Hardware Implementation of Producing Variable Conduction Angles of a Switched Reluctance Motor

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ABSTARCT

In this paper the hardware implementation of producing the voltage pulses of variable duty cycle which are applied at the gate driver terminal of the switching devices used in the converter of a switched reluctance motor have been presented. These voltage gated pulses which corresponds to phase excitation sequence of the motor are necessary to run the motor. The proposed counter was tested in the laboratory with the 8/6 poles drive, and operation of the machine at variable conduction angles was found to be excellent. The implemented method of producing the variable conduction angles is simple, cheaper and easy to implement and does not require prior knowledge of programming.

Key Words: **Conduction Angle, Count Sequence, Up/Down Counter, Switched Reluctance Machine**

1. INTRODUCTION

Switched reluctance motor has salient poles on stator and rotor. Laminated rotor of the motor carries no winding, whereas stator carries winding only. The stator and rotor have different number of poles. The windings which are connected in series with power semiconductor switches form a phase. Usually the SR machine has a multi-phase arrangement [1].

The doubly-salient pole structure of the motor results in non-linear magnetic behaviour and magnetic saturation of the motor.

Proper position dependent switching relative to inductance profile, electronic control and magnetic circuit are key factors for the performance of switched reluctance motor [1].

For optimal operation of the motor, the necessity of selection of the appropriate switch-on and conduction angles is inevitable. The switch gate signals relative to the rotor position are applied at the gate-emitter terminal of the switching devices which are used in the converter of the motor.

A conduction angle can be defined as the duration of the gate pulse for which the switching device remains in its' conduction state or 'ON' state.

The literature review presented in this paper is mainly related with the basic control parameters of the drive system which are switch-on, switch-off and chopping current level. Foremost is the hardware design of the counter to produce the variable conduction angles. A digital angle control of the drive in which the digital angle controller receives the

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angle commands from feedback loop and translates them into transistor conduction angle has been presented in [2]. The microcomputer based control has presented control functions such as feedback control with speed loop, sequencing control, starting and position synchronized angle control [2].

The commutation of switched reluctance motors using two-or-three position sensors has been described in [3] also possible sets of angles called modes are presented by simulated and experimental results.

Another work presented in [4] used the fuzzy controller which was implemented by using a digital signal processor to minimize torque ripple in the motor. The issue of advance angle and appropriate conduction angle has also been addressed. A DSP (Digital Signal Processing) controller has been developed to perform efficiency optimization and an adaptive turn-on angle control strategy to improve the phase current profile with minimum rms [5].

The effect of turn-on and conduction angles on torque production has been discussed in [6]. A moveable conduction angle control using digital tuning technique based on BCD (Binary Code Decimal) code has been given in [7].

The work discussed in [2-7] has a number of drawbacks such as expensive, requires more time and knowledge of the programming.

This paper focuses in particular on the hardware implementation of up/down counter for producing the low frequency switching gated signals applied to switching devices used in the converter. These voltage pulses define the phase excitation sequence of the machine. The advantage of this work is that it is cheaper, does not require any knowledge of programming and easy to implement. The experimental results have been compared with the original gate signal obtained from the encoder of the existing machine shown in Fig. 1 [1] to validate the accuracy of the results.

2. CURRENT WAVEFORM

The general equation for stator current of the machine is given by:

$$\upsilon = Ri + \frac{d\Psi}{dt} \tag{1}$$

where v is represents applied voltage and ψ is flux linking the coil.

Equation (1) can be written as:

$$\upsilon = L + \frac{di}{dt} + \frac{dL}{d\theta} \times \omega \tag{2}$$

where ω is the rotational speed in rad/sec. The rate of flow of the energy is given by

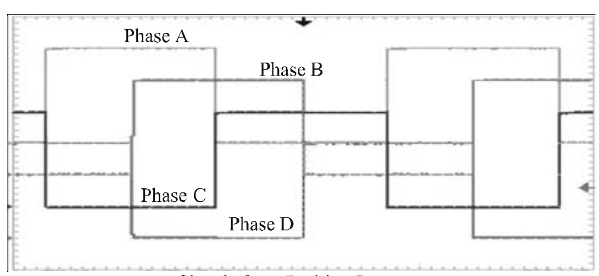
$$\upsilon i = \frac{dt}{dt}\left(\frac{Li^2}{2}\right) + \frac{i^2}{2} \times \frac{dL}{d\theta} \times \omega \tag{3}$$

where the first term on right hand side of the equation shows the rate of increase of stored magnetic energy and the second term is the power converted from electrical energy to mechanical output power.

The torque equation neglecting magnetic non linearity

$$T(\theta, i) = \frac{i^2}{2} \times \frac{dL}{d\theta} \tag{4}$$

The switch-on angle is selected at minimum inductance allowing the current to rise to its maximum value and then rising inductance and motional emf cause the current to reduce until switch is opened at desired switch-off



Signals from Position Detector

FIG. 1. VOLTAGE PULSES OBTAINED FROM THE ENCODER OF AN EXISTING MACHINE; A, B, C, D, DEFINE VOLTAGE GATED PULSE FOR PHASE A, PHASE B, PHASE C AND PHASE D

angle as shown in Figs. 2-3. The current falls rapidly under influence of opposite polarity of applied voltage [8]. The simulation results of the current waveforms shown in Fig. 2 produced under variable conduction angles as indicated with switch-on angles selected in advance of the start of the rising inductance, and fixed switch-off angle selected before the inductance reach to its maximum value.

Similarly, Fig.3 shows the simulation results of current waveforms under different conduction angles with a fixed switch-on angle. The turn-on and turn-off angles (conduction angle is difference between turn-off and turn-on angle) are selected in the increasing inductance which contributes positive torque (motoring torque).

3. EXPERIMENATL RSULTS

There are different counters available such as up/down counter, 555 counter, ripple counter, divide-by-N-counter, synchronous counter etc. The counters normally count in binary and are triggered by the clock pulse. An up/down counter is shown in Fig. 4.

Low frequency and clock signals are obtained from the encoder which is mounted on the shaft of the existing switched reluctance motor.

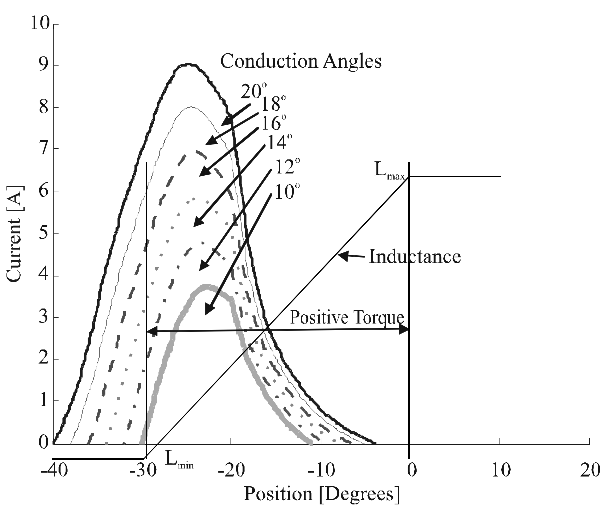


FIG. 2. CURRENT WAVEFORMS AS A RESULT OF VARIABLE CONDUCTION ANGLES AT FIXED SWITCH-OFF ANGLE [VOLTAGE=100V, SPEED = 1000RPM, RESISTANCE=2.5]

In order to synchronize the rising edge of the low frequency gate signal with rising edge of clock signal, a hysteresis comparator was designed and hence later was attuned such that both signals were properly synchronized at their rising edge.

The terminal $(\overline{UP/DOWN})$ is always held low. The enable terminal $(\overline{CARRY\ IN})$ is active low, the counter advances down on each positive-going clock transition [9]. The counter counts down from the PRESET VALUE. As soon as the count reaches zero, it activates the $(S-R)$ Latch and disable the count.

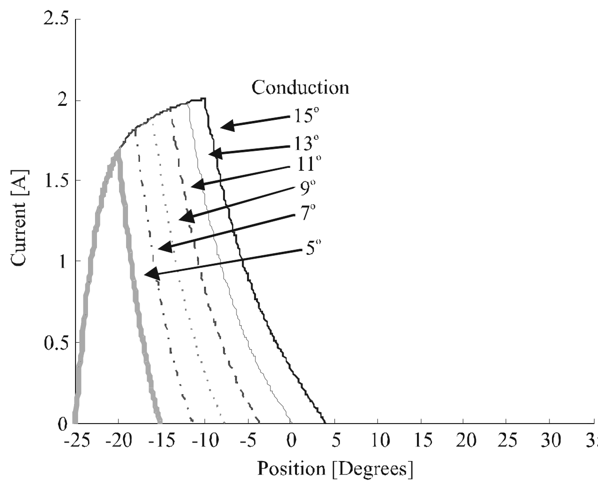


FIG. 3. CURRENT WAVEFORMS PRODUCED AS A RESULT OF VARIABLE CONDUCTION ANGLES AT FIXED SWITCH-ON ANGLE [VOLTAGE=100V, SPEED=1000RPM, RESISTANCE=2.5]

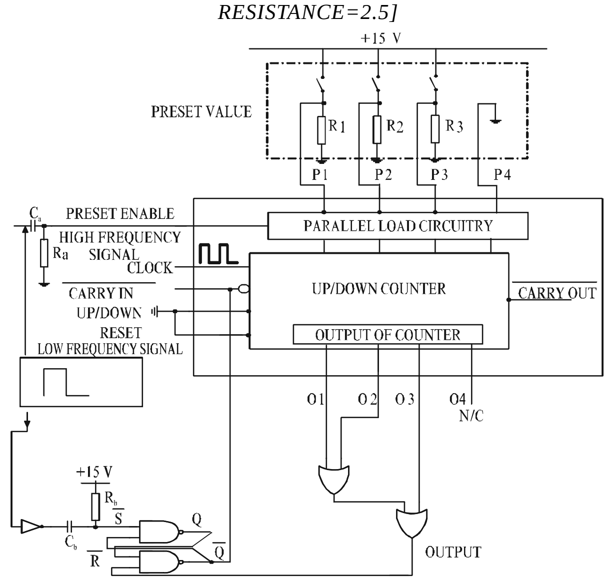


FIG. 4. UP/DOWN COUNTER

The truth table shown in Table 1 gives the binary count sequence for the counter. The required variable conduction angle is also presented. The input switch gate signal obtained directly from the encoder of the machine is compared with the output of counter to validate the accuracy which is found to be excellent. This is depicted in Fig. 5.

The hardware design of the counter consisted of about ten ICs on the breadboard. Due to the complexity of the circuit, the decoupling capacitor across each IC separately was introduced to decouple one part of circuit from another.

4. CONCLUSION

The hardware developed and implemented for producing the variable conduction angles of the switching devices for the converter of a switched reluctance motor. The developed hardware is easy to implement and does not require any prior knowledge of the programming. The validation of the experimental results shows good agreement.

TABLE 1. BINARY COUNT SEQUENCE FOR COUNTER

Q_2	Q_1	Q_0	Count	Conduction Angle [Degree]
0	0	0	0	0
0	0	1	1	5
0	1	0	2	10
0	1	1	3	15
1	0	0	4	20
1	0	1	5	25
1	1	0	6	30

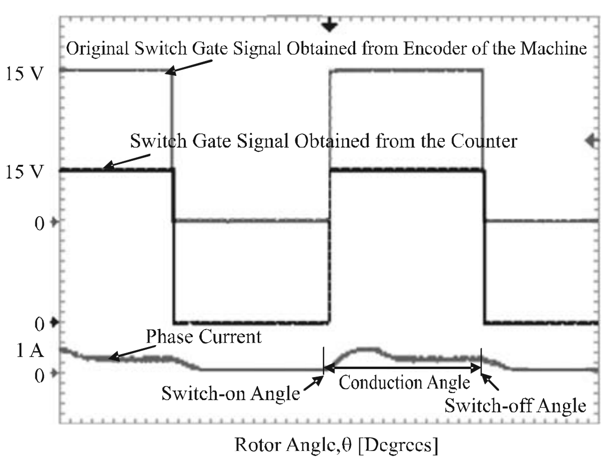


FIG. 5. OSCILLOSCOPE TRACES OF SWITCH GATE SIGNALS AND PHASE CURRENT

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