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Modeling and Analysis of Slip Power Recovery Controlled Induction Motor Drive

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Abstract- **A control system based on PI_PI controller is used to improve the dynamic performance of slip power recovery motors, in which one PI controller is used as auto speed regulator (ASR) and second is used as auto current regulator (ACR). This controller tracks the need of speed and limit the stator current. The parameter values of PI controller are adjusted relaying on mathematical model value such as electromagnetic time constant and magnification factor. The simulation results of this control strategy for motor drive show that this system has high anti-disturbance capacity, fast response, low overshoot, so the system dynamic performance is improved.**

Keywords-PI_PI controller; motor drive speed control; modeling and simulation.

I. INTRODUCTION

The technology of slip power recovery controlled by chopper for slip ring induction motor has been widely applied in high-voltage large-capacity motor because of higher power factor, higher efficiency and lower control voltage than those without chopper. In this, both inner current loop and outer speed loop are designed with conventional proportional-integral-derivative (PID) controller to control the motor drive automatically.

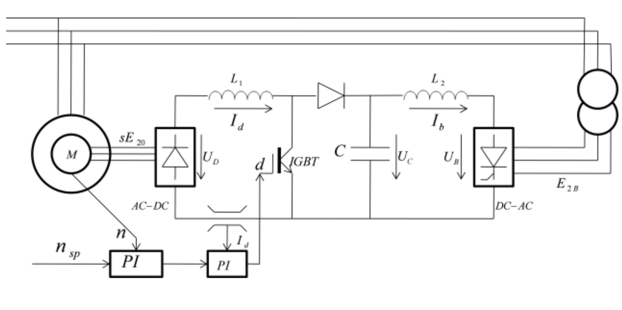

Figure1. Control scheme of slip power recovery with chopper for motor drive

In this paper, a double-closed-loop control system based on PI_PI controller is presented to improve the dynamic performance of slip power recovery drives. This motor drive control system is shown in Figure 1, in which, one PI controller is used as auto speed regulator and second is used as auto current regulator.

We will further illustrate the designs steps and the effectiveness of this control scheme via simulation experiments in MATLAB/SIMULINK.

II. PROPOSED CONTROL SCHEME

This new type of double closed loop control system shown in Fig. 1 is proposed for the speed control of the nonlinear, time varying and complex motor system, in which one PI controller is used as auto speed regulator and second is used as auto current regulator.

A. Principle of speed regulation

From the slip power recovery circuit shown in Fig. 1, the three-phase full-wave diode bridge rectifier connects to the rotor windings via slip rings, converters a portion of slip power into DC which in turn converted into line frequency AC by a three-phase-thyristor inverter and fed back to the AC mains. The inductor L_1, L_2 between rectifier and inverter are placed to reduce the DC current ripple. The diode between L_1 and L_2 is used to keep current when IGBT is off and isolate when IGBT is on. The capacitor C is used to store the energy in the loop by keeping voltage U_c at low ripples.

By using IGBT as chopper, the inverter is always fixed at the smallest inverter angle of about π/6rad and the equivalent additional reverse electromotive force is obtained by changing the duty cycle of IGBT chopper. As a result, the electromagnetic torque and motor speed is changed. So the purpose of changing the motor speed can be achieved by adjusting the duty ratio of IGBT chopper.

Neglecting higher order harmonics and power losses in rectifier and converter, equivalent circuit combined with converter, DC link, IGBT chopper and inverter is shown in figure 2.

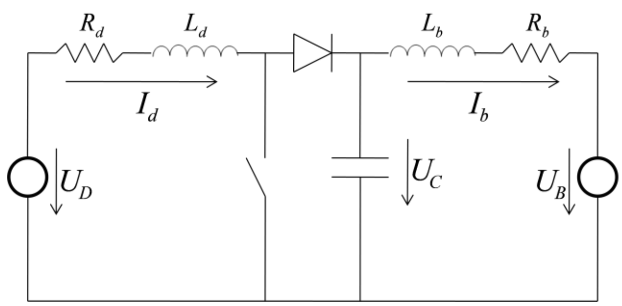

Figure2. DC Equivalent Circuit

Where, U_D is the rotor rectifier voltage, U_B is the active inverter DC voltage, R_d is the equivalent resistance of rotor rectifier circuit, L_d is equivalent inductance for the rotor rectifier, R_b is equivalent resistance of the inverter circuit, L_b is equivalent inductor for the inverter circuit.

A. Mathematical model

Mathematical model is the foundation of system analysis and correction. In engineering applications, the range of variation of capacitance voltage Uc is small. Let us assume that Uc is constant and the disturbance of U_c is approximately equal to 0. Using the average model method, the average value equivalent circuit is obtained as shown in Fig. 3.

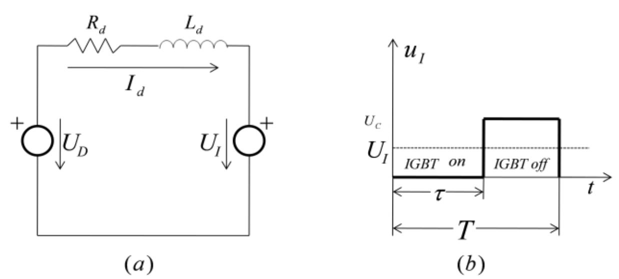

Figure3. (a) The average value equivalent circuit and (b) waveform of back voltage

In figure 3, considering the power switching device IGBT has lag aspect, the transfer functions of this circuit is given as follows:

$$U_i = \frac{(1-d)U_c}{T_s s + 1}$$
(2.1)

$$U_D = 2.34 E_{20} S \qquad (2.2)$$

$$\frac{I_d}{U_D - U_I} = \frac{1/R_d}{\frac{L_d}{R_d}s + 1} = \frac{K_{Lr}}{T_{Lr} + 1} \qquad (2.3)$$

Where

$d = \frac{\tau}{T}$ duty ratio of IGBT

T_s = sum of IGBT trigger pulse cycle and three-phase bridge rectifier out of control time

$S = \frac{n_0 - n}{n_0}$ slip of induction motor drive

$$R_d = 2(\frac{R_s}{k^2} + R_r) + \frac{3X_D S}{\pi}$$

$$L_d = 2\frac{3X_D}{100\pi} + L_1$$

The mechanical motion equation of motor drive system is given as:

$$T_e - T_L = \frac{GD^2}{375}\frac{dn}{dt} \qquad (2.4)$$

Where

Electromagnetic torque $T_e = C_M I_d$

Torque coefficient $C_M = \dfrac{2.34E_{20} - \frac{3X_D}{\pi} I_d}{2\pi f / p}$

Then

$$\frac{n(s)}{I_d(s) - I_L(s)} = \frac{375 C_M}{GD^2}\frac{1}{s} = \frac{1}{T_m s} \qquad (2.5)$$

From the above-mentioned formula, the block diagram of open-loop system is developed as shown in figure 4.

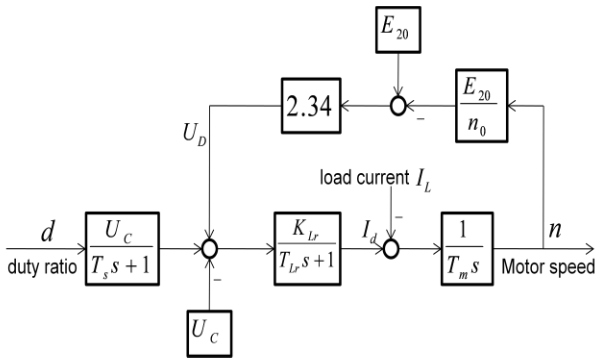

Figure4. Block diagram of open-loop motor drive system

III. Double Closed Loop Control System Design

A. *Design of ACR_PI in inner current loop*

In double closed loop design procedure, the first step is to design the controller for inner current loop and to tune the parameters. The current response is fast because the time constant of inner loop is small. According to a typical design method explain in [5], PI controller for auto current regulator (ACR) used for meeting the demand of servo performance is designed as follows.

The form of PI controller can be written as

$$W_{ACR}(s) = \frac{K_{ic}(\tau_{ic}s+1)}{\tau_{ic}s} = K_{ic}\left(1+\frac{1}{\tau_{ic}s}\right) \qquad (3.1)$$

The parameters of ACR can be chosen as follow

$$\tau_{ic} = T_{Lr} \qquad K_{ic} = \frac{\tau_{ic}}{2T_s * U_C * K_{Lr}}$$

Then the transfer function of inner-closed-loop $W_{CL\_i}(s)$ will be similar to a typical second-order system, which is given as:

$$W_{CL\_i}(s) = \frac{1/(2T_s)^2}{S^2 + 2\frac{\sqrt{2}}{2}\left(1/\sqrt{2}T_s\right)S + 1/(2T_s)^2}$$

$$= \frac{1}{2T_s^2S^2 + 2T_sS + 1} \qquad (3.2)$$

B. *Design of ASR_PI in outer speed loop*

In double closed loop design procedure, the second step is to design the control1er for outer speed loop and to tune the parameters. This controller is designed by using Ziegler-Nichols rules for tuning PID controller. Ziegler and Nichols proposed rules for determining value of the proportional gain K_p, integral time T_i, and derivative time T_d based on transient response characteristic of a given plant.

There are two methods called Ziegler-Nichols tuning rules, in second method we first set $T_i = \infty$ and $T_d = 0$. The proportional control action only increases K_p from 0 to a critical value K_{cr} at which the output exhibit sustained oscillations. Thus, the critical gain K_{cr} and the corresponding period P_{cr} are determined. Ziegler and Nichols suggested to set the values of the parameter K_p, T_i and T_d according to table 1.

TABLE.1 Ziegler-Nichols tuning rule based on critical gain K_{CR} and critical period P_{CR}(second method)

Type of controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

The PID controller tuned by the second method of Ziegler-Nichols rules gives

$$G_c(s) = K_p\left(1+\frac{1}{T_is}+T_ds\right)$$

$$= 0.6K_{cr}\left(1+\frac{1}{0.5P_{cr}s}+P_{cr}s\right)$$

$$= 0.075K_{cr}P_{cr}\frac{\left(s+\frac{4}{P_{cr}}\right)^2}{s} \qquad (3.3)$$

Now, by using this method the ASR_PI controller for outer speed loop is designed.

The form of PI controller can be written as

$$W_{ASR}(s) = \frac{K_{is}(\tau_{is}s+1)}{\tau_{is}s} = K_{is}\left(1+\frac{1}{\tau_{is}s}\right) \qquad (3.4)$$

IV. Simulation and Experimental Results

The simulation tests have done by using PI_PI controller in double closed loop for motor drive speed regulation system.

Using MATLAB/SIMULINK, the simulation model of motor drive speed control is built. Figure5 shows the model of speed control system using PI_PI controller.

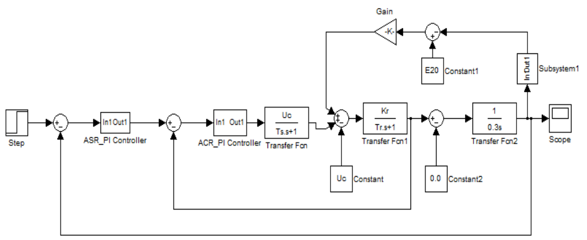

Figure5. Simulation model

A slip ring induction motor of 500 kW, 2.3 kV and 50 Hz frequency is used for experiment. Parameters of this motor are given below.

Pole pair = 2

Stator resistance R_s = 1.115Ω

Rotor resistance R_r = 1.085 Ω

Inductance of stator winding L_s = 0.005974 H

Inductance of rotor winding L_r = 0.005974 H

Magnetizing reactance L_m = 0.2037 H

That response curve of the motor speed is shown in Figure6, which shows that response having peak overshoot of 21.97 rpm and settling time of 1 second. Figure7 shows the speed curve of induction motor in which rotor speed is changed from 144 rad/sec to 100rad/sec.

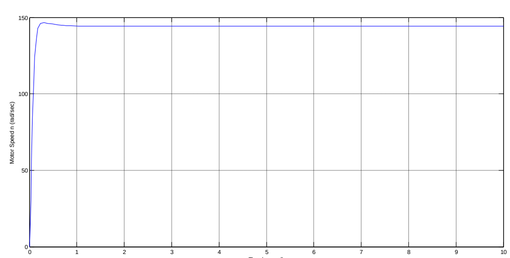

Figure6. Speed curve of dynamic response

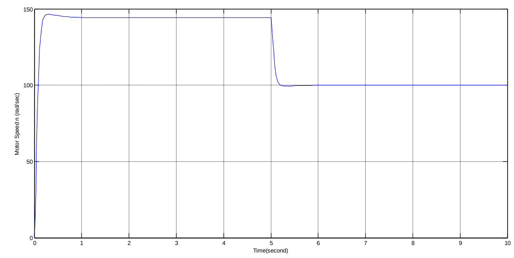

Figure7. Speed curve of dynamic response when speed change from 144 rad/sec to 100 rad/sec.

V. Conclusion

In this paper, simulation of a double closed loop slip power recovery in induction motor, with chopper is obtained by using PI controller as both speed regulator and current regulator. The PI controller for double closed-loop is designed and the simulations are performed. The simulation results show that the PI_PI double-loop speed control system reduced the peak overshoot and obtained the rapid and smooth response against the modeling uncertainty and disturbance. So, it is an effective method to improve the robust and adaptability performance for induction motor.

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