Switched Reluctance Motor Controller Design Using Novel Cam Positioner

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***Abstract* — This paper presents the idea of manufacturing and fabricating a controller for four phase, 8/6 poles switched reluctance motor (SRM). The experimental results drawn from this controller are showing that the efficiency is a function of the applied voltage to the stator winding due to load variation, and found the best applied voltage that produced a better efficiency by this system is 85 VDC. The speed reaches 3070 RPM by this controller; the main focus of this paper is the role of the controller. Zero reference proximity switch, absolute encoder, the electronic cam positioner, the classic converter, (10 – 150) VDC main supply and the mentioned motor have been employed to perform this drive system.**

***Index Terms* — Switched Reluctance Motor, Controller, Variable Reluctance Motor**

I.INTRODUCTION

The reluctance motor operates on the principle that a magnetically salient rotor is free to move to a position of minimum reluctance to the flow of flux in a magnetic circuit. The phenomena have been known ever since the first experiments on electromagnetism. In the first half of the 19th century, scientists all over the world were experimenting with this effect to produce continuous electrical motion.

In 1838, W. H. Taylor obtained a patent for an electromagnetic engine in the United States and subsequently on 2nd May 1840 he was granted a patent [1] in England for the same engine. The engine was composed of a wooden wheel on the surface of which was mounted seven pieces of soft iron equally spaced around the periphery. The wheel rotated freely in a framework in which four electromagnets were mounted.

The electromagnets were connected to a battery through a mechanical switching arrangement on the shaft of the wheel such that excitation of an electromagnet would attract the nearest piece of soft iron, turning the wheel and energising the next electromagnet in the sequence to continue the motion.

However these motors and other subsequent inventions all suffered from torque pulsations and were soon superseded by the invention of the d.c. machine and the a.c. induction machine. Over 140 years after these early experiments, the advent of suitable power electronic switches has meant that the mechanical commutator of the early reluctance motors can be replaced by an electronic one. The modern research work commenced in early eighties by Lawrenson and associates at University of Leeds, UK [2,3] and Ray, Davis and Blake at University of Nottingham [4,5,6]. Improved magnetic materials and advances in machine design have brought the switched reluctance motor into the variable speed drive market [7]. Unlike induction motors or d.c. motors the reluctance motor cannot run directly from an a.c. or d.c. supply. A certain amount of control and power electronics must be present. The power converter is the electronic commutator, controlling the phase currents to produce continuous motion. The control circuit monitors the current and position feedback to produce the correct switching signals for the power converter to match the demands placed on the drive by the user. The purpose of the power converter circuit is to provide some means of increasing and decreasing the supply of current to the phase winding. Many different power converter circuits and control strategies have been proposed for the switched reluctance motor [4-12].

II.CONVERTER TOPOLOGY FOR CONTROLLER

The basic requirement for the converter of the SRM to be built is that, each phase of the SRM should be able to conduct independently of the other phases. The most versatile SRM converter topology is the classic bridge converter topology with two power switches and two diodes per phase as shown in Fig. 1. This type of converter has been used for the present controller. Fig. 2 shows the four modes of operation of the converter. During the conduction mode of winding L1 for phase A, both switches (Q1 and Q5) are in ON state. The input dc source magnetizes this phase. This mode is usually initiated before the start of the rotor and stator pole overlap, so that the phase current reaches the reference value before the phase inductance begins to increase.

This helps to reduce the torque ripple. When current reaches the reference value the converter steps into current regulation mode. In this mode the current is maintained at the reference value by switching one of the phase switches while leaving the other one continuously ON until the commutation time starts. Both the phase switches are turned OFF to initiate the commutation and phase starts to demagnetize through the two diodes. During the commutation the off-going phase winding sees a voltage of – $24V_{dc}$. While one phase is demagnetizing, another phase is magnetized. This helps to reduce the torque ripple during the commutation. The advantages of this converter topology are:

- Control of each phase is completely independent of the other phases.
- The voltage rating of all the switching devices and diodes is $24V_{dc}$, which is relatively low.
- The converter is able to freewheel during the chopping period at low speeds, which helps to reduce the switching frequency and thus the switching losses of the converter.
- The energy from the off-going phase is transferred back to the source, which results in useful utilization of the energy. The main disadvantage of this topology is the higher number of switches required in each phase which makes the converter expensive. Further, for low-voltage applications the forward voltage drops in two devices may be significant compared to the available dc bus voltage.

The connections of the PLC output card and the converter are:

1. The MOSFET (Q1 & Q5) are getting the control signal from the output terminal O3:0/0 of card #3 located in the PLC.
2. The MOSFET (Q2 & Q6) are getting the control signal from output terminal O3:0/1 of card #3 located in the PLC.
3. The MOSFET (Q3 & Q7) are getting the control signal from output terminal O3:0/2 of card #3 located in the PLC.
4. The MOSFET (Q4 & Q8) are getting the control signal from output terminal O3:0/3 of card #3 located in the PLC.

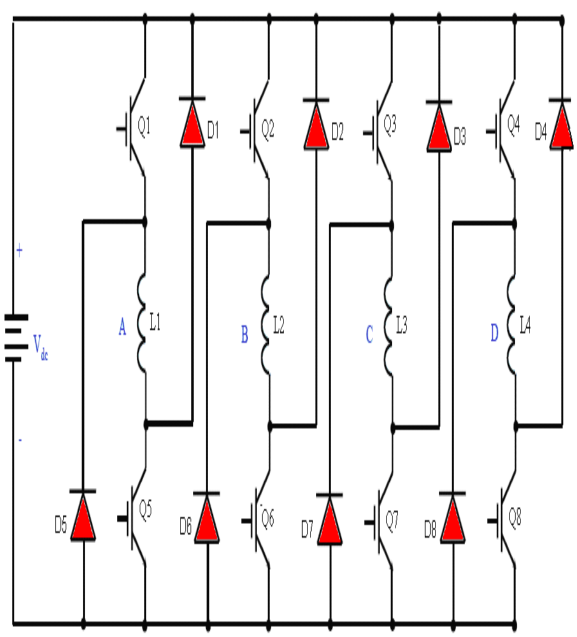

Fig. 1: SRM Classic Converter.

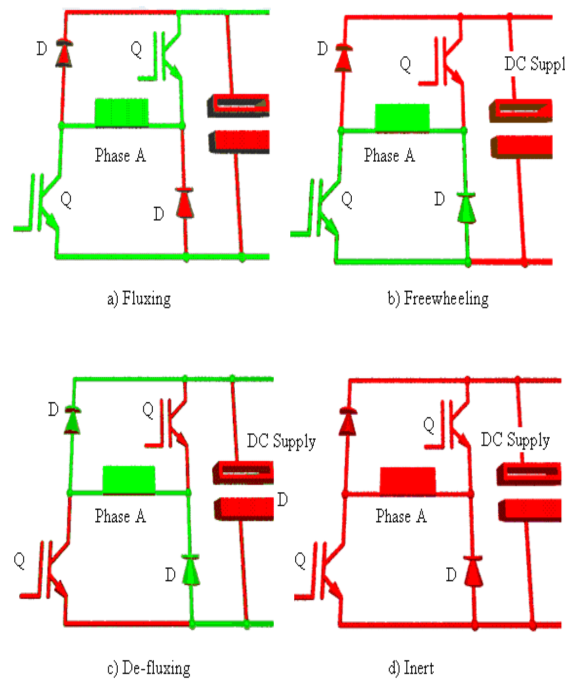

Fig. 2: The Four-Modes of Operation of Classic Converter

III. TRACKING SYSTEM FOR THE ROTOR POSITION.

The electronic cam positioner and absolute encoder were employed in this type of controller as shown in Fig. 3. The shaft of the switched reluctance motor is coupled to the shaft of the encoder through coupling. The terminals of absolute encoder are connected to electronic cam positioner to get the exact position of rotor. The output of the cam positioner in this controller is 24 V_{dc} delivered to the control side (MOSFETS INPUTS) of the converter according to the set values of the dwell angle (firing angle) for each phase.

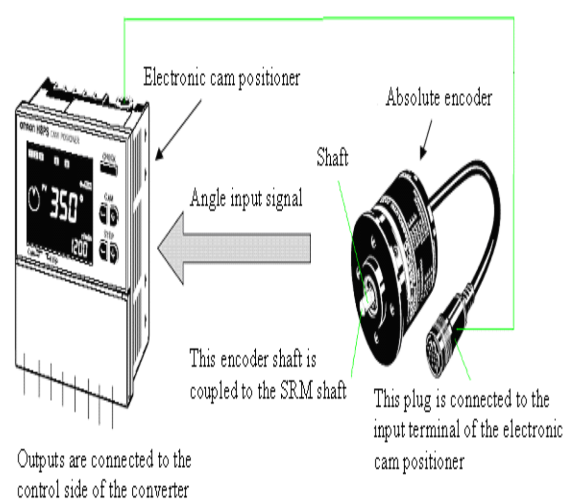

Fig. 3: Connection of the Cam Positioner, Absolute Encoder and Connections.

Fig. 4 shows the block diagram of control system used for SRM. The absolute encoder reads the rotor angle displacement and sends data to the electronic cam positioner, which is used as a controller. Zero degree for the rotor location is set on the electronic cam positioner. According to the firing angle program DC voltage is fed to control side of the converter (input terminals of the MOSFET). The MOSFET will not turn ON until the fed control signal from the electronic cam positioner is turned ON. As a result the DC power supply will be fed to SRM windings. The developed torque attracts the rotor toward the activated coil and moves it from intermediate (misaligned) to aligned positions. Soon the rotor and stator poles are aligned to each other. At this position, the voltage is disconnected from the specific coil winding and will activate the next coil of the following phases, controlled by the firing angle program.

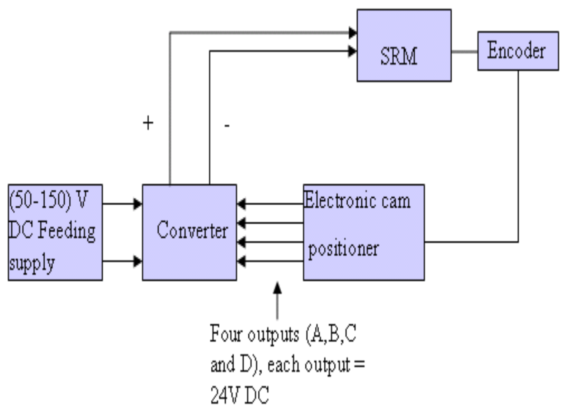

Fig. 4: The Block Diagram for the Control System of SRM.

IV.FIRING ANGLE SEQUENCE FOR THE ELECTRONIC CAM POSITIONER

To explain the suggested firing angle program, it is better to show the three positions for the 8/6 poles SRM. Fig. 5 shows both the stator and rotor poles are distributed symmetrically. The positions defined with respect to phase A, as shown in Fig. 5a, is the aligned position. Fig. 5b shows the unaligned position and Fig. 5c shows the intermediate (misaligned) position.

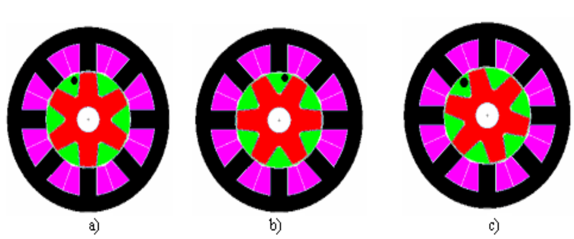

Fig. 5: Structure of an 8/6 SRM: a) Aligned position, b) Unaligned position, c) Misaligned position

From the misaligned position of the rotor and stator poles, the firing angle sequence program can be built. One single revolution is equal to 360 degrees, and as the 8/6 SRM motor has 4 phases, the number of degrees allocated to four phases is 60 degrees, as calculated below:

$$\frac{One \quad revolution}{No.\ of \quad rotor \quad poles} = \frac{360}{6} = 60^{\circ} \quad \text{for four phases}$$

Degrees of angle displacement for each phase:

$$\frac{Degrees \quad for \ 4 \ phases \ = 60}{No \ of \quad phases \ = 4} = 15^{\circ} \text{ for each phase.}$$

The electronic cam positioner sends a DC voltage control signal output each 15 degrees to the input terminal of the MOSFET. The firing angle or the dwell angle (15 degrees) supposed to be ON and OFF six times (six steps) for each phase.

One revolution is equal to:

360 degrees = dwell angle × no of phases × no of steps

$$= 15 \times 4 \times 6 = 360$$

Practically the maximum value of 360 degrees cannot set, because it means zero as well and the zero has been used in the program, so the last value is set as 359 degrees. The dwell angle = off angle – on angle.

Fig. 6 shows the dwell angles for step # 0 and step # 1 for four phases and they are;

The firing angles of phase A for step # 0 is:
θ_{on} = 0 degrees, θ_{off} = 15 degrees.
The firing angles of phase A for step # 1 is:
θ_{on} = 60 degrees, θ_{off} = 75 degrees.
The firing angles of phase B for step # 0 is:
θ_{on} = 15 degrees, θ_{off} = 30 degrees.
The firing angles of phase B for step # 1 is:
θ_{on} = 75 degrees, θ_{off} = 90 degrees.
The firing angles of phase C for step # 0 is:
θ_{on} = 30 degrees, θ_{off} = 45 degrees.
The firing angles of phase C for step # 1 is:
θ_{on} = 90 degrees, θ_{off} = 105 degrees.
The firing angles of phase D for step # 0 is:
θ_{on} = 45 degrees, θ_{off} = 60 degrees.
The firing angles of phase D for step # 1 is: θ_{on} = 105 degrees, θ_{off} = 120 degrees.

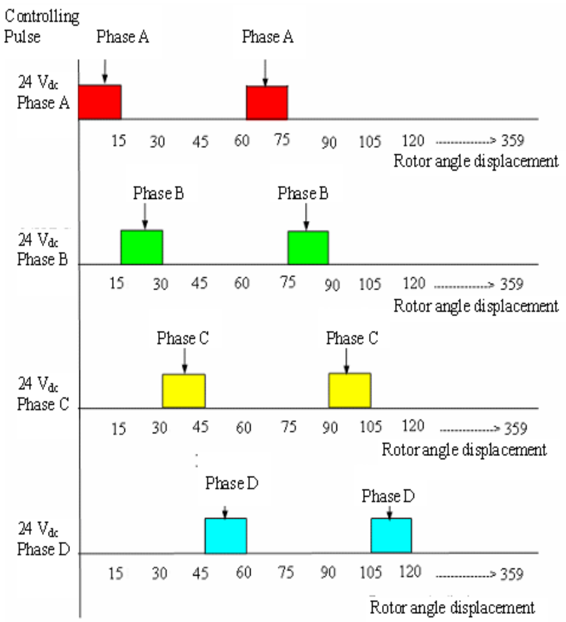

Fig. 6: Firing Angle Sequence of the 4 Phases for Step # 0, and Step # 1.

Table 1 shows the code for the firing angle that programmed the electronic cam positioner for controlling the 4 phase 8/6 poles SRM.

Table 1: Firing Angle Sequence for the Electronic Cam Positioner

	Step 0		Step 1		Step 2		Step 3		Step 4		Step 5	
	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off
Phase A (1)	0	15	60	75	120	135	180	195	240	255	300	315
Phase B (2)	15	30	75	90	135	150	195	210	255	255	315	330
Phase C (3)	30	45	90	105	150	165	210	225	270	285	330	345
Phase D (4)	45	60	105	120	165	180	225	240	285	300	345	359

V.SRM AND ITS CONTROLLER.

Fig. 8 shows a general view of the SRM and its controller with various components. The controller is an electronic cam positioner, that can easily be configured. One input (proximity switch) located in the SRM, used this proxy to identify the zero degree for the rotor. Four outputs are connected to the control side of the converter.

The converter is supplying the DC voltage to each individual phase A, B, C or D of SRM according to the firing angle sequence program of the electronic cam positioner. The power supply employed for this SRM is (50-150) V_{dc}. However the maximum applied voltage is 95 V_{dc}. Four outputs are connected to the input control of the MOSFET converter. The speed of the switched reluctance motor through this controller is greater than 3000 RPM.

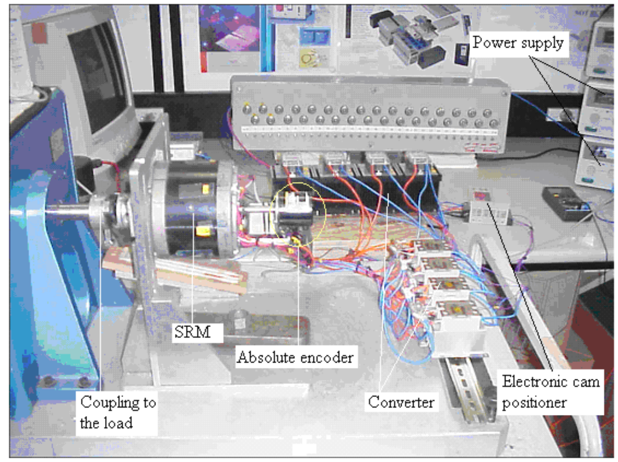

Fig. 8: SRM and Controller.

VI.EXPERIMENTAL RESULTS

Table 2 shows the efficiencies results of applying different voltages to the stator winding. The maximum efficiency for the tested motor is 82% when the applied voltage to the stator winding is 85 V_{dc}. The minimum efficiency is 56.1% when the applied voltage is 23 V_{dc}. It can be easily said that the maximum efficiency occurs at optimum voltage and hence the flux. Further increasing the voltage, reduces the efficiency which can be attributed to saturation of the magnetic circuit.

Table 2: Maximum Efficiencies for Different Applied Voltages to the Stator winding

23	0.561
30	0.627
40	0.7
50	0.724
60	0.753
70	0.763
80	0.79
85	0.82
90	0.762
95	0.746

VII.CONCLUSIONS

The control system for SRM employed the cam positioner and the absolute encoder. The absolute encoder reads the rotor angle displacement sending data to the electronic cam positioner, which is used as a controller. It starts according to the firing angle program to set an output control DC voltage to the input control of the MOSFET converter.

The speed of the SRM with this controller is varying from 130 to 3070 RPM according to the applied voltage to the stator winding, which starts from 23 to 95 V_{dc}. The maximum efficiency for the tested motor is 0.82 when the applied voltage to the stator winding is 85 V_{dc}. The original efficiency of the base motor is 0.76. It is hoped that by proper design and control, the efficiency can be further improved.

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