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Vibration and Noise Analysis of 4Φ Switched Reluctance Motor Drive

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Abstract

The Switched Reluctance Motor (SRM) is getting large attention for industry application due to their simple construction, high starting capabilities, high reliability, and high efficiency and also rotor carries no windings, no slip-rings there is no brushes, it requires less maintenance. In spite of the merits, it had some demerits like acoustic noise and vibration is one of major issues in SRM. The DSP-TMS320F28335 processor were implemented due to their high performance for the control applications.In this work the Random Pulse Width Modulation (RPWM) technique is used to reduce the acoustic noise and vibration by varying random turn on and turn off angle control.The acoustic noise and vibration signals are measured using accelerometer and sound level meter in 1HP, 8/6poles of SRM drive. The experimental analysis of vibration signals are measured using Lab VIEW at different speeds and load conditions. The acoustic noise signals are measured using Sound level meter .Both the Acoustic and vibrations are analyzed experimentally for different speeds and load conditions. The experimental results show that the noise and vibration analysis and also compare the sinusoidal PWM is better than Random PWM techniques.

Keywords*: switched reluctance motor (SRM), acoustic noise, vibration signals, Lab VIEW, DSP-TMS320F28335 processor, random pulse width modulation (RPWM)*

1. Introduction

Switched Reluctance Motors (SRM) have an inherent advantages such as simple structure with non winding construction in rotor side because of its characteristic which has a high tolerances, robustness, low cost with no permanent magnet in the structure, and possible operation in high temperatures or in extreme temperature variations[9]. The torque production in switched reluctance motor comes from the tendency of the rotor poles to align with the excited stator poles. The operation principle is based on the difference in magnetic reluctance for magnetic field lines between aligned and unaligned rotor position when a stator coil is excited the rotor experiences a force which will draw the rotor to the aligned position. However SRM construction with doubly salient poles and its non-line magnetic characteristics the problems of acoustic noise and torque ripple are more severe than these of other traditional motors.

Random pulse width modulation (RPWM) approaches can make the harmonic spectrum of inverter output voltage be continuously distributed without affecting the fundamental frequency component of an acoustic noise and mechanical vibration of an ac motor drive are greatly reduced.Randomizing the switching frequency has found to be the most efficient method of RPWM. In converters with fixed switching frequency the power is concentrated in discreet harmonics of the output voltage. In [6], New Random Switching Technique was presented, in this techniques used to reduce the harmonics spectra of a single phase SRM drive.The torque ripple and acoustic noise is an inherent drawback of SRM drive [10]. The phase current commutation is the main cause of the torque ripple. The torque ripple can be minimized through magnetic circuit design in a motor design stage or by using torque control techniques. By controlling the torque of the SRM, low torque ripple, noise reduction can be increasing of the efficiency can be achieved in [10]. There are many different types of control strategy from simple methods to complicated methods.

In this paper, the split link converter is used to reduce the cost of the converter [7], it has high efficiency under heavy load conditions. In [2], DSP (TMS320F28335) processor were implemented because of the fast operation compare with other processor. The Vibration not

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only creates noise to hurt human health but also has the energy at the time affect the equipment life as well as operation stability. The influence of vibration can be minimized or eliminated using vibration test analysis. The various vibration measurements are used to analysis the vibration signals and also consider how to reduce the further improvements. The vibration sensor is used to measure the vibration using Lab VIEW. Lab VIEW is a graphical programming language that can be used for acquiring signals, measurement analysis, and data presentation. It allows creating a Virtual Instrument (VI) that allows manipulating signals and obtaining measurements.

This paper presents the vibrations are analyzed experimentally for different load conditions and various speed changes of the SRM drive. Control algorithm was developed and tested by TMS320F28335 processor and the experimental analysis is performed to test the vibration signals with different speed and load conditions. This paper is considered brief about SRM and converter in section 2 and Section 3 discussed the Random pulse width modulation techniques with TMS320F28335 processor. Section 4 discussed the Acoustic noise and vibration ,Section 5 discuss an experimental setup of SRM drive. Section 6 discussed Experimental results and concluding comments in section 7.

2. Switched Reluctance Motor

In Switched Reluctance Motor the term switched reluctance mean that the switching of phase currents, which is essential to the operation of the motor. The motion may be rotary or liner and the rotor may be interior or exterior. The winding usually consists of a number of electrically separate circuits or phases. In motoring mode operation of the reluctance machine each phase of the stator is usually excited when its inductance is increasing and is unexcited when its inductance is decreasing, the opposite is true in generating mode. The SRM has salient poles both on stator and rotor; the stator winding of SRM comprises a set of coils, each of which is wound on the pole. The rotor rotates; the phase flux linkage should have a triangular or sawtooth wave form. The SRM is a doubly salient, singly excited machine at which the electromagnetic torque is developed due to the variable reluctance principle. Both the stator and rotor made up of steel stampings, rotor carries no winding or magnet. The number of poles of the rotor is different from that of the stator. The shaft carries a rotor position sensor which is used to turn on and turn off the various switching semi converter device is influenced by the signals obtained from the rotor position sensor.

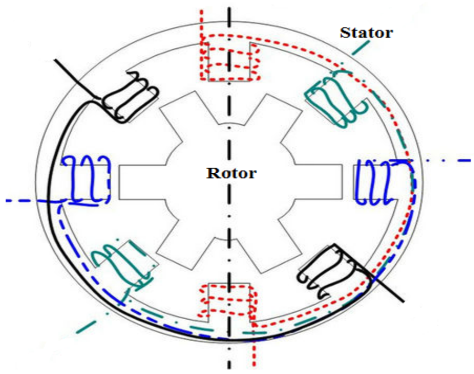

Figure 1. Structure of SRM drive

The motor is excited by a sequence of current pulses applied at each phase. The individual phases are sequentially excited forcing the motor to rotate. When the voltage is applied to the stator phase the motor creates torque in the direction of increasing inductance. The inductance profile of SRM is triangular with minimum inductance when it is an aligned position and minimum inductance when unaligned. It has low cost and simple construction at the same time it’s having high vibration and noise. The switching sequence for clockwise (CW) rotation is given in the Table 1. The structure of SRM drive is shown in Figure 1.

Table 1. Switching Sequence of Hall Sensor Outputs

Hall Sensor Outputs		Switching Sequence			
A	B	1	2	3	4
0	0	0	0	1	1
0	1	0	0	1	1
1	1	1	0	0	1
1	0	1	1	0	0

In [7], the 4Φ SRM drive split-link power converter was implemented because it's having high efficiency, in this converter the two phase windings are connected in the same leg, it will be used to minimize the cost of the power converter and also number of switching devices is reduced. The Figure 2 shows the Split-link converter circuit.

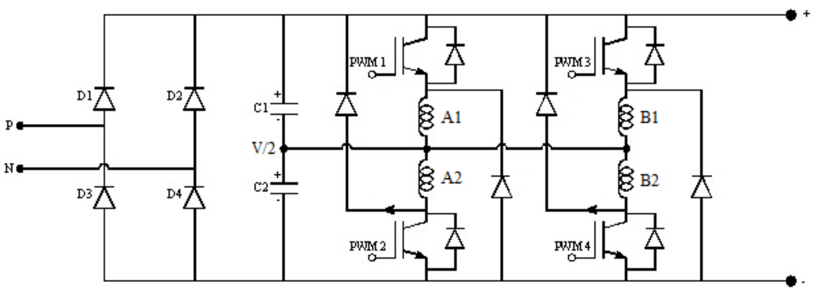

Figure 2. Split-link converter circuit with SRM drive

3. Random Pulse Width Modulation

Random pulse width modulation (RPWM) approaches can make the harmonic spectrum of inverter output voltage be continuously distributed without affecting the fundamental frequency component, and thus the acoustic noise and mechanical vibration of the drive is greatly reduced by varying the random turn on and turn off angle.

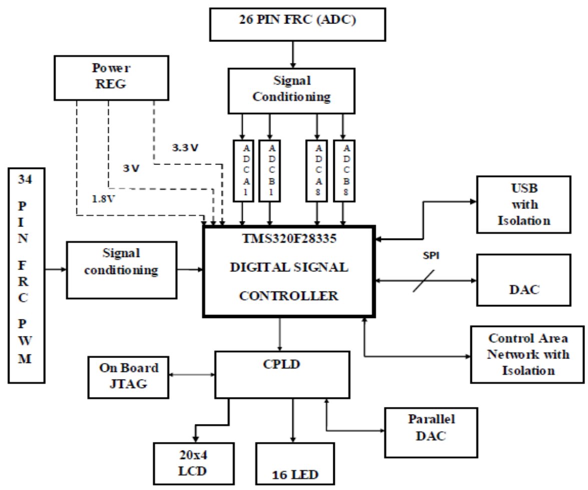

Figure 3. Functional block diagram of DSP controller

Figure 3 shows the experimental Setup with an IGBT inverter driving a 1Hp 4Φ SRM drive. A dc motor was used as the load. The random PWM controller was realized using a TMS320F28335 DSP Evaluation ON Module Board and an IGBT driver circuit. A parallel port for the communication between a PC and control board. Figure 3 Shows the functional block diagram of DSP controller.

4. Vibration and Acoustic Noise Measuring using LabVIEW

Vibration is simply the cyclic or oscillating motion of a machine or machine component from its position of rest.Even machines in the best of operating condition will have some vibration because of small, minor defects.Sound is pressure waves sent out by an object through the medium in which it is immersed. The sound pressure is measured in dB during a noise test.The sound pressure is measured in a SRM drive to eliminate reflected noise and external sources. A accelerometor is placed 1Hp motor to measure sound from different speed and load conditions. As the noise level varies in different load and speed conditions due to the influence of the sources.

In this system both vibration and acoustic noise levels are measured by using Lab VIEW software.Now virtual instrumentation(VI) to create a customized system for test, measurement, and industrial automation by combining different hardware and software components. DAQ systems are concerned with the acquisition, analysis, and presentation of measurements and other data.Acquisition is the means by which physical signals, such as voltage, current, pressure, vibration and temperature are converted into digital formats and brought into the computer. Figure 4 shows the NI cDAQ with vibration sensor.

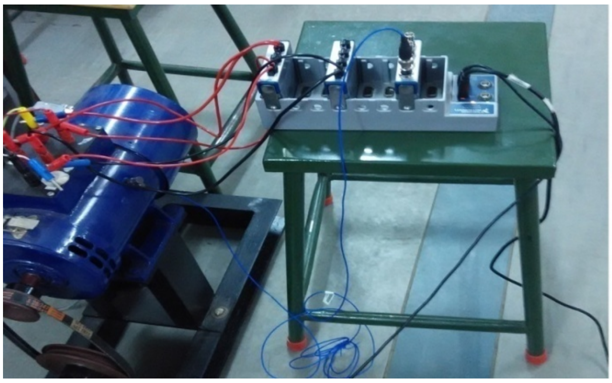

Figure 4. NI cDAQ with accelerometer

NI CompactDAQ makes programming easier because the same driver is used for all measurements. This solution saves space and simplifies service and support. NI 9234 Accelerometer is used to measure the vibration at different speed and load conditions.

5. Hardware Arrangement of SRM Drive

The hardware setup of SRM is a 4phase, 1Hp, 120V, 8/6 pole machine. The SRM power module having the arrangement of rectifier with split-link converter circuit.In this system an encoder type position sensor was used to measure the voltage pulses.DC motor was coupled with SRM shaft,it act as a eddy current load. Hall-effect current and voltage sensors are used to measure the voltage and current. The torque is measured by using load cell; it will indicate the torque values in torque indicator. An accelerometer is mounted on the SRM,it was connected through the NI cDAQ card. The real time vibration signals are measured using Lab VIEW software. The sound level meter is used to measure the acoustic noise by varying the different speed and load. The whole drive system is controlled by DSP (TMS320F28335) processor. The hardware arrangement of SRM drive is shown in Figure 5.

Figure 5. Hardware arrangement of SRM drive

6. Experimental Results Analysis

The experimental results of vibration and acoustic noise for 4Φ SRM drive system was investigated for various load and speed conditions. The mechanical vibration and noise can be analyzed in two PWM techniques; there are Sinusoidal Pulse Width Modulation and Random Pulse Width Modulation techniques.

6.1. Vibration Analysis using SPWM

The vibration response of an electrical machine is usually measured with an accelerometer mounted on the machine housing. The experimental result of vibration for conventional system was investigated for various speed changes and load changes. The vibration can be analyzed with different speed and load conditions.

6.1.1. Speed Changes at 500rpm

The vibration amplitude at a speed of 500 rpm for no load condition is 0.0035mm/s^2. The Figure 6 shows the vibration waveform at 500rpm.

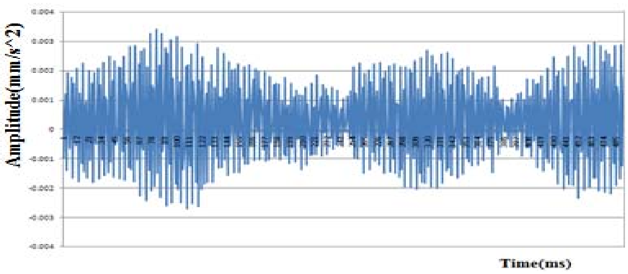

Figure 6. Vibration waveform at 500 rpm

6.1.2. Speed Changes at 1500rpm

The vibration amplitude at a speed of 1500 rpm for no load condition is 0.005mm/s^2. The Figure 7 shows the vibration waveform at 1500rpm.

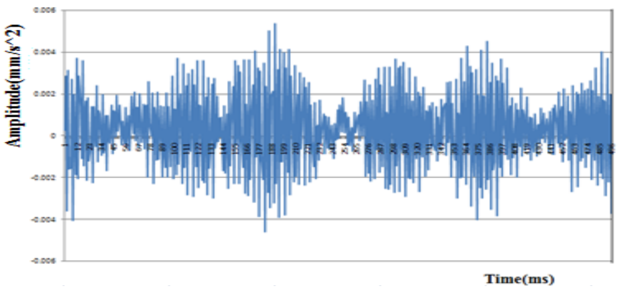

Figure 7. Vibration waveform at 1500 rpm

6.1.3. Speed Changes at 3000rpm

The vibration amplitude at a speed of 3000 rpm for no load condition is 0.006mm/s^2. The Figure 8 shows the vibration waveform at 3000rpm.

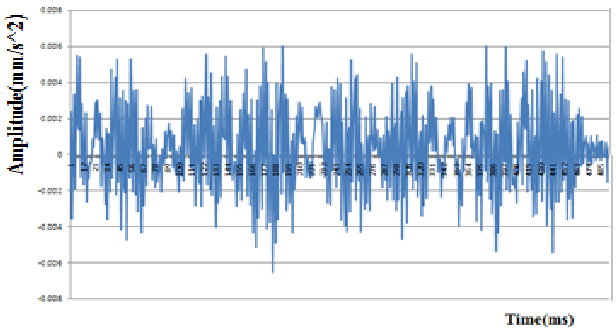

Figure 8. Vibration waveform at 3000 rpm

6.1.4. 25% of Load Analysis

The vibration level at a speed of 2000 rpm for 25% of load condition is 0.0058mm/s^2. The Figure 9 shows the vibration waveform at 25% of load.

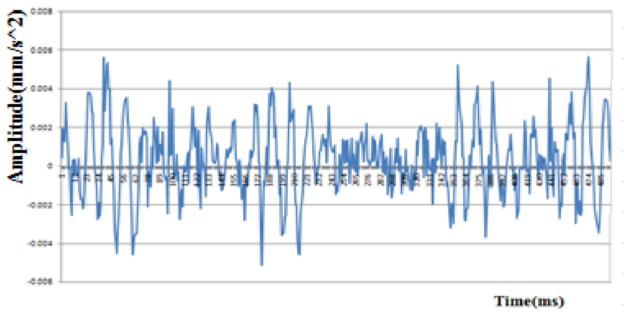

Figure 9. Vibration waveform at 25% of load

6.1.5. Half Load Analysis

The vibration level at a speed of 2000 rpm for 50% load condition is 0.0063mm/s^2. The Figure 10 shows the vibration waveform at half load.

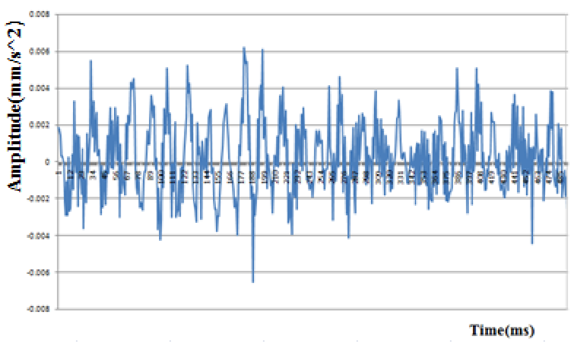

Figure 10. Vibration waveform at half load

6.1.6. Full Load Analysis
The vibration level at a speed of 2000 rpm for full load condition is 0.007mm/s^2. The Figure 11 shows the vibration waveform at full load.

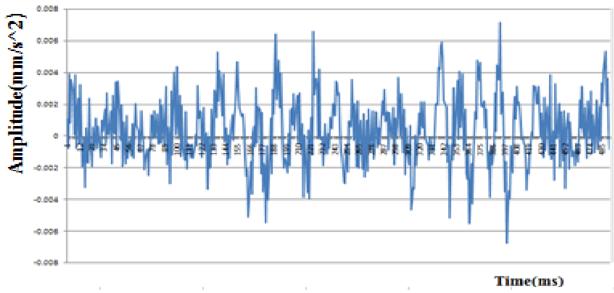

Figure 11. Vibration waveform at full load

6.2. Vibration Analysis using RPWM
In sinusoidal pulse width modulation technique having more vibration but in this proposed method the Random pulse width modulator technique is used to reduce the vibrations at different load and speed conditions.

6.2.1. Speed Changes at 500rpm
The Figure 12 shows the vibration level at a speed of 500 rpm for no load condition is 0.0026 mm/s^2.

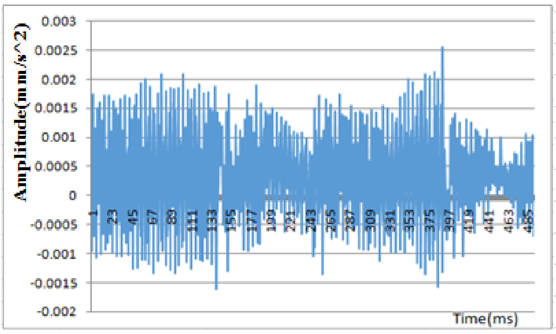

Figure 12. Vibration response at 500 rpm

6.2.2. Speed Changes at 1500rpm
The Figure 13 shows the vibration level at a speed of 1500 rpm for no load condition is 0.0034mm/s^2.

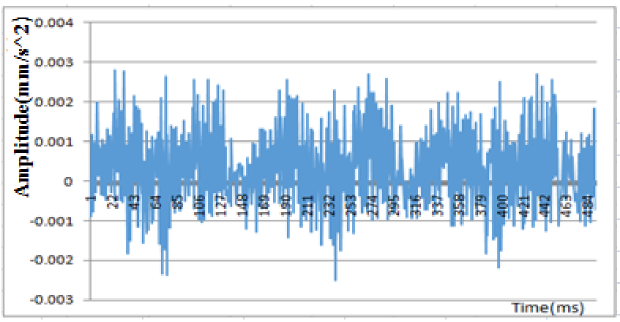

Figure 6.8 Vibration response at 1500 rpm

6.2.3. Speed Changes at 3000rpm

The Figure 14 shows the vibration level at a speed of 3000 rpm for no load condition is 0.0039mm/s^2.

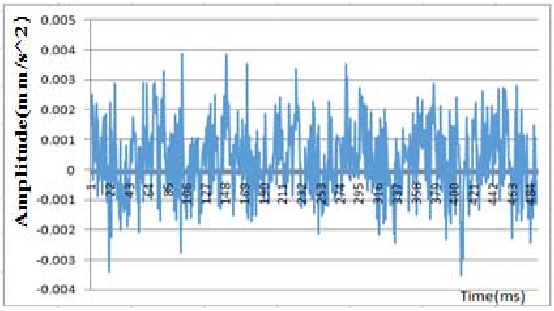

Figure 14. Vibration response at 3000 rpm

6.2.4. 25% of Load Analysis

The vibration level at a speed of 2000 rpm for 25% of load condition is 0.0038mm/s^2. Figure 15 shows the vibration response at 25% of load.

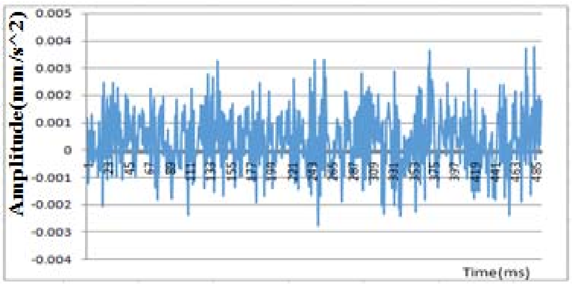

Figure 15 Vibration response at 25% of load

6.2.5. Half Load Analysis

The vibration level at a speed of 2000 rpm for 50% of load condition is 0.004mm/s^2. Figure 16 shows the vibration response at half load.

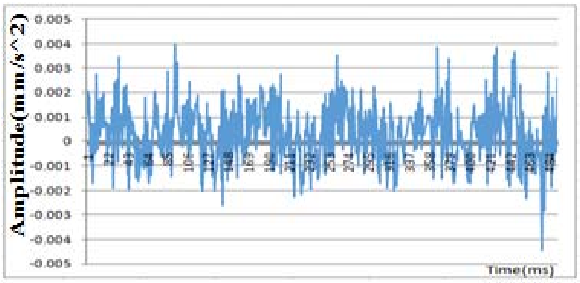

Figure 16. Vibration response at half load

6.2.6. Full Load Analysis

The vibration level at a speed of 2000 rpm for full load condition is 0.0042mm/s^2. Figure 17 shows the vibration response at full load.

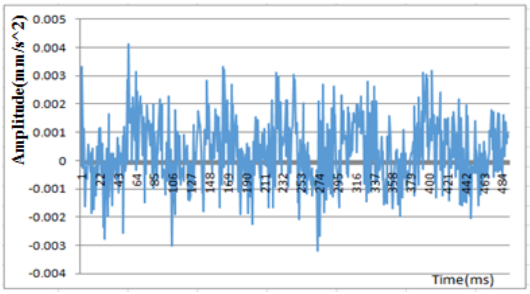

Figure 17 Vibration response at full load

6.3. Comparision

Table 2 shows the various vibrations at different load and speed conditions. The vibrations are compared with SPWM and RPWM techniques.

Table 2. Vibration analysis

Load	Speed	Amplitude(mm/s^2) Sinusoidal Pulse width Modulation (SPWM)	Random Pulse width Modulation (RPWM)
No Load	500	0.0035	0.0026
	1500	0.005	0.0034
	3000	0.006	0.0036
Variable Load	25% Load	0.0058	0.0038
	Half Load	0.0063	0.0040
	Full Load	0.007	0.0042

The various noise analysis are carried out with different load and speed conditions. In 3000 rpm the maximum noise level is 99.2dB, at full load condition the maximum noise level is 103.1dB in SPWM techniques. The Table 3 shows the various noise level with their corresponding speed.

Table 3. Noise analysis

Load	Speed (RPM)	Noise(dB) Sinusoidal Pulse width Modulation (SPWM)	Random Pulse width Modulation (RPWM)
No Load	500	78.1	65
	1000	80.4	70.1
	1500	82.6	80.3
	2000	84.5	82.1
	2500	89.1	84
	3000	99.2	90
Variable Load	500	78.4	66.1
	1000	85.2	79.6
	1500	90.3	86.4
	2000	93.5	88
	2500	100.2	92.2
	3000	103.1	93.5

7. Conclusion

In this paper present the noise and vibration analysis at different load and speed conditions in 4Φ SRM drive. The vibration is measured with accelerometer. It is used to measure the vibrations at various conditions. If full load will be applied to the machine means the more vibrations was occurred after that we use new switching techniques (RPWM), it was reduced the vibrations compared with SPWM techniques. A sound level meter is used to measure the acoustic noise at different speed and load conditions. The experimental results shows the noise and vibration analysis of SRM drive at different load and speed conditions.

References

[1] Adrian David Cheok. DSP-Based Automated Error-Reducing Flux-Linkage-Measurement Method for Switched Reluctance Motors. *IEEE Transactions on Instrumentation and Measurement.* 2007; 56(6): 2245-2253.
[2] Abdel-Karim Daud, Basim Alsayid. DSP Based Simulator for Speed Control of the Synchronous Reluctance Motor Using Hysteresis Current Controller. *Energy and Power Engineering.* 2013: 363-371.
[3] Chris S Edrington. Investigation of Electromagnetic Force Components in SRM under Single and Multiphase Excitation. *IEEE Transactions on Industry Applications.* 2005; 41(4): 978-988.
[4] Jui-Yuan Chai. On Acoustic-Noise-Reduction Control Using Random Switching Technique for Switch-Mode Rectifiers in PMSM Drive. *IEEE Transactions on Industrial Electronics.* 2008; 55(3): 1295-1309.
[5] Michael M Bech. Random Modulation Techniques with Fixed Switching Frequency for Three-Phase Power Converters. *IEEE Transactions on Power Electronics.* 2000; 15(4): 753-761.
[6] Nguyen Minh Khai, Duck-Shick Shin. A New Random Switching Technique for the Single Phase Switched Reluctance Motor Drives. *IEEE Transtaction.* 2007: 1778-1783.
[7] Prasad. DSP based Speed Control of 4 phase 8/6 Switched Reluctance Motor Drive using DC Split Converter. *J. Electrical Systems.* 2012: 47-56.
[8] Paramasivam, Arumugam. Real time DSP-based adaptive controller implementation for 6/4 pole switched reluctance motor drive. *Songklanakarin J. Sci. Technol*. 2005: 523-534.
[9] Ramasamy G, Rajandran RV. Modeling of Switched Reluctance Motor drive System using Matlab/Simulink for Performance Analysis of Current Controllers. *IEEE Transaction.* 2005: 892-897.
[10] Raul Rabinovici. Torque ripple, vibrations, and acoustic noise in switched reluctance motors. *HAIT Journal of Science and Engineering.* 2(5-6): 776-786.