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Improving Power System Performance by Speed Regulation and PID Controller

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Abstract: There are many techniques can be adopted for improving power system performance. This is because the difference between generated and required powers. In general, this difference causes frequency deviation in all electrical network. Therefore, most of the scientists invented some techniques which help in controlling frequency of electrical models. Changing speed regulation method and applying PID controller are some these techniques. Therefore, this paper highlights these two mechanisms. First technique is speed regulation which will be changed in four values. These values are lower, equal, and higher than critical speed regulation (Rcr). Speed regulation changes tested model from unstable situation to stable with suitable response. However, steady state frequency deviation and power losses remain continuously. Therefore, second technique is added. It is applying PID controller. Similarly, the gains PID controller are varied three times. Practical characteristics of the model are demonstrated. They show a clear enhancing in different features such as rising time, settling time, peak time, and peak value. PID controller helps largely in melting continuous frequency drop and power losses gradually. In fact, the model of suggested system is designed by MATLAB program. In brief, speed regulation, PID controller are main techniques in keeping frequency of power systems in normal values. This supports efficiently in avoiding numerous electrical disturbances.

Keywords: Frequency control, PID controller, Speed regulation, Enhancing dynamic performance.

1. INTRODUCTION

The stability of electrical power systems is considered one of the main factors that must be studied in their design [1]. One of the elements that influence system stability is load demand. As a result, system frequency changes according to the difference between supplied power and load demand [2, 3]. The generators in the system adjust frequency smoothly to create equilibrium between stations and load. The acceptable range of frequency variation without incurring damage is between 48 Hz and 52 Hz when the normal frequency is 50 Hz [4]. Load Frequency Control (LFC) represents an important tool in controlling the performance of an electrical system to avoid numerous faults. There are multiple methods to control the frequency of electrical power systems, such as changing speed regulation and using a PID controller. The role of LFC is to maintain a balance between generated power, load demand, and losses [5].

Various control techniques can be adopted to keep the system within a normal operating range. For example, when the system requires constant frequency, the operator does not need generator control [6]. However, the operator must adjust the velocity and other characteristics of the generator to maintain regular frequency [7]. In this context, any variation in parameters impacts performance. The generator must be controlled to maintain a constant frequency; this type is known as flat frequency regulation [8, 9]. Additionally, parallel frequency regulation is a technique used to share load between two areas where the generators need adjustments to produce constant frequency in the system [7, 8]. Moreover, the PID controller is considered one of the most common techniques adopted in load frequency control [10]. It involves an algorithm that can be directed in various ways and functions like a device [11]. Other useful techniques include the flat tie-line technique, selective frequency technique, and tie-line load-bias control, which are used to manage additional operational situations in electrical power systems and keep frequency constant [12].

2. Mathematical Modelling of LFC

LFC works on a system consisting of several main parts: the generator, load, prime mover, and governor [13]. Therefore, for mathematical analysis of LFC, it is necessary to analyze these parts separately before combining them [14]. Regarding the generator, by applying the swing equation, then [15]:

$$\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \qquad (1)$$

By consuming small variation in speed and taking Laplace transform, will get equation (2) below:

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (2)$$

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)] \qquad (3)$$

For load, it is generally assumed as inductive load. Therefore, equation (4) shows its components down:

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad (4)$$

Where ΔPL: non-frequency sensitive part of load variation

Δω: frequency sensitive part of load variation.

D: coefficient refers to load variation duo to frequency variation.

With respect to prime mover, it is the source of generated power. It can be represented as the ratio between variation in produced power (ΔP_m) to steam valve position ΔP_v

$$G_T = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T s} \qquad (5)$$

Where τ_T: turbine constant and its range varies from 0.2 to 2.0 sec.

With respect to governor, increasing load makes output power higher than input power [16]. Then, kinetic energy in the turbine will decrease and the governor will supply more fuel for compensating the reduction of speed [17].

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \qquad (6)$$

In terms of domain, equation (6) above will be:

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \qquad (7)$$

Where ΔP_g: transferred power from hydraulic amplifier to the steam valve

τ_g: time constant

By collecting the above parts, the block diagram of single phase electrical system with LFC is shown in figure 1 below.

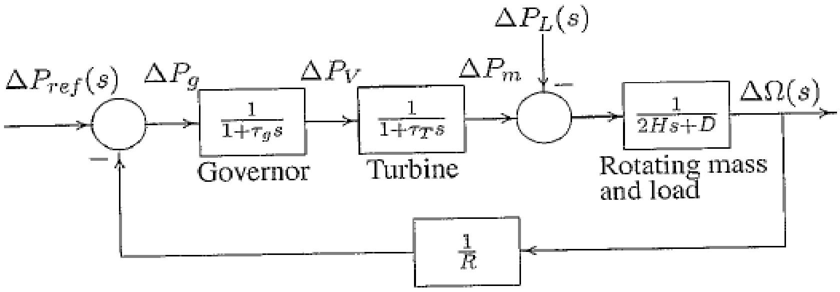


Figure 1. Block diagram of LFC in single area network

For suggested model, the time constants of the governor as well as turbine are 0.25 seconds and 0.5 seconds correspondingly. Moreover, inertia constant (H) of generator is 8 seconds. In addition, the coefficient frequency variation (D) equals to 1.6.

1. Automatic Voltage Regulator

Automatic Voltage Regulator (AVR) is used to automatically maintain and regulate the voltage output of an alternating current (AC) generator or power supply within a specified range. It is commonly used in various applications where stable and consistent voltage levels are required, such as in electrical power systems, industrial machinery, and electronic equipment.

AVR stabilizes the output voltage regardless of fluctuations in the input voltage or load conditions. It continues monitoring the output voltage and adjusting the excitation of the generator's field winding or the control signal of a power supply to maintain a constant voltage level. The Block diagram of AVR is shown in figure 8 below.

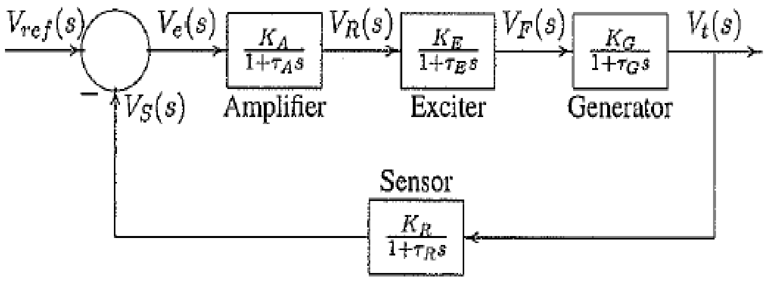


Fig. 8: The simple AVR Block diagram.

2. PID controller

Proportional-Integral-Derivative (PID) controller is one of popular methods which are applied in control field such as temperature control, position control, speed control, frequency control and so on [5, 6]. Equation (8) below is the general equation of PID control [14, 15]:

$$u(t) = K\left(e(t) + \frac{1}{Ti}\int_0^t e(\tau)d\tau + Td\frac{de(t)}{dt}\right) \quad (8)$$

While u is setting variable, e is the error and calculated by this formula ($e=y_{sp} - y$), K is proportional gain, T_i is integral time, however T_d represents derivative time. The block diagram of PID controller is shown in the figure 2 [18].

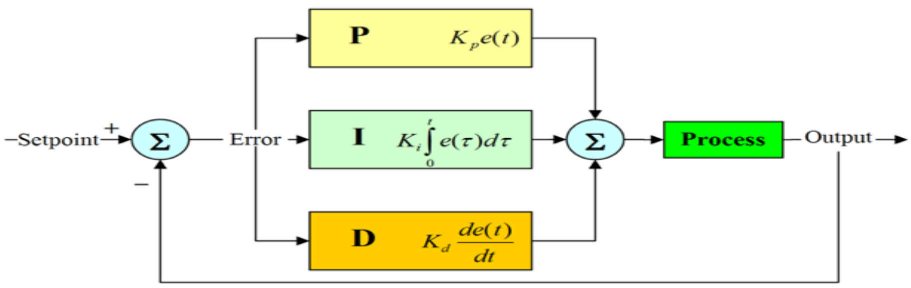


Figure 2. The model of PID controller [18]

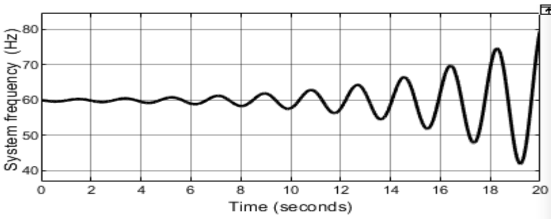
PID controller can be turned by more than numerous approaches. The most popular method is Ziegler-Nichols method and trial-and-error manual tuning method [19]. These techniques help effectively in identifying the parameters of PID controller. The model depends mainly on finding just one point on the Nyquist curve with finding intersection points at negative side of axis [20]. In clear, the point must be limited by two main factors which are the frequency as well as the gain [21]. In addition, Ziegler-Nichols method applies easy experiment then takes out some characteristics of dynamic performance after that these characteristics are used to recognize the parameters of PID controller [22]. In this paper, trial-and-error manual tuning method will be applied.

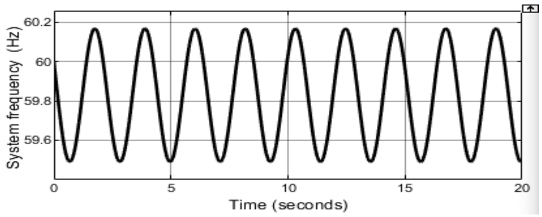
3. Result and discussion

In this section, the results of two mentioned techniques in improving suggested model performance will be discussed in two parts. First part will study the performance of tested model with applying LFC. Second part will use AVR to enhance the response of tested system. The results of these two parts will be demonstrated obviously below.

5.1. System performance with LFC

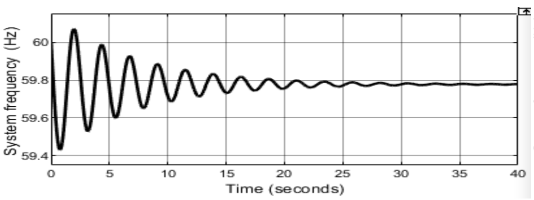
In the beginning, the stability of LFC with suggested system will be estimated in time domain response by changing speed regulation (R) in four cases as compared with critical speed regulation (R_{cr}). These cases are R equals 0.7 R_{cr}, R equals to R_{cr}, R equals 1.3 R_{cr} and R equals 3 R_{cr}. In addition, R_{cr} of the proposed system is 0.009676 p.u. The calculation of critical speed regulation is applied through some theoretical computations. These case studies are discussed obviously below.

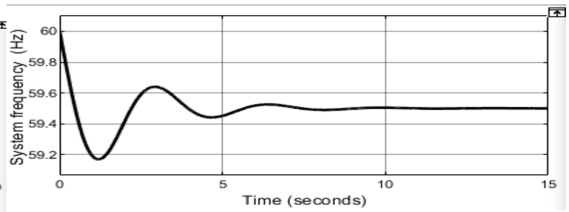




(A) R = 0.7 R_{cr}

(B) R = R_{cr}





(C) R = 1.3 R_{cr}

(D) R = 3 R_{cr}

Figure 3. The oscillation of system frequency at different speed regulation

From figure (3) above, tested system is unstable in case (a) and (b). In case (c), R increases to be higher than Rcr. Then, the performance of tested model demonstrates shrinking frequency oscillation gradually. This oscillation disappears around 35 seconds then the system becomes stable. In case (d), frequency oscillation disappears during 7.5 seconds. However, there is still steady state frequency deviation equals to -0.5 Hz.

After that, LFC is equipped with a secondary integral (KI/s) loop. This loop enables automatic generation control (AGC). The gain of this integral loop is 10. This loop helps in overcoming steady state frequency drop and recovering normal frequency. Frequency response of the tested model with integral loop is shown in figure 7 below.

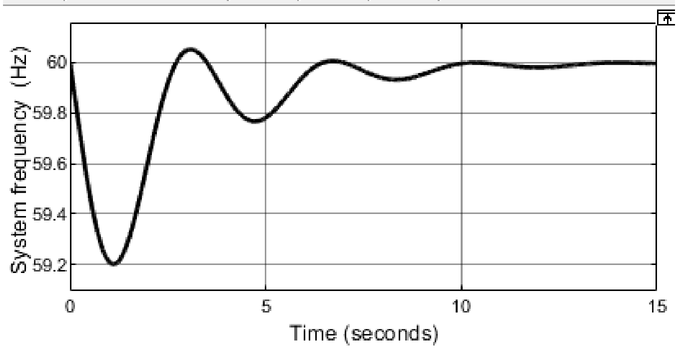
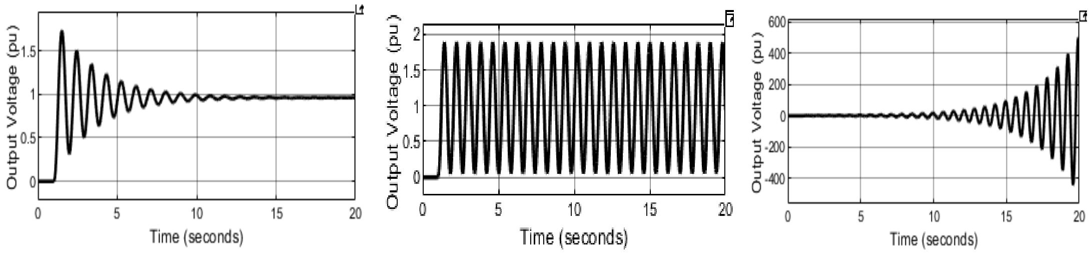


Figure 3. frequency response of tested system with integral loop.

From figures 3 and 4 above, LFC cannot control the response of the model if R is lower or equal to R_{cr}. When R more than R_{cr}, LFC helps in reducing frequency deviation. However, in many situations, LFC cannot reduce frequency deviation to zero. As a result, there is steady state frequency reduction in tested model although connecting LFC. Therefore, it needs to equipping additional integral loop to overcome this steady state frequency reduction.

5.2. System performance with AVR

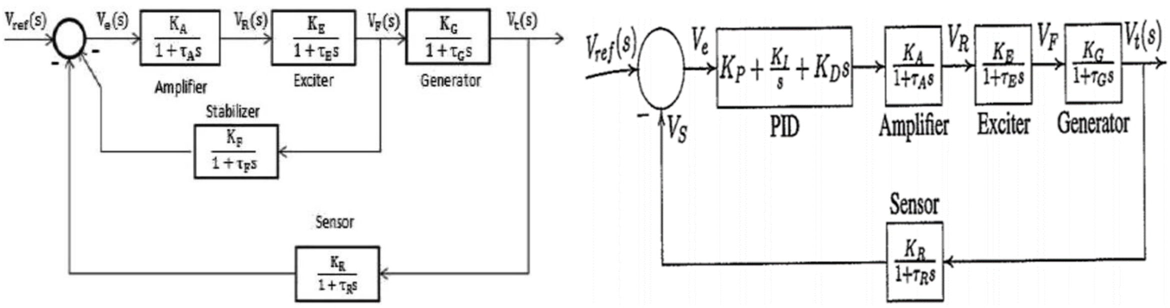
This part highlights the ability of AVR in enhancing the voltage of tested model. In the beginning, the stability of AVR will be evaluated through altering its amplifier gain (K_A) as compared with its critical value (K_{Acr}). There are three case which are K_A lower than K_{Acr}, K_A equals to K_{Acr}, K_A higher than K_{Acr}. K_{Acr} equals to 43.3. Gain (K) values of exciter, generator as well as sensor are 1, 0.8 and 1, correspondingly. In addition, the time constants (τ) of the amplifier, exciter, generator as well as sensor are 0.05 second, 0.5 second, 1 second and 0 second respectively. However, K_A is varied during the situations as mentioned before. The results of these situations are shown in figure 5 below.



(A) $K_A = 0.7\,K_{Acr}$ (B) $K_A = K_{Acr}$ (C) $K_A = 1.3\,K_{Acr}$

Figure 4. Response of AVR at different amplifier gains.

Figure () above shows obviously that AVR is unstable when K_A is equal or higher than K_{Acr}. As a result, K_A should be lower than K_{Acr} for keeping AVR working correcting and saving the model in stable area. This is the first important condition. However, the response of AVR is unacceptable yet because it requires about 20 second to hide oscillation and this is long time. Therefore, in this paper, AVR will be equipped with rate feedback stabilizer firstly and with PID controller secondly as shown in figure 12 below.



(A) AVR with rate feedback stabilizer (B) AVR with PID controller

Fig. 12: AVR model with the rate feedback stabilizer and PID controller separately.

4.2. Adding PID controller

During this part, suggested system with R equals to 3 R_{cr} is supported by PID loop which helps in enhancing system performance and overcoming steady state frequency deviation as well as power losses issues. Design of suggested system with PID controller in MATLAB program is shown in figure 7.

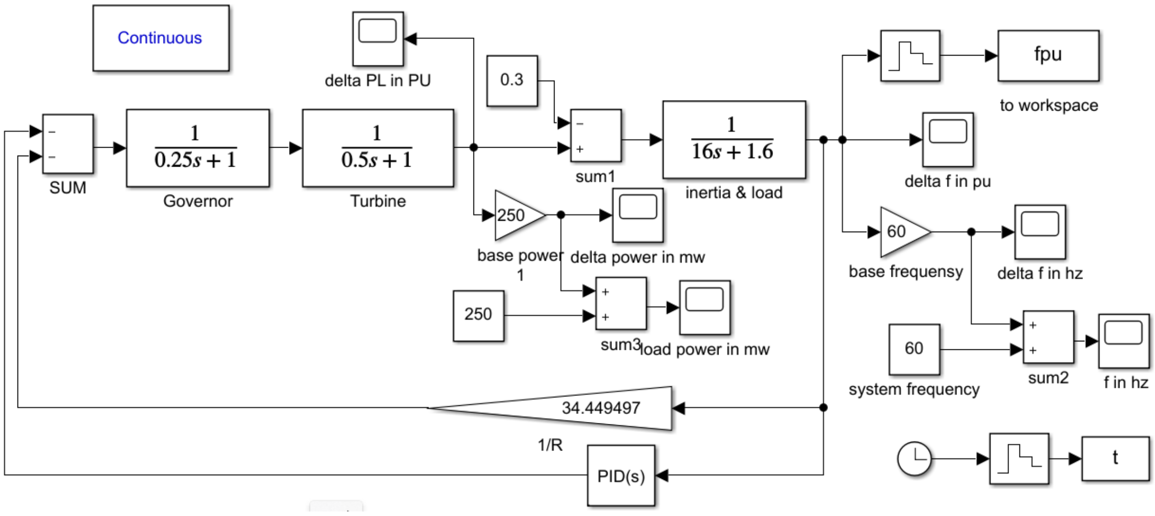


Figure 7. MATLAB design of suggested system with PID controller

In this part, the gains of PID controller are changed three times. The performance of tested system is demonstrated during each case. In first case, gain of proportional (P) equals 5, gain of integral (I) equals 3, and gain of derivative (D) equals 1. With respect to second as well as third cases, the gains are P= 20 I= 10 D= 5, and P= 50 I= 30 D= 10 respectively.

The result shows that system performance without PID has continues frequency reduction about (-0.5 Hz) although R is increased to three times critical speed regulation (R_{cr}). PID controller helps largely in overcoming this problem. When the gains of PID small, system frequency can recover its normal value but it requires rising time exceeds 50 seconds as shown in the figure 8 below. With increasing PID gains, rising time decreases to less than 15 seconds. Moreover, other practical settling time, peak time, overshoot, undershoot, and peak become much better with increasing PID gains. The result of these cases is shown in the figure 8.

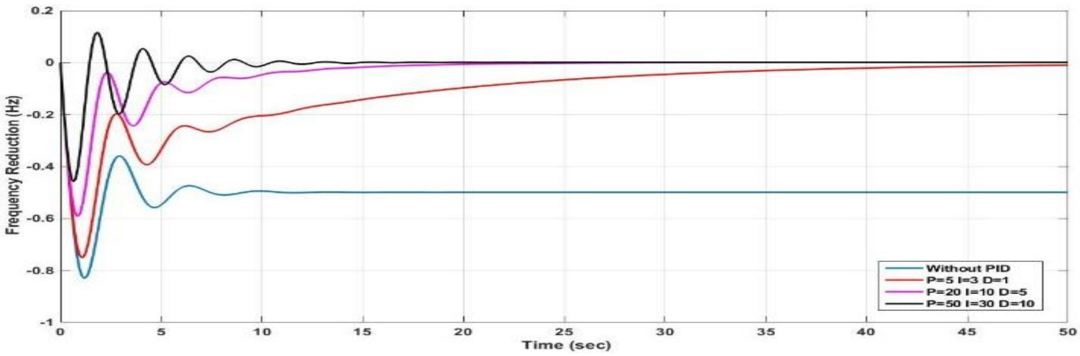


Figure 8. Frequency drop in (Hz) of suggested model with and without PID controller

With respect to power, load power change of the tested model cannot be recovered its best value without PID controller. In fact, there is power losses around (5 MW) in addition to required load power. This is because continues frequency reduction. However, the power returned to normal value with PID controller. Figure 9 shows that obviously.

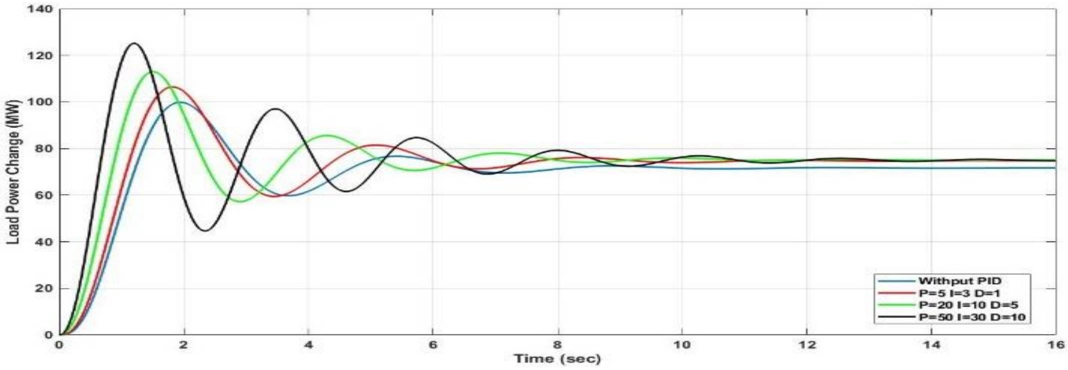


Figure 9. Load power change (MW) of tested model with and without PID controller

Moreover, increasing the gains of PID controller helps effectively in shrinking rising time, settling time, peak time, overshoot, undershoot, and peak value. In clear, table 1 compares these characteristics for frequency deviation obviously. This table creates a clear idea about the development of these magnitudes for each factor in the frequency waves separately during these four situations. In fact, with same speed regulation, rise time of tested model decreases from 0.3778 seconds without PID controller to 1.0306e-10 seconds with PID controller. Similarly, settling time reduces from 8.3110 seconds to 10.1429 seconds. Moreover, peak value falls from 0.0138 seconds to 0.0076 seconds. Furthermore, peak time shrinks from 1.1930 seconds to 0.6490 seconds. These developments are considered an important enhancing in the model performance.

Table 1. Characteristics of frequency drop with and without PID controller

Case study / Data	With Speed change without PID	With Speed change & P=5, I=3, D=1	Speed change & P=20, I=10, D= 5	Speed change & P=50, I=30, D= 10
Rise Time	0.3778	0.0076	3.8842e-06	1.0306e-10
Settling Time	8.3110	38.0609	17.1945	10.1429
Settling Min	-0.0138	-0.0125	-0.0099	-0.0076
Settling Max	-0.0060	-1.6867e-04	-3.6809e-07	0.0019
Over shoot	66.1943	7.3129e+03	2.6789e+06	7.8042e+10
Under shoot	0	0	0	1.9683e+10
Peak	0.0138	0.0125	0.0099	0.0076
Peak Time	1.1930	1.0730	0.8520	0.6490

In addition, table 2 shows the varying in rising time, settling time, peak time, overshoot, undershoot, and peak value for load power changing signals.

The outcomes below demonstrate that with same speed regulation, rise time reduces from 0.7430 seconds without PID controller to 0.4259 seconds with PID controller. Also, settling minimum falls from 0.2390 to 0.1785 from without PID controller to with PID controller. similarly, peak value shrinks from 0.3995 in the first case study (R= 3 R_{cr} without PID controller) to 0.5008 in the fourth case study (R= 3 R_{cr} with PID controller). Lastly, peak time also drops from 1.9410 seconds to 1.2010 seconds between first and fourth situations.

Table 2. Characteristics of load power changing with and without PID controller

Case study / Data	With Speed change without PID	With Speed change & P=5, I=3, D=1	Speed change & P=20, I=10, D= 5	Speed change & P=50, I=30, D= 10
Rise Time	0.7430	0.6955	0.5647	0.4259
Settling Time	7.6230	7.4187	7.6378	10.5040
Settling Min	0.2390	0.2378	0.2290	0.1785
Settling Max	0.3995	0.4259	0.4520	0.5008

Over shoot	39.3408	42.0074	50.6736	66.9467
Under shoot	0	0	0	0
Peak	0.3995	0.4259	0.4520	0.5008
Peak Time	1.9410	1.8150	1.5040	1.2010

To sum up, dynamic performance of electrical power system can be enhanced by two main factors which are controlling speed regulation and adding PID controller. The first method is not enough in overcoming all performance issues. The second technique is enhancing 7 first technique in disappearing steady state frequency reduction and continuous power losses.

4. Conclusion

In conclusion, the dynamic performance of a tested model is studied in this paper by two main techniques. The first technique is changing speed regulation. Tested model is designed by MATLAB program with changing power load up to 0.3 pu. This method helps effectively in transferring system from unstable situation to stable situation through increasing speed regulation to three times critical speed regulation. However, there are steady state frequency reduction and continuous power losses cannot be shrunk by this technique [23]. Therefore, second technique is applied with speed regulation. It is equipping PID controller. By applying PID controller, continuous frequency reduction as well as power losses are disappeared gradually. In addition, changing gains of PID controller helps largely in enhancing dynamic performance of tested model such as reducing rising time, settling time, peak time, and peak value [24]. In clear, the results show obviously reducing rising time from 50 seconds to 15 seconds. Furthermore, the practical features of frequency drop in addition to load power changing are calculated. They show evidently an improvement in most of these data like rising time, settling time, peak time, and peak value. Therefore, the comparison between first and fourth case studies demonstrates that PID controller helps largely in improving most of practical characteristics of frequency deviation as well as load power waves. For demonstrating a clear view on this comparison, a practical analysis on the outcomes has been performed. The analysis is applied for both frequency deviation as well as load power changing signals. This analysis shows the variation in rising time, settling time, peak time, overshoot, undershoot, and peak value. To conclude, changing speed regulation and adding PID controller are playing an important role in controlling electrical power systems for avoiding unstable situations. However, speed regulation technique cannot exceed all performance issues [25,26]. Therefore, adding PID controller with changing speed regulation helps effectively in enhancing model performance and satisfies best performance for any electrical system.

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