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Simulation of Smart Speed Variation in Electric Vehicles Using Fuzzy Logic Controller

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Abstract

Roads today are often equipped with speed breakers, which, although intended to control vehicle speed and reduce accidents, frequently cause inconvenience and potential hazards, especially when drivers encounter them unexpectedly. Speed breakers were introduced to curb the risks of collisions due to overspeeding; however, their physical implementation can disrupt vehicle movement and comfort. This study proposes a smart speed variation system for electric vehicles using a Fuzzy Logic Controller, aimed at eliminating the need for physical speed bumps while ensuring road safety. In the proposed system, a transmitter is placed at the entry point of a road segment with a designated speed limit. This transmitter sends a specific frequency corresponding to the speed limit, which is received by oncoming vehicles equipped with a compatible receiver. Upon receiving the signal, the vehicle automatically adjusts its speed to comply with the set limit. When the vehicle exits the restricted zone, it receives another signal permitting it to resume normal speed. This intelligent speed control system enhances driving comfort, ensures safety by maintaining regulated speeds, and contributes to energy efficiency in electric vehicles. The system was developed and simulated using

MATLAB/Simulink with fuzzy logic to handle the dynamic control of vehicle speed based on environmental inputs. The simulation results confirm that speed variation can be effectively achieved through vehicle-to-infrastructure communication, demonstrating a viable alternative to traditional speed control mechanisms.

Keywords: Simulation; Fuzzy Logic; Controller; Smart Speed Control; Electric Vehicle

INTRODUCTION

Means of transportation which involves medium to move people, animals or goods from one geographic location to another has evolved over the years. The evolution which was necessitated by the quest to achieve day to day activities faster, started with transportation by foot before the use of beasts of burden. Although these primitive means assured a cleaner environment, the need for faster means was the drive to the invention of locomotive engines which involves the combustion of fossil fuel. These means, even though fast, has raised concerns because of the ill effect of combustion on the environment (Zhai et al., 2020). This includes health issues such as respiratory sickness and climate change which leads to natural disasters like flood and hurricanes. Other concerns include the huge demand for energy to sustain the transport sector. In other words, due to the fact that transportation is viewed as one of the markers that drives the economy of societies (Veer et al., 2019), it is responsible for half of the total energy consumed in the world (Zhai et al., 2020). Factually, it is responsible for 20 % to 30% of the world's pollution (Veer et al., 2019). This has therefore necessitated the invention of energy efficient vehicles like the Electric vehicles (EV) (Zhai et al., 2020; Zhang et al., 2020).

Electric Vehicle (EV) which consist mainly of electric motor transmission system, controller, battery pack and a battery monitoring system as shown in figure 1.1, is gaining popularity in the transport sector and has been studied to demand less energy (Vodovozov & Raud, 2021). In other words, the cost of electric energy consumed by this medium of transportation is less compared to the cost of using fossil fuel. This is made possible as a result of numerous researches that has made it energy efficient. Unlike the conventional cars which converts only 12% - 30% of energy stored in gasoline to use, it is affirmed that EV converts70%-80% of energy given to it to power the wheels (Vodovozov & Raud, 2021). With this advantage and it contributing to a cleaner environment, EV could be considered the promising technology in the transport sector.

The aim of this research paper is to develop smart speed variation in electric vehicles using fuzzy logic controller.

Review Of Related Works

Speed has become the other name of success. As the drivers always reason in their mind that the more they speed up their vehicle, the more the trips they will make and therefore the more income they will get. Generally, authors in (Veer et al., 2019) highlighted four different motors which are used In the development of HEV. One of the motors highlighted is the Switched Reluctance motor (SRM). This motor which can start and charge vehicles is easier to control, it has rugged construction, it has better fault tolerance, and outstanding torque speed. The application of this motor is always in situations where constant power is required in all regions of the EV. However, one major disadvantage of this motor is electromagnetic interference, torque ripple and it requires special convertor topology. To overcome this, several control techniques and design methods have been proposed over the years. This includes the use of the seeker optimization algorithm and the multistage fast design method which is used to determine the best speed the motor will start at one pulse. To achieve speed control, Proportional Integral (PI) controllers were used. It, being characterized with high overshoots and settling time is which fuzzy sliding mode was used for a better speed controller. The speed range of the motor was concluded to be 5400rpm to 13900rpm. sensors and those with position sensors. For those with no position sensors, the back electromotive force EMF signals of brushless in wheels was exploited for the simplification of the antilock braking system(Veer et al., 2019). To control the speed of BLCD, digital pulse width modulation (PWM) has always been used. Controllers used to achieve PWM control include PI controller,

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 fourth motor highlighted by (Veer et al., 2019) is the induction motor. Although characterized with low maintenance and high efficiency, one major setback of this motor is the expensive controller required for its operations. In its control, when fuzzy logic controller is used.

With the knowledge of electric motors converting electrical energy to mechanical energy and sometimes used to convert mechanical energy to electrical energy, optimization of this component has been on the increase. In that light, authors in Zhu et al., 2019 worked on level optimization design and dynamic control strategy in less rare earth hybrid permanent magnet motor. During the work comprehensive sensitive analysis was carried out to stratify design parameters. To achieve optimized motor design, response surface method and multiple objective genetic algorithms was implemented. To achieve optimized control, response compensation strategy was established to suppress torque ripple and speed vibration. The limitation of the work is that the solution provided never considered smart braking or deceleration to achieve safety.

With the quest to improve the safety in electric vehicles, Asiabar & Kazemi, 2019 focused on electric vehicles with in-wheel motors. According to his presentation, in wheel motors in electric vehicles are characterized with the advantage of having a lot of space in the interior by eliminating the transmission systems and the propulsion unit. However, the disadvantage is that riding comfort deteriorates and the road holding capacity decreases as a result of these motors attached to the vehicle without springs. Aside this, the major drawback is the deviation of the vehicle during a maneuver scenario from the intended track. To overcome this, the authors proposed a direct yawn

movement controller for a four wheel motor drive electric vehicle using adaptive slide motor control. The proposed solution consists of two controllers. First is a PID controller used as upper level controller used to keep the longitudinal velocity constant during manoeuvre and second, a fuzzy logic controller used as a lower level controller to aid the correction any deviation for the desired track. The tool used for this work is Mat lab/Simulink. The down side of this is that although safety was the main consideration, however, smart deceleration was not considered in the study.

Authors in Xu et al., 2021 considered the distinctive acceleration and the deceleration characteristics of electric vehicles to develop micro traffic flow model to control movement of EV. This solution was proposed to solve problems as a result of traffic congestion which is characterized with a lot of stop and go movement. This movement can be as a result of the lane changing behaviour of the driver or as a result of the sudden stop of the driver ahead for one reason or the other. It was observed that the micro traffic model for EV are better than traffic models of traditional vehicles because of their unique acceleration and deceleration... 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.

METHODOLOGY

Smart System Communication Structure

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.

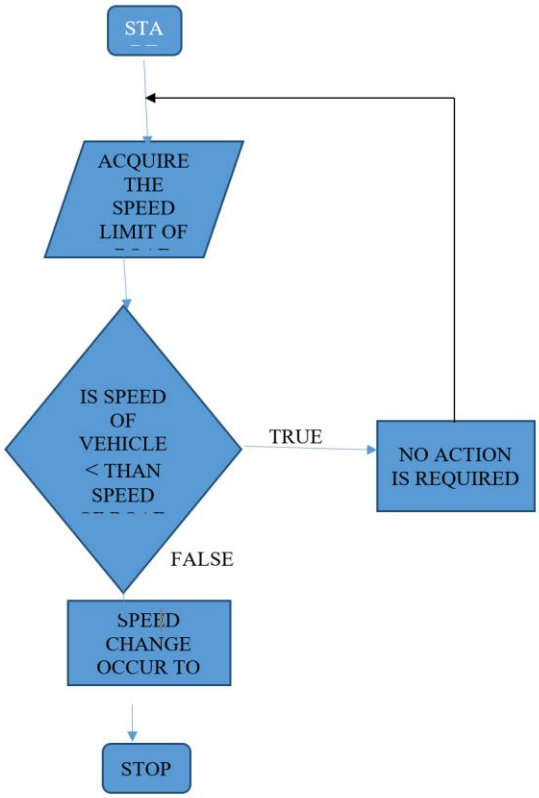


Figure 3.4: Flow Diagram of the control process.

The flow diagram figure 3.4 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;

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

But Area of the antenna $A = 4\pi D^2$ (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

$$PD = \frac{P_t}{4\pi D^2} \tag{3.3}$$

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

$$PD = \frac{P_t G_t}{4\pi D^2} \tag{3.4}$$

WhereG_t; is the transmitter gain.

But effective aperture is given as;

$$A_{effective} = \frac{\lambda^2}{4\pi} G_r \tag{3.5}$$

Where λ is the wavelength.

$$P_r = A_{effective} \times PD \tag{3.6}$$

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.

The input of the system is assumed as voltage source (V) applied to the motor's armature, while the output is the rotational speed of the shaft dθ/dt. The rotor and shaft are assumed to be rigid.

Also assumed a viscous friction model, the friction torque is proportional to shaft angular velocity.

$$\text{Torque} \propto i \quad (3.9)$$

$$T = K_t i \quad (3.10)$$

The back e m f, (e) is proportional to angular velocity of the shaft by a constant factor Key.

$$e = K_e . \frac{d\theta}{dt} \quad (3.11)$$

The Newton's law and Kirchhoff's law was applied to motor system to generate the equations needed for modeling.

$$J\frac{d^2\theta}{dt^2} = T - b\frac{d\theta}{dt} \Longrightarrow \frac{d^2\theta}{dt^2} = \frac{1}{J}(K_t i - b\frac{d\theta}{dt}) \qquad (3.12)$$

$$L\frac{di}{dt} = -Ri + V - e \Longrightarrow \frac{di}{dt} = \frac{1}{L}(-Ri + V - K_e\frac{d\theta}{dt}) \qquad (3.13)$$

The model in the figure 3.6 below was created using Simulink by adding components from the Simulink library. Then all the components were saved to a single subsystem block. Later the output (speed) was observed for different inputs (voltages).

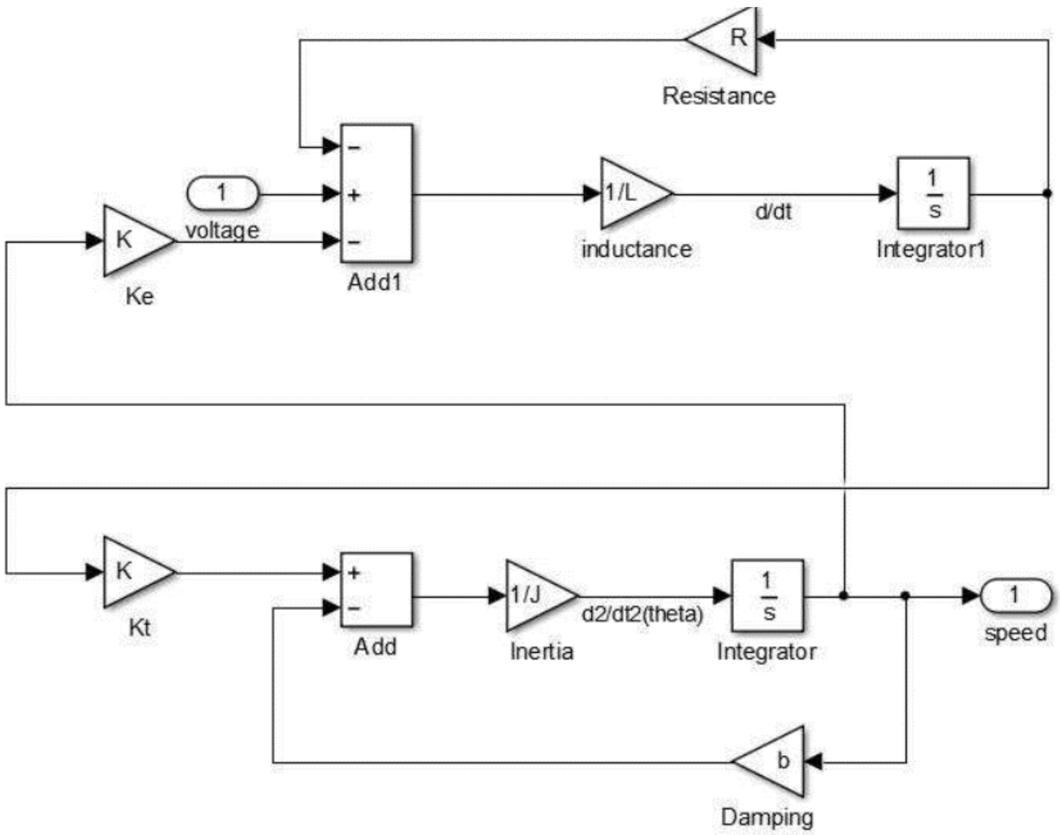


Fig.3.6 Simulink Model.

Simulation

Equations (3.10), (3.11), (3.12) and (3.13) are the four equations describing the system. . A Laplace transform can be used to analyses the system since it has been linearize the transfer functions of the transmitter point, the vehicle receiver, the dynamic of acceleration and velocity are modelled as:

G = 1/s (0.5s + 1)which approximate the dynamics of throttle body and vehicle inertia (3.14)

During simulation, attention must be given to the control surface of the fuzzy logic controller. The control surface usually gives a good indication of how the controller should perform.

Figure 3.7 below is example of a kind of control that is based on Mandani principle for fuzzy logic control synthesis.

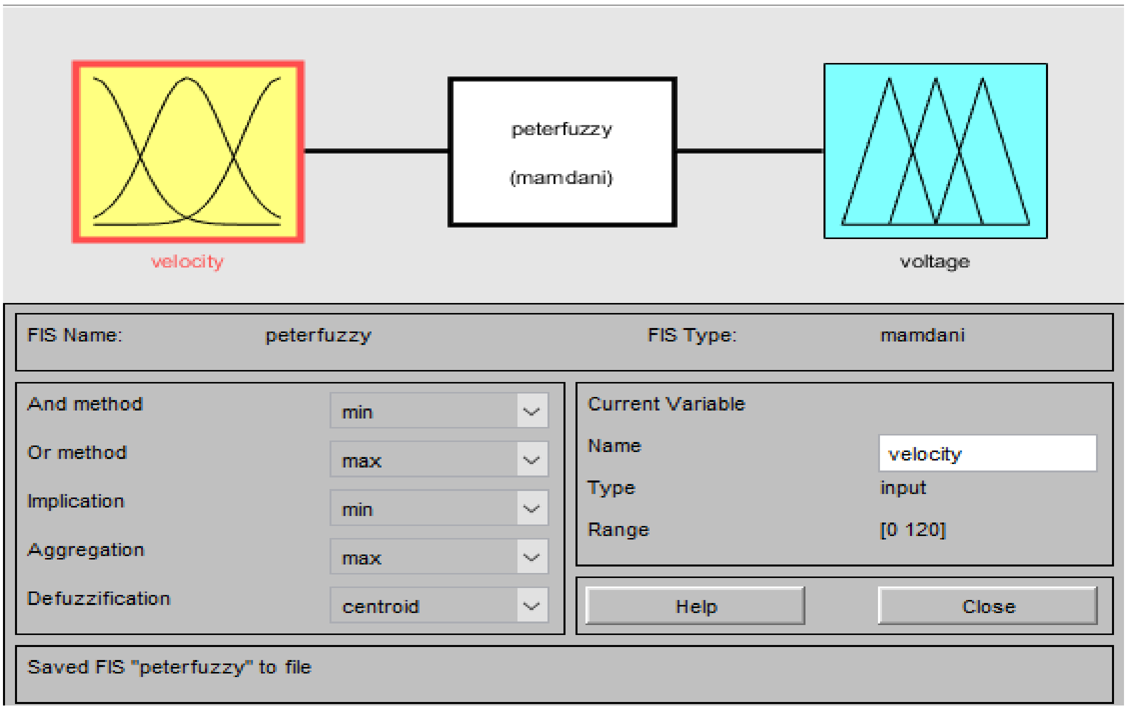


Fig 3.7: Mandani interface in Matlap/Simulink.

Mandani Model

There are three types of fuzzy models that are currently in use, the first of which was introduced by Mamdani in 1975. The second was developed by Takagi-Sugeno-Kang (TSK) in 1984. The third was developed by Kosko (1996) and it is called the standard additive model (SAM). The Mamdani model is a rule-based model. It is one of the most widely used fuzzy models. It constitutes the base for the TSK and SAM models, because they are derived from Mamdani model and, in fact, the antecedent part is the same in all three models. This system is easy to inter change using Mathlap/Simulink platform. The general format of the Mamdani model can be expressed in linguistic rules that describe a mapping from the input universe of discourse to the output, i.e., initial velocity(*U) to final output velocity(V)* for multi-input-single-output case (MISO).

Then, the designer should go back to the drawing board and design a new controller, taking into consideration the short coming of the faulty controller. So after tuning of the Simulink model in figure (3.6), acceleration dynamics G = 1/s (0.5s + 1) was added to the Simulink model as tuning factor. The model becomes what is in figure 3.8:-

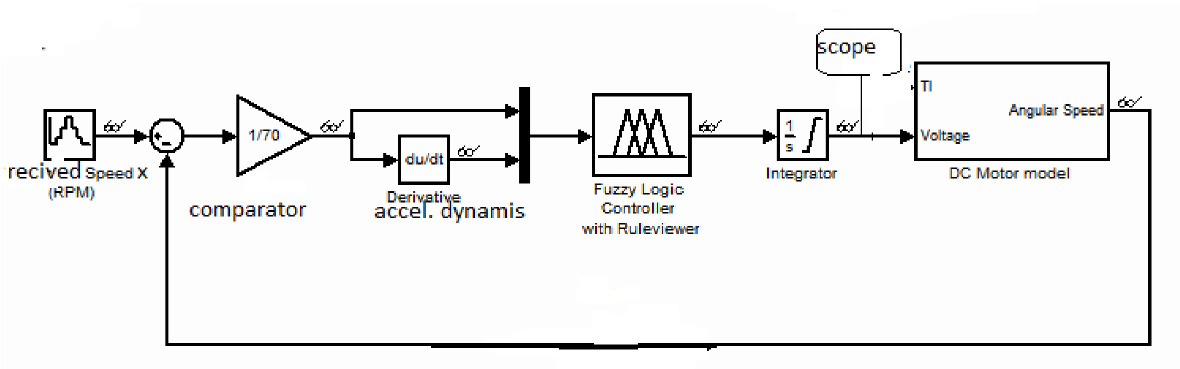


Figure 3.8: Simulations of the FLC model of vehicle dynamics as it received the zone speed signal.

As shown in Figure 3.8, the system consists of an input which receives the zone speed limit, from the transmitter installed along the road. Before travelling on the street. This received speed is passed through a summer which is connected to a comparator block. The summer block, aids feedback of the initial speed which either ramps up or down to meet up with the received speed. Furthermore, the output of the summer which is connected to the comparator block is to ensure that there is no overshoot of velocity when either ramping up or down. The output of the comparator block is then fed to the block that determines the acceleration dynamics of the car. The output of this block and the initial speed is fed into the fuzzy logic controller block. To ensure a gradual increase or decrease of the voltage to be supplied to the electric motor.

Fuzzification

A fuzzy controller deals only with linguistic rather than crisp variables. Hence, a step called fuzzification is needed for each received input data. Fuzzification means converting the obtained input data to a degree of membership for each fuzzy set in the membership functions so that we can use it in the fuzzy controller rules. In these project the rules used are;

- at low speed, the system output low voltage
- at medium or right speed the system outputs medium voltage
- at high speed, the system outputs high voltage
- 0km/h to 15km/h is slow speed
- 15km/h to 60km/h is right speed
- 60km/h to120km/h is fast speed.

Putting the above rules values in a table below:

Table 3.1: Input - Output variables intervals.

Variable	Slow Range	Right range	Fast Range
Voltage (v)	0 to 4.19	4.19 to 6	6 to 12
Speed (km/h)	0 to 15	15 to 60	60 to 120

After defining the Input-Output range values for the controller, we should assign linguistic terms for each input and output interval, and then choose a membership function. These linguistic terms are known as fuzzy set.

As shown in figure 3.3, the process of building of a fuzzy logic controller contains a fuzzy logic block which consist one input (velocity) and one output (voltage) supplied to the electric motor in the vehicle. The assumption is that the maximum velocity of the vehicle is 120km/h. at this speed the voltage supplied to the electric motor is 12V. This therefore suggests that the velocity is mapped to the voltage. This will be guided by the equation (3.15)

$$current\ velocity = \frac{120 \times voltage\ map}{12} \tag{3.15}$$

In achieving control, the membership functions are set as shown in figure (3.8) that has the input set to slow speed, right speed and fast speed. Also the velocity is set from 0 to 120 km/h. Slow speed is set within the coordinates of 0, 0, 60, having a peak at slow speed at 0km/h. The right speed is peak at 60km/h and the fast speed is peak at 120km/h.

These above rules where used to set the system control below:-

During the tests, the variety of values for each input and output variable had to span the whole intervals of exposition necessary so that the performance of the controller can be greatly improved (Driankov and Saffiotti, 2001).

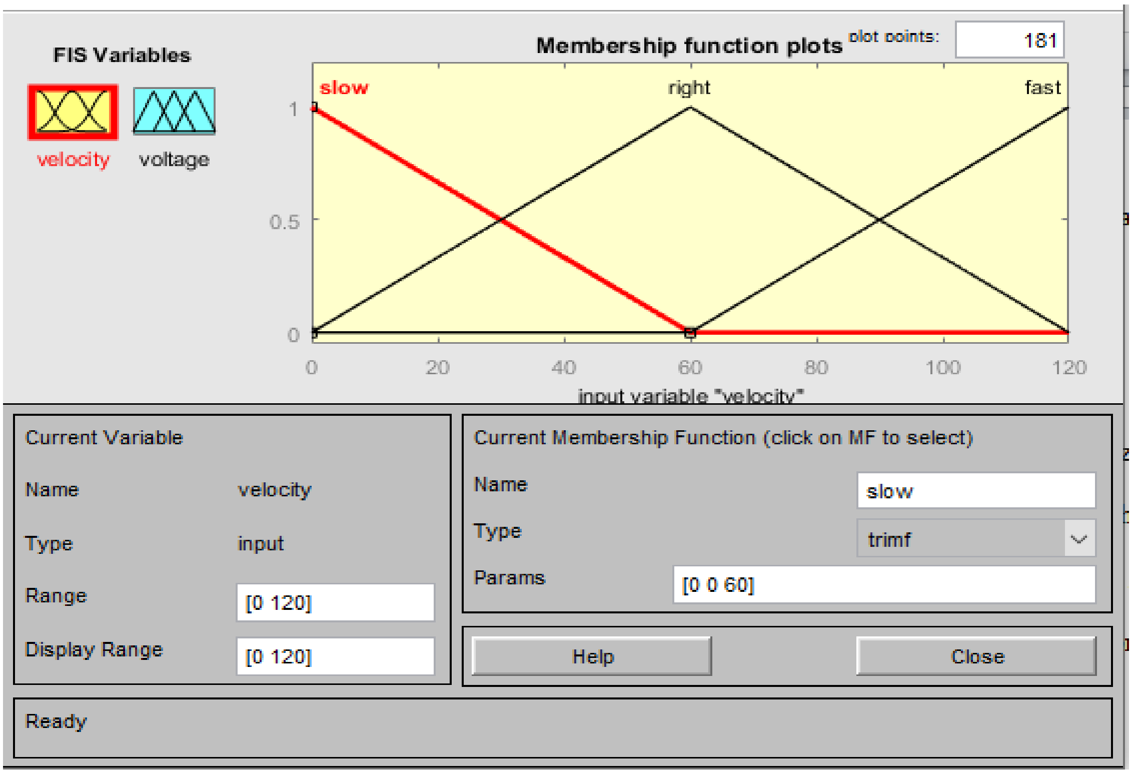


Figure 3.10: Membershp function of the variable velocity input

The output as shown in the simulink FLC model in figure 3.9 is mapped from 0V to 12V. The membership function was designed to have low voltage which peaks at 0V, medium voltage which peaks at 6V and high voltage which peaks at 12V. Afterwards, the rules were designed such that at low speed. The system output low voltage. At medium or right speed the system outputs medium voltage and at high speed, the system outputs high voltage. This is shown in rule settings in figure 3.10.

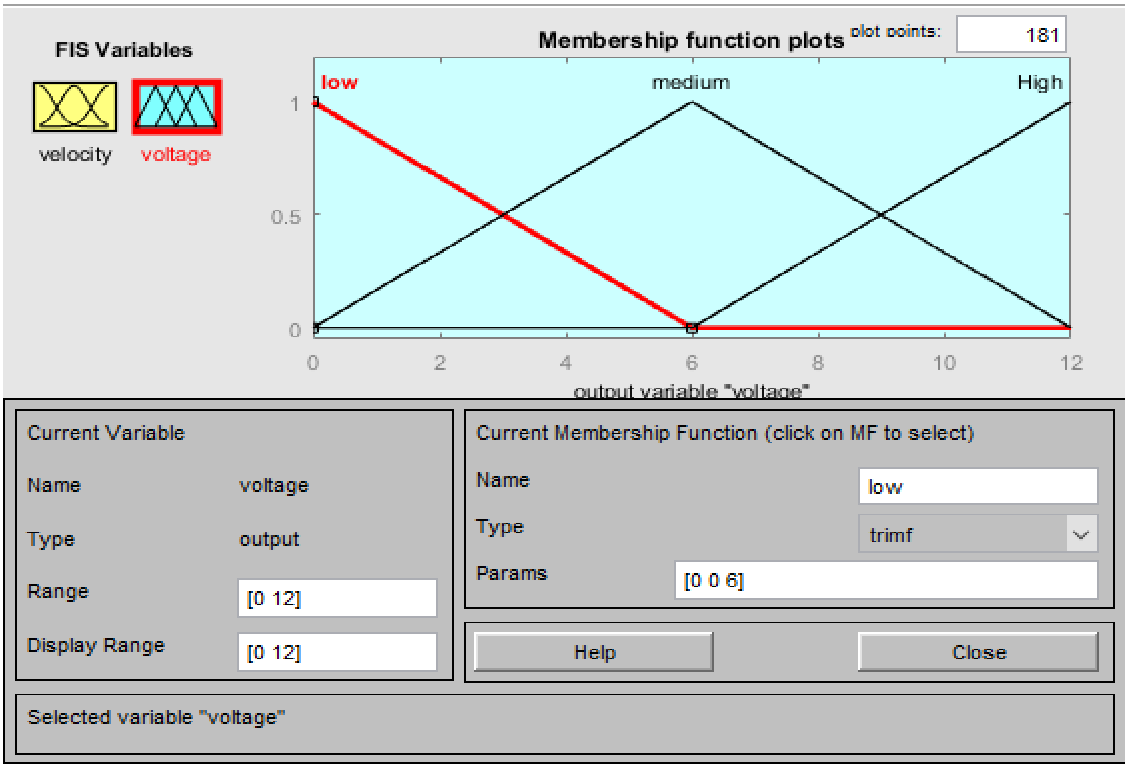


Figure 3.11: The membership function of the variable voltage output

Defuzzification

Designing of the Fuzzy logic Control was used to map the output of the cruise control from acceleration to a speed command that can be fed to the motor in the form of voltage. The equation of this control is based on both motor specification and the desired response time.

Therefore, from equation 3.7;

$\Delta a = a_{des} - a_{act}$ this is reduction of acceleration due to zone signal.

$a_{des} = a_{act} + \Delta a$ this is increase of acceleration when out of zone.

$$\frac{v_{des}}{t} = \frac{v_{act}}{t} + \Delta a \qquad (3.16)$$

Now, the actual speed is measured in [m/s] while the desired speed to the motor in [rpm]. Thus, based on motor specification, we choose a constant K_1 as:

$$V_{act}[rpm] = vact\,[m/s] / \text{K1} \qquad (3.17)$$

Was also define a second constant K_2 so that:

$t = K_2$

From all above, we get the final equation as follow:

$$V_{des} = \frac{v_{act}}{K_1} + \Delta a K_2 + K_3$$ ----- This is the speed limit (3.18)

Where:

V_{des}: Speed commands send to the motor in [rpm]

V_{act}: vehicle actual speed [m/s]

K_1: constant based on motor calibration specification.

K_2: response time

K_3: constant speed to prevent the car driving backward

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.

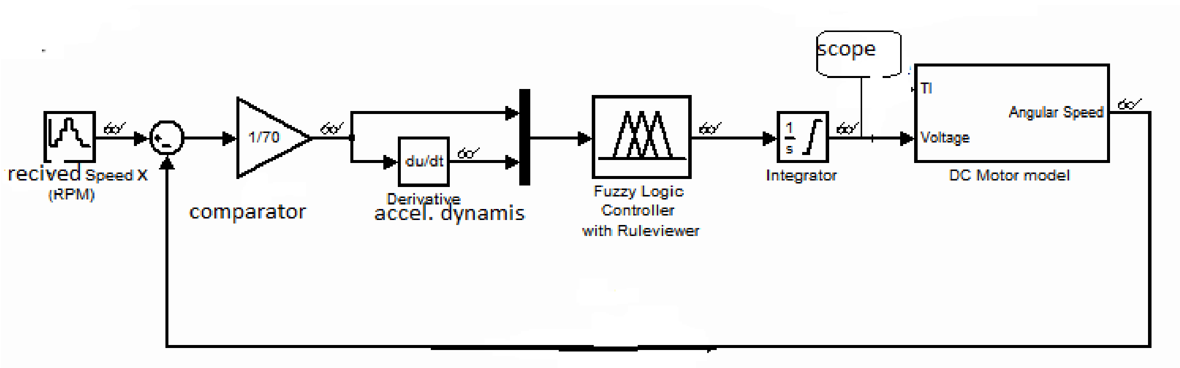
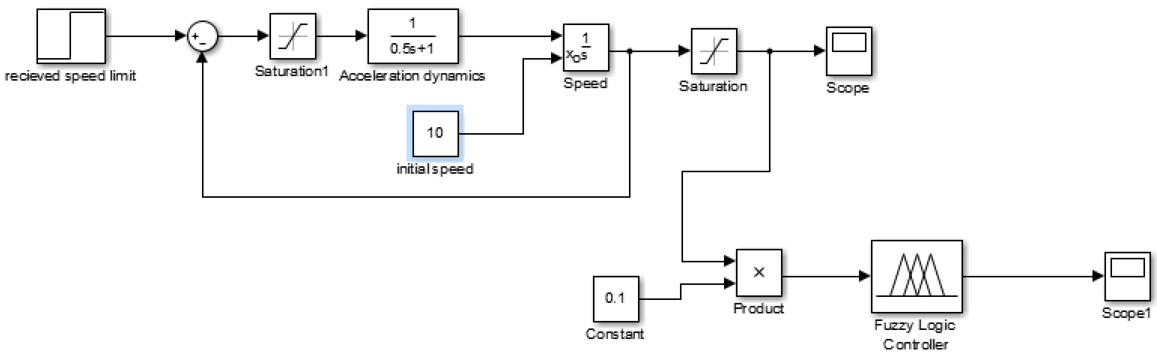


Figure 4.1: Simulation of FLC model of the system with initial x speed of 10km/h

As shown in figure 4.2, 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 4.3 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 steady.

Deceleration Test

In testing for deceleration, the system as shown in figure 4.4 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 4.5 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 4.6 shows how the voltage supplied for running the EV decreases from 7.4volts to 5.85 volts about the same time.



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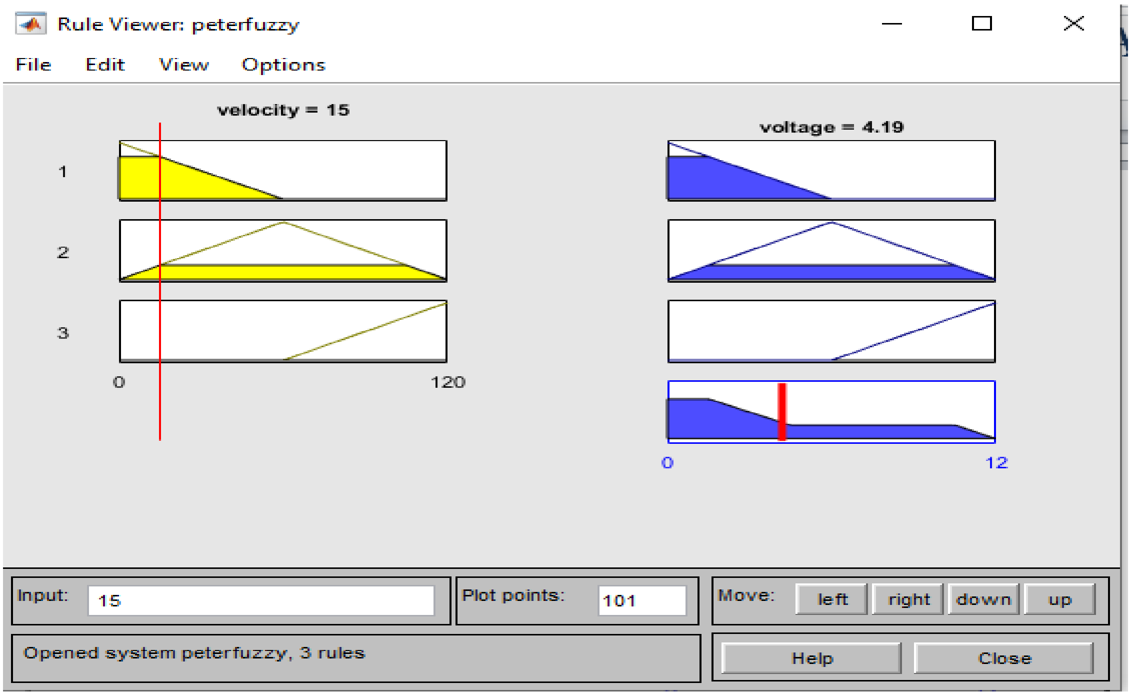

Figure 4.7: First result of the voltage response in accordance to the velocity received

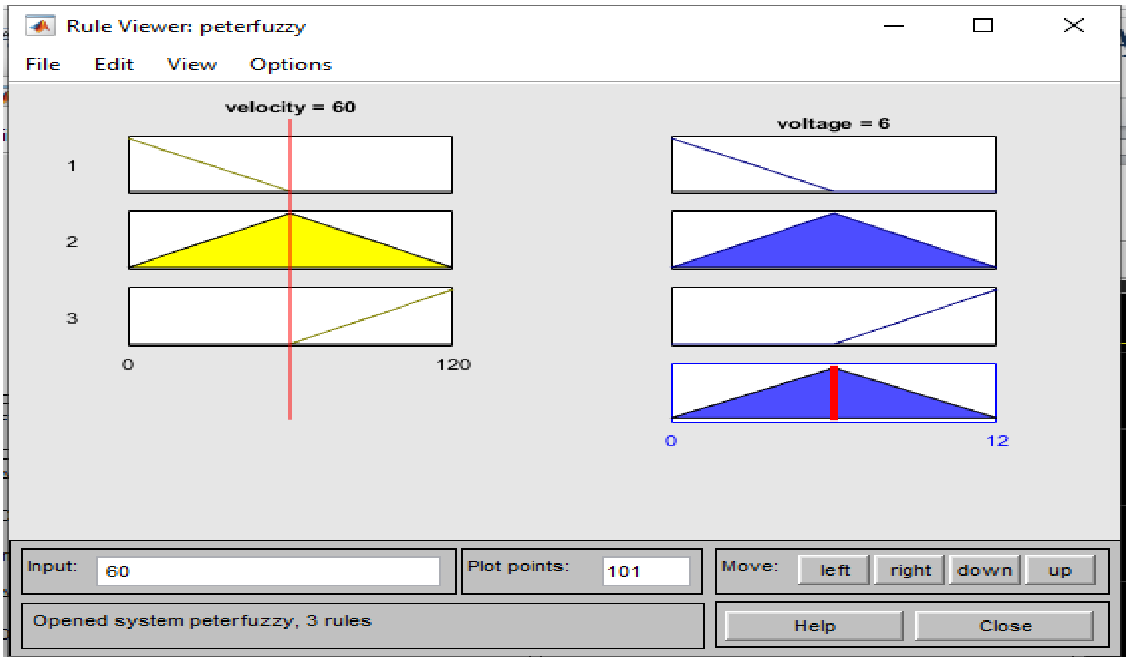

Figure 4.8: Second result of the voltage response in accordance to the velocity received.

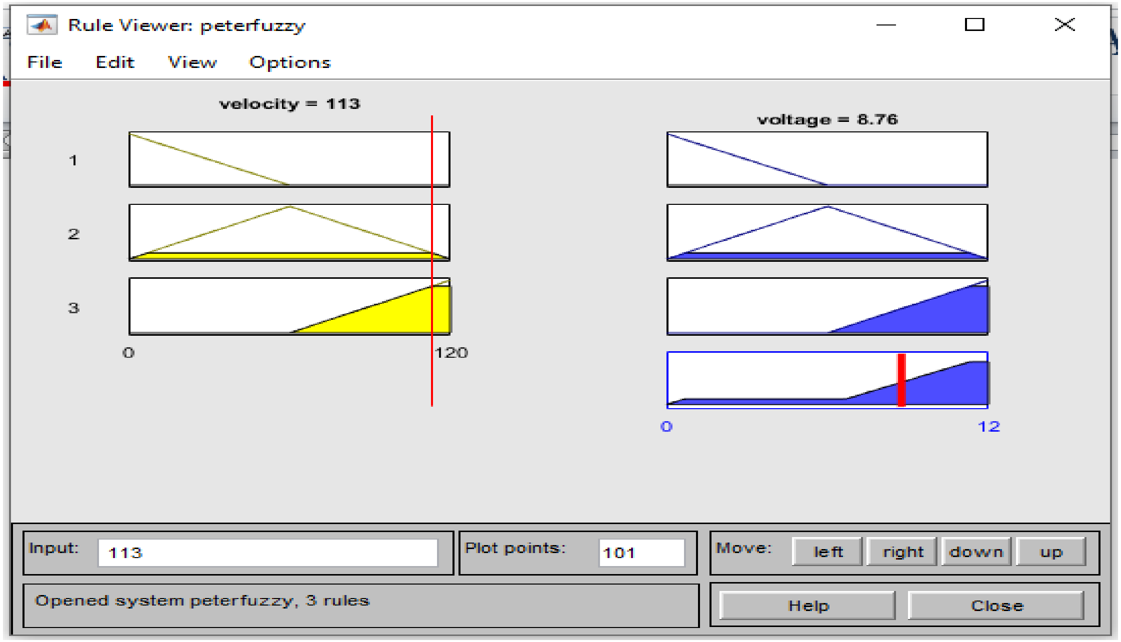

Figure 4.4. Third result of the voltage response in accordance to the velocity.

Table 4.1: Showing the response to the fuzzy logic simulation.

Fuzzy Membership	Slow	Right	Fast
Velocity (km/h)	15	60	113
Voltage (v)	4.19	6	8.76

CONCLUSION

In the quest to remove speed bumps, the research developed a vehicle to infrastructure smart speed control of electric vehicle. This was achieved via the use of Simulink and fuzzy logic. At the end of the research, variation in speed was achieved based on received speed limits signals from the sign board transmitter of various zones like; school zone, "U" turn zone etc. carefully treating individual generated input signals for driving actuators. As a whole, the proposed system is capable of handling traffic management challenges with minimal human supervision. This system does not require the driver to physically make use of the brake to stop, increase or reduce the speed of the car.

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