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Design of Brush DC Motor's Speed Controller Using PI Method with Adjusted Hydrogen Fuel Feed on The PEMFC

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Abstract

Hydrogen is one of the alternate way that become a solution of the crisis of energy problems. Fuel cell transform the hydrogen into electric power, heat, and water. The power that was made by the fuel cell can be used for a lot of things, and transportation is one of them. This research main point is to make a design of a speed controller for a DC motor as a main object using the power that was created by fuel cell. The controller is a system that will increase the efficiency of the hydrogen used ,as a main supply, with controlling the flow rate of hydrogen that flowed into the fuel cell in order to avoid the over flowing of hydrogen that will cause the hydrogen wasted. The controller will also boost the DC motor's response. To conduct the research, the method that is the most suitable for the case is PI control system that will boosted the transient response from the system which stands from a proportional, derivative, and integral parameters that will be tuned by using a root-locus method with the purpose to make a system that has a quick rise time and low %overshoot that will make the system has rise time=10.1s, settling time=66s, peak time = 40.9s, % Overshoot=8.66%, steady state=1 as the transient response's result.

Keywords: Fuel Cell, PI Control, DC Motor

1. Introduction

Electromechanical is a system that combines electrical and mechanical processes. One important thing that often become the object of research in this field is the electric motor [1]. DC motors are an important source of movement in the field of electromechanical [2]. To control the DC motor can be done in various aspects, one of which is on the rotational speed. Rotational speed is an important variable that needs to be controlled because the rotational speed is the main output of a motor.

The similarity between the actual output with the desired output or set point is said to be the criteria of a reliable motor. To obtain these criteria, then the motor must be conditioned or controlled. The process of DC motor speed control can be done through controlling the incoming voltage to the motor [3]. The supply voltage is related to the source of energy that been used. Hydrogen is one of the alternative fuel that can be used as an energy source. One popular technology used to utilize hydrogen as a fuel is a fuel cell. Talking about controlling the output voltage in the fuel cell, to obtain the maximum current density from this technology, the condition membrane's humidity and the amount of feed hydrogen is a variable that must be considered [4]. Enlarge the hydrogen feed rate will indirectly increase the speed up reactions and increase the fuel cell output voltage. The ratio of available reactants compared to the required ratio of reactants will affect the resulting current density which will affect the resulting voltage [4]. It means that by limiting the hydrogen feed into the fuel cell with the constant load resistant someone can decide the output of fuel cell [5]. By using these method, adjusting the feed rate of hydrogen can indirectly regulate motor speed by adjusting the output voltage of the fuel cell.

Speed drive control is one of the important things that need to be controlled in the implementation of the developed drive systems for reasons of efficiency and safety. Speed control system is more efficient compared to the system without control because it can reduce fuel that been used. The user is able to increase or decrease the speed according to the conditions and the needs. The PEM fuel cell implementation in the transportation has recently attracted great interest. Tolj Ivan and friends had already perform this experiment in the golf cart [6]. Hwang and Chang also developed a hybrid powered light electric vehicle with hybrid power. It combines PEMFC with lithium-Ion battery pack [7]. Those experiment brings a hope about an alternative power source in the transportation. Based on those research before, this research will combine the experiment of Hwang and Chang with Claire and Benziger to build a speed controls system for brush DC motors by adjusting the output of the fuel cell by setting the feed flow rate of hydrogen into the fuel cell. PI is a control system that will be implemented into the research design. The controls are expected to come using PI

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control with the expectation that the transient response has % overshoot of less than 10% and a fast rise time response with zero offset. In order to achieve the goal of the research which is an appropriate PI control, it is necessary to identify the characteristics of the motor's RPM to the feed flow rate of hydrogen and the dynamic characteristics of the overall system. The suitability of the design will then be tested by comparing the results of the implementation of the system and the design for later analysis and reporting.

2. Experiment

The system that will be built in this research is a speed control system of a DC brush motor by adjusting the feed hydrogen into the fuel cell. The set point in RPM is given through a program that will be run by arduino. Arduino will set the valve that feeds the hydrogen to the fuel cell. When the hydrogen flow varies according to the set point, the voltage that produced by fuel cell will also changes. Voltage changes will directly affect the speed of the brush DC motor. Rotation data of the motor are recorded and returned as feedback to the control system. The information carried by the feedback is a difference of value between the set point and the actual rotation (error). This error will be processed by the arduino to then give the command to the actuator.

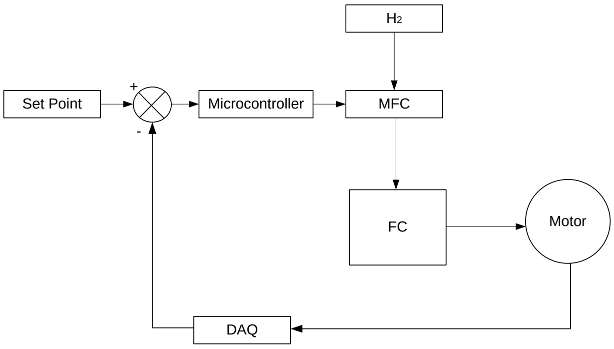

Fig.1. Block System

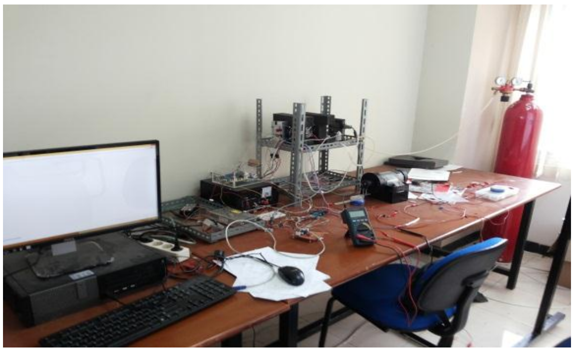

Fig.2. The realization of block system

3. Result and discussion

3.1. Overall system identification test

The system is consist of some sub-systems that need to be tested before the implementation of the control. The main purpose of this identification test is to obtain the characteristic output system in the response of the variant input. In this case, the purpose is to see the relation between RPM and flow rate of hydrogen feed. The testing process is done in open loop condition, with integrating all of sub – system which the output responses recorded by microcontroller. The set point that had been given is a value of hydrogen feed flow rate into the fuel cell. The set point, as an input, will get 0.2slpm increment for each test starting with 0.4slpm as the lowest scale and 3.8slpm as the highest scale. The data will be taken in the 30 seconds of period with frequency 0.1s per data. There are 300 data for each set point.

Table.1
Overall system identification data

No	SP(slpm)	First Response	Time(s)	Average RPM	RPM Max
1	0,4	96	9,6	278,3198653	514
2	0,6	65	6,5	317,9493243	498
3	0,8	55	5,5	408,8344595	591
4	1	48	4,8	445,3783784	624
5	1,2	40	4	421,6621622	581
6	1,4	33	3,3	492,5337838	647
7	1,6	29	2,9	509,2331081	664
8	1,8	27	2,7	519,5101351	657
9	2	28	2,8	525,4864865	657
10	2,2	26	2,6	529,3581081	664
11	2,4	24	2,4	546,4662162	673
12	2,6	23	2,3	552,0743243	680
13	2,8	20	2	563,4527027	690
14	3	23	2,3	552,1385135	706
15	3,2	19	1,9	582,2432432	723
16	3,4	19	1,9	584,0439189	723
17	3,6	16	1,6	597,4358108	730
18	3,8	16	1,6	598,222973	730

3.2. System Modeling

The system modelling process is a process that has a purpose to create a model of the system from the overall input – output characteristic in order to identification of a suitable controller design. This process will use identification toolbox from Matlab 2013a as the main software. The toolbox will process 385 data that had been taken in 40 seconds period with 0.1s as the sampling time.

Table.2
Top 3 Models

Model	Pole	Zero	Percentage	Tr	Ts	Overshoot
Tf 1	5	0	94,8%	25,5	51,6	0%
Tf 2	4	4	94,62%	20,9	97,2	21%
Tf 3	4	1	93,48%	104	195	0%

On the process of model simulation, it can be concluded that system will has the RPM output with 1020 times the set point value which is a step signal. The simulation will be showed on Fig. 3. This system should not be implanted without any control process into any technology if it has the characteristic output like the simulation.

Equation (1) is a transfer function of Tf1 model from Table.2. The chosen model than should do the stability test to decide the model can be controlled or cannot. The test is using Routh – Hurwitz method that the result is showed in Table.3.

Table.2. show the top 3 model with the highest percentage of accurate in the output.

$$G(s) = \frac{2.218}{s^5 + 0.542s^4 + 0.4808s^3 + 0.1145s^2 + 0.03134s + 0.002172} \quad (1)$$

Table.3
Routh array

Orde		Constant		*Sign*
s^5	1	0,4808	0,03234	+
s^4	0,542	0,1145	0,00217	+
s^3	0,269	0.0283	0	+
s^2	0,057	0,00217	0	+
s^1	0,018	0	0	+
s^0	0,00217	0	0	+

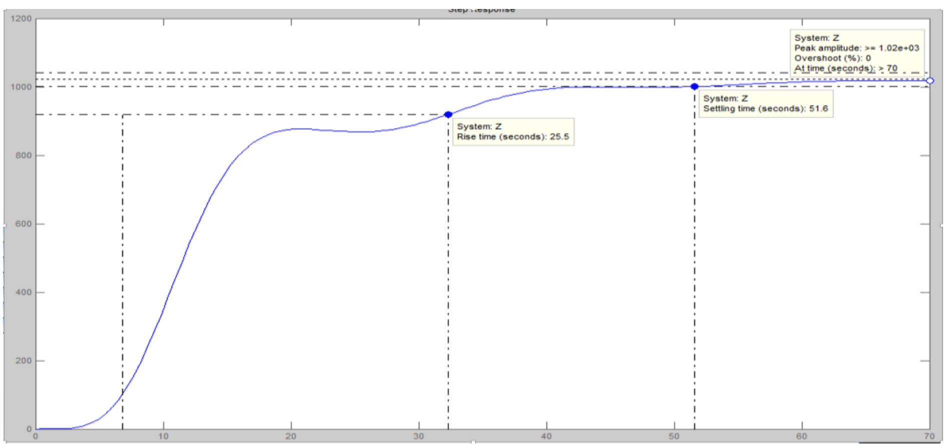

Fig.3. Natural response of the system

3.3. Design of PI controller

Fig. 3 shows the importance of controlling process in the system. Design of PI controller process can be done based on the model from modelling system process. The characteristic of transfer function from the chosen model like rise time, settling time, overshoot, and steady state error is the most important factor on the design process. The process of controller design is using root locus method. Root locus is a method that had been used to locate all of the roots from model's transfer function and the maximum value of the gain that can be given to the system in order to maintain the stability of the system. The process started by searching the location of the roots and the maximum gain. After that, Kp is added as the proportional control's gain. Proportional gain is given by tuning process based on the limit of maximum gain in the root locus diagram which is 0.0016. The best result of system's response that had been obtained by tuning process given by a proportional gain with 1 x 0.00102 as the gain. System will has Tr = 5.48s, Ts = 132s, %Os = 43.7, but with big steady state error which is 0.51. The transient response of the system in close loop state after get the proportional control is showed in Fig. 4.

System with proportional control showed a fast response but has a big steady state error. Proportional – integral control is needed to overcome the problem about steady state error. The gain is being tuned with 1.3 x 0.00102 as the maximum gain like the recommendation of root locus diagram. The best response result is showed on Kp = 0.000746 and Ki = 0.0000962 with Tr = 8.73s, Ts = 72s, %Os = 9.95, and zero offset. The close loop response of system with PI controller is showed on Fig. 5.

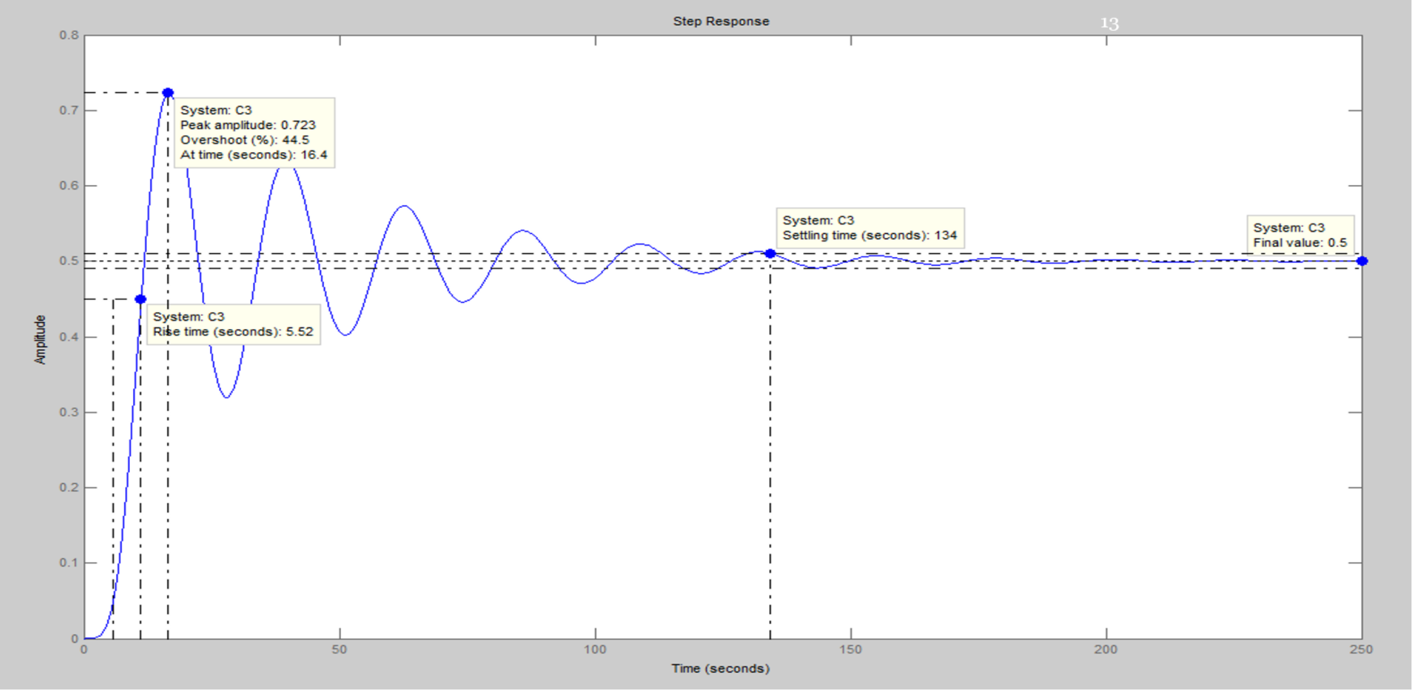

Fig.4. Transient response of the system with proportional control

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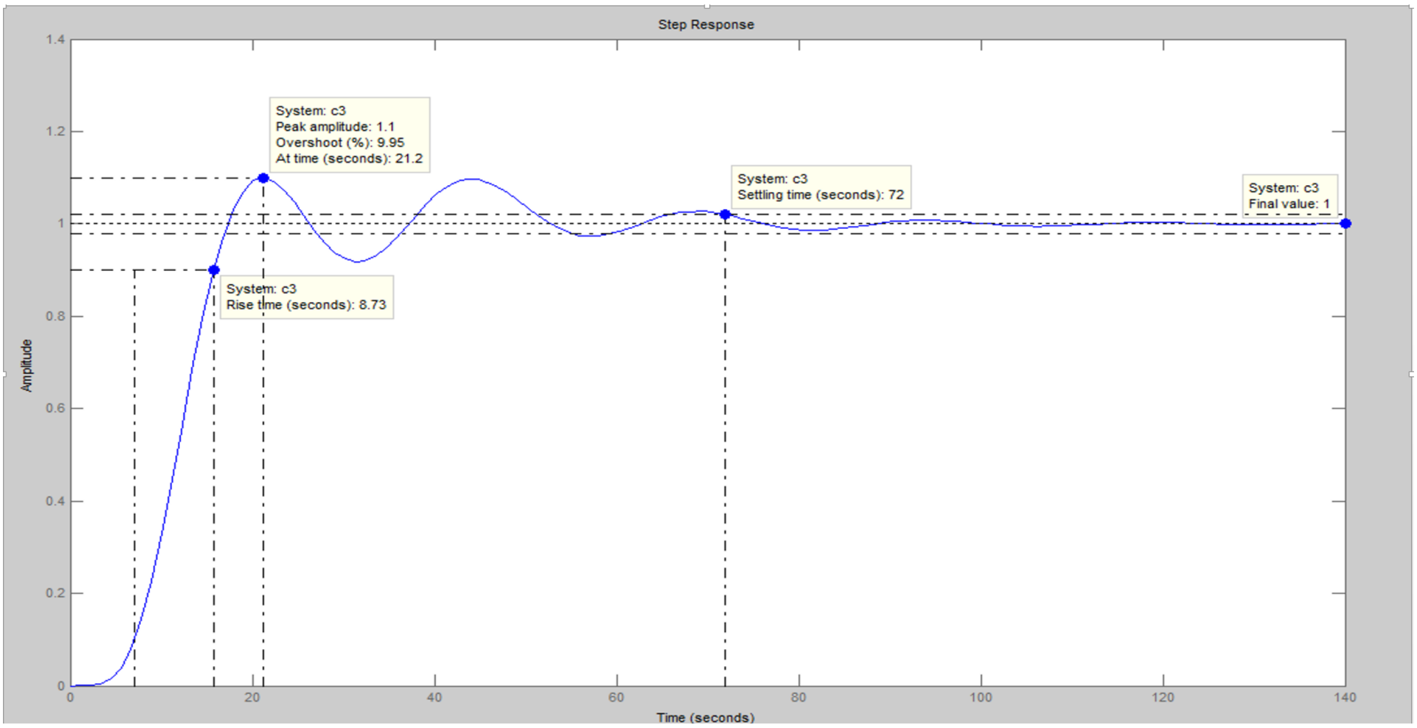
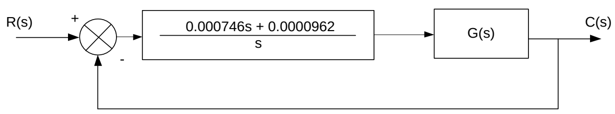


Fig.5. Transient response of the system with PI controller

3.4. The implementation of PI controller

PI controller that had been designed and simulated before should be implanted into the system in order to get the data about response of the system to the controller. The implementation process is doing by implanted the controller constant, Kp, Ki, into the system through the main program in arduino. Block system with PI controller is showed on Fig. 7.



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ig.6. Block system with PI controller

The control signal is the value of hydrogen feed flow rate that should be given by MFC to fuel cell in order to produce the voltage output with the value that motor needs to spin equal to the set point. The implementation process takes 50 s with the frequency of sampling is 0.1 s per data. The data of implementation is showed on Fig. 8.

From Fig. 8, it can be conclude that the transient response from the system with PI controller does not show a good result. System cannot give the RPM as the output equal to the set point. The problem happens because the control signal has a low value because of the low gain. The effect of low control signal is flow rate of hydrogen feed is too low and system cannot produce enough voltage to spin the motor. After the conclusion that the designed PI controller is not recommended to be implanted into the system, researcher will design a new controller with new gain trough tuning process. The controller should has a good response when implanted into the system but should not has a significant differences in the value with the maximum gain that recommended by root locus method. The result of new gain tuning process is shown on Fig. 9.

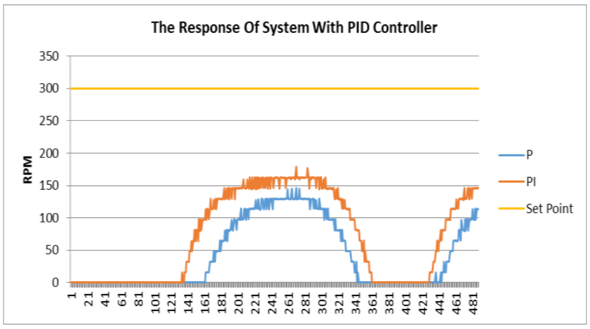

Fig.7. Implementation of PI control into the system

Fig. 9 depict that the best response is the response with 0.05 as the gain. To overcome the problem in the steady state while maintaining the good part of response in the beginning, system should get integral controller. The block system with the Pi controller is showed in Fig. 10 and the response is showed in Fig. 11.

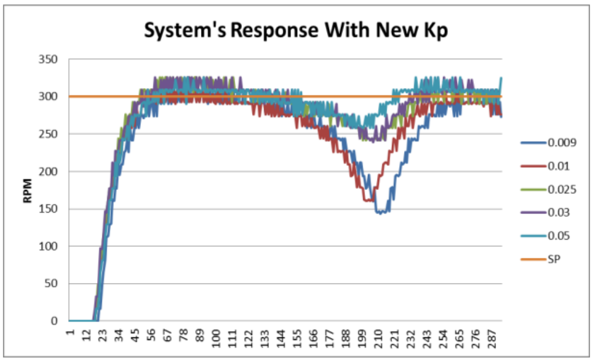

Fig.8. System’s response with new Kp

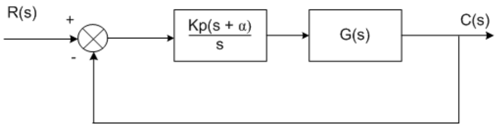

Fig.9. Block system with Pi controller

Ki is obtained by tuning the α in the block from 0.01 – 0.1. The best result is given by α = 0.1 which mean Ki = 0.005.

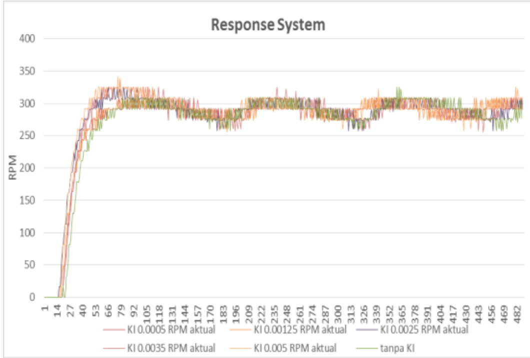

Fig.10. Response of the system with variate Ki

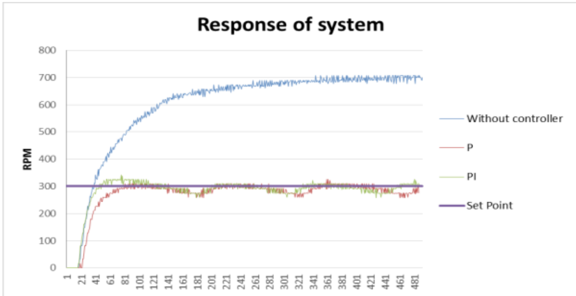

Fig.11. The comparison between response of the system with and without controller

Table.4
Transient response of the system with variation of Ki

Parameters	KI = 0.0005	KI = 0.00125	KI = 0.0025	KI = 0.0035	KI = 0.005	Proportional Only
Rise time (Tr(s))	23	23	19	19	20	25
Settling time (Ts(s))	5,9	5,6	4,9	4,8	4,9	5,8
Peak time (Tp(s))	7,9	8,6	6,1	8	7,8	36,2
%Os	6,59	6,59	12,20	16,67	11,61	17,65
10% Value of Ss	29,01	29,01	29,01	29,01	30,621	27,667
90% Value of Ss	261,09	261,09	261,09	261,09	275,589	249,003
2% Value of Ss	284,298	284,298	284,298	284,298	300,0858	271,1366
Steady state value(RPM)	290,1	290,1	290,1	290,1	306,21	276,67
First Response(Data-n)	22	20	18	22	19	22
Response 10%(Data-n)	23	21	20	23	21	25
Response 90%(Data-n)	46	44	39	42	41	50
Settling (Data-n)	59	56	49	48	49	58
Maximum value	309,22	309,22	325,49	338,45	341,76	325,49

4. Conclusion

The PI control for Brush DC motor’s speed controller by adjusting the hydrogen feed into the PEM fuel cell have been successfully designed and implanted. The PI design process has the result that the recommended gain is Kp = 0.000746, Ki = 0.0000962, which will makes the system has the transient response like Tr = 8.73s, Ts = 72s, Tp = 21.2s, % Os = 9.95 %, and steady state value = 1. The designed PI control is not recommended to be implanted in the system because it will cause the system cannot give the output equal to the set point. The new design of controller to overcome the problem before bring the new controller with Kp = 0.05 and Ki = 0.005 and will cause the system has average error 18.79 RPM and steady state error 6.21 RPM as the result of proportional – integrated control and average error 29.938 RPM with steady state error 23.33 RPM as proportional control.

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