



# “Speed control of BLDC motor drive using PI, Fuzzy Logic and Neural Network controllers for an Electric Vehicle”

**JONNA VENKATESH**

Department of Electrical Engineering,  
Andhra University College of Engineering (A)  
Visakhapatnam, Andhra Pradesh, India.

**Dr . R. Srinu Naik**

Associate Professor, Department of Electrical Engineering,  
Andhra University College of Engineering (A)  
Visakhapatnam, Andhra Pradesh, India.

## Abstract

In this project we implement the speed control of Brushless direct current (BLDC) motor for Electric Vehicle load by using different control techniques like PI controller and Soft computing techniques like Fuzzy Logic controller and Adaptive Neural Network controller in MATLAB simulink. BLDC motor is one of the popular motors in the industry and automotive. In automotive, this motor is often used in an electric vehicle (EV) due to its high efficiency. A model of electric vehicle mainly consists of BLDC (brushless DC motor), and an inverter. Due the efficient characteristics of BLDC (such as wide speed range, high efficiency and good power densities), these motors are highly preferred for electric vehicles. BLDC information expects six discrete rotor positions for operation of inverter. These sensors provide the information of position. A supply of voltage 220v is connected to the 3-phase inverter is implemented using power IGBTs for feeding BLDC motor and the Hall sensor signals from the motor is designed to obtain desired speed. The BLDC Motor is mechanically coupled to the Rear axle of the Vehicle motor so the torque is transferred from motor side to the load side. Soft computing techniques like Fuzzy Logic and Neural Network controller is also used to determine the performance characteristics of the motor due to different controllers. Torque and the Velocity of an in-wheel BLDC motor on performance of the two-wheel drive electric vehicle is studied through simulation. The controller efficiency and sensitivity has been checked by MATLAB-Simulink software.

Key Words: BLDC motor, Electric Vehicle, PID Controller, Fuzzy Logic, Neural Network .

## **INTRODUCTION**

BLDC motors were first introduced by T.G. Wilson and P.H. Trickey in 1962 for some specific low power applications and named as a “DC machine with solid state commutation”.

Higher power BLDC motors came on the market after the development of the high power transistors and permanent magnet materials. The first high power BLDC motor (50 horsepower or more) was designed by Robert E. Lordo at Powertec Industrial Corporation in the late 1980s.

The first Electric Vehicle was built in 1834, which is about, 180 years back. It was built on a non-rechargeable battery that was available at that time. After the invention of lead-acid battery, rechargeable battery based EV was possible and was built in 1874, by, David Salomons. With this development, it was possible to develop commercial products, by 1886. So all these developments, led to, popularisation of EVs, in the mainstream automobiles, in the global. By 1900, among 4200 automobiles that were sold in USA, 38% were EVs and by 1912, around 34000 EVs were registered in US. The EVs started disappearing in 1930’ there are two developments, which led to this happening. First development was, that, Henry Ford, has gone for mass production of, ‘Ford, Model T’, in 1925. And was able to reduce the price of it, by over one third of its, conventional price, at 1909. So due to this, the EV became much costlier, compared to IC engine based cars.

Another development, which supported the first development, was the invention of Automobile Starter motor.

### **Introduction to BLDC Motor:**

BLDC motor is widely used in many applications due to its advantages like need less maintenance, have smaller structure compare to another motor with the same power rating, high efficiency and low losses due to the use of permanent magnet in the rotor and faster response due to low rotor inertia. The disadvantage of this motor is the need of an electronic driver to commutate the motor and make

the BLDC motor system become expensive. Nevertheless, if efficiency is essential then the BLDC motor system is inexpensive considering many advantages

which can be obtained. This is the reason why many EV (electric vehicle) developers use BLDC motor as the propulsion system. The BLDC motor control circuit uses two sensors which are current sensor and speed sensor.

Brushless dc (BLDC) motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the problems are encountered in these motors for variable speed operation over last decades continuing technology development in power semiconductors, microprocessors, adjustable speed drivers control schemes and permanent-magnet brushless electric motor production have been combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications.

This report focuses on the three phases, star connected BLDC motors. Control of the BLDC motor depends on position of the permanent magnet rotor. Electronic commutation increases complexity of the BLDC motor drives compared to the other motors. Precise simulation model of the BLDC motor is required to study behaviour of the motor for different control algorithms. Therefore a model of the 3 phases, star connected BLDC motor drive with ideal trapezoidal back-EMF waveforms is presented further. The mathematical model of the BLDC motor and principle of its operation are also discussed in details. To control speed of the BLDC motor, a digital Pulse width modulation controller is implemented in the model. The BLDC motor drive model is validated through experimental results.

### **Introduction to Electric Vehicles:**

EVs can be classified in various ways. It can be classified in terms of propulsion devices, or energy sources, or even the energy carriers which are used as medium to transfer energy from energy sources to propulsion devices. based on propulsion systems, EVs can be classified as pure electric vehicle or hybrid electric vehicle. A pure electric vehicle uses electric motor as a sole device for propulsion. While an HEV uses both electric motor and IC engine for propulsion. Popularly pure electric vehicles are also known as EVs while HEVs are known as HVs.

EVs on the basis of energy sources, pure electric vehicle will be further classified into battery electric vehicle and fuel cell electric vehicle. So, an HEV uses both liquid fuel and battery as energy source while a battery electric vehicle uses battery as a sole energy source. On the other hand, a fuel cell electric vehicle uses both battery and fuel cell as energy sources. A similar classification can be done on the basis of energy carriers where the energy carrier for battery is electricity while the energy carrier for a fuel cell is hydrogen. A model of electric vehicle mainly consists of BLDC (brushless DC motor), battery and an inverter. Inverters are fed by BLDC. Due the efficient characteristics of BLDC (such as wide speed range, high efficiency and good power densities), these motors are highly preferred for electric vehicles. BLDC information expects six discrete rotor positions for operation of inverter. These are generated by Hall Effect sensors. These sensors provide the information of position, those are needed to synchronize the excitation of stator with position of rotor and this synchronization is done to produce constant torque.

### **Introduction to soft computing techniques:**

#### **Fuzzy Logic**

Due to continuously developing automation systems and more demanding small Control performance requirements, conventional control methods are not always adequate. On the other hand, practical control problems are usually imprecise. The input output relations of the system may be uncertain and they can be changed by unknown external disturbances. New schemes are needed to solve such problems. One such an approach is to utilize fuzzy control. Since the introduction of the theory of fuzzy sets by L. A. Zadeh in 1965, and the industrial application of the first fuzzy controller by E. H. Mamadani in 1974, fuzzy systems have obtained a major role in engineering systems and consumer's products in 1980s and 1990s. New applications are presented continuously. A reason for this significant role is that fuzzy computing provides a flexible and powerful alternative to contract controllers, supervisory blocks, computing units and compensation systems in different application areas [12]. With fuzzy sets nonlinear control actions can be performed easily. The transparency of fuzzy rules and the locality of parameters are helpful in the design and maintenances of the systems. Therefore, preliminary results can be obtained within a short development period. Fuzzy control is based on fuzzy logic, which provides an efficient method to handle inexact information as basis reasoning. With fuzzy logic it is possible to convert knowledge, which is expressed in an uncertain form, to an exact algorithm. In fuzzy control, the controller can be represented with linguistic if-then rules [13].

#### **Artificial Neural Network controller.**

We introduce the multilayer perceptron neural network and describe how it can be used for function approximation. The back propagation algorithm (including its variations) is the principal procedure for training multilayer perceptrons, it is briefly described here. Care must be taken, when training perceptron networks to ensure that they do not over fit the training data and then fail to generalize well in new situations. Several techniques for improving generalization are discussed [18]. Three neural Network control techniques are model reference adaptive control, model predictive control, and feedback linearization control. These controllers demonstrate the variety of ways in which multilayer perceptron neural networks can be used as basic building blocks. But in this project we are used model predictive control for speed regulation of BLDC motor [14]. There are a number of variations of the neural network predictive controller that are based on linear model predictive controllers [19]. Model Predictive Control is a uses a neural network model of a nonlinear plant to predict future plant performance. The controller then calculates the control input that will optimize plant performance over a specified future time horizon. The first step in model predictive control is to determine the neural network plant model (system identification).

## **BLDC MOTOR**

### **Construction of Brushless DC (BLDC) Motor:**

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotate at the same frequency. BLDC motors do not experience the "slip" that is normally seen in induction motors.

#### **Stator:**

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery. Traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings are constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings are distributed over the stator periphery to form an even number of poles. There are two types of stator windings variants:

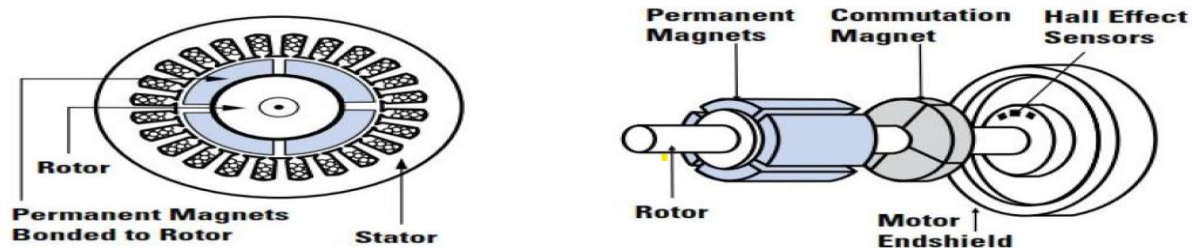
trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF).

#### Rotor:

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets.

#### Hall Sensors:

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall effect sensors embedded into the stator. Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.



#### Principle operation of Brushless DC (BLDC) Motor:

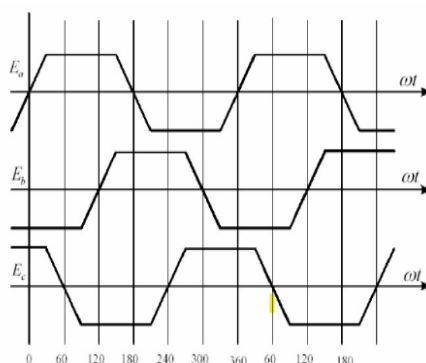
BLDC motors are more or less similar to the synchronous motor. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. This application note focuses on 3-phase motors. A brushless dc motor is defined as a permanent synchronous machine with rotor position feedback. The brushless motors are generally controlled using a three phase power semiconductor bridge. The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter bridge. Based on the rotor position, the power devices are commutated sequentially every 60 degrees. Instead of

commutating the armature current using brushes, electronic commutation is used for this reason it is an electronic motor. This eliminates the problems associated with the brush and the commutator arrangement, for example, sparking and wearing out of the commutator brush arrangement, thereby, making a BLDC more rugged as compared to a dc motor. The basic block diagram brushless dc motor as shown Fig.2.2. The brushless dc motor consists of four main parts power converter, Brushless dc machine (BLDC) sensors, and control algorithm. The power converter transforms power from the source to the BLDC which in turn converts electrical energy to mechanical energy. One of the salient features of the brushless dc motor is the rotor position sensors based on the rotor position and command signals which may be a torque command, voltage command, speed command and so on the control algorithms determine the gate signal to each semiconductor in the power electronic converter.

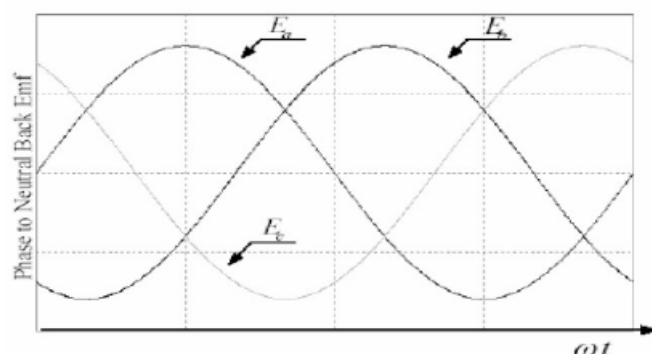


**Fig.2.2 block diagram of brushless DC motor**

The structure of the control algorithms determines the type of the brushless dc motor of which there are two main classes voltage source based drives and current source based drives. Both voltage source and current source based drive used with permanent magnet synchronous machine with either sinusoidal or non-sinusoidal back emf waveforms. Machine with sinusoidal back emf may be controlled so as to achieve nearly constant torque. However, machine with a non sinusoidal back emf offer reduces inverter sizes and reduces losses for the same power level.



**Fig.2.3 Trapezoidal Back EMF**



**Fig 2.4 Sinusoidal back EMF**



### 1 BLDC drives operation with inverter

Basically it is an electronic motor and requires a three-phase inverter in the front end as shown in Fig. 2.5. In self control mode the inverter acts like an electronic commutator that receives the switching logical pulse from the absolute position sensors. The drive is also known as an electronic commutated motor.

Basically the inverter can operate in the following two modes.

- Angle switch-on mode

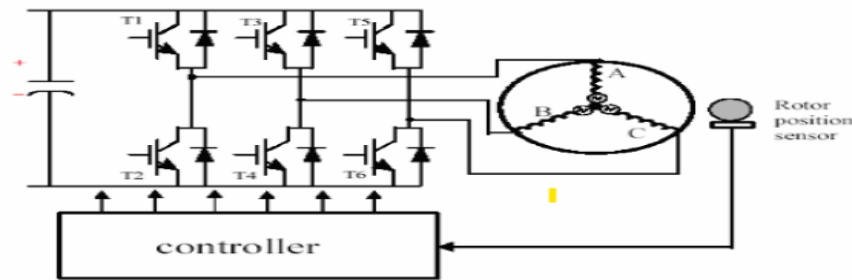


Fig 2.5 Circuit Diagram

- Voltage and current control PWM mode

### Specifications of BLDC Motor:

No of poles	8
Rated Voltage	24 V
Peak Value of Rated Current	40 A
Rated Speed	6000rpm
Rated Torque	50 N-m
Initial Torque	0.32 N-m
Flux linkage constant	0.175
Moment of inertia	$5.5e-3 \text{ Kg-m}^2$
Per Phase Stator Resistance	$2.8750 \Omega$
Per Phase Self-Inductance	$8.5e^{-3} \text{ H}$

### ELECTRIC VEHICLE:

An electric vehicle (EV) is one that operates on an electric motor, instead of an internal combustion engine that generates power by burning a mix of fuel and gases. Therefore, such a vehicle is seen as a possible replacement for current-generation automobile, in order to address the issue of rising pollution, global warming, depleting natural resources, etc. Though the concept of electric vehicles has been around for a long time, it has drawn a considerable amount of interest in the past decade amid a rising carbon footprint and other environmental impacts of fuel based vehicles. In India, the first concrete decision to incentivise electric vehicles was taken in 2010. According to a Rs 95-crore scheme approved by the Ministry of New and Renewable Energy (MNRE), the government announced a financial incentive for manufacturers for electric vehicles sold in India. The scheme, effective from November 2010, envisaged incentives of up to 20 per cent on ex-factory prices of vehicles, subject to a maximum limit. However, the subsidy scheme was later withdrawn by the MNRE in March 2012.

But the IC engine vehicles typically use liquid fuels and gaseous fuels which are coming from either oil or natural gas. While pure electric vehicle such as battery electric vehicle and fuel cell electric vehicle use either electricity or hydrogen as energy carriers. So if we see the types of fuels and the sources which are required to generate these fuels, we can clearly see that electricity can be generated by almost all the energy sources. Therefore, EVs have a definite advantage compared to IC engine which requires oil and natural gas as its fuel.

### EVs in comparison with ICEV:

The principle of transmission of mechanical energy used in a typical IC engine based vehicle. IC engine cannot operate in wide torque and speed regions on its own. Therefore, it requires the support of clutch and multiple transmission gears to achieve multiple speed and multiple torque profiles required in a vehicle application. So when the clutch is engaged, the IC engine is coupled to the gear box and energy is transferred from the IC engine to the wheels using gearbox. So when a different torque and speed requirement needs to be delivered from IC engine, the clutch is disengaged and a different gear is used to meet the requirement such that the required torque and speed is achieved at the wheels. So a typical IC engine based vehicle uses multiple gear systems. So it can be around five gears for a typical car and it is around 16 gears for a big trucks or buses.

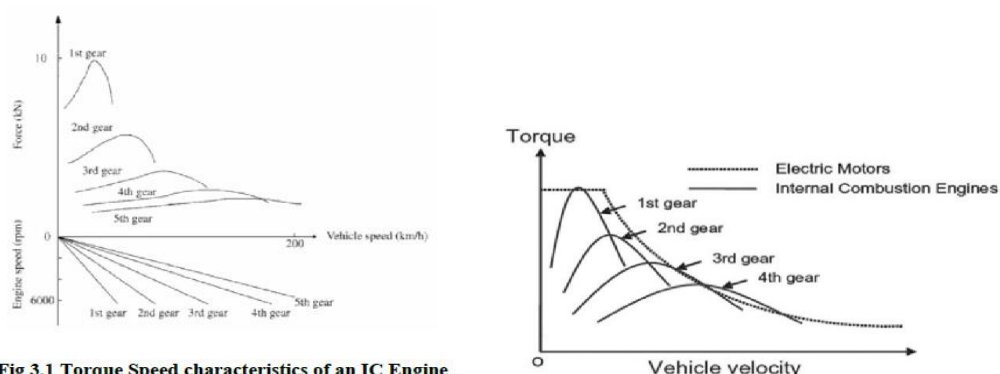
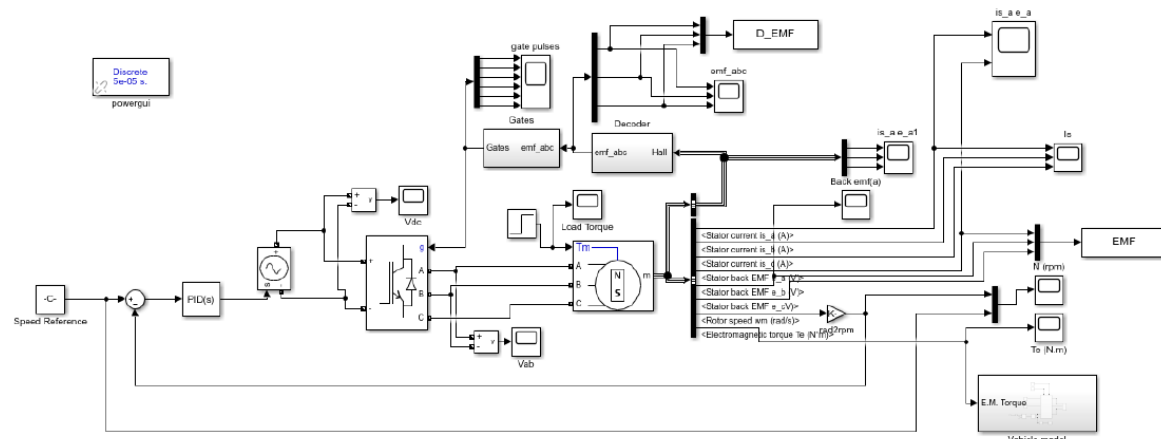


Fig 3.1 Torque Speed characteristics of an IC Engine

### Vehicle Specifications:

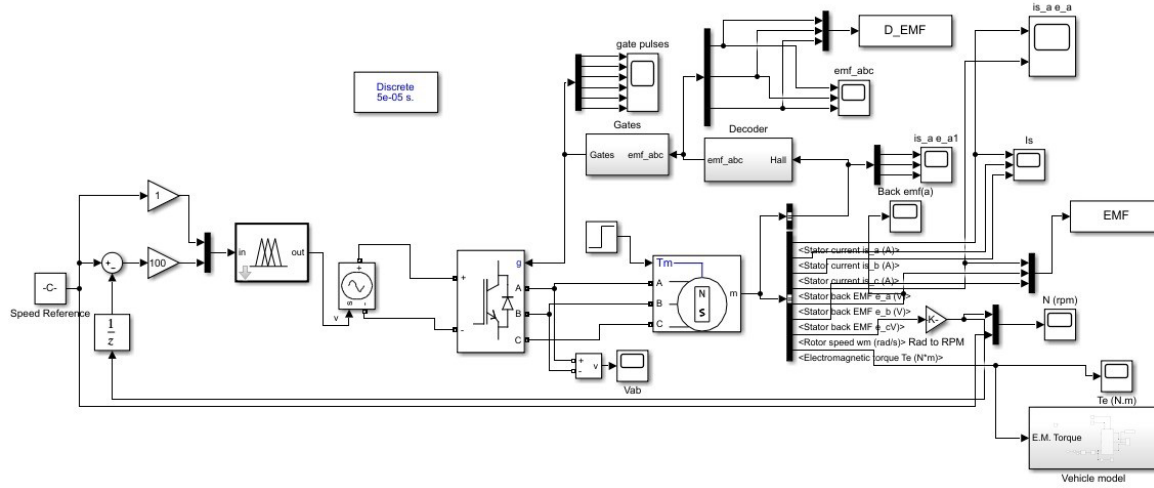
Load on the Vehicle (Except Vehicle Mass)	200 Kg
Vehicle Mass	500 Kg
Centre of Gravity height	254mm
Drag Coefficient	1.2
Front Axle	140 mm
Rear Axle	150 mm
Frontal Area	1.33m <sup>2</sup>
<b>Tire Parameters</b>	
Stiffness Factor (b)	10
Shape Factor (c)	1.9
Peak Factor (d)	1
Curvature Factor (e)	0.97
Tire Diameter	18 cm
Tire Inertia	1e-2 kg*m <sup>2</sup>
Rolling Resistance	0.005

**For PI Controller:**

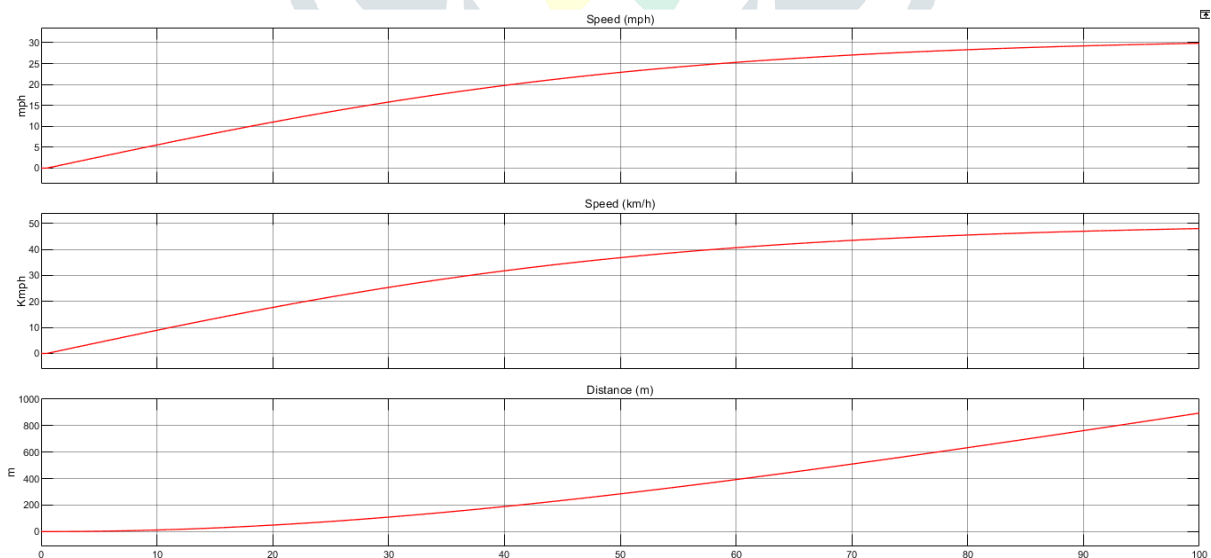
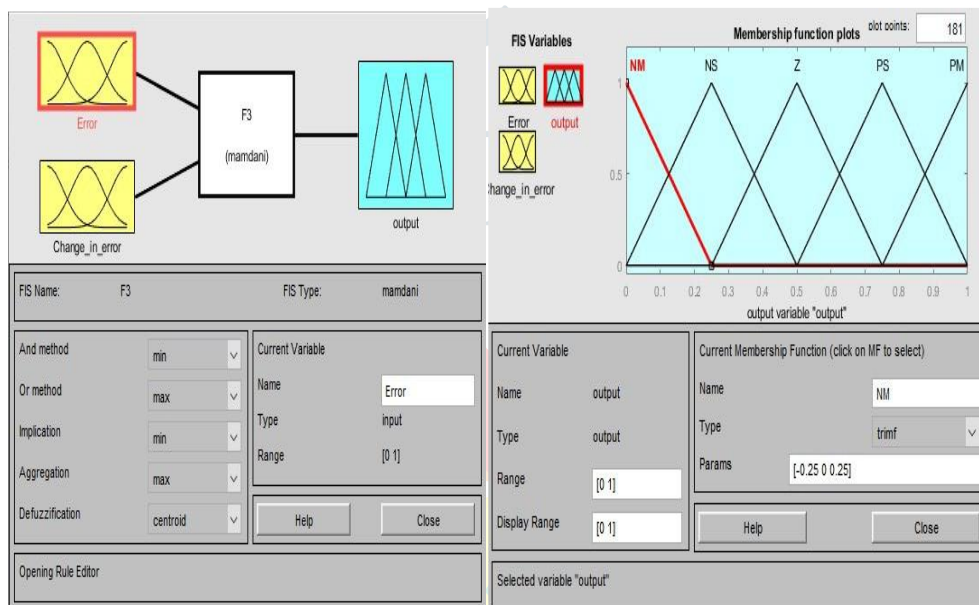


## Electric Vehicle model

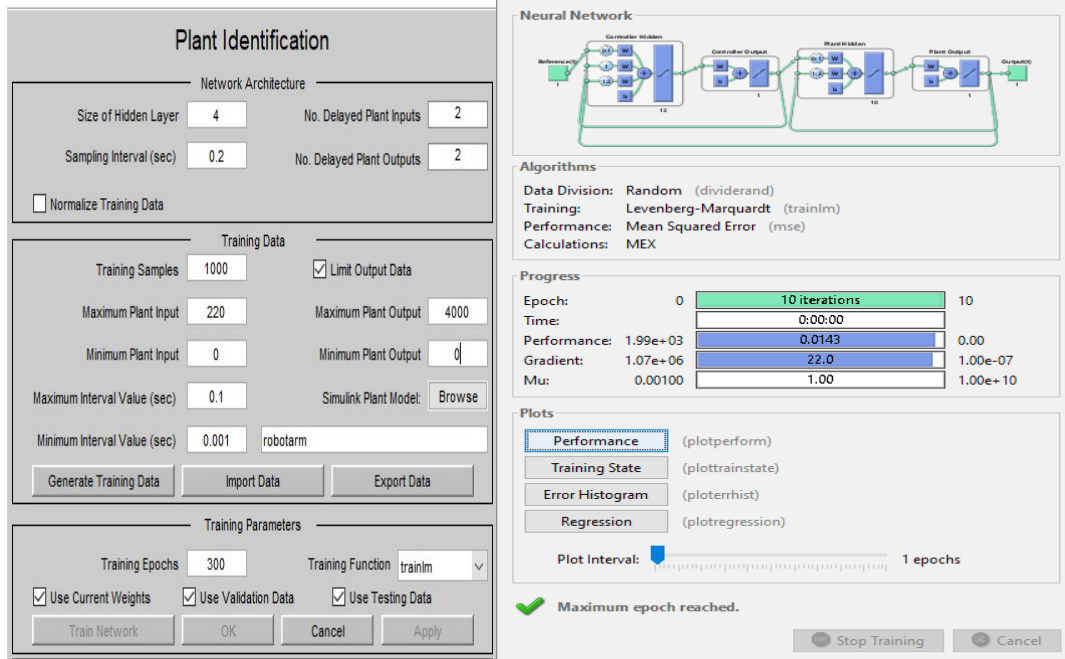
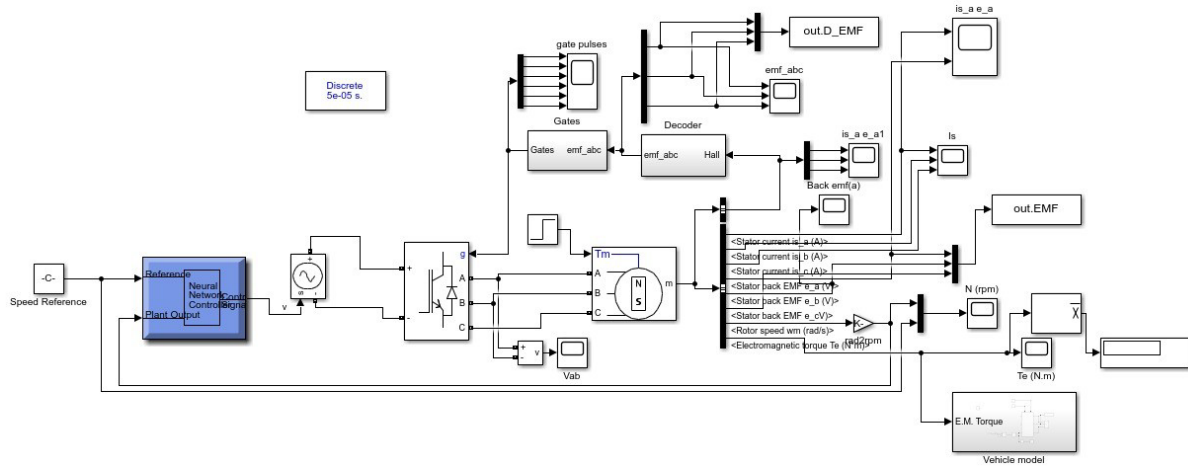




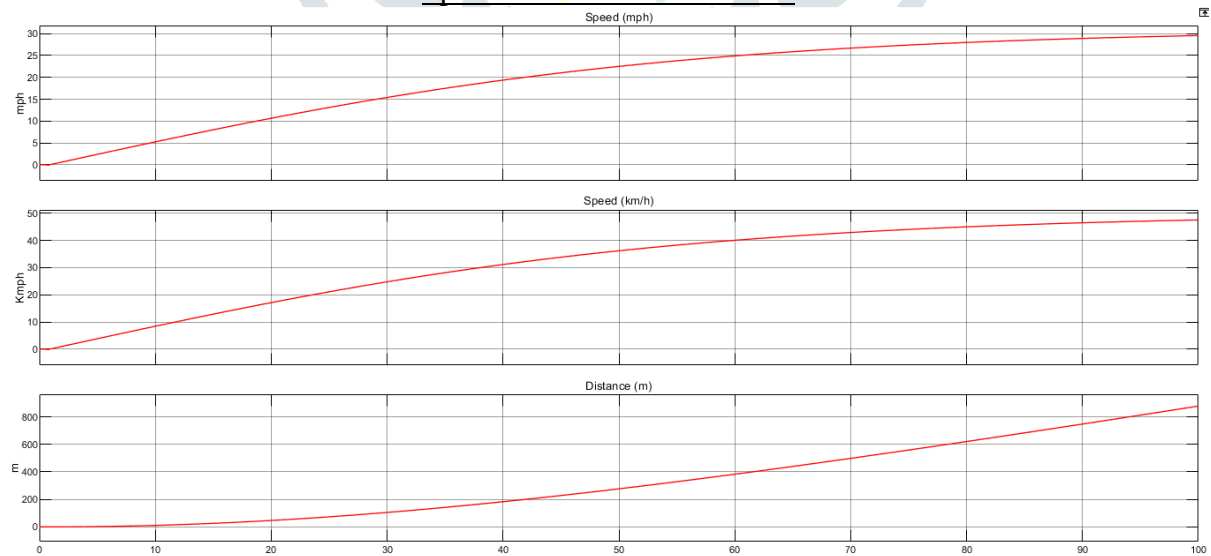
### Membership Functions of error and Change in error:



### Neural Network Control:



### Speed and Distance travelled





### Observation and Discussion:

	PI Controller	FL Controller	NN Adaptive controller
Settling time	2.25 s	1.42 s	0.24 s
Speed	37.12 kmph	48.05 kmph	47.57 kmph
Torque	50.36 Nm	49.38 Nm	49.55Nm
Velocity	10.31 m/s	13.35 m/s	13.42 m/s

### Observation:

- ☐ The Settling time of the torque is LOW in NN adaptive controller than the other two controllers and PI controller
- ☐ The rate of rise in Velocity is HIGH for NN adaptive controller than the other two controllers and PI controller gets the least.
- ☐ High Torque can be obtained effectively for PI Controller comparatively.
- ☐ High speed is obtained effectively for Fuzzy Logic Controller

### CONCLUSION

The above figures represent the outputs and the simulations of the BLDC Motor drive. Simulation results of implemented PI, Fuzzy Logic, Artificial Neural Network based BLDC motor controller shows accurate results. all results were proved that ANN controller is drawing enhanced output over the other two conventional controller. Under different working conditions ANN controller is found more quick and accurate in BLDC motor speed control. ANN controller is more reliable due to accurate and quick speed regulation even at load fluctuating. FL controller is easy to design and implement because of the simple rules. The PI, FL and NN adaptive control has its own merits and can be used based on the designer requirements.

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