



Performance Evaluation of Load Frequency Control in Reheat Power Systems with Filtered PID Controllers

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A B S T R A C T

This study aims to design and analyze a Load Frequency Control (LFC) system for a power plant with a reheat turbine, using PID-based controllers with various filter configurations to optimize frequency stability under load fluctuations. A series of PID, PD, and PDF controllers is implemented and tested through MATLAB simulations, focusing on key dynamic performance indicators such as rise time, peak time, settling time, and maximum overshoot. The findings reveal that PD and PDF controllers—particularly those that omit droop characteristics and incorporate filters—consistently outperform conventional PID controllers regarding faster response and improved transient stability. The integration of filters plays a crucial role in dampening oscillations and reducing overshoot, which is essential in maintaining system robustness during load disturbances. However, the study also identifies that the absence of droop control introduces limitations in achieving steady-state accuracy. Despite improvements in dynamic performance, the system continues to exhibit steady-state deviations, highlighting a trade-off between transient responsiveness and long-term stability. This underscores the need for hybrid or adaptive control strategies that combine fast response benefits with droop-based steady-state correction. The study contributes valuable insights toward developing more resilient and efficient frequency control mechanisms in modern power generation systems.

INTRODUCTION

Stability in an interconnected power system refers to its ability to return to stable operation after being disrupted by disturbances. [1]. Stability is crucial in power systems design and operation, as it ensures that the electrical energy system can maintain stable voltage and frequency while meeting load demands. [2]. Deviations in these parameters can negatively impact network operations and customer devices, particularly power electronic devices, which are highly sensitive to variations in voltage and frequency. Additionally, poor energy quality contributes to power losses, which is another issue of concern [3].

In Indonesia, the standard frequency value for an electric power system is 50 Hz [4]. The balance of active power determines the frequency in a power system. Any shifts in active power demand, generation, or sudden load changes within a control area can cause frequency deviations [5]. Active power imbalances between generation and demand in the electrical grid lead to frequency disturbances, which must be managed through control mechanisms at generating plants. Traditional power systems with conventional generating units can adjust generation flexibly to meet utility demand [6].

In this context, Load Frequency Control (LFC) is essential for maintaining a high-quality energy supply. LFC is a key element for ensuring power system stability by keeping frequency within specified limits [7] [8]. The primary role of LFC is to adjust frequency deviations and manage tie-line power exchanges, bringing system frequency to its rated value and maintaining normal power exchange on tie-lines [9]. LFC systems incorporate a control system tailored to the power grid, helping to stabilize frequencies and tie-line power flows after load changes [10]. It is done by controlling the integral gain in the governor [11].

Among the controllers commonly used in LFC systems is the Proportional-Integral-Derivative (PID) controller, which is popular for its straightforward design, effective performance, and ease of implementation [12]. A PID controller can stabilize microgrid frequency by balancing system frequency errors. It operates to control frequency whenever the system registers a deviation, providing an effective method to manage system stability [13].

To develop effective LFC systems, numerous research approaches have been proposed and extensively studied. Rahmadhi's research explored the use of a low-pass filter in the LFC system, demonstrating that adding a filter to the PID

controller in power generation control helps reduce noise caused by load fluctuations [14]. Rohadatul's study investigated an LFC system using a PID controller with PIDTune [15].

This study aims to design and evaluate the performance of a Load Frequency Control (LFC) system in a reheat-type power system using PID controllers and filters. The analysis focuses on assessing the effectiveness of a single controller in achieving frequency stability and minimizing the impact of load variations on the power system. Additionally, the study seeks to identify the most effective controller in terms of rise time, peak time, steady-state time, and maximum overshoot, using simulations in MATLAB software.

This study narrows its focus to the performance analysis of Load Frequency Control (LFC) systems specifically applied to reheat-type power plants, utilizing various forms of PID controllers in combination with filter configurations. This scope is deliberately set to ensure consistency with the research objectives and to maintain analytical depth. The limitations of the study are clearly defined. First, the evaluation is concentrated on several types of PID-based controllers, including P, PI, PD, PID, PDF, and PIDF, to assess their comparative effectiveness. Second, all simulation models and performance testing are exclusively carried out within the MATLAB environment, enabling controlled and replicable experimentation. Third, the testing conditions incorporate both scenarios with and without the inclusion of droop characteristics to observe the controllers' behavior under different regulatory conditions. Lastly, the analysis of controller performance is confined to key dynamic parameters, namely rise time, peak time, steady-state time, and maximum overshoot. These constraints are set to ensure a focused investigation into the dynamic response capabilities of each controller configuration while acknowledging areas for future expansion, such as real-time implementation, broader performance metrics, or multi-area system integration.

METHOD

The LFC system simulation was conducted using MATLAB software. The system was tested with controller configurations both with and without a filter, and with and without droop characteristics with load input. The system block diagram illustrates the control flow. Transient analysis was used to evaluate system performance across various transition parameters. The block diagram of the LFC system without controller can be seen in Figure 1.

Mathematic Modelling of Reheat Load Frequency Control

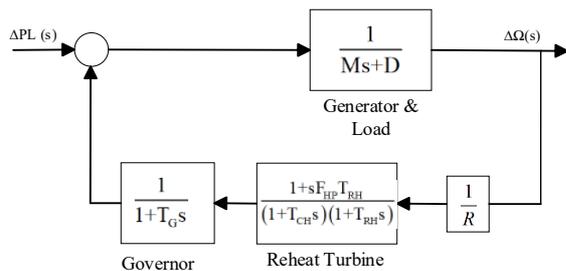


Figure 1. Block Diagram of Reheat Type LFC with Load Input [16]

The closed-loop transfer function of the LFC system to the load input can be seen in Equation 1.

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{\left(\frac{1}{Ms+D}\right)}{1 + \left(\frac{1}{1+T_G s}\right) \left(\frac{1+sF_{HP} T_{RH}}{(1+T_{CH} s)(1+T_{RH} s)}\right) \left(\frac{1}{Ms+D}\right) \left(\frac{1}{R}\right)} \tag{1}$$

For the block diagram of the LFC system with the controller can be seen in Figure 2.

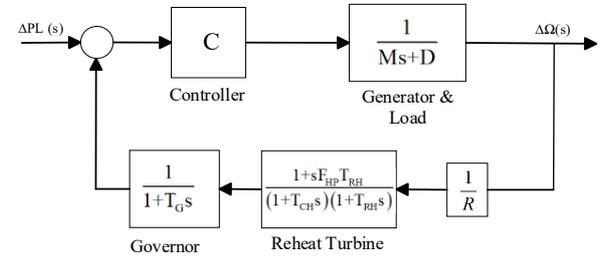


Figure 2. Block Diagram of Reheat Type LFC with Controller with Load Input

With the closed loop transfer function of the LFC system to the load input can be seen in Equation 2.

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{C \left(\frac{1}{Ms+D}\right)}{1 + C \left(\frac{1}{1+T_G s}\right) \left(\frac{1+sF_{HP} T_{RH}}{(1+T_{CH} s)(1+T_{RH} s)}\right) \left(\frac{1}{Ms+D}\right) \left(\frac{1}{R}\right)} \tag{2}$$

For the block diagram of the LFC system with controllers using filters can be seen in Figure 3.

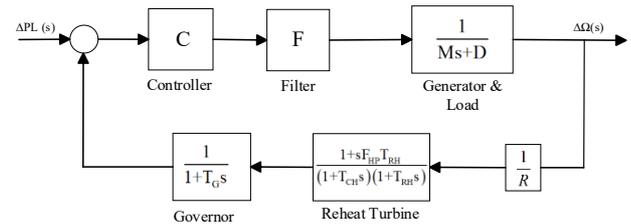


Figure 3. Block Diagram of Reheat Type LFC with Controller Using Filter with Load Input

With the closed loop transfer function of the LFC system to the load input can be seen in Equation 3.

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{C(F) \left(\frac{1}{Ms+D}\right)}{1 + C(F) \left(\frac{1}{1+T_G s}\right) \left(\frac{1+sF_{HP} T_{RH}}{(1+T_{CH} s)(1+T_{RH} s)}\right) \left(\frac{1}{Ms+D}\right) \left(\frac{1}{R}\right)} \tag{3}$$

Controller Design

Table 1. PIDTune Standard Model Controller Types [17]

| Controller Type | Mathematical Representation |
|--|---------------------------------------|
| Proportional (P) | K_p |
| Proportional-Integral (PI) | $K_p + \frac{K_p}{T_i s}$ |
| Proportional-Differential (PD) | $K_p + K_p T_d s$ |
| Proportional-Integral-Differential (PID) | $K_p + \frac{K_p}{T_i s} + K_p T_d s$ |
| Proportional-Differential with a first-order filter on the Differential part (PDF) | $K_p + \frac{K_p T_d s}{N s + 1}$ |

Proportional-Integral-Differential with a first-order filter on the Differential part (PIDF)

$$K_p + \frac{K_p}{T_i s} + \frac{K_p T_d s}{N s + 1}$$

The proportional-integral-differential (PID), which integrates the three components of P, I, and D to produce a more accurate system response, is a more sophisticated controller. The Proportional-Differential controller with a First Order Filter (PDF) has a filter to lessen the impact of noise on the differential section. Lastly, to enhance performance on systems influenced by noise, the Proportional-Integral-Differential controller with a First-order Filter (PIDF) provides a full combination of P, I, and D together with an extra filter on the differential component. Filter configurations are typically employed for systems with substantial noise interference, and the choice of this controller type is contingent upon the system requirements and the intended performance.

Design Criteria

Table 2. Design Criteria for Reheat Type Load Frequency Control: Transition Analysis of Load Input

| Design Criteria | Design Value |
|-------------------|--------------|
| Rise Time | < 4.000 s |
| Peak Time | < 8.000 s |
| Steady State Time | < 10.000 s |
| Peak Value | < 1.1 |
| Maximum Overshoot | < 20% |

Table 2 outlines the performance benchmarks used in the transition analysis of load frequency control (LFC) for reheat-type systems under load input conditions. These benchmarks comprise five key parameters that assess system dynamics. The first is Rise Time (Tr), the duration needed for the system output to rise from its initial state to a specified range (commonly 10%–90% of the final value), with a set target of under 4.000 seconds. The second parameter, Peak Time (Tp), refers to the time taken to reach the first peak in the transient response, which should be below 8.000 seconds. The third, Settling Time (Ts), represents the interval required for the system to settle within an acceptable error margin (typically ±2% or ±5% of the final value), with a target of less than 10.000 seconds. Peak Value (yp) denotes the highest amplitude attained during the transient phase and must remain below 1.1. Lastly, Maximum Overshoot (Mp) defines the greatest percentage by which the system response exceeds its intended final value, with an acceptable limit of 20%. These criteria are established to ensure the system can respond swiftly, stably, and accurately to load disturbances in reheat-type LFC applications.

RESULTS AND DISCUSSION

This section shows and describes the results of the reheat type of Load Frequency Control (LFC) control system using a controller with and without filter configuration. Analysis of the reheat type Load Frequency Control (LFC) control system with load input with a unit step input. Analysis on a controller in the form of a Proportional (P) controller, Proportional Integral (PI), Differential Controller (PD), Differential Integral Controller (PID), Differential Controller with First Order Filter Differential Part (PDF), and Differential Integral Controller with First Order

Filter Differential Part (PIDF). The results of the analysis showed a comparison of the design criteria.

Simulation Result of LFC System Using Controller Without Droop

Table 3. Information on Analysis of Single Type Reheat Type Transition against Load Input without Droop Characteristics

| Transition | P | PI | PD | PID | PDF | PIDF |
|------------|--------------|---------------|--------------|--------------|--------------|--------------|
| tr | 2.645 | 3.110 | 0.183 | 32.836 | 0.183 | 33.109 |
| tp | 7.082 | 6.725 | 0.629 | 115.800 | 0.629 | 144.580 |
| ts | 15.181 | 18.764 | 0.308 | 6.844 | 0.308 | 65.326 |
| yp | 0.731 | 1.143 | 0.989 | 0.998 | 0.989 | 0.999 |
| Mp | 5.554 | 14.311 | 0.642 | 0 | 0.642 | 0 |

Table 3 shows that the PD and PDF controllers meet all design criteria, delivering the fastest rise time (0.183 s) and a low overshoot (0.642). Their strong derivative action enables a quick response to load disturbances. In contrast, PID and PIDF controllers exhibit poor performance, with excessive peaks and settling times, making them unsuitable for fast frequency regulation.

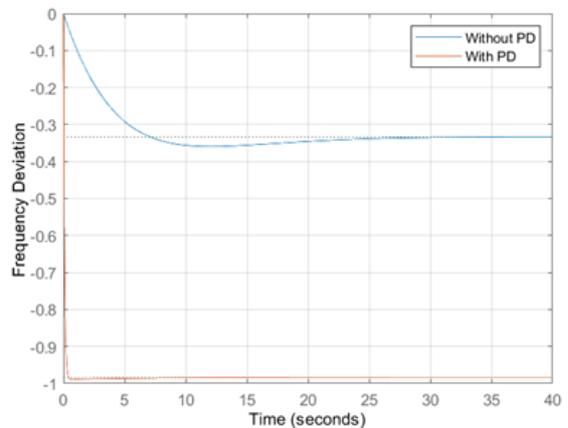


Figure 4. PD Controller LFC Transition Analysis Response to Load Input Without Droop Characteristics

The transient response of the Load Frequency Control (LFC) system with a PD controller devoid of droop characteristics is displayed in Figure 4. The system swiftly stabilizes following a load disturbance, as seen by the response's short rising time and minimal maximum overshoot. This demonstrates that the PD controller efficiently predicts changes and enhances damping through its derivative action, resulting in improved system stability and fewer oscillations.

The system response with a PDF controller without droop is shown in Figure 5. A smoother transient curve is obtained by adding a first-order filter to the derivative component as opposed to using a pure PD controller. The filter successfully attenuates high-frequency noise that could impair system performance while preserving a quick rise time and minimal overshoot. This illustrates how the PDF controller can provide robustness against signal disturbances in addition to responsiveness.

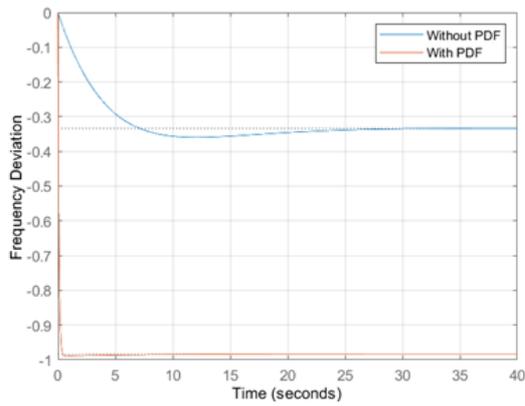


Figure 5. PDF Controller LFC Transition Analysis Response to Load Input Without Droop Characteristics

Simulation Result of LFC System Using Controller with Droop

Table 4. Information on the Analysis of Type Reheat Type Transition with Load Input with *Droop* Characteristics

| Trans ition | P | PI | PD | PID | PDF | PIDF |
|-------------|--------------|--------------|--------------|--------------|--------------|--------------|
| t_r | 0.264 | 25.094 | 0.066 | 5105.6 | 0.066 | 5130.9 |
| t_p | 1.085 | 112.76 | 0.257 | 1701 | 0.257 | 1623 |
| t_s | 15.200 | 50.013 | 6.945 | 9076 | 6.945 | 9120.4 |
| y_p | 0.771 | 0.999 | 0.991 | 0.999 | 0.991 | 0.999 |
| M_p | 50.534 | 0 | 7.093 | 0 | 7.093 | 0 |

Based on Table 4, when droop is present, steady-state faults occur that no controller can correct. With rise times of 0.066 s and little overshoot, PD and PDF controllers continue to exhibit outstanding transient performance, indicating their applicability for quick corrective action. Nevertheless, time-domain needs are not met by controllers such as PI and PID, which exhibit slow and erratic responses.

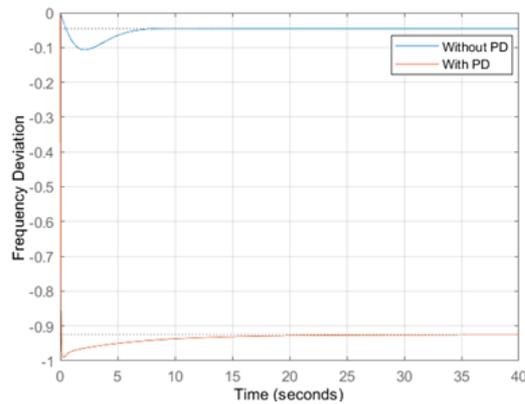


Figure 6. PD Controller LFC Transition Analysis Response to Load Input with Droop Characteristics

Droop's impact on the PD-controlled system is depicted in Figure 6. The ultimate measurement differs from the original reference, indicating a steady-state inaccuracy, even though the initial transient response is still rapid. The intrinsic feature of droop control, which introduces a proportionate offset between frequency and load, is the cause of this inaccuracy. In spite of this, the PD controller is still able to respond quickly with manageable overshoot, which makes it appropriate for uses where quick correction is more important than perfect steady-state accuracy.

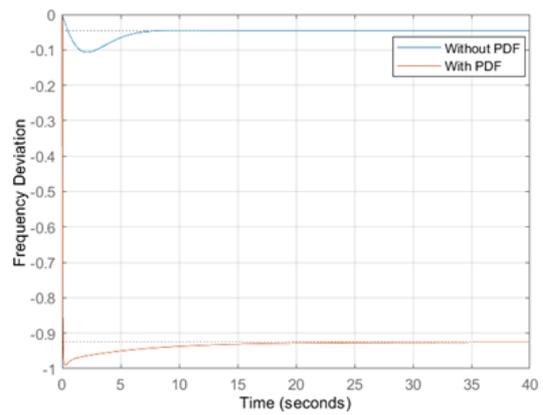


Figure 7. PDF Controller LFC Transition Analysis Response to Load Input with Droop Characteristics

Even with the addition of droop features, the PDF controller retains a steady and smooth transient response, as seen in Figure 7. The derivative control aids in a prompt remedial action, while the filter lessens signal fluctuations. Nevertheless, droop causes a discernible steady-state inaccuracy, much like in the PD example. This demonstrates that both PDF and PD controllers have limitations in systems that need zero steady-state frequency variation.

Simulation Result of LFC System Using Controller with Filter Without Droop

Table 5. Transition Analysis Information of Single Controller and Filter Reheat Types against Load Input without Droop Characteristics ($\tau=0.025$)

| Trans ition | P | PI | PD | PID | PDF | PIDF |
|-------------|--------------|---------------|--------------|--------------|--------------|--------------|
| t_r | 2.614 | 3.079 | 0.137 | 3.529 | 0.137 | 3.326 |
| t_p | 6.993 | 6.732 | 0.379 | 7.600 | 0.379 | 7.285 |
| t_s | 15.161 | 18.751 | 0.220 | 11.012 | 0.220 | 17.93 |
| y_p | 0.732 | 1.146 | 0.991 | 1.056 | 0.991 | 1.087 |
| M_p | 5.600 | 14.611 | 0.828 | 5.588 | 0.828 | 8.724 |

Based on Table 5, PD and PDF controllers significantly improve with a lower filter time constant, providing acceptable overshoot (0.828%) and a faster rise time (0.137 s). Filters contribute to smooth and responsive behavior by reducing noise in the derivative term. Long settling times and greater overrun are still present in PI and PID controllers, suggesting slower corrective capabilities.

Table 6. Transition Analysis Information of Controller and Filter Reheat Types with Load Input without Droop Characteristics ($\tau=0.05$)

| Trans ition | P | PI | PD | PID | PDF | PIDF |
|-------------|--------------|---------------|--------------|--------------|--------------|--------------|
| t_r | 2.583 | 3.048 | 0.130 | 3.489 | 0.130 | 3.291 |
| t_p | 7.063 | 6.740 | 0.275 | 7.571 | 0.275 | 7.269 |
| t_s | 15.141 | 18.737 | 0.417 | 11.007 | 0.417 | 18.019 |
| y_p | 0.732 | 1.149 | 1.054 | 1.057 | 1.054 | 1.089 |
| M_p | 5.647 | 14.919 | 7.264 | 5.738 | 7.264 | 8.921 |

Based on Table 6, with rise times further decreasing to 0.130 s and overshoot staying below 8%, PD and PDF continue to perform better than other controllers at $\tau = 0.05$. Derivative filters

are very effective at tuning transient responses at this setting, as demonstrated by the balance between speed and stability. PID and PIDF controllers show marginal improvements but are still slower in reaching steady state and more prone to oscillations.

Table 7. Transition Analysis Information of Controller and Filter Reheat Types with Load Input without Droop Characteristics ($\tau=0.075$)

| Transition | P | PI | PD | PID | PDF | PIDF |
|------------|-------|-------|-------|-------|-------|-------|
| t_r | 2.555 | 3.017 | 0.136 | 3.445 | 0.136 | 3.252 |
| t_p | 6.968 | 6.750 | 0.302 | 7.541 | 0.302 | 7.253 |
| t_s | 15.12 | 18.72 | 0.478 | 11.00 | 0.478 | 18.09 |
| y_p | 0 | 1 | | 3 | | 8 |
| γ_p | 0.732 | 1.152 | 1.124 | 1.059 | 1.124 | 1.091 |
| M_p | 5.699 | 15.23 | 14.30 | 5.894 | 14.30 | 9.126 |
| | | 4 | 2 | | 2 | |

Based on Table 7, as τ rises to 0.075, PD and PDF controllers start to exhibit a little delayed reaction and an increased overshoot (14.3%). By weakening derivative response, the filters lessen the system's sensitivity to abrupt changes. In contrast to PI and PID controllers, which continue to suffer from delay and oscillation, these controllers stay within reasonable design tolerances.

Table 8. Transition Analysis Information of Controller and Filter Reheat Types with Load Input without Droop Characteristics ($\tau=0.1$)

| Transition | P | PI | PD | PID | PDF | PIDF |
|------------|-------|-------|-------|-------|-------|-------|
| t_r | 2.527 | 2.987 | 0.145 | 3.404 | 0.145 | 3.215 |
| t_p | 6.869 | 6.762 | 0.328 | 7.516 | 0.328 | 6.876 |
| t_s | 15.09 | 18.70 | 0.739 | 10.99 | 0.739 | 18.16 |
| y_p | 9 | 5 | | 9 | | 0 |
| γ_p | 0.733 | 1.156 | 1.179 | 1.061 | 1.179 | 1.094 |
| M_p | 5.752 | 15.55 | 19.89 | 6.057 | 19.89 | 9.345 |
| | | 6 | 6 | | 6 | |

Based on Table 8, as τ rises to 0.1, this table shows a decrease in PD and PDF performance, with overshoot becoming close to 19.9%, which is the upper limit of the design threshold. Although the rise time is still acceptable, the increasing overshoot suggests that the efficacy of transient control may be jeopardized by higher filter values.

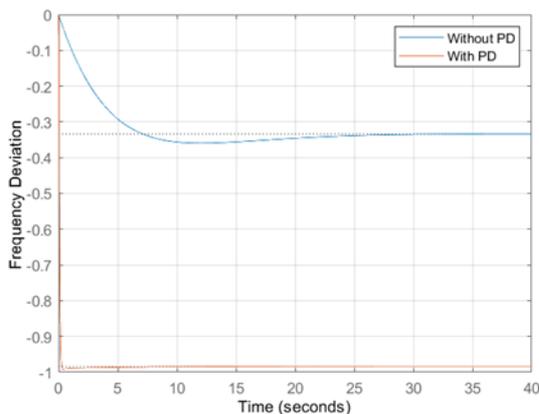


Figure 8. PD Controller LFC Transition Analysis Response to Load Input Without Droop Characteristics ($\tau = 0.025$)

The system behavior with a PD controller without droop and with a derivative filter ($\tau = 0.025$) is shown in Figure 8. Improved noise immunity is achieved by the filter without noticeably sacrificing speed. The resultant response is still crisp and well-damped, demonstrating how well the filter works to improve the controller's usable performance, particularly in sensitive or loud settings.

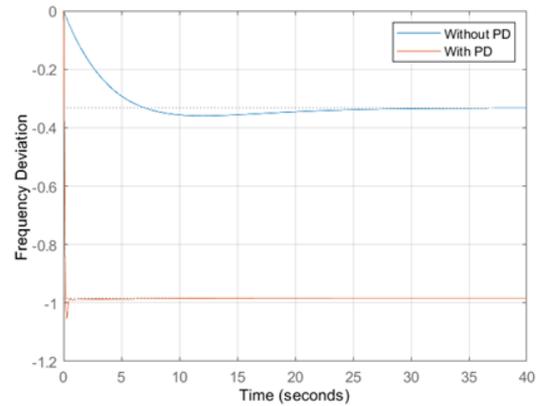


Figure 9. PD Controller LFC Transition Analysis Response to Load Input Without Droop Characteristics ($\tau = 0.05$)

When the filter constant is increased to $\tau = 0.05$ in Figure 9, the response is marginally slower than in Figure 8, but it is still within allowable design bounds. Despite a little increase in settling time, the system still exhibits good transient behavior. When adjusting filter parameters, this trade-off between responsiveness and noise reduction is essential.

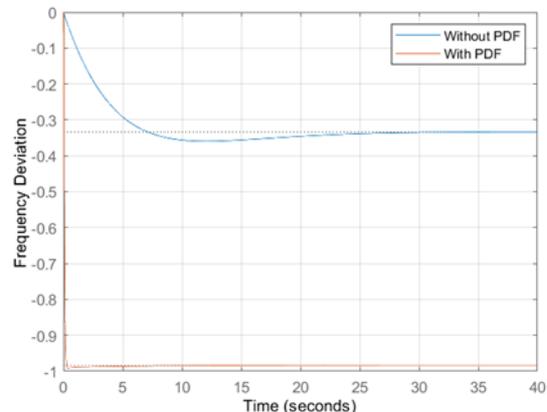


Figure 10. PDF Controller LFC Transition Analysis Response to Load Input Without Droop Characteristics ($\tau = 0.025$)

At $\tau = 0.025$, Figure 10 displays a well-managed response from the PDF controller. By stabilizing the derivative input, the filter helps avoid abrupt oscillations or spikes. Overshoot is kept to a minimum and the transition curve is smooth. This shows that the controller is appropriate for settings that require a smooth recovery and less sensitivity to high-frequency disturbances.

Figure 11 shows that the PDF controller with $\tau = 0.05$ is still performing well, albeit with a somewhat longer settling time than $\tau = 0.025$. The system maintains sufficient control performance despite the less acute reaction, demonstrating that moderate filter values can successfully strike a balance between responsiveness and robustness.

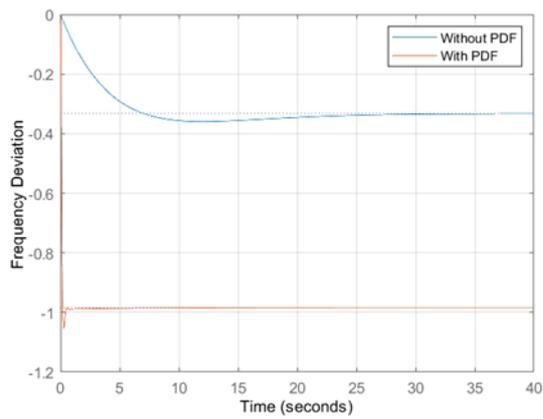


Figure 11. PDF Controller LFC Transition Analysis Response to Load Input Without Droop Characteristics ($\tau = 0.025$)

Simulation Result of LFC System Using Controller with Filter and Droop

Table 9. Information Analysis of Single Controller and Filter Type Reheat Transition against Load Input with *Droop* Characteristics ($\tau=0.025$)

| Tran sition | P | PI | PD | PID | PDF | PIDF |
|-------------|--------------|-------------|-------------------|-------------|-------------------|------------|
| t_r | 0.255 | 25.04 7 | 0.053 | 25.04 9 | 0.053 | 25.04 7 |
| t_p | 1.067 | 192.4 60 | 0.124 | 185.6 90 | 0.124 | 192.4 6 |
| t_s | 15.20 8 | 49.96 5 | NAN | 49.96 7 | NAN | 49.96 5 |
| γ_p | 0.776 | 1 | 1.079 | 1 | 1.079 | 1 |
| M_p | 51.54 7 | 0 | 16.55 7 | 0 | 16.55 7 | 0 |

Based on Table 9, even with filters fitted, this setup validates the detrimental effects of droop. High overshoot (16.557%) and steady-state deviation persist because of the absence of integral correction, whereas PD and PDF preserve very quick rise times (0.053 s) and acceptable peak timings. Droop continues to result in lengthy settling periods, while PI and PID controllers perform worse in terms of speed.

Table 10. Information Analysis of Single Controller and Filter Type Reheat Transition against Load Input with *Droop* Characteristics ($\tau=0.05$)

| Tran sition | P | PI | PD | PID | PDF | PIDF |
|-------------|--------------|--------------|--------------|--------------|--------------|--------------|
| t_r | 0.255 | 25.00 1 | 0.062 | 25.00 2 | 0.062 | 25.00 1 |
| t_p | 1.045 | 81.38 5 | 0.151 | 81.36 2 | 0.151 | 81.38 5 |
| t_s | 15.21 6 | 49.91 9 | NAN | 49.92 0 | NAN | 49.91 9 |
| γ_p | 0.783 | 0.998 | 1.209 | 0.998 | 1.209 | 0.998 |
| M_p | 52.83 3 | 0 | 30.63 4 | 0 | 30.63 4 | 0 |

Based on Table 10, PD and PDF exhibit rising overshoot (30.634%) at $\tau = 0.05$, suggesting that the controller becomes overly responsive to initial adjustments. Long-term frequency stability cannot be maintained due to the existence of droop and

the absence of integral action, even though rise time (0.062 s) is still adequate. Once more, PI and PID are unable to adequately rectify steady-state error, and settling durations continue to be too long.

Table 11. Information Analysis of Single Controller and Filter Type Reheat Transition against Load Input with *Droop* Characteristics ($\tau=0.075$)

| Tran sition | P | PI | PD | PID | PDF | PIDF |
|-------------|--------------|--------------|--------------|--------------|--------------|--------------|
| t_r | 0.262 | 24.95 4 | 0.070 | 24.95 5 | 0.070 | 24.95 4 |
| t_p | 1.018 | 82.37 7 | 0.179 | 82.35 3 | 0.179 | 82.37 7 |
| t_s | 15.22 4 | 49.87 2 | 6.877 | 49.87 3 | 6.877 | 49.87 2 |
| γ_p | 0.792 | 0.998 | 1.291 | 0.998 | 1.291 | 0.998 |
| M_p | 54.49 5 | 0 | 39.47 6 | 0 | 39.47 6 | 0 |

Based on Table 11, further performance deterioration is shown in this table, where PD and PDF overshoot values of 39.476% are significantly above permissible bounds. Under droop conditions, these controllers are unable to stop long-term frequency deviation, despite their quick early response times. Even with filtering, integral-based solutions are unable to completely eradicate steady-state error, and the PI controller shows a delayed recovery.

Table 12. Information Analysis of Single Controller and Filter Type Reheat Transition against Load Input with *Droop* Characteristics ($\tau=0.1$)

| Trans ition | P | PI | PD | PID | PDF | PIDF |
|-------------|--------------|--------------|--------------|--------------|--------------|--------------|
| t_r | 0.272 | 24.90 8 | 0.078 | 24.90 9 | 0.078 | 24.90 8 |
| t_p | 0.998 | 83.41 1 | 0.201 | 83.38 6 | 0.201 | 83.41 1 |
| t_s | 15.23 1 | 49.82 6 | 6.854 | 49.82 6 | 6.854 | 49.82 5 |
| γ_p | 0.802 | 0.998 | 1.348 | 0.998 | 1.348 | 0.998 |
| M_p | 56.56 3 | 0 | 45.62 6 | 0 | 45.62 6 | 0 |

Based on Table 12, out of all setups, PD and PDF controllers produce the worst overshoot values (45.626%) at the highest filter constant ($\tau = 0.1$). This demonstrates that controller performance is severely deteriorated when τ is increased when droop is maintained. Despite being useful in lowering noise, filters are unable to compensate for droop and the absence of integral action. In this configuration, none of the tested controllers satisfy the design requirements.

CONCLUSIONS

The PD and PDF controllers demonstrate optimal performance in maintaining frequency stability in reheat Load Frequency Control (LFC) systems. Without droop, both PD and PDF controllers provide a faster and more stable response, making them the preferred controllers for this application. The use of filters further

enhances the system's transient response by reducing overshoot, ensuring a smoother and more controlled transition to steady state. However, while filters improve the response quality, they do not fully resolve steady-state stability issues when droop is present, as the system still experiences steady-state deviations. Thus, PD and PDF controllers without droop, whether with or without a filter, are the most effective solutions for achieving optimal performance in reheat LFC systems facing load disturbances.

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NOMENCLATURE

| | |
|----------------|--|
| $\Delta\Omega$ | Frequency Change |
| H | Constant of Inertia |
| ΔP_L | Changes in Expenses |
| D | Load Damping Constant |
| R | Speed Regulation |
| T_{RH} | Reheat Turbine Time Constant |
| T_{CH} | Turbine Time Constant |
| T_{RH} | Percentage of power generated in the reheat turbine Controller |
| C | Controller |
| F | Filter |
| t_r | Rising Time |

| | |
|-------|-------------------|
| t_p | Peak Time |
| t_s | Steady State Time |
| y_p | Peak Value |
| M_p | Maximum Overshoot |

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