# Installation, Testing and Dynamic Simulation of 4 KW (5.5 Hp) Switched Reluctance Motor Drive

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## ABSTRACT
The first part of paper describes step by step installation of Switched Reluctance Motor & its drive. A special procedure for installation (Mechanical as well as Electrical) is developed in order to reduce acoustic noise, EMI interference and torque ripple of a motor. A serious electrical interference problem is solved using special designed screened cable. The second part of paper describes dynamic simulation of SR Motor using analog behavioral modeling using Pspice software. The third part of paper presents mechanical modeling mechanical modeling & simulation of the SR Motor.

## General Terms
Electromagnetic Testing, EMI Interference, ZX subcomponent

## Keywords
Switched Reluctance Motor, Torque, Q-factor, and Dynamic Characteristics.

## 1. INTRODUCTION
Todays industry needs high efficiency, energy efficient & cost effective drive. Mostly, Induction Motor Drive & DC Drives are used in the industry. Switched reluctance Motor (with some minor limitations) is the best solution for replacement of above drive. The Switched Reluctance Motor has several advantages such as simple construction, robust mechanism, brushless operation, & low inertia with high torque to mass ratio. The Switched Reluctance Motor Drive is the best solution as it satisfies above. The motor is constructed with eight stator poles with coils and rotor is having six poles without windings and no magnets on it. [1]. The stationary proxy switches are mounted inside the motor to give correct feedback to controller. In the Switched Reluctance Motor, torque is produced by tendency for magnetic circuit to adopt minimum reluctance. This is achieved by maximizing the inductance in synchronous with the rotor position [2][3]. In this paper, the method of installation, testing, measurement of electrical parameters and dynamic simulation for mechanical as well as electrical part of Switched Reluctance Motor is presented. PSpice software is used for the determination of dynamic characteristics. A Switched Reluctance Motor is a closed loop control system and its torque is controlled by suitable commutation strategy which is synchronized with knowledge of rotor position (Rotor Speed and Rotor Angle).The production of torque is independent of current flowing through the phase winding of SRM. The recently published papers [4], [5], [6], [7], [8] studied for dynamic study of the SR Motor and effort has been taken to provide simple but useful solution to reduce acoustic noise, EMI interference and torque ripple of a motor by developing a special procedure for installation & electromagnetic testing of a Switched Reluctance Motor & its drive. A special tool called ABM is used in Pspice programming for mechanical & electrical modeling of the SR Motor.

## 2. INSTALLATION OF 4 KW (5.5 HP) SR MOTOR AND ITS DRIVE.
Switched Reluctance Motor is manufactured by considering the dusty environmental conditions chemical works, marine works etc. For this purpose the machines are built to follow the IP55 industrial standards. The SR motors are designed to work in the temperature range of -10 to +40 degree with any altitude. Therefore standard procedure is adopted to install the SR motor and its drive.[9]

### 2.1 Electrical Wiring of SR Motor
The major problem of torque ripple and correspondingly mechanical vibrations are noted therefore a proper mechanical mounting is required before the wring of the SR Motor. However the improper electrical wiring also causes misfiring of sensor’s firing angle. Therefore the motor’s earth terminal must be connected to controller’s earth terminal and screened cable is required for the same. For mains wring we have selected 9 ampere screened cable with fuse rating of 16 ampere. A remote control is designed to control the operation of SR Motor for START, STOP, INCH, RESET, SPEED, FORWARD and REVERSE direction. During the wring of motor, there is need to isolate controller wring from mains wring to avoid electrical noise interference.

## 3. MEASUREMENT OF ELECTRICAL PARAMETERS
On one hand, a separate analog circuit is developed for measurement parameters such as flux linkage, HT100 hall sensor is used for measurement of load current. On the other hand a separate 1.4mm thick rotor disc is developed with following specifications with special rotor holding arrangement.

**Table 1. . Specifications of rotor disc.**

| Sr. No | Parameter | Specification |
|---|---|---|
| 1 | Diameter of disc | 200mm |
| 2 | Thickness | 1.4 mm |

| | | |
|---|---|---|
| 3 | Radial Gap | 28 mm |
| 3 | Nos. Teeth | 120 |
| 4 | Bore Diameter | 28 mm |

## 3.1 Dynamic Simulation

For effective modeling of SR Motor we suggest a analog behavioral modeling method using Pspice [10]. For dynamic simulation, following are the most important relations used for torque, speed and position.

$$T = J.\frac{d\theta}{dt} \qquad (1)$$

Where

$w = \frac{d\theta}{dt}$ and $w = 2\pi f_s$ Therefore

$F_s = S = \text{Speed} = \frac{w}{2\pi}$ becomes

$$S = \frac{d\theta}{dt} \times \frac{1}{2\pi} \qquad (2)$$

where S is the rotor speed (Rev / Sec)

$$T_{Total} = J \times \frac{d}{dt}\left(\frac{d\theta}{dt}\right) = J \times \frac{d^2\theta}{dt^2} \qquad (3)$$

$$\therefore T_{Total} = T(\theta, i) = \sum_{k=1}^{ph} T(\theta, i) - T_L$$

$$\frac{dw}{dt} = \frac{1}{J} \sum_{k=1}^{ph} T(\theta,i) - T_L \qquad (4)$$

Equation (3) can be written as

$$T_{Total} = 2\pi \times J \times \frac{dS}{dt} \qquad (5)$$

For modeling the torque and speed , we can consider

$$V = \frac{1}{C}\int i \times dt \text{ and can be written as} \qquad (6)$$

$$i = C \times \frac{dv}{dt} \qquad (7)$$

By observing equation (5), (7) and (2), we can now model the speed as a current flowing through the capacitor, torque as a voltage across the capacitor with moment of inertia 2 Л*J. The rotor angle will be the proportional voltage at the node; therefore it is assumed that 1 volt correspondence to 1 radian. In switched reluctance motor the torque is proportional to the square of the current flowing through winding therefore the torque is unipolar Figure (1) shows equivalent circuit of above equations [11 ].

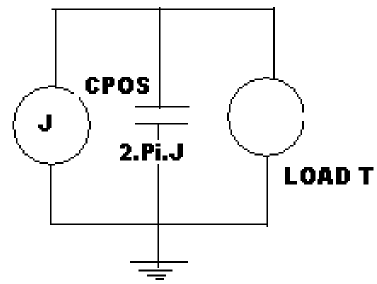


**Fig 1: Rotor Motion Circuit**

The following Table gives conversion of mechanical part in to equivalent electrical parameters.

**Table 2. . Conversion Table**

| Parameter | Mechanical System | Electrical System |
|---|---|---|
| Moment of Inertia | Inertia (J) | Capacitor |
| Torque | T | Voltage/Current |
| Rotor Angle | Angle of Rotation | Voltage Across ‘C’ |
| Rotor Speed | Speed of Rotor | Current through ‘C’ |

## 3.2 Mechanical & Electrical Modeling

For verification of dynamics of a SR Motor, we have to consider the losses such as damping losses, eddy current losses and frictional losses etc. Following are the parameters to be considered for simulation,

i. Phase/winding inductance (mH)
ii. Phase/winding Resistance (Ohm)
iii. Phase/winding Capacitance(F)
iv. Mutual Inductance of the winding. (mH)
v. Back EMF of the winding
vi. Torque producing current Itq(mA)

The actual values of point (i) to (iv) can be directly used in Pspice with .PARAM command and (v) and (vi) requires analog behavioral modeling of Pspice software. Simulation of Quality factor is done using spice programming. A new concept of floating component [11] ZX is used to model a variable inductor. It is inserted as a sub circuit in the main program of simulation. Following program is developed to analyze the quality factor of an inductor circuit of stator phase. The Stator circuit is compared with the R-L-C circuit where resistance ‘R’ is the winding resistance, ‘L’ is the inductance of winding and c is the capacitance of the Pspice Program for simulation of variable Q- is listed below [12].

***Simulation of Q – Factor for SR Motor**

```
L1 1 2 10mH
C2 2 3 1uF
X1 VIN 0 Rref 3 0 ZX
Rref Rref 0 40E
.PARAM ControlVoltage=0.5, 2, 0.5
Vcontrol Vin 0 dc 0.5
Vsrc 1 0 PULSE (0V, 1V, 0.5MS, 1US, 1US, 0.5MS, 4MS)
.TRAN 0.1m 4m 0 0.01m
.probe
*SUB CIRCUIT ZX
.subckt ZX 1 2 3 4 5
eout   4 6 poly(2) (1,2) (3,0) 0 0 0 0 1
fcopy  0 3 vsense 1
rin    1 2 1G
vsense 6 5 0
.ends
.end
```

## 4. Simulation Results

After installation of SR Machine the Pspice program is developed containing different modules such as spice modeling of clock, logic gate, limiter circuits, switches, angle, and a variable inductor circuit using ZX sub-component. Fig. 1 shows conversion of angles into equivalent radian required to estimate rotor position. The variation of Q is observed as input changes with a sinusoidal function. This can be seen in fig.2. Rotor position and variation in inductance can be observed in fig.3. During the simulation process, Rotor angle 'θ' is varied in different steps of equivalent DC voltage at input of ZX sub-component. The variation of inductance voltage using ZX sub component is observed in fig. 4.

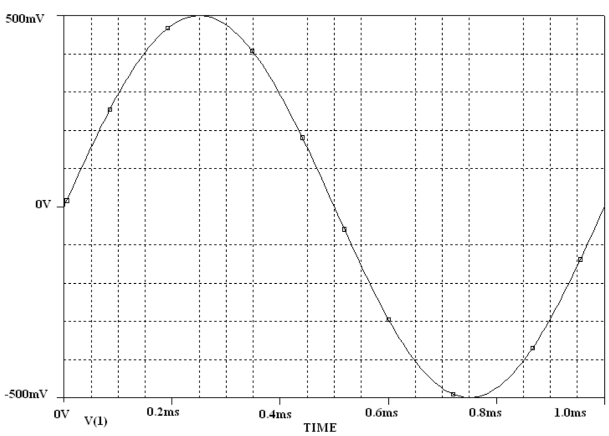


**Fig 1: Conversion of angles into equivalent radian**

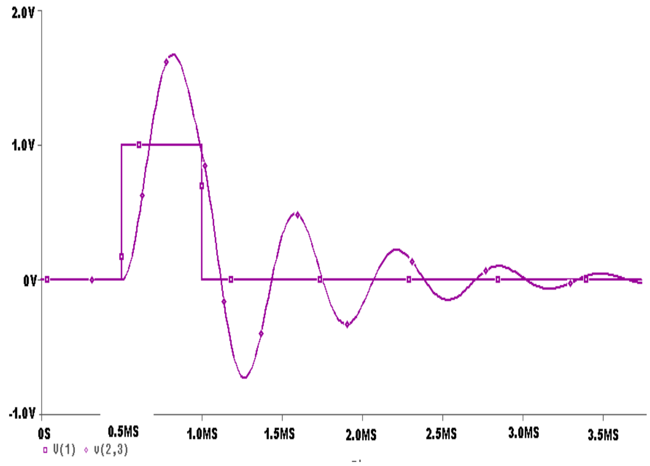


**Fig 2: The variation of Q as input change in sinusoidal function.**

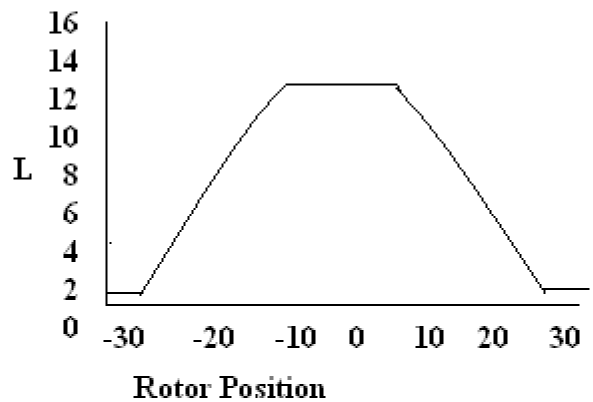


**Fig 3: Rotor position and variation in inductance**

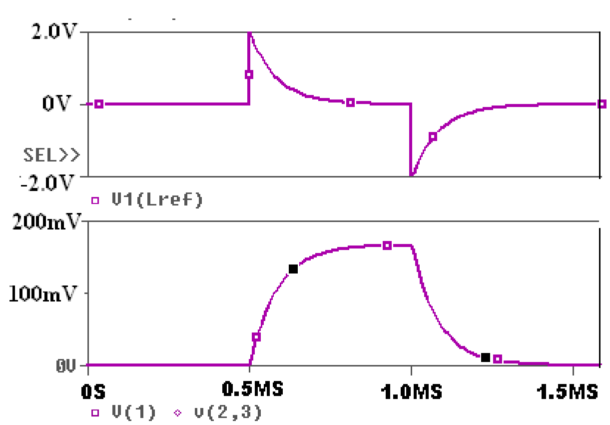


**Fig 4: The variation of inductance voltage using ZX sub- component**

## 5. CONCLUSION

A special procedure is developed for installation of a 4 Kw (5.5 Hp) Switched Reluctance Motor & its drive in order to reduce the problems such as electromagnetic interference caused by mains wiring, mechanical vibration caused by torque ripple. Analog circuit is developed for testing the electromagnetic parameters of the motor with simple rotor locking arrangement. Further dynamic simulation program is developed using special tool called analog behavior modeling of Pspice. A variable inductor is developed using Pspice and Quality factor of this motor's winding is simulated. Simulated result is compared with practical results and found closely match.

## 6. ACKNOWLEDGMENTS

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