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# Research and Design of AC Motor Fuzzy Soft-Start Controller

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**Abstract:** According to the characteristics of the ac motor starting process, design a fuzzy soft start controller, realize constant current of ac motor soft start control. Using fuzzy soft start controller uses the two-dimensional structure, current deviation and deviation change rate as input, Mining Mamdani inference method of fuzzy reasoning. The controller output to the adjustment of the thyristor trigger Angle. The results simulated by using Fuzzy toolbox to design. The results show that the fuzzy soft start controllers reasonable structure, simple rules, and easy to implement, motor soft start control to good effect. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Soft start, AC motor, fuzzy control, Simulation.

## 1. Introduction

AC motor is the most important power load, the starting process often produces a large starting current, impact on the grid, affect the safe operation of the grid. According to the characteristics of the ac motor starting process, design a fuzzy soft start controller, realize constant current of ac motor soft start control. Using fuzzy soft start controller uses the two-dimensional structure, current deviation and deviation change rate as input, mining Mamdani inference method of fuzzy reasoning, the controller output to the adjustment of the thyristor trigger angle, the results simulated by using Fuzzy toolbox to design. At present, the soft starting way mainly adopt the method of thyristor AC voltage regulator, in the process of motor ultra move by controlling the size of the thyristor trigger angle, can make the voltage of the stator of the motor starting current and setting the law of change according to the work requirement. Motor starting method and starting current can be arbitrary adjustment and setting, makes optimum starting process. The commonly used thyristor voltage regulator control circuit as shown [2].

At present the main loop of the ac motor soft start basic three-phase thyristor voltage regulation control of ac motor step-down start. The initial starting, AC contactor KM1 closed, KM2 disconnection. In the AC input voltage of main circuit are respectively connected in series with two anti parallel thyristor. Obtain the synchronous voltage signal using the synchronous transformer, as the reference signal of the pulse generator [3].

AC motor stator current filter and starting current given value as the input signal fuzzy regulator. Fuzzy controller is first calculated starting current setting value and the deviation and the rate of change of current feedback, then the current and current deviation as the input, after blurred fuzzy reasoning, finally, the fuzzy inference results of solving fuzzy decision is the output regulation.

Fuzzy controller output trigger angle signal is sent to the pulse generator. This paper introduces the parameter self-tuning fuzzy control technology

applied in soft starting in the limiting current, using fuzzy reasoning, fuzzy decision to control motor starting current size process, system realizes the smooth start [10].

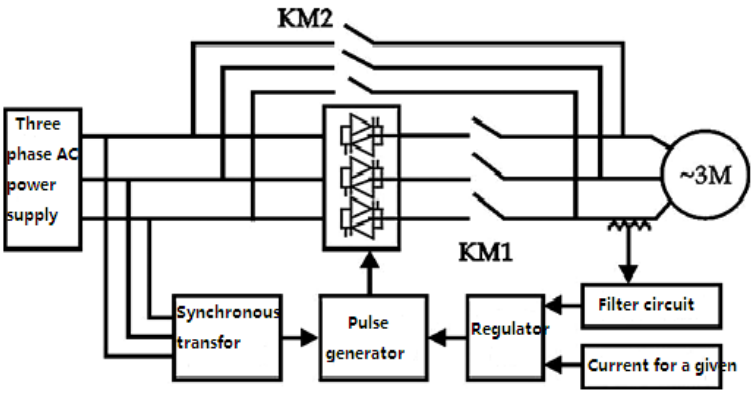


**Fig. 1.** Thyristor voltage regulator control circuit.

## 2. Fuzzy Control Scheme

Motor soft start the traditional method is to use PID closed loop control of current limiting soft start of motor. But since the start of AC asynchronous motor is a nonlinear time-varying system, Using PID closed-loop control and in the process of starting current impact problem to solve the problem of asynchronous motor is not very good [9]. So, this article USES the quick adjusting ability of parameter self-tuning fuzzy control technology, applied to the motor soft start control. Fuzzy control is a kind of intelligent control methods, its biggest advantage is not dependent on the accurate mathematical model of controlled object, it can overcome the influence of nonlinear factors, the change of the controlled object parameters has stronger robustness. The conventional fuzzy controller has the advantages of short response time, small overshoot, and good robustness, and is suitable for complex nonlinear time-varying systems, is relatively easy to establish model, etc. [4].

### 2.1. Based on the Self Tuning Fuzzy Control System

Fuzzy controller has good dynamic quality, at the same time, there are still some problems: First of all, conventional fuzzy controller control rules set up and it is fixed, difficult to get optimal control index. Relative to the motor soft start process of this kind of complex controlled object, using this kind of controller can not obtain the expected control effect, and to adapt to changes in system and environment ability is poor. Therefore we use the parameter self-tuning fuzzy control technology, in the process of operation according to the deviation and deviation rate, controller selects different variables to satisfy the different requirements of dynamic and static performance. And, based on the quantitative, scale factor self-tuning method, because the algorithm is simple and efficient, the control effect is good, it is suitable for motor soft starting this kind of real-time control system. The structure of the fuzzy controller is for the two-dimensional fuzzy controller, AC motor soft start controller design is to achieve a constant current for starting process.

So choose the starting current value deviation and the deviation change rate as input of the fuzzy controller, by the thyristor trigger angle adjustment as the output of fuzzy controller, at the same time set up a integral part of regulating the amount of accumulated time [5]. Thyristor actual maximum adjustable in the range of φ 0 ~ 150° (φ for thyristor continued flow angle), so after the integrator plus a limiter. Fuzzy controller block diagram shown in Fig. 2.

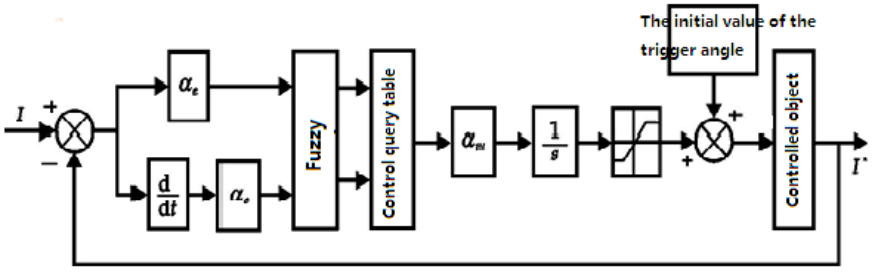


**Fig. 2.** Schematic diagram of fuzzy controller.

In figure "I" for the start of the current setting, I* as the feedback current measurements, αe as quantitative parameter deviation, quantification factor αc as the deviation changes, αu to control the amount of scale factor.

## 2.2. Determine the Linguistic Variables and Membership Function

Take the language variable of current deviation is E, the theory domain X = {-, 10 -, 6-3, 0, 3, 6, 10}, the fuzzy subset theory domain is Ai (I = 1, 2,... 7), value of the corresponding language {positive big (PB), the median (PM), positive small (PS), and 0 (Zero), negative small (NS) and negative median (NM) and negative big (NB)}, fuzzy reasoning output to control the amount Δα. Take its linguistic variables for U, theory domain is Z = {- 10,-6, 3, 0, 3, 6, 10}, The fuzzy subset theory domain is Ci (I = 1, 2,... 7), value of the corresponding language {positive big (PB), the median (PM), positive small (PS), and 0 (Zero), negative small (NS) and negative median (NM) and negative big (NB)}, Fuzzy subsets of Ci and membership function of fuzzy subset Ai take the same as shown in Table 1 [8].

**Table 1.** Fuzzy variables (E, U) membership value.

| Linguistic variables | Quantitative level | | | | | | |
|---|---|---|---|---|---|---|---|
| | -10 | -6 | -3 | 0 | 3 | 6 | 10 |
| PB | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| PM | 0 | 0 | 0 | 0 | 0.25 | 1 | 0 |
| PS | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Zero | 0 | 0 | 0.25 | 1 | 0.25 | 0 | 0 |
| NS | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| NM | 0 | 1 | 0.25 | 0 | 0 | 0 | 0 |
| NB | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

Take the current deviation change language variables as E, C, Theory domain Y = {- 10, -6, 3, 0, 3, 6, 10}. The fuzzy subset theory domain Bi (j = 1, 2, 3), corresponding language value is {negative (N), zero (Z) and positive (P)}. The corresponding membership functions are shown in table 2

**Table 1.** Fuzzy variables (E, U) membership value.

| Linguistic variables | Quantitative level | | | | | | |
|---|---|---|---|---|---|---|---|
| | -10 | -6 | -3 | 0 | 3 | 6 | 10 |
| P | 0 | 0 | 0 | 0 | 0.5 | 1 | 1 |
| Z | 0 | 0 | 0.5 | 1 | 0.5 | 0 | 0 |
| N | 1 | 1 | 0.5 | 0 | 0 | 0 | 0 |

## 2.3. To Establish the Fuzzy Control Rules

According to the process of soft starting of AC motor constant current control principle and actual operating experience, Fuzzy conditional inference using if A and B then C. 17 fuzzy control rules are as follows:

1. If E=PB then U=NB
2. If E=NB then U=PB
3. If E=PM and EC=P then U=NB
4. If E=PM and EC=Z then U=NM
5. If E=PM and EC=N then U=NS
6. If E=NM and EC=N then U=PB
7. If E=NM and EC=Z then U=PM
8. If E=NM and EC=P then U=PS
9. If E=PS and EC=P then U=NM
10. If E=PS and EC=Z then U=NS
11. If E=PS and EC=N then U=Zero
12. If E=NS and EC=N then U=PM
13. If E=NS and EC=Z then U=PS
14. If E=NS and EC=P then U=Zero
15. If E=Zero and EC=N then U=PS
16. If E=Zero and EC=Z then U=Zero
17. If E=Zero and EC=P then U=NS

## 2.4. Fuzzy Logic Inference and Defuzzification Decision

There are different ways to solution of fuzzy judgment, when implemented by single chip microcomputer. In order to reduce the computational complexity, but the average maximum membership degree method is adopted. In the simulation software, computer hardware processing, powerful can choose gravity method, also called weighted average method. Using Mamdani [1] fuzzy logic reasoning Mamdani inference method using fuzzy implication.

$$R: \alpha \rightarrow b = \alpha \wedge b \quad \text{and} \quad A \rightarrow B = A \times B, \tag{1}$$

The fuzzy output reasoning algorithm for

$$C' = A' \cdot (A \times C) \cap B' \cdot (B \times C), \tag{2}$$

In many rules, shows the fuzzy relations as follows

$$C' = A' \cdot R_1 \cap B' \cdot R_2 = A' \cdot \bigcup_{i=1}^{n} (A_1 \times C_i) \cap B' \cdot \bigcup_{j=1}^{n} (B_j \times C_j), \tag{3}$$

From table 1 and table 2, type (1) (2) (3) the fuzzy relation can be obtained

$$R_1 = \begin{Bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0.25 & 1 & 1 & 1 & 0.25 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0.25 & 1 & 1 & 1 & 0.25 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{Bmatrix}$$

$$R_2 = \begin{Bmatrix} 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{Bmatrix}$$

### 2.5. The Scale Factor and the Selection of Quantization Factor

Fig. 2 $\alpha_r$ for deviation quantitative factor, $\alpha c$ deviation change for quantitative factor, $\alpha a$ to control the amount of a scale factor. In the design of fuzzy control, can be according to the basic theory of variable domain and the domain of fuzzy set to determine the initial value [6]. But in fact, the basic theory of domain variables can only be estimated according to the theory the general scope. Detailed numerical online debugging setting is required.

## 3. The Fuzzy Controller Design and Simulation Test

By using the Matlab toolbox of Simulink, Fuzzy toolbox and SimPowersystems toolbox as shown in Fig. 3 AC motor soft start simulation system of fuzzy control. Ac motor parameter is: the rated power 2.2 kW, rated voltage 220 V, 0.435 Ω stator resistance and the stator inductance 2 mH, 0.816 Ω rotor resistance and the rotor 2 mH inductance, mutual inductance 69.31 mH, moment of inertia of 0.089 kg/m$^2$ [13].

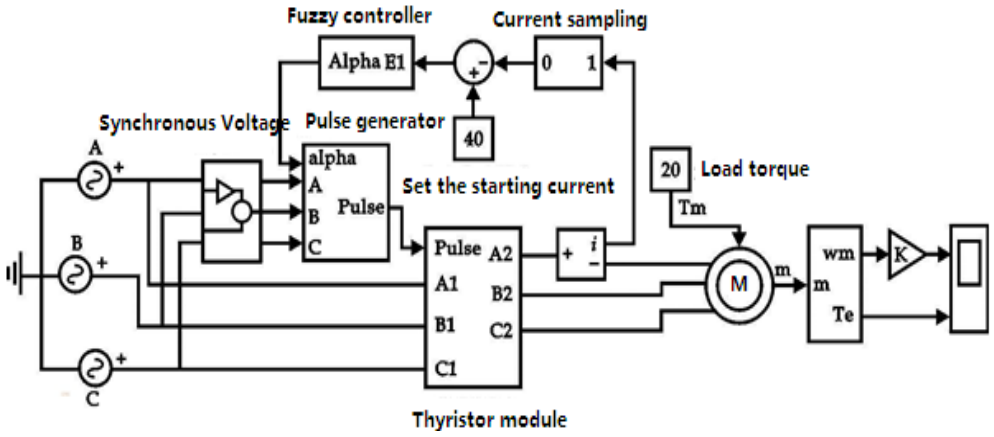


**Fig. 3.** Fuzzy control ac motor soft start system simulation diagram.

Fig. 3 fuzzy control AC motor soft start system simulation structure of thyristor trigger angle of initial value set at 90°, the starting current is set to 40 A, the load torque is set to 20 N.m. After setting, the proportionality factor of fuzzy controller is set to $\alpha$r for 0.38, $\alpha_c$ is set to 0.3, $\alpha_a$ is set to 15. Visible velocity response curve and as shown in Fig. 4, current response curve is shown in Fig. 5.

As can be seen from the Fig. 4 speed response curves, AC motor starting time of 1 s, the overshoot is less than 1 %, to reach a maximum speed tended to be stable after 2 cycles. Startup process of motor speed rising steadily, soft start effect is good. From Fig. 4 torque response curve can be seen, in the 0 ~ 0.2 S time, electromagnetic torque when the positive, negative, this is because in the initial starting, the thyristor conduction angle is smaller, the motor phase current interruption. After 0.2 s along with the rising of the thyristor conduction angle, the electromagnetic torque tends to smooth. By the influence of harmonic voltage, electromagnetic torque has certain fluctuation, until after 1 s, the electromagnetic torque and load torque is equal to the given, motor in steady state, Soft start to finish.

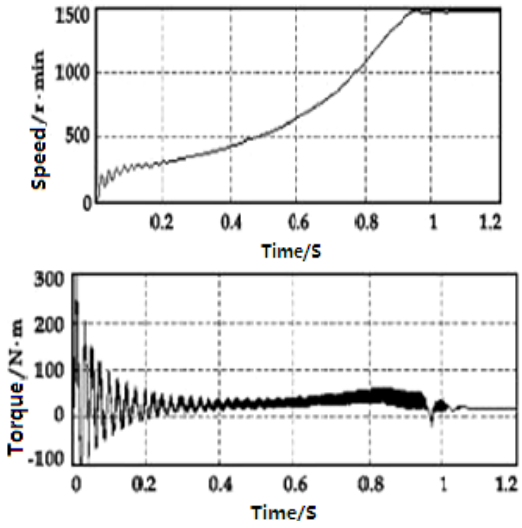


**Fig. 4.** Velocity response curve.

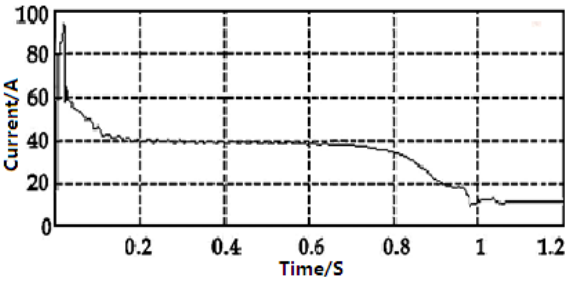


**Fig. 5.** Current response curve.

From Fig. 5 current response curve can be seen, in addition to start the initial short period of time (1-2 cycles) there is impact current, in the process of AC motor start, motor current keep set 40 A near, constant current control effect is good. When after the completion of the ac motor started, motor current back to around 12 A, into the stable working condition.

## 4. Conclusions

In this paper, design of ac motor fuzzy soft start controller uses the two-dimensional structure, similar to the conventional proportional derivative controller, goal deviation and the deviation change rate as input to adjust volume, So the system steady-state error is difficult to eliminate [7]. But fuzzy soft start controller is applied to an AC motor start the adjustment process, after reaching the rated speed, the AC motor soft start task to complete, fuzzy soft start controller will also be removed from the main circuit, thus avoiding the system stability time when the regulation. Moreover fuzzy soft start controller structure is simple, less number of rules, easy to implement by single chip microcomputer, after the design results of the simulation research shows that motor speed to rise smoothly, small overshoot, short time of dynamic adjustment process [12]. Achieved the purpose of constant flow control during startup, soft start effect is good.

But from the simulation we can see, effect of the controller to start process of motor current intermittent and harmonic voltage and no timely adjust the output. There are substantial fluctuations cause electromagnetic torque, this is because the fuzzy controller parameters in the work process. Change can not be with the working condition of the motor caused by the automatic adjustment [11]. So how to adjust the parameters of fuzzy controller to adapt to these changes, but also worthy of further study.

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