PERFORMANCE ANALYSIS OF SWITCHED RELUCTANCE MOTOR; DESIGN, MODELING AND SIMULATION OF 8/6 SWITCHED RELUCTANCE MOTOR

Vikas S. Wadnerkar * **Dr. G. TulasiRam Das **** **Dr. A.D.Rajkumar *****

*Mr. Vikas S Wadnerkar is with Essar steel, Hazira, Surat as a Faculty Electrical Engineering and
**Dr. G. Tulasi Ram Das with JNTU College of Engineering , Hyderabad and
***Dr. Rajkumar are with College of Engineering, Osmania University, Hyderabad.

ABSTRACT

The Switched reluctance Motor (SRM) is an old member of the Electric Machines Family. Its simple structure, ruggedness and inexpensive manufacturing capability make it more attractive for Industrial applications. However these merits are overshadowed by its inherent high torque ripple, acoustic noise and difficulty to control. In this work Design, modeling, simulation and analysis of Switched Reluctance motor has been done. Various models of Switched reluctance Motor Linear and nonlinear model with different control strategies are simulated in MATLAB/SIMULINK. The control strategies used are PI Control, Hysteresis Control and voltage control. The result obtained from simulation has been verified practically. The control signal and circuit design for operation of a Switched Reluctance Motor (SRM) drive has been described. The control circuit has been realized using microcomputer system. The technique developed is suitable for implementation with recent DSP processors. The result obtained from the prototype drive compared with those obtained in MATLAB simulation. The microprocessor/microcontroller/DSP has permitted the reduction of the hardware to a minimum. The technique developed can easily be used in implementation based on more powerful processors. In the scheme the problem caused by the harmonics has not been considered.

Key Words: *SRM, PI Control, Hysteresis Control, Voltage Control, Nonlinear*

1. INTRODUCTION

The electrical drives play an important role on the productivity to any industry. The requirement of drives depends upon the available mains and load characteristics. Brushless variable speed drive using SRM have become popular relative to other drives and represents an economical alternative to PM brushless motors in many applications. In last few years the SRM have gain increasing attention since they offer the possibility of electric drives which are mechanically and electrically more rugged than those build up around the conventional AC and DC motors. In case of SRM drive, the technical superiority of the AC drive is obtained or even enhanced at a very low cost. This is possible due to the simple motor construction and the requirement of a simple uni-.polar power modulator for controlling the speed.

In order to get performance oriented Drive, The accurate modelling of a Motor is to be done. The performance of machine can be checked with the help of Matlab / Simulink. This helps to design the Controller for the motor. Modeling can be done with the help of mathematical equations.

This Paper compared different techniques for the modelling of a SRM in view of its nonlinear magnetization characteristics due to the doubly salient structure(1). It proposes an application of ANN to identify the nonlinear model of SRM`s from operating data (2). The simulated performance of SRM Drive system is presented to analyze the effect of switching angles on transient and steady state performance of the Drive in terms of speed, Current and torque response (3). A new analytical representation and simulation of the phase inductance of SRM using matlab/Mfile is presented (4). Simulation method has many advantages:

- It is free from expression
- Can be applied widely
- Demonstrates inductance profile using motor parameters only

- Saves run time

The paper presents dynamic modeling of a commercially available 1-HP, 4 Phase 8/6 SRM using nonlinear 2D look up tables created from its measured flux linkages and static torque data. A model for each phase consists of a flux linkage estimator; a current look up table and a torque look up table (5). This paper presents a simplified nonlinear model for the SRM, which uses the fundamental mathematical functions to describe the saturation of the flux linkage depending on the winding current and rotor position. The model requires a minimum of pre-calculated or measured input data (6). A matlab/Simulink environment to simulate 6/4 SRM is described. Dynamics from Linear to nonlinear model has been discussed (7). The AC small signal modelling technique is proposed for liberalization of SRM model such that a conventional PI controller can be designed accordingly for PWM current controller (8). A nonlinear dynamic model of SRM is presented and a concise model of the phase inductance versus current and rotor position relationship of an SRM is proposed(9). Describe torque production in a saturated SRM using the unsaturated form of he torque equation (11).

2. SWITCHED RELUCTANCE MOTOR

In Switched Reluctance Motor the torque is developed because of the tendency of the magnetic circuit to adopt the configuration of minimum reluctance i.e. the rotor moves in line with the stator pole thus maximizing the inductance of the excited coil. The magnetic behavior of SRM is highly nonlinear. But by assuming an idealistic linear magnetic model, the behavior pattern of the SRM can be adjusted with ease of without serious loss of integrity from the actual behavior pattern.

3. CONSTRUCTION OF SRM

The physical appearance of a Switched Reluctance motor is similar to that of other rotating motors (AC and DC) Induction Motor, DC motor etc. The construction of 8/6 (8 stator poles, 6 rotor poles) poles SRM is shown in fig.20. It has doubly salient construction. Usually the number of stator and rotor poles is even. The windings of Switched Reluctance Motor are simpler than those of other types of motor. There is winding only on stator poles, simply wound on it and no winding on rotor poles. The winding of opposite poles is connected in series or in parallel forming no of phases exactly half of the number of stator poles. Therefore excitation of single phase excites two stator poles. The rotor has simple laminated salient pole structure without winding. This is the advantage of this motor as it reduces copper loss in rotor winding. The stampings are made preferably of silicon steel, especially in higher efficiency applications. For aerospace application the rotor is operating at very high speed, for that cobalt, iron and variants are used. The air gap is kept as minimum as possible, especially 0.1 to 0.3mm. The rotor and stator pole arc should be approximately the same. If the rotor pole arc is larger than the stator pole arc it is more advantageous.

4. DEVELOPMENT OF TORQUE

The most general expression for the torque produced by one phase at any rotor position is,

$T = [\partial\ W` / \partial\Theta]_{i\ =\ Const}$ ………………..(1.1) Since W`=Co-energy = ½ F Φ = ½ N I Φ…1.2)

This equation shows that input electrical power goes partly to increase the stored magnetic energy ($½L*i^2$) and partly to provide mechanical output power ($i^2/2 \times dL/d\Theta \times \omega$), the latter being associated with the rotational e.m.f. in the stator circuit.

Neglecting saturation non-linearity

L = Inductance = NΦ/ I……………….. (1.3)

$T = ½\ i^2\ dL/d\Theta$……… ………. .(1.4)

This equation shows that the developed torque is independent of direction of current but only depends on magnitude of current & direction of dL/dΘ.

5. GENERALIZED EQUATION OF MOTOR:

The voltage equation is,

$V= r\ i + d\Psi\ / dt$ …………………..…(1.5)

$\psi=Li=N\phi$..(1.6)

For r = 0

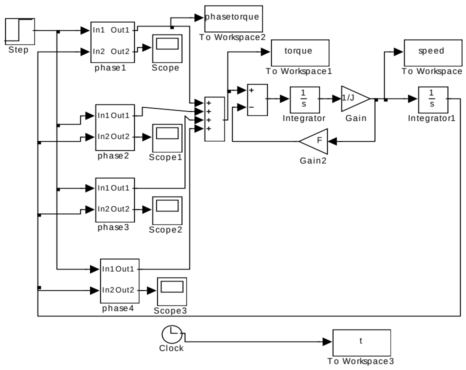
$V = L\ di/dt + i\ (dL /d\theta)\ (d\theta/dt)$

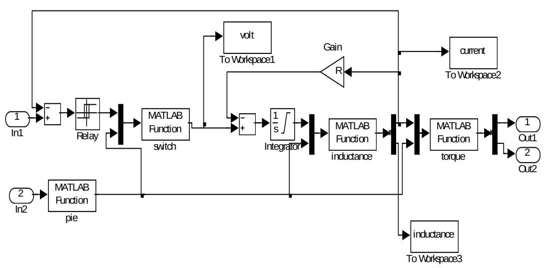
$V = L\ di/dt + i\ \omega\ (dL /d\theta)$………………(1.7)

6. MODELLING OF SRM

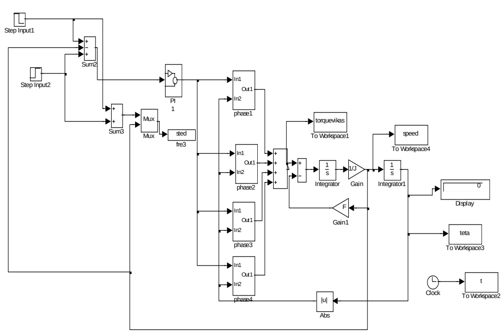
- Linear Model of SRM (Fig 1)

From Above equations of SRM the model for simulation is developed. Fig: 1

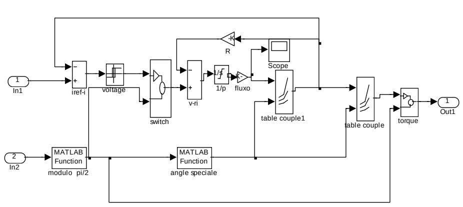




Expansion of one of the phase (Fig 2)



- Nonlinear Model of SRM (Fig 3).



Expansion of one of the phase (Fig 4).

7. CONTROL STRATEGIES

Different control strategies such as

- Voltage control,
- PI control,
- Hysteresis control

For linear as well as nonlinear modeling has been applied to get simulation results. All simulation results are shown below.

8. SIMULATION RESULTS OF SRM

Simulation has been made with Hysteresis control and Voltage control for single pulse operation. Various results obtained as shown in fig.4, fig. 5 and fig. 6. Chopping control results are also shown.

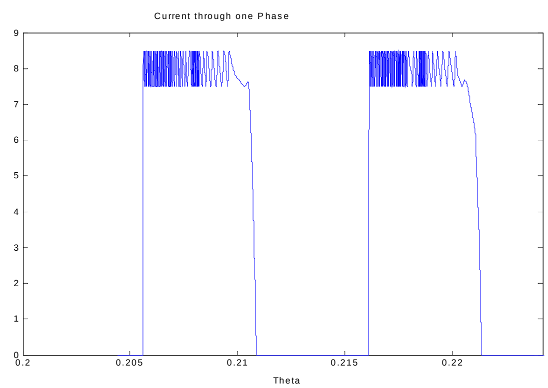


Fig. 5 Current Chopping in one phase(x-axis current in amp, y-axis angle)

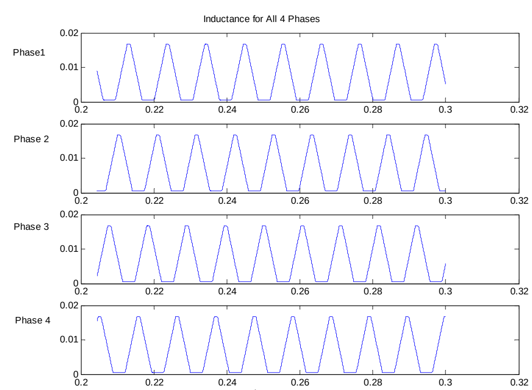


Fig 6. Inductance profile for four phases w.r t. angle Θ.

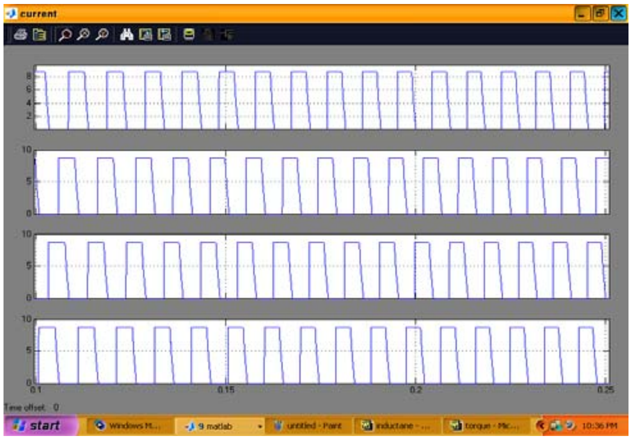


Fig.7 Current in all the four phases with reference to angle

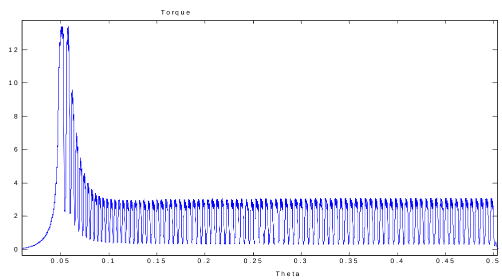


Fig 8. Torque in one of the phase

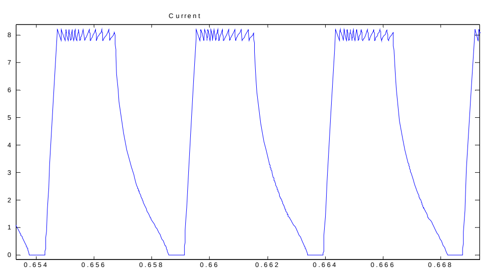


Fig 9. Current in winding Non linear Hysteresis control
(x-axis current in amp, y-axis angle)

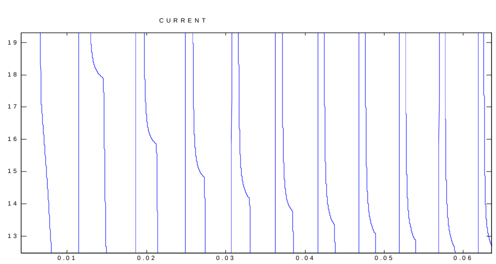


Fig 10. Current in phase of the SRM Voltage control – Linear mode (verified with experiment)

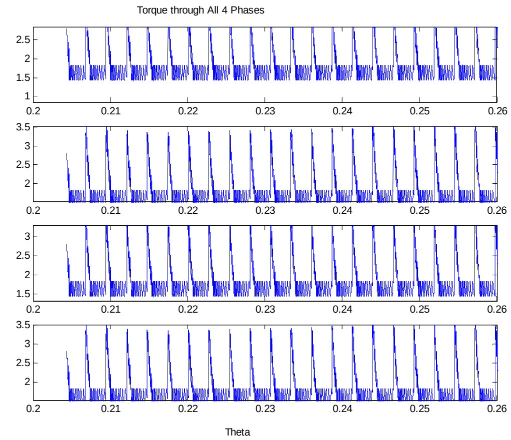


Fig 11. Voltage control – Linear mode

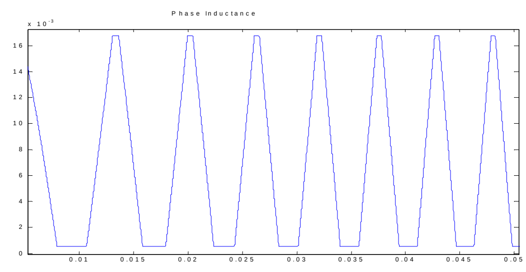


Fig 12. Inductance profile Voltage control – Linear mode

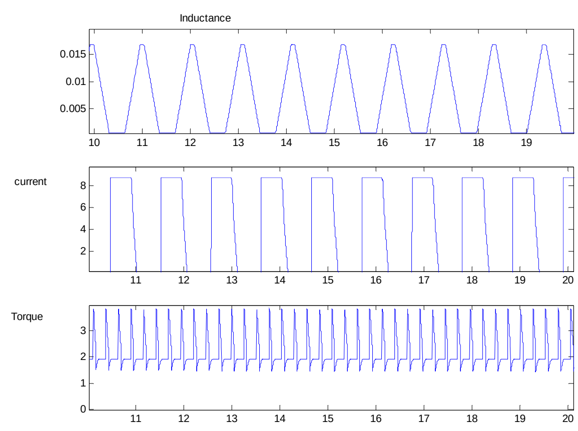


Fig 13. Inductance, Current and Torque in one of the phase of Stator winding

9. SYSTEM HARDWARE DESIGN

The system circuit consists of the following modules. The block diagram of proposed scheme is shown in fig. 14.

1. Power supply module
2. Converter module.

3. Motor.
4. Pulse modulator module.
5. Microprocessor module.
6. Regulated power supply circuit module.

Design of Stator and rotor is shown in Fig 14. All other components and system has been designed to control 8/6 SRM.

Electrical Specifications: Supply voltage 110 to 200 volts DC.,Power Rating 500 watt.,Speed 6000 rpm

<u>Mechanical Specifications:</u>

- No. Of stator poles = 8
- No. of rotor poles = 6
- Air Gap = 0.3 mm
- No. of turns per phase = 100
- Stator pole width 8 mm, rotor pole width 10mm
- Cross sectional area of conductor $0.5mm^2$

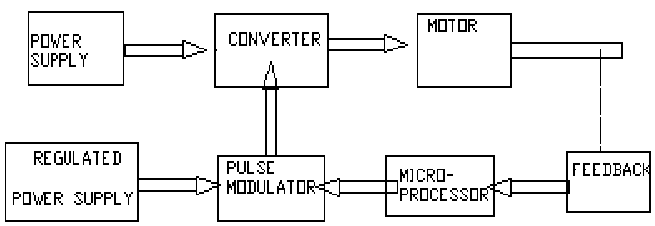


Fig 14. The converter model

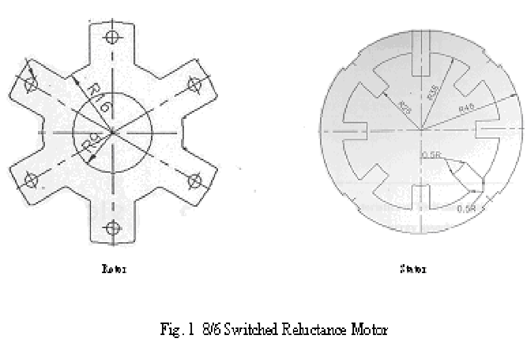


Fig 15: Design of stator and rotor winding

Photograph: The experimental setup

10. EXPERMINTAL RESULTS

The experimental results are obtained and compared with simulation results. The test on the Drive system for open loop operation is performed. Practical verification has been done with the help of test bench as shown Current through one of the phase in blocked as well as in running condition has been taken. The speed of SRM for various ON time (pulse width) is tested. The results are shown below (fig 16-20).The various test results from pulse modulator also been observed. The practical set up for the developed system is shown in photograph. The simulation results obtained in MATLAB are shown (fig 1-13). Given above for Inductance, Current and torque in voltage control & Hysteresis control.

CH1= 10V 20ms/div

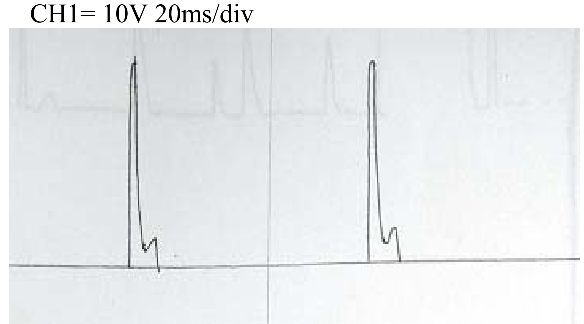


Fig16: Current in one of the phase (Practical verification)

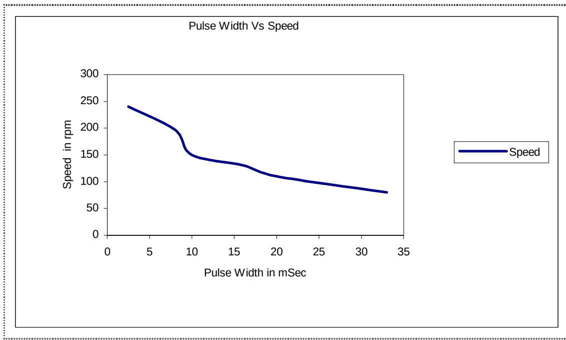


Fig 17: Speed Vs ON Time (Practical verification)

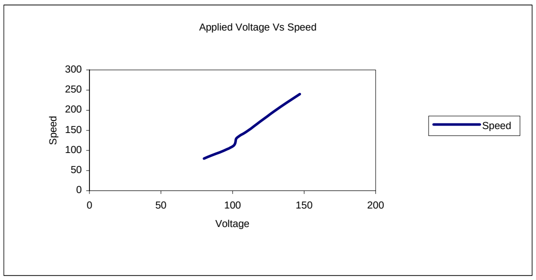


Fig 18: Applied voltage Vs Speed

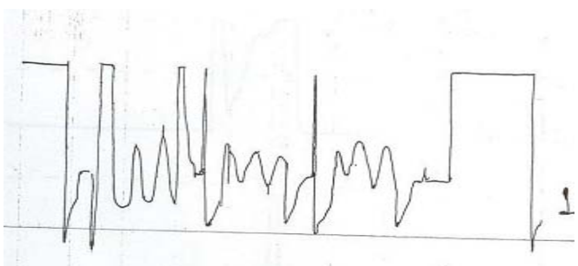


Fig 19: Torque in Single Winding (Practical verification).

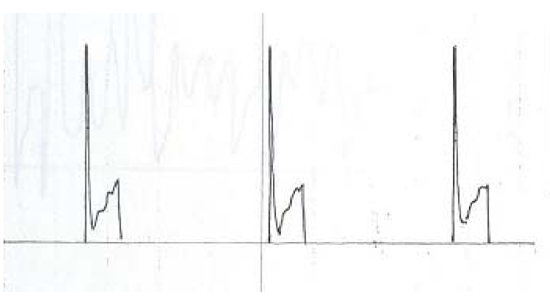


Fig20: Current in one of the phase (Practical verification)

11. CONCLUSION

From the simulations it is being observed that the torque is developed during change of inductance. For constant inductance (unaligned position) torque developed is zero. To get positive torque Voltage should apply during + dL/dϴ where as negative torque will develop during - dL/dϴ. Therefore exact switching (turn on and turn off angles) is needed. Simulation helps to get exact switching angles. Also the speed variation can be observed in case of nonlinear. From the design of the motor it can be concluded that the structure of the motor is very simple as compared to other AC and DC motors. The speed of the motor increases with decrease in switching 'ON' time i.e. as switching frequency increases, the speed of the motor increases as shown in fig 16. This is sufficient to conclude that we can increase the speed with increase in switching frequency. The present scheme is open loop scheme as the rotor position encoder is not present. The closed loop control of SRM can give best results with wide speed range. Micro controlled or DSP based system can be developed by which sensor less operation of speed control can be achieved. The torque minimization can be also be done using sophisticated controllers. The present work is an approach to make a SRM drive and can give all information related to control strategy.

12. ACKNOWLEDGEMNT

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Note: The experimental results are taken using thermographic printer therefore results shown above are scanned from the original results.