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Inductance Based Sensorless Control of Switched Reluctance Motor

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ABSTRACT

This paper presents a sensorless control of switched reluctance motor (SRM) driven by the four phase asymmetric bridge inverter. In this method to obtain the rotor position of switched reluctance motor by means of resonant circuit method. The resonant circuit comprising of the motor and the power electronic converter, motor phase inductance and the parasitic capacitance of converter switches. For salient machines, in general, the associated resonance frequency of the circuit depends on the rotor position. The method is characterized by the fact that very short voltage pulses are used to trigger resonance between the magnetic energy stored in the phase inductances and the energy stored in parasitic capacitances associated with the power semiconductor devices, power cables and motor phase windings. The analysis, design and simulation of indirect rotor position estimation of SRM is simulated using MATLAB SIMULINK.

Keywords: Position estimation, Resonance, Switched Reluctance Motor, Short Voltage Pulse.

1. INTRODUCTION

Switched reluctance motor (SRM) has been widely investigated in recent years due to its several advantages, such as rugged and simple structure, low construction cost, lack of permanent-magnet, high reliability and good performance over wide speed range; these advantages make SRM a competitor to other motor technologies for various applications including electric vehicles and consumer electronics.

One class of sensorless methods for switched reluctance motors is based on the excitation of a series resonant circuit comprised by the position-dependent inductance of an idle motor phase, an external capacitor and a resistor.

It is shown that the combination of motor and converter can be modelled by means of a number of resonant circuits which are mutually coupled due to the magnetic inductive coupling between motor phases [1]. By means of an eigenmode analysis, the influence of voltage pulses, applied to a single phase or simultaneously applied to different phases, on the initiated resonances, and thus on the rotor position estimation, is measured.

The cross sectional view of 8/6 SRM is shown in the Fig. 1 It consists of eight stator poles and six rotor poles. Each phase is energized separately using power electronic converter circuits. The windings are on the stator only, with no windings or magnets on the rotor, thus saving materials on the rotor. Torque ripple is high but can be reduced by controlling the overlapping phase currents.

2. SENSORLESS ROTOR POSITION ESTIMATION

A Mechanicalsensorless rotor position estimation is considered desirable because of compactness in weight and volume, lower cost due to elimination of the mechanical assembly and mounting associated with a

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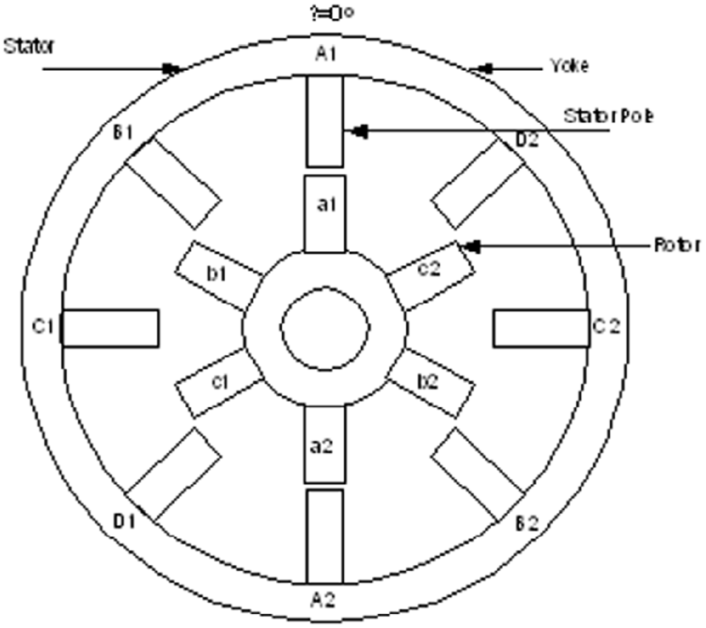

Figure 1: Cross Sectional View of 8/6 SRM.

rotor position sensor, and no rotating parts and no wear and tear, thus no maintenance requirements for its life. The driving factor behind sensorless operation of any electrical drive including that of SRMs is the quest for low-cost drives with high performance [2],[3]. Three broad classes of rotor position estimation have emerged in research and development:

1. Observer-based schemes give a continuous estimation of rotor position.
2. Incremental inductance-based measurement uses current rise time or fall time or its magnitude to obtain discretely the rotor position.
3. Inductance-based estimation of rotor position uses the two different techniques of demodulation and constant current or constant flux linkage applied to sensor signals and sensing phases, respectively, to give a continuous estimation.

3. INDUCTANCE BASED ESTIMATION

The relationship between inductance and rotor position for each excitation current is unique over half a rotor pole pitch regardless of the rotor speed. This particular feature of an SRM is then used to find the rotor position from the estimated or measured inductance of a machine phase winding from the stored information of inductance vs. rotor position for each current in the control circuit [4], [5]. The burden of storing the inductance vs. rotor position information for all currents could be simplified in many ways and is discussed elsewhere.

4. RESONANT CIRCUIT METHOD

In this method, a signal is injected into an inactive phase at a frequency to produce resonance at the unaligned position of the rotor [6]. The impedance measured only reflects the resistive component and the reactance component given by the difference between the aligned and unaligned inductive reactance. This resonant frequency has to be smaller than the frequencies at which the equivalent reactance becomes capacitive and usually is the case [7]. The reactance at very high frequencies is capacitive because of the inter-turn winding capacitance.

In order to appreciate the effects of the frequency on the measured equivalent resistance and reactance of the circuit in the inactive phase, consider the per-phase equivalent circuit of the SRM with core losses.

The core losses are modelled through a resistive element, *Rc,* across the inductor and motional emf. The core loss resistor may be considered a constant. Note that the motional emf is given by:

$$e = i_o \omega_m \frac{dL}{d\theta} = R_{em} i_o \tag{1}$$

The term given by the product of the speed and rate of change of inductance with respect to rotor position resembles a resistor, *Rem*. This resistor part of the motional emf is small compared to the inductive reactance of the machine, particularly at a resonant frequency that is in the range of a few kHz to tens of kHz [8]. Neglecting then this component, the resulting equivalent circuit is shown in Fig. 2. From this circuit, the series equivalent circuit may be derived with a resistance $R_{eq}$and inductance L_{eq}as shown in Fig. 3. In terms of the circuit parameters R_s, $L(\theta)$, and excitation frequency ω_c, they are derived as:

$$R_e = R_s + \frac{\omega_c^2 \tau_c^2}{1 + \omega_c^2 \tau_c^2} R_c \tag{2}$$

$$L_e = \frac{L(\theta)}{1 + \omega_c^2 \tau_c^2} \tag{3}$$

Where

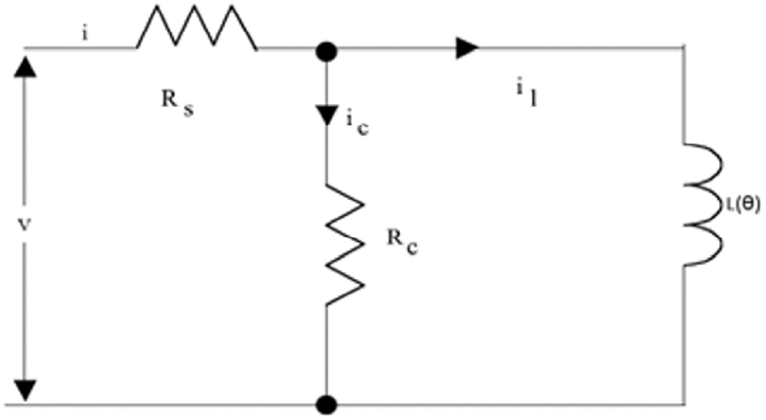

Figure 2: Simplified per-phase equivalent circuit of the SRM.

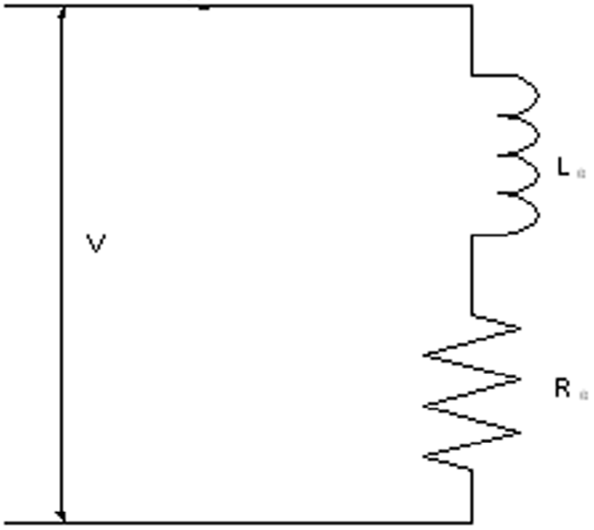

Figure 3: Series per-phase equivalent circuit of the SRM.

$$\tau_c = \frac{L(\theta)}{R_c} \tag{4}$$

For a given frequency, as the inductance increases when the rotor poles move from the unaligned to the aligned position with the stator poles, the time constant τ_c increases and the equivalent resistance increases, whereas the equivalent inductance decreases.

The effect of an increase in the excitation frequency ω_c as seen from the derived relationships is that, for the same rotor position, there is a significant increase in the equivalent resistance but a decrease in equivalent inductance. Therefore, using only a measurement of inductance in this circuit will not yield measurements with high resolution as the equivalent inductance becomes a constant over a larger portion of the region between the unaligned and aligned rotor positions.

Alternatively, the resonant method increases resolution of the measured impedance by designing resonance at the unaligned position by selecting a capacitor to be connected in series with the machine phase. Here, the impedance is measured against the inductance. Note that at the unaligned position the measured impedance equals only the equivalent resistance of the circuit, whereas at the aligned position the impedance will be due to the equivalent resistance and the differential inductance between the aligned and unaligned positions [9].

This increases the resolution of the impedance significantly compared to the method without the capacitor. The resonant frequency is given by:

$$\omega_{rs} = \frac{1}{\sqrt{CL_e}}, rad/\sec \tag{5}$$

where C is the value of the external capacitor included in series with the inactive phase.

The impedance, inductance, and rotor position are obtained by demodulating the current and locking on its peak in each excitation period [10]. With the proper locking arrangement, the noisy interference from the switching phase can be excluded. One such arrangement may be devised by setting the switching frequency of the active phase very differently from the resonant frequency of the inactive phase.

5. SIMULATION OF SWITCHED RELUCTANCE MOTOR FOR FOUR PHASE

The simulation is done by a four phase asymmetrical bridge inverter is shown in Fig. 4. This circuit consists of two switches and two diodes per phase as shown in the Fig. 5. The switches are used for energizing the winding and the diodes are used in the recharging of the source when the phases are turned off.

For energizing of the Phase 1 winding the switch S1 and S2 are being turned ON and during the energizing of the phase 2 winding the switches S1 and S2 are turned OFF and S3 and S4 are turned on and the diodes start conducting in forward biasing state and phase 1 winding is recharging of the source.

5.1. Model Description

This simulation presents a 0.5hp 8/6 SRM drive using the SRM specific model based on measured magnetization curves. The SRM is fed by a four-phase asymmetrical power converter having four legs, each of which consists of two IGBTs and two free-wheeling diodes. During conduction periods, the active IGBTs apply positive source voltage to the stator windings to drive positive currents into the phase windings. During free-wheeling periods, negative voltage is applied to the windings and the stored energy is returned to the power DC source through the diodes. The fall time of the currents in motor windings can be thus

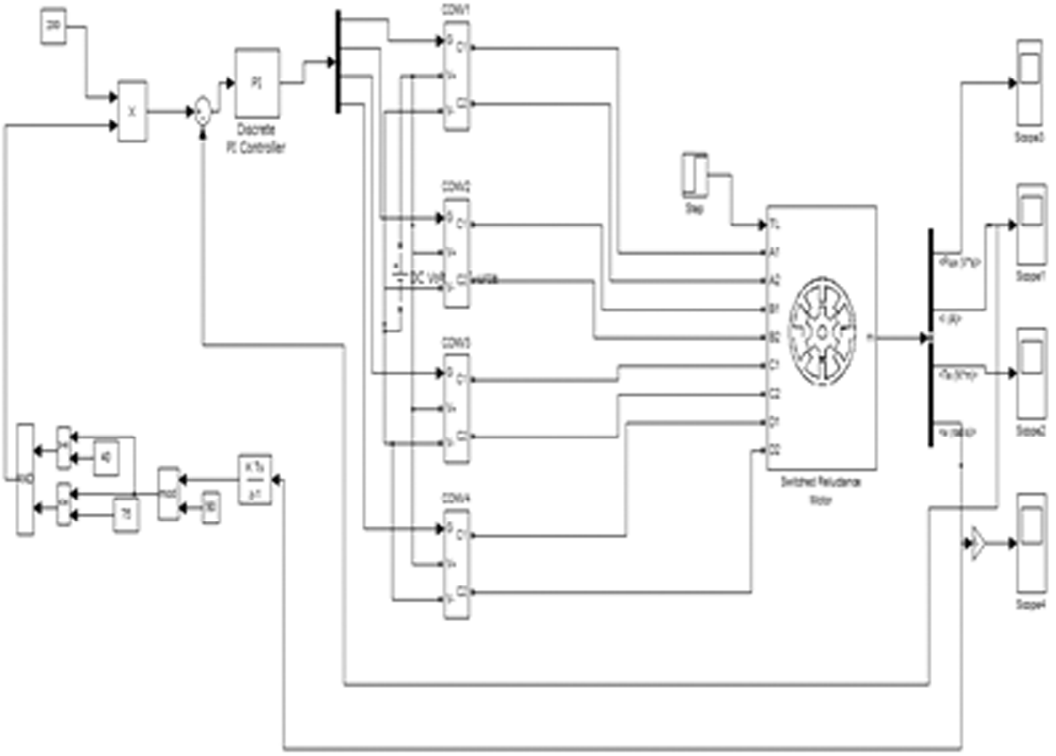

Figure 4: Simulation of Switched Reluctance Motor for Four Phase Model.

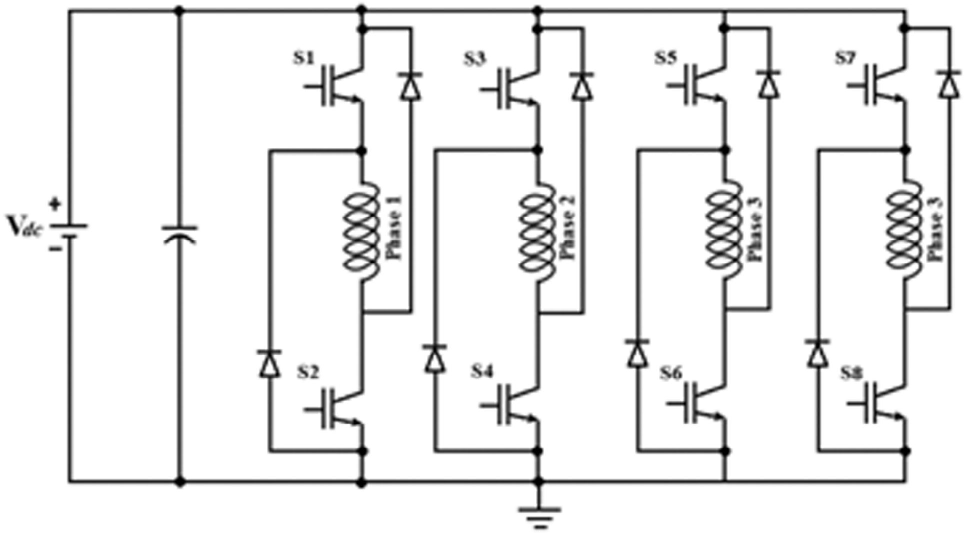

Figure 5: Asymmetrical Bridge Inverter

reduced. By using a position sensor attached to the rotor, the turn-on and turn-off angles of the motor phases can be accurately imposed. This switching angle can be used to control the developed torque waveforms. The phase currents are independently controlled by three PI controllers which generate the IGBTs drive signals by comparing the measured currents with the references. The IGBTs switching frequency is mainly determined by the PI controllers.

5.2. Simulation of the SRM Drive

In this simulation, a DC supply voltage of 115 V is used. The converter turn-on and turn-off angles are kept constant at 40 deg and 75 deg, respectively, over the speed range. The reference current is 3 A and the PI controller is chosen. The SRM is started by applying the step reference to the regulator input. The acceleration rate depends on the load characteristics. To shorten the starting time, a very light load was chosen. Since only the currents are controlled, the motor speed will increase according to the mechanical dynamics of the system. The SRM drive waveforms (magnetic flux, windings currents, motor torque, motor speed) are displayed on the scope. As can be noted, the SRM torque has a very high torque ripple component which is due to the transitions of the currents from one phase to the following one. This torque ripple is a particular characteristic of the SRM and it depends mainly on the converters turn-on and turn-off angles.

The corresponding waveforms shows the output of the SRM for the flux, current, torque and speed.

The flux waveform of the SRM model is given in the Fig. 6 it shows that the flux is kept constant throughout the operation of the motor. The current waveform of the SRM model is given in the Fig. 7 the current is maintained constant with the light loading of the SRM.

The Fig. 8 shows the waveform of the torque, the starting torque is high up to 0.5 seconds and the torque is maintained constant for further. The Fig. 9 shows the speed waveform of SRM model it shows that the speed is being settled at 1500 rpm from the above waveform.

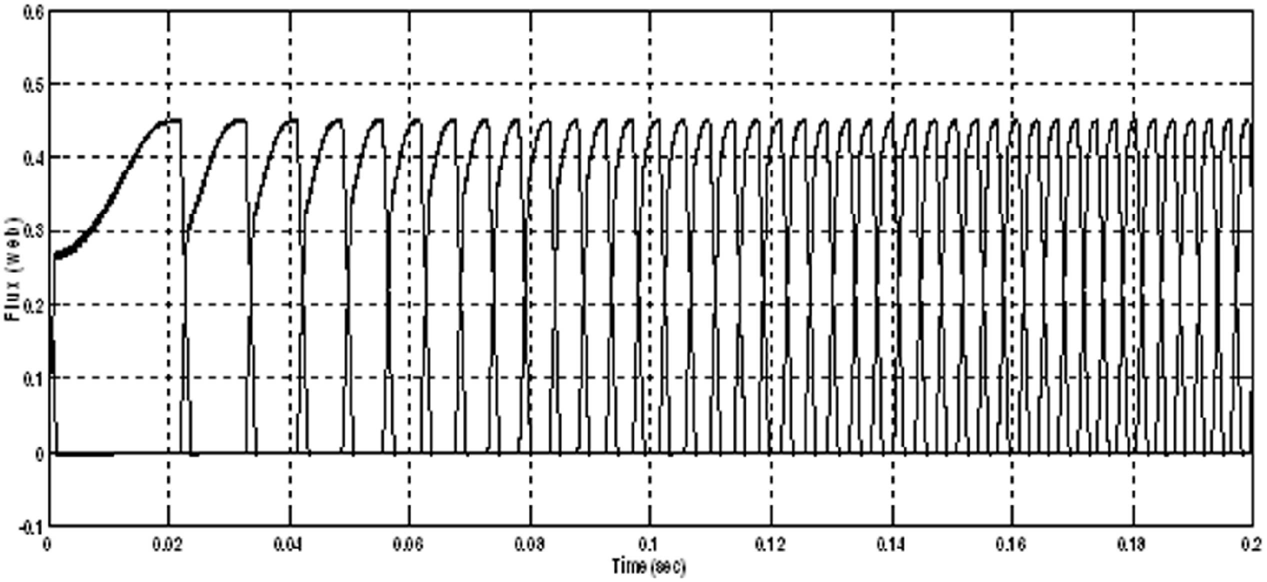

Figure 6: The Flux waveform of SRM

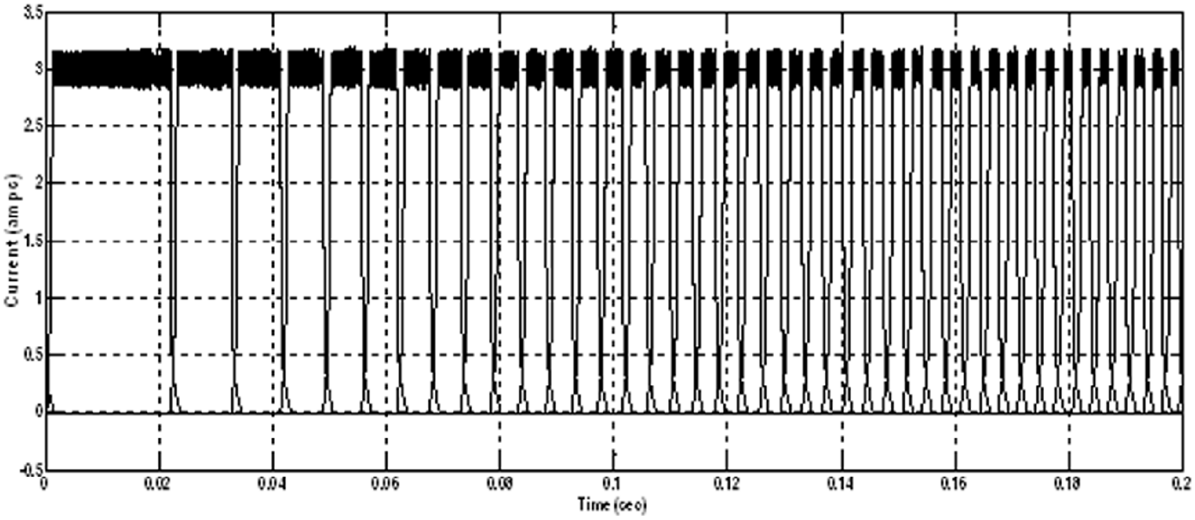

Figure 7: The Current waveform of SRM

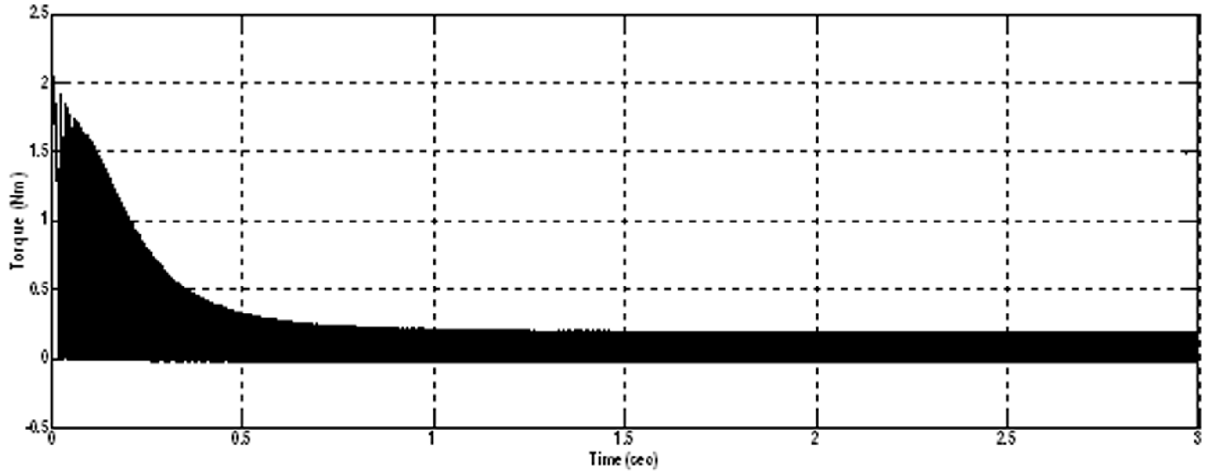

Figure 8: The Torque waveform of SRM

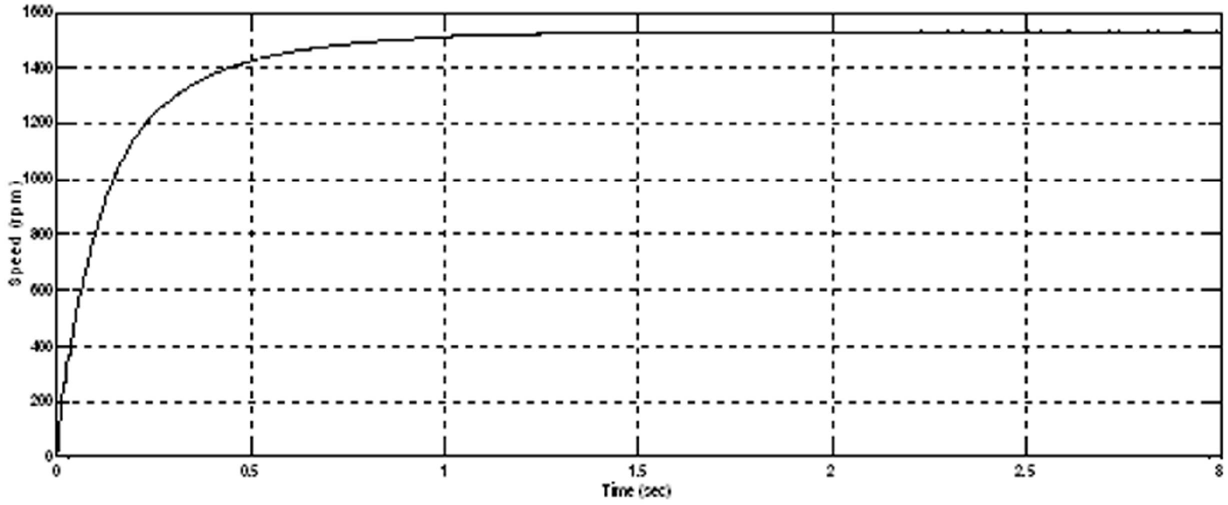

Figure 9: The Speed waveform of SRM

6. CONCLUSION

This paper has proposed a position-estimation method for SRMs based on resonant circuit method. The combination of a phase winding with the power-electronic converter defines a resonant circuit, comprising the motor phase inductance and parasitic capacitances of the phase winding, power-electronic switches, and power cable. The associated resonance frequency depends on the rotor position.By means of measuring the resonance of the induced phase voltage, the rotor position can be retrieved within one electrical cycle of the motor.

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