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Simulation of Fuzzy and PI control of Asymmetric Bridge Converter fed Switched Reluctance Motor Drive

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ABSTRACT

The concept of this work helps to develop a switched reluctance motor (SRM) drive. Because of salient feature like four quadrant, rigid structure, high-speed capability and low cost from other types of motors, switched reluctance motor is more predictable in high speed applications. Its on-board integrated charger is formed using the embedded motor drive components. Good driving and regenerative braking performances are achieved by proper control. In idle condition, the performance of the drive with on-board integrated charger can give good line drawn power quality. The established charger consists of Asymmetric bridge converter from replacing H-bridge Switch Mode Rectifier with dc source. This type power circuit with SRM drive concept has been stimulated using the MATLAB/ Simulink software with PI and Fuzzy controller. The output results obtained as speed response drawn by SRM are compared and necessary drive regulation was satisfactory.

Index Terms: SRM, Asymmetric Bridge Converter, PI control, Fuzzy logic control .

I. INTRODUCTION

To minimize fossil energy consumption, the utilization of green energy sources has increasingly gained attention worldwide. In addition, the use of electric vehicles also effective in achieving this goal [4], [7]. Moreover, this EV can be regarded as movable energy storage device. Also it can be incorporated with the grid to effectively use its battery-stored energy.

To design such Electric Vehicle it is necessary to consider the performance of driving medium such that the efficiency of the vehicle will be mastered to considering range [1], [2]. For such analysis in drive performance it should have complete study about the particular motor drive to be used in particular concern. Electric machines can be broadly classified into two categories on the basis of how they produce torque [5], [9].

Now going depth in discussion about a switched-reluctance motor (SRM), possesses a doubly salient and singly excited structure, and there is no conductor or any permanent magnet on its rotor. So it progress following advantages: 1) rigid structure; 2) high power density; 3) low cost; 4) highly developed torque and acceleration capabilities; 5) suitable for high-speed driving; 6) absence of cogging torque; 7) simple converter schematic with fault tolerance. Hence, SRM is suited for the EV propulsion systems [2], [3]. Also easy four quadrant operation can be achieved since using asymmetric bridge converter [3].

An experimental SRM drive is established. Its power circuit consists of a dc source and an SRM asymmetric bridge converter. The proper controls are made to possess good acceleration/deceleration, reversible driving, and regenerative braking characteristics. Initially for developing EV at some extent there exist many drive configurations also their participation mainly in occurrence to prove their efficiency. But at some cost each drive came to face some drawback even though their performance was good [10].

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That is the best time to introduce SRM drive where it overcome all the demerits results from other source drives. The SRM high-speed driving performance is further enhanced via commutation shift and voltage boosting. Correct operation and good performances in all modes are obtained through the designed control schemes and are demonstrated experimentally.

II. SYSTEM CONFIGURATION

The system configuration and the photograph of the developed SRM drive are shown. Its major components are listed as follows:

1) Power Supply: A 400V dc supply.
2) SRM: four-phase, 8/6, 400 V, 3000 r/min, 500 W.
3) Power circuits: The Asymmetric Bridge converter in the SRM drive was constructed using one switch per single phase with IGBT power modules (3P-PM) CM100RL-12NF (600 V/100 A, Mitsubishi) and a one leg IGBT power module CM100DY-12H (600 V/100 A, Mitsubishi) [11].The schematics of the employed power modules are depicted. Selection of the switch is such that it should confess the minimum switching loss where the resultant performance of the drive can be controlled [12], [13]. Also selection of poles in motor construction also help to reduce the torque which increase the speed response also give better settling time.

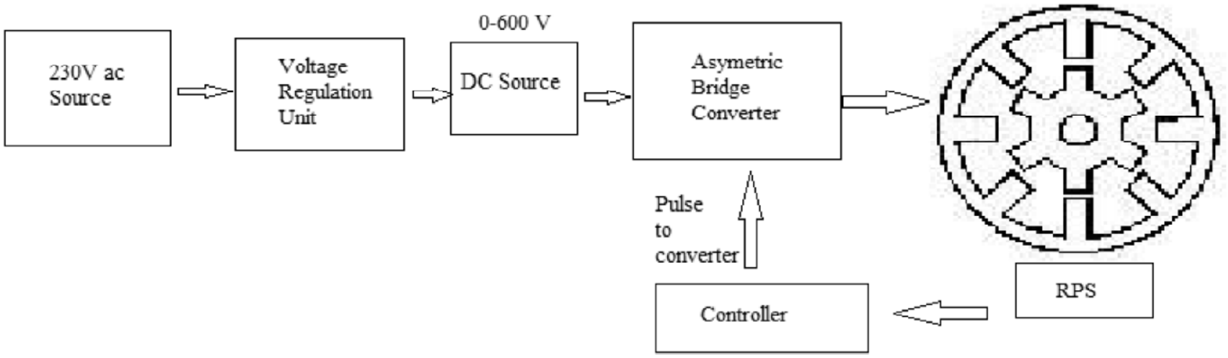


Figure 1: Block diagram for the drive system

III. MOTOR CHARACTERISTICS

The basic operating principle of the SRM is quite simple; as current is passed through one of the stator windings, torque is generated by the tendency of the rotor to align with the excited stator pole. The direction of torque generated is a function of the rotor position with respect to the energized phase, and is independent of the direction of current flow through the phase winding. Continuous torque can be produced by intelligently synchronizing each phase's excitation with the rotor position.

By varying the number of phases, the number of stator poles, and the number of rotor poles, many different SRM geometries can be realized.

Generally, increasing the number of SRM phases reduces the torque ripple, but at the expense of requiring more electronics with which to operate the SRM. At least two phases are required to guarantee starting, and at least three phases are required to insure the starting direction. The number of rotor poles and stator poles must also differ to insure starting.

IV. TORQUE-SPEED CHARACTERISTICS

The torque-speed operating point of an SRM is essentially programmable and determined almost entirely by the control. This is one of the features that make the SRM an attractive solution. The envelope of

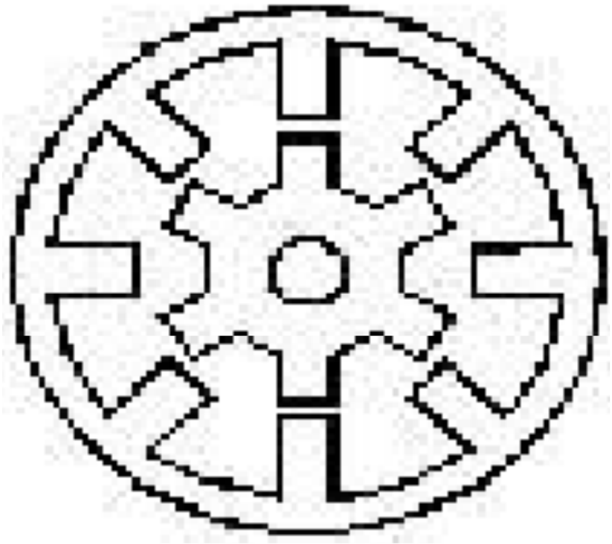


Figure 2: 4-phase, 8 rotor poles/6 stator poles

operating possibilities, of course, is limited by physical constraints such as the supply voltage and the allowable temperature rise of the motor under increasing load.

Like other motors, torque is limited by maximum allowed current, and speed by the available bus voltage. With increasing shaft speed, a current limit region persists until the rotor reaches a speed where the back-EMF of the motor is such that, given the DC bus voltage limitation we can get no more current in the winding—thus no more torque from the motor. At this point, called the base speed, and beyond, the shaft output power remains constant, and at its maximum. At still higher speeds, the back-EMF increases and the shaft output power begins to drop. This region is characterized by the product of torque and the square of speed remaining constant.

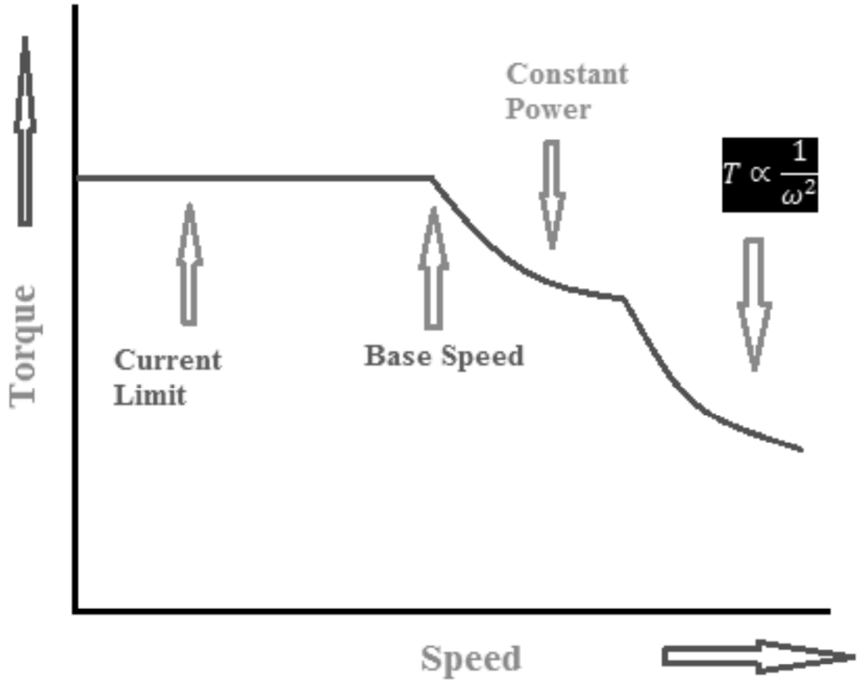


Figure 3: SRM Torque-Speed Characteristics

V. CONTROL SCHEMES

SRM Converter:

Requirements of SRM converter:

A main problem in certain application is the selection of converter topology. The SRM Converter has some essential requirements, they are:

- Minimum one switch is capable to conduct freely in each phase of the motor. The converter would be capable to excite the phase before it enters the generating or demagnetizing region. The converter needs to satisfy several other necessities in order to increase the converter performance; such as fast Demagnetization time, faster excitation time, high power, higher efficiency, and fault acceptance.
- The converter must be able to allow phase overlap control because the converter energy can be provided to one phase whereas at the same time it is removed from the other phase.
- In order to decrease the voltage stress through the semiconductor switches, the converter takes to be single rail of power source. Upon the construction of motor, the converter would have to be single rail of power source.

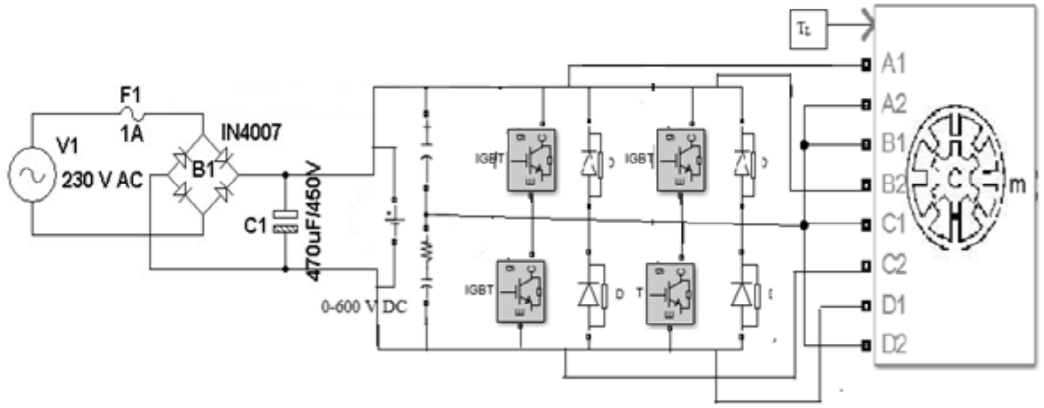


Figure 4: System configuration developed SRM drive on-board charger of the.

V. ASYMMETRIC BRIDGE CONVERTER

Asymmetric bridge converter is used for high switching voltage to have fast developed of the excitation current. In each phase the converter consists of two power electronic switches and two diodes so that the unipolar switching strategy is achieved. In every phase, the lower switch is used in charge of commutation, while the PWM switching control can be performed by the upper one. Every phase can be controlled separately. Magnetization, demagnetization and freewheeling mode are defined as the three current modes of operation. In the inner current control loop of the SRM drive, less current ripple and improved frequency reaction can be obtained by using unipolar switching approach.

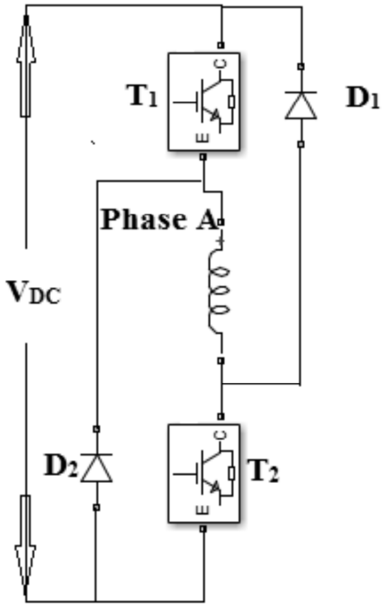


Figure 5: Single Phase Asymmetric Bridge Converter

VII. ENERGIZING EQUATIONS

The torque is relative to the square of the current, hence the current can be single polar to produce single directional torque Note that this is quite contrary to the case for ac machines.

The resultant torque has some ripple during the commutation interval hence that torque ripple can be given as:

$$t_{rpl} = \left| \frac{T_{\max} - T_{\min}}{T_{av}} \right| \tag{1}$$

From the known voltage equation we can derive the resultant torque as follows:

$$v = Ri + \frac{d\varphi(i,\theta)}{dt} \tag{2}$$

$$\varphi(i, \theta) = L(i, \theta).\ i$$

The induced back-emf, e, is obtained with the angular frequency of the rotor ù as:

$$e = \frac{dL(i,\theta)}{d\theta} . \frac{d\theta}{dt} i = \frac{dL(i,\theta)}{d\theta} .\omega . i \tag{3}$$

Since normal unipolar current “I” is always positive so sign of e determined will be (+VE), this will force the current to decrease against the supply voltage and it converts the electric power supplied into mechanical output and thus motoring stage occurs.

$$\frac{dL}{d\theta} > 0,\ motoring\ mode$$

$$\frac{dL}{d\theta} < 0,\ generating\ mode$$

The electromagnetic torque can be determined from a power balance. It is

$$vi \cdot dt = Ri^2 \cdot dt + i \cdot \frac{\partial\varphi}{\partial i} di + \frac{\partial\varphi}{\partial\theta} d\theta \tag{4}$$

The given eqn. represents the entire change of energy as the change of magnetic field energy dWF and mechanical work dWm.

$$dW_m = \left(i \cdot \frac{\partial\varphi}{\partial\theta} - \frac{\partial W_F}{\partial\theta} \right) d\theta \tag{5}$$

By introducing the magnetic co-energy W_c, the above eqn. can be simplified as

$$W_c = \int_0^{\tau_2} \varphi \cdot di \tag{6}$$

In linear range both W_f and W_c are equal and in the non-linear range of middle and high saturation they can deviate considerable from each other.

$$T_S(i,\theta) = \frac{\partial W_c(i,\theta)}{\partial\theta}, i = constant \tag{7}$$

From the expression of co-energy the instantaneous electromagnetic torque Ts (i, Θ) produced by each phase, is given from the partial derivative of the phase co-energy and is given by

$$W_e = \int_0^{t_2} \varphi \cdot di = \frac{1}{2} \cdot L(\theta) \cdot i_s^2$$

$$T_s = \frac{1}{2} \cdot i_s^2 \cdot \frac{dL}{d\theta} \tag{8}$$

VIII. (A) SIMULATION OF SPEED CONTROL USING PI CONTROLLER

To refine the speed of response and to eliminate the steady state error it is essential for the combination of proportional and integral terms. By giving feedback to the converter the performance of the PI controller can be improved and it conquers the disturbances. The forced oscillation and steady state error can be eliminated in PI controller during the operation of P controller and on-off controller respectively.

However, introducing integral mode has a negative effect on stability of the system and in speed response. So that speed response will not increase in PI controller. This problem can be detected by introducing derivative mode. It has the capability to predict the errors and to decrease the reaction time of the controller. If the speed response is not a criteria normally PI controllers are used.

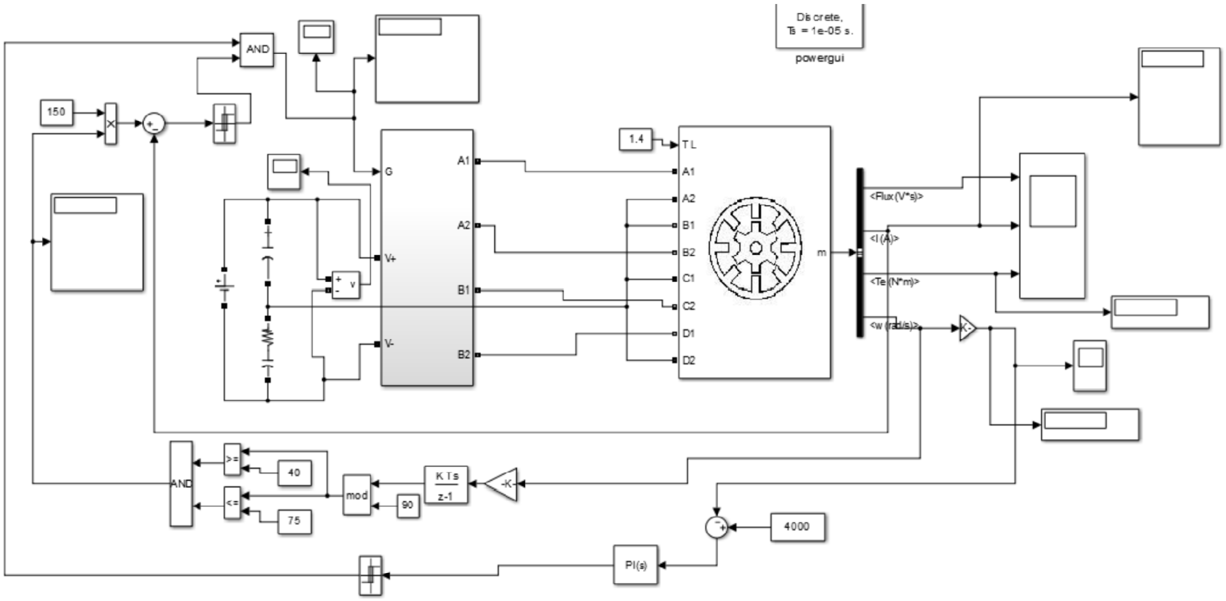


Figure 6: Simulation for PI controller

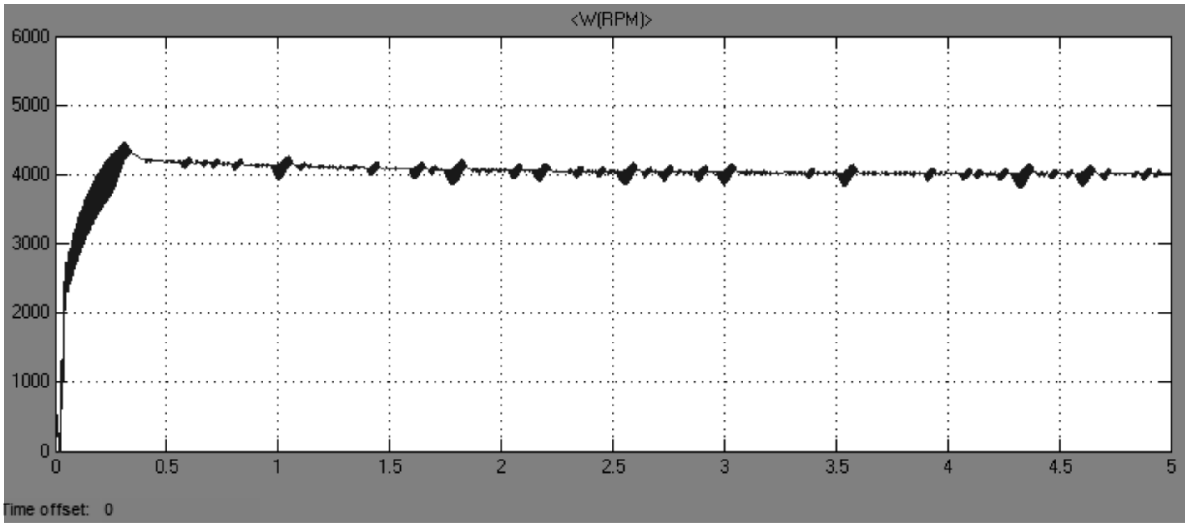


Figure 7: Speed response for PI controller

The above output waveform of speed control of SRM drive using PI controller which has been designed using Simulink model exclaims with run speed 4009 rpm with settling time of 0.75 seconds. From the above notification the main confess to introduce this controller to down the steady state error.

(B) SIMULATION OF SPEED CONTROL USING FUZZY CONTROLLER

Also introducing fuzzy controller further the response can be improved by containing the settling time of speed which also achieved within 0.4 seconds. The following Simulink model illustrates the controller response for the drive to have perfect range of control system:

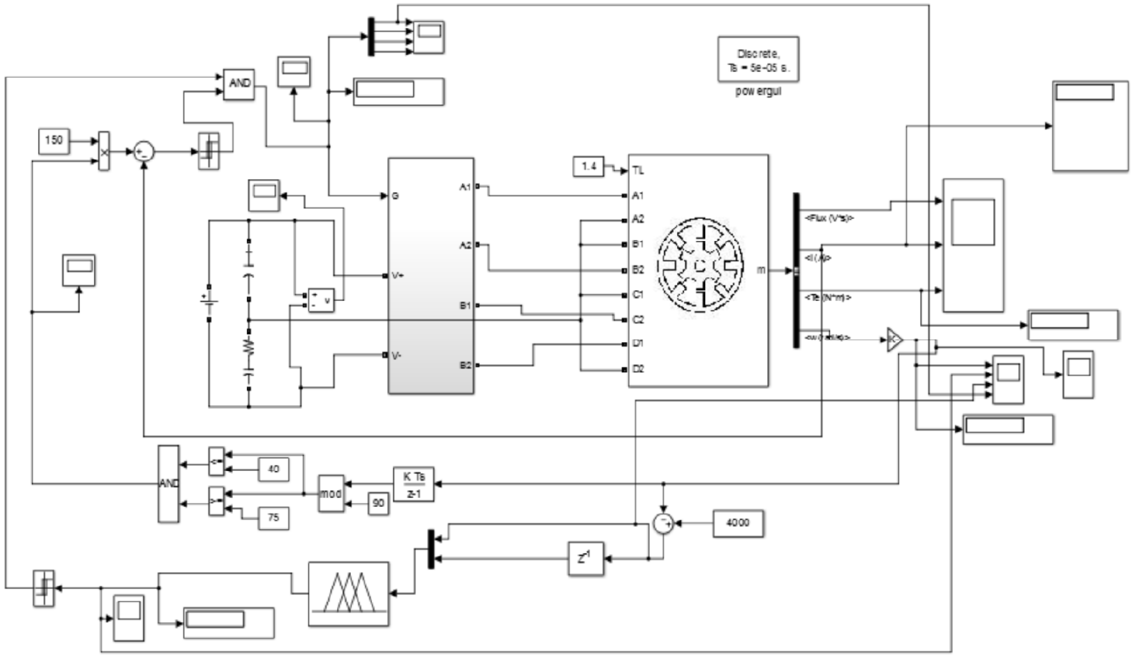
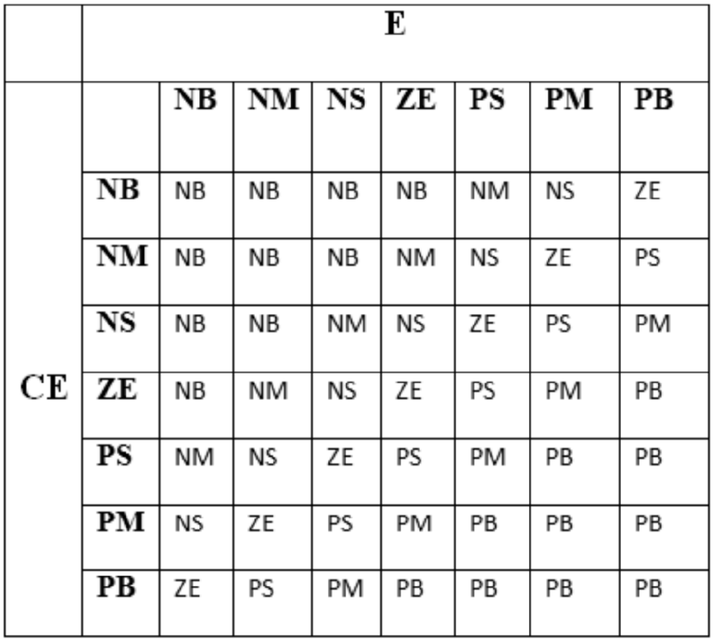


Figure 8: Fuzzy control SRM drive

Lotfi Zadeh proposed the Fuzzy logic in year 1965; in all inventive fields it has various applications. The merits of fuzzy logic controller are the clarification for a problem can be analysed and the design of the controller can be easily implemented. The design of fuzzy logic system is not based on the mathematical model of process. There are four different stages in this logic controller (i) Fuzzification, (ii) Rule base, (iii) inference mechanism and (iv) Defuzzification. The fuzzification is nothing but it comprises the process of transpose crisp values into grades of membership for linguistic terms of fuzzy sets. The transpose from a fuzzy set to a crisp number is called a defuzzification. The inference engine and the knowledge base were the components of an expert system. The knowledge base stores the factual knowledge of the operation of the concern experts. Fuzzy inference engine is the process of calculating from a given input to an output using fuzzy logic. In inference engine, If – Then type fuzzy rules converts fuzzy input to the output. Mamdani type fuzzy logic controller is most commonly used in a closed loop control system, because it reduces the steady state error to zero.

The designed fuzzy rules used in this research are given in Table 1. The fuzzy sets have been defined as: negative big (NB), negative medium (NM), negative small (NS), zero (ZR), and positive small (PS), positive medium (PM) and positive big (PB) respectively. Many research papers have developed SRM models based on fuzzy logic, hybrid fuzzy and neural techniques.

To verify effectiveness in this work strategy, an adjustable speed drive system with four phase SRM drive fed with bridge converter in which speed control is achieved using fuzzy controller.



		E						
		NB	NM	NS	ZE	PS	PM	PB
CE	NB	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NB	NB	NM	NS	ZE	PS
	NS	NB	NB	NM	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PM	PB	PB
	PM	NS	ZE	PS	PM	PB	PB	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

Figure 9: Rule Table of Fuzzy logic controller

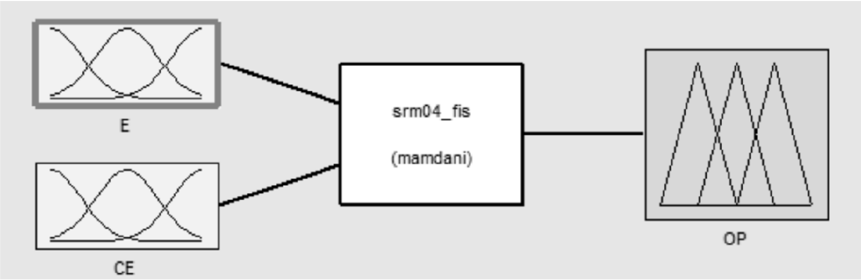
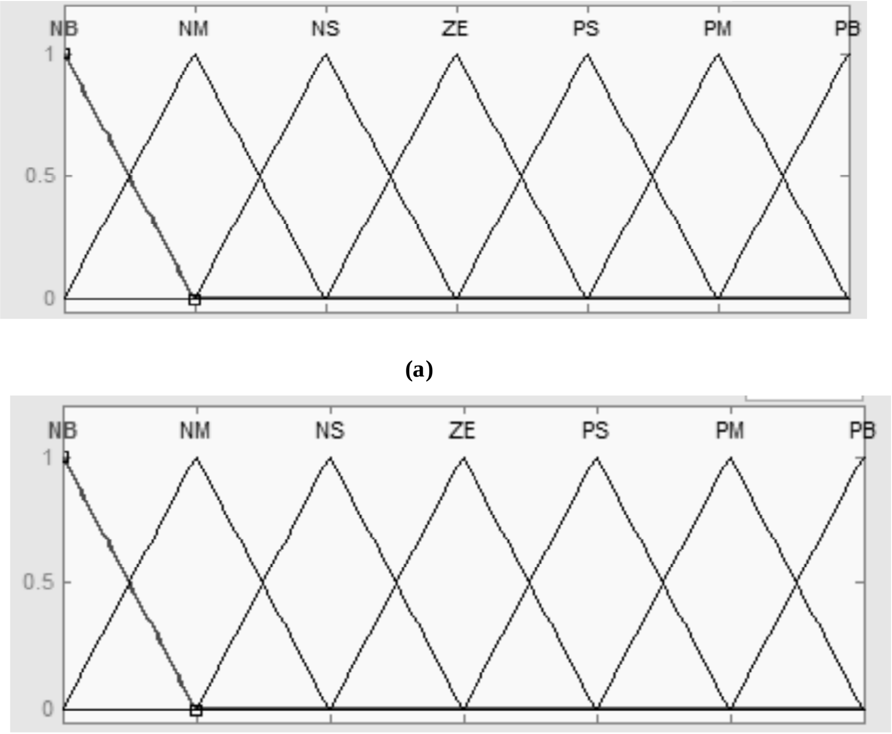
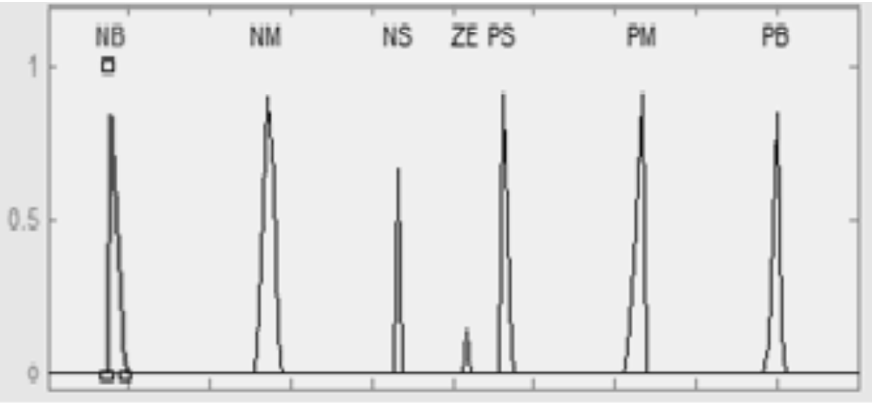


Figure 10: Fuzzy inference system of SRM



(a)

(b)



(c)

Figure 11: Membership functions (a) Speed error (b) Change in error (c) Output speed error

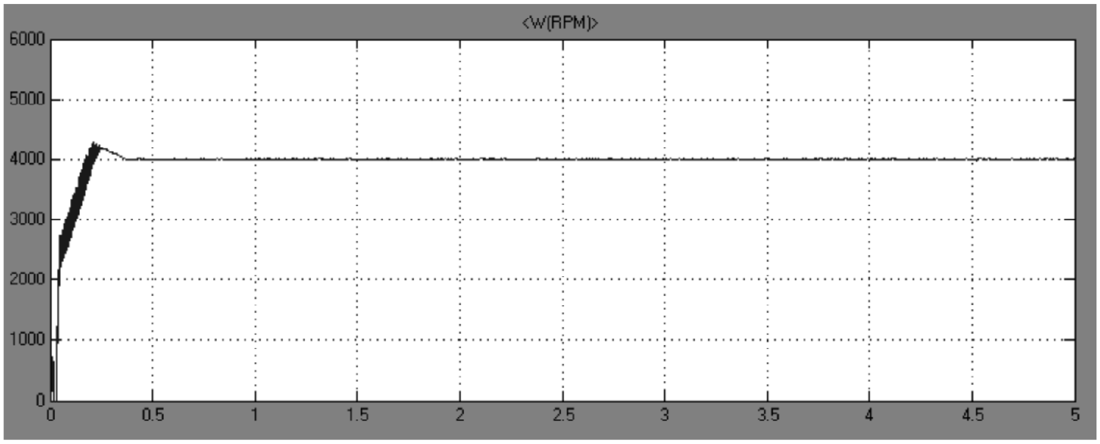


Figure 12: Speed (RPM)

IX. CONCLUSION

The above proposed concept initially compares the output response of the four phase SRM drive with two types of controller. The main reason behind considering four phases with 8 stator and 6 rotor poles is to minimize the torque ripple. Generally ripple constraints will be less in going for increasing poles in the motor construction. Also there are some advantages why here we go with fuzzy controller concept are flexibility, convenient user interface, easy learning and computation, finally with conceptual model. As a result the SRM dynamic performance is forecasted and by using the MATLAB/Simulink the model is simulated. The conclusion from this simulation results that when compared with PI controller, the Fuzzy logic controller meets the required output. It gives excellent reference tracking of speed and enhances the regulation. Further this work can be over ride for designing the on-board charger in making any electric vehicle system.

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