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Research on Speed Control System of AC Asynchronous Motor

Fengtao Zang, Wei Liu

School of Information and Control Engineering, Jilin Institute of Chemical Technology, Jilin, Jilin, 132022, China

Abstract: With the continuous development of modern industry, the engineering practice is becoming more and more complicated. in view of the poor speed regulation performance of AC motor, such as slow response speed and weak anti-interference ability, based on the modular design idea, based on the theory of constant voltage-frequency ratio control and vector control, starting with the mathematical model of asynchronous motor, the simulation experiments are completed through MATLAB simulation software, and the components of the simulation model are analyzed step by step. The corresponding simulation waveforms are obtained from the two models. The simulation results show that the vector control method has better dynamic and static performance, especially in the case of sudden load.

Keywords: AC Asynchronous Motor; Vector Control; Constant v/f Control; Frequency Control.

1. Introduction

AC motors exhibit high controllability and excellent performance. However, their disadvantages such as complex structure and difficult maintenance render them unable to meet the technical requirements for high reliability and stability in complex modern production processes. Additionally, the imperfect hardware circuits of early speed control systems limited their industrial application scope [1]. This predicament has been gradually resolved with advancements in power electronics control technology and continuous developments in motor control theories. Currently, AC speed regulation has become the primary choice in motor systems, and the use of speed control technology to achieve energy-efficient motor operation has emerged as a key research focus worldwide. Therefore, this paper concentrates on studying motor speed control methodologies.

2. Theoretical Analysis

2.1. Vector Control

The speed regulation process of DC motors is relatively straightforward, with superior dynamic response capability. In contrast, for AC motors, the magnetic field is continuously rotating and irregular [2]. To achieve effective control, it is essential to delve into the physical mechanisms of the internal magnetic field to ensure the armature magnetic field and magnetomotive force are fully orthogonal and independently controlled. The core principle involves establishing an asynchronous motor model analogous to a DC motor through coordinate transformation, enabling the regulation of AC motors in a manner similar to DC motor control. The structural transformation diagram is shown in Figure 1.

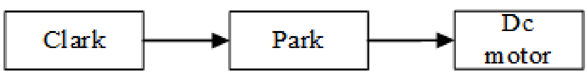

Fig 1. Vector control structure transformation

Firstly, using the Clarke transform, the mathematical expression of the physical model of the asynchronous motor is transformed from the three-phase coordinate system to the two-phase stationary coordinate system. Then, using the Park transform, the conversion from the two-phase stationary coordinate system to the two-phase rotating coordinate system is further completed, which is equivalent to the DC current component in the synchronous rotating coordinate system.

In this way, after a series of coordinate transformations, the mathematical model of the asynchronous motor is reduced in order, greatly simplifying the originally very complex controlled object model, making it easier to understand and analyze the operating characteristics of the motor, and providing a theoretical premise for the implementation of simulation [3].

2.2. Constant Voltage-Frequency Ratio Control

Constant Voltage-Frequency Ratio Control (U/F Control) is a widely used speed regulation strategy. Derived from the steady-state equations of induction motors, this method maintains a constant magnetic flux in the motor by ensuring that the ratio between voltage and frequency remains unchanged during dynamic variations in voltage and frequency, thereby stabilizing the stator flux linkage [4].

The constant voltage frequency ratio control system includes setting of acceleration and deceleration time, U/F curve, SPWM modulation, and driving components. The setting of the speed up and down time is used to regulate and limit the frequency up rate of the motor, ensuring smooth operation of the motor during startup and shutdown, and avoiding the impact on torque and current caused by excessive speed increase [5]. The U/F curve can obtain the corresponding voltage value from the frequency, ensuring that the motor can maintain a constant voltage frequency ratio during operation. At low frequencies, voltage compensation is usually set. The SPWM and driving components will generate sine pulse width modulated driving signals with the set voltage and frequency to control the inverter and achieve variable voltage and frequency speed regulation of the motor.

3. Simulation Modeling

3.1. Simulation Modeling of Vector Control System

Based on the working principles of vector control, a modular design approach was adopted. Utilizing the Simulink and SimPower System toolboxes in MATLAB, the entire simulation system was decomposed into six independent submodules: the induction motor module, inverter circuit module, speed loop (ASR module), current loop feedforward decoupling module, current loop (ACR module), and SVPWM modulation module. These modules were sequentially integrated according to their functional hierarchy [6-7]. Finally, a complete simulation model of the AC induction motor vector control system was constructed on the Simulink platform. The schematic of this simulation system is illustrated in Figure 2.

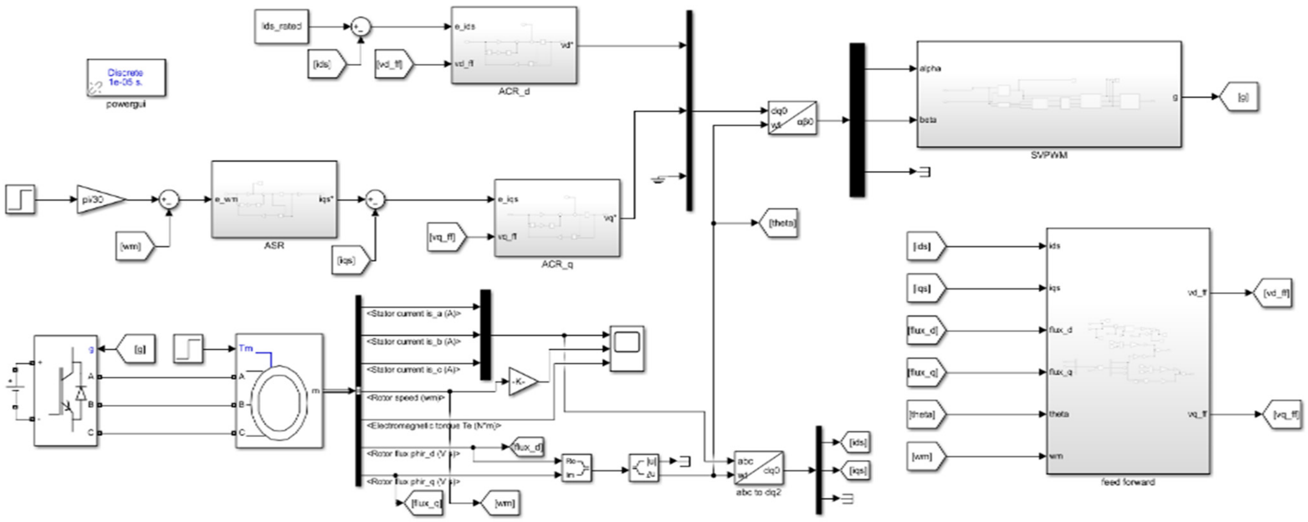

Fig 2. Simulation of Vector Control System

3.2. Modeling of Constant Voltage Frequency Ratio Control System

Following the modeling philosophy of vector control, the Constant Voltage-Frequency Ratio (V/F) control system was decomposed into individual sub-functional modules. The simulation system primarily consists of four components: the induction motor module, ASR module, inverter module, and SPWM modulation module. The simulation model of the system is illustrated in Figure 3.

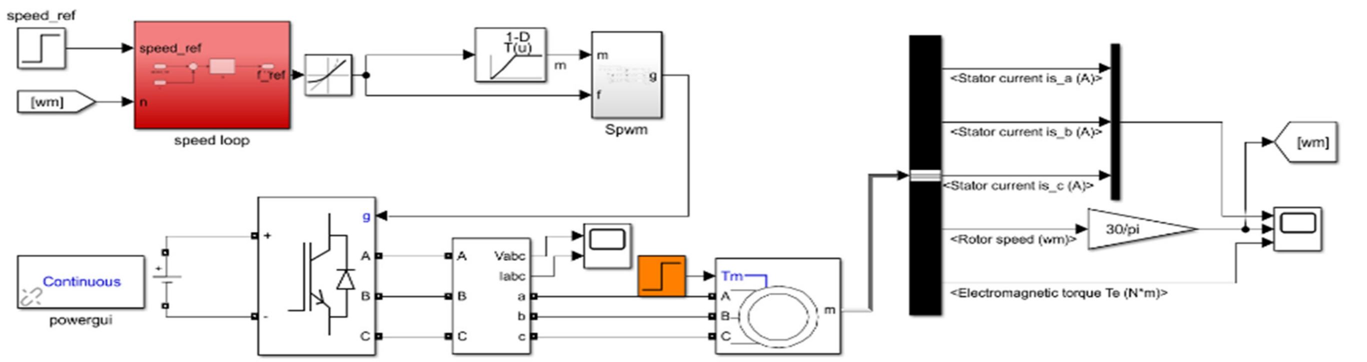

Fig 3. Simulation of Constant Voltage Frequency Ratio Closed System

4. Analysis of Simulation Results

4.1. Simulation Results of Vector Control System

Obtain the simulation waveform diagram of the vector control system from the system diagram of the control strategy and the structural diagrams of each submodule. As shown in Figure 4, analyze the startup, no-load, speed regulation, and loading stages of the simulation system separately.

From 0 to 0.251 seconds, the motor is in the starting phase. At this time, the current rapidly rises to the maximum current of 18 A, and at the same time, the torque of the motor gradually increases to reach the maximum set value of 20. The ASR briefly reaches and maintains a saturated state, and the motor speed rapidly increases at maximum acceleration. Due to the zero-point problem of ACR, the speed overshoot occurs. At 0.265s, the speed overcharges to 1213 r/min, and the PI control torque is negative, causing the speed to decrease. At 0.276 seconds, the motor speed reaches the set initial value of 1200 r/min, ASR exits saturation state, the current rapidly decreases, and the torque drops sharply to the motor's no-load torque, which is approximately 0.

At 0.28-0.5 seconds, the motor is in the no-load stage. This stage is mainly used in production practice to detect whether the motor starts normally. Generally, the motor parameters that need to be monitored include speed, vibration, current, voltage, etc. If they are all within the normal range, the next operation can be performed. If the parameters are not within the allowed range, the system will warn or even trip.

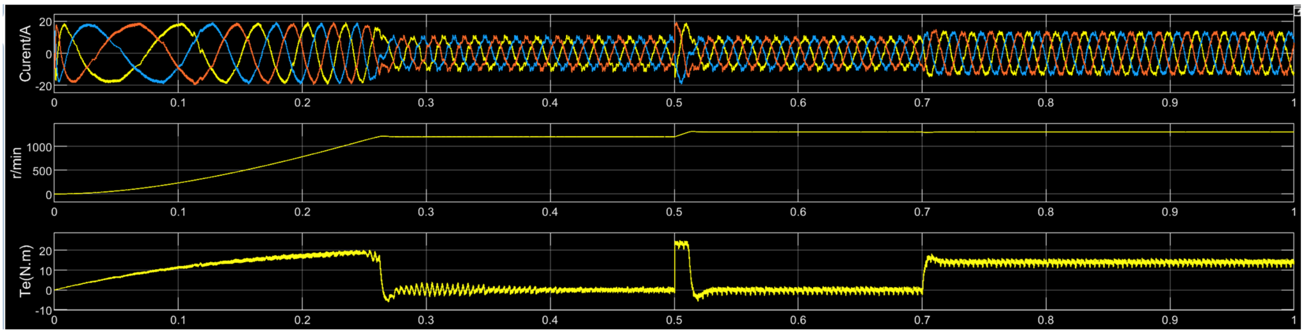

Fig 4. Simulation waveform of vector control system

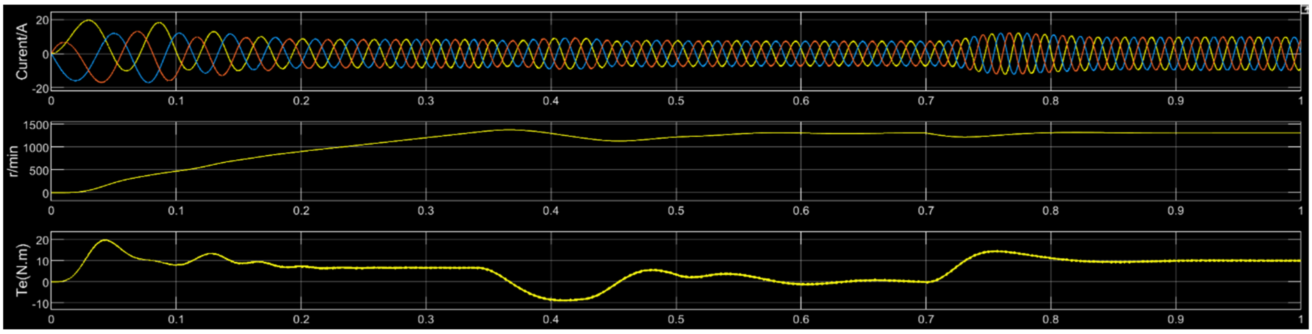

Fig 5. Simulation waveform of constant voltage frequency closed control system

The speed regulation stage is from 0.501 to 0.523 seconds, during which the motor speed is changed to a final value of 1300 r/min. This stage is mainly used to test the dynamic response capability of the speed regulation.

0.70-0.72 seconds is the motor loading stage. When a load is added, the current increases, the speed suddenly drops, and the torque instantly increases. The PI controller will quickly pull the speed back to 1300 r/min and then maintain a balanced state again.

The simulation results show that the output speed of the vector control strategy can quickly follow the set speed changes and has good tracking ability. At the same time, the torque can also change rapidly, which is basically consistent with the actual operating state of the motor.

4.2. Simulation Results of Constant Voltage Frequency Ratio Control System

Similarly, based on the overall block diagram and functional diagrams of each module controlled by constant voltage frequency ratio, the simulation waveform of the control system is given. Figure 5 shows the simulation waveform output of the system.

Observing the image, it can be concluded that this method has average dynamic torque capability and static speed regulation performance. In the case of sudden load, the motor torque and speed will oscillate significantly, and then maintain balance at a larger slip. The recovery process is slow. At the same time, the rapid increase in frequency during the start-up process may result in significant fluctuations in torque amplitude.

5. Summary

This article starts from the principles of vector control and constant voltage frequency ratio control, uses modular design methods to model and simulate both, and analyzes the results. The experimental results show that by selecting simulation parameters within an appropriate range, the waveform is consistent with the theoretical analysis, and the system can operate normally. The vector control method has fast dynamic response speed, small overshoot, and better instantaneous characteristics. However, the constant voltage frequency ratio control strategy cannot effectively control torque during dynamic processes, so the dynamic control effect obtained using this strategy is not very ideal. This further proves the rationality and effectiveness of the model built in this experiment.

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