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Analysis of PID Control Algorithms for Transfer Function Model of Electric Vehicle

Vinayambika S. Bhat, Akshitha G. Shettigar, Nikhitha, Nidhi Dayanand, K. P. Vishal Kumar

ABSTRACT--- In Electric Vehicles (EV) energy is stored in rechargeable batteries which is used to drive one or more electric motors. As electric vehicles are making big waves in automobiles world, modelling and simulation of Electric Vehicle have got high attention among researchers. Controlling an Electric Vehicle is not an easy task, as the design and operational parameters vary along with the road conditions. The article presents the design and simulation of conventional control algorithms for Electric Vehicle. The transfer function model of the Electric Vehicle is considered for the design and analysis in MATLAB/Simulink platform. It is found that Proportional Integral Derivative (PID) controller is simple and feasible, along with better-closed loop performance with and without disturbance. The work includes the control of the electric vehicle by designing three different control algorithms: i) Cohen-Coon (CC), ii) Wang-Juang-Chan (WJC) and iii) Chine-Hrones-Reswick (CHR) algorithm for the second-order transfer function model. The resulted controller is also simulated using equivalent First-Order Plus Dead Time (FOPDT) model of an electric vehicle. A comparative study has been carried out using its time domain specifications. Also, Performance Indices namely 1) Integral Square Error (ISE), 2) Integral Absolute Error (IAE), 3) Integral Time Absolute Error (ITAE), and 4) Integral Time Square Error (ITSE) are evaluated in order to identify the superiority of control techniques.

Index Terms— Electric Vehicle, PID Controller, Performance Indices, Transfer Function

I. INTRODUCTION

Challenges in energy saving are astronomical, and there is a spiraling increase in the cost across the world. A major source of the greenhouse effect is due to the increasing number of vehicles which results in environmental pollution [1]. Electric Vehicles (EV) have lesser harmful emissions and are capable of dealing with pollution problems in an efficient way. EVs use one or more electric motors for propulsion. Technological progress in engineering arena with specific reference to EVs has immensely contributed in making the sustainable society and better quality of human life.Internal Combustion Engine (ICE) is a greatest contributor to urban air pollution and also second highest contributor to global warming with approximately 21% emission of greenhouse gasses and the depletion of fossil fuels and their increasing prices, have significantly amplified interest in EV controller [2].

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Vinayambika S Bhat, ECE, Mangalore Institute of Technology and Engineering, Moodbidri, India.

Akshitha G Shettigar, ECE, Mangalore Institute of Technology and Engineering, Moodbidri, India.

Nikhitha, ECE, Mangalore Institute of Technology and Engineering, Moodbidri, India.

NidhiDayanand, ECE, Mangalore Institute of Technology and Engineering, Moodbidri, India.

K P Vishal Kumar, ECE, Mangalore Institute of Technology and Engineering, Moodbidri, India.

Many researchers have been working on the modelling and controlling of an EV. Due to their sustainability and cheaper running cost, EV are likely to be the way of the future. Developments throughout the 20th century have resulted in simpler and more efficient electric vehicle [3]. EVs have cutting edge compared to other technology that they only consume energy, but at the same time store and transport electricity and can reduce the emissions that contribute to climate change. The fuel to Electric Vehicles is extremely cheap as compared to traditional ICE engine vehicles. It also produces less heat and air pollution. In addition, EVs are economical and eco-friendly. This very feature of EVs makes them an incredible alternative for fuel vehicles.

The article is delimited with following structure: The section II gives the description of an Electric Vehicle; Section III describes the design of PID controller using Cohen-Coon, Wang-Juang-Chan and Chine-Hrones-Reswick tuning techniques. The section IV, presents the simulation results of control algorithm with and without disturbance, followed by a culmination section.

II. DESCRIPTION OF AN EV

The EV was invented around the middle of the 19th century [4]. It is powered by rechargeable batteries and is propelled by a motor. The rechargeable batteries which are used as energy storage devices play a significance role in Electric Vehicle application [5]. EV is nearly silent and hence prevents noise pollution. Three main components of the EV are an electric motor, a controller and a rechargeable battery.

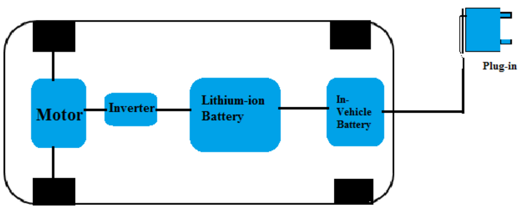

Fig. 1: Block Diagram of Electric Vehicle Model [4]

The electric motor is controlled by a controller. The rechargable battery provides the power to elctric motor as shown in the Fig. 1. Electric motor gets power from the battery pack. The EV system takes the input voltage from the electric motor and outputs the rotational speed of the electric motor [6]. Electric motors operate efficiently over a greater range of speeds and also generate high torque at low

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speed. The potentiometer, Direct Current (DC) controller, batteries, and motor makes up main parts of the EV.

Potentiometer: A pair of potentiometer is attached to the gas pedal for safety reasons. The potentiometer is used to signal the controller about the amount of power to be transferred. It is also called as variable resistor. Both the potentiometers deliver the same signal to the controller. Full power indicates that the gas pedal is being floored by the driver. The controllers check whether the readings of both the potentiometers are the same to avoid faulty conditions.

Batteries: EVs utilize the batteries to power the propulsion. These are designed in such a way that they can provide power over a sustained period. Three varieties of batteries namely lead acid, lithium ion, and nickel-metal hydride can be used in EVs. The different researches reveal that EV has higher efficiency compared to its counterparts as cost of fuel in ICE is substantially higher than the equivalent cost of electricity in EVs.

DC Controller: Batteries delivers the power to the controller, which in turn distributes to the motor [7]. The potentiometers provide the signal that tells the controller how much amount of power it has to deliver. It delivers a controlled amount of power to the motor which can be either zero when the car is stationary, or it can be full when the driver operates the accelerator pedal or any power level in between. The controller is employed to regulate the torque generated by the motors by modifying the energy flow. If and only if both the potentiometer signals are equal, the controller operates.

Motor: Motor needs a controller and batteries to run. The controller delivers power to the motor and turns the wheels, causing the vehicle to move. Approximately 90% of energy is lost during the process of conversion to mechanical energy from electrical energy. The limitations in the motor are that it may self-destruct due to the heat generated by over driving.

III. CONTROL ALGORITHMS

Fig. 2 depicts the general block diagram of closed loop Single Input Single Output (SISO) system.

Where r = set-point; y = process output; u = manipulated variable; d = disturbance; e = difference between set-point and process output (r-y); $G_p(s)$ = transfer function model of the plant; and $G_c(s)$ = controller.

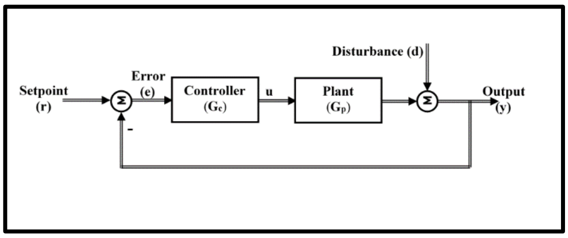

Fig. 2: Closed Loop SISO System General Block Diagram [8]

The original EV model is considered to be a Second Order Transfer Function (SOTF) model with its general form as shown in (1), with its First Order Plus Dead Time (FOPDT) model in the form as shown in (2). Various control algorithms must be designed and a comparative study has to be done in order to identify the most suitable control algorithm for the electric vehicle model.

$$G(s) = \frac{K}{T^2 s^2 + 2\xi T s + 1} \quad (1)$$

$$G(s) = \frac{K e^{-Ls}}{Ts + 1} \quad (2)$$

The PID controller is of the form as shown in (3) and (4),

$$G_c(s) = K_p\left(1 + \frac{1}{t_i s} + t_d s\right) \quad (3)$$

Alternatively,

$$G_c(s) = K_p\left(1 + \frac{1}{K_i s} + K_d s\right) \quad (4)$$

The following control algorithms have been designed and applied to the SOTF model as well as the FOPDT model.

A. Cohen-Coon Tuning Method:

The tuning rules based on Cohen-Coon methodology are more preffered compared to its counterparts [9]. This methodology emphasizes on how to decay the amplitude ratio for load disturbance and minimize the integrator error. It is based on the FOPDT model.

By taking the FOPDT plant model (2), the α and τ values using (5) and (6) as,

$$a = \frac{KL}{T} \quad (5)$$

$$\tau = \frac{L}{L+T} \quad (6)$$

For PID controller, the Proportional gain K_p, time integral t_i, time derivative t_d are given as the gain values obtained using this method is as follows:

$$K_P = \frac{1.35}{a}\left(1 + \frac{0.18\tau}{1-\tau}\right) \quad (7)$$

$$t_i = \frac{2.5 - 2\tau}{1 - 0.39\tau} \quad (8)$$

$$t_d = \frac{0.37 - 0.37\tau}{1 - 0.81\tau} L \quad (9)$$

B. Wang-Juan-Chan Tuning Method:

Wang et al. proposed this meyhodology for slecting the PID control parameters. The methodology is based on the optimum Integral-Time-Absolute-Error criterion, and thus most effective and easy to develop [10]. This method can be applied for the FOPDT model of the process system if the K, L, T values are known. The PID parameters can be found using (10), (11) and (12).

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$$K_p = \frac{((0.73+0.3T)/L)(T+L/2)}{K(T+L)} \quad (10)$$

$$t_i = T + \frac{L}{2} \quad (11)$$

$$t_d = \frac{(L/2)T}{T+(L/2)} \quad (12)$$

C. Chine-Hrones-Reswick Tuning Method:

This tuning approach based on the main issues consisting of how to regulate set-point and how to reject the disturbances [11]. It aims to find the quickest response with 0% overshoot or quickest response with 20% overshoot. Tuning for set point differs from tuning for load disturbances responses. Here, 0% overshoot tuning for disturbance rejection is used. The set of equations to be used are as follows,

$$K_p = \frac{1.2}{a} \quad (13)$$

$$t_i = 2L \quad (14)$$

$$t_d = 0.42L \quad (15)$$

Performance of the system is generally gaged by performance index. It emphasizes important characteristics of the response that are considered to be paramount for performance [12]. In order to analyze the performance criterion of a system, error and the time at which it occurs are very important factors which must be considered simultaneously. By utilizing the magnitude of error, the integral expressions increase for either positive or negative error. This result is useful to get a fairly good underdamped system. Reference [13-15] shows the formulae to calculate the Performance Indices such as IAE, ISE, ITAE, and ITSE, which are given by eq. (16)-(19).

$$IAE = \int_0^T |e(t)| dt \quad (16)$$

$$ISE = \int_0^T |e^2(t)| dt \quad (17)$$

$$ITAE = \int_0^T t|e(t)| dt \quad (18)$$

$$ITSE = \int_0^T t|e(t)^2| dt \quad (19)$$

IV. SIMULATION RESULTS AND ANALYSIS

For any real-time process, the mathematical model can be classified into three categories namely stable systems; unstable systems; and systems with dead time. The stable system model (20) from [16] is considered as the mathematical model for electric vehicle. The equation is given as,

$$G(s) = \frac{0.913242}{1.39s^2 + 1.215s + 0.913242} \quad (20)$$

For the above transfer function, the equivalent FOPDT model is found out as,

$$G(s) = \frac{1.0021e^{-0.968s}}{0.757s+1} \quad (21)$$

By using the above mentioned tuning methods and considering the (22) and (23) to find the gain values, the PID parameters obtained are as listed in the Table. I.

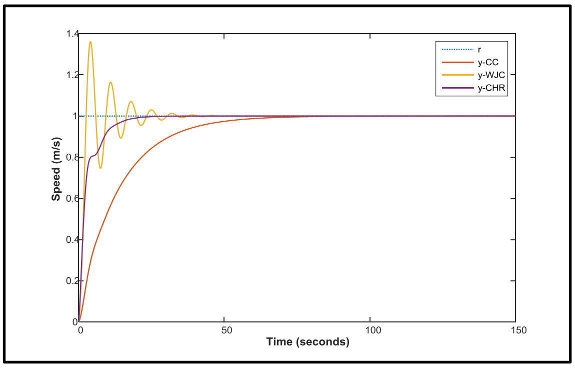
$$K_i = \frac{K_p}{t_i} \quad (22)$$

$$K_d = K_p * t_d \quad (23)$$

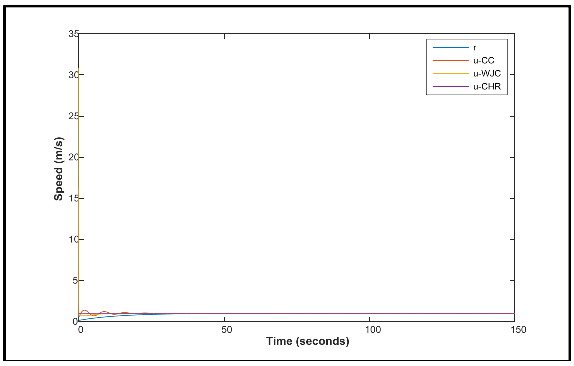
Table. I: Controller parameters

Method	t_i	t_d	K_p	K_i	K_d
CC	1.709	0.288	0.129	0.075	0.037
WJC	1.250	0.298	0.522	0.918	0.156
CHR	2.366	0.414	0.728	0.308	0.301

The servo and regulatory response of models with PID controller are simulated in MATLAB-Simulink. The results of all the three tuning methods are compared as shown in the Fig. 3 to Fig. 6, where r = set-point; y = process output of the system.



(a)



(b)

Fig.3: Closed loop servo response of the second order transfer function model (a) for set-point r = 1 (b) Corresponding controller output

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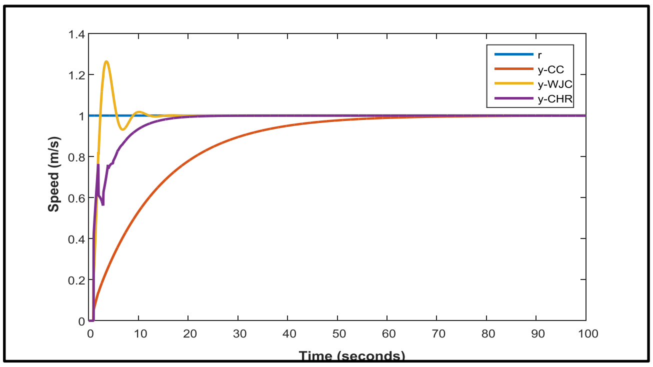

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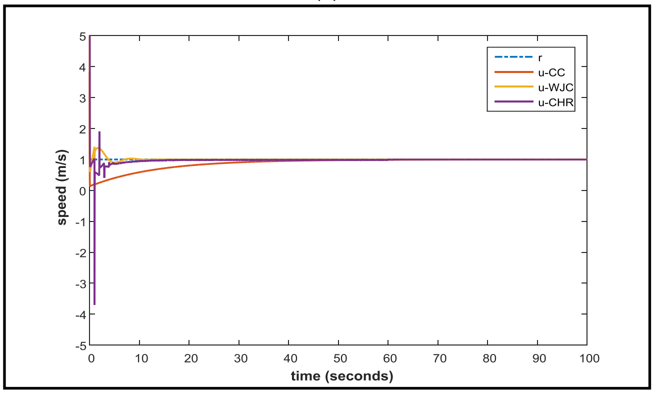
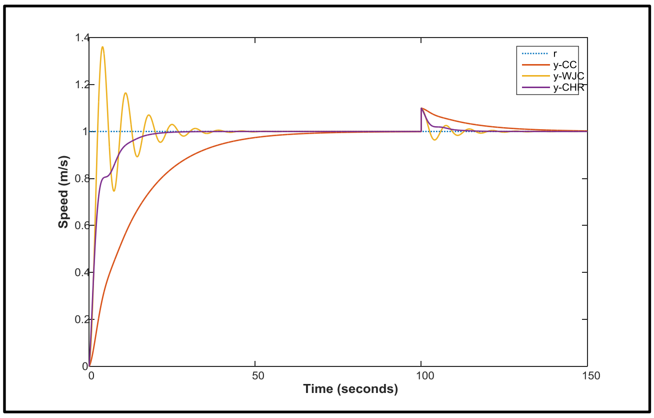
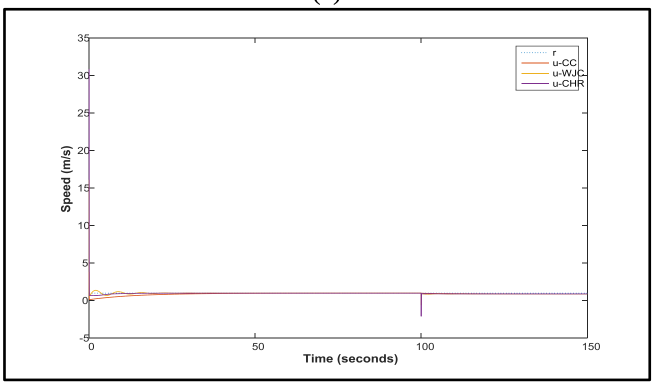


(b)

Fig. 4: Closed loop servo response of equivalent FOPDT model (a) for set-point r = 1 (b) Corresponding controller output

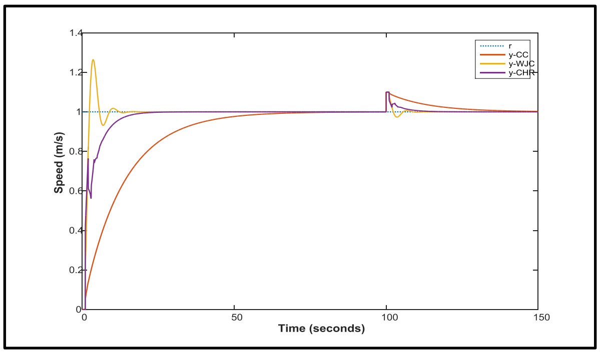


(a)

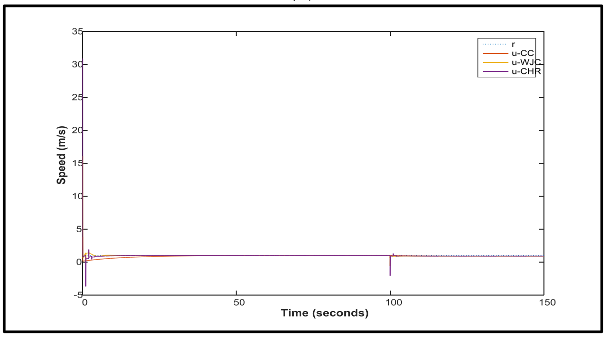


(b)

Fig. 5: Closed loop regulatory response of the second order transfer function model (a) for set-point r = 1 and disturbance d = 0.1 (b) Corresponding controller output



(a)



(b)

Fig. 6: Closed loop regulatory response of equivalent FOPDT model (a) for set-point r = 1 and disturbance d = 0.1 (b) Corresponding controller output

The basic tenets in adopting different tuning method, ascertain the parameters, is to analyze which method gives a stable and robust response. In addition to the step responses, the Performance Indices are calculated and tabulated in Table.II to Table. V. The time domain specifications such as settling time (t_s) and peak overshoot (M_p) are also tabulated for closed loop response without disturbance in the Table. VI.

Table. II: Comparison of Performance Indices of SOTF model for the servo response

Method	IAE	ISE	ITAE	ITSE
CC	13.32	6.532	181.9	43.82
WJC	3.874	1.536	27.25	3.642
CHR	3.247	1.416	13.9	2.312

Table. III: Comparison of Performance Indices of FOPDT model for the servo response

Method	IAE	ISE	ITAE	ITSE
CC	13.3	6.682	176.1	43.96
WJC	2.218	1.378	4.724	1.303
CHR	3.24	1.564	12.57	2.39

Table. IV: Comparison of Performance Indices of SOTF model for the regulatory response

Method	IAE	ISE	ITAE	ITSE
CC	14.61	6.526	326.6	50.68
WJC	4.241	1.552	68.6	5.215
CHR	3.57	1.43	47.75	3.751

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Table. V: Comparison of Performance Indices of FOPDT model for the regulatory response

Method	IAE	ISE	ITAE	ITSE
CC	13.26	6.682	173	43.95
WJC	2.218	1.378	4.731	1.304
CHR	3.241	1.564	12.6	2.39

Table. VI: Time domain specifications: Settling time (t_s) and Peak overshoot (M_p)

Control Algorithms	SOTF		Equivalent FOPDT	
	t_s	M_p	t_s	M_p
CC	53.54	0	52.15	0
WJC	28.5	0.36	8.37	0.26
CHR	16.28	0	15.04	0

V. CONCLUSION

Wang-Juang-Chan tuning method is faster compared to other tuning methodologies. Having said that it tends to have large overshoot and maximum settling time. Whereas, Cohen-Coon tuning method comparatively has minimum overshoot but, it is slow in response. The Chine-Hrones-Reswick method of tuning has an average settling time compared to the other two tuning methods. When Cohen-Coon and Chine-Hrones-Reswick tuning methods are applied, zero overshoot is observed. But, Cohen-Coon method is taking maximum time to settle among the other methods. The Performance Indices of Chine-Hrones-Reswickmethod of PID controller are better among the rest. The work can be extended further to analyze the robustness both in simulation and real-time environment.

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REFERENCES

1. Avtar Singh and AmritKaur, “Speed Control of Hybrid Electric Vehicle Using Optimization Algorithm”, International Journal of Advanced Research in Computer and Communication Engineering, Vol. 3, pp. 6856-6860, 2014.
2. T.A.T., Mohd, M.K. Hassan and WMK. A. Aziz. “Mathematical modeling and simulation of an Electric Vehicle”. Journal of Mechanical Engineering and Sciences (JMES), Vol. 8, pp. 1312-1321, 2015.
3. Nicholas Bova, Zachariah Marrs, Justin Goodwin and Andrew Oliva, “Environmental and Social Issues Concerned with Hybrid Cars”, pp. 1-120, 2010.
4. AryoWicaksono, ArySetijadiPrihatmanto. “Optimal Control System Design for Electric Vehicle” 4th International Conference on Interactive Digital Media, Indonesia. 2015.
5. Guozhen HU, ShanxuDuan, Tao CAI and Baoqi LIU, “Modeling, Control and Implementation of Lithium-ion-Battery Charger in Electric Vehicle Application, Electrical Review, pp. 255-258, 2012.
6. Farhan A. Salem. “Modeling and Control Solutions for Electric Vehicles”. European Scientific Journal, Vol. 9, pp. 221-240, 2013.
7. A. A. Abulifa, A CheSoh, M.K. Hassan, R.K. Raja Ahmad and M.A.M. Radzi, “Modelling and simulation of battery electric vehicle by using MATLAB simulink” IEEE 15th Student Conference on Research and Development (SCPReD), pp. 383-387, 2017.
8. Thanh Vo-Duy and Minh C. Ta, “A signal hardware-in-the-loop model for electric vehicles”, *ROBOMECH Journal*, pp. 1-11, 2016.
9. Ruben kandulna, “Design of PID controller for FOPDT AND IPDT system”, Department of Electrical Engineering, pp. 1-52, 2015.
10. ApurvaTripathi, Ram LautanVerma, Md. SanawerAlam, “Study and Analysis of Various Tuning Methods of PID Controller for AVR System”, International Journal of Research in Electrical & Electronics Engineering, Vol.1,pp. 93-98, 2013.
11. Dr. SatyaSheelandOmhari Gupta, “New Techniques of PID Controller Tuning of a DC Motor—Development of a Toolbox”, MIT International Journal of Electrical and Instrumentation Engineering, Vol. 2, pp. 65-69, 2012.
12. “Modern Control System Theory and Design”, Stanley M. Shinners, Wiley-Interscience 2nd edition, 1998.
13. Karthik Krishnan and G.Karpagam, “Comparison of PID Controller Tuning Techniques for a FOPDT System”, International Journal of Current Engineering and Technology, Vol. 4, pp. 2667-2670, 2014.
14. Fernando G. Martins, “Tuning PID Controllers using the ITAE Criterion”, Int. J. Engng Ed., Vol. 21, pp. 867-873, 2005.
15. Neng-Sheng Pai, Shih Chi Chang and Chi-Tsung Huang, “Tuning PI/PID Controller for Integrating Processes with Deadtime and Inverse Response by Simple Calculations”, Journal of Process Control, pp. 726-733, 2010.
16. “Transfer Function Model for Electric Vehicle – Chapter 3”, pp. 38-47. URL:https://www.google.co.in/url?sa=t&source=web&rct=j&url=http://shodhganga.inflibnet.ac.in/bitstream/10603/27604/8/08_chapter%25203.pdf&ved=2ahUKEwjch5rE6ILfAhVJpI8KHb9FArEQFjAAegQIBBAB&usg=AOvVaw1L_dUCd6A3LT8E2rNk8pJa.

AUTHORS PROFILE

Dr. Vinayambika. S. Bhat is working as Associate Professor in the Dept. of Electronics and Communication Engg., Mangalore Institute of Technology and Engineering, Moodbidri. She completed her B.E and M.Tech from VTU, Belagavi, Karnataka. Also, obtained the Ph.D degree in RobustProcess Control from Manipal Academy of Higher Education, Manipal. She has 14 years of teaching experience. Her area of interest is in Process Control Engineering, Robust and Optimal Control and Power Electronics.
Email: vinayambika@mite.ac.in

Akshitha G. Shettigaris currently pursuing her B.E in Electronics and Communication Engineering in Mangalore Institute of Technology and Engineering (MITE), Moodbidri.
Email:akshithagshettigar@gmail.com

Nikhithais currently pursuing her B.E in Electronics and Communication Engineering in Mangalore Institute of Technology and Engineering (MITE), Moodbidri.
Email: nikhitha978@gmail.com

NidhiDayanandis currently pursuing her B.E in Electronics and Communication Engineering in Mangalore Institute of Technology and Engineering (MITE), Moodbidri
Email: nidhinaik577.nd@gmail.com

K P Vishal Kumar is currently pursuing her B.E in Electronics and Communication Engineering in Mangalore Institute of Technology and Engineering (MITE), Moodbidri. Email: vishalshettigar98@gmail.com

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