Study on "Steam-Electric Double Drive" System Motor Transient Performance

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Abstract. With the development of "steam-electric dual-drive" system in China's factories, it is necessary to understand the performance of the motor and improve the stability of the system. This paper is based on Ansoft software, using field-circuit coupling method for the transient performance of induction motor in the system are analyzed. This paper is based on the three-phase asynchronous motor-generator of Suqian "steam-electric double drive" in Jiangsu province, which is 6800kW, 750r/min. Getting data from three different conditions: racing start, fan load start, big load analysis respectively. Simulate the motor switched from the state of the motor to the state of generator. To obtain the three-phase asynchronous motor in different stages of instantaneous starting current, electromagnetic torque, the air gap flux density and other electrical parameters. The transient performance of the asynchronous motor and the corresponding electromagnetic field distribution are analyzed.

Introduction

Aiming at reducing energy consumption, increasing the net power supply and improving the utilization rate of energy, China's self created technology “steam and electric double drive” system is leading the world. The function of asynchronous motor in the whole system is to maintain the balance and dynamic adjustment of mechanical energy and electric energy, improve the efficiency of the system, and keep the system with high efficiency and energy saving running state [1]. When the large capacity squirrel cage induction motor is starting, the power supply voltage changes or the load torque increases, the sudden change of the starting impact current and the instantaneous torque amplitude caused by the electromagnetic transient causes the motor itself to be damaged [2]. Ansoft Maxwell, as the advanced electromagnetic field finite element simulation analysis software, has a relatively reliable basis for the optimization design of the motor. Through the analysis and study of the operation modeling method of Maxwell2D/3D [3], literature [4] uses Ansoft RMXprt and maxwell2D to simulate the coupling, and then compares the accuracy of the two simulation results to ensure that the results are not very different. Literature [5] uses Ansoft/Maxwell2D and Ansoft/Simplorer software, the method of joint simulation of asynchronous motor is studied so that the simulation results are closer to the real value. But it is worth noting that this method takes a long time. For the improvement and reduce the intensity of work, the external circuit is simulated directly in Maxwell2D in this paper. Based on the Ansoft software, the field circuit coupling method is used to increase the external circuit, and the transient parameters of the motor in different operating conditions are simulated, which provides the basic theoretical basis for the stability optimization of the dual drive system of steam and electricity.
The Establishment of a Finite Element Model

Related Parameters of Asynchronous Motor/Generator

The motor used in the simulation is a three-phase asynchronous motor / generator, the rated power is 6800Kw, the rated voltage is 6Kv, 8 p, the rated frequency is 50Hz, the rated speed is 750r/min, the actual speed is 747r/min, the length of iron core is 1320mm. The stator coil is made of double layer winding. The number of parallel branches is 8, and the rotor bar is a squirrel cage structure. The size of the structure as shown in table 1:

Table 1. Motor related dimensions and parameters.

<table>
<thead>
<tr>
<th>Rated power /Kw</th>
<th>Actual speed /rpm</th>
<th>Outer diameter of the stator /mm</th>
<th>Internal diameter of the stator /mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>6800</td>
<td>747</td>
<td>1500</td>
<td>1130</td>
</tr>
<tr>
<td>Internal diameter of a rotor/mm</td>
<td>Internal diameter of the rotor/mm</td>
<td>Number of rotor slots /pc</td>
<td>Number of stator slots /pc</td>
</tr>
<tr>
<td>1123.6</td>
<td>800</td>
<td>123</td>
<td>96</td>
</tr>
</tbody>
</table>

Asynchronous Motor / Generator Finite Element Modeling

In this paper, Maxwell2D is chosen to model and simulate the motor by accurately calculating the parameters of the motor. The stator and rotor cores of the motor are all made of 50W470 silicon steel plate. The stator winding adopts copper wire, the rotor guide bar adopts copper strip and the rotor shaft is set to be non-magnetic.

The different section precision is set on the different regions of the motor. The squirrel cage and air gap are carefully divided. The stator core of the motor is roughly divided, which not only ensures the accuracy of the calculation, but also reduces the calculation time, as shown in Figure 1:

Figure 1. Finite element dissection model of motor.

Using Field Circuit Coupling Method to Establish External Circuit

When the transient field is used to calculate the finite element potential, according to the Maxwell transient field theory, it is found that the two-dimensional field modeling can not consider the end leakage and the winding resistance, and the potential of the finite element is the pressure drop of the stator end leakage and the voltage drop of the stator winding. Since the resistance value of the stator windings is small, it neglects the voltage drop of terminal leakage resistance when calculating the terminal voltage. The equivalent impedance method is used to simulate the rated load condition through the field circuit coupling method, and the end leakage inductance is loaded into the external circuit. The three-phase AC voltage of the motor is supplied by the external circuit to simulate the starting process of the motor in the actual working condition. Using Ansoft's own software circuit editor, the external circuit is built and coupled with the motor model, as shown in Figure 2:

Figure 2. External circuit.
The end leakage reactance and winding resistance of the motor can be calculated by the following formula.

**End leakage reactance:**

\[ L_B = (N_S q)^2 \mu_0 (0.67 l_B - 0.43 \tau) \]  
\[ X_B = 2\pi l_B p l_B \]  (1)

In the form, \( l_B \) is the end length of the half coil; \( \mu_0 = 0.4 \pi \times 10^{-6} \text{H/m} \).

Each resistance of the stator winding is:

\[ R_1 = K_f \rho \omega \frac{2N_1 l_0}{A_{\alpha 1} \tau} \]  (2)

The \( N_1 \) is the series turns of each coil, \( l_0 \) is the average length of the half turn of the coil, \( A_{\alpha 1} \) is the cross section area of the conductor, and \( K_f \) is the skin effect coefficient.

The motor winding in the external circuit is connected with the two-dimensional finite element model, thus achieving the coupling of the electromagnetic field and the circuit.

**Simulation and Result Analysis**

The simulation is carried out on three starting modes: no-load start-up, fan load starting, large load starting and the motor state is switched from motor state to generator state. The initial speed of the motor rotor is set to 0 RPM, the rotational inertia and the friction damping coefficient of the motor are set through the quality and radius of the motor rotor.

**Motor No-load Startup**

When the motor starts no load, the motor load torque is set to 0. The starting performance simulation curve of the motor after three phase AC voltage source is connected, as shown in Figure 3:

![Figure 3. Motor no-load start-up characteristic curve.](image)

Figure (a) is the speed - time curve of the motor rotor. It can be seen that the motor has a small amplitude vibration at the beginning of the motor, and it reaches a stable state at about 2S after starting and maintains the rated speed of the motor. Figure (b) is the electromagnetic torque - time curve, when the motor starts to accelerate from static state, the amplitude of the electromagnetic torque is very large, and the peak of the electromagnetic torque can reach 250kN m. With the steady increase of rotating speed, the amplitude of electromagnetic torque decreases gradually. At 1.65s, the electromagnetic torque of the motor reaches a maximum value of 100kN. M.

In order to generate enough electromagnetic torque, the corresponding stator winding current is displayed, and the waveform is also corresponding to the electromagnetic torque waveform. When the speed of the motor reaches a stable state of 747rpm, the stator winding current and electromagnetic torque of the motor also decrease with the change rate and close to 0 due to the very small change rate.
Motor Fan Load Start

In the "steam power double drive" system, the asynchronous motor drives the small steam turbine, while the speed and load torque of the small steam turbine are increased in the way of the two square torque. Therefore, the motor can be regarded as loading fan load. Therefore, load simulation can be set to a quadratic function:

\[ T_L = -K \cdot \text{Speed}^2 \] (4)

K is used as the load factor to control the rate of torque rising, and speed is the rate expression of the rotor speed input in the torque, while the negative sign indicates that the torque is opposite to the rotation direction of the motor rotor. So when the rotor speed rises to the rated speed or constant speed, the load on the motor will also change to a constant value. The formula (4) shows that the larger the K value is, the greater the load is when the motor reaches the rated speed, and the slope of the curve increases with the increase of the motor load. Randomly set two load torque coefficients, and the corresponding load curve characteristics are obtained. The results are shown in Figure 4 (a).

![Figure 4. Speed and torque characteristics of motor with different K values.](image)

The two curves are the load torque and time curve when k is equal to 12 and 25 respectively. When the K value is 25, the ratio of 0.5s is 12, the curve is delayed about 0.5s, and the load torque is about 50 kN*m after stable. This is because when the K value is 25, the speed of the motor in the stable state is obviously lower than the rated speed, such as Figure 4 (b), the motor speed is constant at 600rpm, and the motor has reached the maximum load torque at this time. It can be deduced that the maximum value of K at rated speed is about 22. When the K value is 12, the transient start-up process of the motor under the condition of fan load is analyzed. When the voltage source is connected, the starting characteristics of the motor are shown in Figure 5.

![Figure 5. The starting characteristic curve of the motor when the fan is loaded.](image)

When the motor is started, it is similar to the case of no-load startup. The magnitude and magnitude of electromagnetic torque and stator current oscillations are very large, the rotor speed of the motor has a small fluctuation. When the time reaches 2.25s, the motor turns to the near rated speed, the electromagnetic torque and the stator current drop sharply. Then the electromagnetic torque increased slowly and always keep the same as the load torque, the electromagnetic torque was close to 60 kN m. Compared to the load starting of the fan, the speed increase rate of the rotor speed is slightly less than that of the no-load start, but the time of the electromagnetic shock is slightly greater than that of the no-load start. The larger the K value, the longer the startup time and the electromagnetic oscillation time.
Large Load Start

The load torque of the motor is set to -43000 N·M. After connecting the external voltage source, the starting performance curve of the motor is shown in Figure 6.

![Figure 6. High load starting performance curve.](image)

Unlike no-load startup and fan load startup, large load startup system needs 7.5S to achieve a stable speed. Before 1s, the speed of the motor is fluctuating and the rotor speed is frequently switched at the positive and negative values. When the speed is negative, the motor is in the power generation state. As the time increases, the electromagnetic torque increases gradually. When the electromagnetic torque exceeds the load torque, the motor speed increases gradually. When the speed of the motor rises to the rated speed, the electromagnetic torque of the motor is equal to the load torque. When the load torque of the motor exceeds 44000 N·m, the motor will not start properly (the load torque is much smaller than the maximum torque of the motor). Therefore, the load that the motor can withstand during the start-up stage is much smaller than the maximum load value of the motor. At this time, the speed of the motor continues to be negative, and the motor has been kept in the generator state and unable to enter the motor state.

Electric Generator State Simulation

When the steam and electricity dual drive system works normally, the excess steam makes the small steam turbine work in a stable running state, making the speed of the asynchronous motor exceeding the synchronous speed to begin to generate electricity. The simulation motor switches from motor to generator transient. Setting the load rotation direction is the same as the motor rotation direction. The initial speed of motor is set to 747rpm according to the actual working conditions. After instantaneous loading, the generator performance curve is shown in Figure 7.

![Figure 7. Generator state characteristic curve.](image)

The motor went smoothly from 747rpm to 1s after the shock of 753rpm. The corresponding electromagnetic torque and transient current also have a relatively large concussion. But compared to the vibration caused by the motor startup state, the oscillation period is obviously less than the starting state. At the beginning of the oscillation, the peak value of winding current is not much different from the peak value of winding current when the motor starts. The peak value of electromagnetic torque is opposite to the torque peak at motor startup. The motor stabilizes after 0.6 s and continues to output power to achieve energy saving.
Summary
In this paper, the asynchronous motor model of motor and generator under the condition of "steam electric double drive" system is established. Based on the Ansoft software and its own circuit editor software, the three transient state starting states of the motor and the transient switching state of the motor are simulated and analyzed by using the field circuit coupling method to edit the external circuit. The results of the analysis are as follows:

1. Establish the relationship between starting current, electromagnetic torque and speed of motor under different working conditions. During the starting process, the electromagnetic torque has a large oscillation duration and a long duration. The motor's no load state is 5S ahead of schedule when the motor is loaded. So the vibration time of the motor will last longer with the increase of load torque.
2. The motor has a large electromagnetic shock when the motor state is switched to the generator state, which is shorter than the starting time. But it also has a certain influence on the power quality of the generator.
3. The torque ripple of the motor is very large, which has a great influence on the speed of the motor and the stability of the drag load, and increases more power loss. It is necessary to optimize the main parameters of the motor in the later period, so as to further optimize the transient performance of the motor.

References
[12] Liang Liang Liang, Chen Shikun, using time stepping finite element method to analyze the transient characteristics of the solid rotor asynchronous motor [J], small and medium motors, 1995, 22 (5):3-6.
