Matlab Simulink Implementation of Switched Reluctance Motor with Direct Torque Control Technique

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Abstract - **The switched reluctance motor is one of the types of electrical machines. This type motor receives considerable response from industries in last decades due to high torque, high reliability and inexpensive manufacturing cost. But the main drawback of switched reluctance motor is large torque ripple. This produces vibration and noise in the motor. Therefore in order to overcome that problem the direct torque control technique is implemented. Due to this DTC technique the output torque of the switched reluctance motor can be regulated within the hysteresis band. This paper describes the mathematical model of SRM motor and direct torque control technique. In addition to this the simulink model of switched reluctance motor with direct torque control technique is designed and tested through MATLAB/Simulink software. The parameters like speed and torque are represented graphically.**

Keywords - **SRM Motor, Direct Torque Control, Switched Reluctance Motor, DTC Technique.**
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I. INTRODUCTION

The switched reluctance motor rugged in construction therefore it can be suitable for vibrating and high temperature zone. The torque produced by the switched reluctance motor is not dependent of phase currents polarity. Therefore the less number of semiconductor switches are used in the power converters. In addition to this the loss occurred in the SRM motor is from the stator only. Hence it can be cooled easily.

The switched reluctance motor are mainly used in electric vehicles, vacuums cleaner, washing machine, servo type and variable speed applications. The switched reluctance motor simulink model consists of three main blocks. They are position sensor block, converter block and switched reluctance block. The position sensor block consists of a position sensor which is linked to the rotor of switched reluctance motor. Hence the turn-on and turn-off angles of the switched reluctance motor phases can be measured accurately. To control the developed torque switching angles are used. At the same time the measured current and reference current are compared to generate drive signal for insulated gate bipolar transistor. Hence the hysteresis controller controls the currents independently. The converter block consists of three legs and each leg consists of two insulated gate bipolar transistor and two FW diodes. R Krishnan has presented the detailed switched reluctance motor drive modeling, simulation, analysis, design and applications [1].

II. CONSTRUCTION AND WORKING PRINCIPLE OF SWITCHED RELUCTANCE MOTOR

Actually in electrical machines the switched reluctance motor is the simplest one when compare to other electrical machines. Construction wise there is no permanent magnet or conductors in the rotor of switched reluctance motor. The rotor of switched reluctance motor consists of steel lamination stacked on to a shaft. In addition to this the cost of motor is low due to simple mechanical construction. T. J. E. Miller has explained the Switched Reluctance Motors and their Control techniques [2].

The Figure [1] shows the cross sectional view of a switched reluctance motor. From figure [1] we can see the 6/4 pole arrangement. That is the stator and rotor poles of switched reluctance motor. Three phase supply is given to the 6/4 switched reluctance.
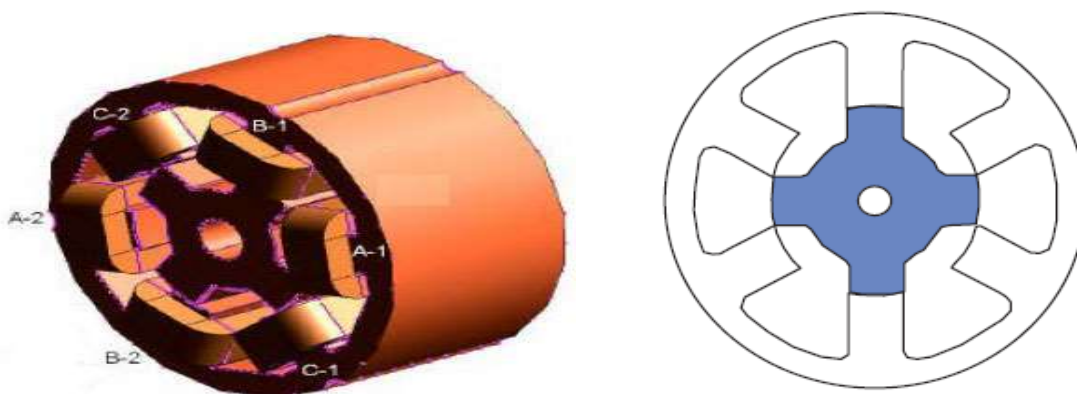

Figure.1 6/4 Three phase SRM motor

On the basis of torque production the electrical machine are classified in to two types. Therefore the one way of torque production is due to electromagnet and the other way of torque production is due to variable reluctance. In switched reluctance motor the torque is produced due to variable reluctance. Hence it is known as switched reluctance motor.

The main principle of SRM motor is to give rise to minimum magnetic reluctance in order to form a stable equilibrium position in electromagnetic system. The nearest rotor poles are attached towards each other. At the time two diametrically opposite poles are excited to produce torque. But de-energize takes place when two rotor poles gets aligned with the stator pole. Now the adjacent stator pole gets energized to attract another pair of rotor poles. The aligned position is nothing but when the rotor poles and the stator poles get aligned in a certain position. At this time the la reaches maximum value. So as reluctance reaches minimum value. Once the L_a value decreases gradually then the rotor poles move away from its aligned position and reluctance value reaches minimum value. Since the L_a value decreases gradually the rotor poles moves away from its aligned position. At a certain point the rotor poles moves to a complete unaligned position from stator poles. At that moment phase inductance value reaches minimum value L_u and reluctance reaches maximum value.
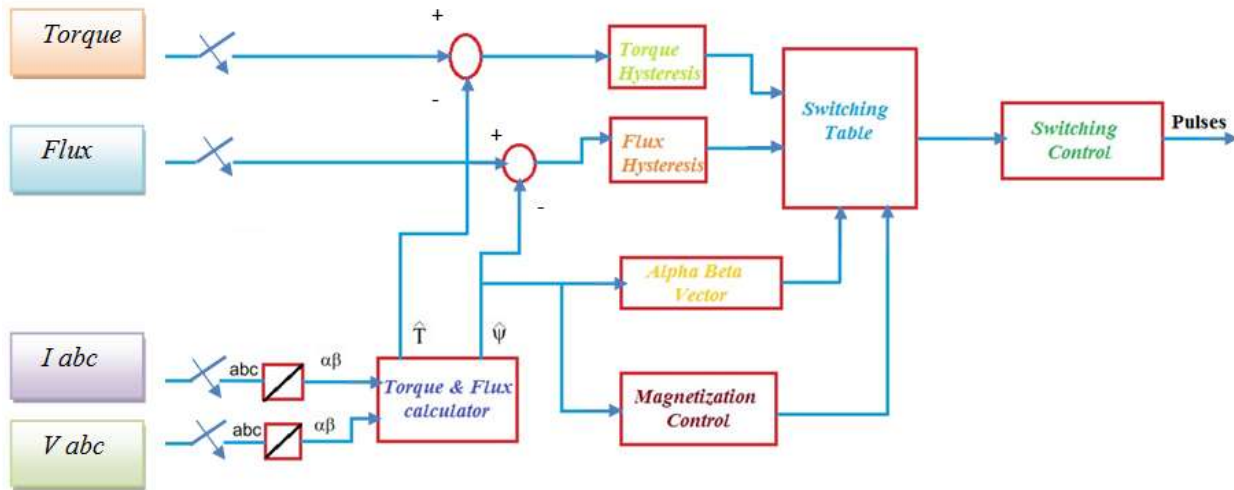

Figure.2. Block diagram of DTC technique

The torque flux calculator block is used to estimate flux components {alpha and beta} and electromagnetic torque. Based on motor equations the estimations are done. The vector block is used to find the alpha and beta. The hysteresis control block is used to control flux and torque. Then from the look table which is present inside the switching table block will select the specific voltage vector. The inverter commutation frequency is limited in the switching control block.

III. MATHEMATICAL MODEL OF SWITCHED RELUCTANCE MOTOR

The numerical and analytical modeling of switched reluctance machine has been explained clearly by Zhang zhihui and Somesan Liviu [3-4]. A New Torque and Flux Control Method for Switched Reluctance Motor Drives have been developed by A. D. Cheok [5]. S Mir designed the Torque Ripple Minimization in Switched Reluctance Motors Using Adaptive Fuzzy Control model [6].

Mathematical equations for switched reluctance motor:

$$V = R_s I + \frac{d\psi\{\theta, I\}}{dt} \rightarrow Equation\{1\}$$

R_s=Resistance / phase

ψ = flux linkage / phase

$$\psi = L\{\theta, I\}I \rightarrow Equation\{2\}$$

L=Mutual inductance {depends on rotor position and phase current}

Phase Voltage equations,

$$V = R_s I + \frac{d\{L(\theta, I)I\}}{dt} \rightarrow Equation\{3\}$$

$$V = R_s I + L\{\theta, I\}\frac{dI}{dt} + I\frac{d\theta}{dt}\frac{d_L\{L(\theta, I)\}}{d\theta} \rightarrow Equation\{4\}$$

$$V = R_s I + L\{\theta, I\}\frac{dI}{dt} + \frac{d_L(\theta, I)}{d\theta}\omega_m I \rightarrow Equation\{5\}$$

$$e = \frac{d_L(\theta, I)}{d\theta}\omega_m I = K_b \omega_m I \rightarrow Equation\{6\}$$

$$K_b = \frac{d_L(\theta, I)}{d\theta} \rightarrow Equation\{7\}$$

Instantaneous input power is the sum of winding resistance loss, rate of change of field energy and air gap power. Therefore the instantaneous input power can be written as,

$$P_I = VI = R_s I^2 + I^2 \frac{dL\{\theta, I\}}{dt} + L\{\theta, I\}I \frac{dI}{dt} \rightarrow Equation\{8\}$$

$$Time, t = \frac{\theta}{\omega_m} \rightarrow Equation\{9\}$$

Air gap power equations,

$$P_a = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{dt} \rightarrow Equation\{10\}$$

$$P_a = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{d\theta} \frac{d\theta}{dt} \rightarrow Equation\{11\}$$

$$P_a = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{d\theta} \omega_m \rightarrow Equation\{12\}$$

$$P_a = \omega_m T_e \rightarrow Equation\{13\}$$

By equating the equations 12 and 13 we get torque {T_e},

$$T_e = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{d\theta} \rightarrow Equation\{14\}$$

Mathematical equations for direct torque control technique:

$$T_e = \frac{3}{2} \left\{ \frac{P}{2} \right\} \frac{L_m}{L_s' L_r} \overline{\psi_s} * \overline{\psi_r} \rightarrow Equation\{15\}$$

$$T_e = \frac{3}{2} \left\{ \frac{P}{2} \right\} \frac{L_m}{L_s' L_r} \psi_s \psi_r \sin \gamma \rightarrow Equation\{16\}$$

The stator flux assessment is done on the basis of stator voltage model and current model. The equation 17, 18 and 19 represents stator voltage equations. In case of current model equation 20 and 21 are used.

$$\psi_{ds}{}^s = \int \left\{ V_{ds}{}^s - i_{ds}{}^s R_s \right\} dt \rightarrow Equation\{17\}$$

$$\psi_{qs}{}^s = \int \left\{ V_{qs}{}^s - i_{qs}{}^s R_s \right\} dt \rightarrow Equation\{18\}$$

$$\psi_s = \sqrt{\psi^s{}_{ds}{}^2 + \psi^s{}_{qs}{}^2} \rightarrow Equation\{19\}$$

$$\frac{d}{dt} \overline{\psi_r} = \left\{ \frac{\{L_m i_s - \psi_r\}}{T_r} - \omega_r \psi_r \right\} \rightarrow Equation\{20\}$$

$$\overline{\psi_s} = \left\{ \frac{L_m}{L_r} \psi_r + \sigma L_s i_s \right\} \rightarrow Equation\{21\}$$

IV. SIMULATION MODEL OF SWITCHED RELUCTANCE MOTOR WITH DIRECT TORQUE CONTROL TECHNIQUE

In the MATLAB simulation of switched reluctance motor the following specification are used: Number of phases = 3, Number of stator and rotor poles = 6/4, Frequency [F] = 50 Hz, DC supply voltage [Vdc] = 240 volts, Turn on and off angle = 45 deg and 75 deg respectively, Reference current = 200 amps, Hysteresis band = +10, -10. Friction = 0.01 N-M s, Stator resistance [Rr] = 0.01 ohms/phase, Moment of inertia [J] = 0.0082 Kg-m/sec, Unaligned inductance = 0.7 m H, Aligned Inductance = 20 m H. The simulation of a 6/4 switched reluctance motor based on MATLAB/Simulink environment has clearly presented by F Soares and C Branco [7].
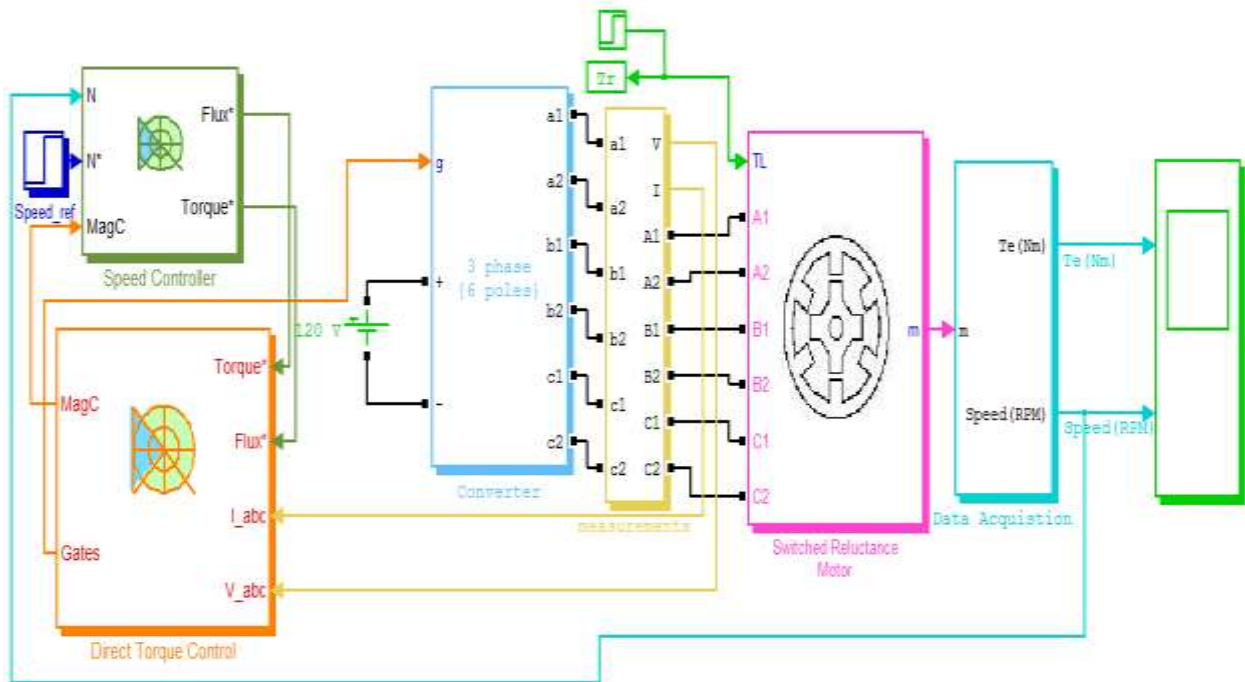
Figure.3 MATLAB simulink model of switched reluctance motor with DTC technique
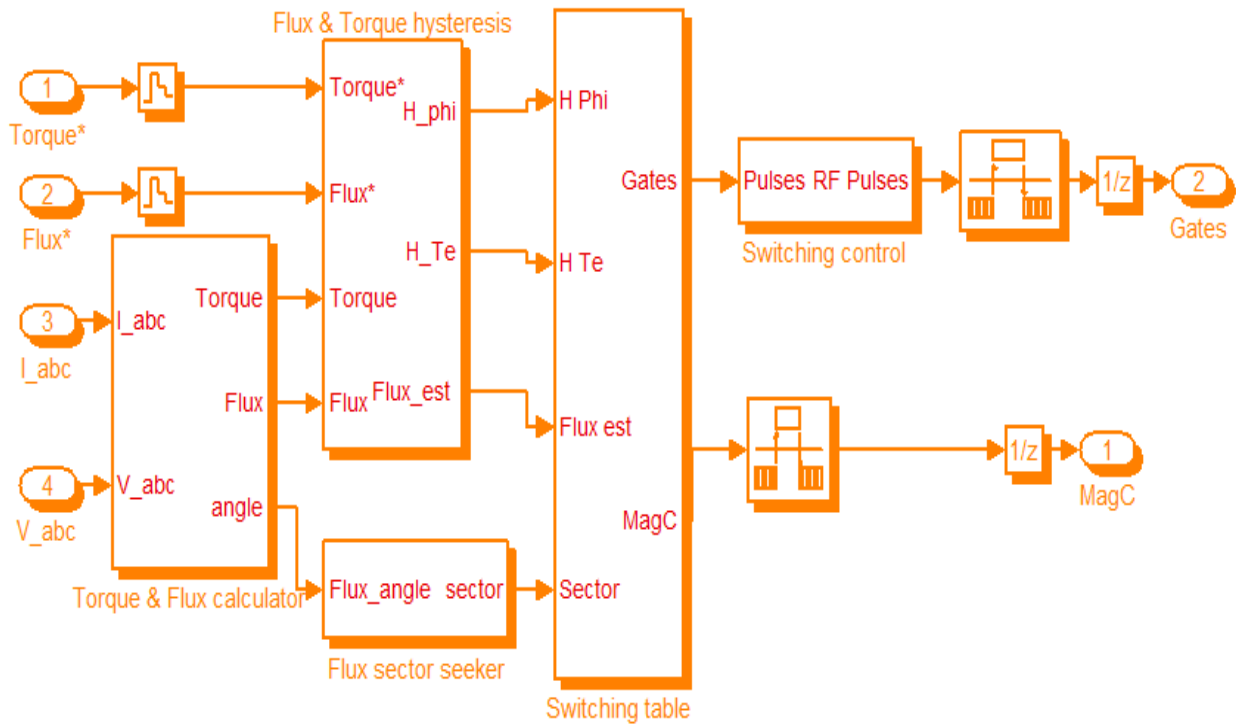

Figure.4 MATLAB simulink subsystem model of direct torque control block
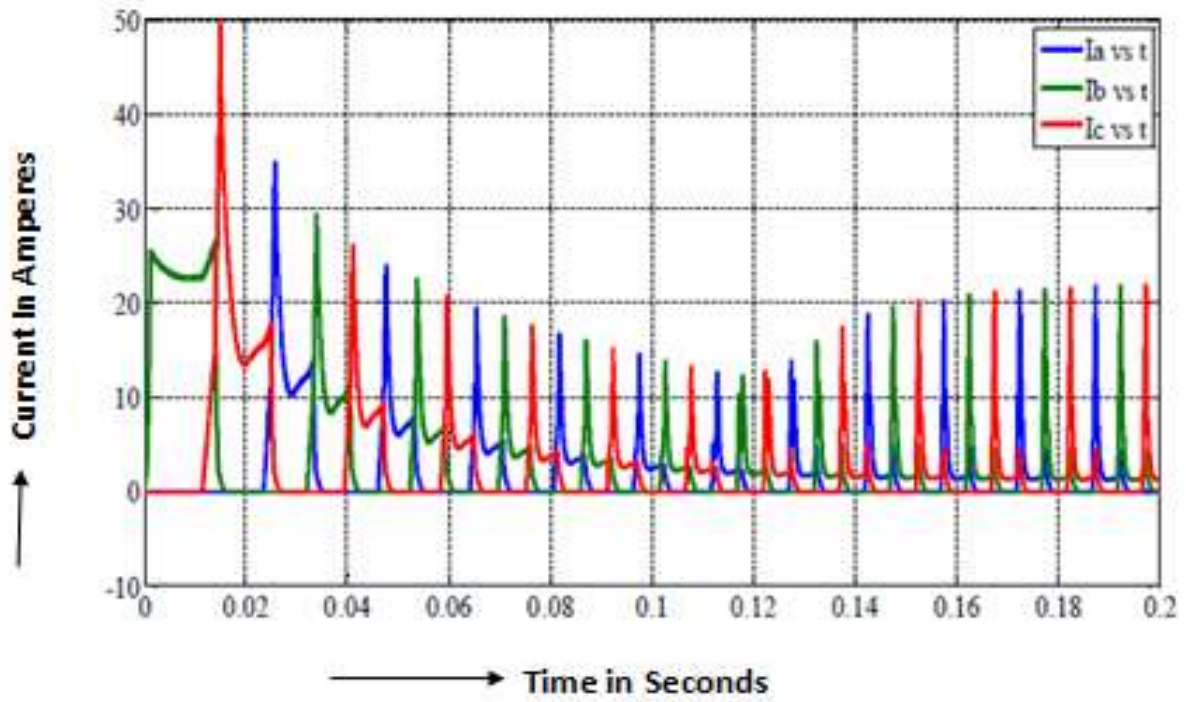
V. SIMULATION RESULTS
[A] Current
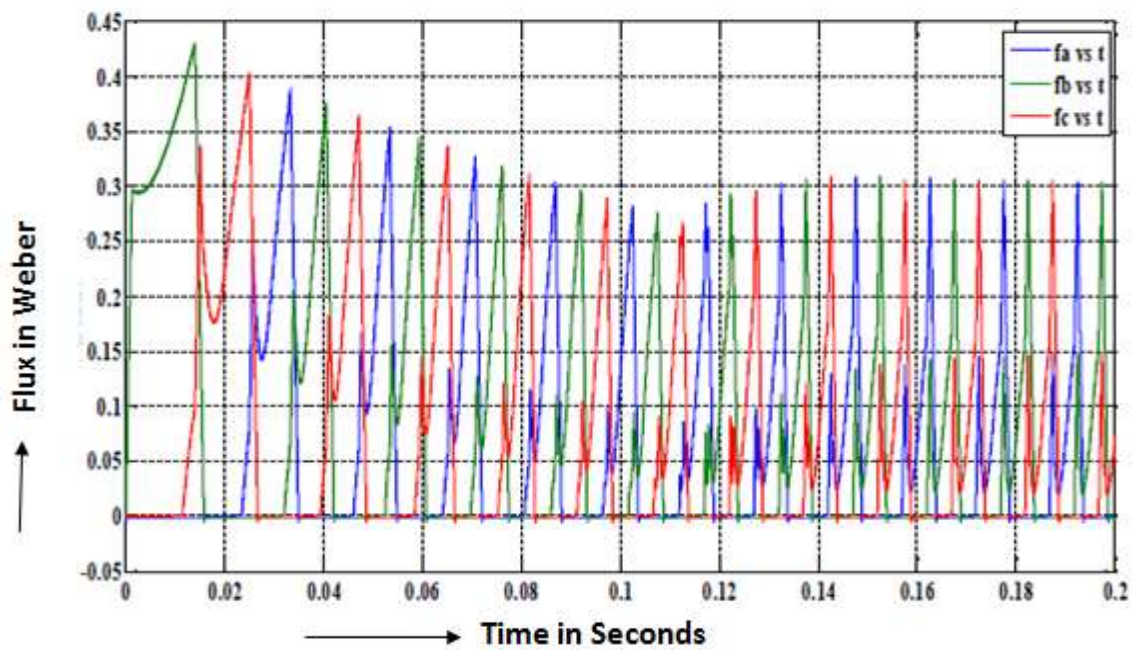
Figure.5. Current in Ampere

[B] Flux

Figure.6 Flux in Weber
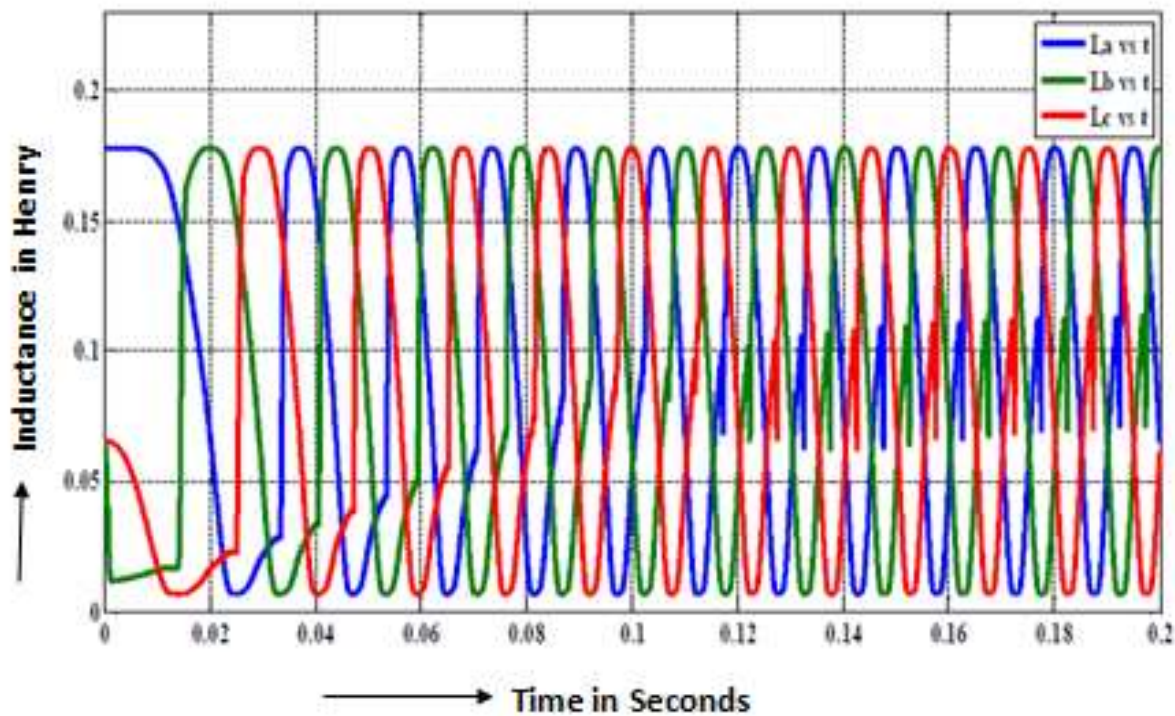
[C]Inductance

Figure.7 Inductance in Henry
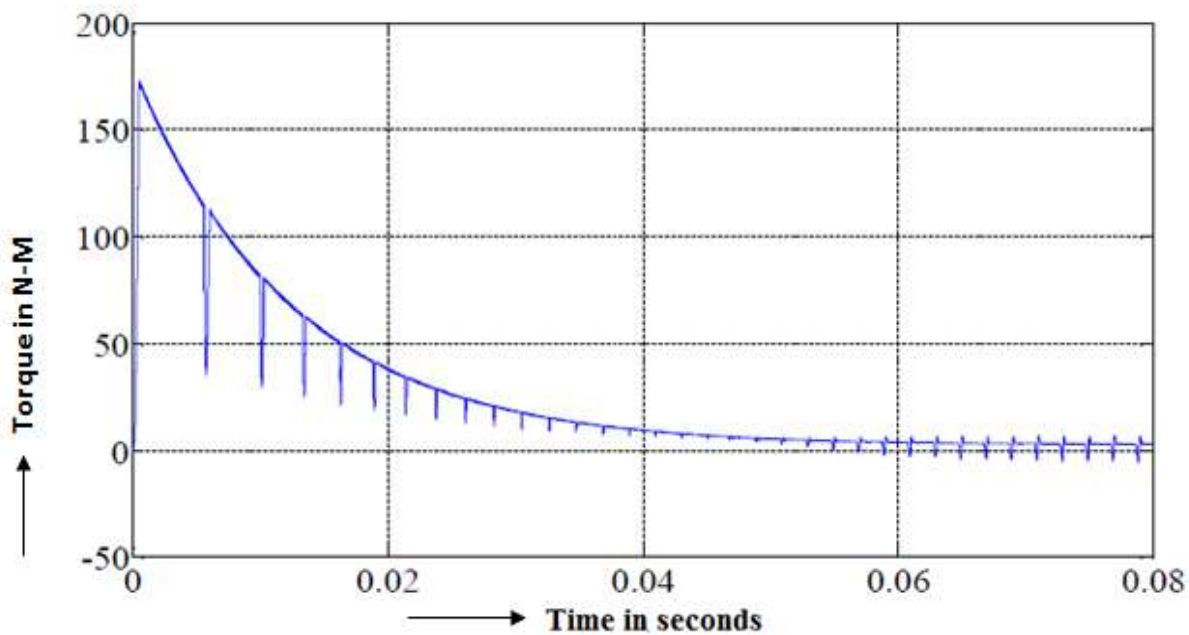
[D] Torque

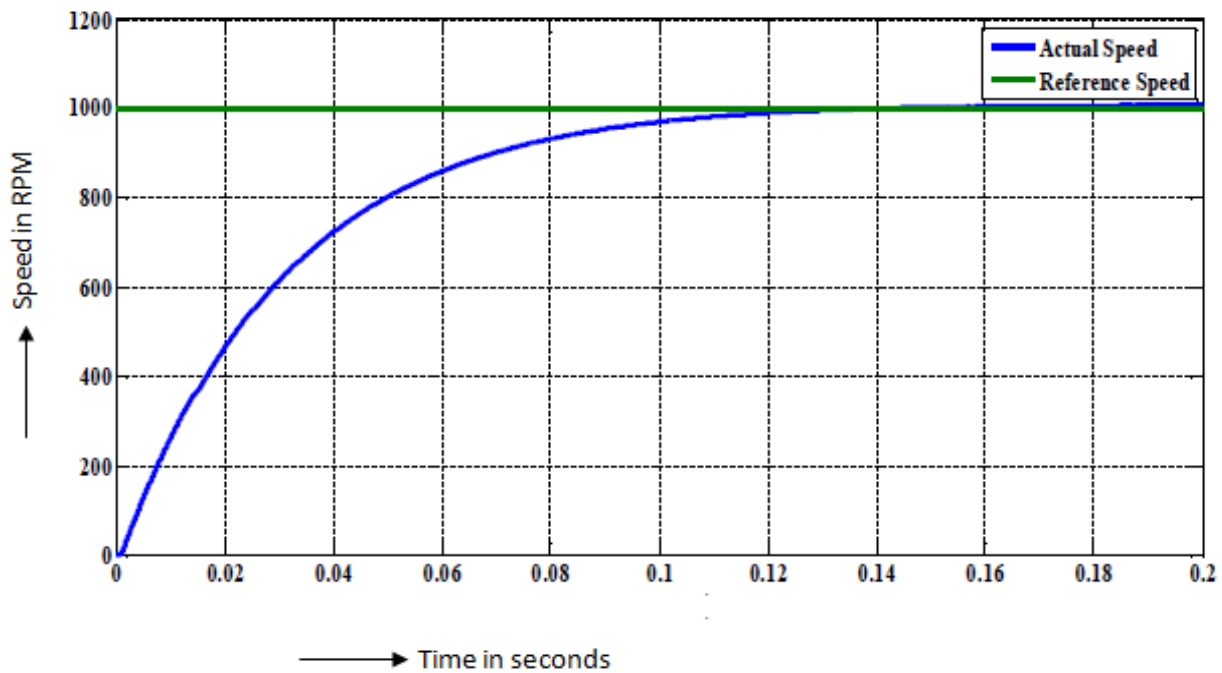Figure.8 Torque in Newton-Meter

[E] Speed

Figure.9 Speed in Revolution per Minutes

From Figure [8] it is observed that the torque is directly proportional to the square of current, therefore the torque of the switched reluctance motor is independent of current direction but it depends on $\dfrac{dL}{d\theta}$ value. If this value is positive then the torque of switched reluctance motor is also positive. In case if it is negative then torque of the switched reluctance motor is negative. But this torque contains lot of noise and harmonics.

VI. CONCLUSION

The switched reluctance motor are mainly used in electric vehicles, vacuums cleaner, washing machine, servo type and variable speed applications. The switched reluctance motor gives high performance in harsh conditions like dusty environment and high temperature. In this research paper switched reluctance motor model with direct torque control is designed through MATLAB software and also tested successfully by presenting the torque and speed values graphically. The potential of switched reluctance motor is highly greater particularly in motion control.

VII. REFERENCES

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VIII. BIOGRAPHY

Mr.J.Vikramarajan received his Master degree in Power Electronics and Drives and Bachelor degree in Electrical and Electronics Engineering from VIT University, India. He has published several international research books and journals. His research interests are electrical machines, power electronic applications, power quality, power electronic converters and power electronic controllers for renewable energy systems.