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ACOUSTIC NOISE REDUCTION IN SWITCHED RELUCTANCE MOTOR USING FLC

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ABSTRACT

Switched Reluctance Motor (SRM) has been effectively used for its high efficiency and higher power to torque ratio. But the only demerit it has, is its radial force and acoustic noise. When SRM achieves higher speeds, it tends to produce more force between stator and hence acoustic noise with higher decibels value. In this paper, a design is used for reduction of both radial force and acoustic noise for 8/6 SRM using the fuzzy logic controller by controlling the speed and the current as a feedback loop. The mathematical models are done to resolve glitches associated to radial force and acoustic noise. The proposed system has been implemented in MATLAB/Simulink environment and primarily focused to reduce acoustic noise at higher speed in SRM.

1. INTRODUCTION

Switched Reluctance Motor (SRM) is a special type of motor that has many applications in industrial fields such as aeronautics, defense, hybrid vehicles, washing machines, etc. because of its high reliability, higher ratio of torque to power, lower price, higher effectiveness with lower torque in higher speeds. Theonly shortfall is that high torque ripples, which results in higher radial force which also results in higher noise called as acoustic noise. Controlling torque ripple becomes difficult in SRM as it has high output power density. In SRM, torque ripple along with radial force are important factors for acoustic noise generation. Generally, the noise in machines is divided into mechanical, electrical, magnetic and aerodynamic. But the noise in SRM is linked with vibration of the stator yoke due to radial magnetic force [1]. Authors Ling and Yang [2] proposed a control method for the control of radial force in SRM of 12/8 poles by energizing all poles in phase with equal current.

The acoustic noise could be generated due to winding vibrations by exciting stator vibrations. The current in the stator windings may come in contact with the magnetic field [3] The radial force is proportional to phase current and rotor position [4]. Radial force is proportional to air gap length, rotor position, parameters of rotor along with phase current and winding turns [5]. Between rotor and stator, a radial attractive force is generated which excites vibration in stator due to mechanical resonant frequency [6].

An SRM [1] was built for reduction of acoustic noise with equations for calculating radial force and torque was done and important parameters of SRM. This aims to reduce torque ripple and radial force by optimizing current waveform using fuzzy logic control. But overall radial force of $16X10^5$ with higher ripple rate has been produced. A solution [6] with reduced RMS current is represented but lack in enhancing the conventional square waveform current regulation in reducing acoustic noise and vibrations is detected. An SRM [7] model was built and controlled by Hybrid Heuristic based Fuzzy Gain scheduling PI controller for reduction of torque ripple and speed control. An author proposed [8] an investigation of reduction of mechanical vibration and acoustic noise using PI, PID and Fuzzy logic controller. This results in reduction of torque ripples and noise but the motor was rotated and kept constant at a speed of 300 RPM for the experiment. Controlling of SRM [9] is investigated using artificial raindrop algorithm tuned PI control in Direct Torque Control (DTC) method.

2. PROPOSED METHOD

A fuzzy logic controller is implemented to lessen torque ripple, radial force and acoustic noise for 8/6 SRM at 1250 RPM speed.

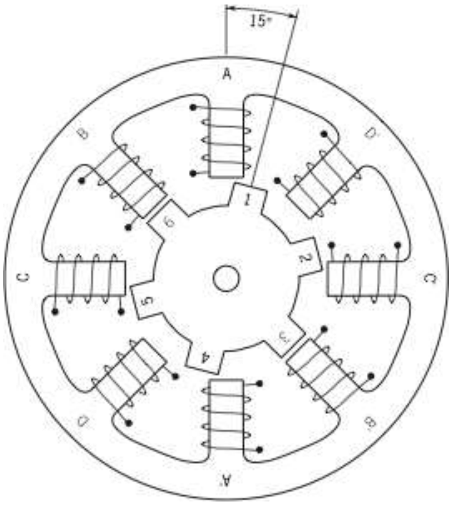

Figure 1. 8/6 SRM

The SRM taken is an 8/6 model with 8 stator windings and 6 rotor blades. The controller used is a Fuzzy logic controller for controlling the current and torque and these are again converted to pulses or signals, which are given to the converter/inverter connected to the SRM. By controlling the torque ripple, radial force is controlled and in turn acoustic noise is lessened to the level of 2dB.

SRM Mathematical model

The mathematical equation [1] for the SRM mentioned below are used for modeling of a controller.
The torque of SRM with respect to flux linkages, rotor position, and current:

$$T_j = \frac{\partial W_c(i_j,l_j,L_r,\theta)}{\partial \theta} \tag{1}$$

$$T_e = \sum_{j=1}^{n} T_j \tag{2}$$

T_j - Torque of j^{th} phase
W_c - Co-Energy
θ - Rotor position
l_j - Length of Air gap
i_j - Current of j^{th} phase
L_r - rotor Stack length
T_e - Electromagnetic torque

The final torques and the radial force is given as

$$T_e = \frac{l_g}{2\mu_0 L_r r} \cdot \frac{\varphi^2}{\theta^2} \tag{3}$$

$$F_n = \frac{\partial W_c(i_j.l_j.L_r.\theta)}{\partial L_g} = K.\left(\frac{-r\,.\,L_r\,.\theta}{2\mu_0}\right) \tag{4}$$

where,

$$K = \frac{{\mu_0}^2.N_{ph}.{i_j}^2}{{I_g}^2} \tag{5}$$

N_{ph} – Turns per phase
r – radius of rotor

SRM Acoustic Noise

The acoustic noise depends on the circumferential difference resulted due to radial force which is in N/m^2. The circumferential deflection is given as: -

$$D_{circum(f_{exc})} = \frac{12 F_{n(f_{exc})} . R_m . \left(\frac{R_m}{h_s}\right)^3}{\sqrt{\left\{1-\left(\frac{f_{exc}}{f_m}\right)^2\right\}^2 + \left(\frac{\delta}{\pi} . \frac{f_{exc}}{f_m}\right)^2}} \quad (6)$$

$$f_{exc}(n) = n . f_p = \frac{n.\omega.N_{rp}}{60} \quad (7)$$

where,

D_{circum} = Dynamic Deflection (m)
F_n = Radial force (N/m^2)
δ = Damping factor
N_{rp} = Number of rotor poles
f_p = Fundamental frequency of phase current (Hz)
f_{exc} = Excitation frequency (Hz)
R_m = Radius of stator yoke
h_s = Stator pole height
m, f_m = Circumferential mode number and mode frequency

The power of sound radiated by the SRM is written as,

$$P = 4 . \sigma_{rel} . \rho . c . \pi^3 . {f_{exc}}^2 . D_{circum} . R_{out} . l_{stk} \quad (8)$$

where,

P = radiated sound power (w)
σ_{rel} = Relative sound intensity
k = Wave number
C = Speed of Sound (m/s) in the medium
$\rho . c$ = 415 N.s/m^3 for air at 20^0C (ρ *density of air*)

The MATLAB/Simulink model for the proposed system is:

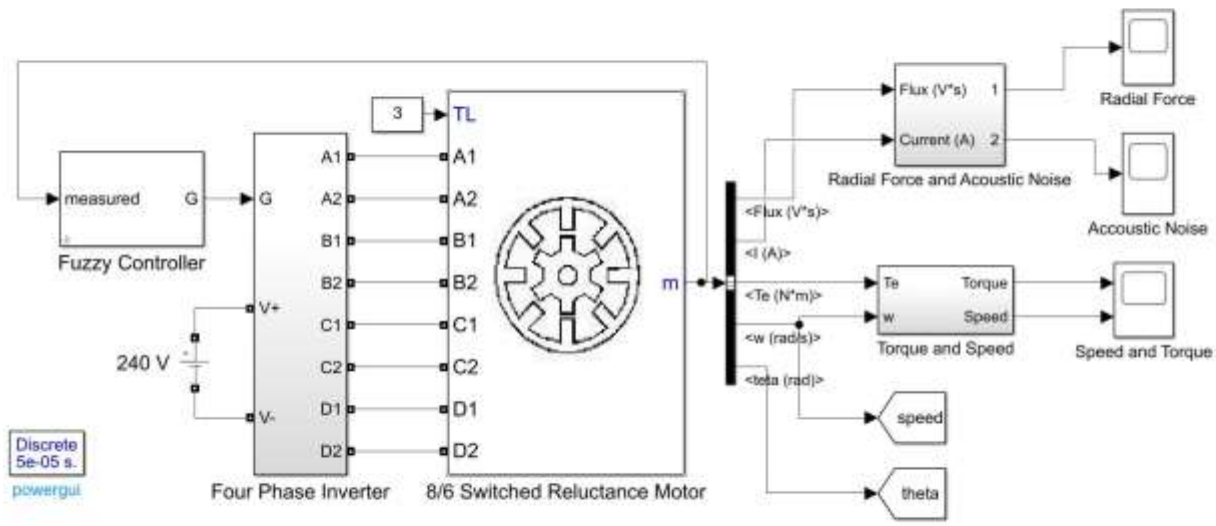

Figure 2: Proposed system in MATLAB/Simulink

The 8/6 SRM model with four-phase inverter converting DC to four phases AC for the SRM is shown. The measured values are taken as feedback and given to the Fuzzy logic controller. The controller accepts speed and current as an input and generates pulses to SRM converter.

The four-phase converter with freewheeling diodes are:

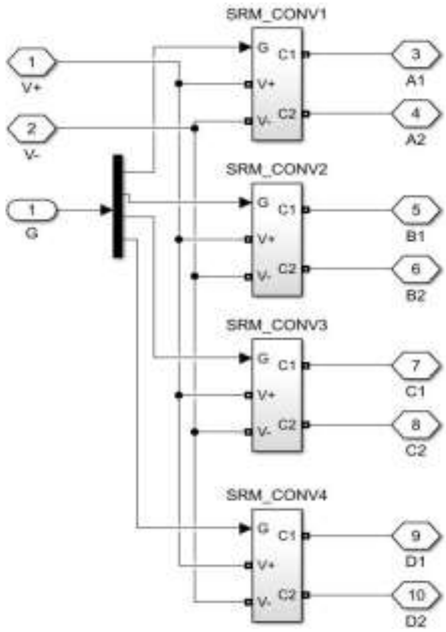

Figure 3: Four-Phase Converter for SRM

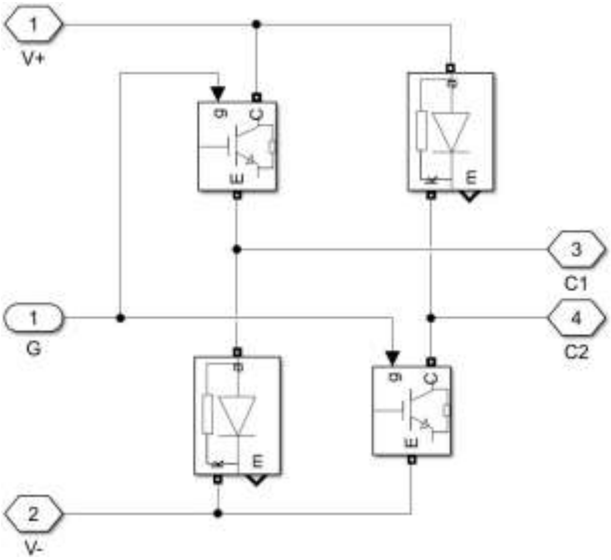

Figure 4: Single Phase Inverter for one phase of SRM

The gate pulses are given from the controller to the converter. The switches used are transistors, which are IGBT, which are used for higher power applications. The diodes are used as freewheeling diodes for protection of system from reverse current.

The model shown below represents the calculation and presentation of acoustic noise and radial force. The model is built by using the equations from (6) to (8). The D_{circum} and the power of the radial force P and F_n are shown.

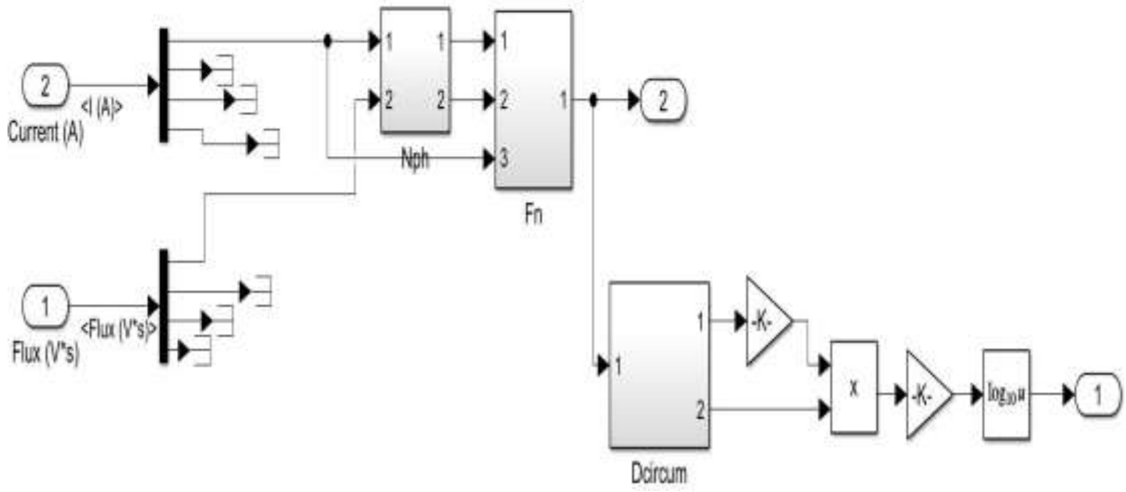

Figure 5: Model block for measuring radial force and acoustic noise

The controller which is fuzzy logic based is shown below. The input taken is speed, which is in turn converted to the current. This current is compared with the actual current and is used to generate the gate pulses for the converter using the fuzzy logic. The output and the input of the logic are shown below for which the system generates the radial force and acoustic noise.

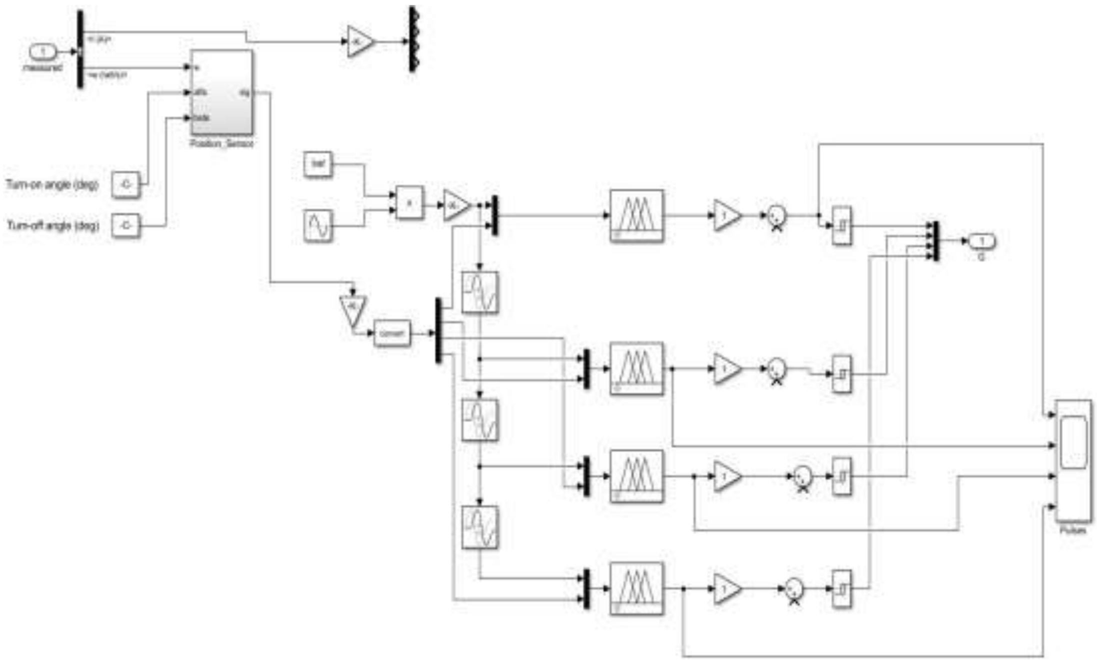

Figure 6: Model block for generation of pulses through Fuzzy controller

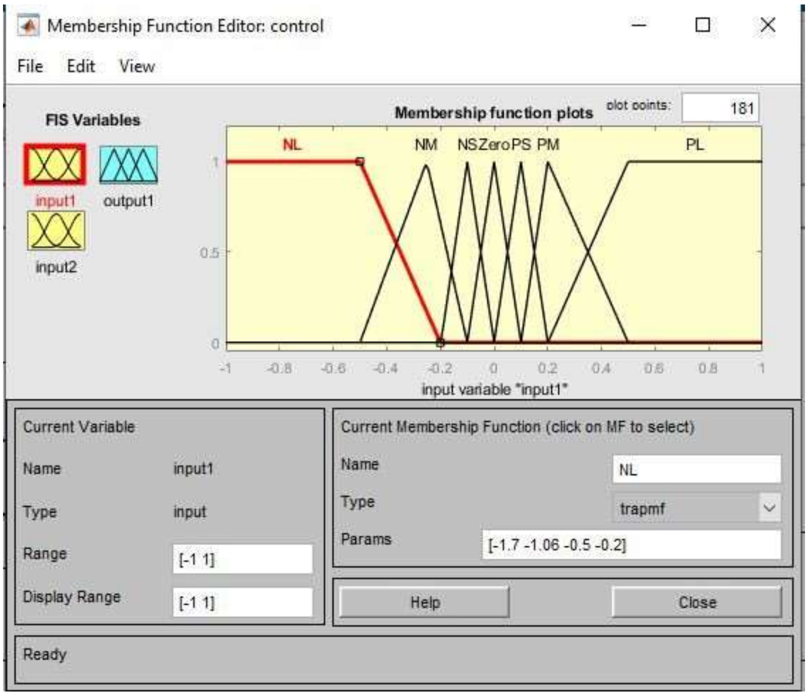

Figure 7: Input block for Fuzzy controller

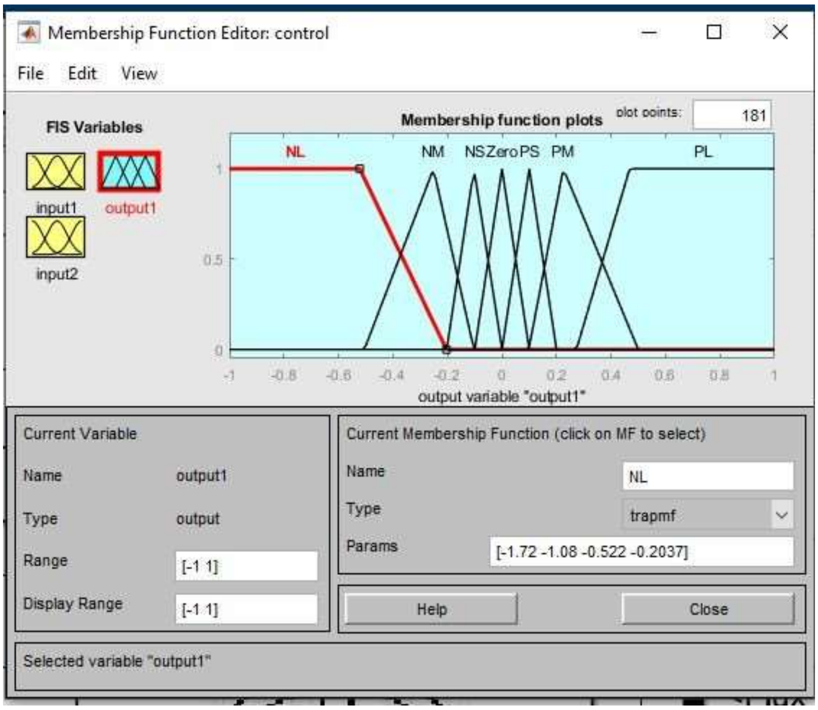

Figure 8: Output block for Fuzzy controller33

3. RESULTS AND DISCUSSIONS

The SRM is considered to be one of the very good motors for its higher efficiency and higher power to torque ratio. But generally, the SRM has problems of high radial force and acoustic noise at higher speeds. But in this proposed system when rotating the motor at speed of 1200 RPM the noise produced was at very low level. The results and the comparisons with existing are presented.

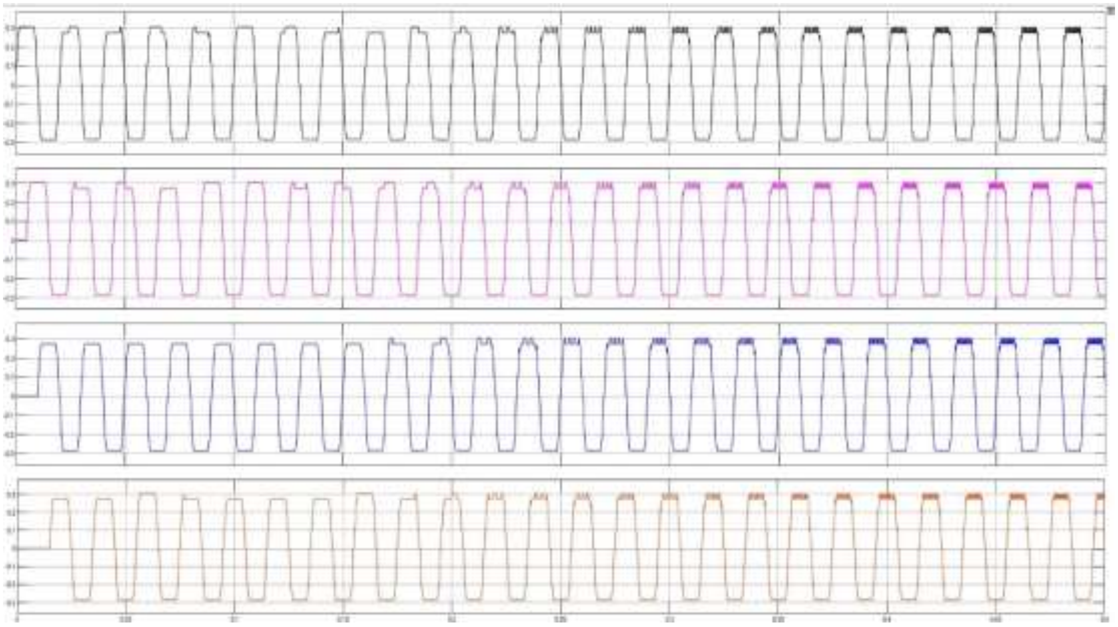

Figure 9: Four-phase converter pulses

The four phases shifted 60 degrees from each other. These gate pulses given to the converter to control the speed, torque ripple and the acoustic noise.

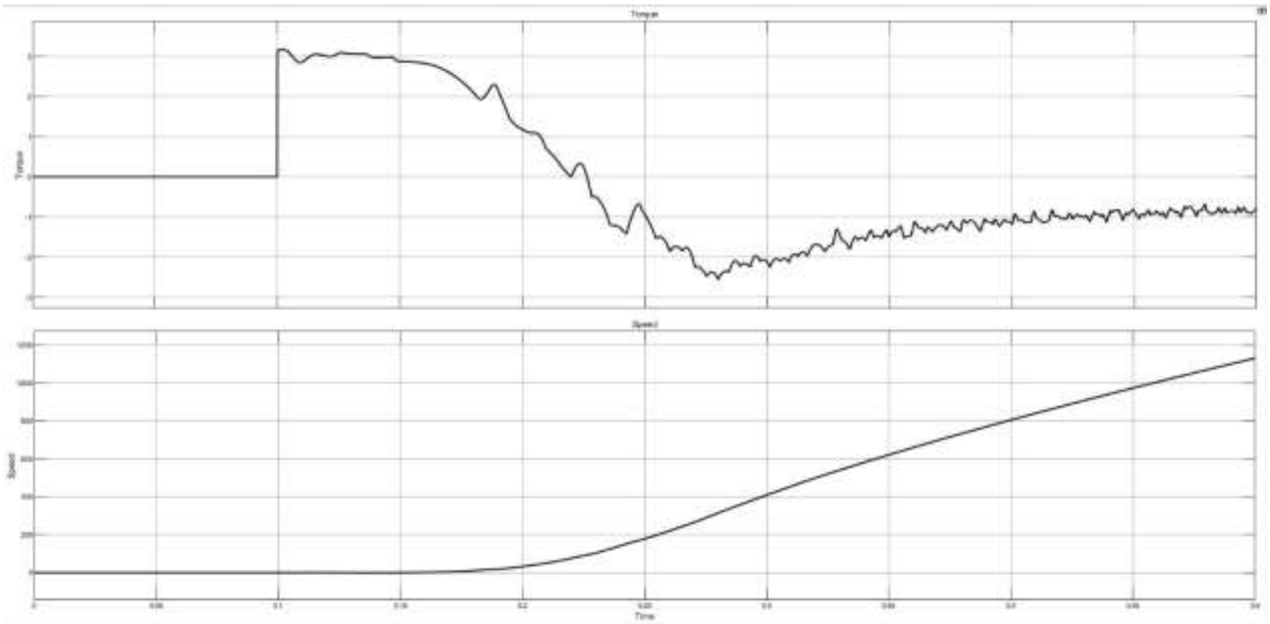

Figure 10: Torque and Speed for SRM

The figure shows the waveform for the torque and the speed at 1200 RPM. The torque reaches constant as soon as the speed turn out to be constant. The SRM rotates at the user defined speed. The load torque chosen for the system is 3Nm.

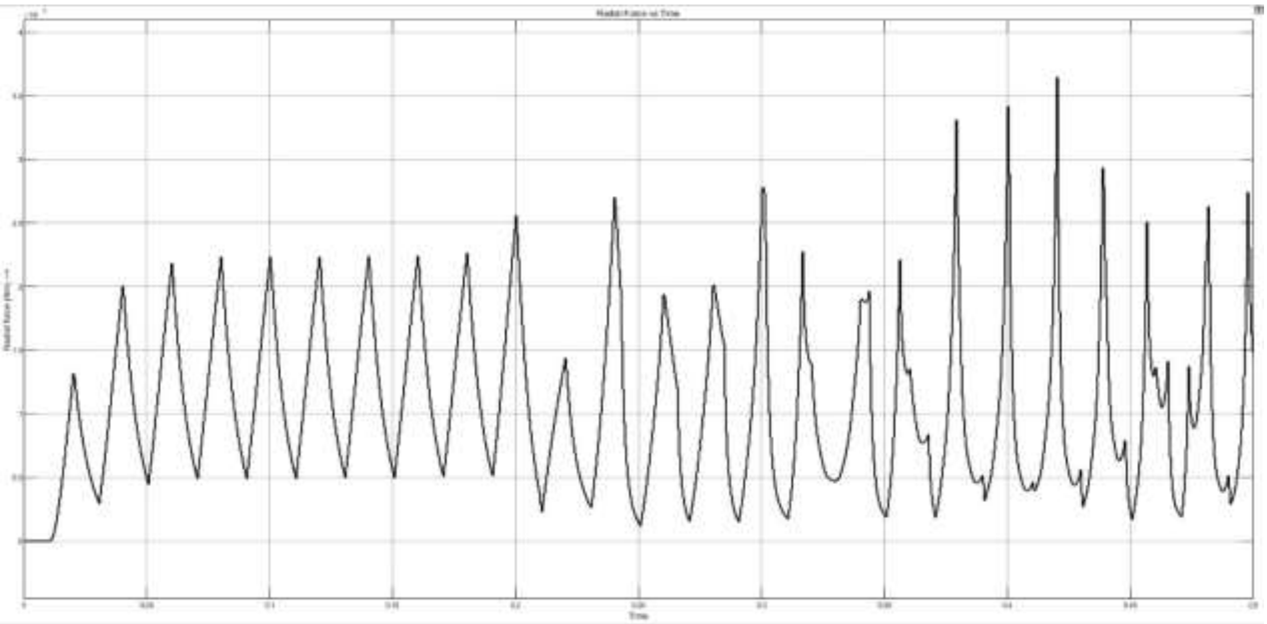

Figure 11: Radial force of 8/6 SRM

The radial force is represented above with the value of 3.5 x 10^5 Nm. This is low radial force when compared to papers [1] and [9] at a speed of 1200 RPM. The acoustic noise obtained is 2dB at higher speed and is depicted below.

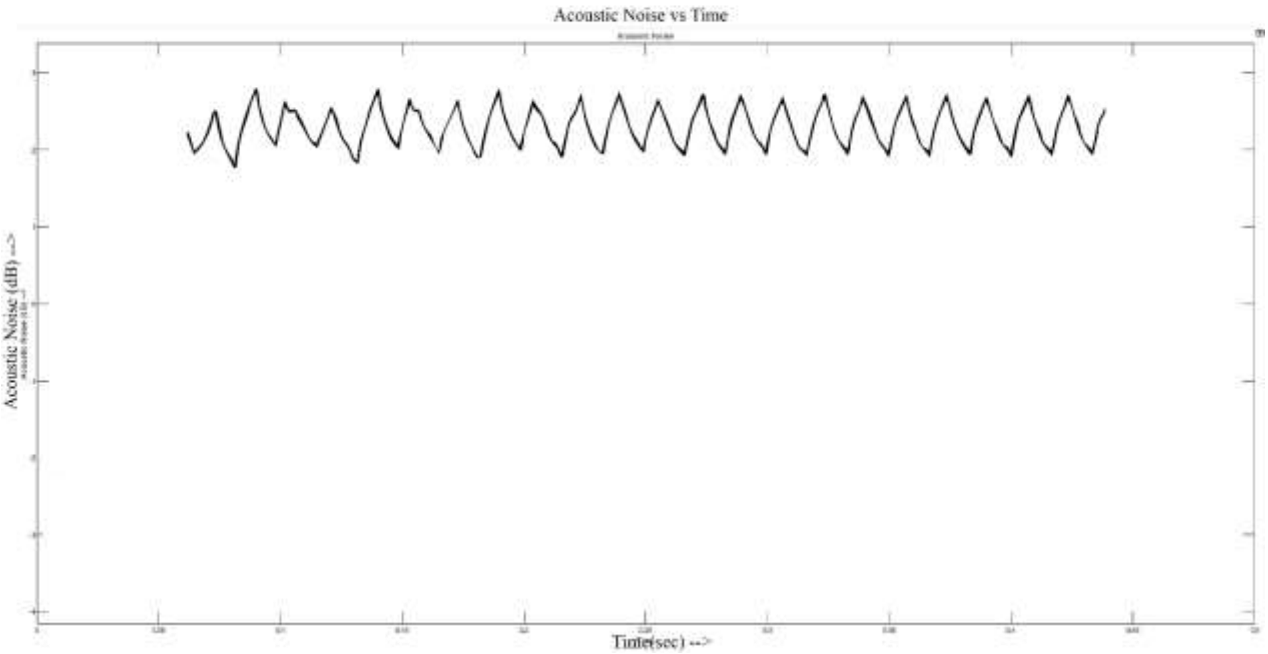

Figure12: Acoustic noise for 8/6 SRM

Table 1: Comparative table of Acoustic noise

Comparison	Radial force	Acoustic noise
Existing [1]	16x10^5	12 dB
Existing [9]	20x10^5	7.5 dB
ProposedMethod	3.5x10^5	2 dB

As seen from the comparison, the proposed method when compared to [1] and [9] produces less radial force and acoustic noise. Hence fuzzy logic controller reduces the torque ripple by maintaining the speed at constant level with lesser acoustic noise and radial force.

4. CONCLUSION

In this paper an 8/6 SRM in MATLAB/Simulink for the reduction of acoustic noise and radial force is analyzed and proposed. The results compared with existing controllers and proved that the fuzzy logic controller for controlling the speed and current of SRM has reduced the radial force and the acoustic noise. The simulated results evidenced that the higher speed in SRM can be achieved with less acoustic noise.

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