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Enhancing the Western Mountain Power Plant controller effectiveness by managing the system's step response to abrupt load fluctuations

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ABSTRACT

This paper presents one of the most accurate, stable, and fast-response modern control models, which is considered as a special case of closed-loop control systems known as the Proportional Integral Derivative (PID) controller tuning system or the Model-based tuning, which is based on a proportional-integral-differential control system parameters through which different forms of control modes are presented and compared to reach the final best response. The response of the sub-patterns of the plant governor was shown and how to benefit from these results in the precise control of the frequency of the generated power to achieve system stability as quickly as possible, in addition to programming it as a controller of the type of programmable logical controller (PLCs) with one of the control programs for monitoring and data acquisition for the speed and load controller inside the gas turbine station (GT). The main role of PLC was simulated using this PID controller in MATLAB to calibrate the controller as a type of controller in Supervisory Control and Data Acquisition (SCADA). The results were shown in the form of logical graphic curves representing the step response to the sudden change in the load added to the network according to the total power generated where the accuracy of PID in the response results makes this application an integrated system that can be formed as a basic structure for many practical applications. Given the potential electrical hazards associated with an imbalance in the load lines across the network, it is imperative to enhance the controllers within the generating unit by using such kind of protection and controlling scenarios.

1. Introduction

A blackout is defined as a complete collapse of the electrical grid due to a combination of factors that leads to a major imbalance between the amount of energy generated and the amount of energy consumed (Hasan M. Salman, Jagadeesh Pasupuleti ,Ahmad H. Sabry, 2023). The electrical grid control center manages energy distribution. It watches energy use and decides when to turn generators on or off based on demand. If there are problems, it tells stations to produce more energy to meet needs after cutting off some loads. A complete blackout differs from a partial blackout, which may be optional (carried out by network operators) for maintenance or load-shedding purposes or mandatory as a result of a cut in the electricity transmission cables[1]. The grid does not store any energy, as the generation and demand are continuously balanced to be permanently equal based on load forecast curves and studies. Therefore, we conducted such a study to provide the best comprehensive prevention solutions that are supposed to include all beneficiaries of the energy generated by this network, whether individuals

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or companies. We observed that the most important damage that occurs to the beneficiaries of this energy is the sudden large power increased provided to them by the electrical network, which may cause malfunctions and losses. If its cost is estimated, it will reach millions of dollars annually (The European Commission (EC), Vienna : International Atomic Energy Agency, 1996). The idea came to researchers to search for the best preventive solution to bring the network to stability in the fastest period before and after loading, especially when connecting loads, which leads to a change in the frequency of the generated energy and its value, which may increase during loading by an amount that may cause these malfunctions and losses. By considering the Western Mountain Gas Power Plant Fig.1 and the protection systems it contains before and after loading it onto the grid, the systems responsible for ensuring that the energy generated by the plant reaches complete stability after loading without any damage resulting from sudden loading, one of which is known as the Gas Turbine (GT) controller, which is generally taken to be the control equipment that addresses the fuel valves as final control elements and sets the flow of the fuel gas and oil. Thus, I&C is responsible for correcting the thermal to mechanical and from mechanical to electrical energy conversion to match the prevailing demand. For this, the SIMADYN D control system was used (SIMADYN D Edition 12.2003), while (SIMADYN D 04.2011) as an improved control system is a better choice since it combines powerful arithmetic operations with more high processing speed, precision, and flexibility. These features are required to solve a wide range of processing tasks universally, even with extremely high throughput rates. Because of this progress in industrial automation systems, an industrial revolution has been achieved owing to the speed and accuracy it has provided in production and the great dispensing of human hands, where the primary goal in this field is to mitigate the impact of sudden network load on all user's electrical devices and maintaining the whole network stability . The load frequency control (LFC) is one of the most important issues in any interconnected power control system, and many types of research have been conducted to solve this problem. (Zhengwei Qu, Waqar Younis, Xianglin Liu, Abdul Khalique Junejo, 2024; Désiré Rasolomampionona; Mariusz Klos ; Can Cirit; Pasquale Montegiglio; Enrico Elio De Tuglie ; 2022) .

Figure 1. Western Mountain Gas Power Plant, Nalut, Libya

2. Methodology

In this study, the Proportional Integral Derivative (PID) control parameters were initially determined using model-based tuning while accounting for nonlinear effects. Subsequently, to address uncertainty, optimized parameters for the PID controller were identified, and a table outlining the system inputs and outputs was created. An efficient control system was designed to regulate controller parameters across various system dynamics under uncertainties. This issue was tackled by comparing the proposed method with actual system measurements, demonstrating its superior performance through reduced settling time, increased speed,

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enhanced damping, and zero steady-state error. Improvements are needed in the SCADA interface (SIMADYN-D or SIMATIC-TDC) to effectively visualize and display data for system control, as well as to facilitate operation and maintenance. Therefore, integrating a PID control system, renowned for its accuracy, stability, and flexibility, is recommended, which operates on a closed-loop principle, where the actual system output is measured and compared to the desired value (set-point), and the resulting error is calculated. Based on this "error", the parallel PID controller of the closed-loop system shown in Fig. 2 calculates the control signal to adjust the system input, minimizing the error as much as possible (GL Zhang,2016).

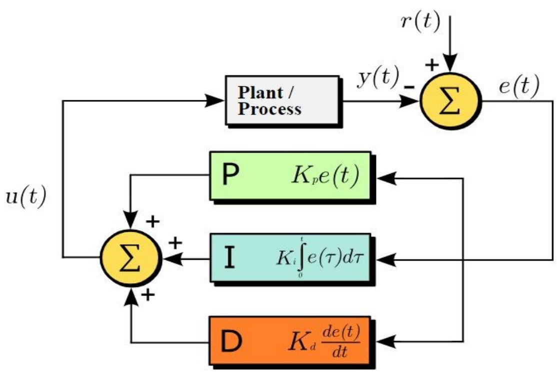

Figure 2. A block diagram of a Parallel PID controller for a closed-loop system.

The Proportional Control (P) is directly influenced by the current error magnitude, meaning that a larger error results in a more robust corrective action. This effect's intensity is governed by the proportional gain (K_P), while Integral Control (I) works by accumulating errors over time, which aids in eliminating the steady-state error that proportional control alone might not address, and the intensity of this effect is determined by the integral gain (K_i). Derivative Control (D) anticipates the future rate of error change, enhancing system response and minimizing overshoots and oscillations. The strength of this effect is dictated by the derivative gain (K_D).

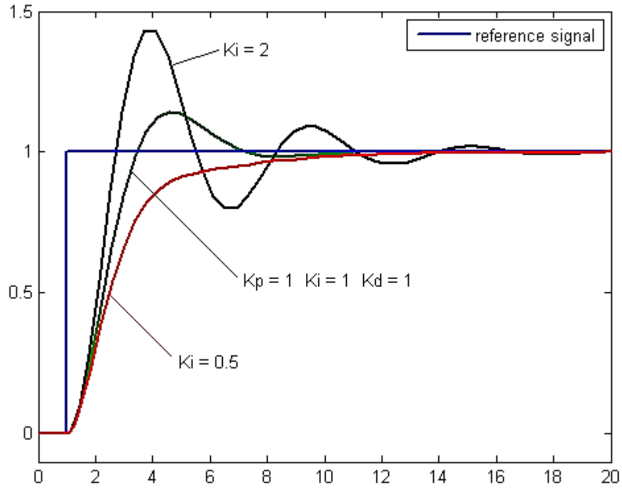

Figure 3. Change in Ki with Ki , Kp and Kd = 1.

The proportional-integral-differential (PID) controller works according to the closed-loop principle, processes the resulting error signal, and provides an output given by the following relation:

$$U(t) = K_P.e(t) + K_i.\int_0^t e(t).dt + K_d.\frac{de(t)}{dt} \quad (1)$$

The resulting PID increases the number of system types by one. It also provides two zeros, which can be used to improve the transient response of the system. Root locus methods can be used to determine these zeros to satisfy the steady-state and transient response requirements of the design. There is also an analytical technique to achieve a specific constant-error performance and specific dominant poles. However, in industrial practice, it is common to adjust the PID compensator in a loop (S. Trimboli,2009; P. V. Gopi Krishna Rao, M. V. Subramanyam, K. Satyaprasad, 2013).

A PID compensator has the transfer function:

$$\text{D(s)} = \frac{U(s)}{E(s)} = K_P + \frac{K_I}{s} + s\,K_D(s) \quad (2)$$

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$$\mathrm{D(s)} = \frac{K_D\, s^2 + K_P\, s + K_I}{s} \tag{3}$$

$$\mathrm{D(s)} = \frac{K_P(\frac{K_D}{K_P} s^2 + s + \frac{K_I}{K_P})}{s} \tag{4}$$

$$\mathrm{D(s)} = \frac{K_P(T_D\, s^2 + s + \frac{1}{T_I})}{s} \tag{5}$$

$$\mathrm{D(s)} = K_P(T_D\, s + 1 + \frac{1}{T_I\, s}) \tag{6}$$

Where $T_D = {K_D}/{K_P}$ is known as the "derivative time", $T_I = {K_I}/{K_P}$ is the "integral or reset time" and $1/T_I$ is called the "reset rate". The tuning parameters provided with commercial PID compensators are often calibrated in these units. The simple type zero control system with open loop transfer function for the Generator (G(s)) is given as:

$$G(s) = \frac{1}{(s^2 + 23\, s + 50)} \tag{7}$$

and for the Turbine is given as:

$$T(s) = \frac{1}{(0.4\, s + 1)} \tag{8}$$

While the error transfer function is given by:

$$G_e(s) = \frac{1}{10\, s + 1} \tag{9}$$

Increasing the proportional gain (K_P) results in a proportional increase in the control signal for a given level of error. This enhancement in the controller's response tends to cause the closed-loop system to react more rapidly, albeit with increased overshoot. Furthermore, increasing K_P tends to reduce, but not eliminate, the steady-state error (e). The incorporation of a derivative term to the controller (K_D) enhances the controller's ability to anticipate error. In contrast to simple proportional control, where the control signal increases only if the error increases, derivative control allows the control signal to become substantial if the error begins to slope upward, even when the error magnitude remains relatively small. This anticipatory behavior tends to introduce damping to the system, thereby reducing overshoot. However, the addition of a derivative term does not affect the steady-state error. The introduction of an integral term to the controller (K_I) contributes to the reduction of steady-state error (e). In the presence of a persistent, steady error, the integrator accumulates, consequently increasing the control signal and diminishing the error. A limitation of the integral term, however, is its potential to render the system more sluggish (and oscillatory). The general effects of each controller parameter (K_P, K_I, K_D) on a closed-loop system are summarized in the table below. It should be noted that while these guidelines are applicable in numerous cases, they are not universal. To ascertain the precise effect of tuning individual gains, further analysis or testing on the actual system is necessary (Y. Wang, 2018; S. Di Cairano, D. Yanakiev,).

Table 1: Effect of Changing Parameters Independently.

PARA-METER	RISE TIME (T_R)	OVER SHOOT (T_P)	SETTLING TIME (T_s)	ERROR (e)	STABILITY LEVEL
K_P	Decrease	Increase	Small Change	Decrease	Degrade
K_I	Decrease	Increase	Increase	Decrease	Degrade
K_D	Small Change	Decrease	Decrease	No Change	Improved if Increase

Due to the inherent complexity in tuning the most fundamental PID loops. The tuning of a PID loop is a scientific process; however, the most prevalent tuning method remains empirical trial and error. Alternative methods exist that necessitate a multi-step process to determine optimal parameter values as the Heuristic and rule-based tuning which require an iterative process while methods such as the Ziegler-Nichols give reasonable results in many simple cases, but aren't able to provide the same structured process and production results as the model-based PID tuning method. MATLAB is recognized as a powerful tool for design, particularly when compared to alternatives such as LabVIEW and Python. Within MATLAB, the Simulink Control Design offers various methodologies for tuning Simulink blocks, including Transfer Function and PID Controller blocks. The initial step in controller tuning is to ascertain the extent of adjustment that can be made without significant implications for the process, if the effects are potentially detrimental, a more measured approach must be adopted. Naturally, the approach will differ depending on whether this is a new installation or an existing plant. In existing installations, the focus is on refining values to create a more stable process.

The gains of a PID controller can be determined through an iterative process of adjustment. Once an engineer comprehends the significance of each gain parameter, this method becomes relatively straightforward. In this approach, the integral and derivative terms are initially set to zero, and the proportional gain is incrementally increased until the output of the loop oscillates. As the proportional gain is increased, the system response becomes more rapid; however, caution must be exercised to prevent system instability. Once the proportional gain has been set to achieve the desired rapid response, the integral term is increased to mitigate oscillations, and the integral term reduces the steady-state error but increases overshoot , and a certain degree of overshoot is necessary for a responsive system to react promptly to changes. The integral term is fine-tuned to achieve minimal steady-state error, and after the proportional and integral terms have been configured to obtain the desired rapid control system with minimal steady-state error, the derivative term is increased until the loop responds acceptably quickly to its set point. Increasing the derivative term decreases overshoot and yields higher gain with stability but may cause the system to become highly sensitive to noise, and frequently, engineers must balance various characteristics of a control system to optimally meet their requirements.

The Ziegler-Nichols method is another widely utilized approach for tuning a PID controller, where it bears significant similarity to the iterative adjustment of the Model-based tuning, wherein the integral and derivative terms are set to zero, and the proportional gain is increased until the loop begins to oscillate. In the control theory, the settling time of any dynamical system is the time elapsed from the application of an ideal instantaneous step input to the time at which the output has entered and remained within a specified error band. The settling time includes a propagation delay, plus the time required for the output to sleep to the vicinity of the final value, recover from the overload condition associated with the slew, and finally settle to within the specified error (Ratna Aisuwarya, 2019).

3.Transient Response Improvement

The feedback control system is shown in Figure.(4), with the input $r(s)$, and output $y(s)$:

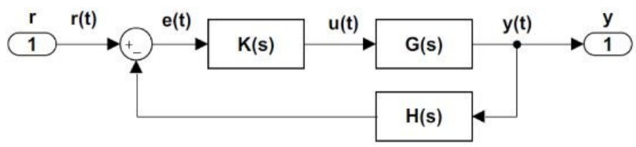

Figure 4. The feedback control system.

$$y(s) = r(s)T(s) \text{ Where } T(s) = \frac{K\,G(s)}{1+K\,G\,H(s)} \quad (10)$$

For the transient system response and steady-state components:

$$y(t) = y_{tr}(t) + y_{ss}(t) \quad (11)$$

the steady-state component of the system response is given as: $y_{ss} = T(0)\, r_{ss}$ for a constant input r_{ss}

Therefore, the transient response is characterized by the roots of the closed-loop characteristic polynomial, given as:

$$\Delta(s) = 1 + K\, G\, H(s) \qquad (12)$$

These roots can be real, complex, distinct, or repetitive. Accordingly, the system's natural response modes are characterized as follows:

- **Real and Distinct Roots**: Let $\Delta(s) = (s - p1)(s - p2) \dots (s - pn)$; then, the system's natural response modes are given as: $\{ep1t, ep2t, \dots, epnt\}$
- **Real and Repeated Roots**: Let $\Delta_m(s) = (s - s1)^m$; then, the system's natural response modes are given as: {es1t,tes1t,…,tm−1es1t}.
- **Complex Roots**: Let $\Delta_c(s) = (s + \sigma)^2 + \omega^2$; then, the corresponding natural response modes are given by: $\{e^{-\sigma t cos\omega t}, e^{-\sigma t sin\omega t}\}$.

4. The General Expression

Assuming that for an order polynomial, the response modes are given as follows:

$$\phi_k(t), k = 1, \dots, n \qquad (13)$$

Then, using arbitrary constants, c_k , the natural response of the system is given as

$$y(t) = \sum_{k=1}^{n} c_k \phi_k(t) \qquad (14)$$

The control system design specifications include the desired characteristics of the transient and steady-state components of the system response with respect to the prototype input. A step input is used to define the desired transient response characteristics. The qualitative indicators of the step response include the following.

1. Rise time (T_R): For overdamped systems ($\zeta > 1$),the rise time is the time taken by the response to reach its final value, and for underdamped systems ($\zeta < 1$) where in MATLAB implementation is chosen to be 0.4 , the rise time is the time when the response first reaches its steady-state value.
2. Peak time (T_P): For underdamped systems, the peak time is the time at which the step response reaches its peak.
3. Response peak (M_P) and percentage overshoot ($\%OS$), where the peak overshoot is the overshoot above the steady-state value.
4. Settling time (T_s): Settling time is the time when the step response reaches and stays within $\pm 2\%$ its steady-state value. alternatively, $\pm 1\%$ these limits can be used.

5. Prototype Second-Order System

To illustrate the above characteristics, we consider a prototype second-order transfer function given by the closed-loop transfer function as:

$$T(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n + \omega_n^2} \qquad (15)$$

The poles for the prototype system are located at: $s = -\zeta\omega_n \pm j\omega_d$, where ($\omega_n = 2$ in MATLAB implement) and

$$\omega_d = \omega_n \sqrt[2]{1 - \zeta^2} \qquad (16)$$

is the damped natural frequency. The step response of the prototype system are given as:

$$y_{step}(t) = T(0)(1 - e^{-\zeta\omega_n t} \sin(\omega_d t + \phi))\, u(t)$$

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where $\phi = tan^{-1}(\frac{\omega_d}{\zeta\omega_n})$ (17)

For the prototype system:

The **rise time**, T_R , is indicated by

$\omega_d T_R + \phi = \pi$ thus, $T_R = (\pi - \phi)/\omega_d$; the rise time is bounded as: $\frac{\pi}{2\omega_d} \leq tr \leq \frac{\pi}{\omega_d}$.

The **peak time** T_P, is indicated by

$\omega_d T_P = \pi$; thus, $T_P = \frac{\pi}{\omega_d}$.

The **peak overshoot** is given as:

$M_P = 1 + e^{-\zeta\omega_n T_P}$; the percentage overshoot is given as: $\%OS = 100e^{-\zeta\omega_n T_P}$, (S. Di Cairano, D. Yanakiev,2018).

The closed loop system model was simulated in MATLAB which is installed in 64-bit Core i7 with 8GB RAM PC. The used value of K_P, K_I and K_D was given in Table (1) gives the setting of PID parameters and Table (2 and 3) give simulated results in terms of rise time, settling time, peak value and percentage of peak overshoot of the system (Gene Franklin,2009).

6. The Speed Start-up Control and Data Acquisition

The start –up torque to start the turbine and generator set is produced partly by the synchronous machine which is fed as an electrical motor by the static frequency converter and partly by the gas turbine. The speed working ranges of both drives are overlapping. Incremental shaft encoders (3 magnetic sensors) are used to detect a multiple of the nominal turbine generator frequency at the shaft circumference. The measured frequency is proportional to the rotation of the shaft per minute. The sensor signals are monitored in the turbine controller and selected in a voter circuit. If one or two measured values fail, this is monitored and signaled as depicted in Fig.(5) (Figures 5 to 9 come from the station's operator manual guide).

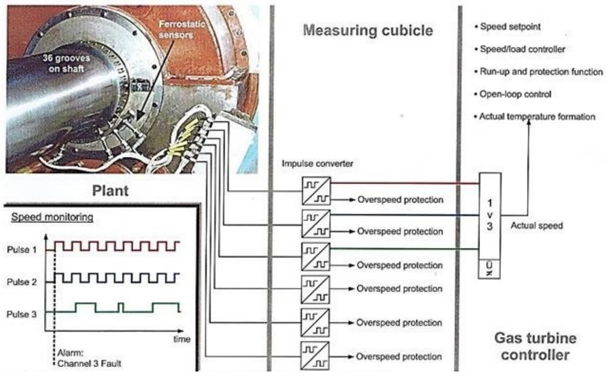

Figure 5. Actual Speed Value Formation.

The speed set point can be adjusted both from a miniaturized control panel and from the operator interface system. The set point can also be controlled with a synchronizing unit. The range of adjustment is between 95% and 103%. In load operation and after turbine generator shutdown, the set point is automatically set in nominal speed as depicted in Fig. (6).

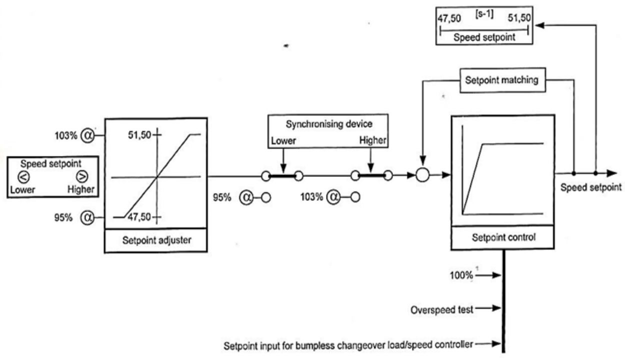

Figure 6. Speed Set-point Model.

It is possible to change from load control operation to speed control operation in the load range (load controller in service /generator connected to the grid). An automatic set point adjustment is made to ensure that the switchover takes place without any appreciable change in the load. The actuation “sudden

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loading" effects a rise of the upper limitation of the speed set point. The strict over load test is performed with the then possible rise of the speed set point into the range of the emergency trip speed.

- **Speed-/load operation:**

The function of the speed/load controller is to match the generator output to the power demand on the grid. The grid is considered to be balanced if the grid frequency is equal to the nominal frequency (50 Hz). If the grid frequency is higher than the nominal frequency, power generation must be reduced. If the grid frequency is lower than the nominal frequency, power generation must be increased . The generator active power is determined with two transducers. The measured signal is gated through a maximum value selection. A channel-fault monitor reports a faulty signal from a transducer.

- **Load Set point:**

The load set point can be set as before from a miniaturized control tile from the operator interface system. The range of adjustment is between 0% and 120% of nominal load as depicted in Fig.(7).

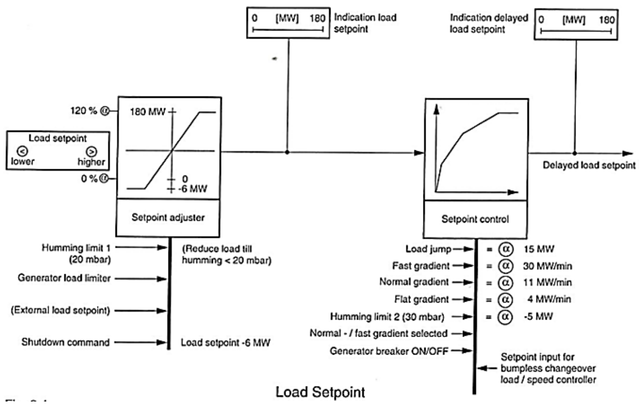

Figure 7. Load Set-point Model.

The set point adjuster can be set as before from a higher-level generating unit controller or a grid controller by means of an analogue control signal. An analogue input for a limit load set point is provided. It can be used to limit the generator load if required. It is possible to change from speed control operation to load control in the load range (load controller in service/generator connected to the grid). An automatic set point adjustment ensures that the switchover takes place without any appreciable change in the load. When humming is detected in the combustion chambers, the load set point is lowered. If the shutdown program is selected , a negative value is selected for the load set point (lower limit of load set-point).

- **Load set-point processing**

After the GT has been synchronized with the grid and the generator breaker has been switched on, loading to the destination set-point is accomplished by means of the set load gradient in set-point control. The output of this set-point control is delayed load set point as depicted in Fig.(8).

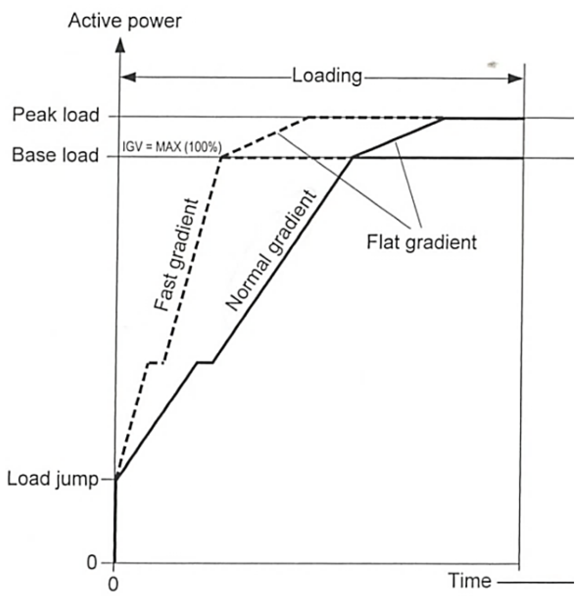

Figure 8. Load Set point Gradients.

Different gradients can be selected for operating modes like "nominal gradient" and "fast gradient". Our loading model is accomplished with step gradient "Fast gradient".

- **Step gradient**

Rapid loading to 15 MW is intended to prevent a gas temperature drop and hence impermissible thermal stress after the preceding start-up to the nominal speed while the load is increased to a load somewhat below base load at the normal gradient of 11MW/min. This sudden load increasing often results from the negligence of the substation employees in performing the duties, which often leads to causing material damage to consumers either individuals or companies.

- **Speed / load controller**

The task of the speed/load controller is to control the load, speed and frequency of the turbine generator in each phase of operation. The main operating phases are synchronization, load operation in stable grid, and operation in a load island. Typical operating modes are described below together with how the gas turbine control system functions . Refer Fig.9 titled "Load Set point Gradients –IGV Controller Off". In the event of a load rejection, which exceeds a threshold or 50% of the nominal load, the operating mode is automatically switched to speed control. Island grid structures may always come into being when a grid unit leaves the interconnected grid system. The task of the control system is to use the primary frequency controller to dimension the fuel feed such that the generated load exactly corresponds to the grid requirements. At the moment when a step load change occurs, the valves are restricted to limit the acceleration of the grid frequency. The load set-point is corrected with the "primary frequency influence" or the "limit frequency influence" in accordance with the rising frequency (speed). In an island grid, the turbine generator acts as a speed controlled generating unit with proportional characteristics (OTTORINO BRUNO ALBERTO LANDI LUCA SANI, 2000).

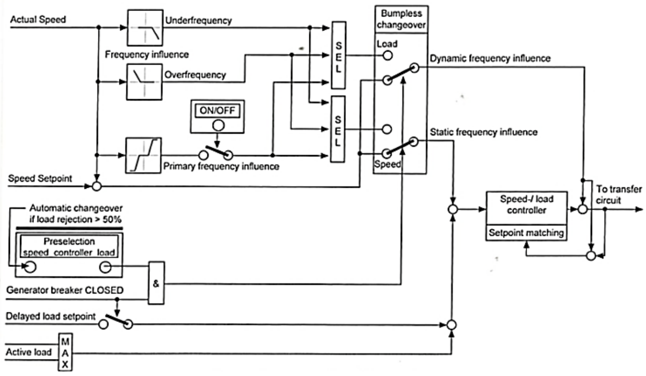

Figure 9. Load Set point Gradients –IGV Controller Off

The effectiveness of the system's control, whether positive or negative, is primarily influenced by the appropriate selection of parameters. Consequently, configuring the PID algorithm parameters is crucial. The expanded response curve method is a closed-loop technique for tuning. When the dynamic characteristic curve of the controlled object is available, this method can be applied to digital PID tuning, similar to its use in analog regulation systems. The process involves the following steps:

1. Setting the system's digital controller to manual mode, by adjusting the controlled quantity near a specified value. Once equilibrium is reached, manually changing the operated value to introduce a step input signal to the object.
2. Recording the controlled quantity's change process under this step input, which represents the soaring characteristic curve of the generalized object.
3. Utilizing the soaring characteristic curve to determine the controlled object's pure lag time τ time constant T_m, and their ratio.

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4. Using the calculated τ, T_m, and their ratio, by choosing a specific control degree, and with consulting the appropriate table to identify the digital PID adjustment parameter values.
5. Implementing the obtained adjustment parameters and observing the control effect then Fine-tune the parameters as necessary until achieving satisfactory control performance.

Since the Simulink model is built in MATLAB and the closed-loop Speed / load controller PID control model has been achieved as shown in Figure (10) all previous steps can be done automatically by the PID tuner to get the best results.

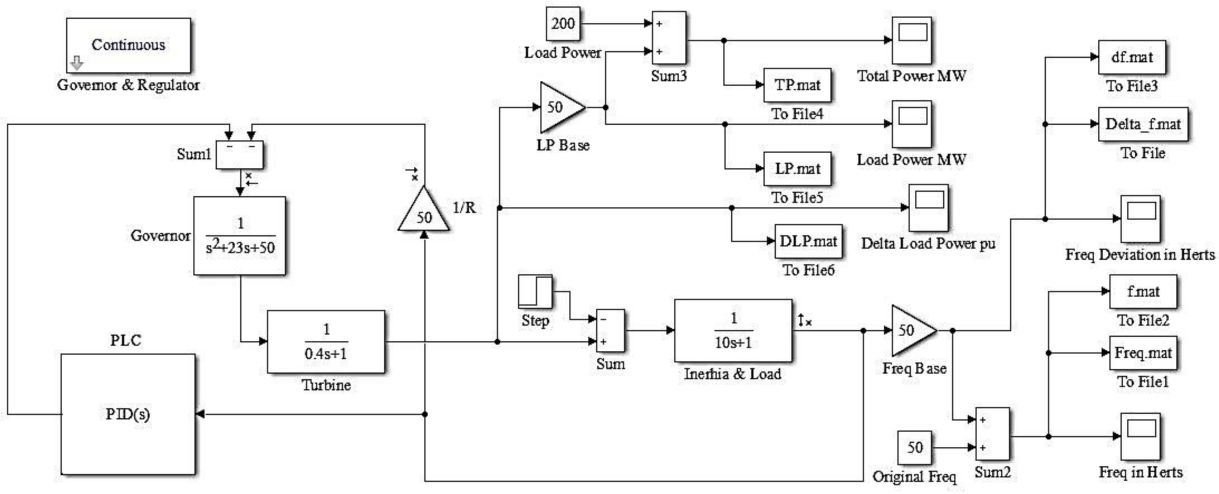

Figure 10. the closed-loop speed / load controller PID control model.

7. The Control Model Capabilities

The system's control effectiveness is examined using few unit step response inputs. Figure (11) displays the resulting output response curves.

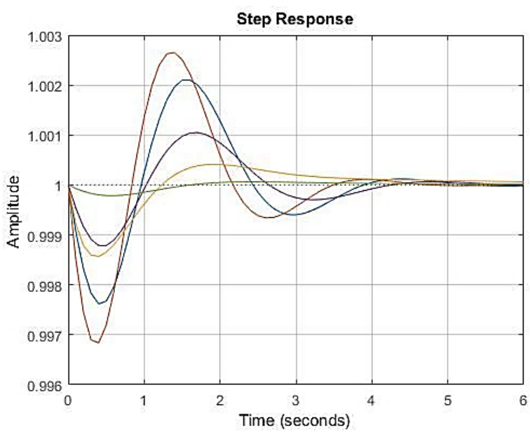

Figure 11. The resulting output response curves.

By evaluating the PID controller parameters that require minimal adjustment to reach optimal settings, the controller can be fine-tuned manually to achieve these ideal values. This process involves manipulating the frequency and power generated impulse response curves generated by the controller, as illustrated in the following figures:

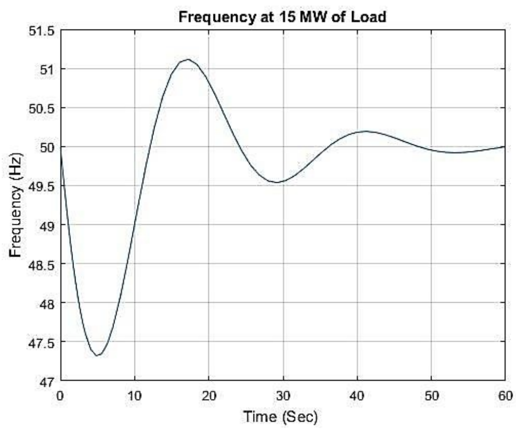

Figure 12. The resulting frequency response before tuning.

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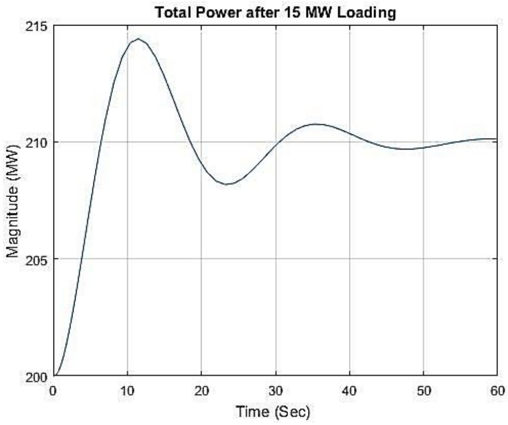

Figure 13. The resulting power generated response before tuning.

8.Transient Response Improvement

Adjusting the proportional (P), integral (I), and derivative gains of a PID controller (D) with the filter coefficients (N) to meet specific design criteria and achieve optimal performance is known as an automated PID tuning according to this equation:

$$P + I\ \frac{1}{s} +\ D\ \frac{N}{1+N\frac{1}{s}} \qquad (18)$$

This process entails determining the optimal values for these parameters to ensure the controller operates as intended. By applying this tuning method to the feedback error of the designed system, the tuning process is depicted in the subsequent figures:

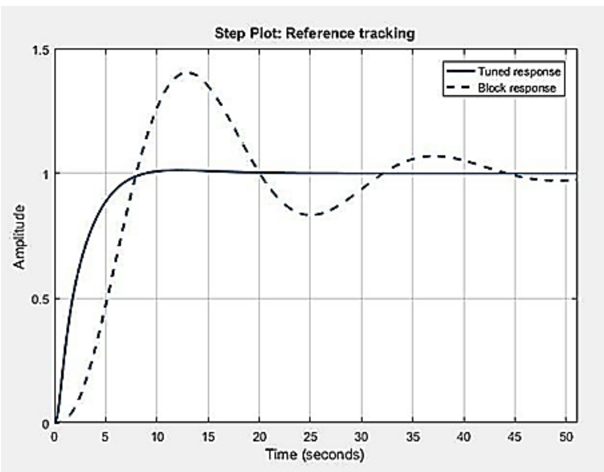

Figure 14. The tuned step response curves.

The step response quality indices mentioned above are all functions of the closed-loop root damping ratio across numerous trials. Four values, each differing in their proximity to the ideal value, were selected for presentation in Table 2. To illustrate this relationship, it is important to consider the variation in step overshoot and the standard settling time:

Table 2: Robustness of the tuned vs. modeled parameters.

Controller Parameter	Block (1)	Block (2)	Block (3)	Block (4)	Tuned
P	8	9	10	15	220
I	28	29	30	35	46
D	3	4	5	6	142
N	100	90	80	70	49

By applying the tuning results we get:

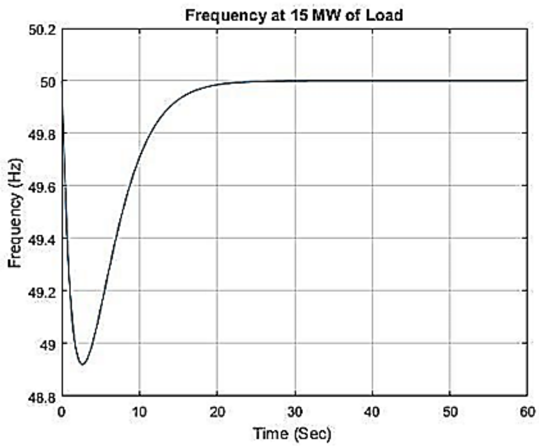

Figure 15. The resulting frequency response after tuning.

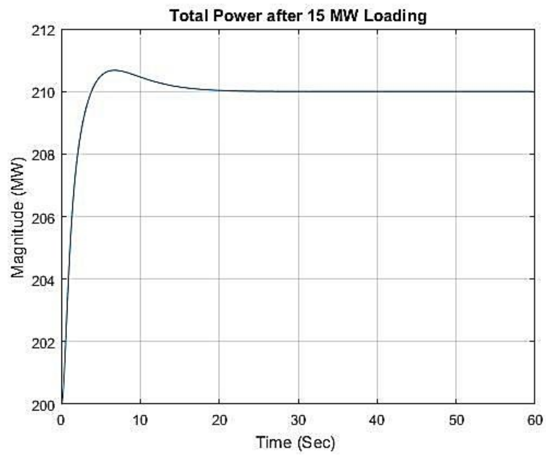

Figure 16. The resulting power generated response after tuning.

https://doi.org/10.61856/41e3fc62

9. Analysis And Discussions

By evaluating the effectiveness of the implemented tuning in optimizing the controller's calibration to achieve outcomes that significantly mitigate the impact of abrupt load increases on the network, the figure below illustrates the amount of change in generated energy, which is a consequence of alterations in the generator's speed (frequency) as in the following figure. These speed variations occur due to fluctuations in the load amount applied to the generator, ultimately affecting the energy output.

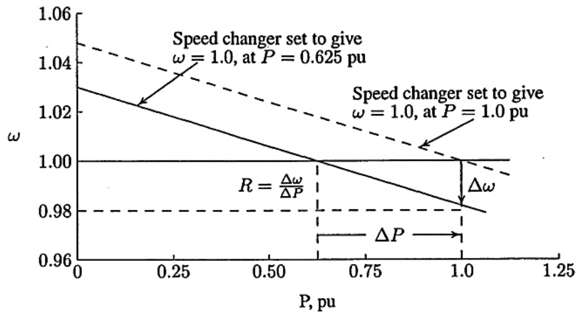

Figure 17. The governor steady-state speed characteristics.

To ensure network stability and protect all energy beneficiaries from risks associated with sudden load increases and device failures, we determined that the optimal solution for enhancing the power generator's response to abrupt load changes is to implement a controller that establishes a link between the error resulting from variations in load, frequency, and generated energy, aiming to swiftly bring these variables to their ideal stable state. By doing so, we can prevent malfunctions at the generating station and mitigate the exposure of connected devices to potential risks (J. Arputha Vijaya Selvi, .K. Radhakrishnan , S. Sundaram., 2007).

Table 3: Indicators of the tuned response vs. modeled

Step Response indicators	Block (1)	Block (2)	Block (3)	Block (4)	Tuned
Settling Time	4.9604	4.3158	5.4993	8.1936	9.9957
Peak Time	1.5720	1.3569	1.6536	1.9234	2.4273
Rise Time	0.05	0.04	0.02	0.03	0.001
Overshoot	0.2115	0.2664	0.1050	0.0414	0.0063
Overshoot %	30.2%	28.4%	21.7%	18.3%	6.37%
Gain margin	22.8 dB	21.1dB	19.4dB	18.2dB	16.8dB

10. Conclusion

The transfer function of the active suspension system was determined through simulation study that examined the PID controller's role in managing the generation system and its relation to frequency changing caused by load changes. The research involved developing various control modes, which demonstrated that properly adjusted parameters from the tuning process outperformed manually modeled parameters (see Table.2), where the study employed four chosen trials to fine-tune the PID controller in this system. The Model-based tuning, or optimization-based PID tuning used by MATLAB Simulink design, enabled to determine the optimal P, I, D and N parameters. The final tuning parameters are influenced by your control goals (such as disturbance rejection and set point tracking), a model of your system, and the engineering specifications for the closed-loop behavior. This method of PID tuning follows a structured process that takes into account both the behavior of your process and your control requirements this includes the settling time, peak time, rise time and overshoot (see Table.3) . In contrast, heuristic and rule-based tuning involve an iterative approach. Techniques like Ziegler-Nichols can yield satisfactory results in many straightforward scenarios, but they lack the structured process and production outcomes that model-based PID tuning offers. Although model-based PID tuning might initially seem more time-intensive, once you establish the correct parameters for your PID loops, the advantages become immediately apparent and are long-lasting. After correctly setting your PID controller the first time, you won't need to revisit it unless there are changes in the process (P. V. Gopi Krishna Rao, M. V. Subramanyam, K. Satyaprasad, 2013).

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