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Fuzzy Logic Controller Based Four Phase Switched Reluctance Motor

KODEM DEVENDRA PRASAD
M-tech Student Scholar
Department of Electrical & Electronics Engineering,
ANURAG FROUP OF INSTITUTIONS (CVSR) Ghatkesar
Medchal (Dt); Telangana, India

B.CHANDRA SHEKAR
Guide Assistant Professor
Department of Electrical & Electronics Engineering,
ANURAG GROUP OF INSTITUTIONS (CVSR) Ghatkesar
Medchal (Dt); Telangana, India.

Abstract: The switched reluctance motor drives has evolved as an alternative to conventional motors in variable speed drives because of advantages like simple and rugged structure, absence of rotor winding, adaptability to harsh environments like coal mining, high speed operation etc. Because of nonlinearity, torque ripple is high in the motor. Switched reluctance motors (SRM) have many advantageous characteristics comparing to those of the conventional AC and DC machines. The mechanical simplicity in construction of the SRM can be seen through their purely laminated-steel structure without permanent magnets, rotor windings and squirrel-cage bars. Thus, SR machines offer high reliability and robustness in operation. The Switched Reluctance Motor (SRM) has highly gains interested in many industrial applications. On the other hand the SRM also have the disadvantage points such as high torque ripple and nonlinearity characteristic. This paper presents the development of the drive system for a four-phase 8/6 switched reluctance motor with fuzzy logic controller for testing and obtaining characteristics of the SRM. By using MATLAB/SIMULINK software.

Keywords — Switched-Reluctance Motor (SRM), Single Pulse Mode, Soft Chopping Mode, fuzzy Logic Controller.

I. INTRODUCTION

In this paper the simulink model for the speed control of switched reluctance motor is done using two different speed controllers. The simulink model for this is designed using both the controllers separately and their performance result is compared. The Switched Reluctance Motor is an electric motor which runs by reluctance torque. These motors usually run at very high speed of 50,000 rpm which is to be controlled for industrial use. The speed controllers applied here are PI and Fuzzy Logic Controller. A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative of the error is not used. Fuzzy logic controller is an intelligent controller which uses fuzzy logic to process the input. Fuzzy logic is a many valued logic which is much like human reasoning.

II. SRM over view

The Switched Reluctance Motor has gained significant interest in the field of industrial drive. It has numerous advantages like simple and robust construction, reliability, low manufacturing cost, high starting torque, high efficiency, and high speed capacity. The stator has concentrated windings wound field coils and the rotor has no coils or magnets. The stator and rotor have salient poles; hence, the machine is a doubly salient machine. Switched Reluctance Motor is a highly nonlinear control plant and operates in saturation to maximize the torque output. The principle of operation is such that the motion is produced as a result of variable reluctance in the air gap between the rotor and the stator. When the voltage is applied to the stator phase, the rotor tries to rotate in the direction of minimum reluctance position producing reluctance torque. In order to achieve a full rotation of the motor, the windings must be energized in the correct sequence. The Switched Reluctance Motor operates in all the four quadrants and it is suitable to operate in hazardous areas also [7].

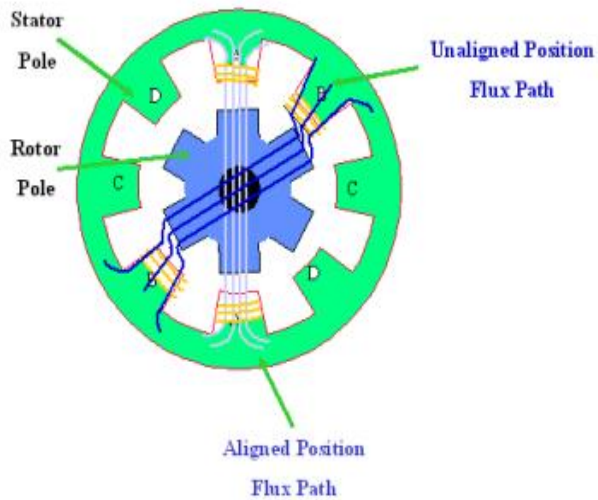

Fig.1.Structure of 4 phase 8/6 SRM.

III. ANALYSIS OF SRM OPERATION

A.Single Phase Equation of SRM

The phase voltage equation of the switched reluctance motor is given by

$$v_a = R_a i_a + \frac{d\lambda_a(i_a, \theta_a)}{dt} \quad (1)$$

$$v_a = R_a i_a + L_a(i_a, \theta_a)\frac{di_a}{dt} + i_a \omega_r \frac{dL_a(i_a, \theta_a)}{d\theta_a} \quad (2)$$

$$e_a = i_a \omega_r \frac{dL_a(i_a, \theta_a)}{d\theta_a} \quad (3)$$

where va is the phase voltage, iais the phase current, Ra is the phase resistance, La(ia,Oa) is the phase inductance in term of phase current and rotor position, θα is the rotor position, eais the back-EMF and a>r is the rotor speed. The instantaneous electric power of a phase is described as follows.

$$P_a = v_a i_a = R_a i_a^2 + L_a(i_a, \theta_a) i_a \frac{di_a}{dt} + i_a^2 \omega_r \frac{dL_a(i_a, \theta_a)}{d\theta_a} \quad (4)$$

The phase instantaneous torque is given by

$$T_a = \frac{1}{2} i_a^2 \frac{dL_a(i_a, \theta_a)}{d\theta_a} \quad (5)$$

The summation of torque for each phase is given as follow

$$T_m = T_a(i_a, \theta_a) + T_b(i_b, \theta_b) + T_c(i_c, \theta_c) + T_d(i_d, \theta_d) \quad (6)$$

The motoring torque is positive. It's produced when phase winding is energized during the positive slope of the phase inductance variation, dLa (ia, 0a)/d0a >0. On the other handthe generating torque is negative.

B. Current Control Modes

The current chopping mode is necessary to control the peak value of phase current at low speed. Both IGBT are switched together at high frequency. This current control scheme is called hard chopping.

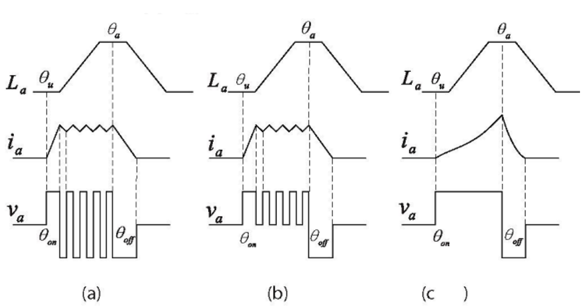

Fig.2. Idealized of phase voltage and phase current of the SR M, (a) Hard Chopping Mode, (b) Soft Chopping Mode, (c) Single Pulse Mode.

Another current control scheme is called soft chopping. The phase current waveforms when SRM operated in hard and soft chopping modes are showing in Fig. 2(a) and Fig. 2(b)respectively.

C. Single Pulse Mode

During high speed operation, both switched is turn-on to energized voltage to the phase winding the turn-on angle is between unaligned position and turn-of is before aligned position. The idealized of phase voltage and phase current are shown in Fig.2(c).

IV. DEVELOPMENT OF THE SRM DRIVE SYSTEM

A. Power Converter Circuit Design

The power converter is selected the conventional 2 switched per phase. The switched device is selected IGBT module CM200DY-12NF that manufactured by POWEREX Inc. which is rated 200A/600V.

B. Gate Drive Circuit Design

The gate driving module EXB850 is selected to drive the IGBT, the EXB850 has an over current protection functions. An over current protection signals is connected to PDPI NA and PDPIN B pins of the DSP.

C. Rotor Position Detection

An incremental encoder R137S is selected to detect the rotor position of the SRM. It is installed with the motor shaft. The encoder is generated two square waves, QEP1 and QEP2 and an index signal. The signals from encoder are sending to the CAP unit of the DSP to calculate the phase electrical angles.

D.Phase Current Detection

The phase current detector is selected halls effect current sensor, the L08P150D15 manufactured by TA MURA Corp. was selected as the current sensors which is rated 150A/4V.

V. PROPOSED CONTROL SCHEME OF SRM

To study the behavior of the proposed SRM, the speed control and two-quadrant control scheme are designed. For the speed control, a PI controller has been adopted to provide a quick transient response while starting the SRM. Fig.3. shows a block diagram of speed control scheme.

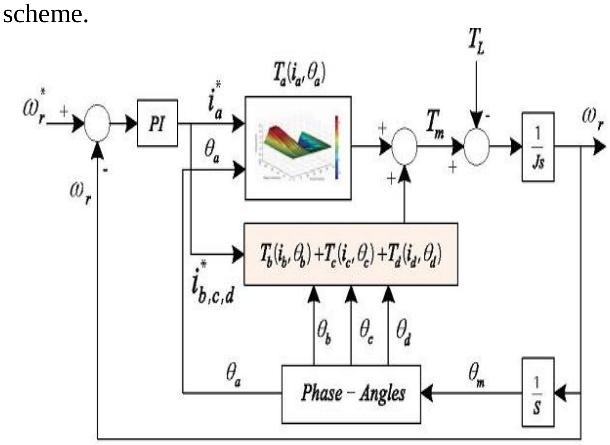

Fig.3. Speed Control Scheme of the SRM.

For the two-quadrant control, a switch mode has been used to select operation mode of the SRM, SW mode1 is control as motoring and SW mode is control as breaking (generating) until rotor speed reduce to zero. Fig.4.Shows a block diagram of speed and two-quadrant control scheme.

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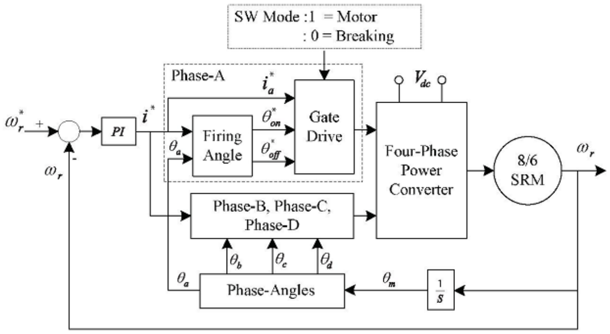

Fig. 4.General block diagram of the speed and two-quadrant control scheme of the SRM.

VI.FUZZY LOGIC CONTROL

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of compensator.

The basic scheme of a fuzzy logic controller is shown in Fig .5. and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

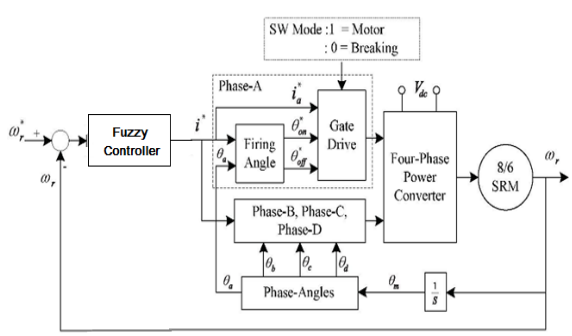

Fig.5.Block diagram of the Fuzzy Logic Controller (FLC) for Proposed Converter.

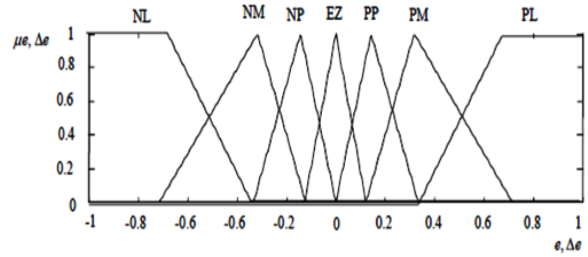

Fig.6. Membership functions for Input, Change in input, Output.

Rule Base:the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table, with '*Vdc*' and '*Vdc-ref*' as inputs

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

VII. MATLAB/SIMULINK RESULTS

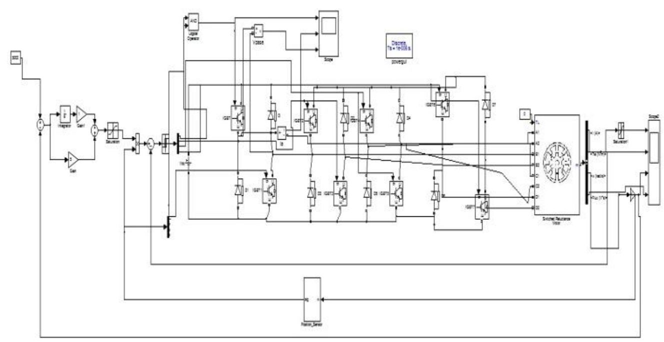

Fig.7.Matlab/Simulink Model of 4 phases SRM with Soft Chopping Mode.

A. N =5000 rpm with PI controller:

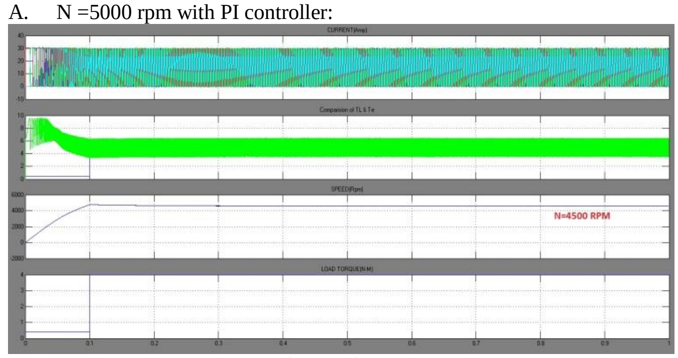

Fig.8. shows the simulated waveforms of current, load torque, speed and Te under 5000 rpm speed using PI controller at full load condition

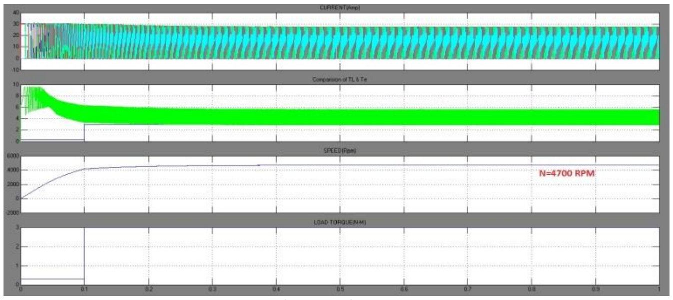

Fig.9. shows the simulated waveforms of current, load torque, speed and Te under 5000 rpm speed using PI controller at 3/4th load condition

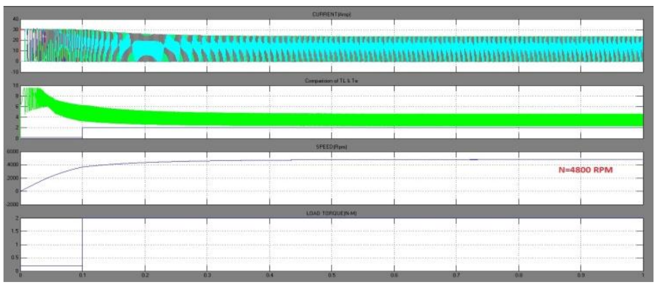

Fig.10. shows the simulated waveforms of current, load torque, speed and Te under 5000 rpm speed using PI controller at half load condition

B. N=3000 rpm with PI controller:

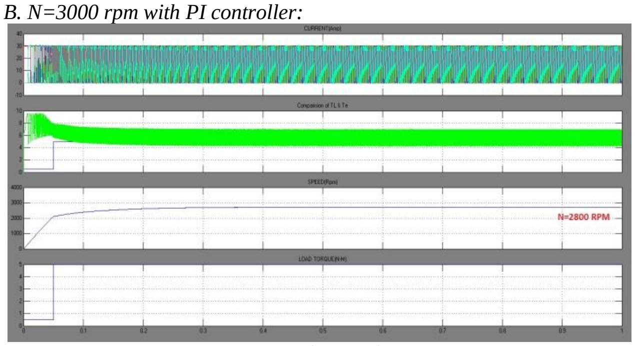

Fig.11. shows the simulated waveforms of current, load torque, speed and Te under 3000 rpm speed using PI controller at full load condition

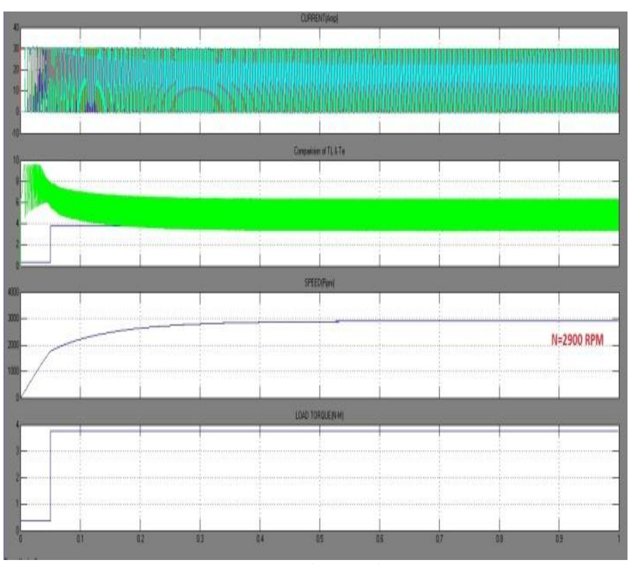

Fig.12. shows the simulated waveforms of current, load torque, speed and Te under 3000 rpm speed using PI controller at 3/4th load condition

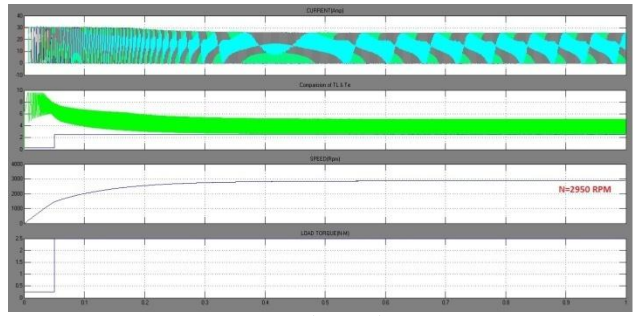

Fig.13. shows the simulated waveforms of current, load torque, speed and Te under 3000 rpm speed using PI controller at half load condition

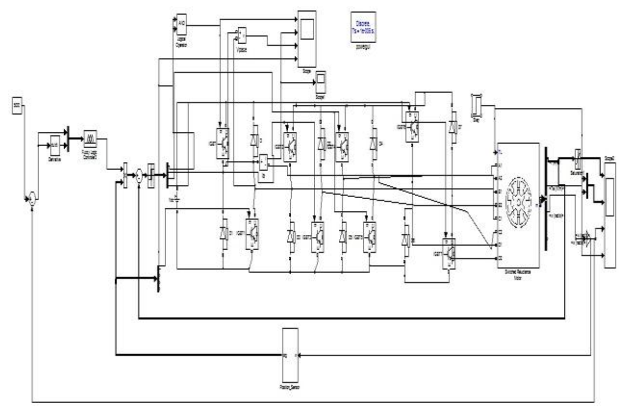

Fig.14.Matlab/Simulink Model of 4 phase SRM with fuzzy logic controller

A.N=5000 rpm with fuzzy logic controller:

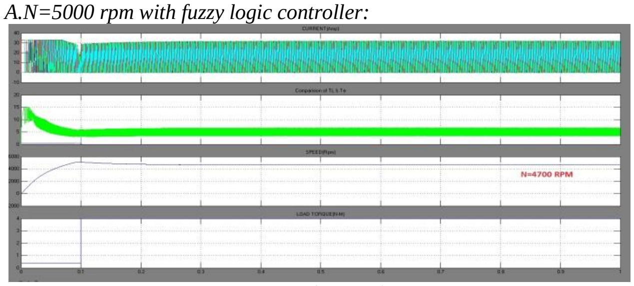

Fig.15. shows the simulated waveforms of current, load torque, speed and Te under 5000 rpm speed using fuzzy controller at full load condition

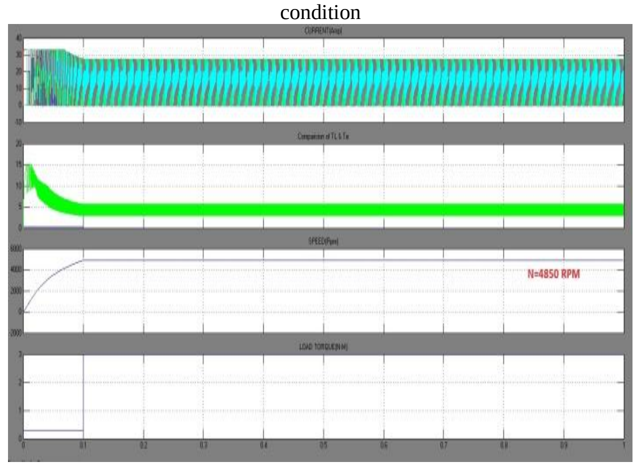

Fig.16. shows the simulated waveforms of current, load torque, speed and Te under 5000 rpm speed using fuzzy controller at 3/4th load condition

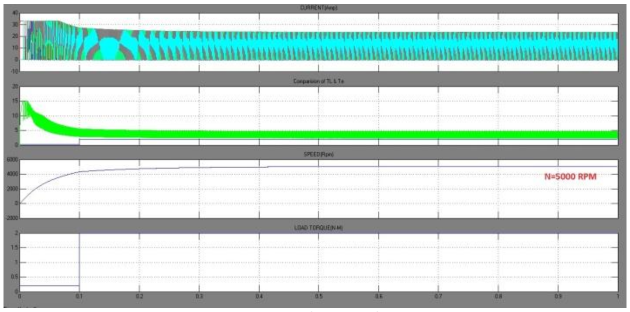

Fig.17. shows the simulated waveforms of current, load torque, speed and Te under 5000 rpm speed using fuzzy controller at half load condition

B. N=3000 rpm with fuzzy logic controller:

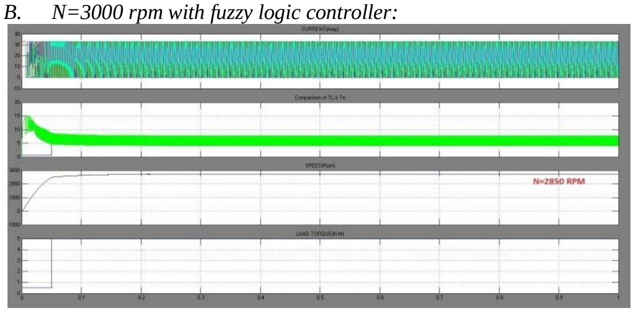

Fig.18. shows the simulated waveforms of current, load torque, speed and Te under 3000 rpm speed using fuzzy controller at full load condition

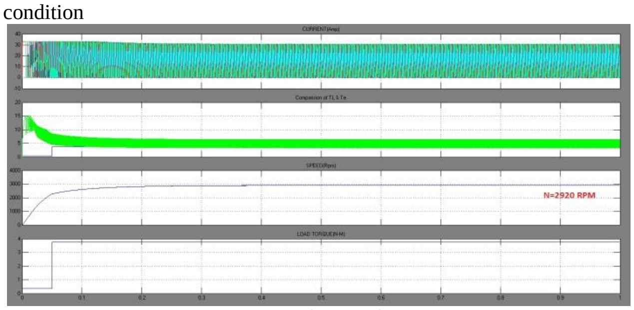

Fig.19. shows the simulated waveforms of current, load torque, speed and Te under 3000 rpm speed using fuzzy controller at $3/4^{th}$ load condition

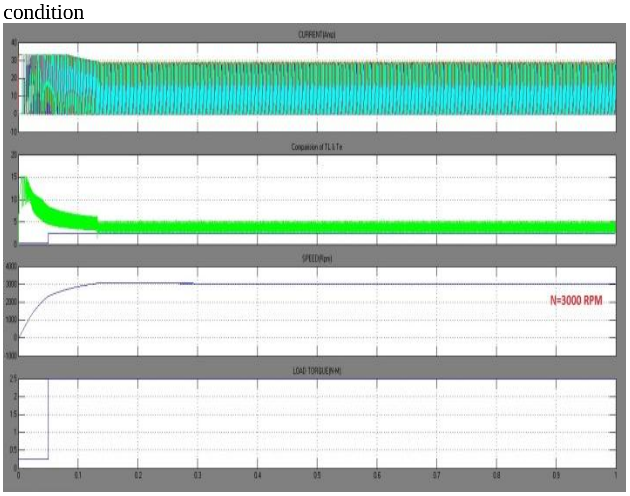

Fig.20. Shows the simulated waveforms of current, load torque, speed and Te under 3000 rpm speed using fuzzy controller at half load condition.

VIII. CONCLUSION

The drive system for a four-phase, 8/6, 3Hp 48V switched reluctance motor have been developed. The proposed control scheme, the speed and two-quadrant controls have been implemented in simulation. The transient responses of the PI speed controllers take time about 22 time Sec. from initial start until steady state. The proposed two-quadrant controllers can control the SRM in both motoring and generating (braking) states. The dynamic performances of SRM are predicted and the model is simulated using MATLAB/simulink environment. The speed control for SRM using Fuzzy logic controller has been design and implemented using both PI and Fuzzy Logic speed Controller. From the simulation results it can be concluded that Fuzzy Logic Controller performs well than PI controller.

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Author's Profile:

KODEM DEVENDRA PRASAD. Received B.Tech from Moghal College of Engineering and Technology Bandlaguda, in the year 2014 and now pursuing M.Tech in the stream of Power Electronics and Electrical Drives at Anurag Group of Institutions (Formerly Known as CVSR College of Engineering), Ghatkesar, Medchal Dist, Telangana. His areas of interests are Electrical Machines, Power Electronics and Power systems.

B. Chandra shekar working as Assistant Professor in Anurag Group of Institutions (Formerly known as CVSR College of Engineering), Jodimetla, Venkatapuram, Ghatkesar (m), Medchal (Dist), Telangana.

B.Tech in EEE - Scient Institute of Technology, M.tech in Power Electronics- ST.Marys College of engineering and Technology, Teaching Experience -9 years. Areas of Interest -Power Electronics, Power systems, Electrical machines & Drives. Published Papers - 3 international Journals till date.