Design of high power switched reluctance motor controller

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Abstract. This paper takes the high power Switched Reluctance Motor (SRM) as an example, and designs the control system of the SRM according to the structure and operation characteristics of the high power SRM. The control system takes STM32 MCU as the core, and is composed of driving circuit, current detection circuit and protection circuit. The control methods commonly used in SRM include current chopper control (CCC), voltage chopper control (VCC) and Angle position control (APC). In addition, PI closed-loop control strategy is used to optimize the system performance, which verifies the feasibility and stability of the design of the motor control system.

1. INTRODUCTION
Today, the development of the motor manufacturing industry is facing the following situations: First, the traditional industry has been seriously challenged, the growth model has encountered bottlenecks, the next development should be innovative, improve resource efficiency and energy efficiency, catch up with the developed countries. Second, the motor energy efficiency improvement potential is large, the market prospect is broad. Energy is the power of industry, and the motor is the terminal equipment of electricity. If the energy efficiency of the motor can be improved, the electricity saved will be considerable. Therefore, China's current energy efficiency improvement has great potential and arduous tasks. The improvement of motor performance is in line with the future development trend. The development of motor must take the road of efficient and green development. [1]

Switched reluctance motor as a new type of motor, its structure than any other motor are simple, in the motor rotor no slip ring, winding and permanent magnet, just in the stator has a simple centralized winding, the end of the winding is short, no interphase cross wiring, easy maintenance and repair. Easy to loss mainly in the stator, motor cooling, there is no permanent magnet rotor, wide speed range, flexible control, easy to realize all kinds of special requirements of torque-speed characteristics, and in a wide range of high efficiency, is widely used in electric vehicle drive, household appliances, general industry, aviation industry and servo system and other fields, covering the range of 10 w to 5 mw power all kinds of high speed drive system, powerful market potential.[2]

In this design, STM32F103C8T6 chip is used as the control chip to realize the combination of low cost and high efficiency. The semi-bridge main circuit, photovoltaic position sensor for position detection, amplifying circuit to collect current signals, design the hardware circuit of the high-power switched reluctance motor drive system, build the hardware circuit platform, develop the appropriate closed-loop control strategy, and realize the software programming and debugging.
2. SRM STRUCTURE AND WORKING PRINCIPLE
The salient poles of stator and rotor of switched reluctance motor are made of common silicon steel sheet, which reduces the eddy current and hysteresis loss of the motor as much as possible. There is no winding or permanent magnet on the rotor pole, no commutator, slip ring, etc., the stator pole is surrounded by a centralized winding, and the two radial relative windings form a phase in series. When the power is switched on, the two stator poles of each phase form a magnetic circuit with the rotor, and the overall structure of the motor is simple.[3]

SRM works on the principle of least reluctance. That is, when the phase is excited, the flux always closes in the path of minimum reluctance. When the magnetic field is distorted, the direction of the magnetic force is tangential, and the rotor rotates under the action of the magnetic force to the minimum position of the reluctance, at which the rotor pole axis reconnects with the stator pole axis. When the phase of the motor is turned on and off, the rotor rotates constantly in response to changes in the magnetic circuit reluctance.[4] This is the basic working principle of SRM shown in Figure 1.

3. SRM CONTROLLER DESIGN
SRM controller is composed of SRM, power converter, controller and position detector. SRM mainly realizes the conversion of electrical energy to mechanical energy and the conversion of output energy to load. A power converter is an energy conversion device that relies on the control of the main chip to provide the base drive. The controller is the control center of the whole system and controls the operation of the motor according to different strategies and algorithms. Position detection obtains motor rotor position information, and current detection monitors the current state of the drive circuit, thus providing reliable operating parameters for the controller. The SRM controller structure is shown in Figure 2.

3.1. STM32 Controller
The controller is the core of the whole system, responsible for receiving and sending commands. There are several options for the selection of the controller chip of the switched reluctance motor speed regulation system. However, as the authority of embedded system, ARM processor is rarely introduced into the control of switched reluctance motor speed regulation system. ARM processor has the advantages of small size, low power consumption, low cost, high performance, plus its rich peripheral interface, and so on. It has become one of the key selection objects of SRM controller chip. In this design,
the STM32F103C8T6 chip based on ARM kernel is selected as the microcontroller of switched reluctance motor. The STM32 controller mainly completes the design of the STM32 minimum system to ensure the normal and orderly operation of the control chip, including the clock circuit, the power circuit, the input signal circuit, etc.

### 3.2. Power Converter

The power converter design mainly includes the design of the main circuit structure of the power converter and the selection of its components. The asymmetrical half bridge structure is used in the power conversion circuit of switched reluctance motor, in which the upper and lower bridge arms each have a switch tube, which is convenient for the implementation of various control strategies. It is a commonly used power converter structure.[5] Power switching device of commonly used power field effect tube (MOSFET), insulated gate bipolar transistor (IGBT), intelligent power tube (IPM), one of the MOSFET switch MHZ frequency can be achieved, and there is no secondary breakdown problem, more suitable for high frequency low pressure area, therefore, the design USES MOSFET as power conversion circuit of switching devices. The power conversion circuit consists of MOSFET to form the asymmetric half-bridge main circuit, taking A-phase as an example, as shown in Fig. 3.

![Power conversion circuit](image3)

**Figure 3** Power conversion circuit

IR2101(S) is a dual-channel, gate driven, high voltage and high speed power driver. It adopts highly integrated level conversion technology, which greatly simplifies the control requirements of logic circuit on power devices and improves the reliability of the drive circuit. At the same time, IR2101(S) has a high pulse current buffer, suspension channel power supply using bootstrap circuit, independent low and high end input channels, can be used to drive multiple power MOSFET or IGBT, its operating voltage up to 600 volts. The power driving circuit is composed of IR2101(S) and other peripheral circuits, as shown in Fig. 4.

![Drive circuit](image4)

**Figure 4** Drive circuit
3.3. Position Detector
At present, the common position detection methods of SRM control system include photoelectric position sensor detection and Hall position sensor detection. In this design, a photoelectric position sensor is used for position detection, which is composed of a slot optocoupler fixed on the SRM stator and a toothed disc embedded on the rotor of the motor. When the SRM is running, the gear disc rotates coaxially with the rotor of the motor, and the number of gear disc is equal to the number of rotor of SRM. When the rotor of SRM rotates, the teeth and slots of the gear disc can pass through the U-type optocoupler in turn.

SRM control system is the location of the signal detection circuit as shown in figure 5, the system of the photoelectric sensor to detect the location of the signal through the pull-up resistors, consisting of diode limiter circuit, the capacitor filter, then a single 3.3 V power supply power supply after the Schmitt trigger of plastic, sent to the location of the STM32 MCU capture port, and thus for the corresponding control operation.

The controller calculates the average speed of SRM rotor at 15 degrees per revolution according to the time of two hops adjacent to the rotor position. The formula is:

\[ \omega = \frac{15}{360} \cdot \frac{60}{\Delta t} = \frac{1}{4\Delta t} (rpm) \]  \hspace{1cm} (1)

3.4. Protection Circuit
In the process of motor operation, there may be short circuit, overvoltage, overcurrent and other conditions. In order to ensure the reliability of the circuit, the design of the protection circuit is essential. In this paper, sampling resistance current detection method is adopted. Through AD, sampling voltage is obtained by amplification through sampling resistance. Then, the comparator compares the sampling voltage with the threshold voltage and outputs protection signal to the controller. When the voltage in the sampling current is greater than the threshold voltage, the PWM output will be disabled, the power MOSFET will be turned off, and the drive circuit will be protected. The sampling resistance current detection method has the advantages of clear circuit structure, low cost, good real-time performance and high precision. The protection circuit is shown in Figure 6.
3.5. Power Circuit
In this SRM controller power design, 60V DC power supply is used. Its functions are divided into the following two parts: First, the power supply voltage is directly added to both ends of the power conversion circuit and SRM, and the SRM phase winding and the motor itself are directly supplied. After the 60V power supply voltage passes through the voltage conversion circuit, power the control circuit and the drive circuit of the SRM control system respectively. The 14V, 5V and 3.3V voltages required by the whole controller are obtained by 60V DC power conversion. The voltage of 14V and 5V is mainly used for the power supply of each integrated chip in the SRM controller. 3.3V is responsible for the power supply of STM32 chip. The design of power conversion circuit is shown in Fig. 7.

4. SRM CONTROL STRATEGIES
In the selection of SRM control strategy, the commonly used are current chopper control (CCC), Angle position control (APC) and voltage chopper control (VCC). In order to make the operation of SRM more stable, the proportional integral derivative (PID) algorithm is used to form a closed-loop control strategy. PID control is a method to realize automatic control according to the deviation between target value and actual value in system control. PID control consists of three parts: proportional control, integral control and derivative control.[6] Depending on the system requirements, different combinations of PI or PD can be used. The system has two feedback signals: current signal and speed signal. That is, double closed loop PI control: current PI inner loop control and speed PI outer loop control. The PI control process is shown in Figure 8.

5. TEST RESULT ANALYSIS
In this paper, the SRM with voltage range of 12~72V and power of 7.5KW is selected as the test motor. SRM motor input power selection DC 60V. In the experiment, the STM32 controller outputs 6 PWM drivers for the three-phase 6/4 pole SRM, the position detector updates the rotor position every 1us, and the real-time protection current detection. In the software design, different control strategies are selected according to the speed requirements. After startup, observe the motor drive output through the oscilloscope, open the upper arm and lower arm signals at the same time, observe the state of operation.

6. CONCLUSION
In this paper, the SRM hardware system platform based on STM32 is established. The 7.5KW SRM is used to complete the speed regulation based on CCC, VCC and APC. Through PI control, the reliability
of the system is improved. Due to the nonlinear characteristics of SRM internal magnetic field, the PI control strategy using linear model does not achieve the optimal performance. Of course, when the system performance requirements are not high, the tuning of PID parameters can often achieve acceptable performance and better economy. If we need to improve the performance of the system, we must study a new control strategy.

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