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Power Optimisation Scheme of Induction Motor Using FLC for Electric Vehicle

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***Abstract* - Due to the increased pollution, and the continuous decrement in the conventional fuels, entire world is looking for an alternative form of transportation system. The transportation systems developed using electricity is the best solutions to overcome the problem. An electrical transport vehicle usually also called as electric vehicle. It can be a two wheeler, a three wheeler, a four wheeler or it can be a very big truck also. The vital things present in electrical vehicle are energy storage system, electrical motor, power conversion circuits, breaking system, and the overall vehicle control systems. Out of all these, an electric motor is vital, as it is an element which is responsible for the torque generation and movement of the electric vehicle. Hence, It is treated as the heart of an electric vehicle. There are many types in electrical motors, which are suitable for the electrical vehicle applications. Some of them are Induction motor, switched reluctance motor, synchronous reluctance motor, BLDC motor etc. Out of all, the induction motor is the robust in its construction, and it requires less effort to control compared to any other types of motors. In this project a detailed study is carried out to improve the power efficiency of an induction motor using fuzzy logic approach. The entire process is carried out and implemented in MATLAB.**

***Keywords* - BLDC motor, Electrical Vehicle, conventional, fuzzy logic, Electrical Motors.**

I.INTRODUCTION

The usage of fossil fuels like petrol and diesel are creating more adverse effect on environment. The number of vehicles is increasing day by day and also pollution is increasing in proportion to that. The conventional fossil fuel resources are also decreasing drastically. Hence, we are experiencing high cost for the fuel in several countries in the entire world.

The following surveys show the usage of conventional fuels and its effect on environment.

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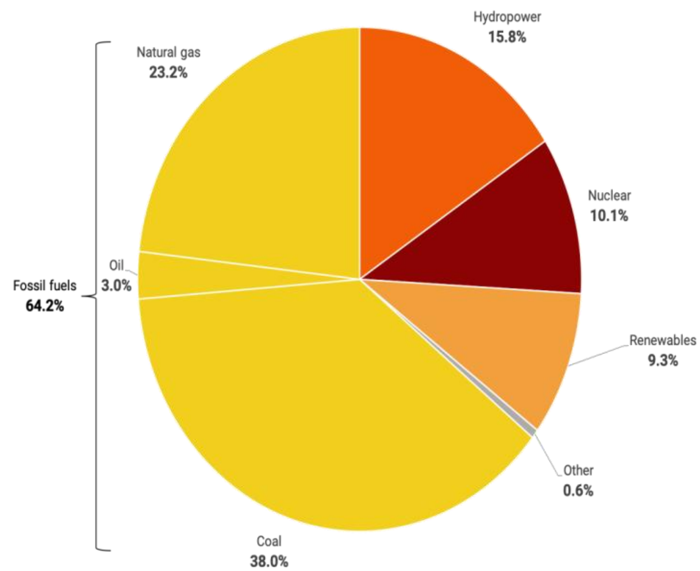

Figure 1 Usage of fossil fuels across the world

A. Electric Vehicles

The above figure shows various developments in vehicle technology. Initially we use to have pure internal combustion engine based gasoline vehicles. It uses to run using any fossil fuel like petrol or diesel.

Later, the concept of hybrid electric vehicles is introduced. In this type of vehicles, the start and start up is done using electric, where as the running is done using IC engine.

Later, the vehicles are completely replaced by battery. The battery is the main power source for a vehicle, and it is charged any number of times. The conventional engine is replaced by an electric motor.

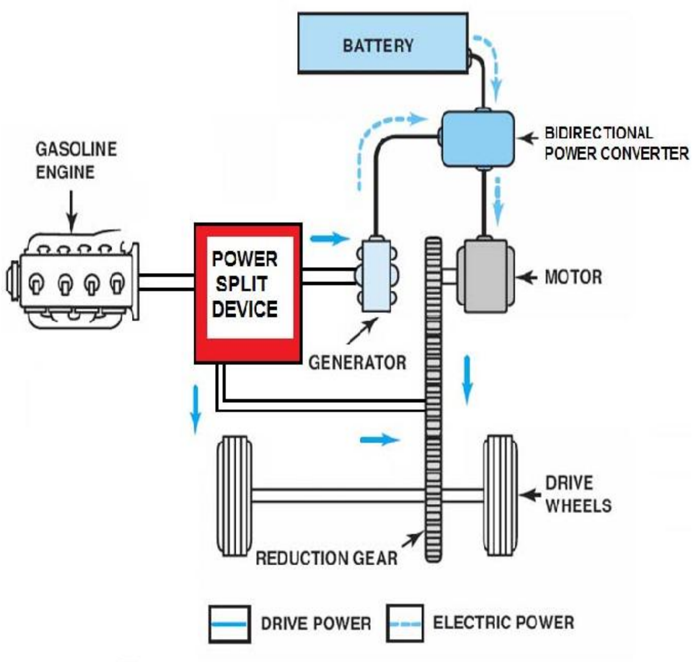

Figure 2 Architecture of Gasoline vehicle.

Following are the major components in gasoline vehicle.
[1]. Engine.
[2]. Power converter.
[3]. Power splitter.

B. Hybrid Electric vehicles

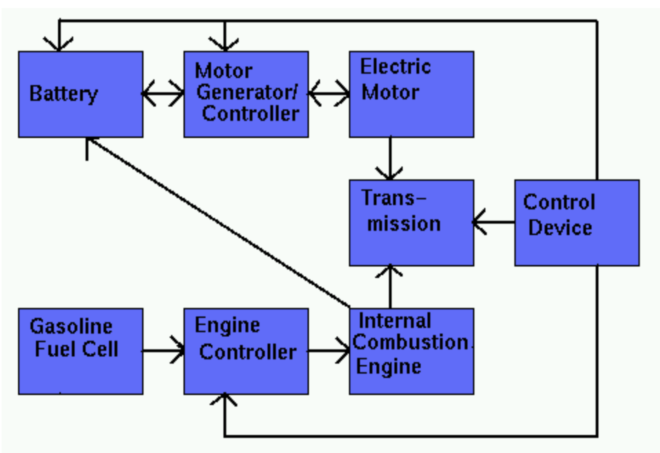

Figure 3 Block diagram of HEV.

The above figure shows the block diagram of a hybrid electric vehicle. It consists of
1. Battery
2. Motor
3. Control device
4. Gasoline fuel cell
5. Engine controller
6. IC Engine.

These types of vehicles are used mostly using IC engines during the running period. These vehicles are not fully electrified. Following are the drawbacks in this type of vehicles.
1. High cost
2. Heavy size due to two types of engines.

Hence, to overcome the above drawbacks, we can use electric vehicles.

C. Full Electric Vehicles

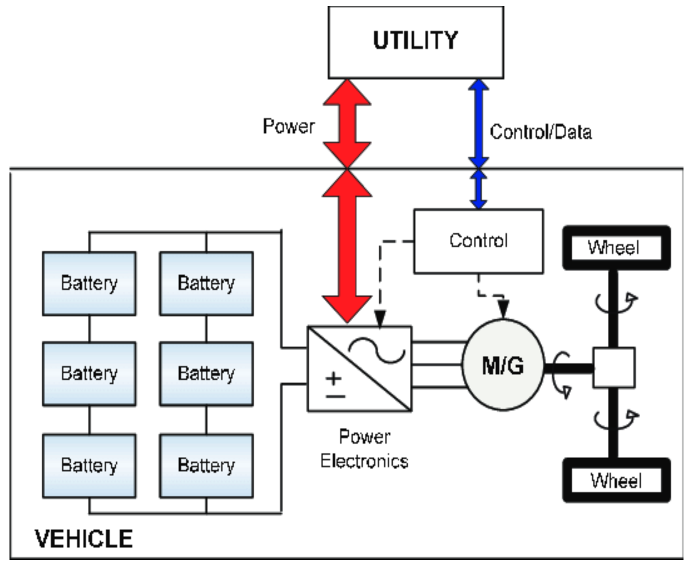

Figure 4 Full block diagram of electric vehicle.

The above figure shows the full components used in electric vehicles.
1. The battery will act like a power source.
2. Power electronic converters are used for power conversion.
3. An electric motor is used as torque generator element.
4. A control circuit/system is developed to control all the autonomous systems in electric vehicle.

Out of all our interest in this work is motor. Following are the various motors used in electric vehicle applications.

D.BLDC Motors

The BLDC motors also used in several EVs manufactured. This motor offers good torque characteristics, but the problem is there are many torque ripple in the torque wave form. The ripple reduction is hectic task in these motors. Hence, It is also having some limitation in using electric vehicles.

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Figure 5 BLDC Motor

E. PM BLDC motor

The other one is PM BLDC motor, which is made up of permanent magnets. The problem with this motor is that getting permanent magnets is difficult. Only china is the sole player in the permanent magnets. Hence, they are costly also.

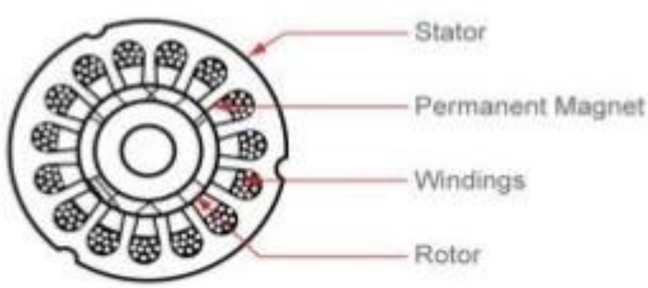

Figure 6 PM BLDC Motor.

II LITERATURE REVIEW

In this section, the related work that is carried out in the context of the power optimization scheme of the induction motor for electric vehicle is presented,

Following aspects are addressed in the open literature available related to the induction motor in electric vehicle applications.

- The analytical modelling for better performance is studied and implemented.
- Strategy of rule selection for fuzzy logic controllers developed.
- FLC control system is designed to improve the performance
- The steady state loss reduction is also carried out in some works.
- Reduction of steady state error and other parameters are also analysed.
- Existing design methods are also reviewed and updated according to the new control strategies of the machines.
- Field oriented control, direct torque control and the sliding mode controllers are analyzed.
- The performance of the linear quadratic controller is also carried out.
- The effect of machine parameters on control algorithm is also studied and implemented according to the new parameters.
- Suitability analysis is carryout to verify the applications in electric vehicle domain.

In this section, various works that are carried out in the domain of the induction motor is presented. Several studies have proved that the induction motor is more suitable for the electric vehicle applications compared to the many other motors available in the industry.

III POWER OPTIMIZATION OF INDUCTION MOTOR

In this section following aspects are discussed and presented.

- Induction motor modelling.
- Various methods to analyze the machine.
- Power optimization scheme for induction motor.
- Fuzzy logic is emphasized.

A. Induction motor model

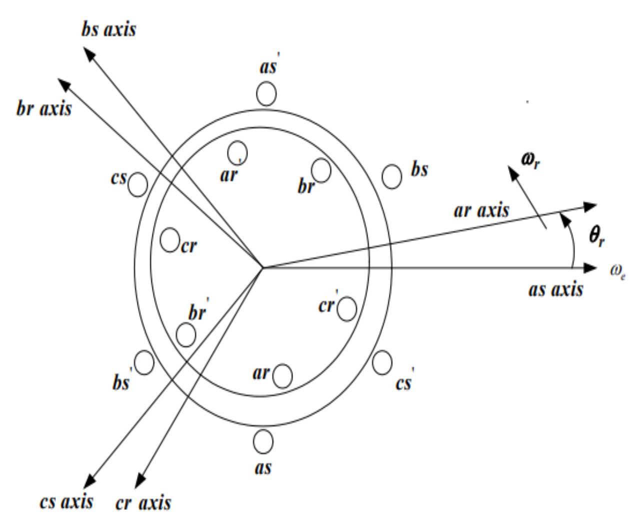

Figure 7 Three phase IM Model.

Induction motor operates on the principle of the electromagnetic induction. It has rotor speed and synchronous speed, the difference in these two speeds is called a slip speed. The relationship between two is given by

$$\omega_{so} = \omega_e - \omega_r \tag{3.1}$$

$$\omega_r = \frac{P}{2}\omega_m . \tag{3.2}$$

Where,
W_m is the mechanical rotor position.
The stator loop equations are given by

$$V_{as} = r_s I_{as} + p\lambda_{as} \tag{3.3}$$

$$V_{bs} = r_s I_{bs} + p\lambda_{bs} \tag{3.4}$$

$$V_{cs} = r_s I_{cs} + p\lambda_{cs} \tag{3.5}$$

The above equations can be re written as

$$V_{ar} = r_r I_{ar} + p\lambda_{ar} \tag{3.6}$$

$$V_{br} = r_r I_{br} + p\lambda_{br} \tag{3.7}$$

$$V_{cr} = r_r I_{cr} + p\lambda_{cr} . \tag{3.8}$$

The above equations can be represented as following system of equations.

$$V_{abcs} = r_s I_{abcs} + p\lambda_{abcs} \tag{3.9}$$

$$V_{abcr} = r_r I_{abcr} + p\lambda_{abcr} \tag{3.10}$$

where

$$(V_{abcs})^T = [V_{as}\ V_{bs}\ V_{cs}] \tag{3.11}$$

$$(V_{abcr})^T = [V_{ar}\ V_{br}\ V_{cr}] . \tag{3.12}$$

The matrix form of representation is given by

$$\begin{bmatrix} \lambda_{abcs} \\ \lambda_{abcr} \end{bmatrix} = \begin{bmatrix} L_s & L_{sr} \\ (L_{sr})^T & L_r \end{bmatrix} \begin{bmatrix} i_{abcs} \\ i_{abcr} \end{bmatrix} \tag{3.13}$$

Where,

$$L_s = \begin{bmatrix} L_{ls} + L_m & -\frac{1}{2}L_m & -\frac{1}{2}L_m \\ -\frac{1}{2}L_m & L_{ls} + L_m & -\frac{1}{2}L_m \\ -\frac{1}{2}L_m & -\frac{1}{2}L_m & L_{ls} + L_m \end{bmatrix} \tag{3.14}$$

$$L_r = \begin{bmatrix} L_{lr} + L_m & -\frac{1}{2}L_m & -\frac{1}{2}L_m \\ -\frac{1}{2}L_m & L_{lr} + L_m & -\frac{1}{2}L_m \\ -\frac{1}{2}L_m & -\frac{1}{2}L_m & L_{lr} + L_m \end{bmatrix} \tag{3.15}$$

$$L_{sr} = L_{sr} \begin{bmatrix} \cos\theta_r & \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) \\ \cos(\theta_r - \frac{2\pi}{3}) & \cos\theta_r & \cos(\theta_r + \frac{2\pi}{3}) \\ \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) & \cos\theta_r \end{bmatrix} . \tag{3.16}$$

To change the reference frame, following transformation matrix is used

$$K_s(\theta_s) = \frac{2}{3} \begin{bmatrix} \cos\theta_s & \cos(\theta_s - \frac{2\pi}{3}) & \cos(\theta_s + \frac{2\pi}{3}) \\ \sin\theta_s & \sin(\theta_s - \frac{2\pi}{3}) & \sin(\theta_s + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{3.17}$$

$$(K_s(\theta_s))^{-1} = \begin{bmatrix} \cos\theta_s & \sin\theta_s & 1 \\ \sin(\theta_s - \frac{2\pi}{3}) & \cos(\theta_s - \frac{2\pi}{3}) & 1 \\ \cos(\theta_s + \frac{2\pi}{3}) & \sin(\theta_s + \frac{2\pi}{3}) & 1 \end{bmatrix} . \tag{3.18}$$

The equations using synchronous frame of reference are

$$V_{qs} = r_s i_{qs} + p\lambda_{qs} + \omega_e \lambda_{ds} \tag{3.20}$$

$$V_{ds} = r_s i_{ds} + p\lambda_{ds} - \omega_e \lambda_{qs} \tag{3.21}$$

$$V_{os} = r_s i_{os} + p\lambda_{os} \tag{3.22}$$

$$V_{qr} = r_r i_{qr} + p\lambda_{qr} + (\omega_e - \omega_r)\lambda_{dr} \tag{3.23}$$

$$V_{dr} = r_r i_{dr} + p\lambda_{dr} - (\omega_e - \omega_r)\lambda_{qr} \tag{3.24}$$

$$V_{or} = r_s i_{or} + p\lambda_{or} \tag{3.25}$$

Using linear parameters, the induction machine model is

$$\begin{bmatrix} \lambda_{qd0s} \\ \lambda_{qd0r} \end{bmatrix} = \begin{bmatrix} K_s L_s (K_s^{-1}) & K_s L_{sr} (K_s^{-1}) \\ K_s L_{sr} (K_s^{-1}) & K_s L_r (K_s^{-1}) \end{bmatrix} \begin{bmatrix} i_{qd0s} \\ i_{qd0r} \end{bmatrix} \tag{3.26}$$

$$K_s L_s (K_s^{-1}) = \begin{bmatrix} L_{ls} + L_m & 0 & 0 \\ 0 & L_{ls} + L_m & 0 \\ 0 & 0 & L_{ls} \end{bmatrix} \tag{3.27}$$

$$K_s L_r (K_s^{-1}) = \begin{bmatrix} L_{lr} + L_m & 0 & 0 \\ 0 & L_{lr} + L_m & 0 \\ 0 & 0 & L_{lr} \end{bmatrix} \tag{3.28}$$

$$K_s L_{sr} (K_s^{-1}) = \begin{bmatrix} L_m & 0 & 0 \\ 0 & L_m & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{3.27}$$

The torque expression is given by

$$\lambda_{0s} = L_{ls} i_{0s} \tag{3.28}$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \tag{3.30}$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \tag{3.31}$$

$$\lambda_{0r} = L_{lr} i_{0r} \tag{3.32}$$

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda_{qr} i_{dr} - \lambda_{dr} i_{qr})$$

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds})$$

The expression for rotor speed is given by

$$p\omega_r = \frac{P}{2J}(T_e - T_L)$$

B. Equivalent circuit

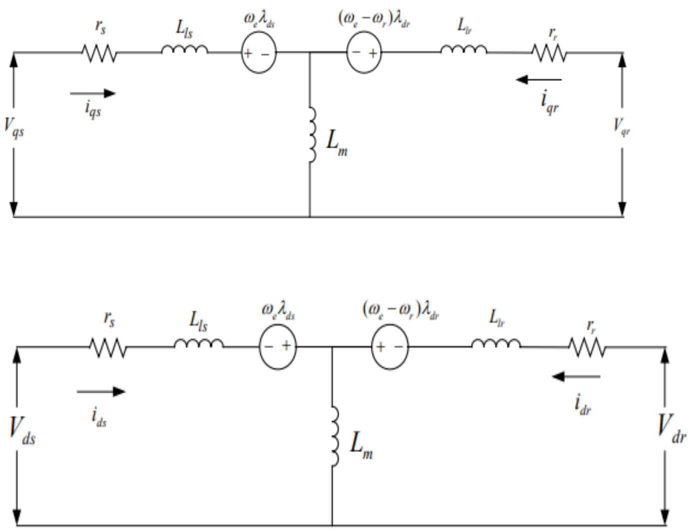

Figure 8 Equivalent circuit for analytical model

C. Fuzzy logic

It involves following stages to solve the optimization problem

- Variable definition.
- Variable creation.
- Fuzzification
- Rule based output generation
- De fuzzification.

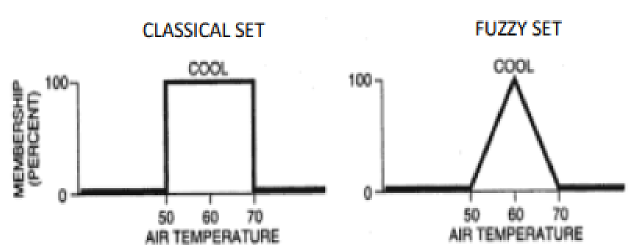

Figure 9 Classical set and Fuzzy Set.

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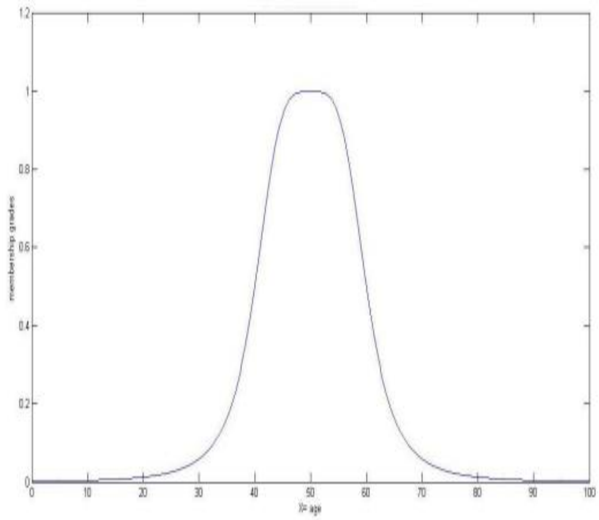
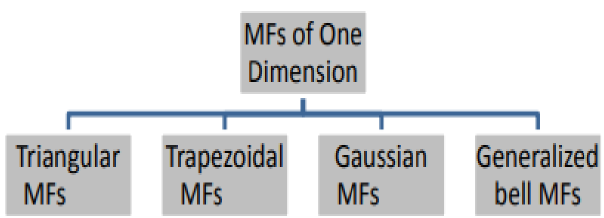
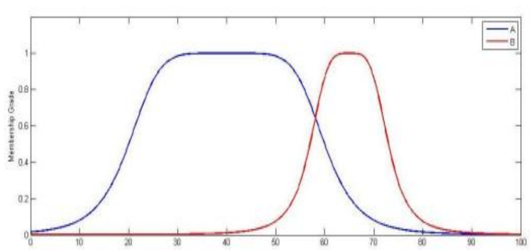


Figure 10 Fuzzy Membership function.

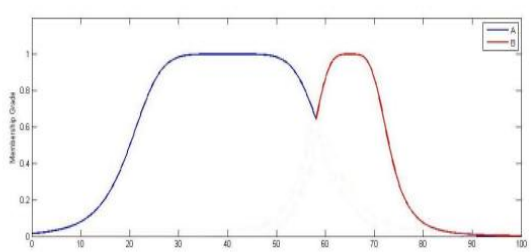
Following are the membership functions in fuzzy logic. The type of membership function decides the accuracy in the solution.



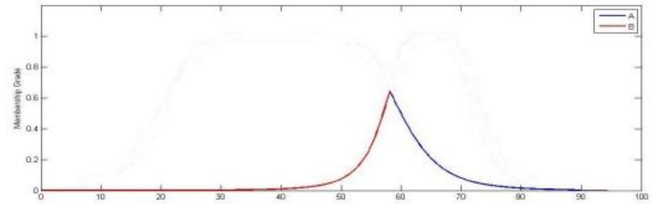
Following are the various examples



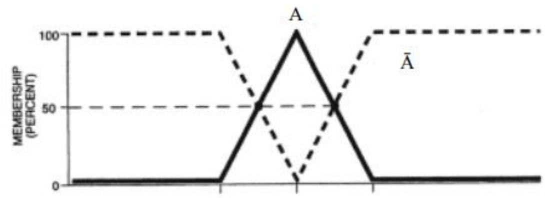
(a) Two Fuzzy sets A and B



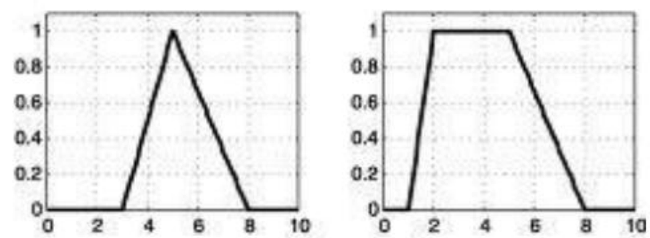
(b) A ∪ B



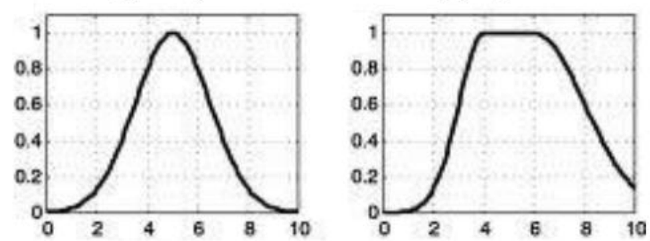
(c) A ∩ B



(d) Fuzzy set A and its Complement Ā



(a) Triangular **(b)** Trapezoidal



(c) Gaussian **(d)** Generalized Bell MF

Figure 11 Various membership functions in real time.

D. Fuzzy logic controller

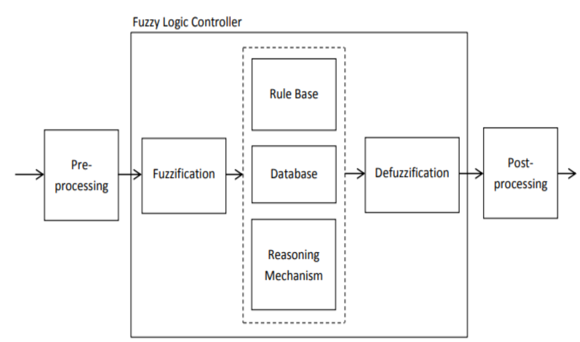


Figure 11 FLC Controller.

The process of de fuzzification is done based on the results obtained. And following are the methods in defuzzification.

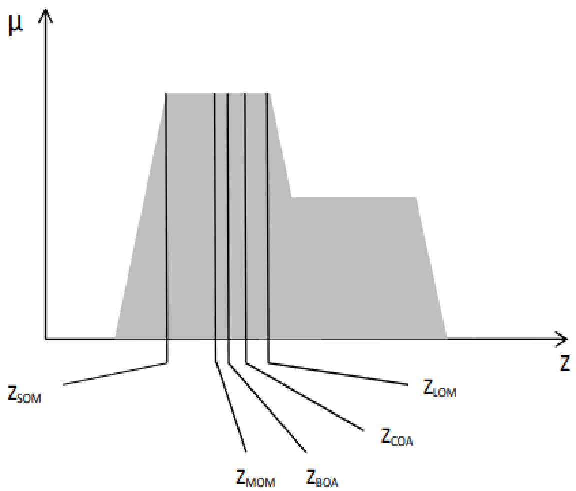


Figure 12 Defuzzification methods.

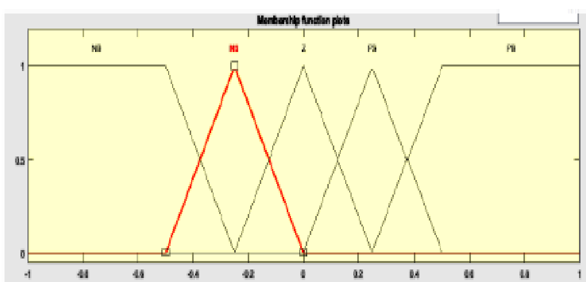


Figure 13 Membership functions for energy optimization.

Table 1 Rules of the FLC

Δwe	*we*				
	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	Z
NS	NB	NS	NS	Z	PS
Z	NS	NS	Z	PS	PS
PS	NS	Z	PS	PS	PB
PB	Z	PS	PS	PB	PB

Following is the rule based function to control the speed of the induction motor:

IV SIMULATION RESULTS

In this chapter, the power optimization of three phase induction motor is proved using the simulations. All the simulations are done in MATLAB/SIMULINK.

Below figures shows the MATLAB model of the induction motor in SIMULINK.

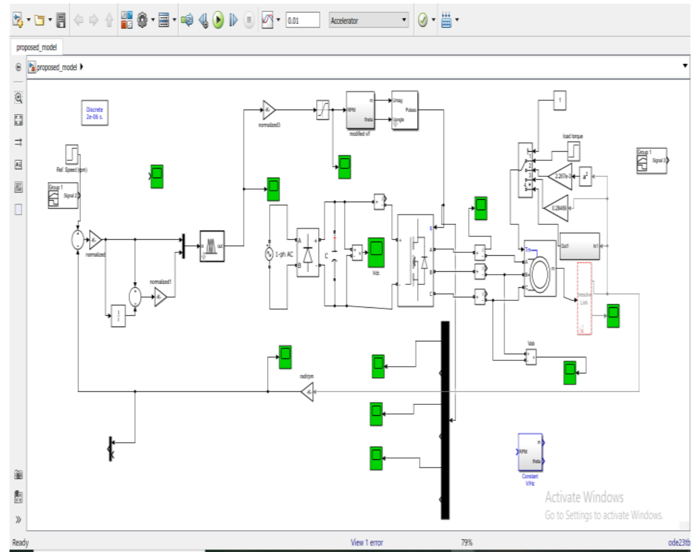


Figure 14 MATLAB Model of the induction motor.

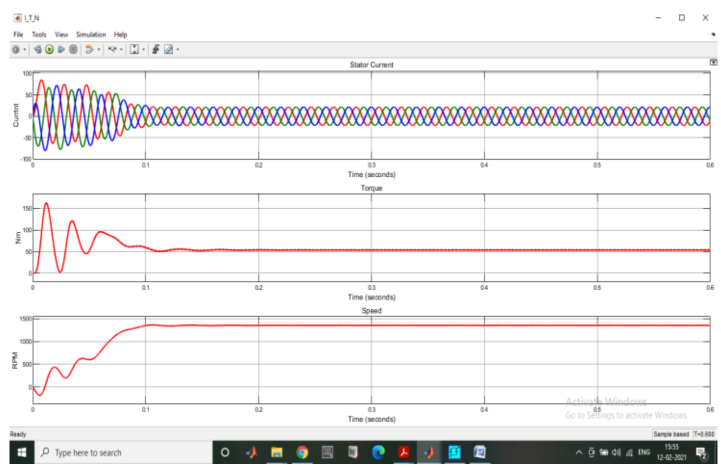


Figure 15 Induction motor Parameters

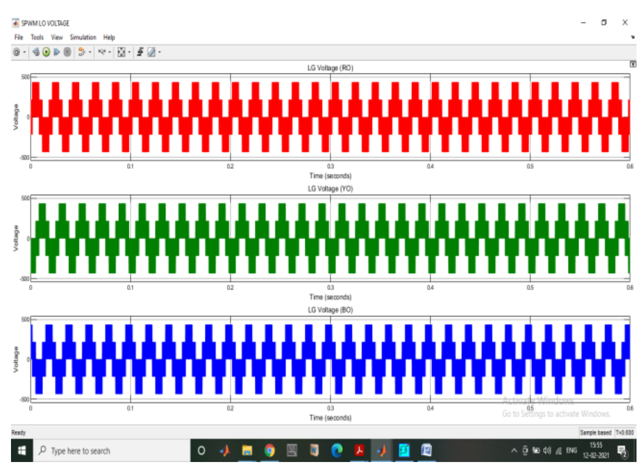


Figure 16 Inverter Phase Voltage

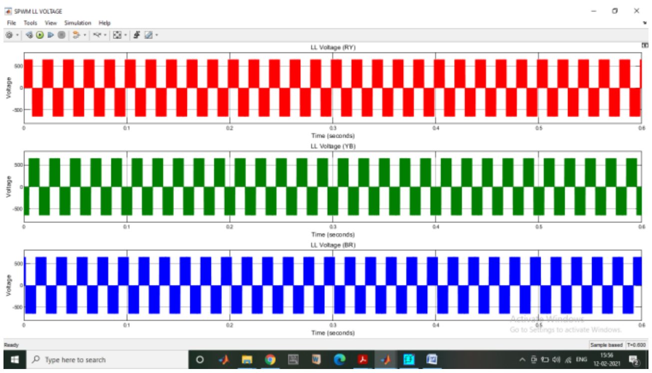


Figure 17 Line to Line voltages

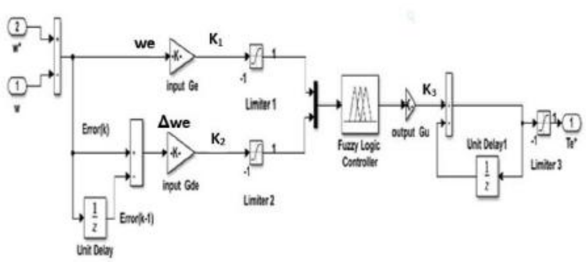


Figure 18 Fuzzy Logic Controller.

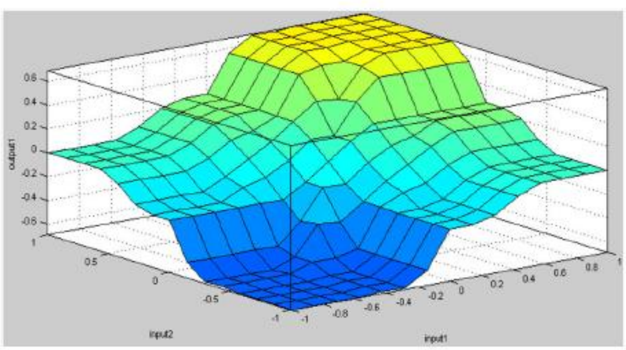


Figure 19 Fuzzy solution surface.

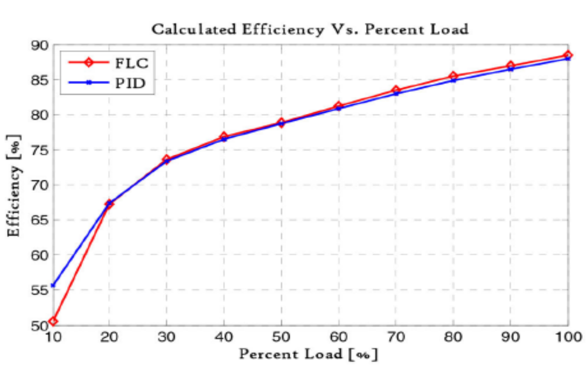


Figure 20 Efficiency comparison of FLC with PID controller.

CONCLUSIONS

Power optimization process of three phase induction motor is carried out using fuzzy logic controller. Following are the conclusions of this work.

- FLC is better than PID controller.
- There is a considerable improvement in the power of the motor using FLC.
- Speed harmonics are reduced considerable using FLC controller.

FUTURE SCOPE

However, the following aspects are not included in present work, which are left as future scope of this project.

- A generalized control method can be proposed, which can be implemented for any rating motor.
- A hybrid controller can be proposed to increase more efficiency.
- The time response can be still improved using a new control method.

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