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Analysis of Non-Linear Dynamic Characteristics of Fuzzy-Based SRM Drive for Electric Vehicle Applications

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Abstract:
The Role of Switched Reluctance Motor (SRM) is widespread in all Smart Manufacturing Industries which includes Electric Vehicle applications and Robotics. Even though the SRM has many features torque ripple is the limiting factor. Fuzzy logic Control, a part of an Artificial Intelligence-based approach, is implemented in PID Controller-based SRM Drive. Conventional PID controllers are used to minimize torque ripples only at the steady state. However, a Fuzzy-based PID controller is used to minimize torque ripples in both the dynamic and steady state. The objective of the fuzzy Logic controller here is to compare the reference torque with the actual torque and to determine the Torque ripples in the motor. The torque ripples are eliminated with the help of a PID control action. Fuzzy logic controller Output is given to the Asymmetric type bridge converter so that the current pulses are applied to the SRM. The Mamdani type fuzzy inference system is used and the defuzzification type is the centroid. Torque ripples are minimized with the proposed fuzzy logic controller-based SRM Drive.

Keywords: Switched Reluctance Motor, Torque, Mathematical model, Fuzzy Controller

1. INTRODUCTION

A good option for a number of general-purpose adjustable speed applications is the Switched Reluctance Motor, due to its innotate simplicity, stamina, and affordability. Due to the lack of rotor windings, an SRM has a higher output power and torque inertia ratio than a comparable induction motor. When compared to conventional Motors, an SRM's main drawback is its increased torque ripple, which exacerbates vibration and acoustic noise [4]. The reason for torque ripples in SRM is due to its non linear torque generating characteristics of SRM. The position of stator and rotor poles in SRM with respect to change in inductance and air gap is the root cause for torque ripples. In high performance servo applications, where smooth operation with minimal torque pulsations is required, torque ripple minimization is crucial. An appropriate controller design can boost the Motor's performance.

In Paper [9], The uses of switched resistance motors have grown in the last several years, ranging from high torque e-vehicle applications to control system stepping motors. A lightweight driving motor and high speed operation are necessary for an efficient electric vehicle design. The important criteria for selection of SRM for Electric Vehicle application is its low torque-to-weight ratio and the rotor is free from magnetic field effect. But The biggest problem with switching reluctance motors is the increasing torque ripple. The author applied the optimization method based on the sliding mode controller for torque ripple minimization and provided the comparison between his work with fuzzy logic controller. A MATLAB simulink model is used to simulate and compare the torque ripple magnitude for both controllers.

In Paper [10] synchronous reluctance motor drives (SynRMs) are the most promising devices used in contemporary industries and electric automobiles. As a consequence, further research has been done on novel SynRMs drive systems. The most recent advancements in the design, modeling, and controlling of these technologies are presented in this review article. First, a brief comparison is given between SynRMs and the primary motor technology. The most popular motor control approaches are analyzed and categorized to help researchers choose the right motor controller for their motor drive systems.

In Paper [11], the author implemented the Switched Reluctance Generator for front drive electric vehicles. In order to improve regenerative braking performance of the E-Vehicle, he developed an optimized switched reluctance Generator system for front drive electric vehicles (EVs) powered by switched reluctance motors (SRM) to increase braking performance and regenerative energy. First, braking energy and safety are jointly taken into consideration to create a partition brake force distribution system. The low and high speed conditions serve as the foundation for the SRG drive system model. The mechanic and invigorative braking system models are implemented into the vehicle braking system.

In paper [12], The author proposed a novel method, model predictive controller based Torque sharing function to eliminate the torque ripple in Switched Reluctance Motor (SRM). Flux–linkage characteristics curve used for modeling of the SRM. Genetic algorithm is used to optimize the Torque sharing Function in the commutation region. The role of Model predictive controller (MPC) along with Torque sharing function is implemented to reduce the frequency conversion problem by current hysteresis controller. The author compared the proposed method with direct instantaneous torque control. Through simulation and experiments on three phase SRM drive based on Model predictive controller and Torque sharing Function based current controller the proposed method provided reduced torque ripples and higher efficiency.

In paper [13], Review of switched reluctance motors and different types of controllers incorporated with SRM for eliminating the drawbacks of SRM clearly explained by the author. He highlights the features of SRM and unique controllers for eliminating the non linearity nature of SRM. He emphasized the need for removal of torque ripples and vibration in SRM .

In paper [14], the author developed an Artificial Bee colony Algorithm for minimizing speed error and torque error in Switched Reluctance Motor (SRM) Drive. He designed two PID Controllers for speed error and current error calculation. Through the optimization algorithm the commutation angle of the motor is adjusted to reduce the torque ripples in the motor. For tuning the gain of two PID controllers and commutation angles of the converter circuit Multi objective function is developed in ABC algorithm. The effectiveness of the proposed controller algorithm is realized with the help of Matlab Simulink platform.

In paper [15], In order to eliminate the torque pulsations in SRM Particle swarm optimization approach implemented in SRM Drive. The objective of this Multi objective PSO is for speed control and reduced Torque. It can be achieved with the help of a fuzzy controller based PID Controller. Assessment of average output torque from the controller is compared with conventional PID Controller. Validation of the proposed controller is carried out on Hardware bed consist of 6/4 SRM.

There are so many algorithms and Controllers has been developed to minimize torque ripple in SRM [9-12]. Each and every algorithm has its own advantages and disadvantages also. This paper will provide the analysis of Torque ripple minimization under dynamic conditions using Fuzzy Logic Controller based PID Controller.

2. BASIC CONCEPTS OF SRM

A salient pole structure is present on both the stator and rotor of the switched Reluctance Motor. Every stator pole has a concentrated winding that receives the motor excitation, while the rotor is a passive laminated steel structure. The torque generation from the SRM is based on the stator poles which are diametrically opposite to each other and it is aligned with the rotor poles. Under this condition Torque is generated from the motor. In order to achieve a constant torque, even if there is a difference between stator and rotor poles, consecutive switching of excitation from stator poles in coordination with rotor poles. The simultaneous excitation of stair poles aligned with the rotor incorporated with the help of rotor feedback. The variation of Inductance L of the stator winding is based on the alignment of rotor and stator poles with reluctance of air gap. If the stator and rotor poles are at aligned condition with varying reluctance, maximum value of Inductance received and at the unaligned condition of stator and rotor poles with varying reluctance airgap Minimum inductance profile is generated. At any instant The key factor for the inductance value of the SRM is based on excitation current i, and rotor position θ.

3. TORQUE GENERATION

The phase windings of both the rotor and stator of SRM are provided with steel laminations. The torque from the motor is based on the magnetomotive force to the magnetic flux. Irrespective of the direction of current flow in the circuit, the Torque is based on the minimum reluctance path in the magnetic circuit. In either way rotation of the motor is possible due to the Sequential alignment of the stator and rotor energization phases.[3]

The torque in terms of co-energy is given by

$T_{total}(\theta, i) = \Sigma T_{phase}(\theta, i)$

The co energy can be calculated from

$$W^1 = \int_0^i \psi(\theta, i)\, di \quad (1)$$

Assuming the magnitude circuit to be linear, the equation for torque can be written as

$$T(\theta, i) = \Sigma \tfrac{1}{2} i^2 (dl/d\theta) \quad (2)$$

The torque generated from the motor is classified as two types i). Motoring torque and ii).breaking torque. Motoring torque is due to synchronization of phase excitation currents with rising inductance. braking torque is due to sequential excitation of phase currents alongside decreasing inductance. The deciding factor for the direction of torque is based on the value of change in inductance with respect to rotor position and it is not based on current path.

With respect to the alignment of stator and rotor poles, torque generated as follows

Positive or motoring torque is generated if the stator and rotor windings of SRM are in aligned position. Misalignment of stair and rotor poles lead to Negative or breaking torque. Fig. 1 exhibits the phase current profile of braking torque.

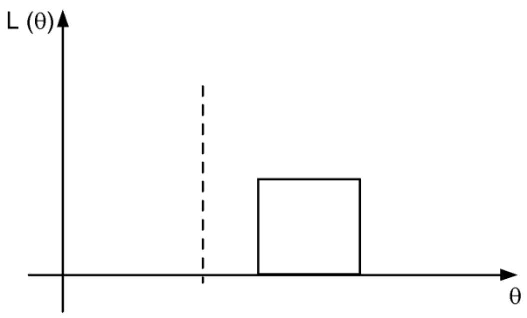

Fig. 1. Phase current for braking torque

Fig. 2 shows the basic block diagram used for modeling and simulation of SRM. The position of the motor is obtained from the encoder or position sensor. From the position, the speed is calculated. Using this speed and the reference speed, the error signal is obtained from the comparator and along with this error signal, the position is fed into the controller which produces the gating pulses for the semiconductor devices of the converter circuit. The phase windings of the motor are excited accordingly. Thus the speed of the motor can be controlled by controlling the gating pulses.

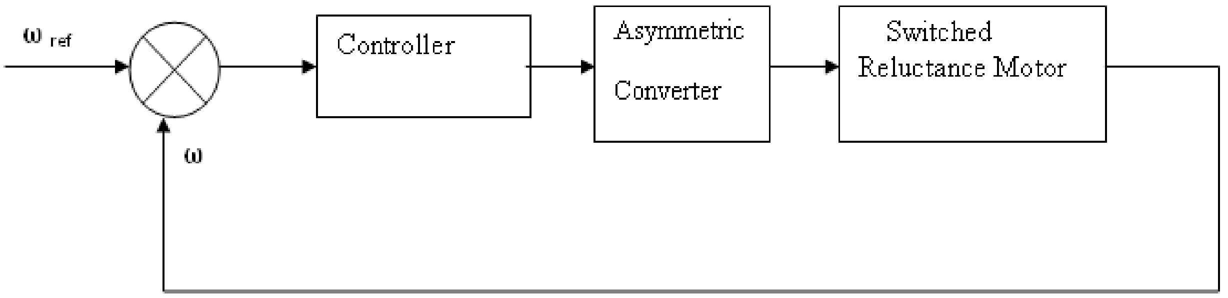

Fig.2 Block Diagram of SRM Drive

Steps in modeling and simulation

The following are the main steps for simulation and analysis of Switched Reluctance Motor in MATLAB.

1. Mathematical Modeling

Representation of the Motor using Block Diagrams

Analysis of results using MATLAB/ Simulink

4. MATHEMATICAL MODELING

The various equations involved in linear modeling of a Switched Reluctance Motor [6,7] are as follows:

Voltage equation of each phase is given as equation (1) and the

$$\frac{d\psi(\theta, I_i)}{dx} + RI_i = Vwithi = \{1,2,3,4\} \quad (2)$$

Flux equation is given in equation (2)

$$\psi i(\theta, Ii) = L(\theta) Ii \quad (3)$$

Motor total torque is calculated using equation (3)

$$T = \frac{1}{2}\sum_{i=0}^{4} \frac{dL(\theta + n - i - 1)\theta_s}{d\theta} i^2 \quad \text{-----} (4)$$

Mathematical equations used in this model are incorporated in the simulink block diagram and the dynamic characteristics of the motor are examined through the simulation output.

The block diagram consists of many subsystems which are combined together to model the Motor. The block diagram in fig. 3 shows the interfacing of 6/4 SRM system with the converter circuit which energizes the phase windings of the motor. The gating pulses are given to the semiconductor devices based on speed of the motor which turn them ON sequentially and corresponding phases are excited.

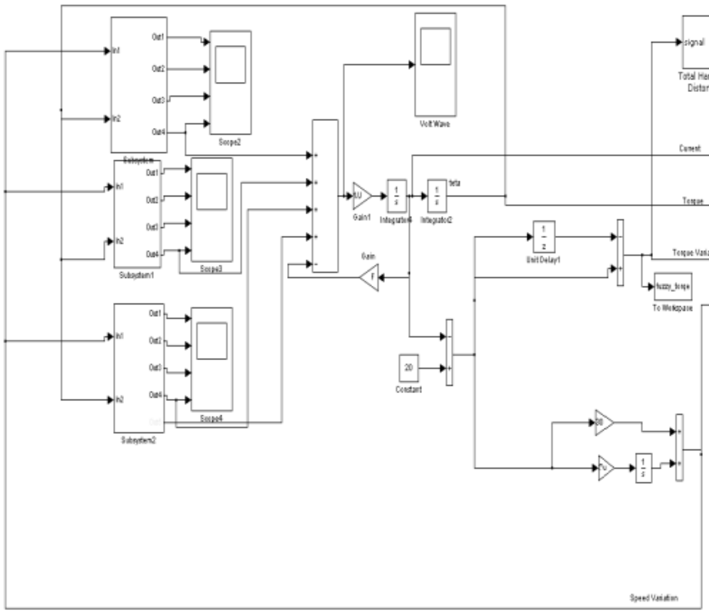

Fig.3 MATLAB simulink diagram for Fuzzy based SRM Drive

5. ANALYSIS OF RESULTS

The various waveforms obtained during the simulation of non linear modeling of SRM are shown in Fig.4. In linear analysis the inductance profile of the Motor is assumed to be linear and the corresponding current, torque and speed waveforms are obtained in Fig. 5.

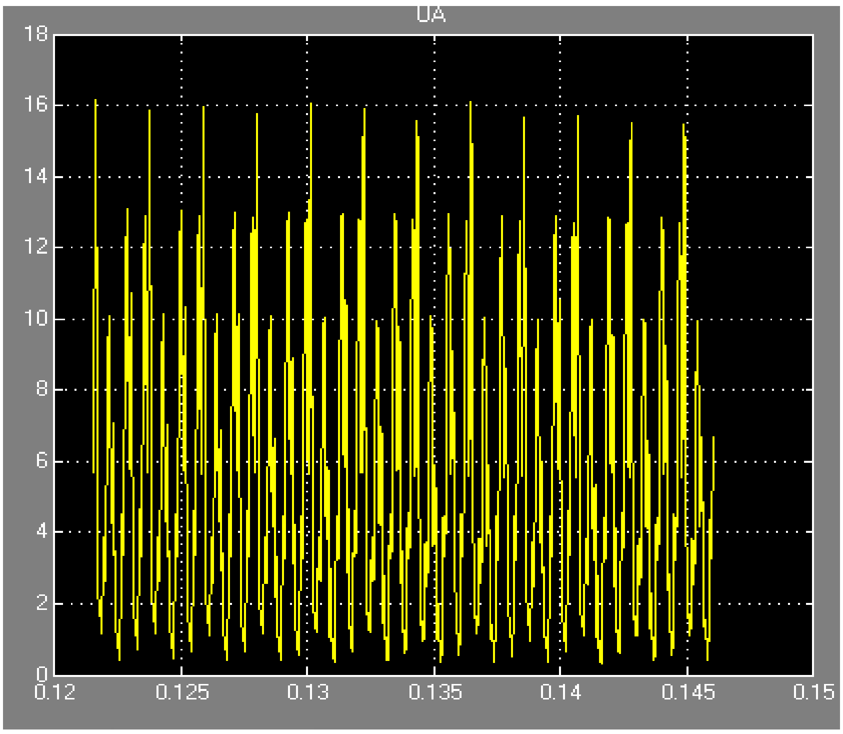

Fig.4 Torque ripple waveform of SRM Drive

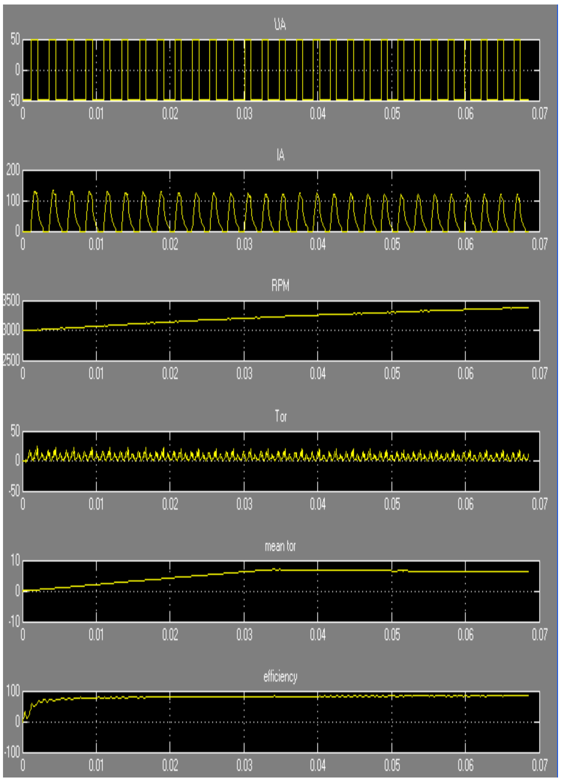

Fig 5. Output response of SRM Drive

6. PROPOSED FLC FOR SRM DRIVE

Based on the schematic of SRM. here the rated torque value with instant torque is compared in the comparator. Mamdani type fuzzy inference engine is used for the fuzzification process. The input variables are converted into crisp values using Gaussian fuzzy membership function.PID controller is implemented in the fuzzy logic by using 49 rule bases. Depending upon the error value corresponding rule base is fired and control signal is generated. defuzzification is carried out using centroid method using trapezoidal membership function. The output from the fuzzy based PID controller is given to asymmetric converter in which the current excitation given to the SRM is controlled depending upon the input from the fuzzy controller. The result of this Fuzzy based SRM Drive is addition on the Proportional Integral (PI) based Fuzzy logic and derivatives of the error signal.

In this Paper through the investigation of energetic characteristics of Switched reluctance motor, torque ripples are identified by using MATLAB/ Simulink. Various hybrid controllers are designed for SRM torque ripple minimization. Among these types Fuzzy Logic controller provides the high speed of response and efficiency compared to the conventional controllers.

7. SIMULATION AND RESULTS

The component models are constructed by using M-file functions in MATLAB for supplying initial control parameters to SIMULINK model. Using M- file coding sample speed of the SRM is given in the PID controller and Fuzzy Logic controller. Through the results we identified that the Conventional PID controller requires more iterations to reach the steady state compared to the FLC.

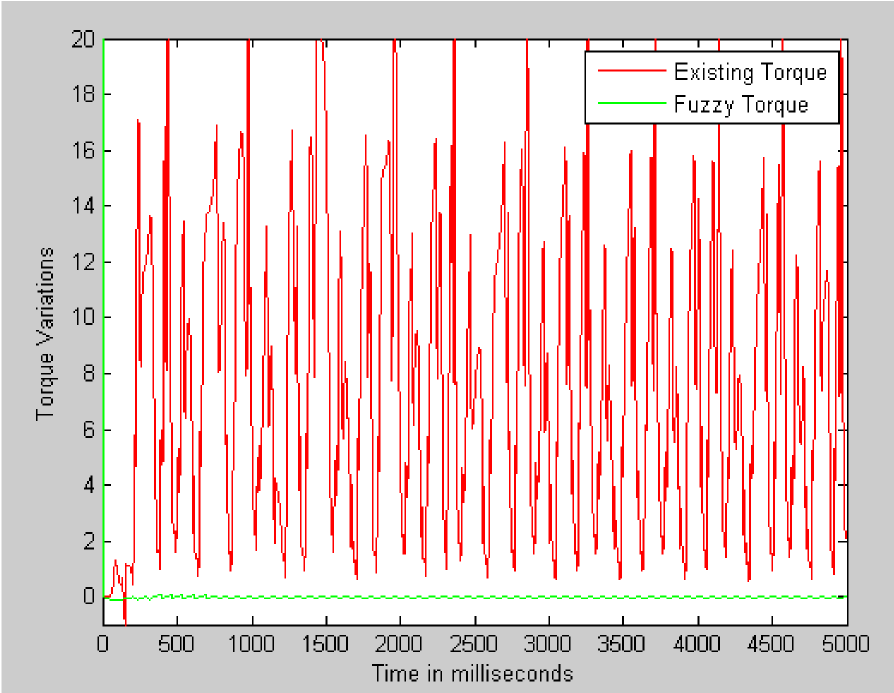

Fig.6 Comparison between torque variations in conventional and Fuzzy Based SRM Control drive

The results of fuzzy based SRM Drive and comparison between the Total Harmonic distortion of conventional and fuzzy based SRM drive is discussed. From the results obtained from simulation, it was found that the torque ripples are minimized upto the minimum level by using Fuzzy based SRM Drive.

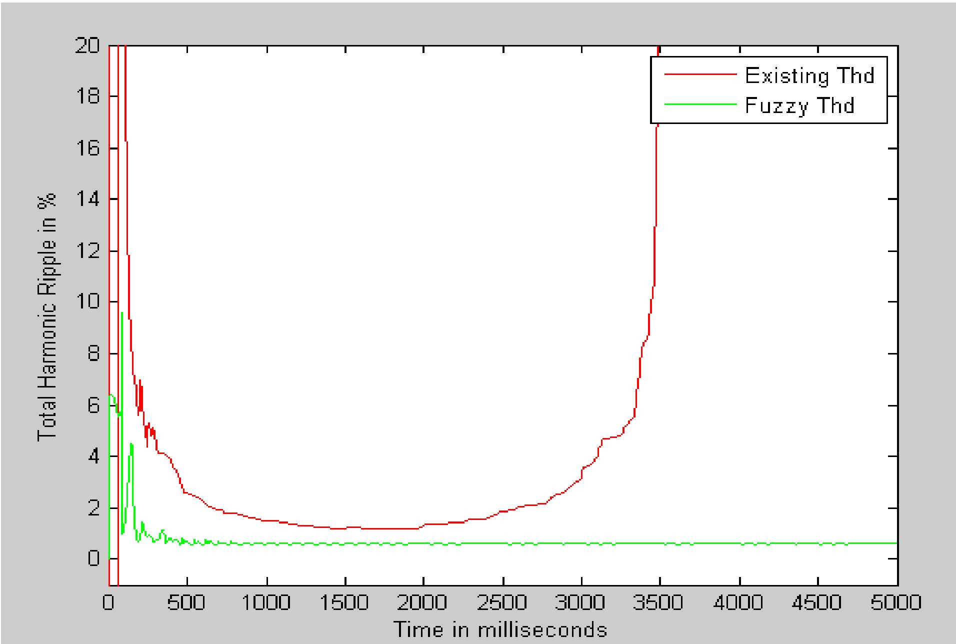

Fig.7 Comparison between Total Harmonic Distortion (THD) of conventional and Fuzzy Based SRM Control drive

Fig. 8 shows the response of fuzzy based SRM Drive in terms of current excitation, Motor Speed and Torque parameters.

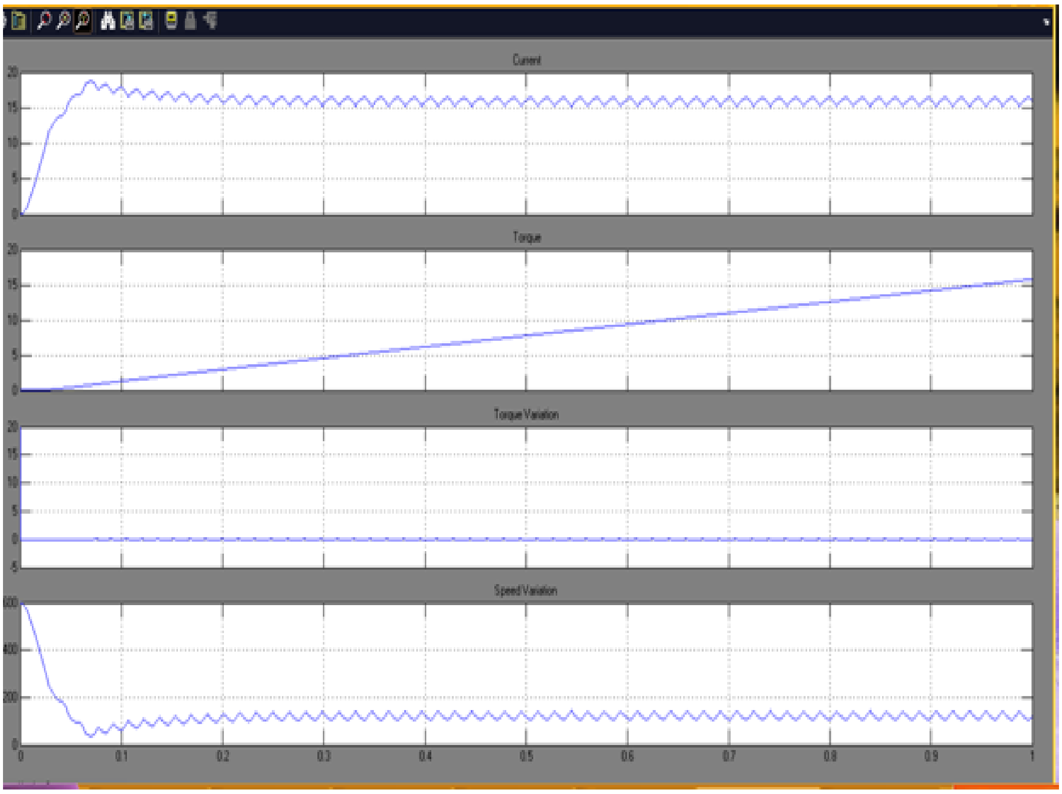

Fig. 8 Response of Fuzzy-basedi SRM Drive

8. CONCLUSION

This paper uses mathematical modeling of the switching reluctance motor to study the dynamic features of the SRM. First the SRM characteristics are analyzed by using mathematical modeling.SRM modeling in simulink environment is done by using M file coding. By using simulink, other parts of the SRM drive are constructed and it is connected to the SRM. Through this analysis, torque ripples are found out. Torque ripples are minimized by using Fuzzy based SRM Drive. The result from the fuzzy logic controller is given to the Asymmetric converter. Efficiency of the SRM is calculated and it is regulated using closed loop Fuzzy based PID control of PWM technique.

9. SCOPE FOR FURTHER WORK

Switched reluctance motor torque ripples are identified Through Dynamic characteristics of SRM and minimized by using the Fuzzy logic controller in the MATLAB Simulink environment. Further there is scope for torque ripple minimization and prediction by using Artificial intelligence controllers so the motor performance will be enhanced.

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