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Setpoint Tracking and Disturbance Rejection in Automobile using Predictive Controller

G. Rohini[1], R. Ragumadhavan[2], G. Bhavani[3], V.V enkatesan[4], P Joel Josephson[5], Kamal Alaskar[6],

[1]Department of Electrical and Electronics Engineering, S.A. Engineering College, Chennai, Tamil Nadu 600077, India, dr.rohinig@saec.ac.in

[2]Department of Electronics and Communication Engineering, PSNA College of Engineering & Technology, Dindigul, Tamil Nadu 624622, India, raguece85@gmail.com

[3]Department of Mechanical Engineering, Vignan's Institute of Information Technology (A), Visakhapatnam, Andhra Pradesh 530049, India, bhavaniviit@gmail.com

[4]Department of Automobile Engineering, GKM College of Engineering and Technology, Chennai, Tamil Nadu 600063, India.venkatesanv81@gmail.com

[5]Department of Electronics Communications Engineering, St Martin's Engineering College, Secunderabad, Telangana 500014, India, pjoelece@smec.ac.in

[6]Department of Computer Application, BharatiVidyapeeth (Deemed to be University) Institute of Management, Kolhapur, Maharashtra 416003, India, Kamal.Alaskar@bharatividyapeeth.edu

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Abstract- Cruise Control is a type of automated driving system that takes control of the automobile's longitudinal control when required.It can handle the acceleration and stop pedal in so many conditions, like traffic congestion, to manage a vehicle's speed and acceleration and to retain a considerable distance or pace compared to the front target car.Cruise control reduces driver workload while also improving vehicle safety, fuel efficiency, and road traffic.To develop an efficient cruise control system, in this study, various controllers are designed for the electric bike to monitor set-point tracking and disturbance rejection. The mathematical model of an electric bike is identified and predictive controllers such as Model Predictive Controller (MPC) and General Predictive Controller (GPC) are designed based on the model. The controllers are then compared with conventional Proportional Integral Derivative (PID) controllers and evaluated usingerror metricsin both cases like setpoint tracking and disturbance rejection. The error metrics of the three controllers are compared and the most efficient and reliable controller is identified.

Keywords- Cruise control, Predictive controllers, Error metrics, Setpoint tracking, Disturbance rejection.

I. INTRODUCTION

Adaptive Cruise Control (ACC) is now an improvement on the traditional cruise control technique, which is now common in the majority of modern marketed automobiles. A traditional cruise control's responsibility is to ensure longitudinal vehicle speed by monitoring the speed specified by the driver. ACC also tracks the speed of the preceding vehicle and adapts to it by speeding or stopping the vehicle autonomously.As technology progresses and the expense of associated equipment decreases, a growing percentage of automobiles would be integrated with this technology to boost vehicle usefulness.An auxiliary sensor, such as radar, is usually utilised to identify the car ahead and estimate speed. ACC methods are divided into two components: vehicle dependent and vehicle independent. The first determines the vehicle's necessary speed pattern. The controller is the dependent component that tracks the pattern by activating the accelerator and braking system.The authors of [1] proposed an ACC controlling approach based on the Extended Kalman filtering (EKF) and a PID controller that may predict the leading vehicle's speed or deceleration by altering the speed of the passing vehicles. The suggested control approach is evaluated using a Genetic Algorithm (GA) to improve the ACC system utilising 4 loss measures under varied PID parameters.In article [2] the authors present a basic architecture for an improved predictive cruise control system that incorporates a data-driven traffic forecasting model and immediate controller design. They present a new multi-view neural network deep learning system to determine traffic situations by looking at historical and actual traffic data obtained from fields, as well as an MPC to determine the immediate ideal speed while reducing power consumption. The authors of [3] created and developed an efficient PID controller for an ACC system. Errors were the objective functions selected for improving the Controller parameters. The particle swarm technique and the teacher learning-based optimization method are used in the construction of the improved PID controller. The outcomes were systematically compared with traditional PID and fuzzy-based controls.

The authors of [4] developed an estimation method that uses immediate mobility information from numerous previous vehicles to provide MPC in low-automation, medium-connectivity circumstances.

The authors represent a new hybrid technique created by combining atom search optimization (ASO) and Nelder-Mead (NM) simplex search methods in the article [5]. The suggested optimization technique ASO-NM is the first study on integrating ASO and NM approaches for optimization problems that have been published. The integration of ASO and NM yields the ideal evolutionary algorithms strategy with a balance of exploitation and exploration. The suggested hybrid ASO-NM was used for the first time to optimise a PID controller design for vehicle cruise control systems.The authors of [6] suggested a forecasting approach that uses immediate moving objects from several previous vehicles to provide MPC in low-automation, medium-connectivity circumstances.The authors of the research [7] developed a predictive control MPC technique that is applied to a rudimentary ACC system.The requisite consistency with the defined input limitations as well as the targeted speed for a steady preceding operating speed was achieved using an MPC controller. In this work, a Linear–Quadratic Regulator(LQR) controller was used for comparability.The authors of [8] propose ACC with look-ahead prediction, based on the ACC concept utilised in current commercial cars, to make rapid choices when operating a car on the freeway. ACC's proposed look-ahead predictive strategy anticipates the comparative state of the vehicle ahead in an adaptive short-horizon utilising a conditioned persistent prediction technique.In article [9], the researchers devised a new non-local controller competent for normalizing a wide variety of oscillating traffic and suitable for practical uses. The controller architecture is built around an optimization technique that has been simplified to a lightweight quadratic programme developed primarily for extensible and practical implementation.

The article is articulated in the following way: Section 1 discusses the base of this study and the previous work related to this study. Section 2 briefs about the mathematical model identified in this study. Section 3 discusses the workflow and the steps involved in this study. Section 4 elaborates on the algorithms used in this study. Section 5 discusses in detail the results obtained from this study and finally, section 6 gives the conclusion of this study.

II. MATHEMATICAL MODEL

The initial step involved in this study involves the identification of the mathematical model of the speed control system. As a result, the mathematical model identified in this study is the model of the Brushless DC motor (BLDC) that is present in the electrical vehicle. The BLDC motor present in the electrical vehicle is responsible for controlling the speed of the electrical motor. Hence the mathematical model of the motor is identified and predictive controllers are designed according to it to develop an efficient cruise control system for the electrical vehicle.The high efficiency and superior controllability of BLDC motors make them popular in a variety of applications. Compared to certain other motor types, the BLDC motor offers benefits for power conservation.A permanent magnet-based rotor and polyphase armature windings-based stator make up a brushless DC motor. It varies from a typical DC motor in that it lacks brushes and commutation is carried out electrically with the aid of an electronic drive that supplies the stator windings.In this study, the BLDC motor's system was identified and modelled using experimentation to produce mathematical modelling.The system identification process leads to the identification of a mathematical modelof the BLDC motor.To do this the input and output of the BLDC motor are collected and given to the system identification toolbox in MATLAB.

III. WORKFLOW

The ultimate aim of this study is to develop a reliable and efficient cruise control system for electric vehicles which is highly maintained by control engineering. In this study, the set point and the disturbance rejection of the controllers used in the cruise control system are monitored. To monitor that the mathematical model of an electric vehicle is initially studied and predictive controllers are designed. Once the controllers are designed they are tested to evaluate their performance using various performance metrics. Later the system is tested using various set point values and disturbance rejection to find the most efficient controller for the cruise control system. Figure 1 given below shows the workflow of this study.

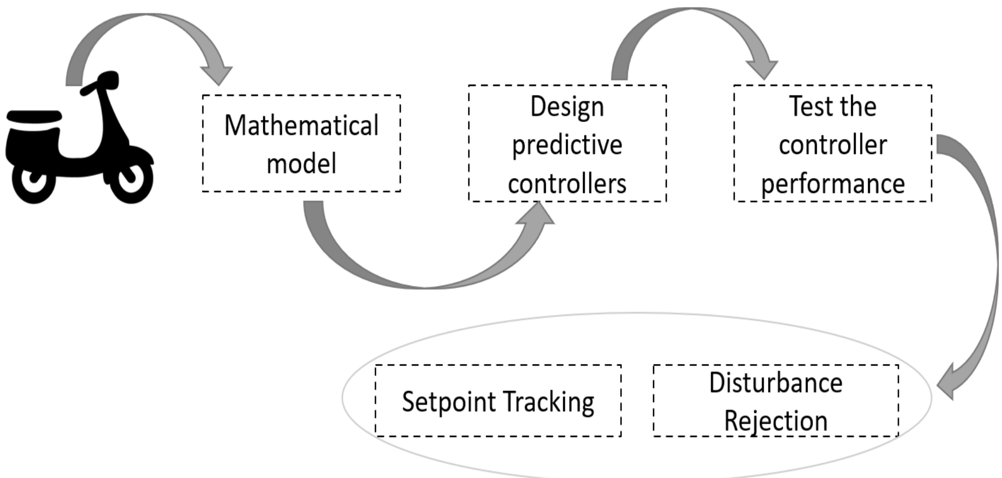

Fig 1. Workflow of the research

Figure 1 given above shows the steps involved in this study. The first step in this study is to find the mathematical model of the electric vehicle which is to be incorporated with the cruise control system. Once the mathematical model is identified and evaluated, the required predictive controllers are designed for the system. In this study, three different controllers are designed such as GPC, MPC and PID. The PID controller is tuned using the Zeigler Nichols (ZN) method. Once the controllers are designed, they are tested to evaluate their performance. The controllers are evaluated at different set point values such as 30, 40, 50, and 60km/hr speed is maintained by the controllers. When the controllers maintain such set point values, the error metrics such as Integral Square Error (ISE)and Integral Absolute Error (IAE) are calculated to evaluate the controller's performance. Later, the system is subjected to disturbances and the controller's performance is evaluated is they are affected by the disturbances or not. The error metrics ISE and IAE are calculated for the three controllers in the disturbance rejection step and the most efficient controller is identified by comparing the error metrics values of all the three controllers of both set-point tracking and the disturbance rejection process.

IV. ALGORITHM USED

The controllers used in this study include the GPC, MPC and the PID controller. It can be difficult to accurately model systems. In this situation, autotuning techniques can be used because they don't require a mathematical model of the system but rather certain specific details about it. The PID controller is tuned using the Zeigler Nichols method. Since the PID controller is a simple and easy controller to use, it is used in almost 95% of the control systems. To control the PID controller of the cruise system of the electric vehicle, the controller is compared and tuned using a conventional tuning algorithm called the ZN tunning method.

A. ZN

In the control system industry, PID controllers are widely used. Over the decades, auto-tuning techniques for such controllers have been developed, notably the well-known ZN technique.When disturbance rejection is the main objective of a process control system, tuning PIDs following this technique is quite common, simple, and produces reasonably good results[10].The integrals and derivatives gains are initially set to zero in this procedure, and the proportional gain is subsequently increased until the system becomes unstable.The technique then determines the integrals and derivatives gains after reducing the proportional gain by a fixed number.

B. GPC

A popular long-term predictive controller algorithm that reacts to process delays and model orders based on long-term forecasts is the GPC algorithm. As a result, self-tuning regulation of industrialization [11] has proven to be extremely efficient. However, as per the current GPC, impressive control behaviour may be accomplished if the model contains a large number of parameters. A thorough description of interruptions, as well as other unexpected dynamics, should be incorporated into the design of a suitable controller. Because GPC is a model-based approach, it requires a high-quality process model to operate well. Modelling an industrial process using basic principles or identification is notoriously challenging. Moreover, unless a mathematical formulation of the process industries is created, this will only approximate the process and will not account for all of its dynamics. A substantial investment of time and resources is required to construct a realistic, all-encompassing model of an industrial process. Consequently, several of the flaws of the model-based approach have been addressed.The main principle of GPC is to compute a series of potential control signals in such a way that it minimises a multiple-stage cost function specified over a timescale. The index to be optimised is the anticipation of a quadratic function evaluating the range between the predicted system output as well as some reference sequence across the horizon plus a quadratic function assessing the control action.Since it is based on the same principles as the other predictive controllers, generalised predictive control shares many ideas with them, but it also differs in a few key ways.

C. MPC

MPC began as a type of heuristic control scheme used throughout industries, but it has now expanded into a unique sub-field of research with both conceptual and practical significance. MPC focuses on constrained control difficulties with optimization requirements. MPC has shown its capacity to address challenging restricted optimization control challenges in complicated industrial applications so far.MPC is regarded as among the most effective and sophisticated control techniques.The fundamental principle of MPC is to predict the future behaviour of the controlled system over a predefined timeframe and estimate an optimum control input that minimises a posterior established cost function while maintaining fulfilment of the system conditions [12].Due to its capability to integrate hard state and input limitations as well as an appropriate performance criterion into the controller design, MPC is particularly effective.

The capacity to immediately address restrictions is the most enticing aspect of MPC. A model may forecast the future behaviour of a stochastic process. An interactive QP or nonlinear programming problem may explicitly include constraints by putting them on future variables. As MPC became more widely utilized in industrial operations and MPC software packages progressed, Quadratic Programming (QP) and sequential QP (SQP) algorithms were progressively developed to handle MPC online optimization challenges. MPC's adoption as a feasible limited control scheme in industrial systems is demonstrated by its widespread deployment in tens of thousands of facilities around the world. MPC improves efficiency by decreasing fluctuation, loop interconnections, and settling periods. Furthermore, the incorporation of optimization constraints provides for an increase in efficiency. MPC has few limitations, notably higher development expenses and durations, a larger demand for process knowledge, and the requirement for a dynamic model that incorporates the most critical features of unit performance. MPC's performance is closely tied to the validity of the dynamic system and the suitable adjustment of its variables.

V. RESULT AND DISCUSSION

The automated cruise control system improves the safety and efficiency of transportation. It responds to the speed of the vehicles in front of it to manage vehicle steering angle and stopping to guarantee a stable range behind it, resulting in a safer and more comfortable driving experience.To make this possible in real-time, the mathematical model of an electric vehicle is identified first. Predictive controllers such as MPC and GPC are then designed and the important parameters of the controllers are analysed using different tuning approaches. After finding such parameters, different set points and disturbances are given to the system to evaluate its performance of the system. To analyse the performance of the controller two error metrics such as ISE and IAE is calculated.

A. Setpoint Tracking

Setpoint tracking is the process of automatically adjusting the speed of the vehicle based on the user's required setpoint.A Setpoint is a target value that a control algorithm tries to keep the output variable at. In this study, to evaluate the performance and the efficiency of the system, different set point values are given to the system. Here different set point values of 30,40,50 and 60 km/hr are given at the various time of 0, 50, 100, and 150th seconds. The output attained by the controllers is plotted concerning time for better understanding and it is shown in figure 2. The figure contains the setpoint given by the users and the output response of all three controllers.

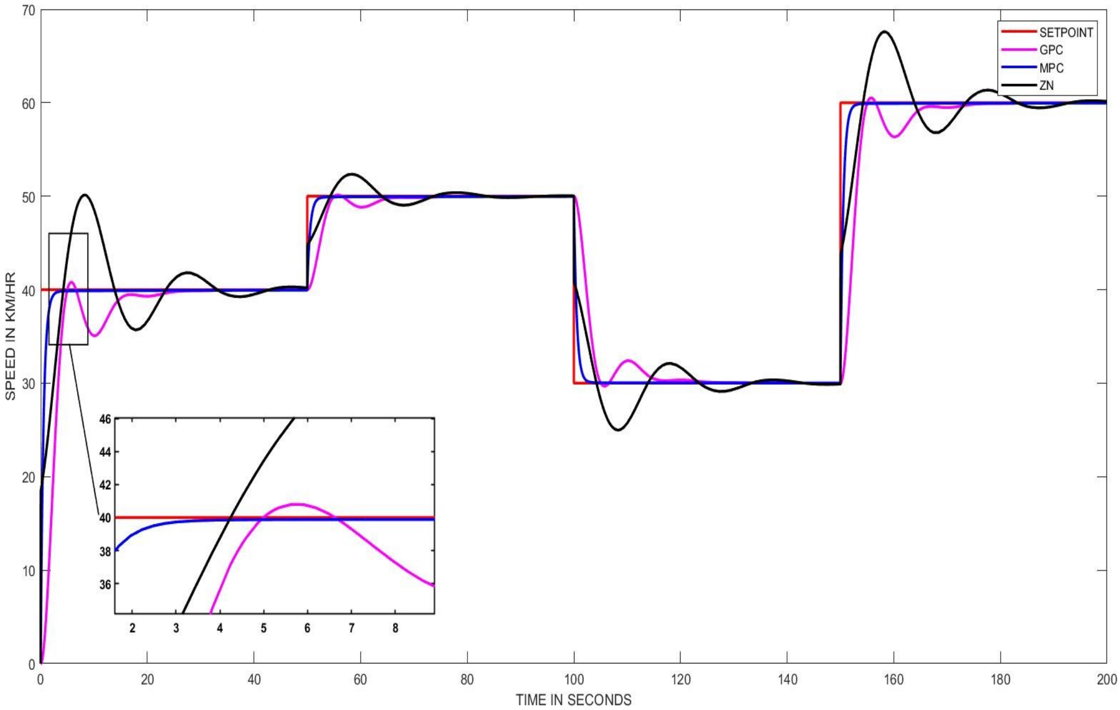

Fig.2 Graphical representation of Setpoint Tracking

Figure 2 given above shows the setpoint tracking of the three different controllers used in this study. In the given figure, it is clear that thedifferent setpoint valuesare set at different timesfor the three controllers. Analysing the plotshows that the MPC controller is the most efficient one with less rise time i.e. the time taken by the controller to reach the 10% of the setpoint value and settling time i.e. the time taken by the controller to reach the setpoint value, there is no overshoot i.e. the controller does not exceed the setpoint value and undershoot i.e. the controller does not fall short below the setpoint value, and most importantly there is no oscillation in the system, making the vehicle run smoothly and the system has no steady-state error. Table 1 given below shows the error metrics of the setpoint tracking of the three controllers.

Table 1. Error metrics of setpoint tracking

Error	PID	GPC	MPC
ISE	5465	2478	772.3
IAE	324.5	221.4	64

Table 1 given above shows the error metrics of the setpoint tracking of the three controllers. From the table the ISE value for the PID controller is about 5465, for the GPC controller it is about 2478 and the MPC controller has the least ISE error value of about 772.3. The IAE error value for the PID controller is about 324.5, for the GPC controller it is about 221.4 and the MPC controller has the least IAE value of about 64. Figure 3 given below shows the ISE error value comparison in set-point tracking.

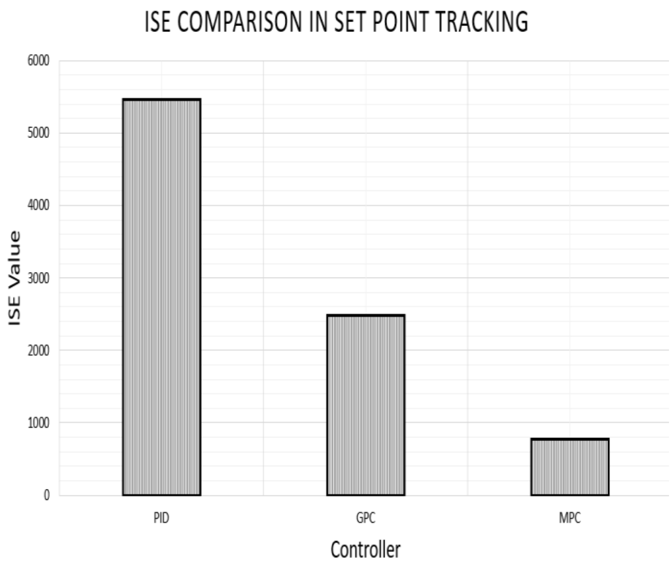

Fig.3 ISE comparison in setpoint tracking

Figure 3 given above shows the ISE error value comparison in set-point tracking for the three controllers. Figure 3 shows that the ISE value is relatively less for the MPC controller when compared to the PID and GPC controllers. Figure 4 given below shows the IAE error value comparison in set-point tracking.

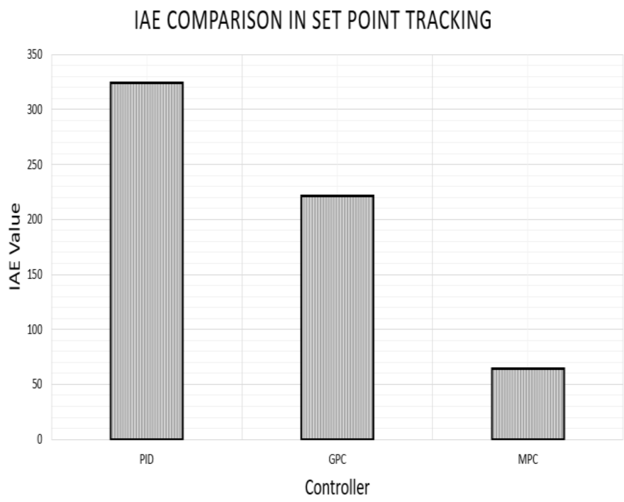

Fig.4 IAE comparison in setpoint tracking

Figure 4 given above shows the IAE error value comparison in set-point tracking for the three controllers. The figure shows that the ISE value is relatively less for the MPC controller when compared to the PID and GPC controllers.

B. Disturbance Rejection

The controller employs a disturbance rejection mechanism to handle unintended forces that make the system deviate from its setpoint value.Disturbance impulses are unintended impulses that alter the outcome of the control system, leading to an increase in system error. Here in this system, voluntary disturbances are applied to the system to check its efficiency of the system. The system has various set point values to which the disturbance is applied and the error metrics are calculated for each of the controllers to find the efficiency of the controllers. Figure 5 given below shows the graphical plot of the disturbance rejection for the three different controllers used in this study.

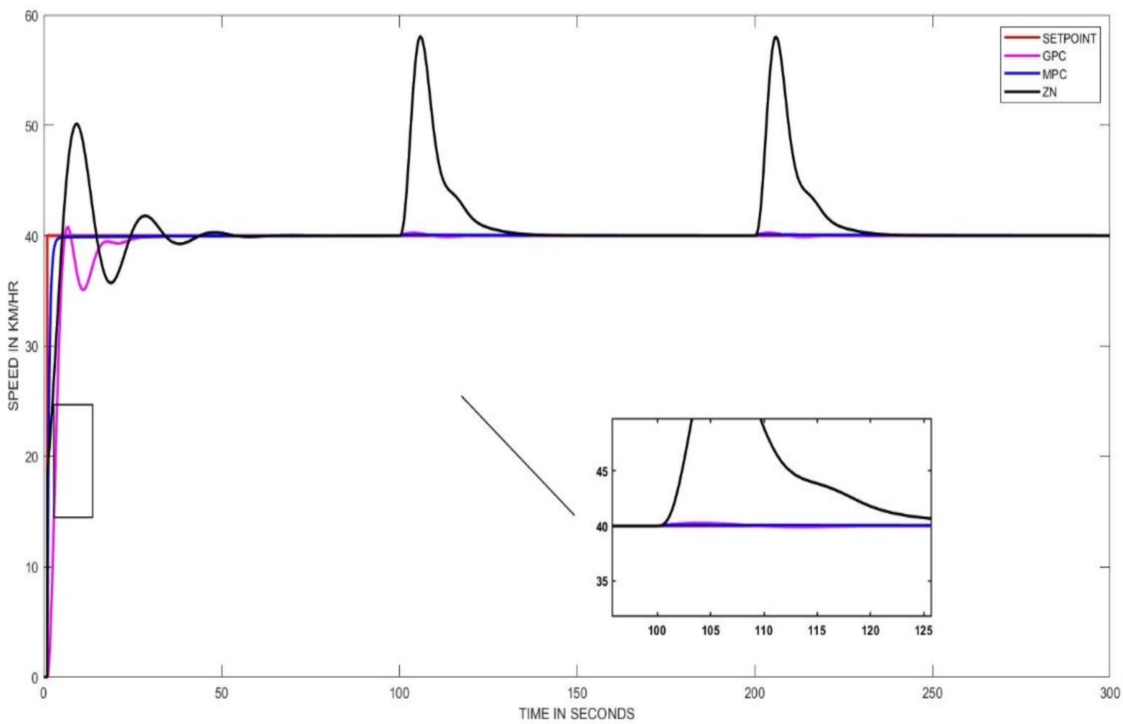

Fig.5 Graphical representation of Disturbance Rejection

Figure 5 given above shows the disturbance rejection of the three controllers used in this study. In the given figure 5, a setpoint value of 40 is set for the three controllers. When the system is induced with disturbance, among the three controllers the MPC controller is the most efficient one as it does not deviate from the set point value even when the disturbance is given. From figure 5, it can be seen that the GPC controller experiences undershoot and the PID controller experiences overshoot in high range. Table 2 given below shows the error metrics of the disturbance rejection of the three controllers.

Table 2. Error metrics of disturbance rejection

Error	PID	GPC	MPC
ISE	6458	1323	412.2
IAE	451	158.9	35.13

Table 2 given above shows the error metrics of the disturbance rejection of the three controllers. From the table the ISE value for the PID controller is about 6458, for the GPC controller it is about 1323 and the MPC controller has the least ISE error value of about 412.2. The IAE error value for the PID controller is about 451, for the GPC controller it is about 158.9 and the MPC controller has the least IAE value of about 35.13. Figure 6 given below shows the ISE error value comparison in disturbance rejection.

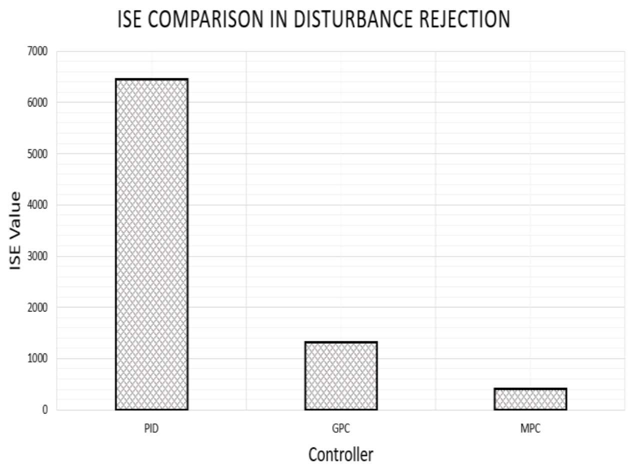

Fig.6 ISE comparison in disturbance rejection

Figure 6 given above shows the ISE error value comparison in disturbance rejection for the three controllers.Figure 6 demonstrates that the MPC controller's ISE value is significantly lower than that of the PID and GPC controllers. The IAE error value comparison in disturbance rejection is shown in Figure 7 below.

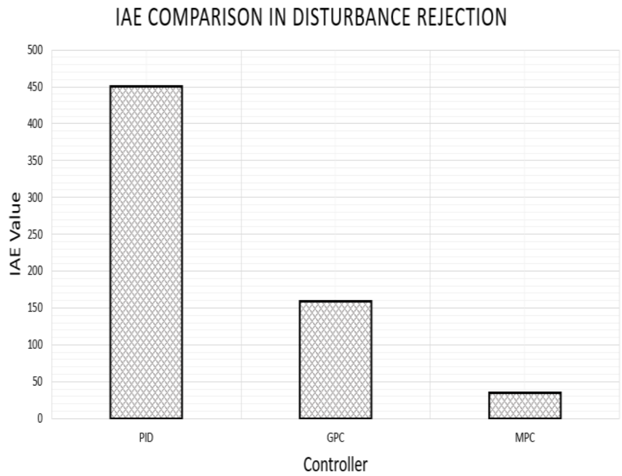

Fig.7 IAE comparison in disturbance rejection

Figure 7 given above shows the IAE error value comparison in disturbance rejection for the three controllers. The figure shows that the IAE value is relatively less for the MPC controller when compared to the PID and GPC controllers.

VI. CONCLUSION

The main use of the cruise control system is to make it easier for the driver driving the vehicle for a longer distance and long period.One of the earliest automated options offered for personal vehicles is ACC.In this study, the cruise control system is developed and initially tested using various predictive controllers to find the most efficient one. Three controllers such as PID, GPC and MPC are used in this study. Initially the mathematical model of the electrical vehicle i.e. the mathematical model of the BLDC motor is identified. The predictive controllers are then designed and tested for their performance. For various set point values, the controllers are tested and their error metrics such as ISE and IAE are evaluated. Similarly, the error metrics for the disturbance rejection for various set point values of the controllers are also calculated. From the error analysis, it is concluded that the MPC controller has a less ISE value of about 772.3 and an IAE value of about 64 in the set-point tracking step. For the disturbance rejection step the ISE and IAE value of the MPC controller is about 412.2 and 35.13, making the controller the most efficient one among the three controllers used in this study.

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