

# Research and Simulation of Electromagnetic Voltage-Regulated Soft Starter Based on Predictive Control

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**Abstract.** Aiming at the problems of large starting current and unsmooth starting of asynchronous motor, an electromagnetic voltage-regulated soft start control method based on predictive control is proposed. The model of motor soft starter based on predictive control algorithm is established. The control principle of predictive control algorithm is analyzed. The CARIMA model is used to adjust the parameters of motor starting process. With the help of MATLAB, the motor direct start model, the electromagnetic control soft starter model based on PID control algorithm and predictive control algorithm are simulated. The results show that the starting current waveform of the electromagnetic voltage regulator soft starter based on the predictive control algorithm is relatively flat, and the control algorithm can achieve a smooth start of the motor.

## 1 Introduction

The development of modern industry has made the application of electric motors more and more extensive. As the industrial production capacity of enterprises has rapidly increased, large-scale production equipment has emerged. The motor capacity for driving these devices is also increasing, especially with the increasing of the number of medium and high voltage high-power AC motors, the starting problem of medium and high voltage and high power motors has been more and more prominent. Therefore, it is of great significance to study the starting process of the motor to achieve excellent starting performance of the motor.

Nowadays, the control algorithms used in motor soft starters mainly include PID control algorithm, neuron PID algorithm, fuzzy control algorithm, and optimized fuzzy PID control algorithm. The control strategy directly affects various parameters of the motor when starting the motor, and it is also the core content of the motor soft start controller.

Predictive control is one type of the computer algorithm that uses a display process model to control the future behavior of an object. Predictive control is not very demanding on mathematical models and the types of models are also diverse. It can handle processes with pure lag directly; it has good tracking performance and strong anti-interference ability as well as strong robustness to model errors and so on. Therefore, predictive control can be said to be the most advanced control technology in modern industry.

This paper presents a control method for electromagnetic pressure soft start based on predictive control. The predictive control model of the motor is established and simulated by MATLAB.

## 2 Predictively controlled CARIMA model

The predictive model is the basic model that describes the dynamic behavior of the system and provides a reference for the control system. The generalized predictive control uses the CARIMA model (controlled autoregressive integral moving average model) as the predictive model. The model can be written as:

$$A(z^{-1})y(t) = z^{-d}B(z^{-1})u(t) + C(z^{-1})\xi(t)/\Delta \quad (1)$$

Where,  $y(t)$ ,  $u(t)$  and  $\xi(t)$  represent the system's input, output, and white noise sequences with a mean of zero.  $A(z^{-1})$ ,  $B(z^{-1})$ ,  $C(z^{-1})$  are polynomial coefficients

of  $z^{-1}$ , and  $A(z^{-1}) = 1 + \sum_{i=1}^{n_a} a_i z^{-i}$ ,  $B(z^{-1}) = 1 + \sum_{i=1}^{n_b} b_i z^{-i}$ ,  $C(z^{-1}) = 1 + \sum_{i=1}^{n_c} c_i z^{-i}$ , where,  $i$  is the coefficient in the formula.  $\Delta = 1 - z^{-1}$  is the difference operator,  $d$  is the hysteresis coefficient.

If  $d > 1$ , then the coefficients of several items at the beginning of  $B(z^{-1})$  need to be zero, that is,

$$b_0 = b_1 = b_2 = \dots = b_{d-2} = 0 \quad (2)$$

If  $d = 1$ , then

$$A(z^{-1})y(t) = B(z^{-1})u(t-1) + C(z^{-1})\xi(t)/\Delta \quad (3)$$

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For the convenience of calculation, the calculation formula of  $d=1$  and  $C(z^{-1})=1$  is generally taken.

In the derivation of the generalized predictive control algorithm, though the closed-loop control function or feedback function is not explicitly given, the rolling optimization process itself contains constant feedback and correction for the given value. That is, when controlling each input and output signal, the actual detected output is firstly compared with the predicted value, and the uncertainty in the prediction process is corrected. The process is actually the feedback correction of the generalized predictive control. Therefore, the system can reduce the requirements of the basic model and improve the robustness of the control system.

### 3 Establishment of predictive control model for asynchronous motor

#### 3.1 Analysis of Mathematical Model of Asynchronous Motor

According to the mathematical model of the asynchronous motor, the parameters of the CARIMA model applied to the motor are derived.

Using the transformation of coordinates, the mathematical model of the asynchronous motor is converted into the d-q rotation coordinate axis, which can be expressed as:

$$\left\{ \begin{array}{l} U_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_r L_q i_q \\ U_q = R_s i_q + L_q \frac{di_q}{dt} + \omega_r L_d i_d \\ T_e = \frac{3}{2} p_n (\psi_f i_q + (L_d - L_q) i_d i_q) \\ J \frac{d\omega_r}{dt} = T_e - T_L \end{array} \right. \quad (4)$$

In equation (4),  $U_d$  and  $U_q$  are the voltage vector components on the d and q axes, respectively;  $i_d$ 、 $i_q$  are the components of the stator current vector on the d and q axes;  $L_d$ 、 $L_q$  are the inductance of the motor on the d and q axes;  $J$  is the moment of inertia folded onto the motor shaft;  $T_e$  is electromagnetic torque;  $T_L$  is the mechanical load torque;  $\omega$  is the rotor electrical angular velocity;  $\psi_f$  is the flux linkage of the stator winding;  $p_n$  is the motor pole count.

The dynamic equation of the motor drive system is:

$$\frac{d\omega_r}{dt} = (T_e - T_L - B_m \omega_r) / J \quad (5)$$

Where,  $\omega_r = \omega / p_n$ ,  $B_m$  is the hysteresis coefficient of friction.

To simplify the dynamic model of the system, given a vector change, set  $i_d=0$ ; Since both  $p_n$  and  $\psi_f$  are constant values,  $T_e$  is proportional to the q-axis current  $i_q$ , then:

$$T_e = \frac{3}{2} p_n \psi_f i_q \quad (6)$$

If the load torque is zero, equation (5) can be equivalent to:

$$\frac{d\omega_r}{dt} = \left( \frac{3}{2} p_n \psi_f i_q - B_m \omega_r \right) / J \quad (7)$$

Equation (7) is transformed by Laplace:

$$G(s) = \frac{3}{2} p_n \psi_f / Js + B_m \quad (8)$$

Then add zero-order hold, after z transform, the transfer function becomes:

$$Z \left\{ \frac{1-e^{Ts}}{s} \frac{3/2 p_n \psi_f}{Js + B_m} \right\} = \frac{bz^{-1}}{1+az^{-1}} \quad (9)$$

From the above formula,  $a = -e^{TB_m/J}$ ,  $b = \frac{3}{2} p_n \psi_f (1 - e^{TB_m/J}) / B_m$ ,  $T$  is the system sampling period.

Using the load torque  $T_L$  as the disturbance of the system, the system difference equation is:

$$\omega_r(t) + a\omega_r(t-1) = b i_q(t-1) + c T_L(t) \quad (10)$$

Multiplying both ends of the above equation by the difference operator  $\Delta$  to obtain:

$$(1+az^{-1})\Delta\omega_r(t) = b\Delta i_q(t-1) + cT_L(t)\Delta \quad (11)$$

where,  $\xi(t) = cT_L(t)\Delta$  is the fluctuation function of the load torque, which can be used as the noise of the system.

Write (11) as a CARIMA model:

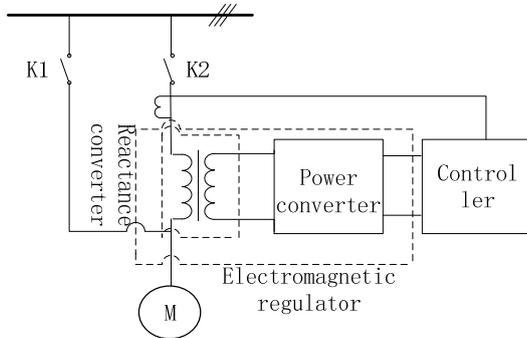
$$A(z^{-1})y(t) = B(z^{-1})\Delta u(t-1) + \xi(t) \quad (12)$$

where,  $A(z^{-1}) = (1+az^{-1})\Delta = 1 + (a-1)z^{-1} - az^{-2}$ ;  $B(z^{-1}) = bz^{-1}$ .

Equation (12) is the CARIMA model of the asynchronous motor.

### 3.2 Controlled model setting of electromagnetic pressure regulating device

The electromagnetic voltage regulation soft start system mainly includes motor, power converter, variable reactor and predictive controller. The varactor and the power converter form an electromagnetic regulator together. The topology of the electromagnetic voltage regulator soft starter is shown in Figure 1. The variable reactor can be used to isolate high pressure and low pressure. It is divided into primary side and secondary side. The primary coil is directly connected in series with the load motor, and the secondary coil is connected to the power electronic power converter. The current of the secondary side coil is changed by controlling the conduction angle of the power converter by the controller, and then the primary side impedance is changed based on the coupling relationship between the primary side and the secondary side of the varactor. The purpose of controlling the motor voltage is achieved by adjusting the terminal voltage of the primary reactor.



**Fig.1** Electromagnetic pressure regulation soft start topology diagram

In the controlled model of equation (12), the input is the stator current of the motor, and the output is the angular velocity of the motor, which is used to control the angular velocity of the motor from zero to the rated speed. The electromagnetic voltage regulating controller controls the conduction angle of the thyristor, and achieves the purpose of controlling the motor speed. For the control quantity in the controller reacts to a trend, in this paper, the motor stator current and angular velocity are used as the control quantities of the controlled model of the electromagnetic voltage regulator controller.

### 4 Simulation modeling and results analysis

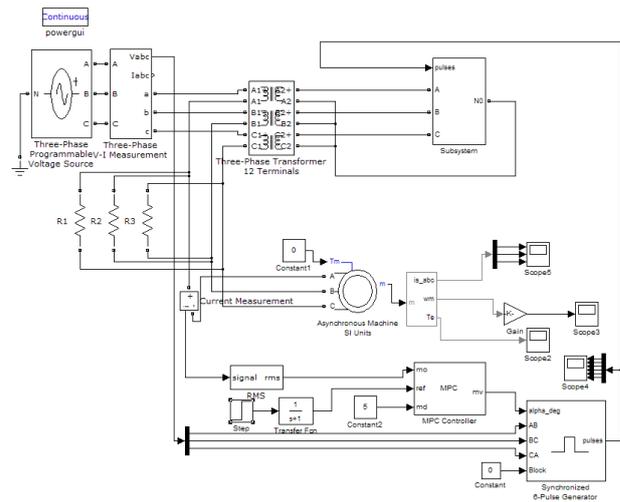
In order to verify the performance of the electromagnetic pressure-regulating soft starter based on predictive control, the simulation was performed by MATLAB.

The main parameters of the motor are as follows: rated power is 7.5KW, rated voltage is 380V, power frequency is 50Hz, rated current is 16A, stator resistance  $R_1 = 0.782\Omega$ , equivalent inductance is 3.9968mH, rotor equivalent resistance is  $R_2 = 0.943\Omega$ , equivalent inductance is 3.9968 mH. The magnetizing

inductance is 79.87mH, the moment of inertia is  $0.30 \text{ kg} \cdot \text{m}^2$ , the pole number of the motor is 2, and the rated number of revolutions of the motor is 1460r/min.

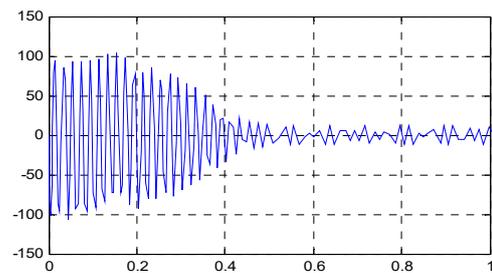
The parameters in the predictive controller are designed as: model length  $P=5$ , control time domain length  $m=2$ , predicted time domain length  $n=5$ , softening factor  $\alpha=0.35$ , control weighting factor  $\lambda = 1$ .

The simulation circuit diagram of the electromagnetic voltage regulation soft start control device based on predictive control is shown in Fig. 2.

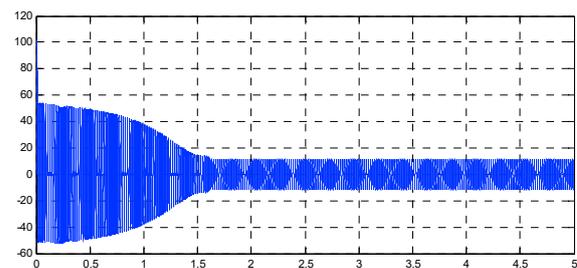


**Fig.2** Simulation circuit diagram

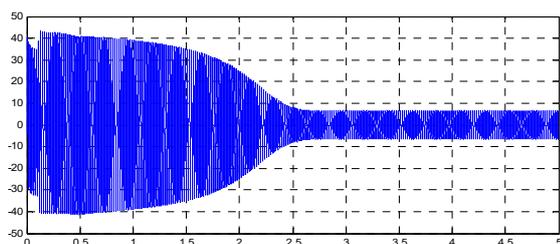
The same motor was used to simulate the no-load start of three different models which are soft start of direct start, PID control algorithm soft start and predictive control. The simulation results are shown in Figure 3.



**Fig.3 a)** Stator current waveform diagram for direct start



**Fig.3 b)** Starting current waveform based on PID controller



**Fig.3 c)** Electromagnetic pressure regulation soft start current waveform based on predictive control

According to the simulation results in Figure 3, the motor can generate a large starting current about 100A at the moment of starting, which is 5 to 7 times of the rated current of the motor, and the starting current is gradually attenuated with the increasing of the starting time. After 0.4s, the start is completed. When the PID controller starts, the starting current decreases but the current fluctuation is still large, the starting time is increased alleviating the starting process. When using the predictive controller for control, the starting current can be further reduced and the starting time is extended, the starting current is relatively smooth, and the starting process of the motor is optimized.

## 5 Conclusion

In this paper, the starting process of the motor is analyzed, and MATLAB is used to simulate three different motor starting control methods. The simulation results show that the electromagnetic soft start control method based on predictive control is satisfactory in motor starting. The predictive control algorithm used as the control of the motor soft starter has certain advantages which can realize the smooth start of the motor better.

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