VARIABLE SPEED CONTROL OF ELECTRIC VEHICLE USING I2V COMMUNICATION

A DISSERTATION

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REQUIREMENTS

FOR THE AWARD OF THE DEGREE

for

MASTER OF TECHNOLOGY

in

Control & Instrumentation

Submitted by:

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I, RITANSHU TIWARI, Roll No. 2K19/C&I/05 student of M. Tech (Control and Instrumentation), hereby declare that the Project dissertation titled **"VARIABLE SPEED CONTROL OF ELECTRIC VEHICLE USING I2V COMMUNICATION"** which is submitted by me to the Department of Electrical Engineering, Delhi Technological University in partial fulfillment for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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CERTIFICATE

This is to certify that the Dissertation entitled "VARIABLE SPEED CONTROL OF ELECTRIC VEHICLE USING I2V COMMUNICATION" submitted by Ritanshu Tiwari, Roll No. 2K19/C&I/05, is the record of bonafide work carried out by him under my supervision and guidance in the partial fulfillment of the requirement for the award of the degree of Master of Technology with specialization in *Control and Instrumentation* of Delhi Technological University.

Date: 30-Oct
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ABSTRACT

Increasing number of vehicles on road has led to the problem of traffic jam, accidents, over speeding and pollution. Thus, to solve these issues researchers across the world indulge to find effective solutions with the help of various techniques like Machine learning, Artificial Intelligence etc. But these techniques are helpful in certain places where the road traffic is structured, and the laws related to traffic violation are enforced properly. But in a country like India where the traffic is unstructured , poor infrastructure and law enforcement is not up to the mark, the ML techniques might not perform efficiently. Thus, speed control of vehicle electronically through I2V (infrastructure to vehicle communication) can be effective. In India speed limiters are available for ICE engines type but their efficiency is low. EV's are the future of transportation in the world , due to this aspect the research method is proposed.

The main motive of this report is to present a method to electronically control the speed of the vehicle especially electric vehicles. For this purpose, a model is developed in MATLAB-Simulink to control the longitudinal speed of the vehicle to reduce road speed limit violations. In this model a DC motor is used for speed control. Further the rotational velocity of DC motor is converted into longitudinal velocity using wheel modelling. Another model is developed in Proteus-VSM to control the longitudinal speed of vehicle with the help of two Arduino Uno configured in master slave configuration to enable the infrastructure to vehicle communication(I2V) via rf 433MHz module. Master Arduino can be fitted into the road-side structure like poles which continuously transmits the data related to speed on that road. The transmitted data is received by the receiver interfaced with the slave Arduino fitted into the vehicle which controls the speed of the vehicle electronically according to the received signal. The proposed methods perform under certain assumptions and both provides convincing results.

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CHAPTER 1

INTRODUCTION

The advent of automobile revolutionized the transportation industry. The transportation of goods and passengers became easy and less time consuming. Starting with steam turbine engine to the Internal combustion engine and battery-operated vehicle , indeed the automobile industry has come a long way. With time, the automotive industries along with the research scientist worked together to improve the performance and efficiency of the automobiles. Through the continuous strive of automotive industries, the vehicles evolved to become state of the art technological machines which enabled companies to extend their product to provide comfort and leisure to its customers. Due to increasing number of vehicles on road, traffic laws enforced to ensure orderly mobility of vehicles and safety. Technology advancement in automobile sector paves the path for vehicles to have more power, high efficiency and improved travel range to a level which changed the transportation completely. The advancements in any technology comes with some challenges and with this, challenges like safety, pollution, and energy demands have increased significantly. Today the vehicles have so much importance and effect on our daily life, and throughout all these years several laws and standards have been developed for effective development in vehicular design, production, to control environmental depreciation through vehicles and improve road safety. For all the mentioned reasons, huge efforts have been done and are in process to meet the desired efficiency of transportations. But with increasing number of vehicles on road, there are numerous concerns which have been addressed like fuel efficiency as almost all the countries have vehicles which uses fossil fuel as energy source . These days the vehicles have considerable fuel efficiency and other fuel sources such as CNG(Compressed natural gas) is being used to power the vehicles in India. The other concerns which include pollution due to vehicles, road safety, and traffic jam are still predominant in countries like India.

With increasing number of cars on Indian roads, unstructured driving, and poor law enforcements, almost 1 lakh accidents happen on Indian roads on daily basis, and people suffer a lot due to traffic jams specially in densely populated cities. Thus, intelligent transportation system can provide the solutions to these problems.

1.1 INTELLIGENT TRANSPORTATION SYSTEMS

ITS is an amalgamation of information and control technologies that includes communication, autonomous control, computer hardware and software. It provides efficient services for modes of transport, traffic management, mobility, and communication between V2I (vehicle to infrastructure), I2V(Infrastructure to vehicle) and V2V(vehicle to vehicle) so that the users are better informed. Also, it ensures that the transportation is safe and efficient at the same time. ITS relies on data collection through sensors and then perform data analysis which further used to control and improve transportation systems.

Working of ITS:

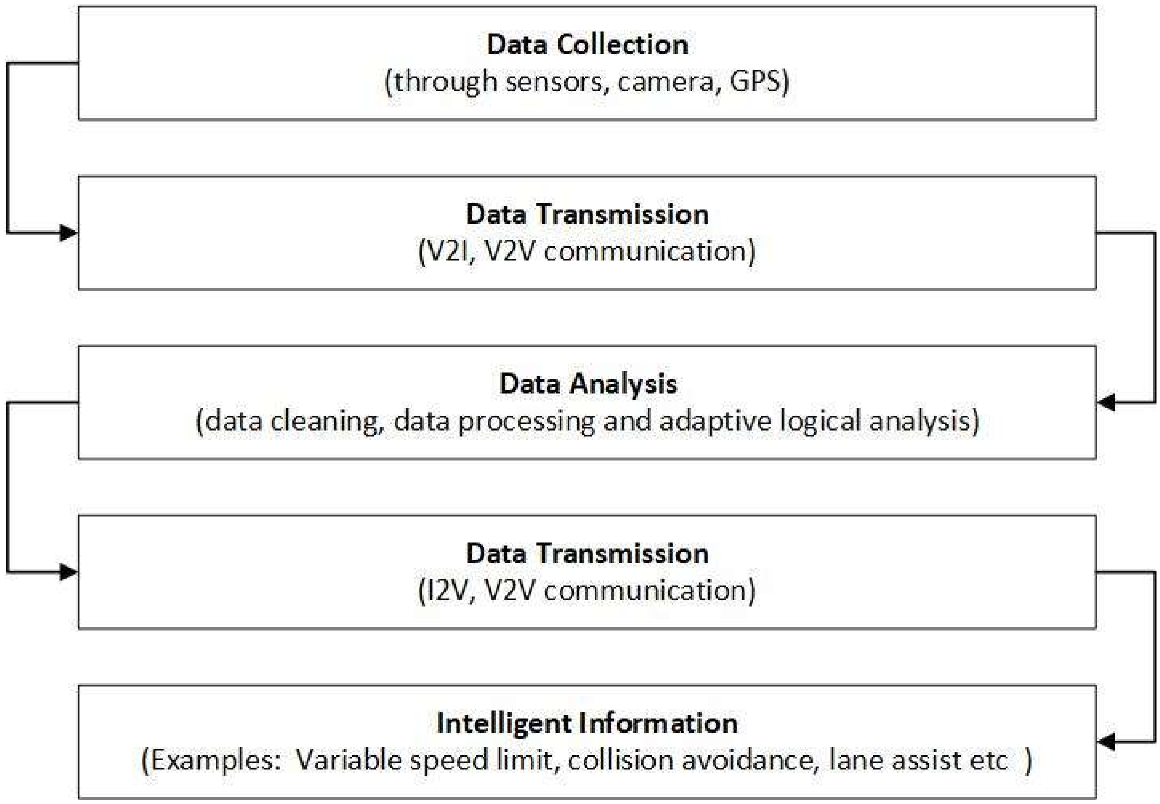


Fig. 1.1. Flowchart Diagram of ITS

Applications of Intelligent transportation Systems are :

1. Traffic light management systems
2. Variable speed limit enforcements
3. Emergency vehicle notification system
4. Automatic toll collection
5. Intelligent Vehicles
6. ADAS(Advance Driver assistance systems) & many more

Traffic light management systems : ITS provides a solution for efficient traffic management through controlling the traffic lights by changing the timings of traffic lights as per traffic density on intersections. Traffic density can be measured through inductive loops or by using computer vision. Thus, reducing the stop time for a vehicle on intersection. Companies like Siemens mobility also provides solution in the form of smart traffic light systems.

Variable speed limit enforcements : Variable speed limits on roads possess a challenge for drivers as they must ensure that they are driving under speed limits to avoid fine and to avoid any accident situation. Thus, it becomes important that a vehicle does not crosses speed limit. This problem can be solved through intelligent control of vehicles by I2V (Infrastructure to vehicle) communication in which the speed limit can be transmitted to vehicle and the vehicle's speed can be controlled with the help of throttle control by the driver or automatic control by the controller.

Emergency vehicle alert system : It transmits signal from one or more emergency vehicle to nearby commuter vehicle so that the emergency vehicle can move fast in a situation of emergency. ITS provides a solution in form of Green Corridor System in which an emergency vehicle encounters only green signal at intersections and also alerts the nearby vehicles so that the vehicles can move away from the lane in which emergency vehicle is moving.

Automatic toll collection: This method uses a RFID(radio frequency identification) technique. Each vehicle has a RFID tag with a unique tag identification number. This ID number is associated with the registration details of the vehicle and to digital wallet of the vehicle owner. It automatically deducts the toll charges from the digital wallet of the vehicle owner when the vehicle encounters a toll plaza.

Intelligent Vehicles : The vehicles that can respond to the changes in its surrounding by generating or transmitting signal to the nearby vehicle, to the infrastructure or to the driver of the vehicle so that the necessary action can be taken by the driver or the controller in case of autonomous vehicle. Intelligent vehicular technologies consist electronic, electromechanical, and electromagnetic devices operating in coherence with computer-controlled devices and transmitters/receivers.

ADAS (Advanced driver assistance systems) : ADAS are a group of electronic technologies that helps driver in various ways like lane assist, park assist, adaptive braking and cruise control etc. ADAS enhances the vehicular technology by automating, adapting to its surrounding and thus, reduce road incidents by minimizing human error. It uses multiple data sources like LIDAR, radar, computer vision and inter-vehicular networking. ADAS has been categorized into different level as per the autonomous level of the vehicle in which 0 level describes that the ADAS has no control over the car but it can provide information to the driver for example night vision, parking sensors, rear-view camera etc. In level 1 and level 2 systems the ADAS in level-1 can take control over one vehicle’s functionality and in level-2 it can control multiple functionalities to aid the driver for example autonomous parking. Level 3-to-5 denotes the increased autonomous behavior of the vehicle where level-5 denotes fully automated vehicle.

1.2 THESIS OBJECTIVE

Intelligent transportation system is an amalgamation between the hardware and software techniques to provide an efficient method of transportation. It also includes communication between Infrastructure to vehicle, vehicle to vehicle etc. ITMS (Intelligent transport management system) is also an ITS with a sole purpose of operational efficiency and automation in the field of transportation. Other features of ITMS are Automatic Vehicle Location System(AVLS), Incident Management System(IMS), Depot Management System(DMS), PIS (Passenger Information System).

And these days with artificial Intelligence and machine learning techniques revolutionized the autonomous field of transportation. These techniques work under several assumptions that the traffic should be structured, drivers should follow lane driving, laws are enforced effectively, but in countries where the traffic is unstructured, and implementation of laws is not good there these techniques might fail. And another issue is over speeding of vehicles on road which is the main cause of accidents and getting speed tickets for crossing the speed limit. Thus, to solve these problems

Aim: To develop and design a model to electronically control the speed of the vehicle through I2V communication.

Software Used: MATLAB-Simulink 2020a, Proteus VSM

Hardware : Arduino Uno, Rf transmitter and receiver, BLDC motor, MOSFETS for inverter bridge.

Parameter to be controlled: Longitudinal speed of vehicle

The longitudinal speed control will be done through transmitting the predefined speed limits continuously. The speed limits received by the receiver interfaced to the controller fitted into the vehicle and the received speed limit is used as a reference to control the vehicle speed.

1.3 THESIS STRUCTURE

The project work is organized as follows:

Chapter 2

Chapter 2 covers the literature survey about the speed control of electric vehicle and about the techniques which have been used by the researchers for speed control.

Chapter 3

The proposed work is divided into two parts. In first part the model developed in MATLAB-Simulink is presented, describing the complete model of the vehicle like dynamics of the vehicle and the controller used for speed control and along with the simulation results.

Chapter 4

In second part the model developed in Proteus VSM is described in which I2V communication is showcased to control the vehicle speed.

Chapter 5

The thesis work is concluded in this chapter by discussing which controller provides the best response with their advantages and disadvantages along with the future scope of the project work.

References

CHAPTER 2

LITERATURE SURVEY

With the increasing number of vehicles on road, the problem related to road accidents, traffic jam, pollution and road speed limit violations have become the major concerns in the field of transportation. Considering the limited fuel resources, the electric vehicle(EV) is certainly the new era of transportation and it has proven an alternative for vehicles with combustion engine further reducing their impact on environment.

But one of the major concerns is speed limit violation and in case of EV it can be more prominent as the power delivery in EV is almost instantaneous as compared to non-EV and in very short period the speed of the vehicle can cross the road speed limit. Thus, speed control is necessary to reduce road speed limit violations. Xue *et al.* proposed speed cascade adaptice control for hybrid electric vehicle through electronic throttle control during run time[1]. Ando *et al.* presented methods for automated driving bus for longitudinal motion[2]. Linghui Xu *et al.* [3] presented speed control of EV using Adaptive Fuzzy PID controller by controlling the armature voltage of the separately excited DC motor (driver system). Anil Kumar Yadav *et al.* [4] presented an approach for optimal speed control of hybrid EV through various control techniques like PID, Observer based controller, Linear quadratic regulator, Pole placement technique, to maintain a speed according to reference speed. The control techniques like model predictive control, motion control through deep learning and adaptive control have been used to control the longitudinal motion of vehicle.

The variable speed limit on roads and highways across the city is to ensure that the driver is not over speeding the vehicle and thus, a way to avoid any mishappening. It is evident that the persisting system is not able to resist the driver of crossing the speed limit on roads. Thus, through this paper a method is presented to reduce the driver indulgence over speed and ensuring the vehicle stays under speed limits. The electronic speed limiter model is simulated in Proteus-VSM through which variable speed control of BLDC motor is done using I2V communication and Arduino uno as microcontroller. The speed limits are transmitted and received through Rf module interfaced with the microcontroller and six-step commutation method is used to control the speed of the motor. The results showed that the method can control the speed under reference speed limits. Turican. D. *et al.* proposed a cruise control system using car2car and car2infrastructure communication[5]. Prasetyo *et al.* used Arduino Mega 2560 for speed control of BLDC motor through Model predictive control algorithm[6]. Aghaee *et al.* also proposed speed control of BLDC motor based on MPC sliding mode multi-loop control strategy using MATLAB and Arduino IDE[7]. Karnavas *et al.* proposed a low-cost microcontroller-based BLDC motor controller using Proteus[8]. Bohm M. *et al.* proposed Bidirectional I2V communication for advanced invehicle ISA systems[9]. Simulation of automatic vehicle speed control is presented by Gruyer D. *et al.* using transponder equipped infrastructure[10].

CHAPTER 3

VEHICLE DYNAMICS

3.1 LONGITUDINAL CONTROL STRATEGY

The objective of longitudinal speed control is to track the variable reference speed. The dynamics of vehicle for longitudinal control is a set of complex equations and these equations are explained by the longitudinal motion resulting from frictional forces between the tyres – road and other aerodynamic forces[3]-[6].

The forward motion dynamics based on Newton's second law describes the longitudinal dynamic model of the vehicle as:

$$m\ddot{x} = F_{xf} + F_{xr} - F_{aero} - R_{xf} - R_{xr} \tag{3.1}$$

where F_x- net longitudinal force : $F_x = F_{xf} + F_{xr}$
and Rx - net rolling resistance : Rx = Rxf + Rxr
Assumption α = 0 degrees i.e., the road is completely horizontal with no inclination thus sin(α) = 0.
Then the eqn.1 becomes

$$m\ddot{x} = F_x - F_{aero} - R_x \tag{3.2}$$

Where, $$F_{aero} = \frac{1}{2} C_a \rho A \dot{x}^2$$

F_{aero} is aerodynamic force experienced by vehicle and it depends on air density, frontal areaand on the speed of the vehicle. R_x and R_f are the rolling resistances of rear and front wheels.
The traction force(F_x) is the result due to contacts between wheel and road, acts on the wheel dynamics as following:

$$I_w \dot{w} = -RF_x + T_w \tag{3.3}$$

where I_w is inertia of wheel, ω the rotational speed of wheel, R is radius of wheel and T_w the applied torque (traction or braking) on the wheel.

The longitudinal velocity can be described as

$$\dot{x} = r_{eff} \omega_w \tag{3.4}$$

Where $\dot{x}$ is longitudinal velocity , r_{eff} is tire effective radius, and ω_w is the rotational coupling and is given by the eqn.

$$\omega_w = GR\omega_t = GR\omega_e \tag{3.5}$$

Here, ω_w is wheel's angular speed , GR is Gear ratio, which is fixed for electric vehicle, ω_e is the motor angular speed.

Let the longitudinal reference speed be a v_{ref} and the tracking speed error defined by:

$$e_v = v - v_{ref} \tag{3.6}$$

The electric motor dynamics can be given by the equation:

$$J\ddot{\theta} + b\dot{\theta} = k_t i \tag{3.7}$$

$$L\frac{di}{dt} + Ri = U - k_e\dot{\theta} \tag{3.8}$$

Where J is the inertial moment, θ is the rotation angle, b is the motor's friction constant, i is electric current, L is the inductance, R is internal resistance, k_t is torque constant, k_e is the back-emf constant.

3.2 MODEL DEVELOPED IN MATLAB-SIMULINK

The block diagram of the developed model is shown by the block diagram:

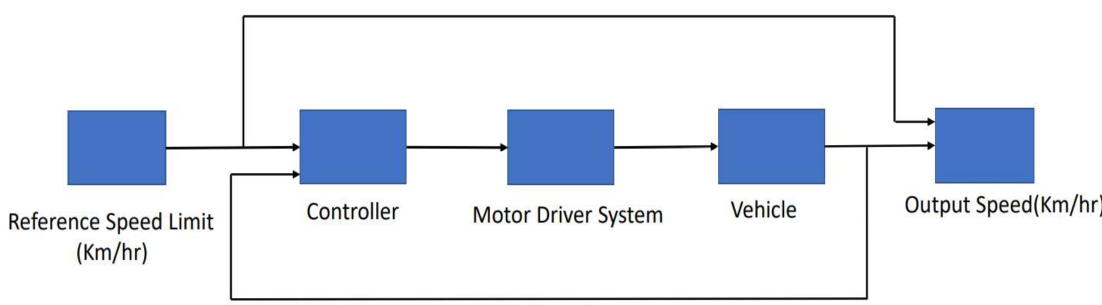


Fig. 3.1. Block Diagram of Simulink model

The Reference speed limit is a graph of speed limit v/s time. A stretch has been selected between Delhi Technological University(DTU, DELHI) to Indira Gandhi International(IGI) airport terminal 3(T3). The route consists of four zones and each zone has its own speed limit. The zone length is selected based on road length, speed limit on that road and simulation time. The simulation time is set to 2000 seconds.

Fig. 3.2. Zonewise reference speed limit between source and destination

3.3 CONTROLLER UNIT

The controller is modelled using longitudinal driver block which is implemented as a speed tracking controller and it also represents the dynamic behavior of the driver. The techniques used for controlling the speed limit of vehicle through longitudinal driver block are explained below:

Proportional Integral Control: The PI controller with anti-windup tracking is used. In PI control technique, error signal is the difference between the measured output and the set point and calculated through feedback loop. In this case the set point is the reference speed limit and measured output the speed of the vehicle.
The eqn. describing the PI control action is given by:

$$y = k_p \times e + k_i \int edt \tag{3.9}$$

Here, e is the input error, and the transfer function is given by:

$$G(s) = k_p + \frac{k_i}{s} \tag{3.10}$$

PI control is faster than I-only control due to the proportional action. PI control prohibits the system from fluctuations and enable it to come back towards the set point. Though the response time of PI is faster than I-only, but it is slower than P-only control. Thus, to improve response time D-control is introduced with PI control. Integrator windup is the issue which is present in PID controllers. Integrator windup arises due to the limit constraint of physical variable or nonlinear saturation in the loop. In this situation the feedback loop breaks, causes error accumulation in the integrator. With reduction in error, the response gets delayed because of the presence of large integrator value which prevents the controller to resume normal operations in time[7]-[10].

Now the solution is either stop integrating the input if it saturates or compare the actual input and the commanded input. If no difference found, then saturation is not present . Otherwise, decrease the integral error by a constant time the difference.

$$u_{\text{int}} = \int k_i (e + k_{aw}(sat(u) - u))dt \tag{3.11}$$

Here, the PI controller is used with feed forward gains. Generally, the PID gains are reactive i.e., based on the error that has already occurred, but the feedforward gains are proactive like velocity feed forward and acceleration feed forward, predicts the command needed to achieve zero error and injects them into control loop. Velocity feedforward works against viscous friction and minimizes error during the constant velocity portion of the move whereas the acceleration feedforward gain works against inertia in the system to minimize error during the acceleration and deceleration phases of the move. The eqn. for PI control technique with anti-windup tracking with feedforward gain is given by:

$$y = \frac{k_{ff}}{v_{nom}} V_{ref} + \frac{k_p}{v_{nom}} e_{ref} + \int \left(\frac{k_i}{v_{nom}} e_{ref} + k_{aw} e_{out} \right) dt \tag{3.12}$$

Where velocity feed-forward k_{ff} = 0.05, k_p = 15, k_i = 1, anti-windup gain k_{aw} = .1, nominal velocity v_{nom}= 100 km/hr

Scheduled PI controller: Scheduled PI with anti-tracking windup with feed-forward gain as a function of velocity is used and the equation is given by

$$y = \frac{k_{ff}(v)}{v_{nom}} V_{ref} + \frac{k_p(v)}{v_{nom}} e_{ref} + \int \left(\frac{k_i(v)}{v_{nom}} e_{ref} + k_{aw} e_{out} \right) e_{ref} dt \tag{3.13}$$

Where velocity gain breakpoints = [0 100], velocity feed- forward gains k_{ff}vel = [.1 .1], k_p = [10 10], Integral gain values k_i = [5 5], nominal velocity v_{nom} = 100 km/hr , anti-windup gain k_{aw} = 0.1.
Also, velocity error e_{ref} is given by:

$$e_{ref} = v_{ref} - v \tag{3.14}$$

Difference between saturated and nominal control ouput e_{out} is described as:

$$e_{out} = y_{sat} - y \tag{3.15}$$

Where y_{sat} is described as

$$y_{sat} = \begin{cases} -1 & y < -1 \\ y & -1 \le y \le 1 \\ 1 & y > 1 \end{cases} \tag{3.16}$$

The braking and acceleration commands are generated using below equations:

$$y_{acc} = \begin{cases} 0 & y_{sat} < 0 \\ y_{sat} & 0 \le y_{sat} \le 1 \\ 1 & y_{sat} > 1 \end{cases} \tag{3.17}$$

$$y_{dec} = \begin{cases} 0 & y_{sat} > 0 \\ -\mathrm{y}_{sat} & -1 \le y_{sat} \le 0 \\ 1 & y_{sat} < -1 \end{cases} \tag{3.18}$$

Predictive Speed Tracking : In Predictive speed tracking control, an optimal single point preview look ahead model(developed by C.C. MacAdam) is implemented using the dynamics as a linear single track (bicycle) vehicle. This model diminishes the previewed error signal at a single point T* seconds ahead in time.
For longitudinal motion the linear dynamics implemented described by the following equations:

$$x_1 = v \tag{3.19}$$

$$\dot{x}_1 = x_2 = \frac{k_{pt}}{m} - g\sin(\gamma) + f_r x_1 \tag{3.20}$$

Where F_r is rolling resistance, m mass of vehicle, x is predicted velocity state vector, k_{pt} is tractive force, and brake limit, v is longitudinal velocity, γ is grade angle which is assumed to be zero in this project.

For rolling resistance the controller uses this equation

$$Fr = -\left[\tanh(x_1)(\frac{a_r}{x_1} + c_r x_1) + b_r \right] \tag{3.21}$$

The single-point model assumes a minimum previewed error signal signal at a single point T* seconds ahead in time. a* is the driver ability to predict the future vehicle response based on the current steering control input. b* is the driver ability to predict the future vehicle response based on the current vehicle state. The block uses these equations.

$$a^* = (T^*)m^T \left[I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{(n+1)!} \right] ge \tag{3.22}$$

$$b^* = m^T \left[I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{n!} \right] \tag{3.23}$$

Where: $m^T = [1 \ \ 1]$

The single point model implemented by the block finds the steering command that minimizes a local performance index J over the current preview interval (t, t+T).

$$J = \frac{1}{T}\int_{t}^{t+T} \left[f(\eta) - y(\eta) \right]^{2} dn \tag{3.24}$$

To minimize J w.r.t steering command, the condition is

$$\frac{dJ}{du} = 0$$

The optimal control solution in terms of a current non-optimal and corresponding non-zero preview output error T* seconds ahead.

$$u^{\circ}(t) = u(t) + \frac{e(t+T^{*})}{a^{*}} \tag{3.25}$$

To determine the preview time window, the relation is given below

$$T^{*} = \frac{L}{v} \tag{3.26}$$

Here, preview distance(L) is 2 meters by default in predicting control of longitudinal driver block.

3.4 MOTOR DRIVER SYSTEM

Motor driver system consists of a PWM controlled voltage block, H-bridge to drive the motor in forward direction. Motor used is permanent magnet type DC motor. The stator in DC motor consists of fixed permanent magnets which produces stationary and uniform magnetic flux in motor. Commutation takes place through carbon brushes placed around the commutator and when the armature rotates , a new set of armature winding gets energized resulting in more rotation of armature.

Thus, the rotational speed depends on the interaction between two magnetic fields i.e., one is caused by the stationary permanent magnets and another magnetitic field generated through rotating electromagnets in armature. And the speed is easily controlled by controlling this interaction between the two magnetic fields[11]. As the magnetic field produced by stator's permanent magnets is fixed so the magnetic field generated through armature must be controlled by controlling the current resulting in stronger or weaker magnetic field thus, faster, or slower speed. The equation for speed of motor is given below where N is rotational speed of the motor and it is proportional to the back emf generated due to the magnetic flux Φ and K_e is electromechanical constant depending upon the nature of the armature's windings

$$N \alpha \frac{V}{K_e \Phi} \tag{3.27}$$

PWM "Pulse Width Modulation" is one of the ways to control the speed of the motor by regulating the amount of voltage across motor's terminals. Speed control through PWM works by driving the motor with a series of "ON-OFF" pulses and varying the duty cycle, the fraction of time that the output voltage is "ON" compared to when it is "OFF", of the pulses while keeping the frequency constant. The power applied to the motor can be controlled by varying the width of these applied pulses and thereby varying the average DC voltage applied to the motor's terminals. By changing or modulating the timing of these pulses the speed of the motor can be controlled, i.e., the longer the pulse is "ON", the faster the motor will rotate and likewise, the shorter the pulse is "ON" the slower the motor will rotate. In other words, the wider the pulse width, the more average voltage applied to the motor terminals, the stronger the magnetic flux inside the armature windings and the faster the motor will rotate, and this is shown below.

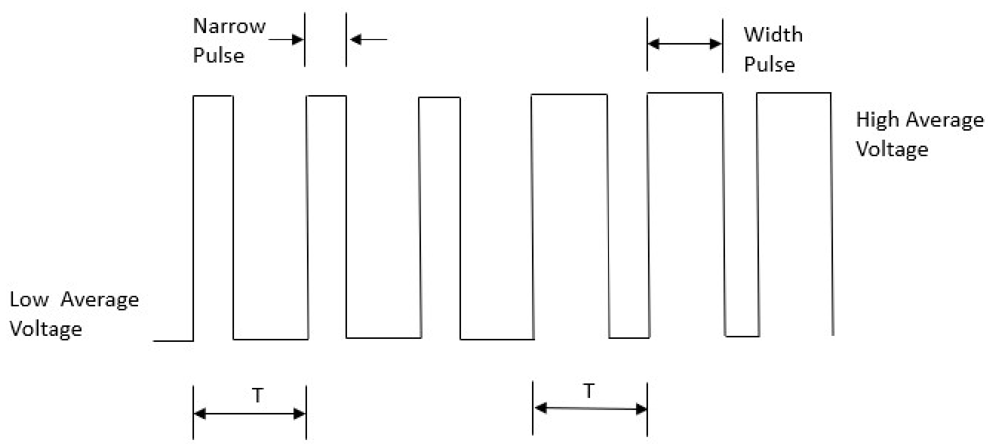


Fig. 3.3. PWM control pulse

H-Bridge: h bridge is a simple electronic circuit which enables us to apply voltage to load in either direction. It is commonly used in robotics application to control DC Motors. By using H-Bridge, we can run DC Motor in clockwise or anticlockwise directions. This circuit is also used to produce alternating waveforms in inverters.

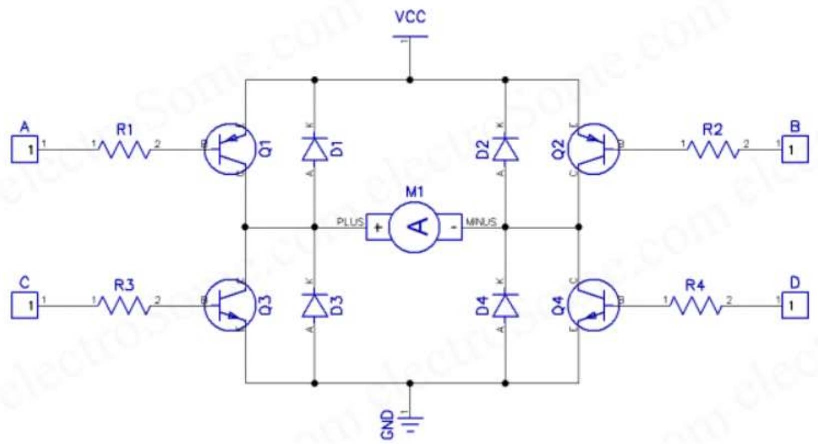


Fig. 3.4. H-bridge circuit to rotate motor in forward or reverse direction

In this circuit all transistors are wired as switches. An NPN transistor (Q3 and Q4) will be ON when we give HIGH to it and a PNP transistor (Q1 and Q2) will be ON when we give LOW to it. So, when (A = LOW, B = HIGH, C = LOW, D = HIGH), transistors Q1 & Q4 will be ON and Q2 & Q3 will be OFF, so the motor rotates in clockwise direction. Similarly, when (A = HIGH, B = LOW, C = HIGH, D = LOW), transistors Q2 & Q3 will be ON and transistor Q1 & Q4 will be OFF, thus the motor rotates in anticlockwise direction. 1N4148 (D1 ~ D4) is uses as freewheeling diode as it is a fast-switching diode. It avoids problems due to negative voltage produced by the back emf the dc motor. Resistors R1 – R4 are used to limit the input current of transistors and are designed in such a way that transistor will work as a switch. Transistor should be chosen according to the current requirements of the DC Motor.

The Parameters used in modelling in Simulink is given in below table.

Table. 3.1. Parameters of Vehicle Model

Parameters	Values	Units
Mass of vehicle	1000	Kg
No. of wheels per axle	2	-
Frontal area(A)	3.0	m^2
Rolling resistance (constant coefficient)	0.015	-
Air Density($\boldsymbol{\rho}$)	1.18	Kgm^{-3}
Rolling radius of wheel	0.3	m
Drag coefficient(C_a)	0.4	-
Magic formula coefficient [B,C,D,E]	[10, 1.9, 1, 0.97]	-

3.5 SIMULATION AND RESULTS

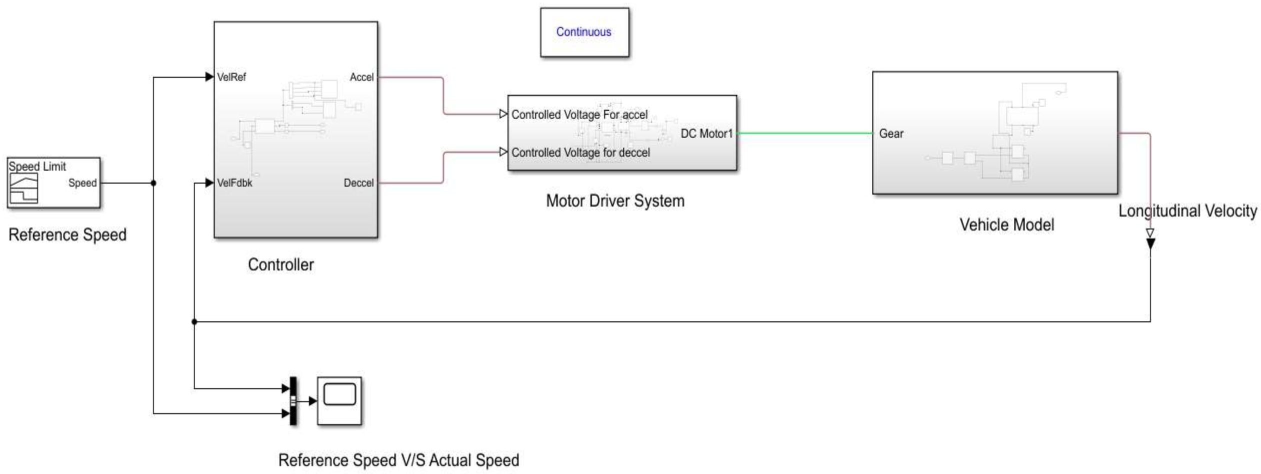


Fig. 3.5. MATLAB-Simulink model for longitudinal speed control

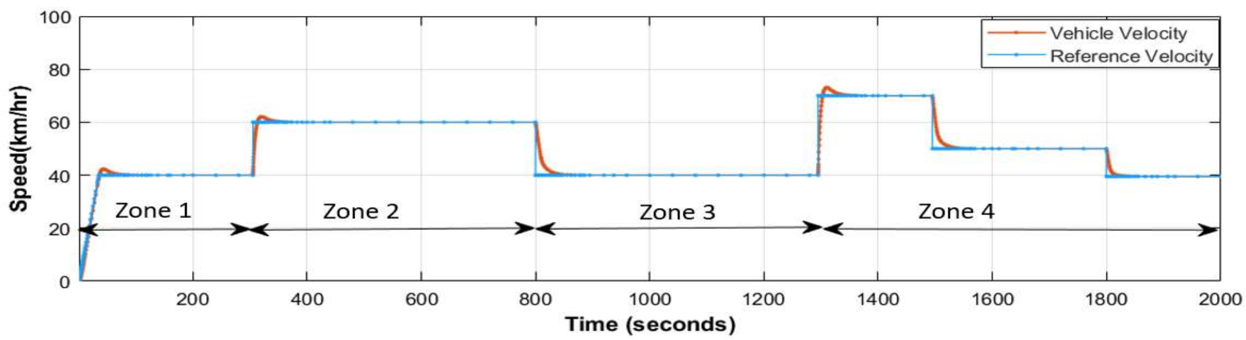


Fig. 3.6. Tracking reference speed through PI control

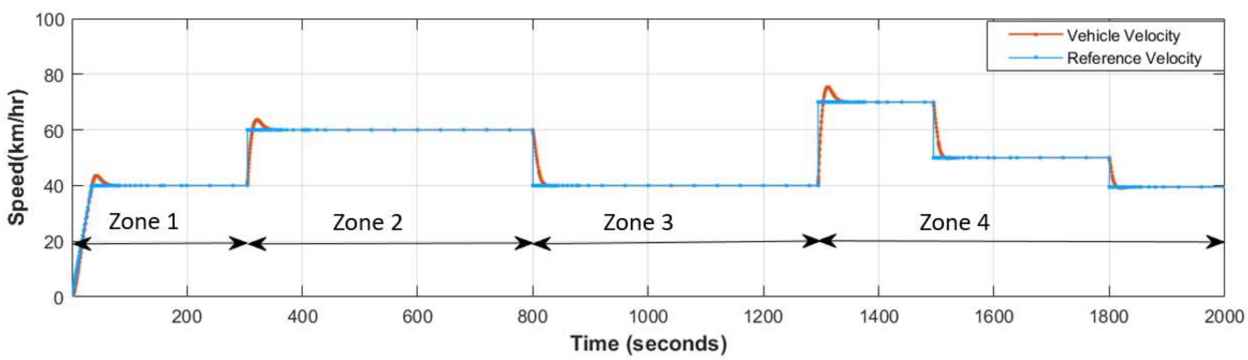


Fig. 3.7. Tracking reference speed through Scheduled PI control

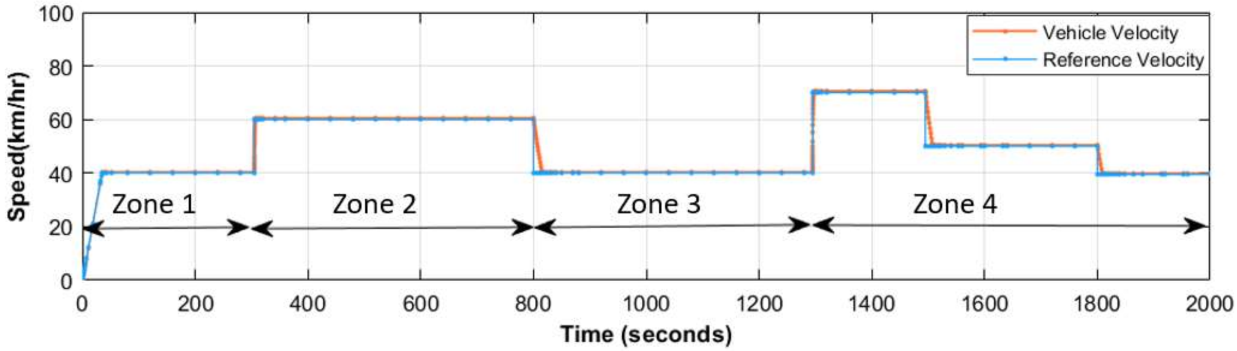


Fig. 3.8. Tracking reference speed through Predictive speed control

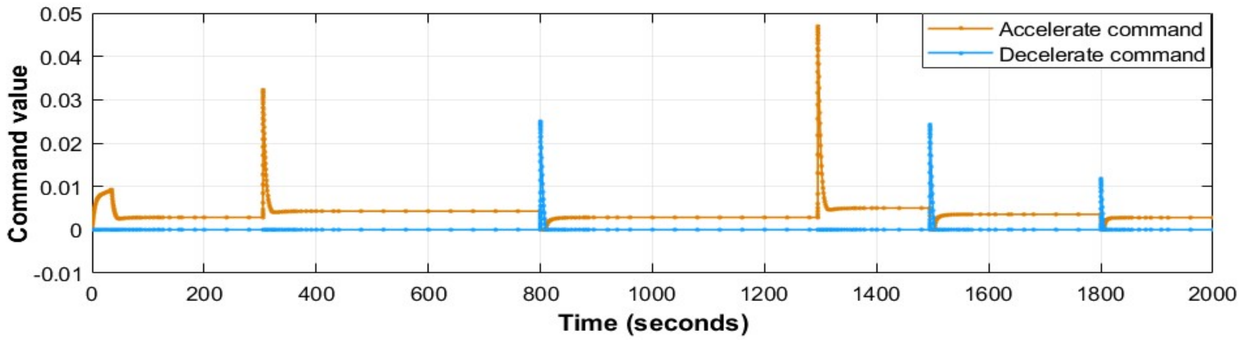


Fig. 3.9. acc/dec command value generated through PI control

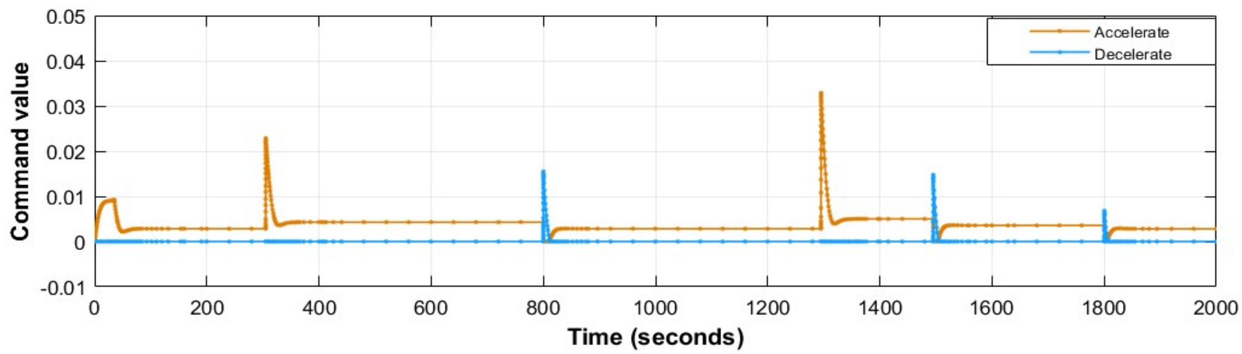


Fig. 3.10. acc/dec command value generated through scheduled PI control

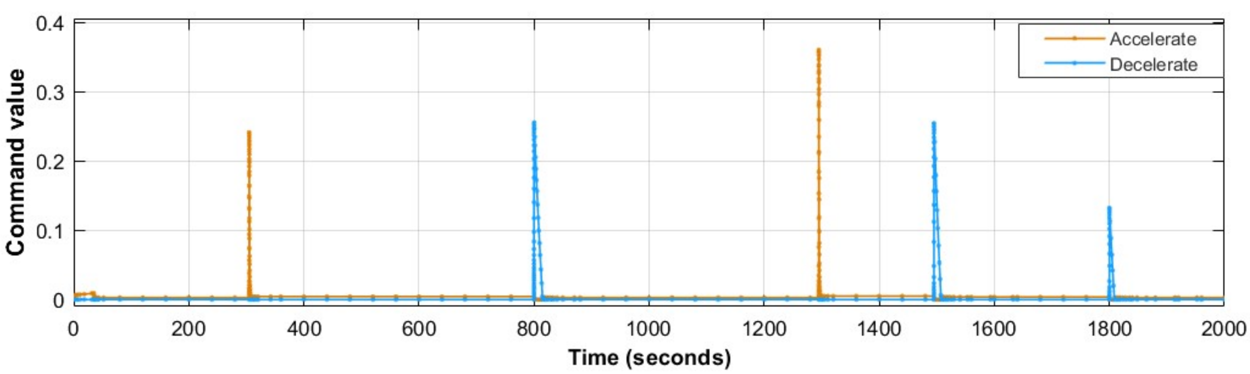


Fig. 3.11. acc/dec command value generated through predictive control

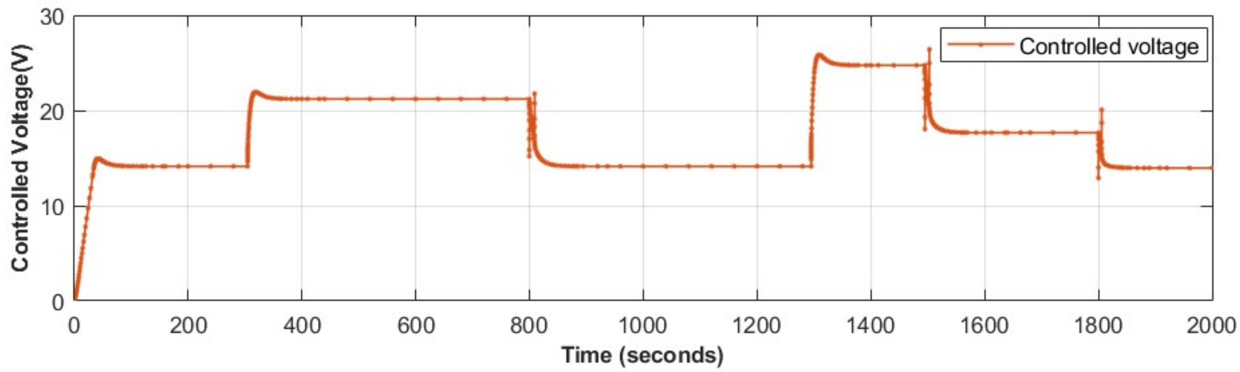


Fig. 3.12. Controlled voltage signal through PI control

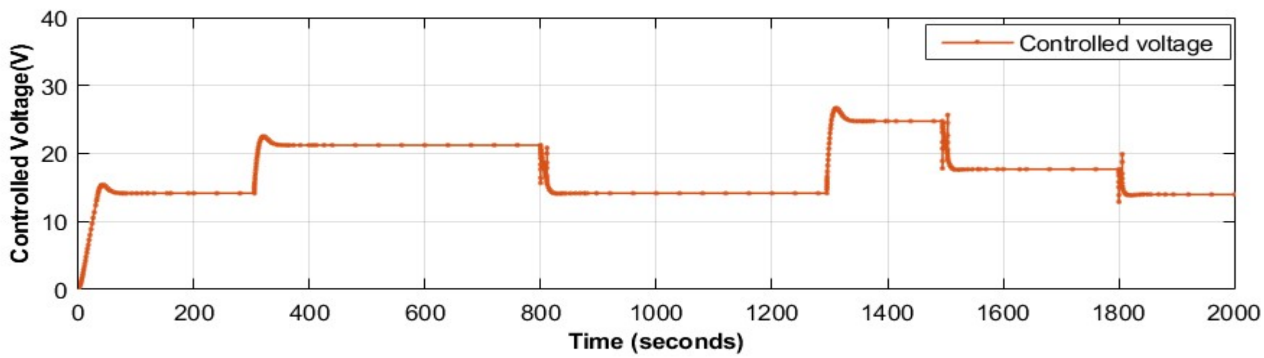


Fig. 3.13. Controlled voltage signal through Scheduled PI control

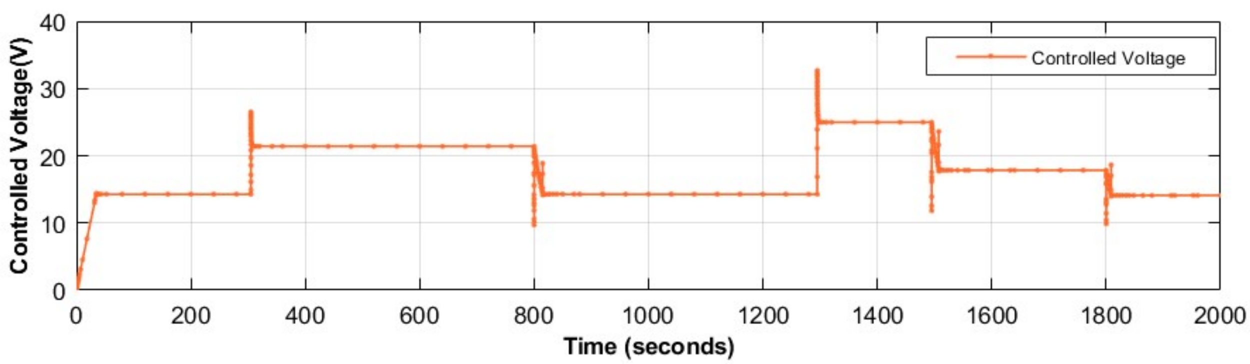


Fig. 3.14. Controlled voltage signal through Predictive control

CHAPTER 4

LONGITUDINAL SPEED CONTROL USING I2V COMMUNICATION

The main objective was to develop a model for infrastructure to vehicle(I2V) communication .i.e., to create an environment in real life scenario where the speed limit on a particular road is communicated to the vehicle and the electronic speed limiter operating coherently with the controller automatically adjust the vehicle speed as per the speed limit signal communicated to it. The communication between vehicle and the infrastructure can happen through Rf transmission which is adopted for this project, through GPRS module where the location and the speed of the vehicle is known continuously, and the variable speed limit signal is transmitted to the vehicle and controlled by the controller through variable speed limiter electronically. This method is most suitable for the electric vehicle as compared to ICE engines. Electronic speed limiters are available in the market for ICE engines, but they have fixed speed limit, and their efficiency is also substandard.

With the advancement in automotive technology has improved the safety and efficiency of the transportation. The AI and ML techniques paved the path for autonomous driving. With increased autonomous levels the system becomes complex and performs better when the traffic is structured like lane driving is followed by drivers. But in the countries like India where the traffic on road is much denser than other countries then it becomes important that the vehicles must be driven under speed limits as over speeding can cause accidents. The efficiency of autonomous vehicle on Indian roads might not be as good as USA and European roads. Thus, Infrastructure to vehicle communication is another method through which the vehicle can be controlled in an efficient manner. In this project the I2V communication is being done using RF module(transmitter and receivers) between two Arduino Atmega 328p controllers configured in master slave configuration. One of the controllers is fitted into the roadside structure like pole etc. which transmits the variable speed limit and the another is fitted inside the vehicle with electronic speed limiter and the receiver to receive the transmitted signal. So, the scenario is created in Proteus VSM where two Arduino controllers are used to control the speed of BLDC motor.

In this paper, a method is presented which imitates a scenario in which the speed of the vehicle is controlled by I2V communication. Here BLDC motor is used in place of vehicle and its speed is controlled through Rf communication. The model is simulated on the assumption that all the vehicles on road are enabled for I2V communication to avoid any mishappening and only longitudinal motion is considered for speed calculations. BLDC motor consists of a PMSM with either trapezoidal or sinusoidal back emf. BLDC motors are used because of their quick dynamic response, high efficiency, acceptable torque-speed characteristics, and long life and application of BLDC motors include automotive application specially in two wheelers and home appliances etc.

4.1 BLDC MOTOR OPERATION AND CONTROL

4.1.1 Power Inverter

Power inverters are used to construct single phase or three phase AC signals to motor windings. These inverters consist of MOSFET, BJT or IGBT's as switches[12-15]. In three phase inverters, there is either 120-degree conduction or 180-degree conduction. In this project 120-degree conduction is implemented where each transistor is turned on for 120-degree[2-6]. In this conduction method only 2-load terminals are connected at any instant and the 3rd terminal is left open as only two switches are on at any given time. Due to this generated waveform is quasi-square waveform. In sensor less control of BLDC motor the back-emf is fed to the controller and each one of the waveforms is out of phase to each other by 120-degree.

4.1.2 Control of BLDC motor

Due to the absence of brushes on the rotor, the bldc motor is commutated electronically at particular rotor positions. For simplicity and easy control of bldc motor, the permanent magnets are magnetized and their displacement on the rotor is selected in such a manner that the trapezoidal back emf gets generated. The rotations in bldc motor can be controlled through six step commutation process also known as 60, 120-degree control technique[16-20].

In this paper Arduino Uno with electronic circuitry is used for efficient control of motor with variable speed limits. The 120-degree six step commutation controlling method is used for its simplicity. In this controlling method, the two terminals of star connected windings are connected to the supply at any given time and the 3rd one remains open. For variable speed control applications, the most common technique which is reliable and efficient at the same time is PWM control through inverter bridge. The required speed is attained by just changing the duty cycle ratio between 0 to 100% of the PWM.

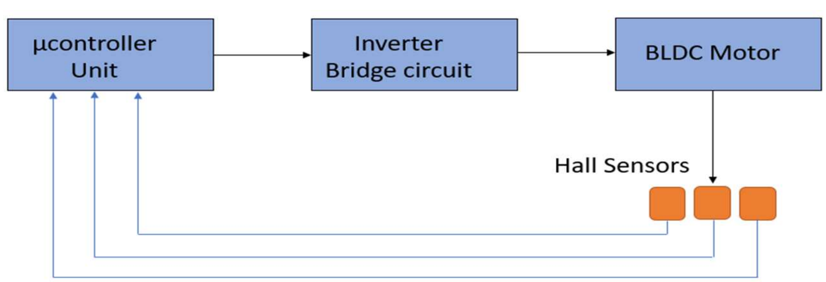


Fig. 4.1. Block diagram for BLDC motor speed control

4.1.3 I2V Communication

The Rf module in Proteus VSM library consists of transmitter and receiver module , transmitting and receiving radio signals between two devices. The transmitter allows unidirectional communication at 433.92MHz frequency at 1Kb rate. Both the transmitter and receiver use ASK(Amplitude shift key) modulation method to data communication[21]. The desired or the reference speed limit is transmitted continuously by the transmitter and the receiver fitted with the driving system receives the signal and that signal is first converted into rpm and then mapped to a corresponding PWM signal which further used to control the speed of the motor. This way the proposed method provides a way to control the speed of the vehicle in real time system.

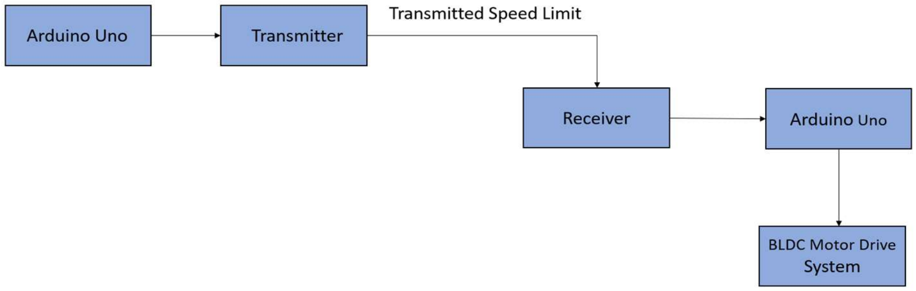


Fig. 4.2. Block diagram of I2V communication

4.1.4 Rf modules(Transmitter/Receiver)

The Rf modules consists of small electronic modules which transmits and receives data at 433.92 MHz frequency.

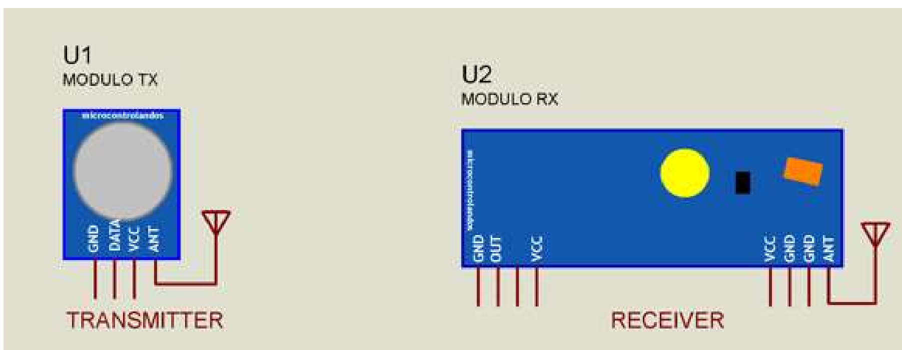


Fig. 4.3. Transmitter and Receiver modules in Proteus VSM

Features of Rf transmitter:

1. Offers unidirectional communication at 1Kb data rate.
2. Operating range is 3-12 V.
3. Uses ASK(amplitude shift keying) modulation for transmission of data.

Features of Receiver module:

1. Operating voltage is 5V maximum.
2. Variable frequency can be set using present node.
3. 433MHz Rf receiver module uses the ASK signal as an i/p.

Specification of 433 MHz transmitter/receiver module:

Table 4.1. Specifications of Transmitter and Receiver modules

Max range with the antenna in normal conditions	100 Meters
RX Receiver frequency	433 MHz
RX Typical sensitivity	105 Dbm
RX Supply current	3.5 mA
RX IF Frequency	1 MHz
RX Operating Voltage	5V
TX frequency range	433.92 MHz
TX supply voltage	3V~6V
TX output power	4~12 Dbm

Working of 433MHz RF transmitter and receiver module:

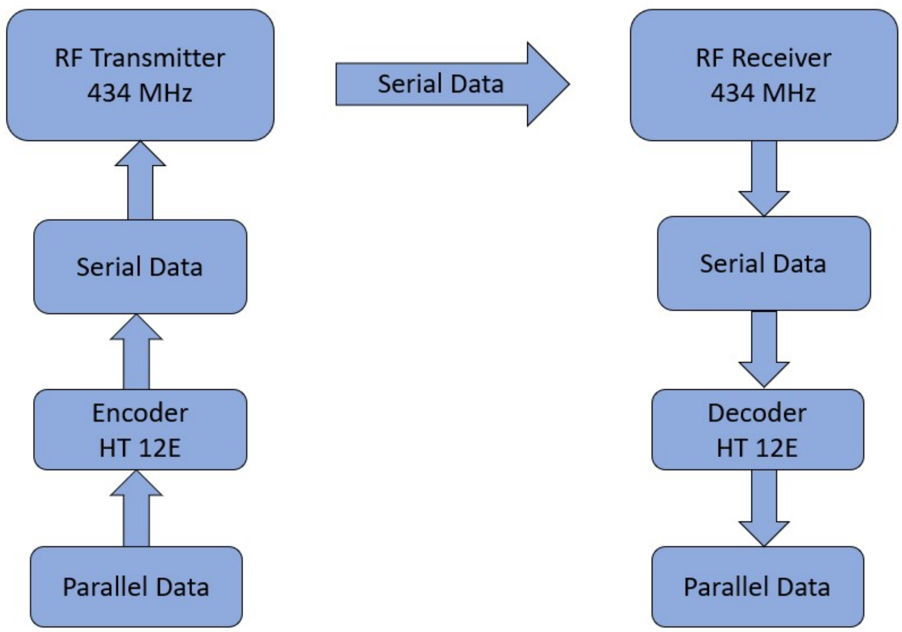


Fig.4.4. Flow diagram of data communication between Transmitter and Receiver

The receiver module receives the data in the form of a signal and sends it to the data pin. The data received by the module is always in an encoded form which can be decoded by either using the microcontroller or the decoder. The 433 MHz RF receiver module helps to receive the 433MHz frequency mainly. But it has a node also that can be changed by users for different frequencies. The variable node can be used to adjust the frequency from 315MHz to 433MHz.

The receiver just receives the data but to decode and view this data, a microcontroller or decoder is required.

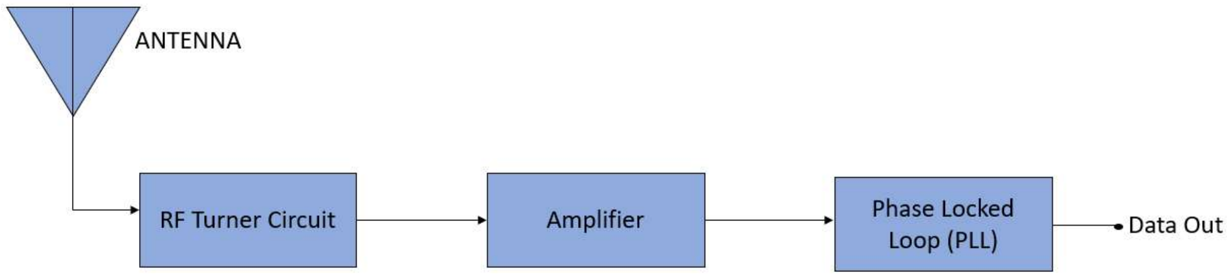


Fig. 4.5. Receiver functioning

The RF receiver module comprises an RF tuned circuit and a couple of Operational Amplifiers to amplify the received carrier wave from the transmitter. The amplified signal is then further fed to a PLL (Phase Lock Loop) later it is received by the decoder which decodes the output stream and gives better noise immunity[22-23].

4.2 WHEEL MODELLING

In this project longitudinal motion is considered. Further, the rotational velocity of motor is converted into linear velocity by tire modelling through programming in microcontroller. In this project, the size of tire is taken as 225/55 17-inch rim diameter where 255 is the width of tire in mm and 55 is the aspect ratio in percentage. The aspect ratio is defined as the ratio of tire height to the tire width in percentage[24-32].

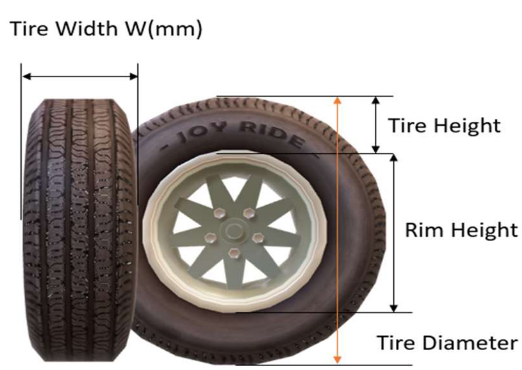


Fig. 4.6. Wheel Modelling

$$AR(\%) = \frac{H(mm)}{W(mm)} \times 100 \tag{4.1}$$

Here, H is tire sidewall height and W is tire width. From this equation we can calculate H as aspect ratio and tire width is given for a tire by the manufacturer. Thus, the wheel diameter is given by the combination of rim diameter and two times of the height.

$$d_w = D + 2H \tag{4.2}$$

The static wheel radius is given by :

$$r_w = \frac{d_w}{2} \tag{4.3}$$

And if the deformation of tire is also considered then the wheel radius is given by

$$r_w = 0.95 \times \frac{d_w}{2} \tag{4.4}$$

The wheel radius used for this project is 339.65mm after calculating for the wheel size 225/55 17”. Now, the revolutions per minute must be converted into linear velocity for a vehicle so that the real time situation can be simulated. Considering the gear ratio remains constant for an EV, the angular velocity can be defined as

$$w = \frac{RPM}{60\sec/\min} \times 2\pi \; rad/rev \tag{4.5}$$

and the relation between the linear and angular velocity is given by

$$v = wr \tag{4.6}$$

Thus, the linear velocity is transmitted through the transmitter to the vehicle and with the help of above equations the rpm for the corresponding speed limit is calculated and provided as the reference rpm limit for BLDC motor. Through this way the speed of motor is controlled.

4.3 DESIGN AND SIMULATION OF SPEED CONTROLLER

The model is developed in Proteus-VSM which consists of two Arduino Uno as microcontroller, one of the two microcontrollers is used to transmit the variable speed limit continuously and another microcontroller fitted into the vehicle receives the transmitted signal and controls the speed of the motor. The schematic diagram is shown below. It consists of two controllers one of them is interfaced with Rf transmitter which transmits the data having reference speed limit. Another Arduino Uno is interfaced with receiver which receives the transmitted signal, the input side of inverter circuit is connected to the Arduino pins and output side is connected to the BLDC motor. The inverter circuit consists of 6-IRF3205 MOSFETs and the other circuitry consists of resistors, capacitors, and logic gates to generate high and low logic levels. Two DSO are also connected to generate back-emf waveforms and the terminal voltage waveform. Two virtual terminals are also connected to show that the data is being transmitted and is received by the receiver.

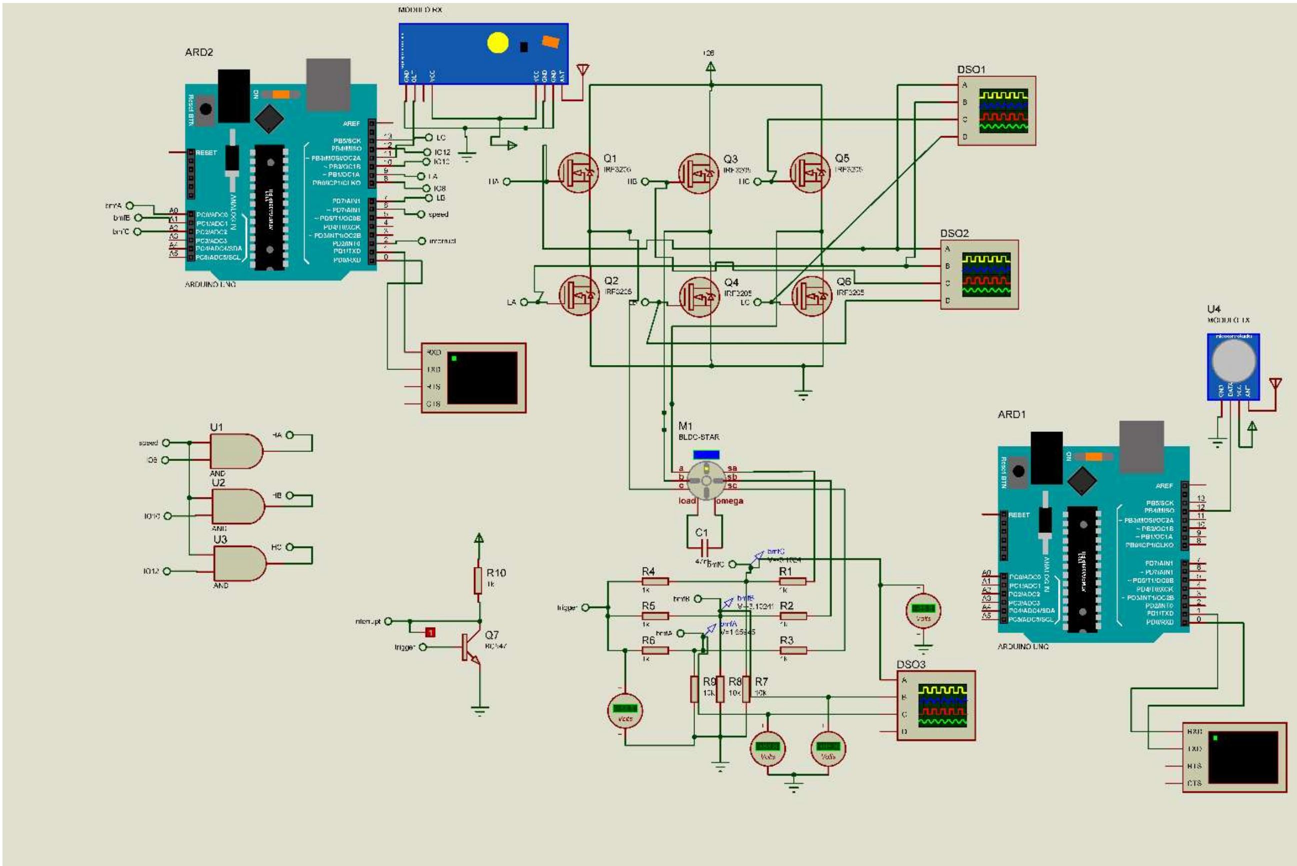


Fig. 4.7. Schematic diagram of model developed in Proteus-VSM

The Arduino are programmed in Arduino IDE. Also, Proteus provides the platform to program the microcontroller unit. It also provides the debugging mode for the developed model. Here, in this model the microcontroller which is a part of motor drive system generates 3 PWM signals which are fed to the HS of the inverter bridge.

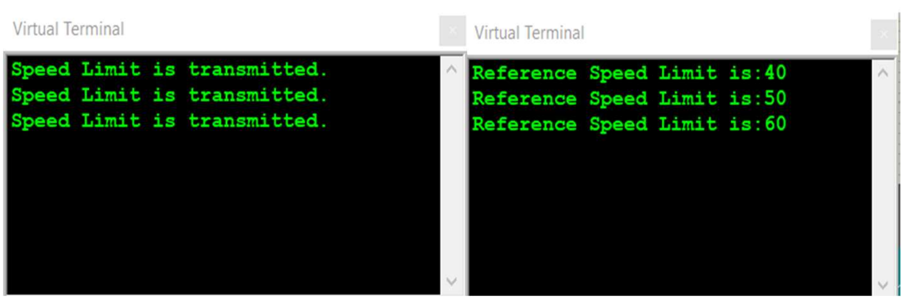


Fig. 4.8. Data communication between transmitter and receiver

The data containing the speed limit is being transmitted continuously and received by the receiver interfaced with the controller fitted into the vehicle. The received data is in Km/hr so it is converted into rpm and then the corresponding PWM signal is generated. The below figures show the High side and Low side of phases , the PWM signals generated by the microcontroller unit for the inverter bridge , back-emf of the motor and the terminal voltage of the BLDC motor.

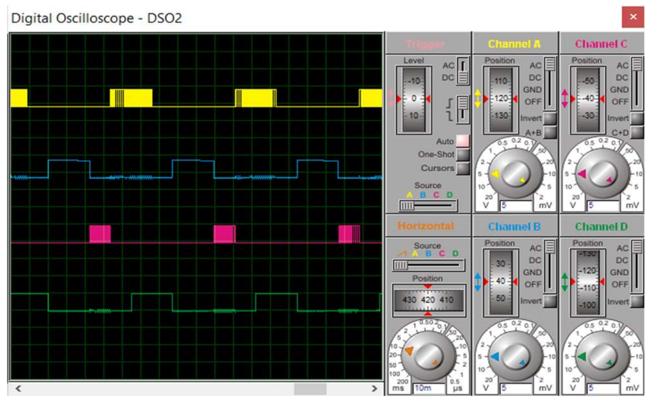
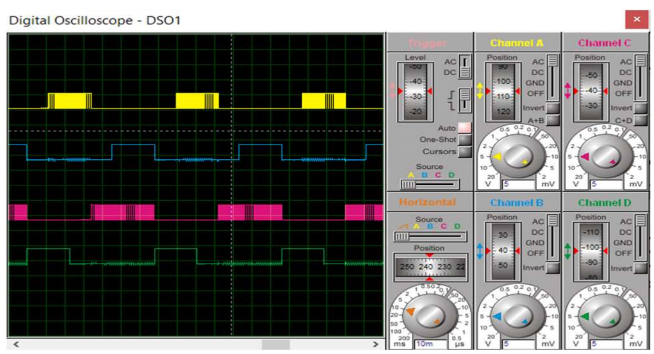
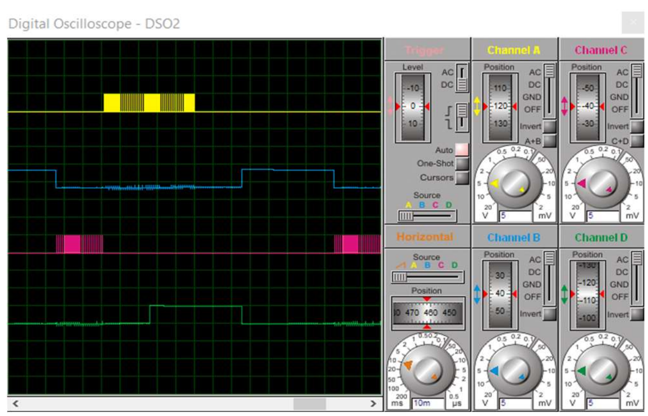


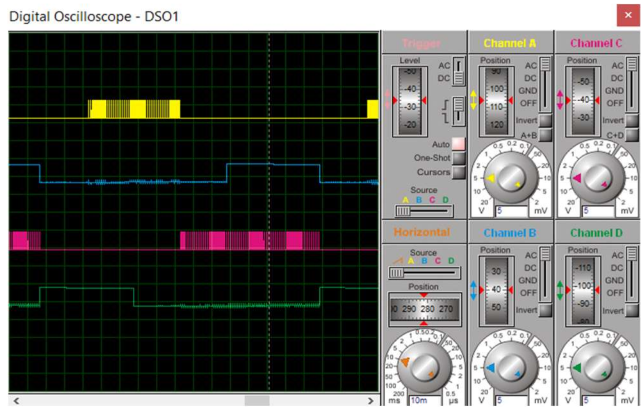
Fig. 4.9. (a)



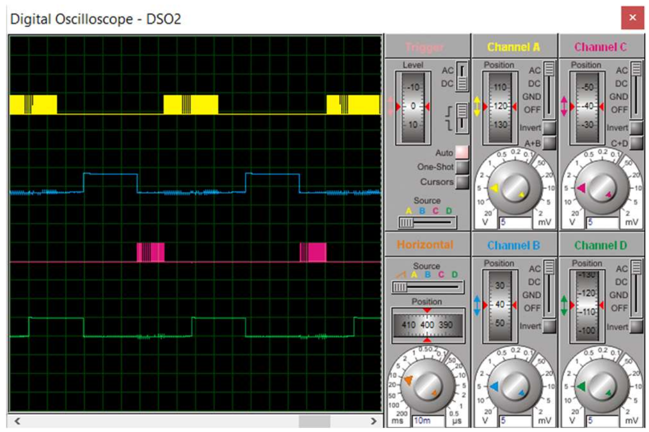
(b)



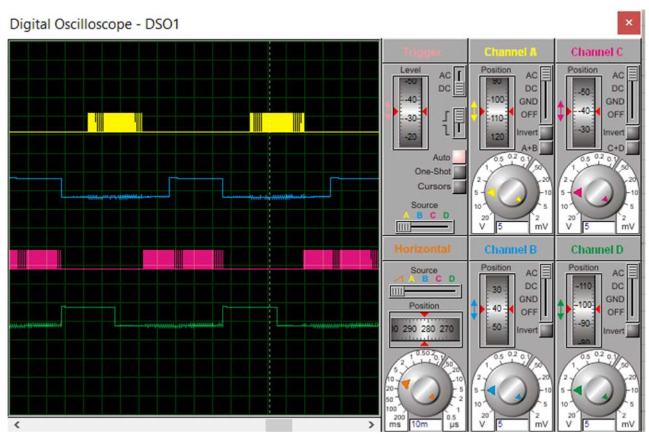
(c)


Digital Oscilloscope - DSO1
Trigger
Channel A
Channel C
Horizontal
Channel B
Channel D

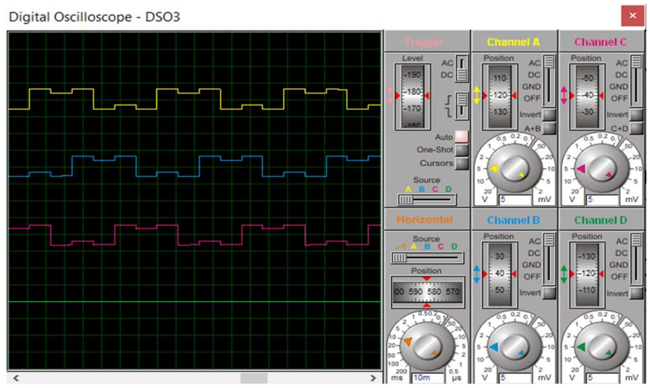
(d)


Digital Oscilloscope - DSO2
Trigger
Channel A
Channel C
Horizontal
Channel B
Channel D

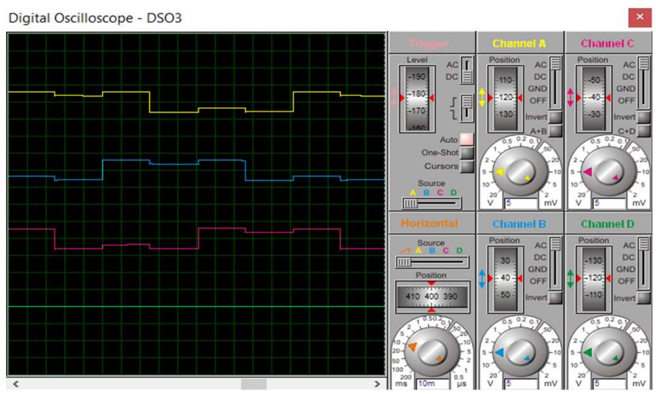
(e)


Digital Oscilloscope - DSO1
Trigger
Channel A
Channel C
Horizontal
Channel B
Channel D

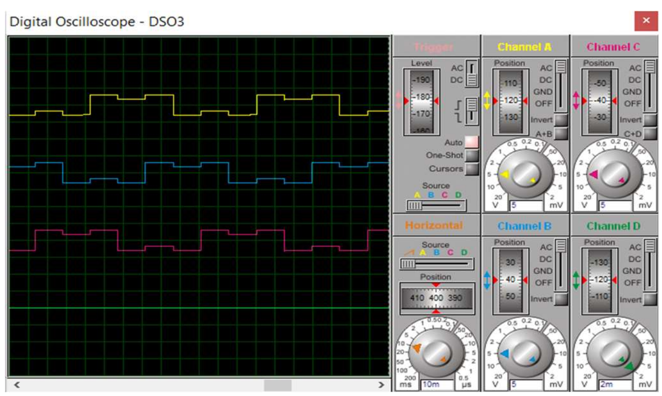
(f)


Digital Oscilloscope - DSO3
Trigger
Channel A
Channel C
Horizontal
Channel B
Channel D

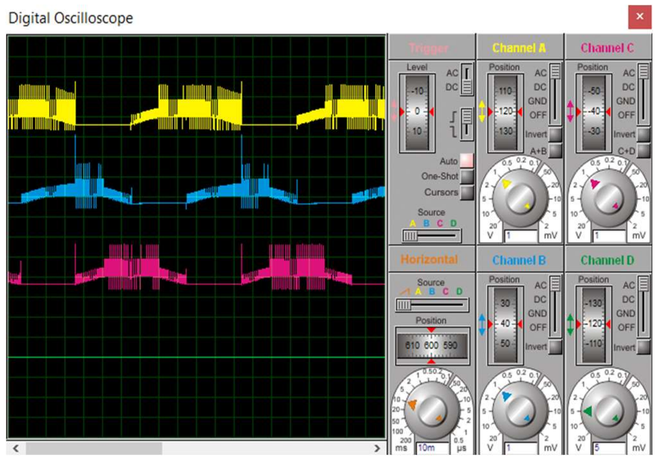
(g)


Digital Oscilloscope - DSO3
Trigger
Channel A
Channel C
Horizontal
Channel B
Channel D

(h)


Digital Oscilloscope - DSO3
Trigger
Channel A
Channel C
Horizontal
Channel B
Channel D

(i)



(j)

Fig.4.9. Figures show the typical waveforms generated by microcontroller-unit for high side and low side of phase (A , B) and (A,C) of Inverter bridge at 40% PWM signal (fig a, and b), 50% PWM signal(fig c and d), 60% PWM signal(fig e and f), and fig. g, h and i show back emf at 40%,50% and 60% respectively. And fig (j) shows the terminal voltage of BLDC motor.

CHAPTER 5

CONCLUSION AND FUTURE WORK

The problem stated in thesis objective has been met successfully through the developed models in simulation mode. The two models developed in MATLAB-Simulink and Proteus VSM presents a method through which the longitudinal speed of the vehicle can be controlled effectively. The model developed in Simulink shows that the predictive speed tracking controller provides the best response among all the controllers because of its preview time window which helps it to avoid any such conditions which might result in error. It generates hard acceleration and braking command to match the reference speed limit. Whereas the second model is presented to showcase the I2V communication. A model is developed in Proteus-VSM to electronically control the speed of the vehicle specially EV's. As the persistent system is not sufficient to control the speed efficiently. Thus, this method can be an alternative method. The model is working perfectly in simulation mode. The graphs generated shows that the model is working perfectly.

Future Work:

This project performs under certain assumptions that only the longitudinal motion is considered, there is no slip conditions, road is horizontal i.e., no grade is present and for I2V communication all the vehicles should be able to communicate with the infrastructure .The future work includes the hardware implementation of the simulated model along with lateral speed control of vehicle with I2V communication.

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