

Performance Analysis of Smart Speed Variation in Electric Vehicles Using the Combination of Fuzzy Logic Controller

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Abstract

Electric vehicles (EVs) have emerged as a response to the increasing environmental impact of combustion engines and the rising demand for fossil fuels, offering a sustainable alternative to meet the growing transportation needs that underpin economic development. Ensuring the safe operation of EVs on existing road infrastructure, particularly in environments with physical speed breakers, remains a critical concern. Speed bumps are commonly used to prevent collisions due to excessive speeding; however, they often compromise driving comfort and pose safety risks when encountered unexpectedly. This study proposes a smart speed control system for electric vehicles using a fuzzy logic controller, aimed at replacing traditional speed breakers. The system operates by deploying a transmitter at the entry point of a speed-regulated road segment, which sends speed limit data to approaching vehicles equipped with a corresponding receiver. Upon receiving the signal, the vehicle's speed is automatically adjusted to the designated limit. Once the vehicle exits the speed-restricted zone, a new signal allows it to resume normal speed. Developed using MATLAB/Simulink, the fuzzy logic-based control system not only enhances road safety and driving comfort but also contributes to energy

efficiency in EVs. The successful implementation of this vehicle-to-infrastructure (V2I) communication model demonstrates the feasibility of intelligent speed regulation, suggesting its integration as a standard feature in future EVs. This approach provides traffic authorities with a proactive means of managing vehicle speed without direct driver intervention.

Keywords: Electric Vehicles; Smart Speed Control; Fuzzy Logic Controller; Vehicle-to-Infrastructure Communication; MATLAB/Simulink

INTRODUCTION

Prior to the introduction of fuzzy logic, probability theory was the only instrument available to specialists for handling uncertain circumstances. However, times have changed in the present. The ability to model under imprecisely defined conditions was actually made possible by these new mathematical tools, and as a result, a semblance or shadow of their applications—which span nearly every area of human endeavor, including the humanities, management, industry, robotics, decision-making, programming, fuzzy control, medicine, biology, and education—has quickly developed. Voskoglou (2017) A system's uncertainty can be roughly defined as the absence of precise knowledge or information about the data that describes it. Two categories of uncertainty are quite evident here, namely vagueness and ambiguity. This type of system has been applied in a variety of fields, such as automated car navigation systems, fuzzy controllers for automated train operations, controllers for robot vision, and graphics controllers for automated police sketchers, among many others. This type of system analysis and control is linguistic in nature and resembles human reasoning; the computation is based on degree of truth rather than true or false of the Boolean logic which is the typical computation modeling. .. This indicates that a fuzzy logic statement may have a degree of truth value that falls between 1 and 0, or between 0.1 and 0.9 with 0 and 1, inclusive. It's a method for managing processes that are challenging to model. Because fuzzy logic can solve problems with an open, inaccurate spectrum of facts, which makes the problem to be accurately solved.

Success now goes by another name: speed. Drivers constantly think that the faster they drive, the more trips they will make and, thus, the more money they will earn. Every year, there are more traffic accidents as a result of this fast driving. Despite the fact that automakers are including improved safety features, the number of traffic accidents is at an

all-time high. The World Health Organization (WHO) just released the Global Status Report on Road Safety (2018), a first-of-its-kind survey. claims that more people die in traffic accidents in India than any other country in the world, including China, which has the largest population. According to WHO estimates, traffic accidents will reach a peak in terms of human mortality by 2030. India is unique in that it has thirteen traffic accident fatalities every hour. According to a piece in Nigeria Auto Journal, published by the Nigeria Journalists Association NAJA (2023), "High Road Crashes, Burden of Nation," 41,693 persons in Nigeria die in traffic accidents each year, accounting for 2.82 percent of all fatalities worldwide. which is rather unsettling. Finding a solution to this issue that is wreaking havoc on humanity becomes the general duty of a socially conscious engineer in order to reduce its happening. The engineering society should make the design of an intelligent and effective system that may mitigate such calamities a top priority.

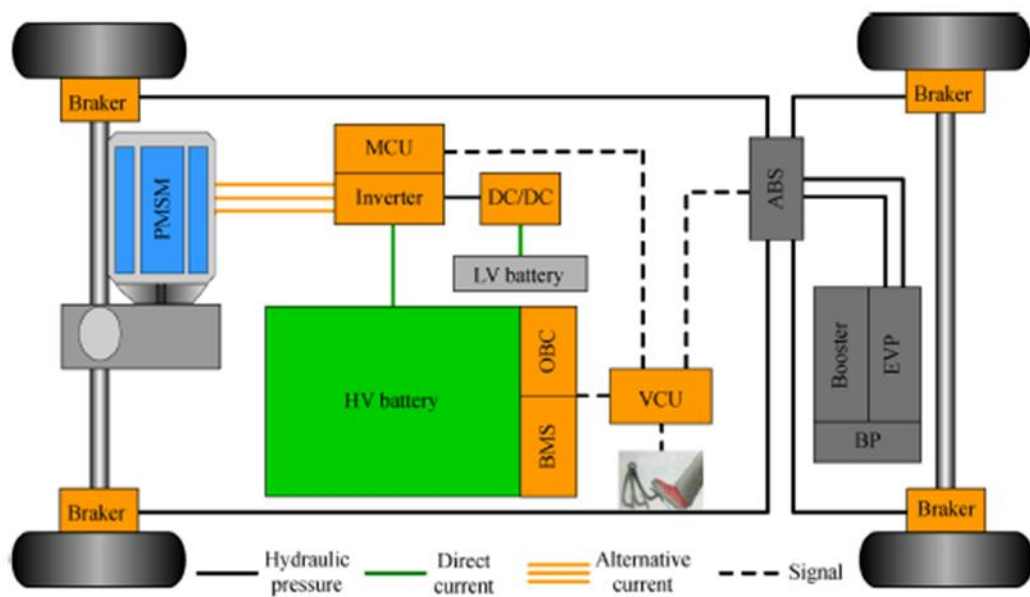
Review of Related Works

In the quest to achieve lesser heating, higher power density and higher efficiency, permanent magnet synchronous motors were introduced to the EV industry. Though it is better in terms of fuel efficiency and traction capabilities, one major setback with this motor is demagnetization due to armature reaction. Aside this, the brushes wears easily and can be damaged if dropped. The induction motor is the fourth motor that Veer et al. (2019) emphasize. This motor has several drawbacks, including excellent efficiency and little maintenance, but its costly controller is a big drawback. When using a fuzzy logic controller, it is under control.

The optimization of this component has increased due to the understanding that electric motors can transfer electrical energy to mechanical energy and are occasionally used to convert mechanical energy to electrical energy. In light of this, authors in Zhu et al., 2019 focused on dynamic control strategy and level optimization design in less rare earth hybrid permanent magnet motors. To stratify design factors, a thorough and careful analysis was done throughout the project. Response surface approach and numerous objective genetic algorithms were used to produce optimum motor design. Response compensation approach was developed to reduce torque ripple and speed vibration in order to obtain optimal control. The work's weakness stems from the fact that the suggested approach never took into account intelligent braking or deceleration to ensure

safety. Asiabar & Kazemi (2019) concentrated on electric vehicles with in-wheel motors in their effort to increase the safety of these vehicles. His presentation states that the advantage of in-wheel motors in electric vehicles is their ability to eliminate the propulsion unit and transmission systems, thus creating a large amount of interior space. The drawback is that these motors coupled to the vehicle without springs result in a drop in road holding capacity and a decline in ride comfort. Apart from this, the main disadvantage is when the car deviates from the intended path when executing a maneuver. ... The authors suggested employing adaptive sliding motor control to create a direct yaw movement controller for an electric car with four wheel drive. It is suggested that two controllers be used. A fuzzy logic controller is employed as a lower level controller to help rectify any departure for the intended track, while a PID controller is used as an upper level controller to maintain the longitudinal velocity constant during maneuvers. This work was done using Matlab/Simulink. The drawback of this is that, despite safety being the primary concern, clever deceleration was overlooked in the research. The authors of Xu et al., (2021) developed a micro traffic flow model to regulate the movement of electric vehicles by taking into account the unique acceleration and deceleration characteristics of these vehicles. This approach was put forth to address issues brought on by traffic congestion, which is typified by frequent stops and starts. This movement may occur from the driver's lane-changing behaviour or from the driver in front of you stopping suddenly for whatever reason. It was noted that due of their distinct acceleration and deceleration, EV micro traffic models perform better than traffic models for conventional vehicles. The limitation of the study is that the model developed was only aimed at controlling traffic which involves the speed of the car. However, the author did not consider traffic control based on speed limit on a street.

Liu et al., 2020 presented the evaluation of a single pedal strategy for the acceleration and deceleration of an EV. This was done to achieve regeneration of energy so as to ensure energy efficiency. The study examined the regenerative braking system using a single pedal in order to recover energy. Figure 2.1 illustrates how a signal is transmitted from the vehicle control unit (VCU) to the motor control unit (MCU) upon release of the pedal. This guarantees that the drive with the PMSM label will have its speed reduced by the inverter. Simultaneously, the antilock braking system (ABS) receives a control signal from the VCU, guaranteeing safe breaker operation.



Considering replacing energy used by the vehicle, authors in (Zhang et al., 2021) presented the wireless charging lane strategy. In the presentation, the vehicle moves on a partial wireless charging lane to intersections where the slow movement of vehicles in traffic is used to recharge the vehicle. This was achieved via the use of wireless- eco driving strategy. In the strategy, electric vehicles are made autonomous, making decisions based on data from adjacent vehicles to calculate its slow movement. Although, as shown in figure 2. the scheme was able the increase driving range, the limitation was that it does not consider speed limit as considered in this research

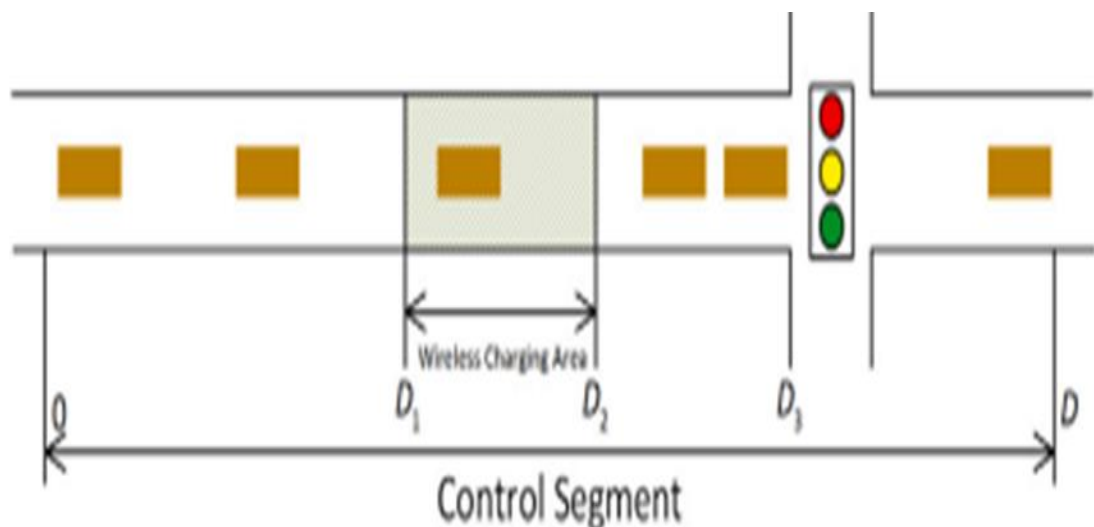


Figure 2. W-eco-driving Source: (J. Zhang et al., 2021)

METHODOLOGY

Smart System Communication Structure

Smart transportation is shown in figure 3. Communication has often been used as a tool for gathering data that aid intelligent transport network. This is evident as the research community has emphasized on vehicle to everything communication. This, however, could be in form of vehicle to vehicle communication, vehicle to grid communication or vehicle to infrastructure communication. Among these, the latter is considered as a strategy to aid speed compliance of electric vehicles base on stipulated speed limit.

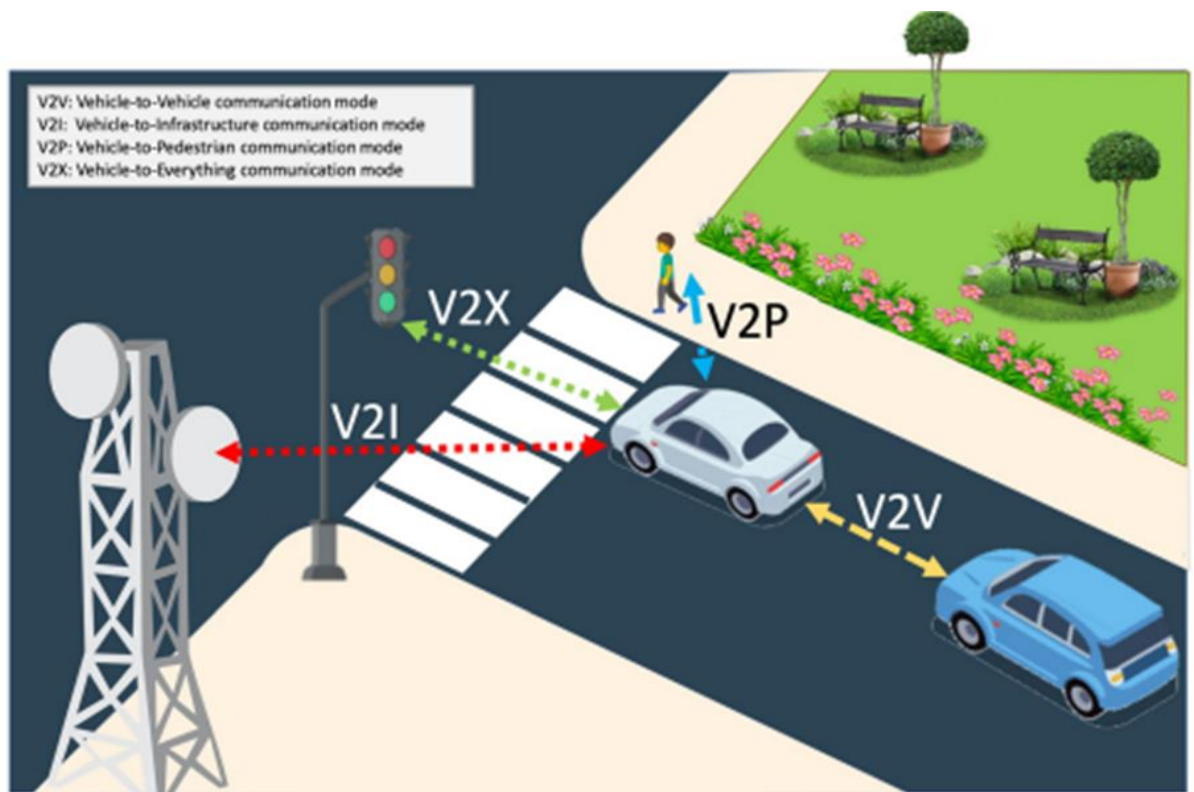


Figure 3. Communications in transport systems (Zeadally et al., 2020)

In this research work, vehicle to infrastructure communication will be used to transmit the speed limits of the street the vehicle is about to journey through. As shown in figure 4. The infrastructure is within the mile pole which transmits the speed limit of the street that the vehicle intended to journey through some miles away to the vehicle. When the vehicle receives this information, the controller will adjust the speed of the electric motor by gradually changing the voltage supplied of the motor in the vehicle so that the

reference speed received is adhered to. With this, there will be no need for speed bumps which can be hazardous to drivers that are not familiar with the street.



Figure 4 Illustration of the scenario

Vehicle System architecture

As shown in figure 4, the vehicle consists of an antenna which received the distance of the next street to be travelled through. The radio frequency signal generated from the pole is modulated with the speed information which is decoded via demodulation. The transmission and reception of the speed limit is achieved via communication network.

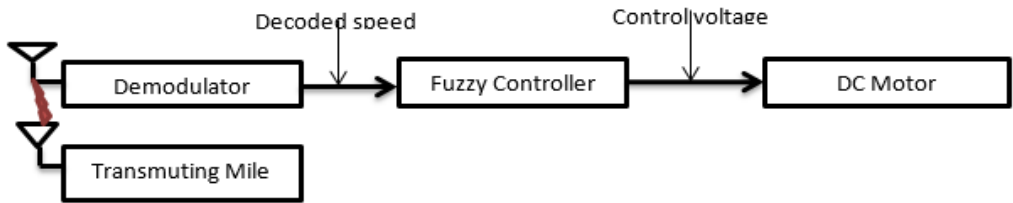


Figure 5. System Block Diagram

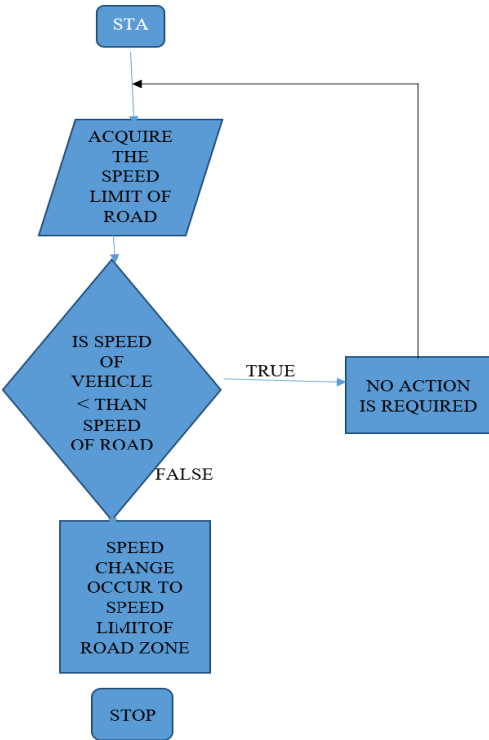


Figure 6 Flow Diagram of the control process.

The flow diagram figure 6 shows the system working during initial stage the system acquire the speed limit of the road zone from the transmitter along the road before entry the zone, then it compares it with the speed of the vehicle. If it is less than the speed limit of zone, no action is performed. On the other hand if the speed is greater than the zone speed signal is send to the EV to reduce the speed. Then the speed is automatically reduced. Because the fuzzy logic controller output is directly linked to the cruise control of the EV without the driver interference.

This power density is given as;

$$\text{Power Density (PD)} = \frac{\text{Recieved Power}(P_r)}{\text{Surface area of the antenna}(A)} \quad (3.1)$$

$$\text{But Area of the antenna } A = 4\pi D^2 \quad (3.2)$$

Where D is the distance between the transmitter and the receiving car

Since in an isotropic medium, it can be assumed that the transmitted power is equal to received power. Therefore, power density can be rewritten as

$$PD = \frac{P_t}{4\pi D^2} \quad (3.3)$$

To consider the system in real life situation it is important to consider the gain of the antenna

$$PD = \frac{P_t G_t}{4\pi D^2} \quad (3.4)$$

Where G_t ; is the transmitter gain.

But effective aperture is given as;

$$A_{effective} = \frac{\lambda^2}{4\pi} G_r \quad (3.5)$$

Where λ is the wavelength.

$$P_r = A_{effective} \times PD \quad (3.6)$$

Therefore the equation can be written as:

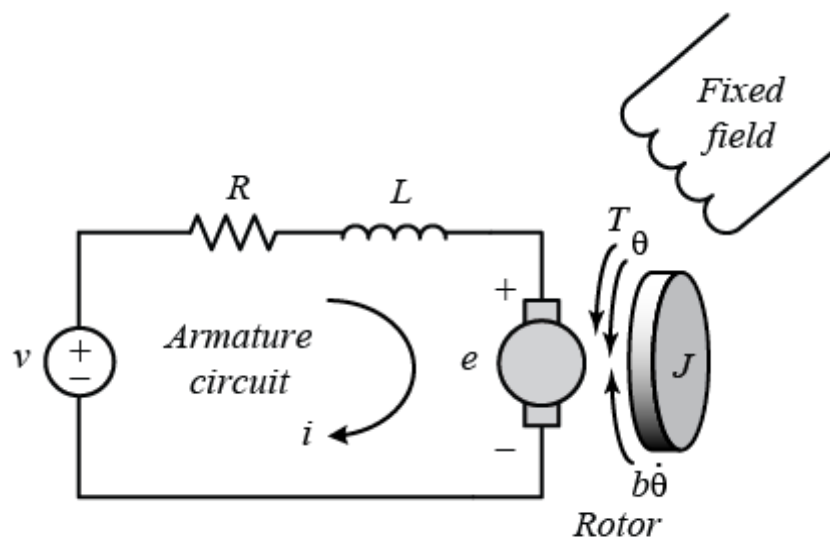
$$P_r = \frac{P_t \times G_t \times G_r \times \lambda^2}{(4\pi D)^2} \quad (3.7)$$

The equation 3.6 therefore mathematically describes the relationship between the transmission power and the reception power during communication. After reception, the message is decoded via demodulation techniques. This is then fed into a fuzzy logic controller and the system which gradually reduces the voltage value fed to the electric motor. As a result, the car makes use of Newton's second law of motion to create the necessary dynamics to obey speed limit.

$$V = u + at \quad (3.8)$$

Where, V is the final velocity, (a) is the acceleration and (u) is the initial velocity. In this work it is the (a) in the above equation, which the fuzzy logic controller will ramp according to the speed limit received by vehicle at any particular time.

Designing of the Control used to map the output of the cruise control from acceleration to a speed command that can be fed to the motor. The equation of this control is based on both motor calibration curve and the desired response time.



. Figure 7. physical setup of DC motor equivalent diagram.

RESULTS AND DISCUSSION

Acceleration test

The system designed and simulated was tested with car initially on a speed of 10km/h which is to ramp up to 20km/h after receiving the speed limit of 20km/h from

the infrastructure. Figure 4.1 illustrates the system simulation with the initial speed of 10km/h.

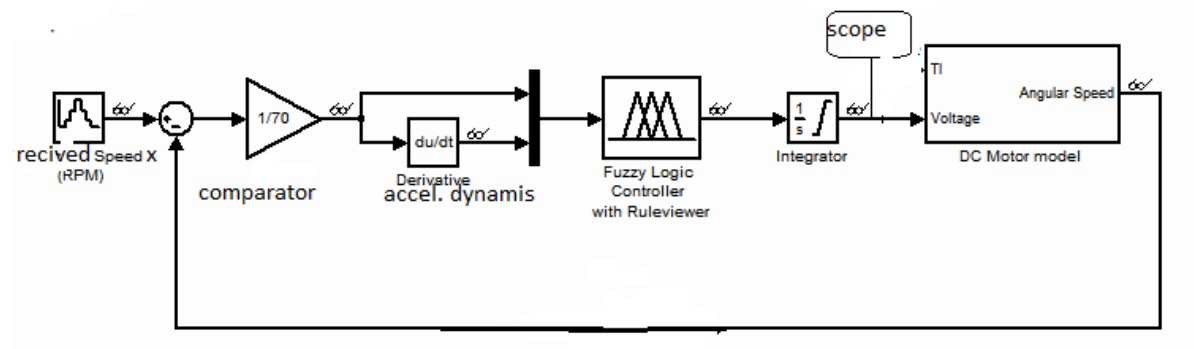


Figure 8. Simulation of FLC model of the system with initial x speed of 10km/h

As shown in figure 8, after simulating the system, the velocity is seen to start at 10km/h and it then ramps up to 20km/h. and it took just 6 seconds time to reach the steady speed of 20km/h. Furthermore, in figure 9 the voltage supplied to the electric motor is shown to start from 3.65V and the increases steadily to 4.62V. Within the same time of 6s, the voltage remains stead

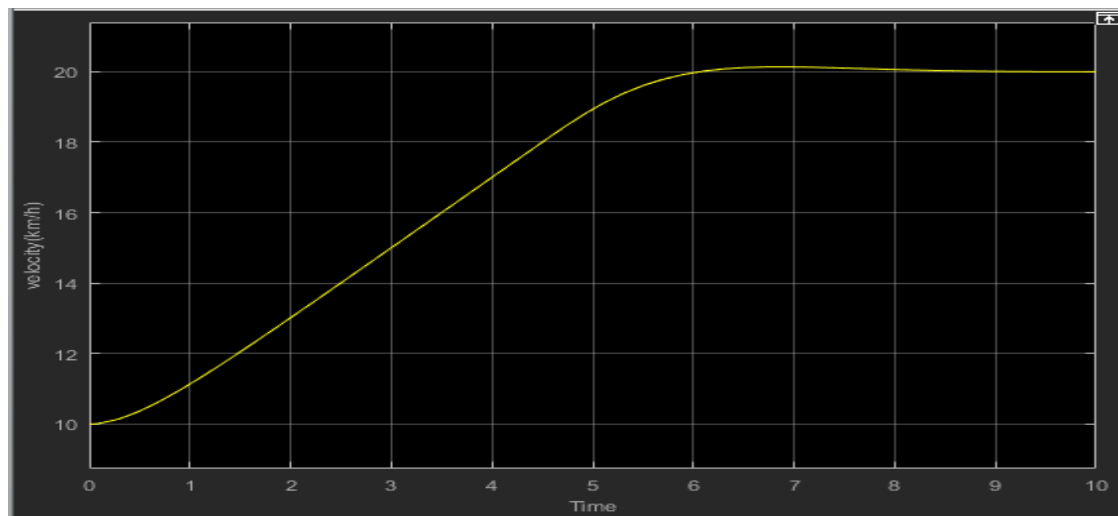


Figure 9. Graphical representation of the acceleration of the vehicle

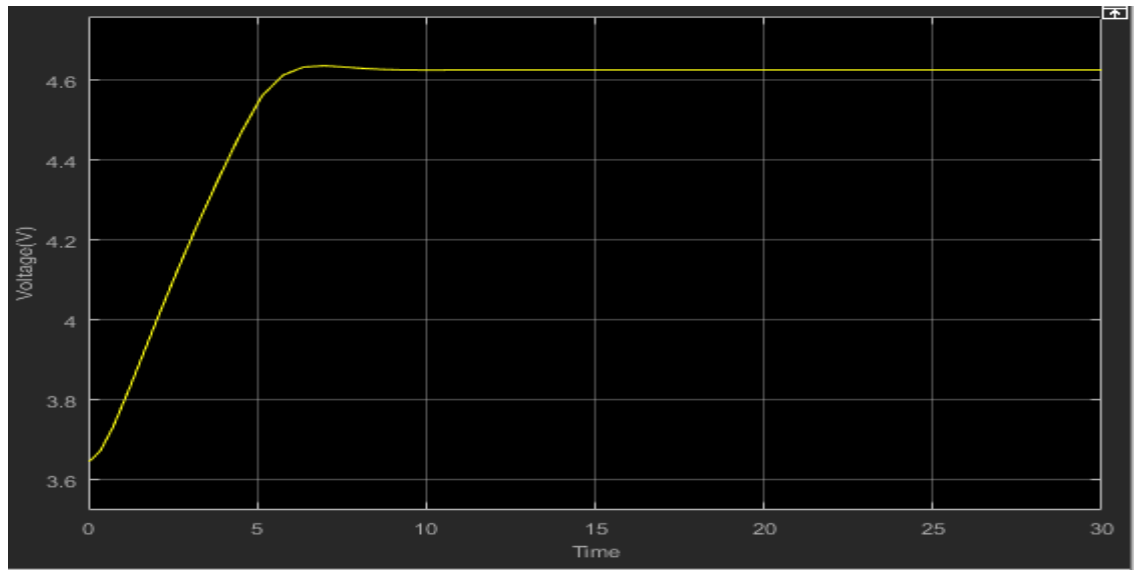


Figure 10. Graphical representation of the increase in voltage in accordance to speed.

Deceleration Test

In testing for deceleration, the system as shown in figure 11 where speed (x) was assumed to be moving at 100km/h as it received the zone speed limit of 50km/h from the infrastructure. Figure 12 shows the response of the system as it decelerates steadily in about 17.5s and remains at 50km/h as it travels through with the allocated speed limit of the road. Figure 13 shows how the voltage supplied for running the EV decreases from 7.4volts to 5.85 volts.

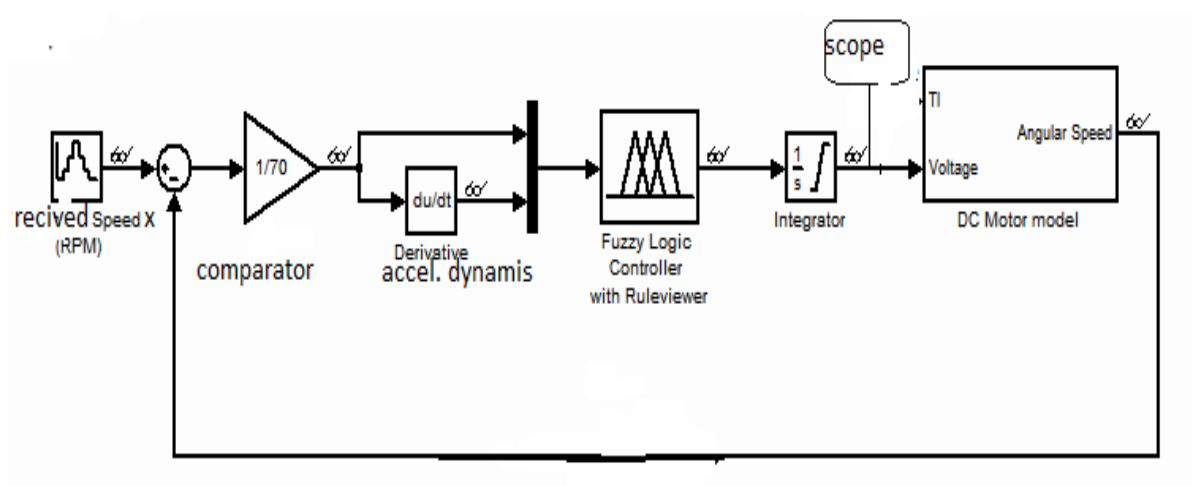


Figure 11. Simulation of FLC model of the system as the initial x speed is 100km/h

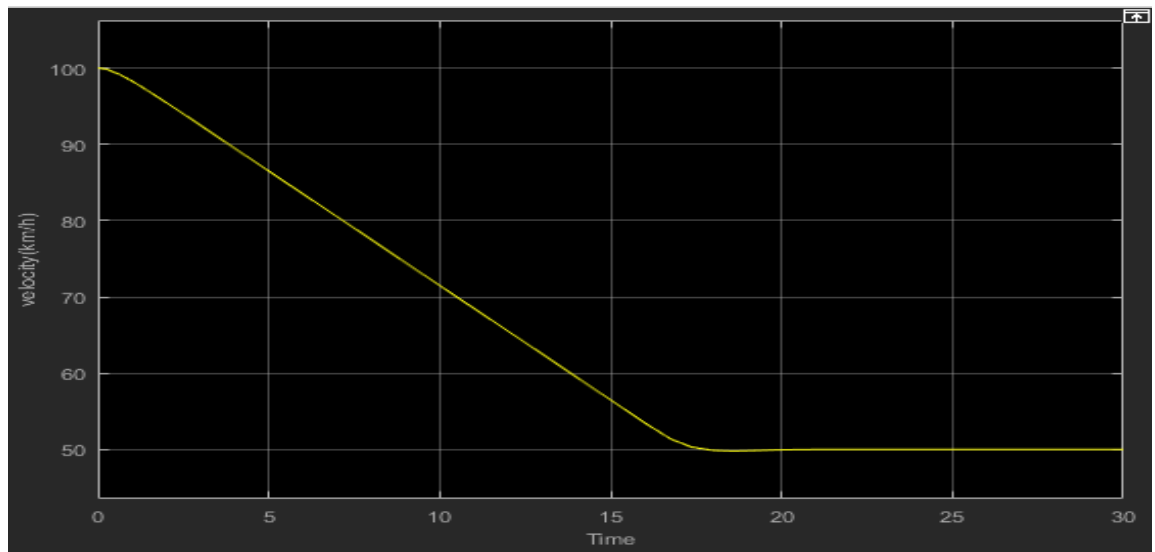


Figure 12. Graphical illustration of deceleration as the vehicle enters speed zone.

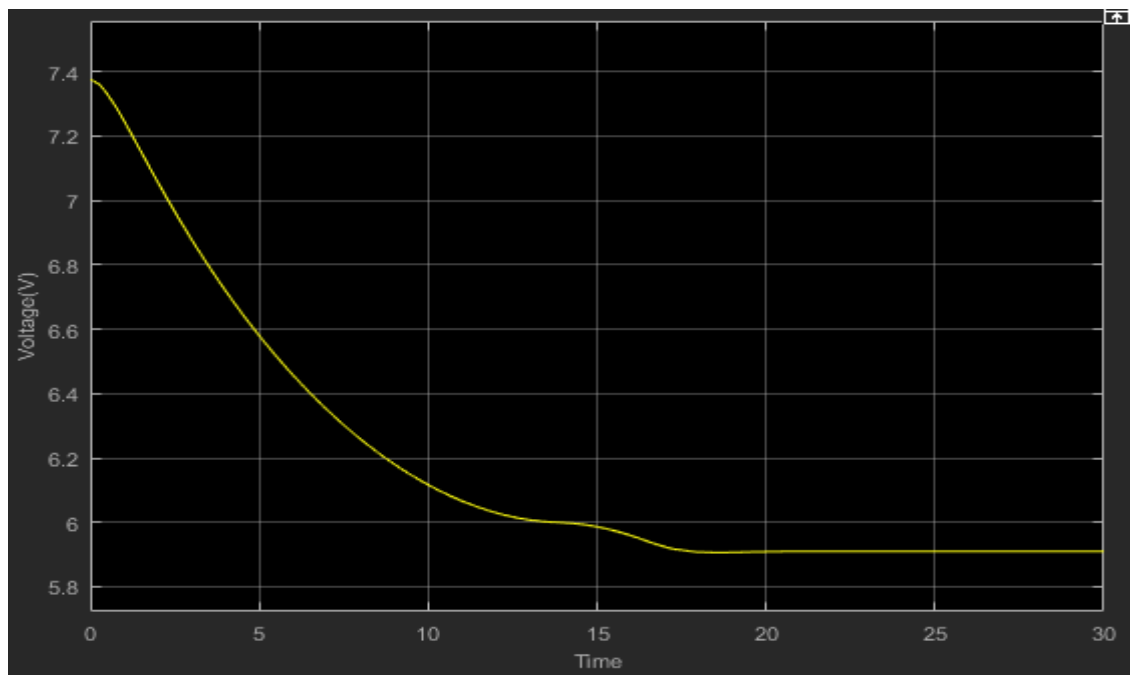


Figure 13. Graphical illustration of the voltage response as a result of deceleration

CONCLUSION

This paper has presented performance analysis of smart speed variation in electric vehicles using the combination of fuzzy logic controller. Variation of voltage during fuzzy logic ramping was found to supply direct proportional speed to the electric vehicle. And it

was also found that fuzzy logic controller can control the speed of the vehicle effectively. It is of important to mention that this system can also be used in highway when calibrated in a different pattern.

The different methods employed to aid acceleration and deceleration of electric vehicle was aimed at ensuring regeneration of energy so as to improve driving range because of obvious electrical energy demand of electric vehicle. The safety consideration from literature that was reviewed was basically to ensure safe distance between two cars on the road thereby, ensuring collision avoidance. The contribution to knowledge in this work, is the development of a strategy to help automatically maintain speed limits during driving operation of electric vehicles in certain area like schools, hospital etc., with marked speed limit zone. Instead of the speed bumps which the vehicle may suddenly run over and result in accident.

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