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Adaptive Control for Speed of Wound Rotor Induction Motor With Slip Energy Recovery

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Abstract

This paper presents how to design speed control of wound rotor induction motors with slip energy recovery. The speed is limited at some range of sub-synchronous speed of the rotating magnetic field. The problem with speed control by adjusting resistance value in the rotor circuit reduces the efficiency of power, because of the slip energy is lost when it passes through the rotor resistance. The control system is designed to maintain efficiency of motor, where it recovers loss energy by returning it to the system to improve the efficiency. A new PI control method of adaptive control [1], [13] is applied for the system with cascade type PI controller on the main loop to keep the speed constant and the internal loop to adjust the rotor appropriated current of the load provides the good transient response without overshoot.

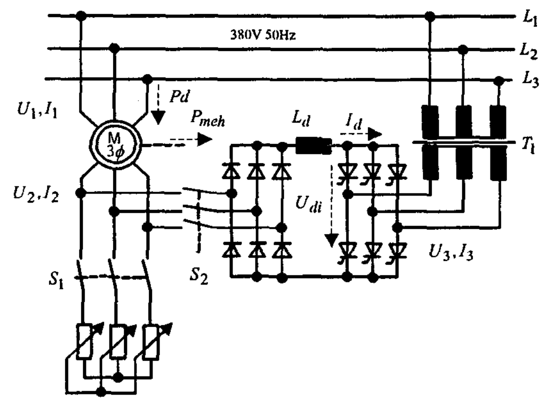

Fig. 1 Power circuit diagram

1. Introduction

Control of the wound rotor induction motors with slip energy recovery is important in higher power rate. The speed at sub-synchronous can be controlled by adjusting resistance in the rotor circuit, that causes the slip power loss in external rotor resistors. But the loss can be converted back to ac. line with the help of a line-commutated inverter, where the three-phase rotor currents are rectified with diodes to feed the power to the intermediate dc.circuit and to make the power unidirectional. The speed control is controlled by changing the back voltage U_{di} at the intermediate dc.link. If the U_{di} is increased, the speed is supposed to decrease in order that the rectified rotor voltage can drive the currents through dc. Circuit.[2],[3],[4],Fig.1 and Fig.2

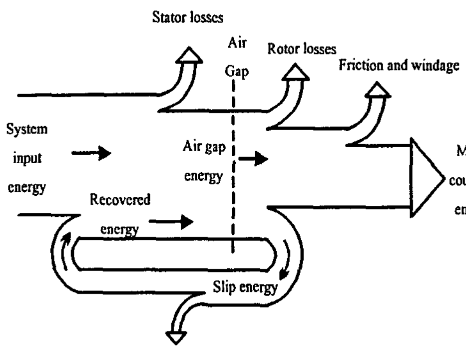

Fig. 2 Power flow diagram

2. Block diagram of control system

In the view of circuit a starting resistor serves to bring the motor up to set up speed range, where the rotor voltage has dropped sufficiently to allow switching in the converter. The dc. Current from rectified circuit should be smooth by a chock Ld in order to obtain continuos current flow over very load range and the line-commutated inverter is designed to feed the slip power back to ac.line. A step-down transformer serves to supply voltage in the intermediate dc.link, which is quite low in the usual speed rang. It helps to reduce the reactive current in line side of the inverter, which is caused by delay, angle around 90-180 degree. The transformer ratio is changed in several steps in order to have optimal conditions over a wider speed range. [9],[13] and Fig.3

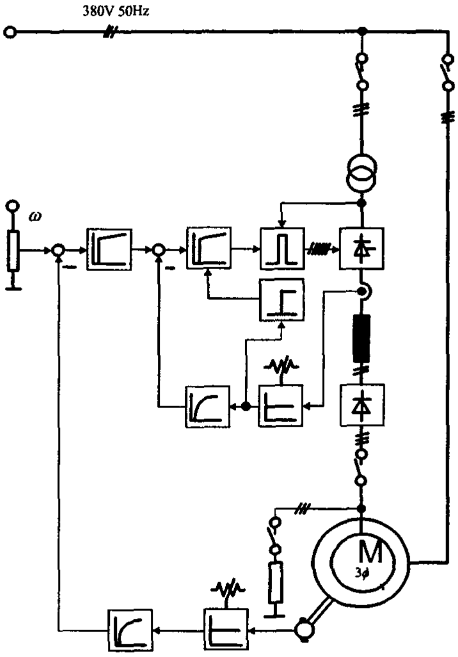

Fig. 3 Block diagram of control system

3. Analysis of the system and design of the controller

The mathematics model of system are analysis with consider from equivalent circuit diagram of dc.link.

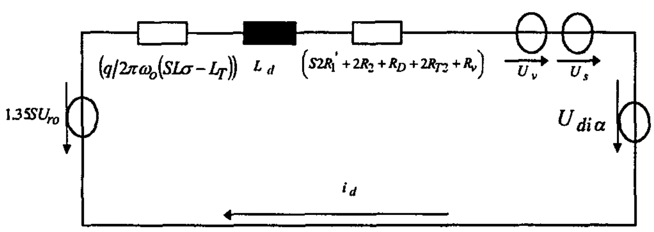

Fig. 4 DC. Link circuit

$$O = 1.35SU_{ro} - S(2R_1 + 6foL\sigma)id - (2R_2 + Rd + Rv - 6foL_r)id - Ld.id/dt - Uv - Us - Udi\alpha \quad (1)$$

Given

$$Ud = -Udi\alpha - Uv - Us \approx -Udi\alpha$$
$$R_A = 2R_1 + 6foL\sigma$$
$$R_B = 2R_2 + Rd + Rv - 6foL_r$$
$$Td = Ld/R_B$$
$$Id_{MAX} = 1.35U_{ro}/R_B$$
$$Tm = J\omega d/M_{MAX}$$
$$\frac{\omega(s)}{\omega d} = \frac{1}{STm}\cdot\frac{M(s)}{M_{MAX}} \quad (2)$$
$$\frac{M(s)}{M_{MAX}} = 4\frac{R_A}{R_B}\cdot\frac{id(s)}{Id_{MAX}} \quad (3)$$
$$\frac{id(s)}{Id_{MAX}} = \frac{1}{1+STd}\left[\left(1 - \frac{Udi\alpha}{1.35U_{ro}}\right) - \frac{\omega(s)}{\omega d}\right] \quad (4)$$

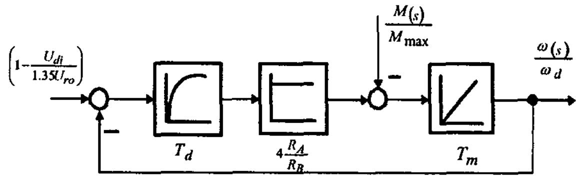

Fig. 5 Block diagram of system

The PI controller to used control this system with cascade control. The outer loop PI for constant speed control and the inner loop for constant torque control by adjust the rotor current appropriate of loop at no loop to rated. [6],[9] and Fig.6

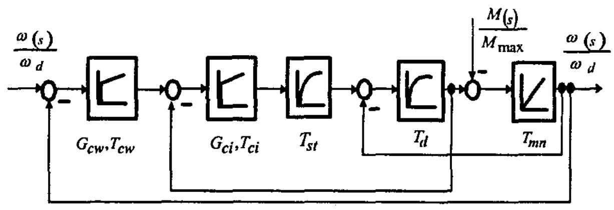

Fig. 6 Current speed cascade control

Optimized method by BO (Betrag Optimum) and SO (Symmetrical Optimum) at the result test time constant of system. It can find gain of PI the inner and outer loop.

$Td = 67.2\ ms$ $\quad a = 2D + 1$

$Tmn = 688\ ms$ $\quad D = \sqrt{2}/2$

$T_M = 415.56\ ms$

$T_{st} = 3.3\ ms$

$$Fcio(s) = Gci\frac{(TciS+1)}{TciS}\cdot\frac{1}{(Tst+1)}\cdot\frac{TmnS}{(TdTmnS^2 + TmnS + 1)} \quad (5)$$
$$T_1 = \frac{Tmn}{2}\left[1 + \sqrt{1 - 4\frac{Td}{Tmn}}\right] = 330\ ms \quad (6)$$
$$T_2 = Tmn - T_1 = 36 ms \quad (7)$$
$$Gci = \frac{T_1}{Tm}\left[\left(\frac{Tst}{2T_2} + \frac{T_2}{2Tst}\right)\right] = 10.17 \quad (8)$$
$$Tci = T_1 = 330\ ms$$
$$Fcwo = Gcw\frac{(TcwS+1)}{TcwS}\cdot\frac{Ts'}{(Ts'S+1)}\cdot\frac{1}{TmS} \quad (9)$$
$$Gs' = \frac{GciTmn}{(GciTmn + T_1)} \quad (10)$$
$$Ts' = \frac{T_1(Tst + T_2)}{GciTmn + T_1} \quad (11)$$
$$Gc\omega = \frac{1}{a}\cdot\frac{Tmn}{Ts''} = 26.7 \quad (12)$$
$$Tc\omega = a^2Ts'' = 37.35\ ms \quad (13)$$

4. Experimental Results

This motor is wound rotor induction motor 4 kW, 220/380V, 50Hz, 17.1/9.9A Power factor 0.8, 1410 rpm. This is testing of the efficiency and power factor show in the Fig.7 , Fig.8.and Fig.9. The step response of speed on adaptive and non-adaptive that show in the Fig.10 and signal current of system at slip 0.1 and 0.4 show in the Fig.11 and Fig.12.

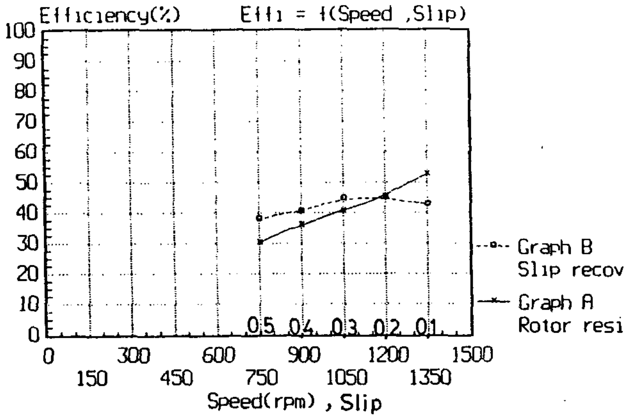

Fig. 7 Efficiency of system at load100%

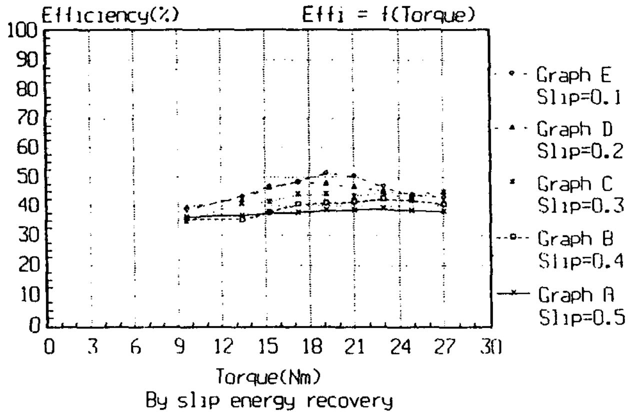

Fig. 8 Efficiency of system at vary load

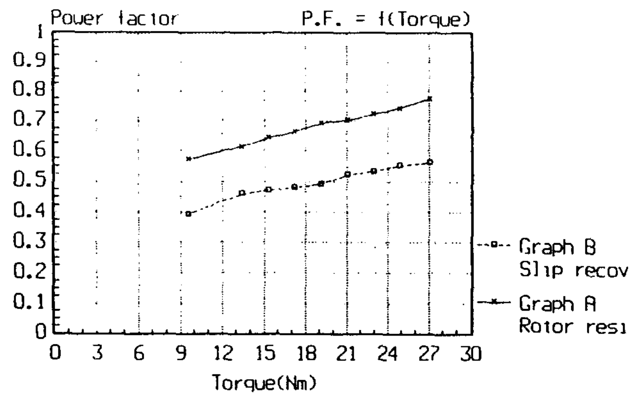

Fig. 9 Power factor of system

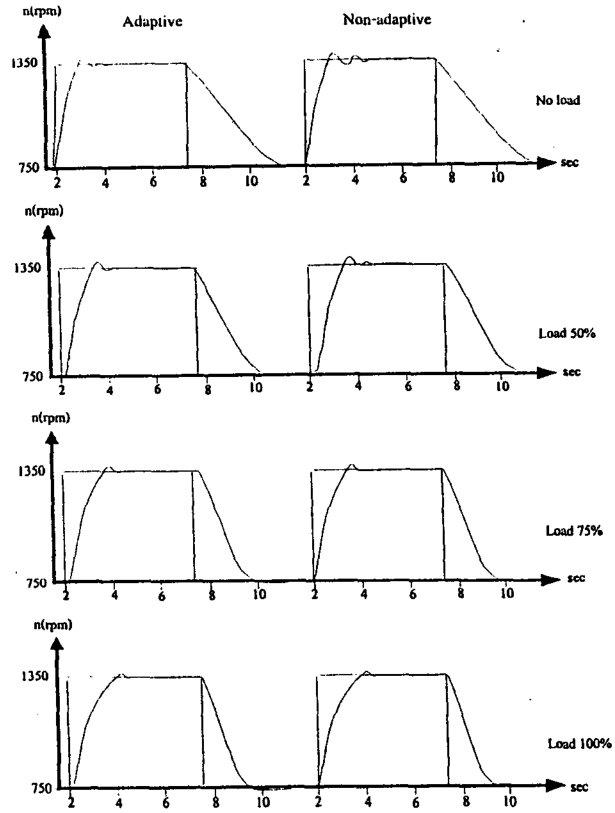

Fig. 10 Step responds of speed at load 100%

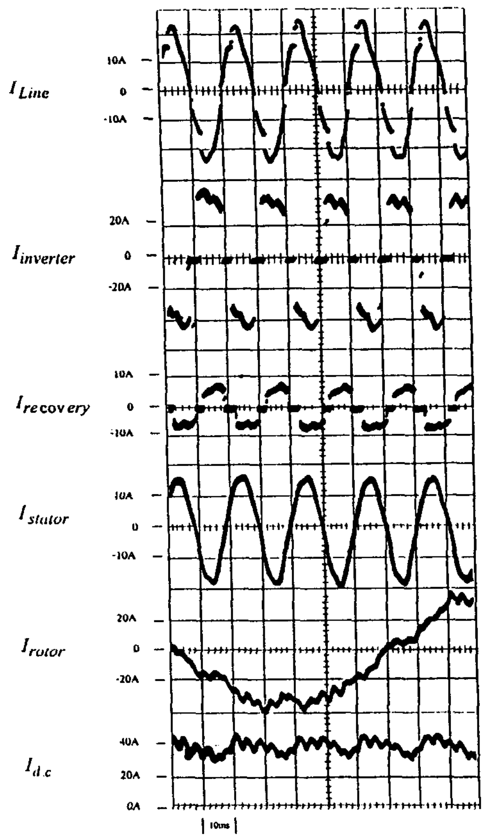

Fig. 11 Signal current of slip 0.1 at load 100%

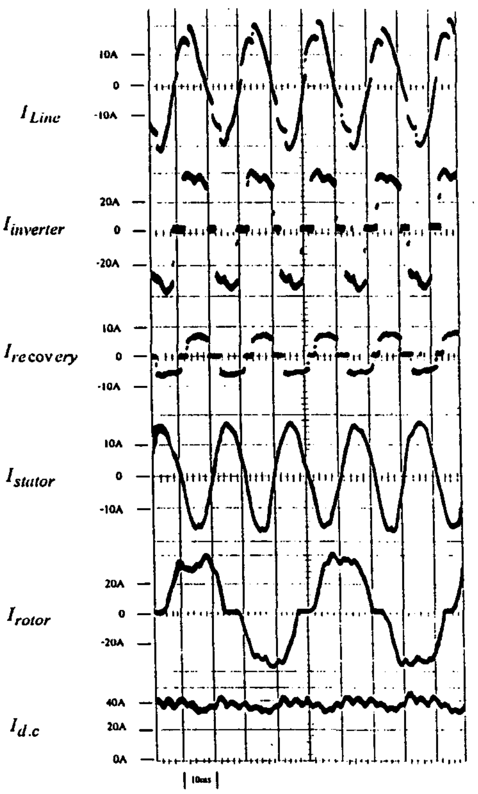

Fig. 12 Signal current of slip 0.4 at load 100%

5. Conclusions

The result of testing at the slip 0.5 has shown that the power 1440-watt can be saved, those makes the efficiency increased 7.7 % more than the conventional resistance control method. The speed can be kept constant while the slip remains in the range of 0.5-0.1 from the moment without load to the achieved moment of required rate.[7] The power factor decreases because the reactive current in line side increases.[2] The step response of speed becomes excellent with satisfied dynamics characteristics by PI controller which uses adaptive PI to tune the automatically from on-load to some rated.[6] The measurement waveform of the stator and rotor currents at different speed explained in Fig.11 and Fig.12 has distortion in line current and rotor currents have crossover because of air gap between stator and rotor. Frequency of rotor current is varied by the slip of motor. DC current has ripple will be smooth by choke Ld [3]

6. References

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7. Appendix

s	Slip
U_{ro}	Rotor voltage at standstill
$1.35sU_{ro}$	Average voltage of B6-Converter
U_{dia}	Average voltage of B6SCRConverter
id	Current in DC. link
q	A number of commutation
fo	Frequency line 50Hz
$L\sigma$	Linkage inductance of motor in Rotor circuit
$q/2\pi S\omega oL\sigma$	Inductance from B6-Converter
$q/2\pi\omega oL_T$	Inductance from B6-SCR Converter
L_T	Short circuit inductance of transformer
Ld	Inductance of choke
Rd	Resistance of choke
Rv	Resistance in power semiconductor
R_1	Resistance of stator transfer to rotor
R_2	Resistance of rotor
Uv	Voltage drop in power semiconductor
Us	Voltage drop in slipring