Soft Starter Study of Induction Motors using fuzzy PID control

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Abstract: Induction motor (IM) is used in many modern industrial applications such as fans, blowers and pumps and so on. Inrush current and torque pulsation exist when IMs starts. IM terminal voltage is reduced by three pairs of anti-parallel thristors to fed IM in traditional soft starter. Therefore, a novel fuzzy PID strategy for the soft starting of induction motors has been proposed in the paper. Based on this strategy the Simulink model of soft starter is implemented in Matlab/Simulink. The results of simulation experiments show that this way is practical.

1. Introduction
In recent years, induction motors (IMs) is widely used in many modern industrial applications, which causes 8 to 10 times its rated current and torque pulsation when their starting. [1-3]The high current may damage the system and the motor itself. The torque pulsation will cause mechanical stresses in the system. The soft starter is used to start the induction motor. PID strategy can only control the current to the set value. So the traditional starting way is difficult to meet the needs of the starting of the induction motor.[4]

Though, a novel strategy for the soft starting of induction motors has been proposed by the author. And based on this strategy the model of soft starter is implemented in Matlab/Simulink. It is consisted of three-phase source, three-phase V-I measurement, three-phase voltage controller, induction motor, synchronized 6-pulse generator, fuzzy controller and PID controller.

Therefore, based on this strategy, the Simulink model of soft starter is implemented in Matlab/Simulink in this paper. The following works have been done in the study: Matlab/Simulink block design; system framework design; fuzzy controller design and PID controller design. [5,6]The strategy is characterized by satisfactory reduced starting current and smooth electromagnetic torque in the starting of induction motor. It has bright prospect in application.

2. Topology structure in main circuit
Figure 1 shows the system structure for the soft starter. The main part of the system is Three-phase AC voltage controller. The main circuit of the voltage controller is consisted of three opposite-parallel thyristors. IM terminal voltage is controlled by adjusting the firing angle. The firing angle is controlled by synchronized 6-pulse generator. Synchronized 6-pulse generator is controlled by intelligent controller.
3. Control strategy design

Figure 2 shows the block diagram for control strategy. Intelligent controller is consisted of fuzzy controller and PID controller. Firing angle is adjusted accurately and quickly to reduce the current and torque pulsation. [7,8]

Because the AC asynchronous motor itself is a high order, nonlinear and strong coupling multi-variable system, it makes it hard to use linear control method [9]. So, fuzzy PID strategy is used in the controlling of soft starter. It has not only the advantages of adaptability of fuzzy control, but also the characteristics of rapidity of PID control [10].

Thus, when the RMS of feedback current I is smaller than the setting current I₀, I₀ is two times rated current, fuzzy control strategy is used. When the RMS of feedback current I is bigger than the setting current I₀, there is obvious torque pulsation. PID control can reduce the current rapidly to reduce torque pulsation.

3.1. Fuzzy controller

Figure 3 shows the model of fuzzy controller.
Table 1. Fuzzy rules table

The output from the module need to be approximately reasoned by the inference engine module, which is consist of some knowledge base rules[11]. The knowledge based rules are in table 1.

| $e$ | NB | NM | NS | ZO | PS | PM | PN |
|-----|----|----|----|----|----|----|----|
| NB  | PB | PB | PM | PM | ZO | ZO | NS |
| NM  | PB | PB | PM | PS | ZO | NS | NM |
| NS  | PB | PM | PS | PS | ZO | NM | NM |
| ZO  | PB | PM | PS | ZO | NS | NM | NB |
| PS  | PM | PM | ZO | NS | NM | NB | NB |
| PM  | PM | PS | ZO | NS | NB | NB | NB |
| PB  | PS | ZO | ZO | NM | NB | NB | NB |

Simulink model for fuzzy controller is implemented in figure 5.
3.2. \textit{PID controller}

Equation (1) shows the basic principle of PID control.

\[
 u(t) = K_p[e(t) + \frac{1}{T_i} \int e(t)\,dt + T_d \frac{de(t)}{dt}]
\]  

(1)

In equation (1) \(u(t)\) is output variable; \(e(t)\) is input variable; \(K_p e(t)\) is proportional control item. \(\frac{1}{T_i} \int e(t)\,dt\) is Integral control item. \(T_d \frac{de(t)}{dt}\) is derivative control item. Figure 6 shows the Simulink model for PID model.

4. \textit{Simulink results}

Squirrel-cage induction motor was used with the following parameters: \(P_n = 2000\text{VA}, U_n = 380V, f = 50\text{Hz}, R_s = 7.5\Omega, L_s = 0.17\text{H}, R_r = 4.5\Omega, L_r = 0.05\text{H}, L_m = 0.37\text{H}, J = 0.1\text{kg}\cdot\text{m}^2, P = 2\). Where \(R_s\) and \(R_r\) are stator and rotor resistors, \(L_s\) and \(L_r\) are leakage inductances of stator and rotor, \(L_m\) is the mutual inductance. \(J\) is the coefficient of inertia. Figure 7 shows the Comparison of DOL starting and fuzzy PID starting. The peak current of Fuzzy PID starting is 4A, while DOL starting is 8A. The peak electromagnetic torque of DOL starting is 13N*\text{m}, while Fuzzy PID starting is only 5N*\text{m}. Fuzzy PID starting has reduced the starting current and torque pulsation obviously.
5. Conclusions

This paper analyzes the motor soft start process, compares the existing fuzzy control strategy and PID control strategy, proposes a strategy based on fuzzy PID control, and realizes the smooth soft start of the three-phase asynchronous motor. Using MATLAB to build the simulation model of the system, Simulink's results show that this strategy based on fuzzy PID control can significantly reduce the torque ripple, effectively solve the problem of large inrush current during motor startup, and has good startup performance and robustness. This strategy can adjust the parameters according to the load conditions, limit the starting current, reduce the stator current, and reduce the impact torque while having a small overshoot. This strategy combines the advantages of previous motor soft start, making it practical and universal.

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