Computer and Information Science
www.ccsenet.org/journal.html
Vol. 1, No. 1
February 2008

The Design of Switched Reluctance Motor Controller Based on DSP

Zhen Guo, Xiaoyan Zhou, Suzhen Wang
School of Electrical Engineering, Qingdao Technological University, Qingdao 266520, China
Tel: 86-532-88782001 E-mail: qs2004b@163.com

Abstract

In this paper, a new design method of the three-phase 12/8 Switched Reluctance Motor controller is presented, including hardware design and software design. It provides a novel power converter which can accelerate winding discharging and optimal current waveforms. Simulation results of the Switched Reluctance Motor are given which show the system can achieve expected performances.

Keywords: Switched Reluctance Motor (SRM), Controller, Novel power converter

1. Introduction

Switched Reluctance Motor (SRM) has an intrinsic simplicity and low cost that make them well suited to many applications. Furthermore, the motor has a high robustness due to the ability to operate with the loss of one or more motor phase and are thus well suited to operate in harsh industrial environment. However, the motor has many drawbacks due to the motor's doubly salient structure as well as highly nonuniform torque output and magnetization characteristics. The double salient structure leads to the inability to excite the motor using conventional ac motor waveforms and thus the inability to apply well established ac motor rotating field theory to the motor. Additionally, the highly nonlinear magnetization characteristics of the motor entail that the control of the motor is complex. Hence, the problem of the SRM controlling has been an ongoing area of research (P.J.Lawrenson, 1992).

The Switched Reluctance Driver is a new type of variable-speed drive, it is very important to design perfect and reliable controller which is mainly made up with microcomputer controller, power converter, drive circuit, sensors. This paper presents the design method of the three-phase 12/8 SRM controller. The simulation and experimental results are given.

2. Primary Equations of SRM

Although SRM operation appears simple, an accurate analysis of the motor's behavior requires a relatively complex, mathematical approach. The instantaneous voltage across the terminal of a single phase of an SRM winding is related to the flux linked in the winding by Faraday's law, so voltage equation is described as

$$v = iR_m + \frac{d\phi}{dt} \tag{1}$$

where v is the terminal voltage, i is the phase current, R_m is the motor resistance, and ϕ is the flux linked by the winding.

Because of the double salient construction of the SRM and its magnetic effects, in general the flux linked in one phase varies as a function of rotor position θ and the motor current. Thus, equation (1) can be expanded as

$$v = iR_m + \frac{\partial\phi}{\partial i}\frac{di}{dt} + \frac{\partial\phi}{\partial\theta}\frac{d\theta}{dt} \tag{2}$$

Often, SRM analysis proceeds under the assumption that the motor remains unsaturated during operation. When magnetic saturation is neglected, the relationship from flux to current is given by

$$\phi = L(\theta)i \tag{3}$$

where the motor inductance L varies only as a function of motor angle. Defining W_c is stored field co-energy, then

$$W_c = \frac{i^2}{2}L(\theta) \tag{4}$$

and the torque equation is

$$T = \frac{i^2}{2}\frac{dL}{d\theta} \tag{5}$$

Equation (5) suggests that positive torque is produced when the motor inductance is rising as the shaft angle is increasing, $\frac{dL}{d\theta} > 0$. Similarly, a negative torque is produced by supplying SRM winding current while $\frac{dL}{d\theta} < 0$.

3. Hardware Description

Due to the advantages of the TMS320F240 in controlling motors (TMS320C2XX), this paper choose TMS320F240 as main control unit. TMS320F240 has nine independent PWM channels, providing maximum flexibility for SRM. TMS320F240 has dual ADC model with eight channels in each ADC. Therefore, phase currents can be read simultaneously. A current controlled SRM drive is implemented by using Evaluation Module (EVM) for TMS320F240 interfaced with a motor interface board and power converter board. The block diagram of the SRM driving control system is given by Figure 1. The following sections describe the major component in detail.

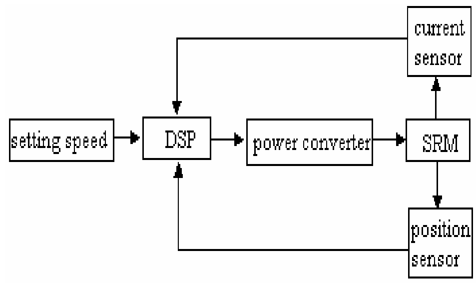


Figure 1. Block diagram of the SRM driving control system

3.1 Power converter

The power inverter is an important issue in SRM control because it largely delicates how the motor can be controlled. SRM do not require bi-directional current like other common ac motors. Therefore, unipolar converters are used as the power converter for SRM drivers. Figure 2 shows the converter that is used in this paper. This particular converter is a modified version of a classical SRM converter. The switches and diodes are rated for the supply voltage with any required safety factor. During motoring operation, both power switching devices are turned on for a particular phase. The amount of current flowing through the SRM winding is regulated by switching on or off power device-GTR, which connect each SRM phase to a DC bus. With DC/DC converter, it can accelerate winding discharging and optimal current waveforms by regulating the voltage value of U_d. This converter provides independent control for each phase and consequently phase overlap operation can be implemented easily.

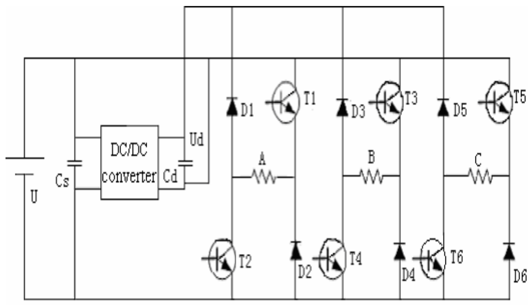


Figure 2. Three-phase power converter

3.2 Current and position sensing

Different currents can be sensed for control purposes. In the particular implementation, phase currents are sensed to implement current controlled SRM drive. TMS320F240 has a dual ADC that enable a user to simultaneously sample and convert two variables. Total time required for the sample is 6.6μs. The phase currents are sensed at every 40μs to implement a 25kHZ current loop. The new PWM duty cycles obtained from current information is loaded at the beginning of a PWM cycle. This is achieved by programming ACTR and SACTR control registers of TMS320F240.

Measuring the rotor position of SRM is very important. Shaft position information is provided using an 8-slot, slotted disk connected to the rotor shaft and three opto-couplers mounted to the stator housing in this paper. The opto-couplers are nominally located 30º apart from each other along the circumference of the disk. Each opto-output is connected to both a capture input and a digital I/O input of TMS320F240. The capture inputs are used once the motor is running, and the digital I/O inputs are used for estimating initial rotor position and for starting the SRM.

3.3 Microcomputer controller

SRM control is described in terms of "low-speed" and "high-speed". Low-speed operation is typically characterized by the ability to arbitrarily control the current to any desired value. This mode of operation is called current chopping mode. As the motor's speed increases, it becomes increasingly difficult to regulate the current because of a reduced amount of time for the commutation interval, so the method of choice of the turn-on and turn-off is employed, This mode of operation is called the single-pulse mode. So the ultimate performance of the SRM is determined by the exact choice of the turn-on and turn-off angles and the magnitude of the phase current. The block diagram of the microcomputer controller is shown in Figure 3. A highly efficient, variable speed drive can be achieved with SRM by using voltage PWM with closed loop position control. The torque command is executed by regulating the current in the inner loop. The turn on timing and the total conduction period determines efficiency and other performance characteristics. The reference current is determined from the load characteristics. The controller needs current feedback information from each of motor phase.

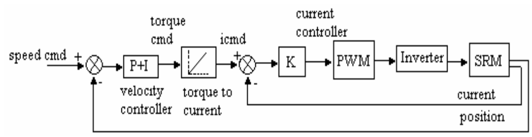


Figure 3. Block diagram of microcomputer controller

When the motor is in the situation of "low-speed", chopping current mode is used. The chopping current wave is shown by Figure 4, where I_m is the chopping value, ΔI is the range of the fluctuation.

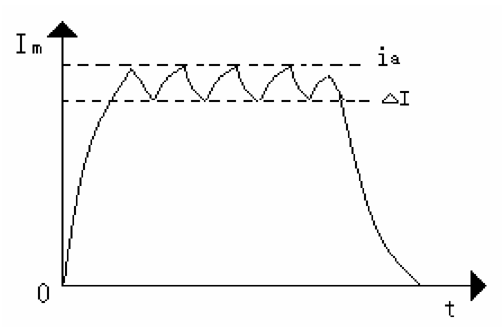


Figure 4. Chopping current wave

When the motor is in the situation of "high-speed", the single-pulse method is used. In order to detect the rotor position of SRM more accurately, frequency doubling technology is employed. The information of position transferred by shaft sensor is treated into 15º pulse signal for the three-phase 12/8 SRM. 15º pulse signal can be turned into 256 single-pulse, so the motor can be controlled more accurately. The relation between Q1 and Q2 is shown in Figure 5.

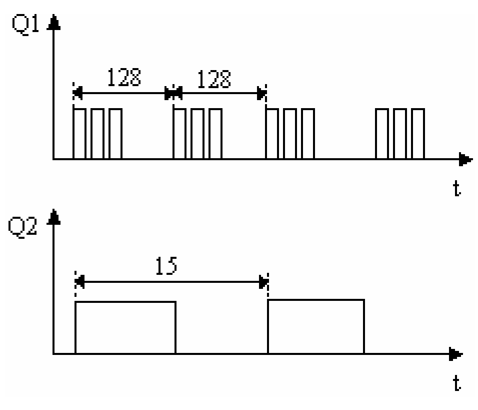


Figure 5. Q1 signal and Q2 signal

4. Software Design

The software written on TMS320F240 EVM implements all the control blocks described in previous sections. There are two loops in the run routines. Firstly, the current loop regulates phase current according to the reference. Secondly, the position loop checks the position and determines the proper rotation direction and proper commutation sequence.

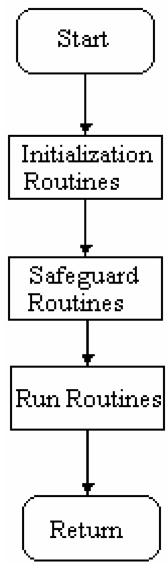


Figure 6. Flowchart of SRM controller

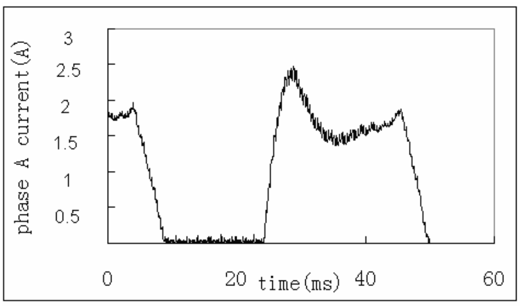
Figure 6 shows the structure of the SRM control software based on TMS320F240. It includes two parts. One is monitoring system, the other is controlling system that can accomplish some calculation in one periodic time, then provide control direction to the motor. Initialization routines mainly include DSP setup, event manager initialization, SRM algorithm initialization. Run routines include time interrupt service routine, capture interrupt service routine.

5. Simulation and experimental results

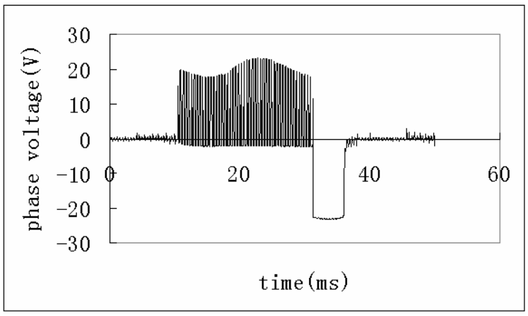
Based on the equations mentioned in section 2, simulation results for the three-phase 12/8 SRM are shown in Figure 7. The characteristics of the SRM used are given by Table 1.

Table 1. SRM parameters

Number of phase, m	3
Number of stator poles, N_s	12
Number of rotor poles, N_R	8
Nominal phase resistance, R_m	8Ω
Nominal aligned inductance, L_a	9.69mH
Nominal unaligned inductance, L_u	1.07mH
DC bus voltage, V_{bus}	200V



(a) Phase A current wave



(b) Phase torque wave

Figure 7. SRM speed 1500r/m simulation wave

Figure 7 describes the characteristics of current and torque of SRM in deferent speed. Different control mode is used in different work condition. By varying turn-on and turn-off angle can obtain different current wave and torque wave.

6. Conclusion

This paper analyzes the structure of the switched reluctance motor controller and provides design information in detail. With the novel power inverter employed, winding discharging can be accelerated and current waveforms can be optimized.

The presented work demonstrates that the measured phase current and voltage, together with the machine parameters, can be used to obtain an ideal controlled method of SRM under different conditions.

References

P.J.Lawrenson. (1992). Switched Reluctance Drives: A Prospective.Proc.ICEM.

TMS320C2XX. User's Guide, Texas Instruments.

F.Filicori et al. (1993). Modeling and Control Strategies for a Variable Reluctance Direct-Drive Motor. *IEEE Tran.*on IE-40 No.1, 2.

Caio.A.Ferreira et al. (1995). Detailed Design of a 30-kW Switched Reluctance Starter/Generator System for a Gas Turbine Engine Application. *IEEE Tran*. On IA-31, No.3, May/June.

TJE Miller. (1993). *Switched Reluctance Motors and Their Control.* Magna Physics Publishing and Clarendon Press, Oxford.

TMS320C24x. (1997). *DSP Controllers-Reference Set*: Vol.1, Texas Instruments Inc.

B.K.Bose, T.J.E. Miller. (1986). "Microcontroller control of switched reluctance motor", *IEEE* Transanctions on Industry Applications, Vol. IA-22, July/August, pp.708-715.

P.J.Lawrenson, J.M.Stephenson, P.T.Blenkinsop, J.Corda,and N.N.Fulton. (1980). "Variable speed switched reluctance motors," *IEE Proc*.,vol.127, pt. B, no. 4, pp.253-265.

R.M.Davis, W.F.Ray, and R.J.Blake. (1981). "Inverter drive for switched reluctance motor: Circuits and component ratings," *IEE Proc*., vol.128, pt. B, no.2, pp. 126-136, Mar.

J.V.Byrne and F.Devitt. (1985). "Design and performance of a saturable variable reluctance servo motor," in *Proc. Motorcon* conf., Chicago, il, Oct., pp.139-146.

J. Ish-Shalom and D.G. Manzer. (1985). "Commutation and control of step motors," in *Proc.14th symp. Incremental Motion, Contr. Syst. and Devices*, June, pp: 283-292.

T.J.Miller. "Nonlinear analysis of the switched reluctance motor drive," General Electric Rep.84CRD079.

M.Ilic'-Spong, R.Marino, S. M. Peresada, and D. G. Taylor. (1987). "Feedback linearizing control of switched reluctance motors," *IEEE Tranns. Automat. Contr*., vol. AC-32, PP.371-379, May.