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Research Article

Study on Switched Reluctance Motor Control System Based on DSP

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Abstract: Accord to the theory of micro-step control, this study is about a design of a four-phase switched reluctance motor based on DSP-driven control system. Firstly, the study is about the design of the hardware circuit, such as the power inverter and its drive, current detection, position detection and the system power supply. And then to build a switched reluctance motor control system, TMS320L2812 as the core of control. Experiments show that this control strategy control is simple, but able to effectively restrain the torque ripple of switched reluctance motor under low speed.

Keywords: DSP controller, micro-step control, switching power supplies, switched reluctance motor, torque ripple

INTRODUCTION

Switched Reluctance Drive (SRD) is the product of the combination of motor technology, modern power electronic technology and microcomputer control technology. With its simple but strong structure, low costs, high reliability and high temperature resistance, it has obtained good controllability under the support of the high developed power electronics and microcomputer control technology. And because of this, it has been put to application to towing transports, general industrial, aviation industrial, household appliances and many other fields.

The main disadvantages of switched reluctance motor are torque ripple. It can not only affect the output characteristics of drive system directly, but also will inevitably increase the vibration and the noise of motor when it's working. Therefore, study on inhibition of the switched reluctance motor torque ripple has focused people's attention all the time. Reference (Husain, 1996) uses local approximation neural networks and learns the expected current wave to achieve the minimization of torque ripple. But it is difficult to achieve real time control because of the complex control scheme. Based on micro-step control strategy, this design of switched reluctance motor drive control system has a simple control system can effectively reduce the torque ripple and have a very good application value.

THE BASIC STRUCTURE OF SRD

As shown in Fig. 1, SRD consists of five major components, such as switched reluctance motor (SRM), power converters, current detection, position detection and controller (Soares, 2001).

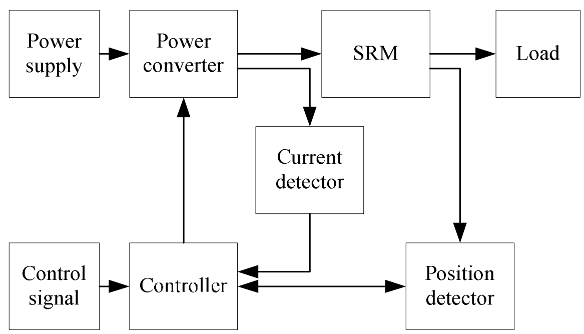

Fig. 1: The basic structure of SRD

THE DESIGN OF THE SYSTEM HARDWARE

Based on TMS320L2812, the switched reluctance motor control system (Liu *et al*., 2005) is as shown in Fig. 2. SR motor is a component of SRD system which finishes the electromechanical energy conversion and is also the major sign of SRD to tell it from other drive systems. But this study focuses on the other main parts of the design, the working principles and characteristics of SR motor will not be presented in detail.

The power converter and its drive: The power converter provides required energy to SR motor. The DC, which is get out of the rectification of AC, will supply power. As is shown in Fig. 3, the design uses split-type DC power inverter. The external power supply is divided into two by two split-phase capacitor C1 and C2. The ends of two phase winding are both connected to the midpoint of the bipolar DC power supplies. The main switch devices and fly-wheel diode of each phase are arranged in order alternatively from top to bottom.

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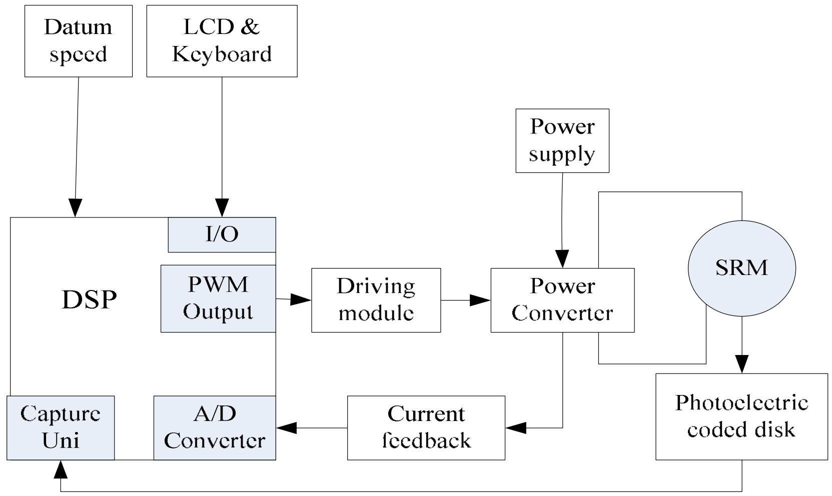


Fig. 2: The structure of SRD control system based on DSP

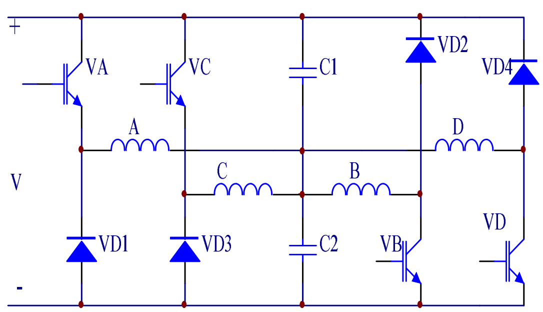


Fig. 3: The power converter

Take phase A and B as example: when VA is turned on, winding A absorbs power from capacitor C1; When VA is turned off, VD1 turns on and the residual energy of winding A is fed back to capacitor C2 in the latter half. When VB is turned on, winding B absorbs power from capacitor C2; when VB is turned off, VD2 turns on and the residual energy of winding B is fed back to capacitor C1. Principles of phase C and D are exactly the same as that of phase A and B. So split-type DC power inverter meets the requirements of the micro-step control.

The switching element of the power inverter is insulated gate bipolar transistor (IGBT) (Hall *et al.*, 2005). IGBT gate voltage can be produced by different drivers (Ki-Chang *et al.*, 2006; Cheng-Tsung and Yen-Ming, 2005). Merits and defects of the gate drive circuit is directly related to the reliability of the system's long-term operation, which consists of IGBT. Thus, an IGBT drive circuit with reasonable design is particularly important. This system uses EXB841, a dedicated integrated drive circuit for IGBT. With its maximum operating frequency of 40 KHZ, it can be applied to all of the IGBT module product ranges. In the inside, it has not only a photoelectric coupler with high isolation voltage, but also an over-current protective circuit. All this design can make the drive circuit of IGBT integrated and simple. Each EXB841 can drive only one IGBT, the drive circuit is as shown in Fig. 4. Through the four PWM outputs of event manager TMS320L2812A, the system controls the four EXB841 separately and thus, it can individually control the make-and-break of each phase of the motor.

The position detection: As to the speed detection, this design uses the position detection with a position sensor. With continuous location of the detected signal, the position detection not only can achieve velocity feedback, but also can determine the relative position of stators and rotors, thereby determining the make-and-break of phase winding. Position detection is one of the key links in the SRD system.

In this control system we use photoelectric encoder to measure the position of rotor and take it as the amount of feedback of closed-loop control. The position signal detected by the photosensitive type of rotor position detector, will be input to CAP1 and CAP2, two capture unit of DSP controller, after arranged. According to the instantaneous rotor position signals, the interrupt service routines of CAP can change phases and calculate the revolving speed of the motor.

Phase current measurement: The phase current measurement of SRD caters to both the needs of the control mode of SR motor current chopping and the needs of over-current protection. Because of the one-way pulse of the output phase current in the SR motor power inverter, we use the method of Hall element sampling. According to the micro-step control strategy and the characteristics of SR motor that the separated phases can't be charged at the same time, we just need two Hall current sensors, named Phase A and Phase B. In addition, Phase B and Phase D, each shares Hall current sensors.

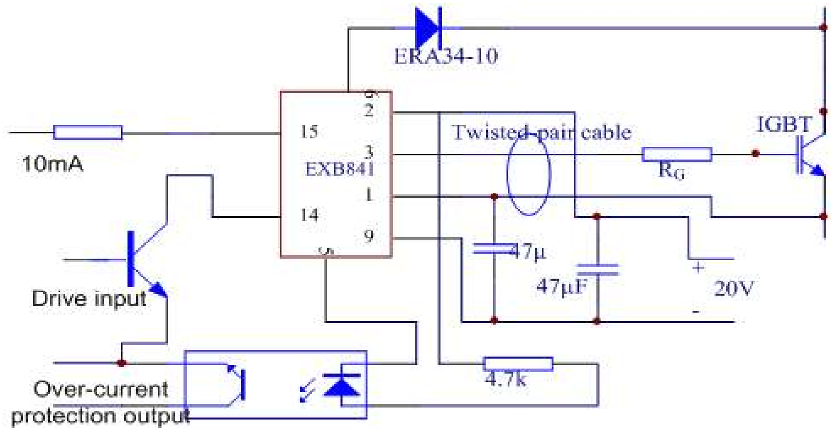


Fig. 4: IGBT drive and the protective circuit

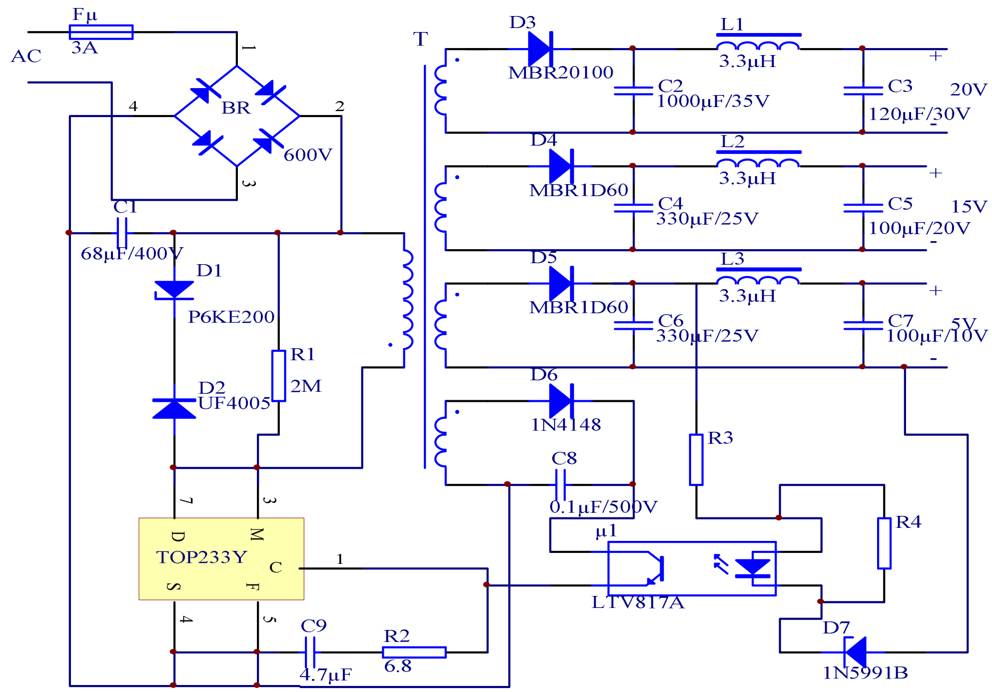


Fig. 5: Schematic diagram of switching power supply

Two direct measuring types of Hall current sensors, CS010G, are used for current detection. After being enlarged, ratio-regulated and circuit-transformed to the appropriate range, the output of the current sensor will be input to ADCIN pin of DSP for system calls.

Design of the switching power supply: DC power supply is an essential part of the entire control system. The whole control system needs 3.3V and 5V and 20V (four roads) and 15V (two roads) and other grades of DC power in total. 5V is the main output and supply for most of the circuits of the system. Other outputs basically supply for the specific module power. So as is shown in Fig. 5, multiplexed output power which is made up of a monolithic integrated switching power supply (TOP233Y), a photoelectric coupler (LTV817A) and a high frequency transformer, is used in this design. Figure 5 only shows a 15V DC output channel and a 20V DC output channel and the other three isolated 20V output are similar with the 15V output channel; In addition, the 5V primary output will be adjusted by three-terminal regulator to 3.3V output.

SRD CONTROL STRATEGY

SRM torque is produced by the tendency of the magnetic circuits' selecting the minimum reluctance structure. Due to the nonlinearity of the SRM magnetic circuit, the SRM torque is usually calculated on the basis of the total magnetic energy, that is:

$$T_k(\theta, i) = \frac{\partial W(\theta, i)}{\partial \theta} \quad (1)$$

In function (1), θ stands for the rotor position angle, i for winding current and k for the phase number of motor.

Ignore the saturation of magnetic circuit for switching reluctance motor and edge effects and assume that the inductance is merely associated with the rotor position, rather the current and then the function above can be simplified to:

$$T_k(\theta, i) = \frac{1}{2} i^2 \frac{dL}{d\theta} \quad (2)$$

In function (2), L is the self-induction of SRM phase windings and the cycle of it is proportional to the Rotor pole logarithm. According to Fourier decomposition and ignoring the influence of high-order harmonics, L can be expressed by this formula:

$$L = L_0 + L_1 \cos(Nr\theta) \quad (3)$$

In function (3), L0 and L1 are the amplitudes of constant and fundamental components of the inductance. Nr stands for the number of rotor teeth. And the electromagnetic torque can be expressed as:

$$T_k(\theta, i) = -(\frac{1}{2} N_r L_{max} i^2)\sin(N_r\theta) = -T_{max}\sin(N_r\theta) \quad (4)$$

Function (4) indicates the fundamental wave electromagnetic torque produced by each phase winding is a kind of space sine wave. The amplitude of electromagnetic torque is proportional to the square of the winding magneto motive force. And the stable zero position of the electromagnetic torque depends on the pole centerline of this phase. So space vector Tk can be taken as the electromagnetic torque of k-phase winding. The phase position of Tk is in accordance with the pole centerline of k-phase winding.

For four-phase SR motor, the stable zero position in space caused by the A, B, C and D four phase winding differ successively from the other in a rotor stepper angle, which is 150 in mechanical angle and 900 in electrical angle. If the four phases are charged with DC of the same amplitude, the orientating function of torque vector TA, TB, Tc and TD will be activated and the rotors of switching reluctance motor will rotate step by step by the stepping angle of 150. If the common reactance of SR motor is neglected and vector superposition of the detent torques is allowed, a star map of the motor torque will be shown as Fig. 6. TAB, TBC, TDA and TCB are the synthesis torque vector produced by the two phases when they are powered up at the same time, as is showed in vector form:

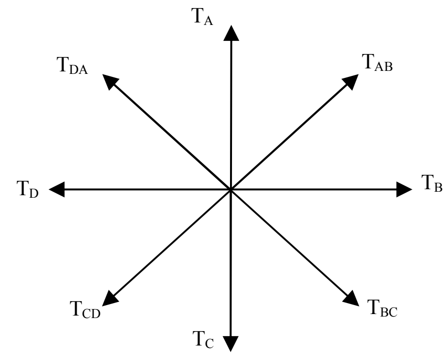


Fig. 6: Star map of the motor torque

$$\overrightarrow{T_{ab}} = \overrightarrow{T_a} + \overrightarrow{T_b} \quad (5)$$

TAB is ahead of TA 450 electrical angle, or 7.50 calculated as by mechanical angle, which is also amount to one-eighth tooth pitch of the rotor. This can also be taken that TAB and TA are staggered in half a step angle. The phase relationship between the torque vectors in Fig. 6 only depends on the distance of the stator pole centerlines.

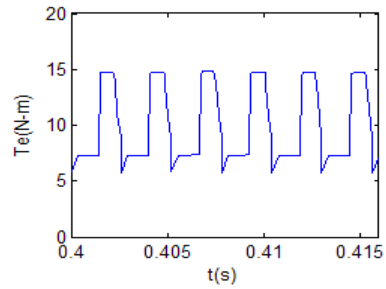
On the basis of the star map of the motor torque, make an assumption: as the torque vector TAB can be synthetic-derived from basic torque TA and TB by the method of vector sum, it is absolutely possible to make use of the current amplitude control to move the phase position of derived torque TAB to any phase positions between basic torque vectors.

In order to guarantee the constant torque, it is easy to find in Fig. 6 that, when the two phases are powered up at the same time, the current is as 0.717 times what it is when one is powered up. As the number of the motor subdivision steps per turn increasing, the stepping angle of motor decreases. Then the smoothness of the motor's output torque will be under good control and torque ripple suppressed.

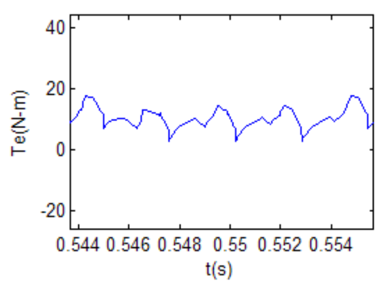
Therefore, the core of switched reluctance motor's micro-step drive is to control the winding current to follow the given current size, which corresponds to the given rotational speed, by achieving equal amplitude of the torque vector. In order to make the actual output current to vary as step-wave current, control the power switch signals of the PWM power converters' modulated output pulse width and take it as a direct control quantity to control the winding current. In short, micro-step control of SRM is realized by adjusting the duty cycle of the PWM.

SIMULATION ANALYSIS AND CONCLUSION

Micro-step control strategy and MATLAB/ simulink simulation software are applied to the



(a)



(b)

Fig. 7: Simulation curve of the torque

simulation of the system and is as shown in Fig. 7. Figure 7a is a steady torque without the micro-step control strategy applied and Fig. 7b is the one with the strategy applied. It can be seen from the simulation results that the steady synthesis torque of the motor, which the micro-step control strategy is applied to, decreases significantly.

Applying the micro-step control theory to the speed regulating system of switched reluctance motor can effectively restrain the torque ripple of switched reluctance motor under low speed and greatly improve the dynamic characteristics of the motor. This control strategy is simple. It provides advantages for the practical application of switched reluctance motor in more fields.

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