



A COMPARATIVE ANALYSIS OF STUDENT PERFORMANCE IN DESIGNING FREQUENCY CONTROL VIA SIMULATION-BASED FORMATIVE ASSESSMENT

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ABSTRACT

This paper focuses on formative assessment of several student groups by executing Load Frequency Control (LFC) in power systems using both MATLAB/Simulink and Google Colab. Four student groups have been formed and have worked together on various aspects of the study, i.e., modelling, simulation, control design, and result analysis. These student groups gained deeper hands-on experience while implementing the controller for the power system. All groups manually tuned the PID controller for the single-area power system. The performance analysis has also been done in MATLAB/Simulink for all groups. Using Google Colab, the formative analysis was performed by importing MATLAB/Simulink results. This work emphasises the importance of frequency regulation for power system stability and demonstrates how project-based learning can simplify complex problems.



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I. INTRODUCTION

Load Frequency Control (LFC) is considered a critical aspect of electrical power system operation due to its effects on system stability and reliability. In earlier decades, researchers primarily relied on traditional control methods, such as Proportional-Integral-Derivative (PID) controllers. These controllers minimise steady-state frequency deviations; however, they often face challenges arising from nonlinear system dynamics and operating-condition uncertainties [1-5]. To overcome these problems, more recent studies have adopted advanced approaches, such as fuzzy logic control, fractional-order controllers, and optimisation methods. All of which aim to enhance the system robustness and dynamic response [5-9]. On the other hand, the development of simulation platforms such as MATLAB/Simulink has become increasingly important for education and research, as they enable complex system behaviour to be modelled and tested in a controlled environment. Such tools provide a practical means of reproducing realistic disturbances and evaluating the performance of different control strategies before implementation in actual power networks [7], [9]. In addition to technical modelling efforts, recent work in engineering education has highlighted the importance of formative assessment in both teaching and research [10-13]. The summative evaluation, which provides feedback only at the end of a task, contrasts with formative assessment, which emphasises continuous feedback throughout the learning and experimentation process. This ongoing interaction allows students and researchers to make incremental improvements in system modelling, controller tuning, and performance evaluation. The students can learn concepts easily. By supporting reflection and iterative refinement, formative assessment not only enhances the overall quality of outcomes but also deepens the learner's conceptual understanding and problem-solving ability [12], [13]. Moreover, with the latest cloud-based platforms, tools such as *Google Colab* have gained popularity for collaborative analysis, coding, and result sharing. Google Colab offers an open-source, Python-based environment where students and researchers can perform data analysis, visualize results, and document findings in real time without hardware or software constraints [14].

MATLAB/Simulink can provide learning for students. This accessibility and collaborative feature make it a valuable complement to MATLAB/Simulink, especially for group-based projects that require active participation and peer learning. Taken together, prior literature underscores the dual importance of (i) robust control strategies for maintaining frequency stability and (ii) modern computational and pedagogical tools that facilitate both research and education in power system studies.

II. METHODOLOGY

II.1 SYSTEM DESCRIPTION

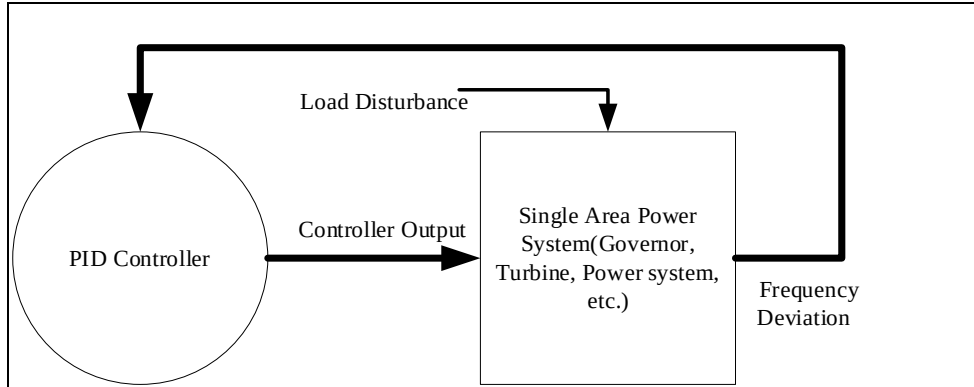


Figure 1: Single-area power system for students learning.

Source: Authors, (2026).

The study focuses on a single-area power system model to evaluate the effectiveness of Load Frequency Control (LFC) under a step load disturbance, as shown in Figure 1. The system includes three main components: the governor, turbine, and generator-load dynamics, represented by standard transfer functions in MATLAB/Simulink. The nominal frequency of the system was set at 50 Hz, and a 1% step load disturbance was applied to test system stability and frequency regulation [9]. The transfer function model of governor, turbine and generator-load dynamics is given below:

$$\text{The Governor Transfer function is } TF_G = \frac{1}{T_G S + 1} \quad (1)$$

$$\text{Turbine Transfer function is } TF_T = \frac{1}{T_T S + 1} \quad (2)$$

$$\text{The Generator-Load Transfer function is } TF_{GL} = \frac{K_s}{T_s S + 1} \quad (3)$$

The values of T_G , T_T , T_s and K_s are 0.08, 0.3, 18 and 120, respectively [9].

II.2 CONTROLLER DESIGN AND TUNING

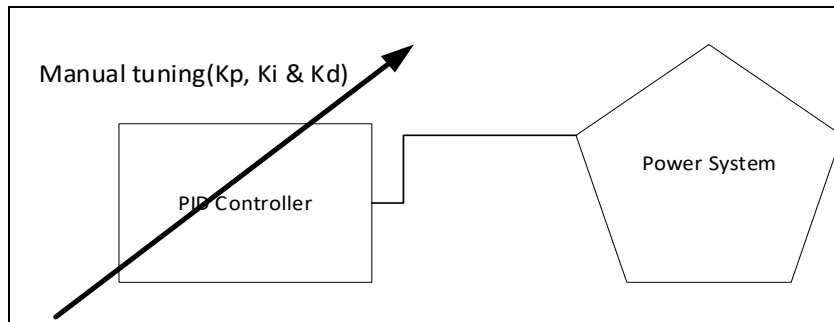


Figure 2: Manual tuning of the PID controller by various student groups.

Source: Authors, (2026).

A Proportional–Integral–Derivative (PID) controller was employed to minimize frequency deviations as depicted in Figure 2. The students need to design a controller for learning various things. Students were instructed to tune the controller parameters (K_p , K_i and K_d) manually through iterative trials or through extensive simulation. This approach encouraged students to build an intuitive understanding of how each parameter influences system response:

- Proportional Gain (K_p):** reduces rise time but can introduce oscillations if too high.
- Integral Gain (K_i):** eliminates steady-state error but may increase settling time.
- Derivative Gain (K_d):** improves damping and suppresses oscillations.

$$\text{Controller } C = K_p + K_i/s + K_d s \quad (4)$$

Manual tuning is performed instead of automatic optimization to reinforce the learning objectives of control design and system behavior analysis.

II.3 STUDENT GROUP IMPLEMENTATION

A total of four student groups participated in the study. They must perform the task on LFC. Each group independently completed the following stages:

- System Modelling** – building the single-area LFC model in MATLAB/Simulink.
- Simulation** – applying a 1% load disturbance and observing system response.
- Manual Controller Design** – tuning PID gains to achieve acceptable system stability.
- Performance Analysis** – exporting time-domain results (frequency deviation and controller output) into Microsoft Excel for further evaluation.

This design ensured that every group experienced the *entire cycle* of modelling, controller design, simulation, and analysis, fostering both technical and analytical skills.

II.4 DATA EXPORT AND STANDARDIZATION

For consistency, all groups exported their MATLAB/Simulink results to a common format with three columns: Time (s), Frequency deviation (Hz), and Controller output (pu). Students must export the data from the simulation tool. This standardization enabled a uniform framework for comparative analysis.

II.5 AUTOMATED ASSESSMENTS IN GOOGLE COLAB

To conduct formative assessment, the simulation results exported from MATLAB/Simulink by all groups were uploaded into a Google Colab notebook. Google Colab can do various analyses for LFC. The notebook, developed in Python, automated the process of importing frequency deviation and controller output data, plotting time-domain responses for visual comparison, and computing key performance metrics, including steady-state error, maximum overshoot, settling time, number of oscillations, and peak values with their occurrence times.

Table 1: Performance metrics of student groups.

Group	Steady-State Error (Hz)	Overshoot (Hz)	Settling Time (s)	Oscillations
Group1_LFC	0	0	0	1
Group4_LFC	-0.0004	0.0016	0	5
Group2_LFC	0	0.0007	0	16
Group3_LFC	0	0.0025	0	25

Source: Authors, (2026).

In addition to quantitative evaluation, the notebook generated automated formative feedback, for example: “*Too many oscillations, increase the Kd*”, which guided students toward possible tuning improvements. The importance of the controller is discussed in this learning. A weighted scoring scheme was then applied to objectively evaluate each group’s performance, with 30% weight assigned to steady-state error, 20% to overshoot, 30% to settling time, and 20% to oscillations. The normalized values were aggregated into a final score (0–100), allowing groups to be ranked and benchmarked against one another. Unlike traditional summative evaluation, this framework emphasized formative assessment by providing students with immediate feedback, opportunities for reflection, and iterative improvement. All analyses are done in Google Colab. The cloud-based nature of Google Colab further ensured accessibility, collaboration, and reproducibility, making it a practical and scalable tool for integrating simulation-based learning with continuous assessment.

III. RESULTS AND ANALYSIS

The performance of four student groups was evaluated based on their MATLAB/Simulink simulations and subsequent formative assessment through Google Colab. Table 1 presents the simulation results for all groups. Table 1 summarizes the primary performance metrics, while Table 2 presents the normalized scores, aggregated totals, and final rankings.

Table 2: Normalized scores and ranking.

Group	Err_score	OS_score	ST_score	OSC_score	Total Score	Rank
Group1_LFC	1.00	1.00	1.00	0.96	99.20	1
Group4_LFC	1.00	0.36	1.00	0.80	83.21	2
Group2_LFC	1.00	0.72	1.00	0.36	81.60	3
Group3_LFC	1.00	0	1.00	0	60.00	4

Source: Authors, (2026).

The manual tuning of all student groups is listed in Table 3. The results indicate that all four groups successfully minimized steady-state error, achieving nearly zero final frequency deviation, demonstrating effective integral action. However, significant differences were observed in oscillatory behavior and damping quality. Group 1 achieved the best performance, with negligible error, no overshoot, and only one oscillation cycle.

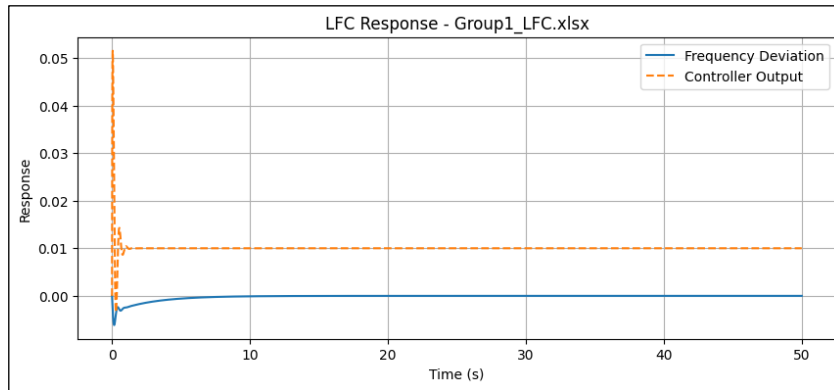


Figure 3: LFC response of Group 1.
Source: Authors, (2026).

The performance analysis is conducted in groups to identify insights. With a total score of 99.2, this group's tuning can be considered the benchmark solution. Group 4 ranked second with a score of 83.2, exhibiting a small overshoot (0.0016 Hz) and five oscillations, indicating slightly underdamped behavior. Group 2 ranked third with a score of 81.6, performing well in steady-state accuracy but experiencing 16 oscillations, showing the need for improved damping via derivative gain tuning. Each group is compared to get the rank. Group 3 received the lowest score (60.0) due to high oscillations (25) and the largest overshoot (0.0025 Hz), suggesting inadequate controller damping and excessive proportional action. The responses of all student groups are depicted in Figures 3-8.

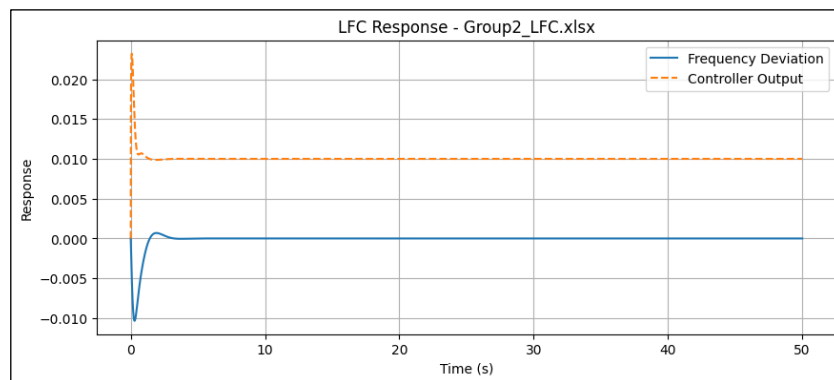


Figure 4: LFC response of Group 2.
Source: Authors, (2026).

Table 3: PID gain values after manual tuning by four student groups.

Groups	Kp	Ki	Kd
Group1_LFC	1.10	1.60	0.30
Group2_LFC	3.00	1.00	0.70
Group3_LFC	0.50	5.00	2.00
Group4_LFC	10.00	0.20	1.00

Source: Authors, (2026).

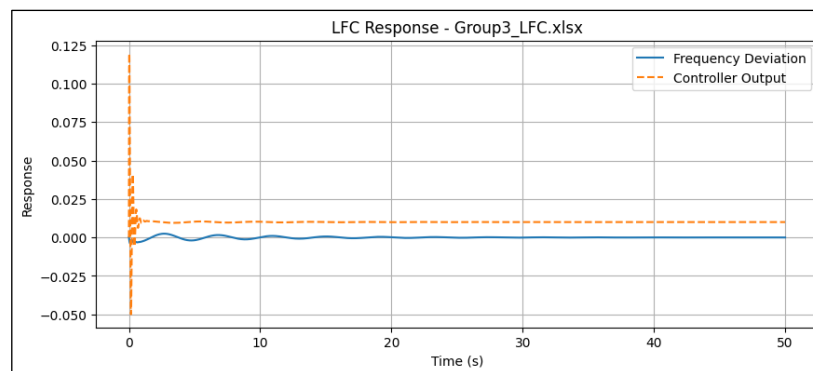


Figure 5: LFC response of Group 3.
Source: Authors, (2026).

The automated formative feedback, as shown in Table 4, reinforced these findings by highlighting strengths such as good steady-state control across all groups, while also pointing out specific weaknesses such as excessive oscillations.

Table 4: Automated formative feedback summary.

Group	Formative Feedback
Group1_LFC	Well-damped response with negligible error and no overshoot; considered benchmark.
Group2_LFC	Good steady-state accuracy but too many oscillations; requires an increase in (Kd).
Group3_LFC	Excessive oscillations and the highest overshoot need major retuning of (Kp), (Ki), and (Kd).
Group4_LFC	Acceptable performance with mild oscillations; derivative gain adjustment suggested.

Source: Authors, (2026).

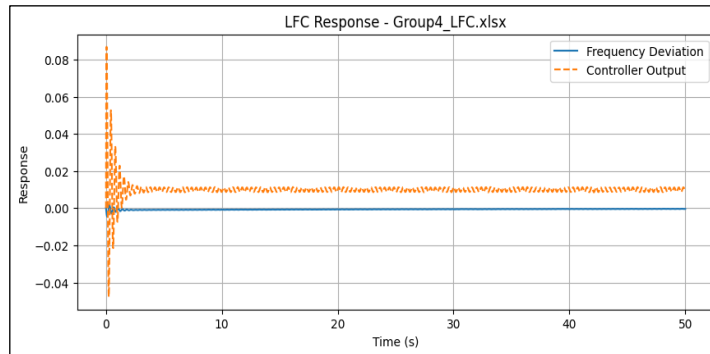


Figure 6: LFC response of Group 4.

Source: Authors, (2026).

Overall, the analysis shows that while students could intuitively achieve frequency regulation, damping characteristics became the key differentiator among groups. The formative assessment is done for all groups. The formative assessment framework successfully provided immediate, targeted feedback, helping students understand the relationship between controller parameters and system dynamics.

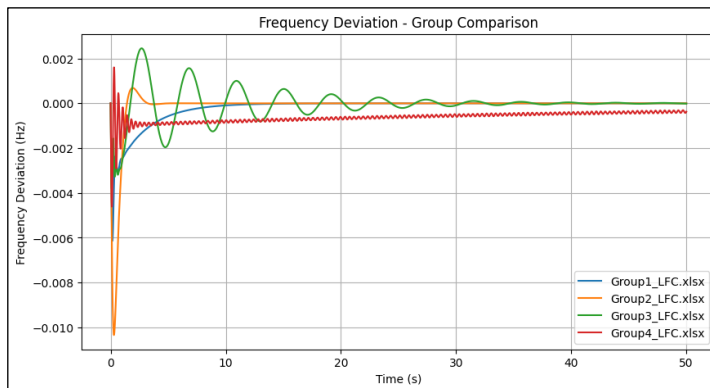


Figure 7: Comparison of the LFC response of various Groups.

Source: Authors, (2026).

From a technical perspective, the results show that all four student groups achieved near-zero steady-state error, confirming that manual PID tuning can effectively regulate the system frequency under load disturbances. However, transient behavior varied significantly. The best performance is identified based on various parameters. Group 1 achieved the best performance with minimal oscillations and no overshoot, while Groups 2, 3, and 4 demonstrated varying degrees of underdamping, reflected in higher oscillation counts. These variations highlight the importance of tuning the derivative gain (Kd) to enhance damping and mitigate oscillatory behaviour, while avoiding excessive proportional action that can worsen transient instability.

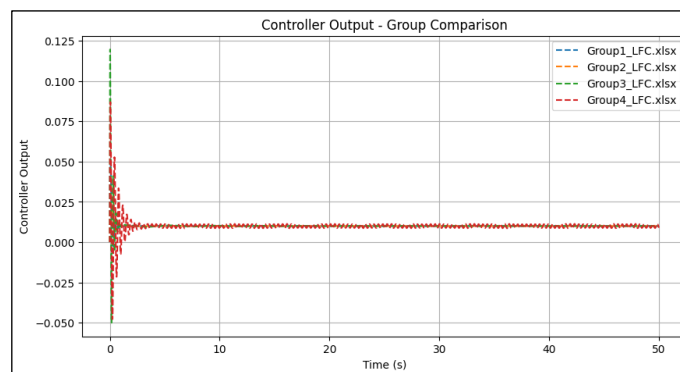


Figure 8: Comparison of controller response for various Groups.

Source: Authors, (2026).

From a teaching and learning standpoint, combining MATLAB/Simulink with Google Colab created an effective environment for formative assessment by providing students with timely, meaningful feedback. This technique will help students learn complex problems. The automated evaluation and ranking system helped students directly relate their tuning decisions to measurable performance indicators, which encouraged them to refine their work through repeated attempts rather than treating the exercise as a single grading event. Working in groups further supported peer learning, comparison, and discussion, making the activity more collaborative and reflective. In addition, because Google Colab is cloud-based and platform-independent, it provides easy access. It ensures that results can be reproduced consistently, making it a useful tool for both classroom instruction and remote learning.

IV. CONCLUSIONS

This work introduced a formative assessment framework for teaching Load Frequency Control (LFC), combining MATLAB/Simulink for system simulation with Google Colab for automated analysis and feedback. The analysis carried out based on various parameters. Four student groups independently developed single-area power system models, applied manual PID tuning, and analysed system responses to a step load disturbance. Although all groups successfully eliminated steady-state error, variations in oscillatory behaviour underscored the importance of proper derivative tuning for achieving stable, well-damped performance. The feedback can be obtained from the analysis. By delivering instant feedback, scores, and rankings, the Google Colab environment enabled students better to understand the link between controller parameters and system dynamics while also encouraging iterative refinement of their designs. The results demonstrate that integrating simulation-based exercises and formative assessment can significantly strengthen technical learning, teamwork, and student engagement.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Idamakanti Kasireddy, Devineni Gireesh Kumar and Neelesh Kumar Gupta.

Methodology: Idamakanti Kasireddy and Devineni Gireesh Kumar.

Investigation: Idamakanti Kasireddy and Devineni Gireesh Kumar.

Discussion of results: Idamakanti Kasireddy, Devineni Gireesh Kumar, Neelesh Kumar Gupta and Prasad Chongala.

Writing – Original Draft: Idamakanti Kasireddy.

Writing – Review and Editing: Idamakanti Kasireddy and Devineni Gireesh Kumar.

Resources: Devineni Gireesh Kumar.

Supervision: Devineni Gireesh Kumar and Neelesh Kumar Gupta.

Approval of the final text: Idamakanti Kasireddy, Devineni Gireesh Kumar, Neelesh Kumar Gupta and Prasad Chongala.

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