary loop of AGC system. The controller is then tested using two steam power plant models that represent multi-area power plant. The steam power plant model was presented in Section 2. The new proposed configuration and analytical design of noise tolerable PID controller was explained in Section 3. The system simulation test and comparison of the performance result was discussed in Section 4. Finally, the last section, take up the summary and conclusion of this study.

## II. STEAM POWER PLANT MODEL

Steam power plant consists of governing system, turbine – generator and load. Governing system is a system which maintains turbine speed. Flyball governor senses frequency deviation ( $\Delta F$ ) then it is multiplied with droop characteristic of the power plant. System was represented in closed loop scheme with negative feedback signal from actual load. This loop was designed to control turbine speed by calculating the steam turbine valve opening ( $\Delta Y$ ). Dynamic of governing system can be modeled by first order model with time constant representing the process has a typical value of 0.1s [1]. Transfer function of the governing system is shown in Equation 1.

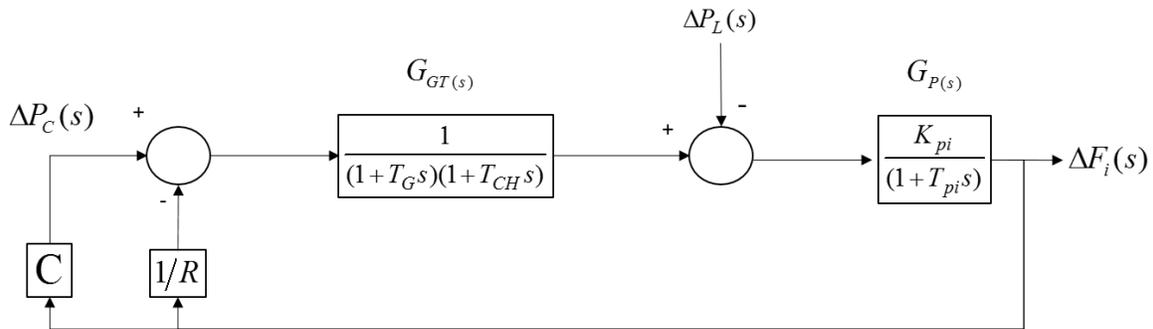


Figure 1 Closed loop steam power plant block diagram

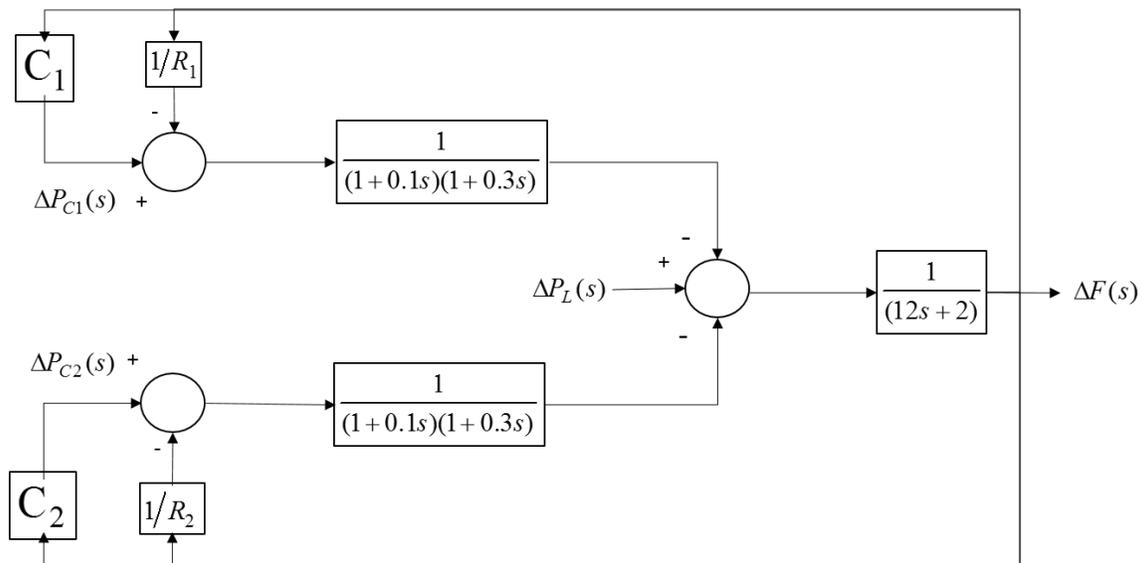


Figure 2 Interconnected block diagram of two steam power plant

$$\Delta Y(s) = \left( \frac{1}{1 + 0.1s} \right) \left( \Delta P_C(s) - \frac{\Delta F(s)}{R} \right) \quad (1)$$

Turbine converts thermal energy in steam, by adjusting valve opener value of steam turbine ( $\Delta Y$ ) to mechanical energy ( $\Delta P_G$ ). There are so many types of steam turbine, in this study we use cross compound with non reheater turbine type. The difference between turbines with reheater is that it is slower than one with non reheater. Turbines with no reheater have first order approximation transfer function. These kind of turbines have a typical value of 0.2s – 0.3s for the time constant. In this study, we chose a turbine time constant of 0.3s. Turbine transfer function is expressed in Equation 2

$$\frac{\Delta P_G(s)}{\Delta Y(s)} = \frac{1}{(1 + 0.3s)} \quad (2)$$

Turbine rotor generated mechanical torque to turn the generator rotor. If generator is connected to the load, there would be current in stator windings which would increase

electrical torque. Torque resultant which worked in the generator rotor will affect the rotor speed. Speed of rotor generator will affect the frequency of the grid. Because the torque has linear value against power, the dynamics of the rotor speed or frequency depend on turbine generated power ( $\Delta P_G$ ), power demand ( $\Delta P_L$ ) and also amount of inertia constant (H) of generator and the damping constant (D). Transfer function of the model of generator and load is represented in Equation 3. Parallel configuration of two generators has an equivalent time constant of 12 second and damping ratio of 2%.

$$\frac{\overline{\Delta P_G(s)} - \overline{\Delta P_D(s)}}{\Delta F(s)} = \frac{1}{12s + 2} \quad (3)$$

Transfer function of the system by considering no change in speed changer ( $\Delta P_C(s) = 0$ ) are shown in Equation 4. The equation represents the dynamic of load change and the frequency change in the grid.

$$\Delta F(s) = - \frac{(0.1s + 1)(0.3s + 1)}{1 + R(12s + 2)(0.1s + 1)(0.3s + 1)} \Delta P_D(s) \quad (4)$$

Amount of power generated depends on the droop characteristic in every power plant. The block diagram that represent the system of two power plants are shown in **Figure 2**.

### III. NOISE TOLERABLE PID FEEDBACK CONTROLLER AT SECONDARY LOOP

Controllers are needed to bring the deviated frequency caused by load changing in permitted value. By modifying controller scheme with droop characteristic of the power plant [2], system damping would be decreased. In this study, controller design guaranteed the stability of the system by using root locus. Using pole placement method, two zeroes of PID controller located in the -3 and -0.2 at real axis of root locus plane. It will cause the system stability guaranteed all over Kp value as seen in Figure 3. PID controller function is represented in Equation 5.

$$U(s) = 10 \left( 1 + 0.3s + \frac{0.2}{s} \right) E(s) \quad (5)$$

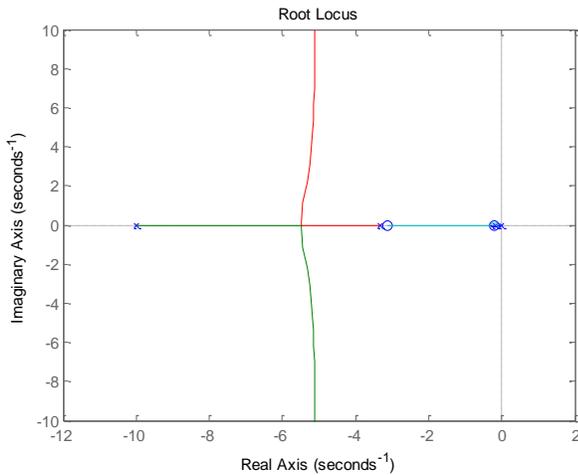


Figure 3 Root locus of steam power plant with PID controller

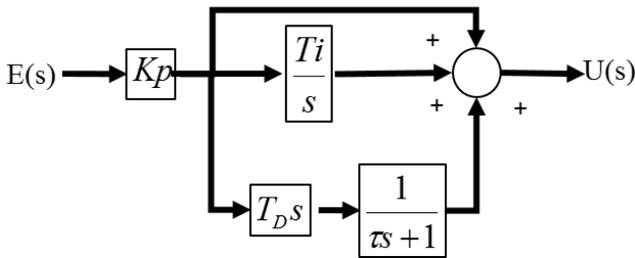


Figure 4 Block diagram of PID controller with low pass filter

#### A. PID with Low Pass Filter

The innumerable switching occurring in the load side produces high frequency noise signal to the system. The PID controller that processes this noisy signal may generate high magnitude control signal that can make overall system unstable. In this LFC case, low pass filter is added in derivative part in PID controller, like in Equation 6.

$$U(s) = 10 \left( 1 + 0.3s \frac{1}{\tau s + 1} + \frac{0.1}{s} \right) E(s) \quad (6)$$

where  $\tau$  is parameter of cut off frequency. Value of  $\tau$  will affect in attenuation of the filter in specific noise frequency value. Block diagram of PID controller which uses low pass filter was represented in **Figure 4**.

The value of cut off frequency depends on noise specification which has value of 1 kHz. By choosing 0.1 rad/s as the cut-off frequency, we have a  $10^{-5}$  attenuation at 1 kHz.

#### B. PID with Averaged Derivative

Averaged derivative function, like in Equation 7, has ability to reduce noise by adjusting time delay element. The time delay should be selected as small as possible. This way the LFC will have the same characteristic as a general PID controller.

$$[f(t)']_{avg} = \frac{1}{T} \int_{t-T}^t \frac{d(f(t))}{dt} dt \quad (7)$$

That function is introduced into the derivative term of the PID controller. It is desired that the noise signal gets attenuated by this term. Using Laplace transform on equation (7), the PID controller with averaged derivative function will be in the form of equation (8).

$$E(s) = 10 \left( 1 + \frac{0.3}{T} (1 - e^{-Ts}) + \frac{0.2}{s} \right) U(s) \quad (8)$$

Block diagram which represents the Equation 8 is shown in **Figure 5**.

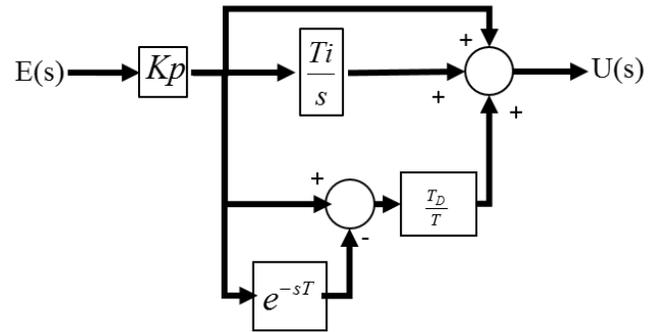


Figure 5 Block diagram of PID controller with averaged derivative

### IV. SIMULATION RESULTS

Simulations were done by providing appropriate approach to the real system. By evaluating some key parameters, one can get an overview about the characteristics of the corresponding system. In this study, the parameters were obtained from the system modeling. Dynamic system equations were derived from the physical laws supplied with data from the real plant or datasheet.

By regulating the amount of power generation to match power demand, it can set the generated power frequency. The noise effect, which is influenced by switching, will be shown in the simulation.

The simulation is run for three load conditions. There are minimal, nominal and maximal load. Minimum load has a value of 10 MW, the assumption is the load changes due to the

equipment in households and offices. These loads are estimated to have a value of 10 MW. The nominal load occurs on shifts after work hours during which equipment in industrial facilities is not used; the load has a value of 100 MW. Maximum load reaches the value of the overall capacity of the plant which is equal to 300 MW.

Testing will be done by giving the variation of controller, variation of parameter controller with noise and load variation. The test is aimed to see whether the controllers able to make the system stable. Next target is the provision of noise at 1 kHz and a variation of the droop characteristic. It will test the designed filter, and its capability of reducing noise and maintaining output frequency at 50 Hz will be evaluated.

A. Variation Parameter Controller ( $K_p$ )

Proportional parameter testing was performed to determine whether the system has stability for the value of  $K_p$  or any droop characteristic. Simulations were done by giving the parameter variations on the controller. Variations of  $K_p$  were given to plant 1 and plant 2 at 10 and 20, 100, and 110, 250 and 260. For  $K_p$  between 10 and 20, both plants have similar frequency drop (Figure 6). In addition, the length of time back from granting load has almost the same value, i.e. by 30 seconds.

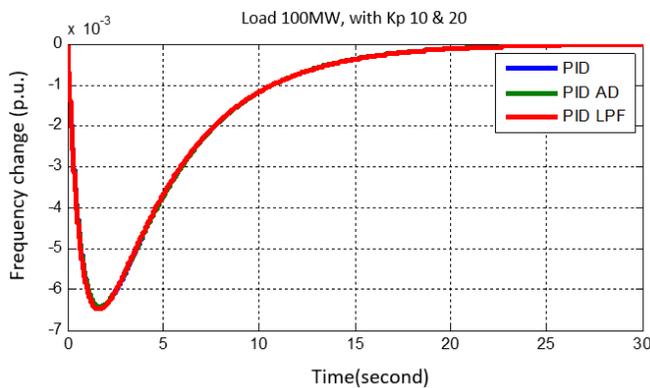


Figure 6 Frequency change for  $K_p$  10 (P1) and 20 (P2)

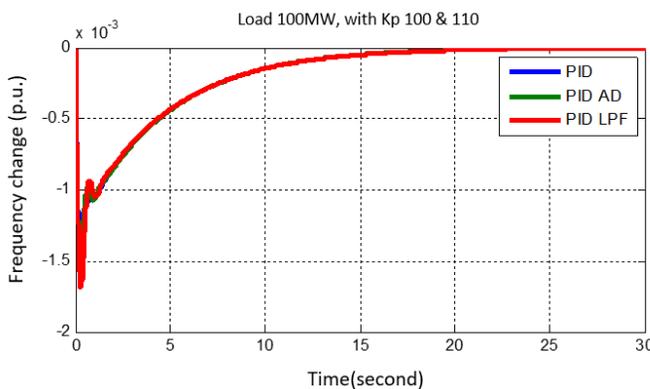


Figure 7 Frequency change for  $K_p$  100 (P1) and 110 (P2)

For variations of  $K_p$  of 100 and 110, the systems have a faster response than the ones with previous  $K_p$  values, as shown in Figure 7. After drop happened, the system needed 25 seconds to bring the frequency deviation back to the desired value. Increasing value of  $K_p$  decreased the frequency drop. This phenomena was consistent with the characteristics of the variations in the value of  $K_p$ , in which higher  $K_p$  corresponds to faster time response.

$K_p$  values between 250 and 260 give faster response than values between 10 and 20, as shown in Figure 8. Similar to previous case, increasing value of  $K_p$  decreased the frequency drop. This phenomena was consistent with the characteristics of the variations in the value of  $K_p$ , in which higher  $K_p$  corresponds to faster time response.

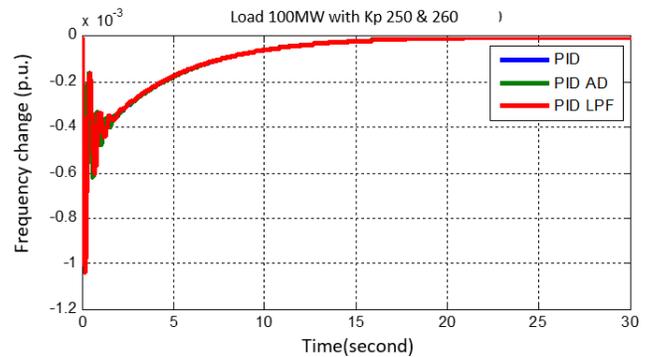


Figure 8 Frequency change for  $K_p$  250 (P1) and 260 (P2)

The value of the ratio of  $K_p$  parameter variations were shown in TABLE I. The smallest frequency drop is given by  $K_p$  values of 250 and 260, while the largest frequency drop is given by  $K_p$  values of 10 and 20.

TABLE I FREQUENCY DROP COMPARISON WITH  $K_p$  VARIATION

$K_p$	Frequency Drop		
	PID (Hz)	PID AD (Hz)	PID LPF (Hz)
10 & 20	-0,32095	-0,3217	-0,3243
100 & 110	-0,07225	-0,0778	-0,0843
250 & 260	-0,04173	-0,0486	-0,0510

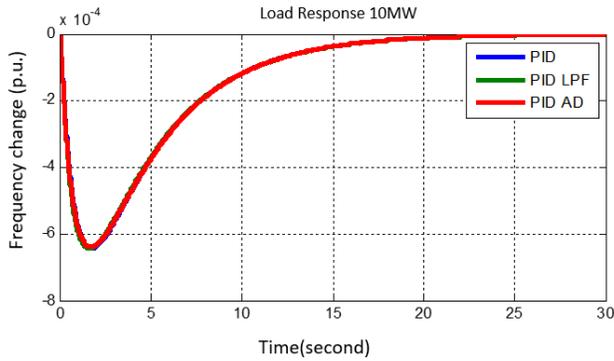
Influence of  $K_p$  parameter variations to the response system was shown in TABLE II. It was shown that the greater the value of  $K_p$ , the more rapid the frequency drop occurs.

TABLE II DROP FREQUENCY TIME FOR  $K_p$  VARIATION

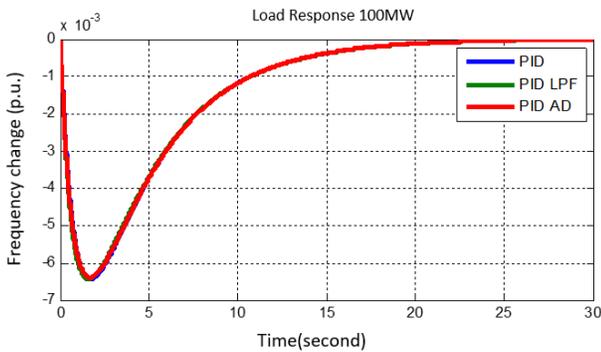
$K_p$	Drop Frequency Time		
	PID	PID AD	PID LPF
10 & 20	1,719 s	1,689 s	1,654 s
100 & 110	0,2576 s	0,2528 s	0,2772 s
250 & 260	0,1374 s	0,1512 s	0,1634 s

**B. Load Variation with Controller**

Rise and fall of the load were simulated by giving a signal in the form of unit load step. It aims to represent changes in the load on the real conditions in which the change was constant. To test the controller based on the previous design, load variations are given to the system. **Figure 9** shows the magnitude of change in the load of 10MW. It can be shown that the response for three method are almost same. For the main purpose, eliminating frequency error values can be done by applying the integral controller.



**Figure 9 Frequency change for 10MW**



**Figure 10 Frequency change for 100MW**

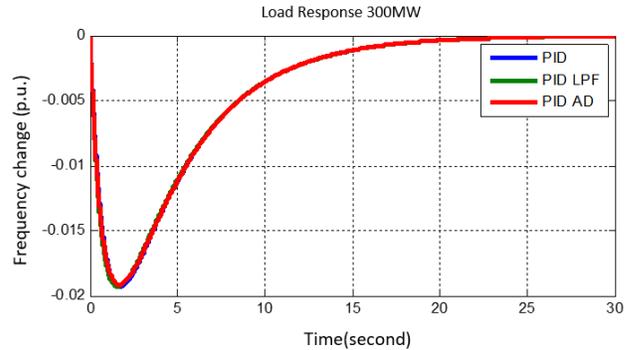
Similarly, the loading effect of 100 MW has a greater decrease value in the frequency with the increasing value of the load. Time needed to bringing back frequency to the nominal value caused by 100MW and 10MW load change have a value which is almost similar, 26 seconds. This phenomenon can be seen in **Figure 10**.

At a load of 300 MW, as shown in **Figure 11**, the value of the frequency drop is greater than before. Amount of time that was needed to bring the frequency back to its nominal value was 25 second.

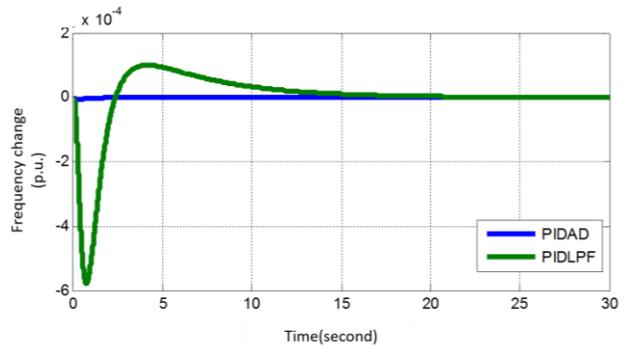
**C. Kp parameter variation with noise 1kHz**

The noise arising from rapid changes in the load was simulated with a signal with an amplitude of 0.1 p.u. and a frequency of 1kHz. In this performed test, the variation is similar to the variation of the test controller parameter Kp. In the first test, Kp value of 10 and 20 were assigned to power plants 1 and 2. **Figure 12** shows the change in response to the noise frequency of 1kHz, where decreased frequency of  $-6.047 \times 10^{-6}$  (pu) occurred for PID control method AD while

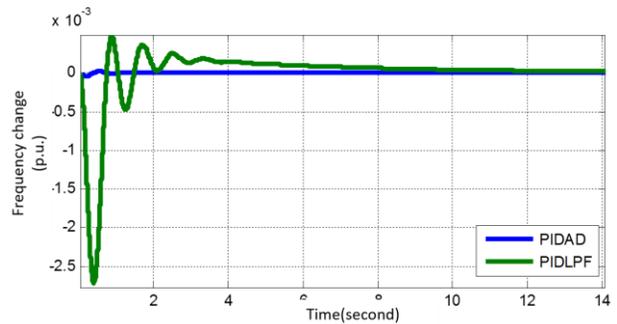
for PID control method with frequency LPF  $-5.787 \times 10^{-4}$  (pu). The other difference occurred in the amount of the time needed for the two methods to bring back frequency to the nominal value. PID LPF control method has a value of 22 seconds for settling time. It is longer than the PID AD control method in which the settling time was 2.5 seconds.



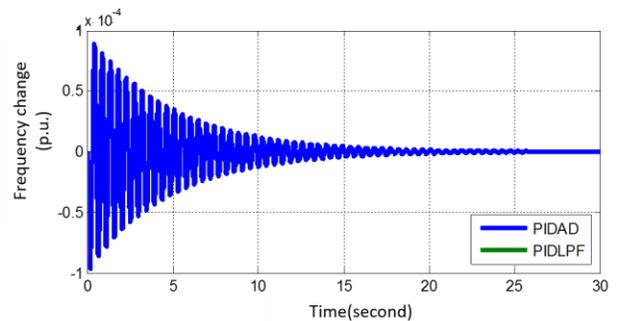
**Figure 11 Frequency change for 300MW**



**Figure 12 Noise 1KHz, Kp = 10 (P1), 20 (P2)**



**Figure 13 Noise 1KHz, Kp = 100 (P1), 110 (P2)**



**Figure 14 Noise 1KHz, Kp = 250 (P1), 260 (P2)**

For variation of controller parameter  $K_p$  of 100 and 110 with a 1kHz noise, the result was shown by **Figure 13**. The magnitude of the frequency drop for the LPF PID control method was  $-2.715 \times 10^{-3}$  (p.u.). As for the PID AD the frequency drop was  $-4.642 \times 10^{-5}$  (p.u.) with a settling time of 2.5 second which is longer than PID LPF method with 22.74 second. With the addition of the value of  $K_p$  will get decreasing value smaller frequency.

For proportional parameter of 250 and 260, the results were different as shown in Figure 14. The difference lies in the stability of both methods. For PID LPF control method becomes unstable, whereas the PID AD control method become oscillating but has finite final value. The comparison of drop frequency value and settling time of variation of parameters proportional to the noise were shown in **TABLE III** and **TABLE IV**.

**TABEL III COMPARISON OF DECREASED FREQUENCY OF 1KHZ NOISE**

Method	Frequency Drop		
	$K_p$ 10 & 20	$K_p$ 100 & 110	$K_p$ 250 & 260
PID AD	-0,00302 Hz	-0,002321Hz	-0,05 Hz
PID LPF	-0,02894 Hz	-0,13575 Hz	Unstable

**TABEL IV COMPARISON OF LENGTH OF TIME BACK OF 1 KHZ NOISE**

Method	Settling time		
	$K_p$ 10 & 20	$K_p$ 100 & 110	$K_p$ 250 & 260
PID AD	2,5 s	1.5 s	30 s
PID LPF	22 s	22,74 s	Unstable

## V. CONCLUSION

From the results of the simulation and testing, we summarized the following observations:

The studied PID control methods, PID AD and PID LPF, have a similar response to PID control method for testing the load and variations in the value of  $K_p$ .

The method of PID LPF has stability problems when the  $K_p$  value was above 250. The method of PID AD remain stable in the that range.

Low pass filter and averaged derivative function were equally capable of resolving the problems of noise in the system. However, the addition of LPF makes the system becomes unstable for  $K_p$  values above 250. By comparing the value of frequency drops, namely for  $K_p$  of 100 and 110 ( value of -0.002 Hz for PID AD and -0.135 Hz for PID LPF), we affirmed that PID AD is a better solution.

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