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Output performance evaluation of the automatic voltage regulator system on pre-filter control technique

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ABSTRACT

The combination of an automated voltage regulator (AVR) system and controllers minimizes fluctuation caused by changes in load, speed, temperature, and power factor. This produces a voltage drop in the generator and destroys electricity equipment. This work corrects the divergence through the placement of a proportional integral and derivative (PID) controller with a low-pass filter (LPF) at the generator's input to enhance the AVR system operating principles. The improved performance was obtained by creating a nonlinear model of a synchronous generator, a PID controller, and an LPF in MATLAB/Simulink. At a load variation of 20 seconds, the suggested PID controller with LPF reduces the rise and peak times to 5.2975 seconds and 12.31 seconds, respectively. This raises the overshoot and settling time to 4.28 seconds and 17.60 seconds, respectively. However, the devised technique delivers a balanced temporal behavior for the selected generator voltages examined. The suggested scheme's performance was compared to that of a traditional PID-controlled AVR system without LPF. The proposed technique provides higher stability, which is demonstrated by the percentage overshoot of 4.5788% (for PID) and 4.2765% (for PID with LPF). This has contributed to the understanding of an AVR control system by improving the performance of the rise time, peak time, overshoot, and settling time for stable generator output voltage.

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1. INTRODUCTION

The automated voltage regulator (AVR) is widely employed in electric power systems and industrial applications to ensure that various apparatus is stable and well-regulated. It can be utilized as a passive or active electrical component as well as an electromechanical system. This system can be used to regulated either alternating current (AC) and direct current (DC) voltage depending on the design [1]. As a result, keeping a consistent voltage at a generator's output terminal is critical for a reliable main power supply. It is necessary because system disturbances like change in load, temperature and speed can affect the terminal voltage. Hence, voltage regulating equipment is essential to keep the voltage constant and ensure a continuous supply of appropriate quality. Considering an interconnected system, manual regulation is more complicated, and require the use of an AVR regulation to mitigate the effects. Usually, generated voltage fluctuates mainly due to several variations in power system such as in load, speed, temperature, voltage and power factor causes loss of equipment or system collapse in severe cases. In the power system, where synchronous machines are largely employed for generating and subsequent transmission of electrical energy to connected loads, the system must operate in steady-state conditions. There is a continuous application of constant load which varies and causes a reduction in both voltage and current magnitude that leads to power losses on the power grid [2]. These load changes that require coordinated means can be achieved through automatic excitation using an AVR stabilizes the power system voltages [3]. If there is a deviation from the obtained results, the generation life expectancy and performance will be affected. Therefore, to achieve effective and improved generator performance, the AVR need to be installed at the generator terminals. The power system has a generator with an AVR to stabilize terminal voltage [4]. The terminal voltage will change when the generator's output voltage changes. The AVR voltage is measured by the governor sensor, thus adjusts the excitation system's terminal voltage to retain the generator's terminal voltage at the appropriate level. This causes the generator's field current to change. This situation also affects the electromotive force (EMF) generated. The generator's power generation is set to a more stable position while keeping the terminal voltage constant.

Yavarian *et al.* [1] discuss a hybrid technique using a signal-to-noise ratio (SNR) and particle swarm optimization (PSO) method. The method is use to design and an intelligent PID controller used in the AVR system. They also incorporated an adaptive neuro-fuzzy inference system (ANFIS) to the system. On the one hand, the SNR-PSO scheme was used to determine optimal PID controller parameters, and on the other hand, ANFIS was used to evaluate ideal PID controller parameters [5]–[7]. The developed SNR-PSO PID controller, on the other hand, provided adequate stability between frequency overshoot and transient oscillations with 0% steady-state error, according to simulation findings. Authors in [8], [9] discuss the steady state error that occur in an optimized digital AVR for a synchronous generator. They used a linear quadratic regulator (LQR) technique for the generator excitation. Using digital-based LQR, the study introduced a new AVR technique for the power system optimization. This uses R and Q weighing techniques and were termed the state and control weighting matrices. Its application creates optimal regulator that was used as a feedback control mechanism to develop the LQR control scheme. The results of the evaluation revealed that DAVR loop for the traditional AVR. Muoghalu *et al.* [10] investigated the use of a linear quadratic Gaussian tuned controller to increase the performance response of an automated voltage regulator (AVR) (LQGTC). The goal of the study was to design a control algorithm using the linear quadratic Gaussian (LQG) method. This idea would offer optimal performance for various operation parameters inherent in an AVR system. The conducted effectiveness test through experiment by testing various desired voltage values, and the results obtained were identical to those achieved while using the unit-step input voltage. However, Rajinikanth and Satapathy [11] used teaching learning-based optimization to design an AVR controller. In their study, a one-degree-of-freedom (1 DOF) two-degree-of-freedom (2 DOF) PID control schemes was proposed. It used the standard teaching learning-based optimization (TLBO) algorithm to implement the schemes on an AVR system. The proposed system with 1 DOF resulted in a settling time of 1.6015 seconds and a 0.0126 percent overshoot. Eswaramma and Kalyan [12] used a PID plus second-order derivative (PIDD) controller to operate an automatic voltage regulator system. They suggested an AVR control system that uses a double derivative PID controller (PIDD). The idea gave rise to a dead-beat reaction which reduced the rise and settling time when compared to a traditional PID controller. However, this caused the PIDD to produce a high overshoot in the overshoots transient part with the addition of the pre-filter to the loop to mitigate the effect. Various simulations were performed for both the closed loops without PIDD, with PIDD, and with PIDD plus pre-filter for the AVR system. The outcome shows an improvement on the conventional controllers and voltage stability was achieved as discussed in [13]–[17]. The study aim is to evaluate the behavior of different traditional control schemes in the AVR system by using various models of PID controller which includes; cascade controller internal model controller (IMC) The controllers were separately added in the AVR closed-loop system to deviate the terminal voltage from the rated value. This action introduced instability into the power system [18]–[21].

The system overshoot is lowered from 75% to 16% due to an improved excitation on the designed PID controller [22], [23]. In a similar vein, Odili *et al.* [23] introduced a metaheuristic tuning technique that is dubbed with the African buffalo optimization (ABO) algorithm. The developed technique is used to optimize PID controller settings and it controls the AVR effectively [24]. Similarly, it is reported that ABO approach can solve the problem of steady-state error and overshoot in the system. A scheme has been suggested by the authors in [25] to compare the various PID schemes. They include: genetic algorithm (GA) scheme, particle-swam optimization (PSO) scheme, ant colony optimization scheme (ACO), bacteria-foraging optimization (BFO) scheme and linear quadratic regulator (LQR) scheme. The ABO has proven to have higher tuning capabilities for AVR system PID parameters for effective time-domain performance indicators. Pan and Das developed a fractional-order (FO) PID to handle the AVR system's multiple contradicting objective functions [24]. In the multi-objective optimization problems, the authors deployed an evolutionary technique that is based on a generic algorithm, this technique has been modified with a chaotic map for higher efficiency. PID and FOPID controllers for AVR systems were compared using a multi-objective optimization framework. According to the simulations, none of the controllers performed better than the others for all of the planned requirements. The setpoint tracking and load distribution has been a conflicting term, this is resolved with the use of a controller that outperforms the PID controller. Having examined the various studies by previous researchers, the study presented by Ibraheem [8] provided a more comprehensive and complete model of a synchronous generator.

In the previous study, the linear quadratic regulator (LQR) controller method sees all states as a measurable quantity and develops a control matrix to aid the application of control law. The process requires a computational method especially when the system is subjected to external disturbance or perturbation due to loading or other environmental uncertainties, the LQR will likely give an incorrect response since the developed control law or algorithm will not be robust enough to account for the disturbance variable not captured by the matrix [9]. This paper improves the operating principles and the performance of an AVR system of the synchronous generator studied in [6]. Therefore, a modified proportional integral and derivative (PID) controller with a pre-filter at the input and a low-pass filter (LPF) attached to the derivative component to solve the problem of external perturbation such as noise that affects the performance of the AVR system is proposed in this paper.

2. SYSTEM ANALYSIS

The proportional integral and derivative (PID) technique is widely utilized in industrial process feedback control and has sustain its usage until this present day. Generally, one can categorize a PID controller as a controller that considers the mistake in the present, past, and future. The digital implementation has changed the form of the present control system and has been useful in many applications. However, this change has little impact on the main element used in the design and analysis of PID controllers. A PID controller (proportional–integral–derivative controller) is a control loop feedback mechanism that determines the current inaccuracy of any developed power system. In the case where the gain is made larger, the steady-state error of a proportional controller is inversely proportional to the proportional gain and causes a decrease in the error. To alter the proportional response, the error is multiplied with a constant known as the proportional gain. The proportional gain is calculated as (1).

$$P = K_p \times \text{error}(t) \tag{1}$$

Any change in the error depicts a high proportional gain and this results to a large change in the system output. High proportional gain leads to an unstable system while a low proportional gain can produce a little output reaction to a large input error. When responding to system disturbances, if the proportional gain is very low, the control action may be too little. It is evident that a low proportional gain of a controller causes a reduction in the rising time and steady-state error but can never eliminate the entire system error. The error time and its magnitude are directly proportional to an integral controller (IC) and this makes the integral an important part of PID. This gives the total of the instantaneous error over time and represents the total offset that need to be corrected. This justifies the reason why an integral control helps in the reduction of the steady-state error, even though it may worsen the transient response. The integral term is calculated as (2).

$$I = K_i \int_0^t \text{error}(t)\text{dt} \tag{2}$$

When the rate of change of the error over time is multiplied with the derivative gain K_d, the process error is obtained. The controller output rate of change is depicted by the derivative term and the goal is to improve the system stability, reduce overshoot, and improve the transient responses. The derivative term is calculated as (3).

$$D = K_d \times \frac{\text{derror}(t)}{\text{dt}} \tag{3}$$

2.1. Control technique of a PID controller

The proportional integral derivative (PID) controller is a suitable controller for three-term control-loop feedback in industrial control systems. By changing the process with the help of a controlled variable, the PID controller reduces system error. PID controller maintains optimal control dynamics at a zero steady-state and ensures quick response time. It improves the system rise time, decrease overshoot, mitigates oscillations and maintains system stability. Also, it has application in higher-order process, this makes PID advantageous over other linear controllers. Figure 1 shows a PID control paradigm block diagram.

By analyzing the Figure 1, the mathematical PID representation is developed using equations and formula. The $r(t), e(t), u(t)$ are referred to the reference input quantities, error, and controller output.

Whereas, the K_p, K_i, K_d are the deterministic parameters of the PID controller that can be referred to the proportional, integral and derivative gains. Meanwhile, the $y(t)$ is the generator voltage output.

$$e(t) = r(t) - y(t) \tag{4}$$

The (4) is fed into the PID to perform error computation and the outcome is mathematical expression of the controller output is given by (5).

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{5}$$

For an ideal PID controller, the (5) is used to show the expression for continuous time domain system. This can be represented using a Laplace transform equation in complex frequency domain while assuming a zero initial condition as (6).

$$U(s) = K_p E(s) + K_i \frac{1}{s} E(s) + K_d s E(s) \tag{6}$$

In simplified form as (7).

$$C(s) = K_p + K_i \frac{1}{s} + K_d s \tag{7}$$

Where $C(s) = U(s)/E(s)$ and is called the PID controller.

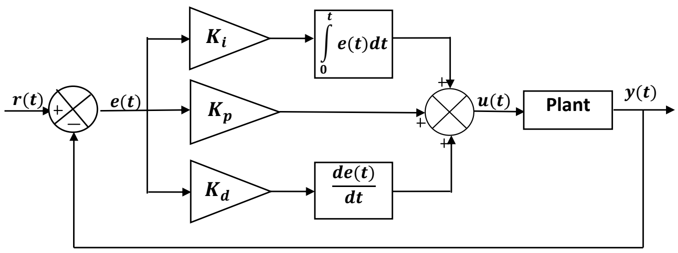

Figure 1. PID control system model

To implement the PID controller in practice, a pre-filter is implemented alongside the derivative components. This would help in solving the problem of noise associated with the system which may interrupt the controller performance through the derivative part. In practice, the PID is modeled using (8).

$$C(s) = K_p + K_i \frac{1}{s} + K_d \left(\frac{sN}{s+N}\right) \tag{8}$$

From the developed model in (8), the PID control algorithm is implemented in this paper and N is the filter coefficient. By tunning the proportional gains of PID controller in MATLAB/Simulink, a fast and robust system is achieved. The tuned parameters are given below.

$K_p = 0.00536$ $K_d = 0.01093$
$K_i = 0.000654$ $N = 39.8$

Substituting the values of the tuned parameters into (8) gives:

$$C(s) = 0.00536 + \frac{0.000654}{s} + 0.01093 \left(\frac{39.8s}{s+39.8}\right) \tag{9}$$

In (9) is the mathematical expression for the designed PID controller in this paper.

3. MATERIALS AND METHOD

The parameters used for the simulation and designing of a PID controller with a pre-filter at the input for the control of an AVR system are shown in Table 1. The simulation results show a linearized model for an AVR system.

Table. 1. Simulation parameters [8]

Parameter	Description	Value	Value
K_d	Damping factor = torque (pu)/speed (pu)	2	Pu
τ_m	Mechanical starting time	8	second
K_a	Conventional AVR gain	50	-
τ_a	Conventional AVR time constant	0.02	second
K_E	Exciter gain	0.17	-
τ_e	Exciter time constant	0.95	second
K_1	Synchronous Machine factor	1.0753	
K_2	=	1.2581	
K_3	=	0.3071	
K_4	=	1.7124	
K_5	=	-0.0476	
K_6	=	0.4972	
τ_3	Time constant of the field circuit	1.8	second
ω_O	Frequency of the system	50	Hz

3.1. Modeling the proposed system

Figure 2 depicts the structure of the proposed AVR system for a synchronous generator. To increase the system's performance response, it shows a linearized exciter model with an amplifier model and a PID plus LPF controller. The model is an AVR closed-loop control system that assures that a synchronous generator's output is maintained at a constant terminal voltage even when the load changes. A low-pass filter or pre-filter at the input, a summing point (or comparator), a PID controller, an amplifier model, an exciter, a generator, and a feedback sensor are all included in the loop [26]. The output is continuously measured and compared to the reference or intended voltage in a feedback control system (input). When an AVR system is modeled without an LPF, there is a linearization of the continuous time-space open-loop, it is combined with a synchronous generator exciter, as described in [8] and illustrated in (10).

$$\left.\begin{array}{l} A=\begin{bmatrix} -\frac{K_e}{\tau_e} & 0 & 0 & 0 \\ \frac{K_3}{\tau_3} & -\frac{1}{\tau_3} & 0 & -\frac{K_3K_4}{\tau_3} \\ 0 & -\frac{K_2}{\tau_m} & -\frac{K_d}{\tau_m} & -\frac{K_1}{\tau_m} \\ 0 & 0 & \omega_o & 0 \end{bmatrix} \quad B=\begin{bmatrix} \frac{1}{\tau_e} \\ 0 \\ 0 \\ 0 \end{bmatrix} \\ C=\begin{bmatrix} 0 & K_6 & 0 & K_5 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad D=\begin{bmatrix} 0 \\ 0 \end{bmatrix} \end{array}\right\} \tag{10}$$

The values of the parameters of the AVR system are given in Table 1. Substituting the values of the various parameters of the AVR of a synchronous generator into (10) gives:

$$A=\begin{bmatrix} -0.179 & 0 & 0 & 0 \\ 0.171 & -0.556 & 0 & -0.292 \\ 0 & -0.157 & -0.25 & -0.134 \\ 0 & 0 & 50 & 0 \end{bmatrix} \quad B=\begin{bmatrix} 5.882 \\ 0 \\ 0 \\ 0 \end{bmatrix} C=\begin{bmatrix} 0 & 0.4972 & 0 & -0.0476 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad D=\begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{11}$$

the state-space representation of the exciter and generator dynamic is further transformed into a transfer function model using the MATLAB code expressed as $[num, den] = ss2tf(A, B, C, D)$ and $G(s) = tf(num, den)$, gives (12).

$$G(s) = \frac{0.05001s^2 - 0.0329s + 3.727}{s^4 + 0.985s^3 + 6.983s^2 + 2.657s + 0.2565} \tag{12}$$

The dynamic model of the amplifier in transfer function form is given by (13).

$$G_A(s) = \frac{K_a}{1 + \tau_a s} \tag{13}$$

Substituting the values of the parameters of the amplifier gives:

$$G_A(s) = \frac{50}{1 + 0.02s} \tag{14}$$

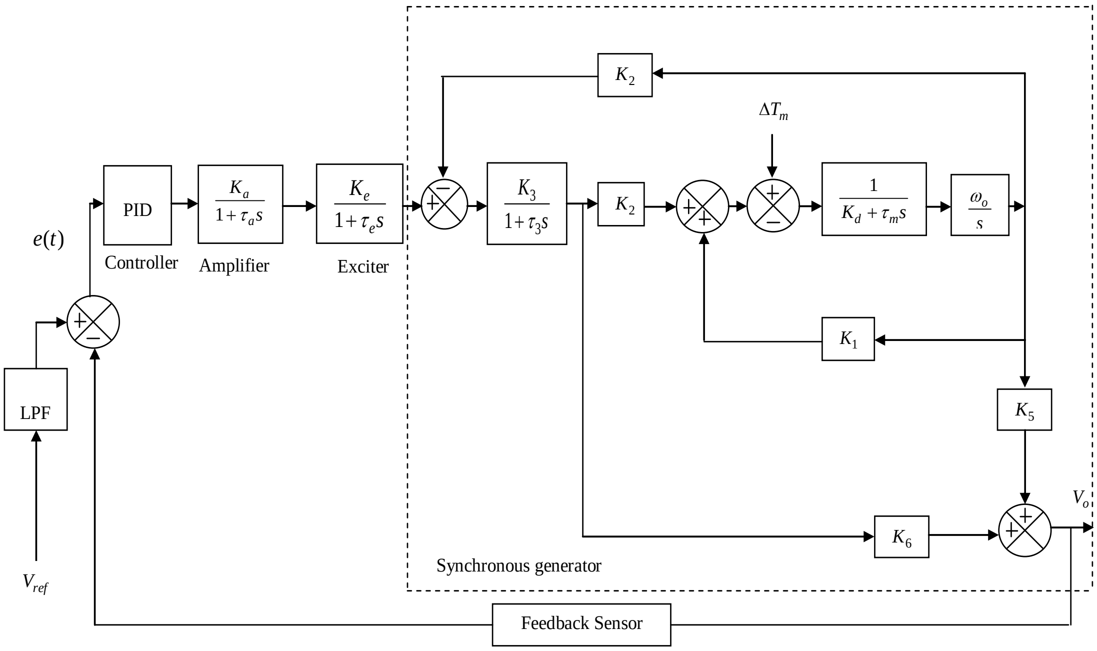

Figure 2. Proposed model for AVR control system

4. RESULTS AND DISCUSSION

The results are presented for various scenarios considering the conventional automatic voltage regulation (AVR) system. This include an AVR system without a PID controller, the integration of PID control algorithm into the loop, and the integration of pre-filter and PID controller in the loop. The generator output voltage for the uncompensated AVR system when the unit step function representing an input voltage is applied to the system. The response is shown in Figure 3. The time-domain analysis of the plot in Figure 4 shows that the rise time $t_r$is 13.5521 seconds, the peak time t_p is 99.420 seconds, the overshoot is 605.7186%, the settling time t_s is 99.9927 seconds, and final value of -1.638×10^6. These characteristics indicate that the generator has cycling output voltage and this indicates instability considering the high overshoot. Also, with the applied unit step input, the output does not meet the desired or reference input. With the unsatisfactory characteristics performance of the uncompensated AVR system, a PID controller was included to the AVR control loop, and simulation was performed for a unit step input. Subsequent simulation is carried out when a low pass filter (LPF) or pre-filter circuit is added at the input. Figure 4 shows the unit step response plot of the simulation results for both cases involving only PID and PID with LPF. The performance analysis of each result is shown in Table 2.

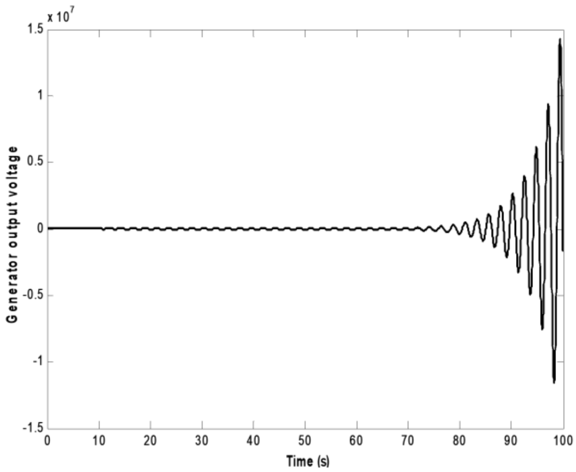

Figure 3. Step response plots of generator output voltage to a unit input

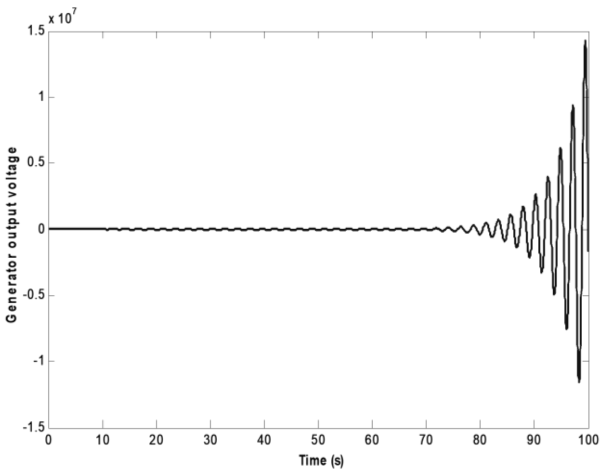

Figure 4. Step response plots of PID and PID with LPF AVR system

The time-domain characteristics of the generator output voltage in Table 2 show that with the introduction of the PID controller, the overall performance parameters improved. The addition of a PID controller provided a rise time of 4.6453 seconds, a peak time of 10.0161 seconds, an overshoot of 4.5788%, a settling time of 16.5366 seconds, and a final value of 1. With respect to these time-domain parameters, it means that the PID-controlled AVR system provided a faster response to the input signal (in terms of rise time and peak time), better stability with reduced peaking and no cycling (in terms of overshoot), and reached or tracked the desired voltage level faster (settling time and final value). With the introduction of LPF at the input, the overshoot was further reduced to 4.2765 percent. In general, the integration of the designed PID controller allowed for the maintenance of the desired voltage level.

Table 2. Analysis of PID and PID with LPF generator output voltage to a unit step input

AVR system	Rise time (s)	Peak time (s)	Overshoot (%)	Settling time (s)	Unit step value
PID	4.6453	10.0161	4.5788%	16.5366	1.000
PID with LPF	5.2975	12.3161	4.2765%	17.6066	1.000

4.1. Performance comparison of PID and PID with LPF for different generator voltages

In this section, further simulations were carried out to compare the time response performances of the PID control technique and the PID with LPF by setting the desired voltage at 25 V, 30 V, 110 V, and 230 V, and the response plots in terms of the actual generator output voltage with their corresponding performance analyses are shown in Figure 5, Figure 6, and Table 3.

Table 3 shows the time domain performance characteristics of the AVR system compensated with a PID controller and a PID controller plus pre-filter circuit (LPF) at the input for different desired generator output voltages. It can be deduced that the PID controller and the PID with LPF controller were able to maintain a similar rise time on average of 5 seconds and a similar peak time on average of 12 seconds for all voltage levels simulated. However, in terms of peak percentage overshoot, the PID with LPF compensation AVR system outperforms the PID-controlled AVR system. This holds for the voltage levels such that for 25 V, the peak percentage overshoot for the PID controller is 11.6362% while PID with LPF gives 0.2765%; for 30 V, the PID controller and PID with LPF offer 12.2281% and 4.2765%, respectively; for 110 V, the peak percentage overshoot was 15.100% and 4.2765% for the PID and PID with LPF compensated systems, respectively; and for 230 V desired voltage, the PID controller offers 16.0051% while PID with LPF gives 6.094% of the peak Another striking observation was the fact that all the PIDs with LPF maintained a robust and constant peak percentage overshoot of 4.2765 in the simulations conducted for desired voltages of 25 V to 110 V, while showing slight variation at the desired voltage level of 230 V. In terms of settling, the PID with the LPF also maintained the same value (17.6066 s) for all simulations of the desired voltage level except for 230 V, where the settling time is slightly different with a value of 19.8884 s.

Generally, the PID-controlled AVR system and the PID with LPF-controlled AVR system can achieve perfect tracking by keeping the generator output voltage at the desired constant voltage, as shown by the final values in Table 4. However, the PID with LPF control system outperformed the PID control system in terms of peak percentage overshoot and rise time in all cases. Furthermore, PID with LPF performed better than PID controller in terms of robustness because it can guarantee that the time domain parameters remain constant even when the desired voltage level changes.

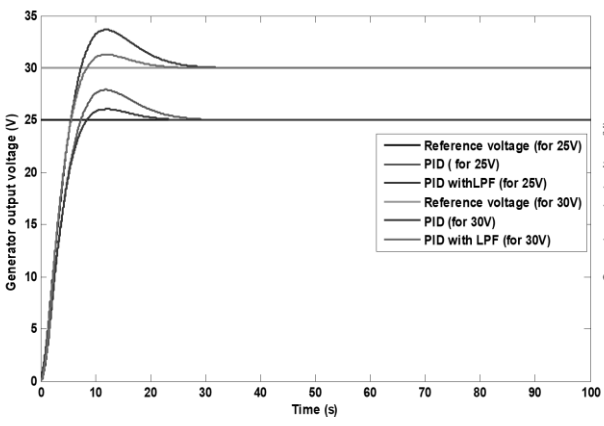

Figure 5. Validation plots for desired voltage of 25 V and 30 V

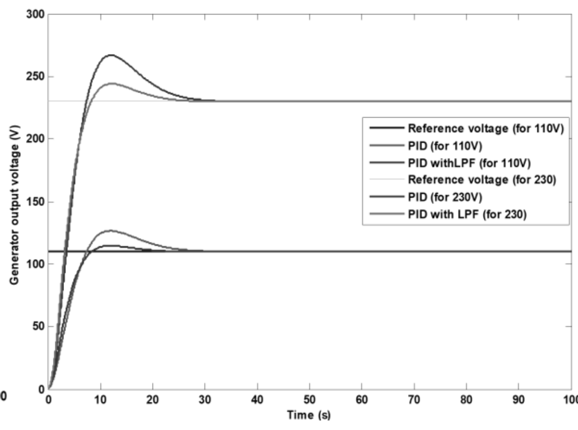

Figure 6. Validation plots for desired voltage of 110 V and 230 V

Table 3. Time-domain performance analysis or various desired generator voltage

AVR system	Rise time (s)	Peak time (s)	Overshoot (%)	Settling time (s)	Ref. value (V)
PID (for 25V)	5.2434	12.0200	11.6362	23.0899	25
PID with LPF (for 25V)	5.2975	12.3200	4.2765	17.6066	25
PID (for 30V)	5.2317	12.0400	12.2281	23.3689	30
PID with LPF (for 30V)	5.2975	12.3200	4.2765	17.6066	30
PID (for 110V)	5.0831	12.1400	15.1007	24.5079	110
PID with LPF (for 110V)	5.2975	12.3200	4.2765	17.6066	110
PID (for 230V)	5.0062	12.1600	16.0051	24.8072	230
PID with LPF (for 230)	5.3090	12.4200	6.0994	19.8884	230

4.2. Validation of the performance of PID and proposed PID with LPF

Simulations are conducted again by introducing a disturbance into the AVR closed-loop control system at 20 seconds to determine and validate the effectiveness and robustness of the PID and the proposed PID with LPF control techniques in handling disturbances, say due to load variation. The response plots in terms of the actual generator output voltage and their corresponding performance analysis tables when a disturbance is introduced into the loop are shown in Figure 7, Figure 8, and in Table 4.

Table 4 is the analysis of the plots in Figures 7 and 8 representing the simulation graphs of a PID-controlled AVR system and a PID with LPF compensation system at a desired voltage of 25 V, 30 V, 110 V, and 230 V, respectively, subject to a unit-step disturbance representing load variation. It can be seen that the only parameter affected by the introduction of disturbance into the system in the form of load variation is the settling time. However, at a desired voltage level of 230 V, it was observed that with PID plus LPF, the settling time remained the same as with the system without disturbance. This shows the superiority of the PID with LPF control AVR system over the PID control AVR system. Thus, it can be said that the proposed system provided robust and efficient regulation of generator output voltage even in the presence of disturbances.

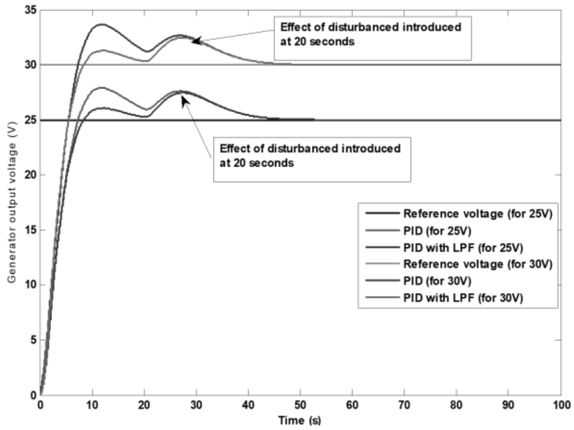

Figure 7. Validation plots for desired voltages of 25 V and 30 V plus disturbance

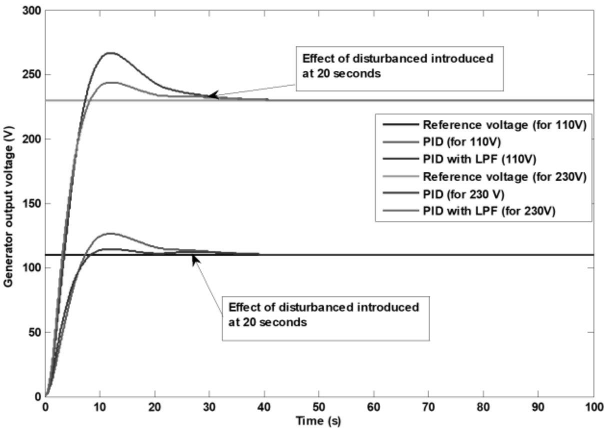

Figure 8. Validation plots for desired voltage of 110 V and 230 V plus disturbance

Table 4. Time-domain performance analysis for various desired generator voltage plus disturbance at 20 seconds

AVR system	Rise time (s)	Peak time (s)	Overshoot (%)	Settling time (s)	Final value (V)
PID (for 25V)	5.2434	12.0200	11.6362	39.3838	25
PID with LPF (for 25V)	5.2975	12.3200	4.2768	39.3483	25
PID (for 30V)	5.2317	12.0400	12.2281	38.5505	30
PID with LPF (for 30V)	5.2975	12.3200	4.2768	38.4994	30
PID (for 110V)	5.0831	12.1400	15.1007	31.4558	110
PID with LPF (for 110V)	5.2975	12.3200	4.2765	29.9005	110
PID (for 230V)	5.0062	12.1600	16.0051	27.5453	230
PID with LPF (for 230V)	5.3090	12.4200	6.0994	19.8884	230

The validation performance results of the PID controlled AVR system and the PID with LPF compensated system at the desired voltages of 25 V, 30 V, 110 V, and 230 V, respectively, subject to unit step disturbance representing load variation shown in Table 4, revealed that the only parameter affected by the introduction of disturbance into the system in the form of load variation is the settling time. At a voltage level of 230 V, it was observed with PID plus LPF that the settling time remains constant even when subject to unit-step disturbance. This indicates the advantage of the PID with LPF control AVR system over the PID control AVR system. Therefore, it can be said that the proposed system provided robust and efficient regulation of generator output voltage even in the presence of disturbances.

5. CONCLUSION

The introduction of a proportional, integral, and derivative (PID) controller with a pre-filter into the control loop of the AVR system has been presented. The dynamic model of an AVR system with a synchronous generator was developed and implemented in the MATLAB/Simulink environment. The characteristics and performance of the system in the time domain were examined via simulations. First, simulation was conducted in terms of response to step when no controller was in the loop, and the result obtained was unsatisfactory. Then a PID controller was designed with the addition of a loop to a pre-filter. The benefits achieved with the introduction of the proposed PID plus pre-filter control scheme was demonstrated by conducting simulations considering a step input voltage, different desired voltages, and response to disturbance. The result obtained showed that the introduction of the proposed PID plus pre-filter control technique largely improved AVR system performance.

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