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EXTRA CONTROL COEFFICIENT ADDITIVE ECCA-PID FOR CONTROL OPTIMIZATION OF ELECTRICAL AND MECHANIC SYSTEM

Erol Can

Erzincan Binali Yıldırım University, School of Civil Aviation, Department of Aviation Electric-Electronics, Erzincan, Turkey

correspondence: cn_e@hotmail.com

Abstract.

Proportional Integral Derivative (PID) controllers are frequently used control methods for mechanical and electrical systems. Controller values are chosen either by calculation or by experimentation to obtain a satisfactory response in the system and to optimise the response. Sometimes the controller values do not quite capture the desired system response due to incorrect calculations or approximate entered values. In this case, it is necessary to add features that can make a comparison with the existing traditional system and add decision-making features to optimise the response of the system. In this article, the decision-making unit created for these control systems to provide a better control response and the PID system that contributes an extra control coefficient called ECCA-PID is presented. First, the structure and design of the traditional PID control system and the ECCA-PID control system are presented. After that, ECCA-PID and traditional PID methods' step response of a quadratic system are examined. The results obtained show the effectiveness of the proposed control method.

Keywords: ECCA-PID, decision-making unit, satisfactory response.

1. Introduction

PID (proportional-integral-derivative) controller control loop method is a control mechanism that has a wide range of uses, such as electronic devices, mechanical devices and pneumatic systems [1–4]. The PID compares the signal sent to the input via the feedback path with the input signal and calculates the error obtained. The PID control system compares the reference signal of input with sensing the output signal of controlled plant via the feedback path. Then, the controller system calculates the error of the obtained signal. This error is sent to P, I, D and after the controller units multiplies this error with a coefficient, it sends new created signals to the input of the target plant system [5, 6]. This process is repeated until the error reaches a minimum value. While PID control studies generally focus on linear systems, studies on a good-performing PID controller are also presented for some system groups with uncertainty [7, 8]. The balancing of the first order time-delayed system using a PID controller with the previously given PID values has been investigated [9, 10] While high order time delay systems are controlled by PID [11–13]. In some studies, it relies on testing the negative feedback control system in continuous oscillation with a step input to calculate the PID gain values. Initially, the integral and derivative terms are disabled by making the gains of zero in the PID controller, and the controller is operated with only a proportional effect. A step input is applied to the input of the system and the K_p gain is increased from zero until a continuous and same amplitude oscillation is obtained at the output of the system [12, 13]. The gain K_p giving sustained oscillation is determined as the sustained oscillation period in seconds. Forcing this method to reach the constant oscillation region may have undesirable results in some applications. Against external factors, the process can easily pass into the unstable region. Therefore, some physical damage to the equipment may occur. It takes a lot of experimentation to calculate its value. However, in some systems, predetermined insufficient controller values may be insufficient to provide the desired stabilisation times. In order to eliminate such situations, an extra control coefficient additive (ECCA)-PID control is recommended, which is based on all these principles, but which can activate the system faster and stabilise the system by providing a shorter settling time. The ideal reference signal is divided into reflection reference values of different magnitudes to form a decision unit to be compared with the error and error change rates. Therefore, extra controller coefficients are produced by observing the error and error rate of change and comparing it with the reflection reference part values of different sizes. It is aimed to provide a faster optimisation with a semi-linear control independently of the controller coefficients entered into the system before. First, the ECCA-PID design working logic is given. Then, in the implementation phase, Conventional PID and Proposed PID are applied to the transfer function of a second-order system and the step response is examined. The ideal response parts expected with the proposed system are tested at the reflection reference values 0–0.5 and 0–1 and the step responses are measured. Considering the results obtained, the proposed method can reach the ideal control point in a very short time, while the traditional system is far from the desired response.

2. Design with PID controller

Although the PD control from three controllers brings attenuation to the system, it does not affect the steady state behaviour of the system. The PI controller, however, increases the relative stability as well as the rise time, although it corrects the steady-state errors. These results lead to the use of PID control, with the use of a combination of PI and PD controllers. K_p, K_i, K_d define the proportional, integral and derivative gain coefficients, respectively. A PID controller consists of PI and PD parts connected in series. The closed loop control scheme for a PID control is given in Figure 1, with e being the error of the output signal, r is the references value.

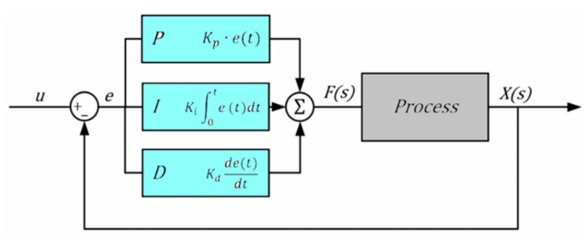


FIGURE 1. The closed loop control scheme for PID.

While the transfer function of PID controller is as below:

$$u(t) = e(t) * K_p + K_i \frac{\mathrm{d}e(t)}{\mathrm{d}t} + K_i \int_0^t e(t)\,dt \quad (1)$$

$$e(t) = r(t) - y(t) \quad (2)$$

Open-loop techniques rely on the results of a bump or step test in which the output of the controller is abruptly manually forced by cancelling the feedback. The graphical slice of the trailing trajectory of the process variable is given in Figure 2 in [10], the curve known as the reaction curve. The sloping line drawn tangent to the steepest point of the reaction curve demonstrates how fast the process reacts to the step change of the controller output. The inverse of the slope of this line, T, which is the measure of the severity of the delay, is the time constant of the process. The reaction curve is also: the dead time (d), which shows how long it takes for the process to give the initial reaction of the process, and the process gain (K), how much the process variable increases according to the size of the step. Ziegler and Nichols determined, by trial and error, that the best values of the tuning parameters P, $\mathrm{T_i}$, and $\mathrm{T_d}$ can be calculated from the T, d, and K values as follows [12, 13]. P is 1.2 T/K_d, $\mathrm{T_i}$ is 2d, $\mathrm{T_d}$ is 0.5d.

A closed-loop technique executes the controller in an automatic mode but with integral and derivative

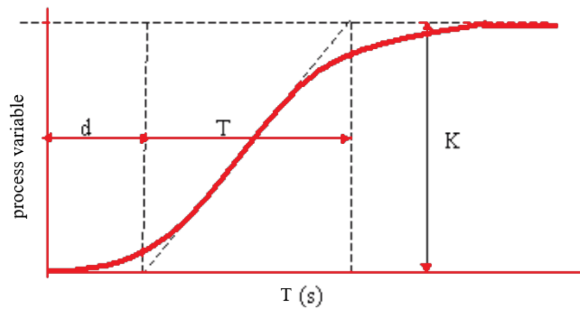


FIGURE 2. Open loop curve.

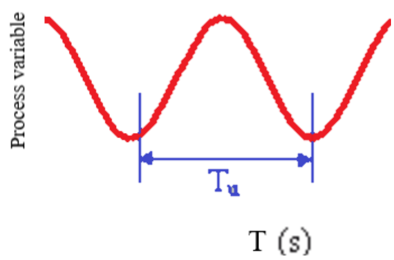


FIGURE 3. Curve for a closed-loop.

turned off. As seen in Figure 3, the gain for the controller is boosted until the smallest error produces a continuous oscillation in the process variable. The gain of the smallest controller that causes an oscillation is named the final gain, $\mathrm{P_u}$. The period of these oscillations is also named the final period, $\mathrm{T_u}$. Appropriate tuning parameters are calculated from the following rules based on these two values [10].

As a results, P is 0.6 $\mathrm{P_u}$, $\mathrm{T_i}$ is 0.5 $\mathrm{T_u}$, $\mathrm{T_d}$ is 0.125 $\mathrm{T_u}$. Despite all these separations and arrangements, the gain K_p giving a sustained oscillation is determined as the sustained oscillation period in seconds. Forcing this method to reach the constant oscillation region may have undesirable results in some applications. The process can move to the unstable region very easily against external factors. Thus, some physical damage to the equipment may occur. So, the ECCA-PID method offers a good alternative to avoid these complex and inconvenient situations of traditional methods. In order to provide a more optimum control, the response expected from the system is divided into partial sizes and compared again with the error obtained, the error and error change rates produced for the control are evaluated, and new coefficients are created to be added to the controller coefficients of the controllers, thus enabling the system to give a better one. $K \in \mathbb{Z}^+ \rightarrow K = \{K_1, K_2, K_3, \ldots, K_n\}$, In order to find the value that will provide the desired control in Rr, the value is to be compared with the error produced by the system; virtual part reference value is $Rr \in \mathbb{R}^+ \rightarrow Rr = \{Rr_1, Rr_2, \ldots, Rr_n\}$, The K values to be produced can be found as follows.

If $e_1 > Rr_1$ *then* K_1

If $K_1 > 0$ *then* $K_p + K_1$ *and* $K_i + K_1$ *and* $K_d + K_1$

If $e_2 > Rr_2$ *then* K_2

If $K_2 > 0$ *then* $K_p + K_2$ *and* $K_i + K_2$ *and* $K_d + K_2$

If $e_n > Rr_n$ *then* K_n

If $K_n > 0$ *then* $K_p + K_n$ *and* $K_i + K_n$ *and* $K_d + K_n$

Unlike other swarm optimization and traditional PID control methods, the proposed method produces linear movements to approach the desired value whenever it is far from the desired value, and in this case, the desired control can be achieved more quickly. Extra control coefficient (ECCA)-PID control is given in Figure 4a while Figure 4b shows the mesh depicting the interaction of the reference and reflection reference values that will contribute to the extra coefficient. The control gains predicted by the decision-making unit can be expressed as the following equations.

$$u(t_1) = e(t_1) * (K_p + K_1) + (K_d + K_1)\frac{\mathrm{d}e(t_1)}{\mathrm{d}t} + (K_i + K_1)\int_0^{t_1} e(t_1)\,dt \tag{3}$$

$$u(t_2) = e(t_2) * (K_p + K_2) + (K_d + K_2)\frac{\mathrm{d}e(t_2)}{\mathrm{d}t} + (K_i + K_2)\int_0^{t_2} e(t_2)\,dt \tag{4}$$

$$u(t_n) = e(t_n) * (K_p + K_n) + (K_d + K_n)\frac{\mathrm{d}e(t_n)}{\mathrm{d}t} + (K_i + K_n)\int_0^{t_n} e(t_n)\,dt \tag{5}$$

If there is too much overshoot and oscillation in the system, the decision-making order of the proposed method can be arranged as follows.

If $e_1 > Rr_1$ *then* K_1

If $K_1 > 0$ *then* $K_p + K_1$ *and* $K_i + K_1$ *and* $K_d + K_1$

Else if $e_1 < Rr_1$ *then* K_{11}

If $K_{11} > 0$ *then* $K_p - K_{11}$ *and* $K_i - K_{11}$ *and* $K_d - K_1$

If $e_2 > Rr_2$ *then* K_2

If $K_2 > 0$ *then* $K_p + K_2$ *and* $K_i + K_2$ *and* $K_d + K_2$

Else if $e_2 < Rr_2$ *then* K_{22}

If $K_{22} > 0$ *then* $K_p - K_2$ *and* $K_i - K_2$ *and* $K_d - K_2$

If $e_n > Rr_n$ *then* K_n

If $K_n > 0$ *then* $K_p + K_n$ *and* $K_i + K_n$ *and* $K_d + K_n$

Else if $en < Rr_{nn}$ *then* K_{nn}

If $K_n > 0$ *then* $K_p - K_{nn}$ *and* $K_i - K_{nn}$ *and* $K_d - K_{nn}$

e is error, de is error change, $e \in \mathbb{R} \rightarrow e = \{e_1, e_2, \ldots, e_n\}$, $de \in \mathbb{R} \rightarrow de = \{de_1, de_2, \ldots, de_n\}$, e and de are expressed as below.

$$e(t_1) = r(t) - y(t_1) \tag{6}$$
$$K_1 = e(t_1) - Rr_1 \tag{7}$$
$$e(t_2) = r(t) - y(t_2) \tag{8}$$
$$K_2 = e(t_2) - Rr_2 \tag{9}$$
$$de_1 = e(t_2) - e(t_1) \tag{10}$$
$$e(t_{n-1}) = r(t) - y(t_{n-1}) \tag{11}$$
$$K_{n-1} = e(t_{n-1}) - Rr_{n-1} \tag{12}$$
$$de_{n-1} = e(t_{n-1}) - e(t_{n-2}) \tag{13}$$
$$e(t_{n-1}) = r(t) - y(t_{n-1}) \tag{14}$$
$$K_{n-1} = e(t_n) - Rr_{n-1} \tag{15}$$
$$e(t_n) = r(t) - y(t_n) \tag{16}$$
$$K_n = e(t_n) - Rr_n \tag{17}$$

Considering the error e_c for a conventional PID control and the effect of the proposed method on the error of the conventional method e_k, $e(t)$ can be arranged as follows.

$$e(t) = e_c + e_k \tag{18}$$

The general equation for the PID can be arranged as follows.

$$u(t_1) = (e_{c1} + e_{k1})(t_1) * (K_p + K_1) + (K_i + K_1)\frac{(\mathrm{d}e_{c1} + \mathrm{d}e_{k1})(t1)}{\mathrm{d}t} + (K_i + K_1)\int_0^{t_1} (e_{c1} + e_{k1})(t_1)\,dt \tag{19}$$

$$u(t_2) = (e_{c2} + e_{k2})(t_2) * (K_p + K_2) + (K_i + K_2)\frac{(\mathrm{d}e_{c2} + \mathrm{d}e_{k2})(t2)}{\mathrm{d}t} + (K_i + K_2)\int_0^{t_2} (e_{c2} + e_{k2})(t_2)\,dt \tag{20}$$

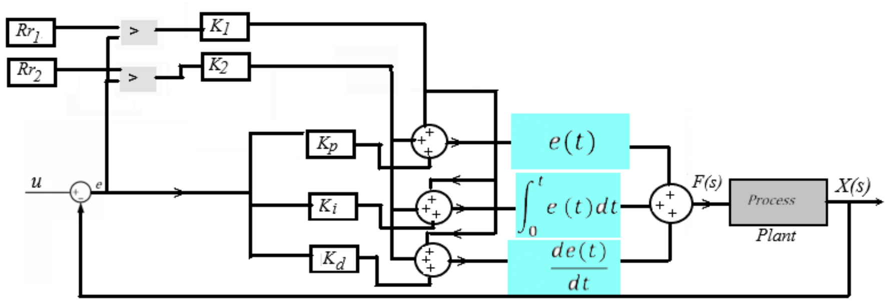
$$u(t_n) = (e_{cn} + e_{kn})(t_n) * (K_p + K_n) + (K_i + K_n)\frac{(\mathrm{d}e_{cn} + \mathrm{d}e_{kn})(t_n)}{\mathrm{d}t} + (K_i + K_n)\int_0^{tn} (e_{cn} + e_{kn})(t_n)\,dt \tag{21}$$

Depending on whether the error is positive or negative, the control diagram of the system is as in Figure 5, in line with the above explanation of the decision-making unit. The equation of the second order and PID system is given in Equation (22).

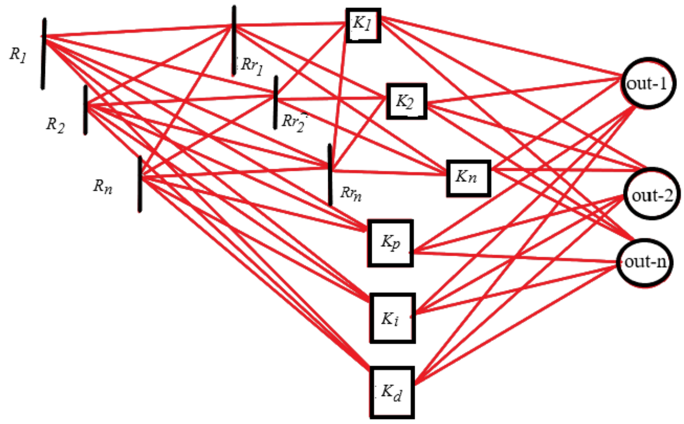
$$\frac{X(s)}{F(s)} = \frac{1}{0.5s^2 + s + 1} \tag{22}$$

The PID control is applied to the system to be tested as in Equation (23).

$$\frac{X(s)}{F(s)} = \frac{K_d \cdot s^2 + K_p \cdot s + K_i}{(0.5 + K_d)s^2 + K_p \cdot s + K_i} \tag{23}$$



(a).



(b).

Figure 4. a) extra control coefficient (ECCA)-PID control, b) relation network between R and Rr.

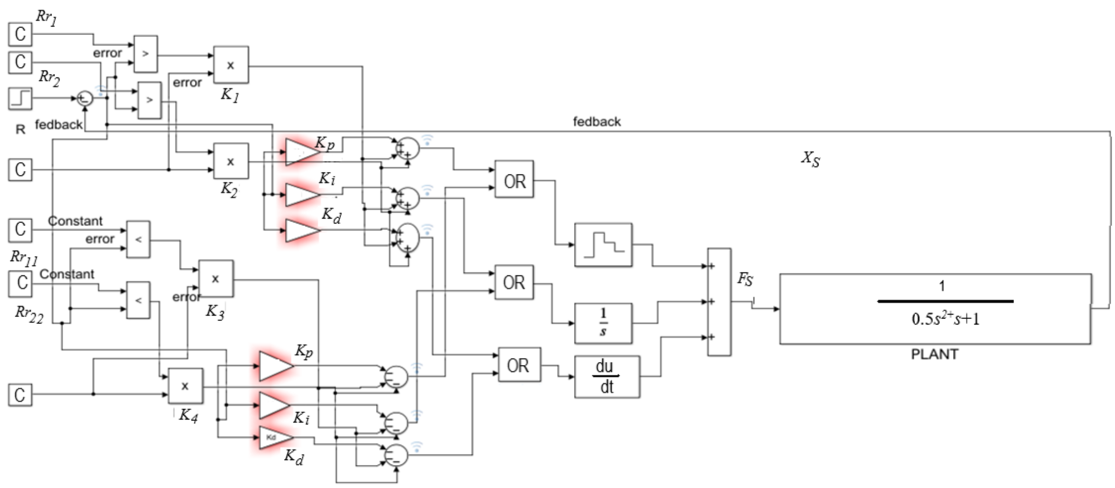


Figure 5. The control diagram of the system, depending on whether the error is positive or negative.

Equation (24) and Equation (25) give the fixed value contributions to the controller systems as a result of the comparison of the reflection reference values in the decision-making unit of the proposed system with the actual controller coefficient values.

$$\frac{X(s)}{F(s)} = \frac{(K_d + K_1) \cdot s^2 (K_p + K_1) \cdot s + (K_i + K_1)}{(0.5 + (K_d + K_1)) \cdot s^2 + (K_p + K_1) \cdot s + (K_i + K_1)} \tag{24}$$

$$\frac{X(s)}{F(s)} = \frac{(K_d - K_1) \cdot s^2 (K_p - K_1) \cdot s + (K_i - K_1)}{(0.5 + (K_d - K_1)) \cdot s^2 + (K_p - K_1) \cdot s + (K_i - K_1)} \tag{25}$$

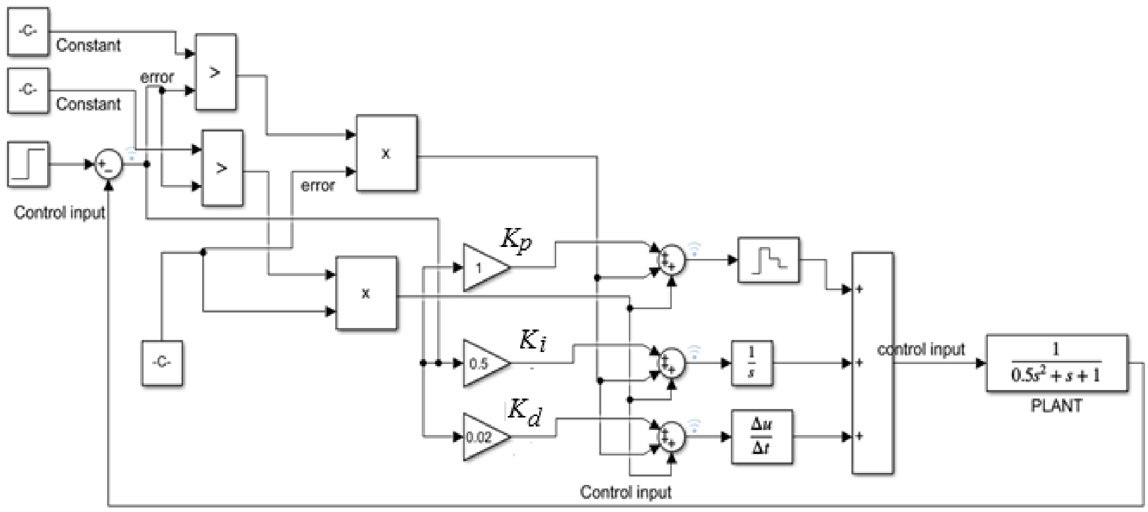


Figure 6. The MATLAB Simulink model of the designed system.

3. (ECCA)-PID control application

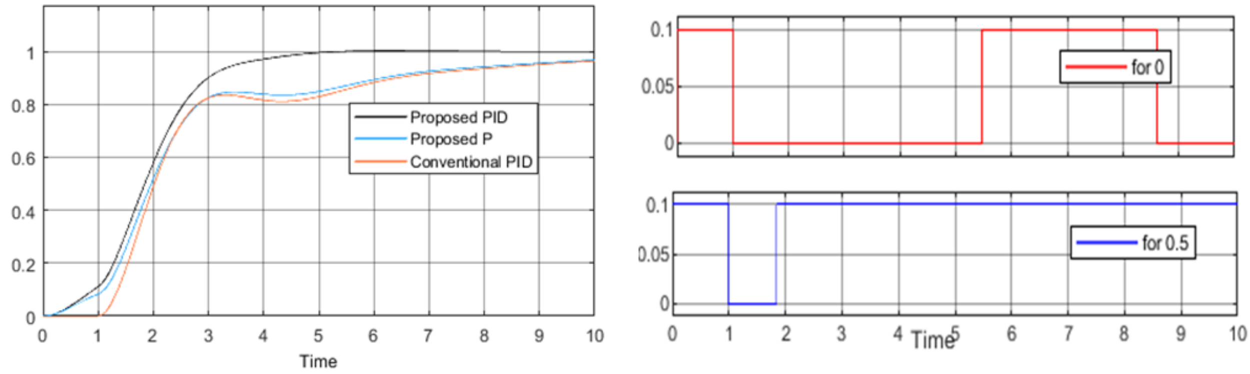
The proposed system is examined over the step response of a second-order system such as $[(1/(0.5s^2 + s + 1)]$. The MATLAB Simulink model of the designed system is given in Figure 6. In the second order system, both traditional PID control method and (ECCA)-PID Control are applied. Figure 7a shows the step response values when two Rr values such as 0–0.5 are given to the proposed system for the step response of the system. While the extra gain values produced by the controller decision unit are given in Figure 7b, the controller output signal and controller errors can be seen in Figure 8. K_p is 1, K_i is 0.5, K_d is 0.02, e is error.

While the rise moment response of the system is as short as 0.1 s for ECCA-PID and ECCA-P, the rise moment response of the system for a traditional PID control is 1.1 s. This means that the rise moment response of the proposed system corresponds to 9 % of the take-off response of a traditional PID controlled system. The settling time for ECCA-P cannot occur in 10 s, but when I-D controllers are added to the total control system, the settling time takes place in 5 s for ECCA-PID. When the system is controlled with a traditional PID, the system is not capable of settling in 10 s. This shows that the desired control can be achieved with the decision-making unit of the proposed system, even if insufficient controller coefficients are selected for the system. Rr values in the range of 0–0.5 taken into consideration by the decision-making unit are trying to reach the desired control point. While the gain factor is increased between 0–1 s and 5.4–8.4 s for Rr 0, the gain factor is increased between 0–1 s and 2–10.4 s for Rr 0.5. The controller output signal becomes stable in 4 s. For the proposed control system, the controller error ends in 5 s, while for the ECCA-P and traditional PID method, the error does not end for 10 s.

Figure 9a shows the step response values when two Rr values such as 0–1 are given to the proposed system for the step response of the system. While the extra gain values produced by the controller decision unit are given in Figure 9b, the controller output signal and controller errors can be seen in Figure 10. K_p is 1, K_i is 0.5, K_d is 0.02.

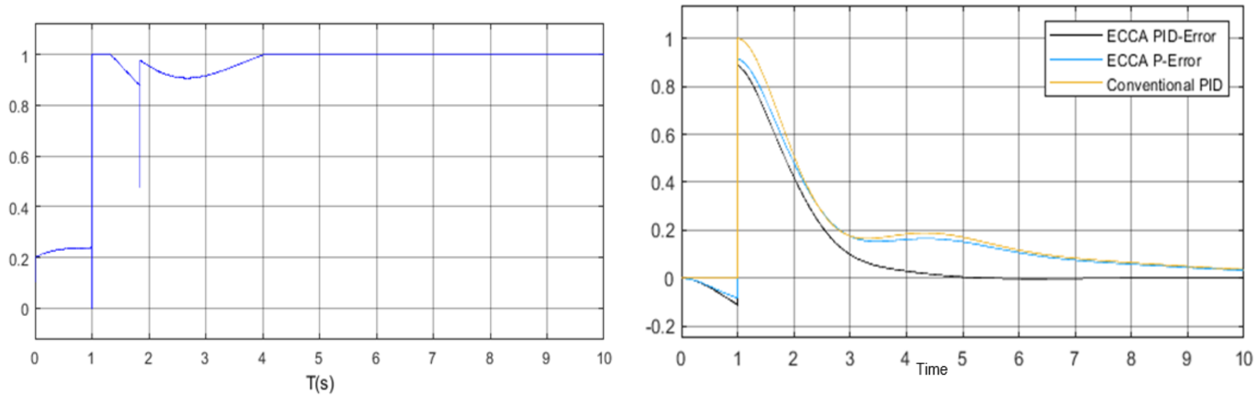
While the rise moment response of the system for Rr of 0–1 is as short as 0.1 s for ECCA-PID and ECCA-P, the rise moment response of the system for a traditional PID control is 1.1 s. This means that the rise moment response of the proposed system corresponds to 9 % of the take-off response of a traditional PID controlled system. The settling time for ECCA-P cannot occur in 10 s, but when I-D controllers are added to the total control system, the settling time takes place in 4 s for ECCA-PID. When the system is controlled with a traditional PID, the system is not capable of settling in 10 s. This shows that the desired control can be achieved with the decision-making unit of the proposed system, even if insufficient controller coefficients are selected for the system. Rr values in the range of 0–1 taken into consideration by the decision-making unit are trying to reach the desired control point. While the gain factor is increased between 0–1 s and 3.9–7 s for Rr of 0, the gain factor is increased between 0–10 s for Rr of 1. While the controller output signal becomes stable in 4 s, It deviates from the ideal control reference value between 2 and 4 s. For the proposed control system, the controller error ends in 4 s, while for the ECCA-P and traditional PID method, the error does not end for 10 s.

Figure 11 shows the step responses and the extra gain values produced by the controller decision unit for Rr 0–0.3. There are controller output signal and controller errors for 0–0.3. The rise moment response of the system for Rr of 0–0.3 is as short as 0.1 s for ECCA-PID and ECCA-P, the rise moment response of the system for a traditional PID control is 1.1 s.



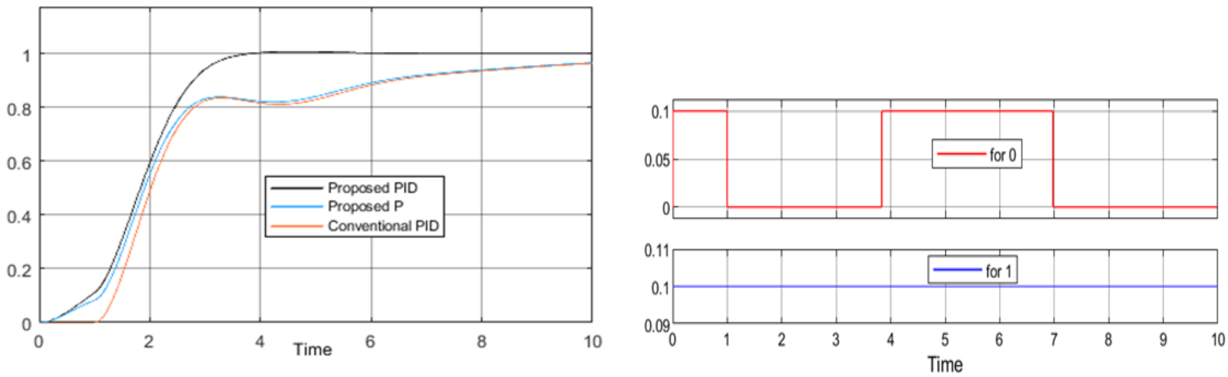
(a). (b).

Figure 7. For Rr of 0–0.5 > e: a) the step responses, b) the extra gain values produced by the controller decision unit.



(a). (b).

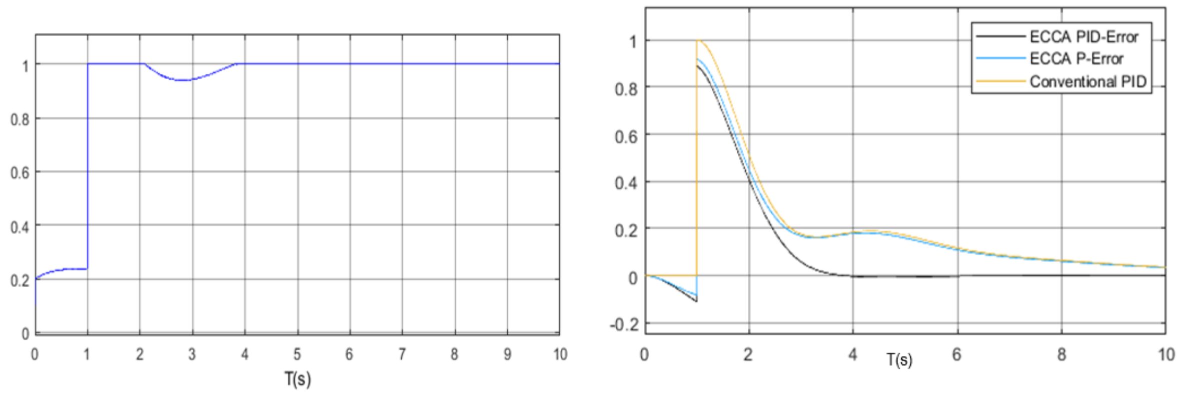
Figure 8. a) The controller output signal, b) errors for controllers.



(a). (b).

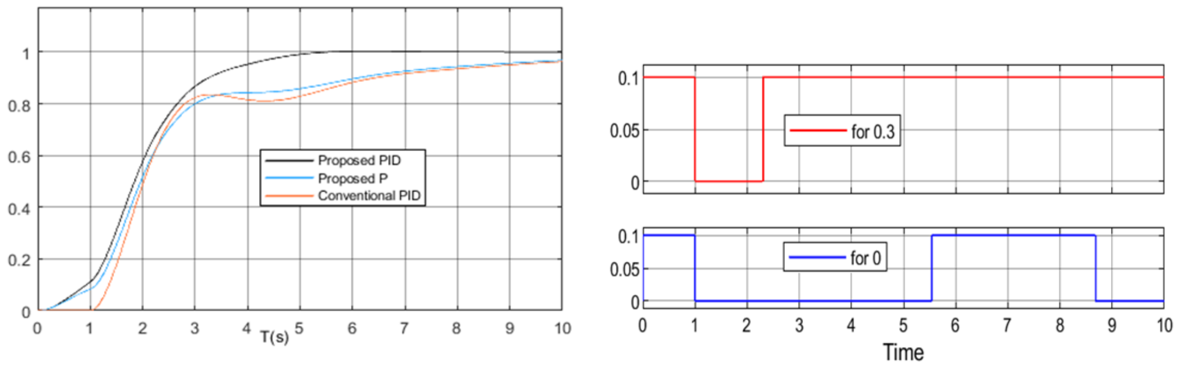
Figure 9. For Rr of 0–1 > e: a) the step responses, b) the extra gain values produced by the controller decision unit.

The 0–0.3 Rr range in ECCA-P provides an earlier rise as compared to the 0–1 range. The settling tim for ECCA-P cannot occur in 10 s, but when I-D controllers are added to the total control system, the settling time takes place in 4 s for ECCA-PID. When the system is controlled with a traditional PID, the system is not capable of settling in 10 s. This shows that the desired control can be achieved with the decision-making unit of the proposed system, even if insufficient controller coefficients are selected for the system. Rr values in the range of 0–0.3 taken into consideration by the decision-making unit are trying to reach the desired control point. While the gain factor is increased between 0–1 s and 5.5–8.7 s for Rr of 0, the gain factor is increased between 0–1 s and 1.2–10 s for Rr of 0. After the maximum collapse occurs in 2.2 s, the controller output signal becomes stable in 4 s. For the proposed control system, the



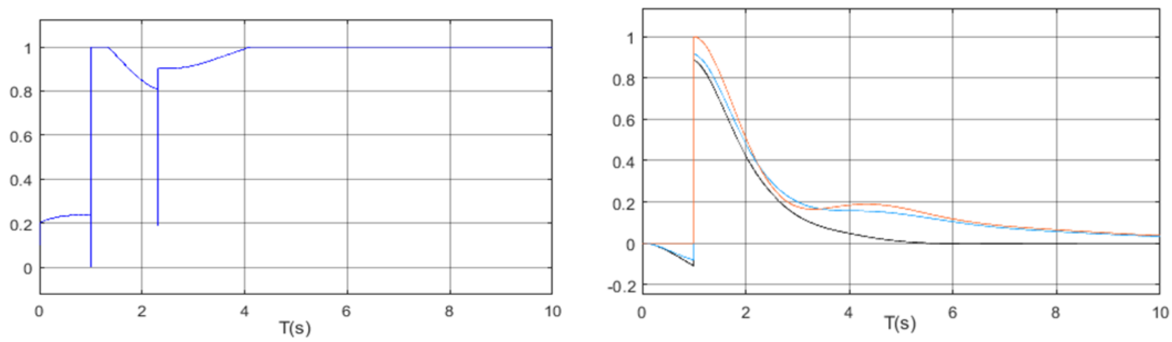
(a). (b).

Figure 10. a) the controller output signal, b) controller errors.



(a). (b).

Figure 11. For Rr of 0–0.3 > e: a) the step responses, b) the extra gain values produced by the controller decision unit.



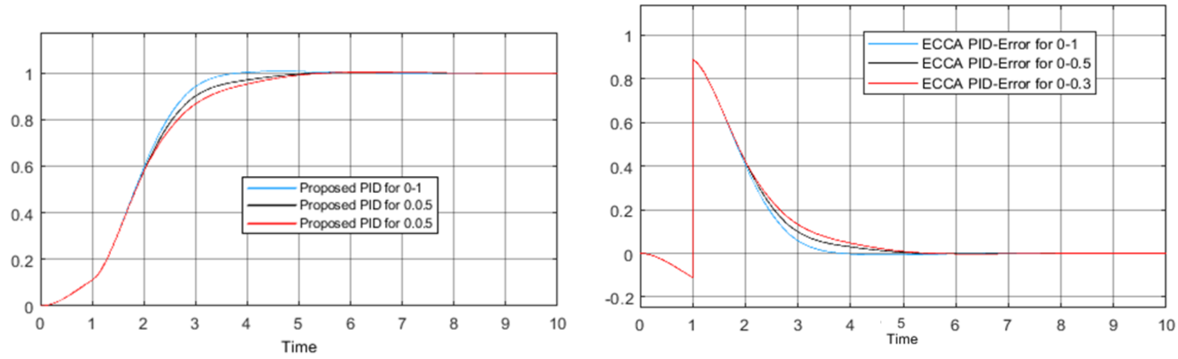
(a). (b).

Figure 12. a) the controller output signal for 0–0.3, b) controller errors.

controller error ends in 6 s, while for the ECCA-P and traditional PID method, the error does not end for 10 s.

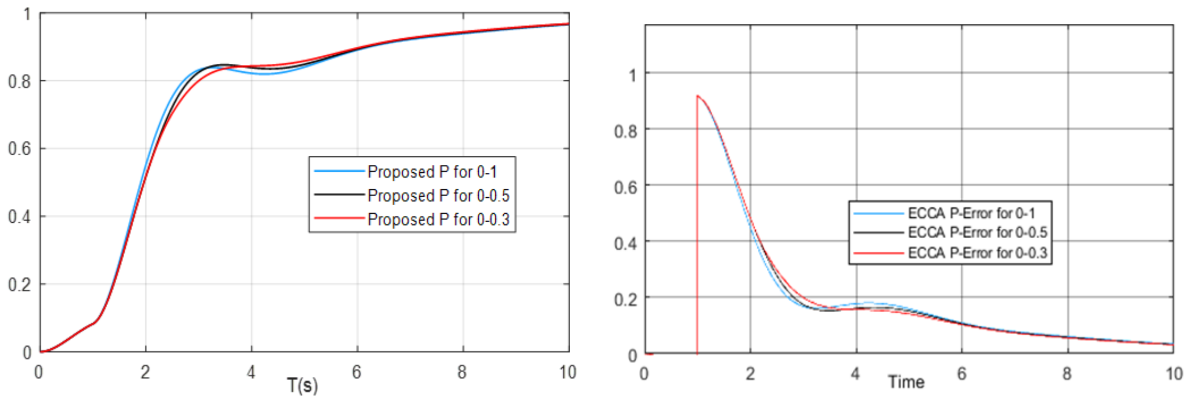
Figure 13 shows the step response of the system controlled with ECCA-PID and the controller errors for different Rr values. Figure 14 shows the step response of the system control with ECCA-P and the controller errors for different Rr values.

ECCA-PID and ECCA-P are tested for control of a quadratic system. Even if the previously determined controller coefficient constants are insufficient or not entered at all, the system controlled by ECCA-PID produces values that will contribute to the controller system by making comparisons with the actual error of the system for different reflection Rr values in the decision-making unit. Thus, unlike traditional PID controllers with linear response, the error variation affects the error variation in a semi-linear manner, independent of the controller coefficients entered into the system before, and brings the control of the system to a satisfactory level.



(a). (b).

Figure 13. With ECCA-PID: a) the step response of the system controlled, b) the controller errors for different *Rr* values.



(a). (b).

Figure 14. With ECCA-P: a) the step response of the system controlled, b) the controller errors for different *Rr* values.

4. Conclusions

In this article, a PID control with extra gain is developed. The structure and design of the traditional PID control system and the ECCA-PID control system are presented. Then, the step response of a second-order system with the conventional method is examined. In the control processes for *Rr* of 0–5 and *Rr* of 0–1 values, the proposed system responds in 0.1 s for the moment of rise, while the traditional PID method responds in 1.1 s. Again, while ECCA-PID provides settling time at 4 s and 5 s, traditional PID cannot provide settling at 10 s. This shows the effectiveness of the proposed system and its contribution to the control systems. Therefore, it seems to be an ideal method for energy conversion systems and motor control units.

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