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Comprehensive Study of Speed Control And Power Loss Analysis Using Rotor Resistance And Slip Power Recovery Method

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Abstract: Wound rotor induction motors have been popular for decades in the cement and mining industry for starting and driving large grinding mill. A wound rotor induction motor is large ac motor that controlled starting characteristics and adjustable speed capability. Slip power recovery wound rotor induction motor drives are used in high power, limited speed range applications where control of slip power provides the variable speed drive system. Traditional method of speed control of slip ring induction motor is variable resistance method but losses occurs are more. So, in this paper rotor resistance method and slip power recovery system is used for the speed control of slip-ring induction motor and analysis of speed and power loss is carried out. MATLAB/Simulink is used to simulate this both method for slip-ring induction motor and prove that in rotor resistance method speed control is possible but the system loss is increase whereas in slip power recovery system by change in firing angle of inverter we can change speed of motor and save power which is loss in resistance.

Keywords: Slip power; MATLAB/Simulink; Firing angle; Slip Power Recovery System

I. INTRODUCTION

Traditionally, speed control of induction motor is achieved by adding resistance at rotor side. The rotor also has a three-phase winding, usually connected in a wye (or star) circuit. The three terminals of the rotor winding are connected to separate slip rings. Brushes ride on these slip rings and the rotor winding is connected to an external liquid rheostat or resistor bank. This resistance, when inserted into the rotor circuit, overall rotor resistance will increase and reduces starting currents. The motor speed can be adjusted by changing the resistance. The continuous power flowing into the resistor is loss as heat. Adding resistance to the rotor circuit also changes the speed at which maximum torque occurs for the motor, so high torques can be produced at low speed for starting loads with high breakaway torque requirements.

Induction motor drives with control of speed have huge applications in the modern industrial set up. More than 75% of the load today in the industry of any country consists of induction motor drives. Wound rotor induction motor drives have found great applications due to the availability of slip power easily available from slip rings, which can be utilized for better speed control. Slip power can be recovered from static converters instead of wasting power in the resistance. High performance induction motor drive application requires low cost, high efficiency and simple control circuitry for the complete speed range. Nowadays, slip power recovery drives (SPRD), also known as Static Scherbius system, is widely used for the limited speed range applications such as large-capacity pumps and fan drives, variable-speed wind energy systems, ship-board variable speed/constant frequency system etc.

Slip Power Recovery System (SPRS) is a variable speed drive for slip ring induction motors. It recovers and delivers the rotor power from the motor to the grid. At changeover speed, SPRS is connected to the rotor and the rotor resistance is disconnected. The diode rectifier converts the rotor voltage to DC voltage. This rectified rotor voltage is counter-balanced by a line commutated inverter. By controlling the 'counter-balancing' inverter voltage, the rotor current, hence rotor speed is regulated. The slip power collected at the slip rings is fed back to the grid through the inverter.

II. PERFORMACNE ANALYSIS OF THE DRIVE

Scherbius drive system provides speed control of slip ring induction motor below synchronous speed. A portion of rotor ac power converted into dc by diode bridge. The controlled rectifier working as inverter convert it back to ac and feed at back to source of power supply can be controlled by controlling inverter counter emf (Vd2) which is control by firing angle. This DC link inductor is providing to reduce ripple in dc link current (Id).

Since, slip power feedback to source, unlike rotor resistance control where it is wasted in resistor so, drive has high efficiency.

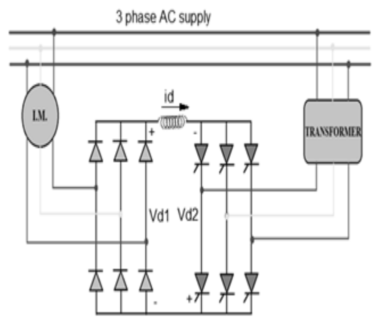

Figure 1 Schematic diagram of slip power recovery system

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As shown in figure 1 neglecting stator and rotor resistance drops

$$V_{d1} = \frac{3\sqrt{6}}{\pi}\frac{sV}{n} \quad \text{Eq. (1)}$$

And

$$V_{d2} = \frac{3\sqrt{6}}{\pi}\frac{V}{m} cos\alpha \quad \text{Eq. (2)}$$

$$m = \frac{V_2}{V_1 + V_2} * 2 \quad \text{Eq. (3)}$$

Where,

$$V_1 = stator\ voltage$$
$$V_2 = rotor\ voltage$$

Where α is the inverter firing angle and , n and m are, respectively, the stator to rotor turns ratio of motor and source side to converter side turns ratio of the transformer Neglecting drop across inductor.

$$V_{d1} + V_{d2} = 0 \quad \text{Eq. (4)}$$

$$s = -\frac{n}{m} cos\alpha = -a\ cos\alpha \quad \text{Eq. (5)}$$

Maximum value of α is restricted to 150 for safe commutation of inverter thyristors. Slip can be controlled from 0 to 0.996a when α is changed from 30 to 150. By appropriate choice of a required speed range can be obtained.

Transformer is used to match the voltages V_{d1} and V_{d2}. At the lowest speed required from the drive, V_{d1} will have the maximum value V_{d1m} given by

$$V_{d1m} = nVs_{max} \quad \text{Eq. (6)}$$

Where s_{max} is the value of slip at the lowest speed if α is restricted to 150. m is chosen such that the inverter voltage has a value V_{d1m}, when α is 150.

$$mV\ cos150 + nV\ s_{max} = 0 \quad \text{Eq. (7)}$$

$$m = -\frac{n\,s_{max}}{cos\,150} = 1.035\ ns_{max} \quad \text{Eq. (8)}$$

Such a choice of m ensures inverter operation at the highest firing angle at the lowest reactive power at lowest speed. This improves the drive power factor and reduce reactive power at all speeds in the speed range of the drive.

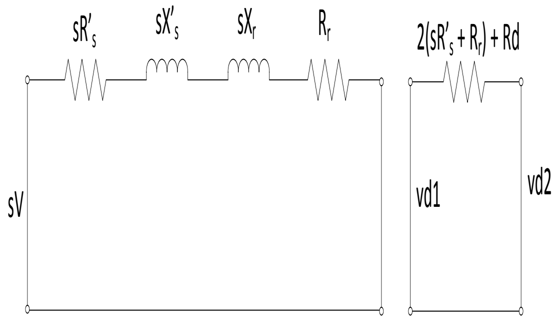

Figure 2 Equivalent circuit of motor drive

Figure 2 shows equivalent circuit of motor referred to the rotor, neglecting magnetizing branch. Derivation of Eq. (9) shows that when referred to the dc link, resistance $(sR_s' + R_r)$ will be $2(sR_s' + R_r)$. This gives approximate dc equivalent circuit of the driveV_{d1} and V_{d2} are given in Eq. (1) and (2), R_d is the resistance of dc link inductor equivalent circuit ignores the commutation overlap in Diode Bridge. Now

$$I_d = \frac{V_{d1} + V_{d2}}{2(sR_s' + R_r) + R_d} \quad \text{Eq. (9)}$$

$$I_d = \frac{\frac{3}{\pi}\sqrt{6}\,V(\frac{s}{n} + \frac{cos\alpha}{m})}{2(sR_s' + R_r) + R_d} \quad \text{Eq. (10)}$$

If rotor copper loss is neglected

$$sP_g = |V_{d2}|I_d \quad \text{Eq. (11)}$$

$$P_g = \frac{|V_{d2}|I_d}{s} \quad \text{Eq. (12)}$$

Now

$$T = \frac{P_g}{w_{ms}} = \frac{|V_{d2}|I_d}{sw_{ms}} \quad \text{Eq. (13)}$$

The nature of speed torque curves is shown in Fig.

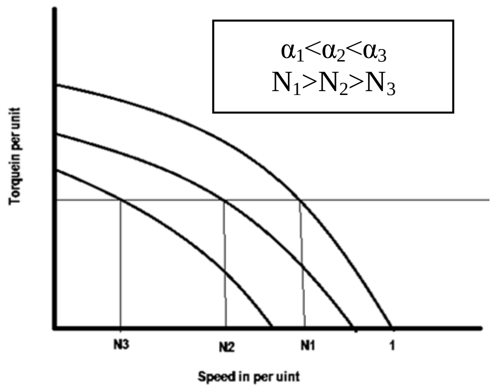

Figure 3 Torque speed characteristic

The drive has application in fan and pumps drives which required speed control in a narrow range only. If maximum speed is denoted by s_{max} then power rating of diode bridge inverter and transformer can be just s_{max} times the motor power rating. For example when speed is to be reduced below synchronous speed by only 20%, power rating of diode bridge inverter and transformer will be just 20% of motor power rating. Consequently, drive has low cost. The rating of inverter and transformer are slip times the motor rating.

III. SIMULATION OF ROTOR RESISTANCE METHOD USING MATLAB/SIMULINK

In this paper rotor resistance and slip power recovery system are used to control the speed of slip ring induction motor. Now first apply the rotor resistance method for the speed control of slip-ring induction motor. From this method we control speed of slip-ring induction motor but due to this method loss of system is increase. The result of speed, rotor current and power loss in resistance this method is present below. The rating of induction motor and transformer are as below.

Table 1 Parameter of Induction Motor

Quantity	Rating
Nominal power	I. 2.6 MW
Voltage	6300 V
Frequency	50 Hz
Rotor resistance	0.0826 Ω
Rotor inductance	0.003714 H
Stator resistance	0.0859 Ω
Stator inductance	0.0051228 H
Mutual inductance	0.23984 H
Inertia	50 kg.m^2
Pole pairs	4

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Table 2 Parameter of Transformer

Quantity	Rating
Nominal power	0.055 MVA
Frequency	50 Hz
V_1 for winding 1	440 V
V_2 for winding 2	6300 V
Magnetizing resistance R_m	1 Ω
Magnetizing inductance L_m	1 H

The simulation of rotor resistance method is as below. In this simulation the opening time of circuit breaker is 4 sec., 7 sec., 9 sec.

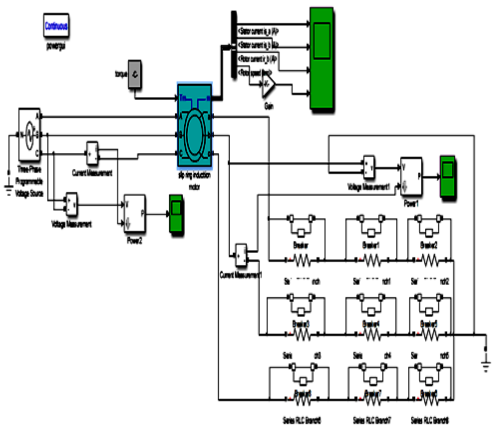

Figure 4 Simulation of rotor resistance method

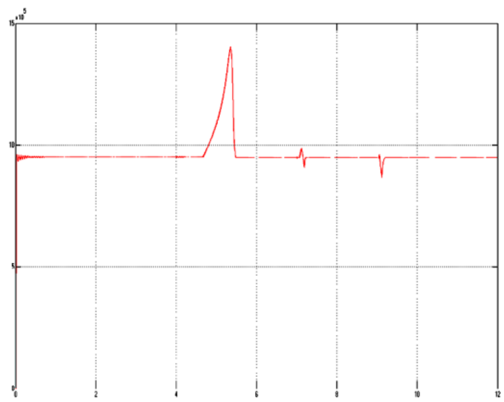

Figure 5 Power supplied (W)

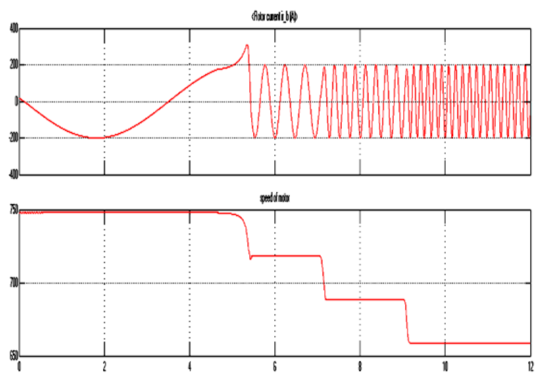

Figure 6 Rotor current (A) and Speed (R.P.M.)

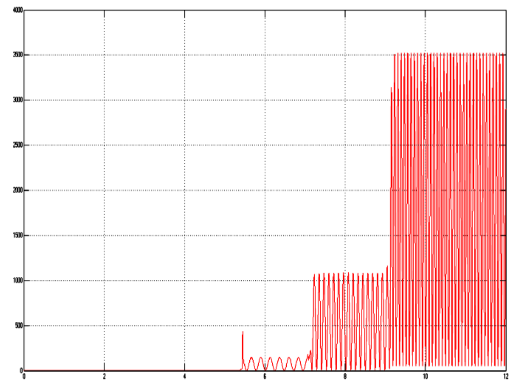

Figure 7 Power loss in resistance (W)

Table 3 Power Loss and Speed at different time

Time (Sec.)	Power loss (W)	Speed (R.P.M.)
0-4	I. 0	II. 748
4-7	150	718
7-9	1080	688
9-12	3500	658

IV. SIMULATION OF SLIP POWER RECOVERY SYSTEM USING MATLAB/SIMULINK

By using slip power recovery system it is possible to minimize the system loss which is present in the rotor resistance method for speed control of slip ring induction motor.

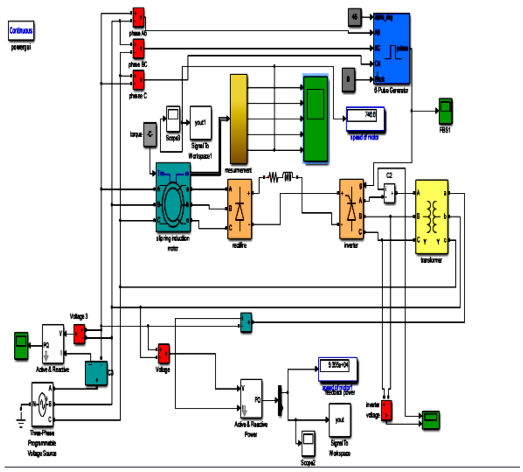

Figure 8 Simulation circuit of SPRS

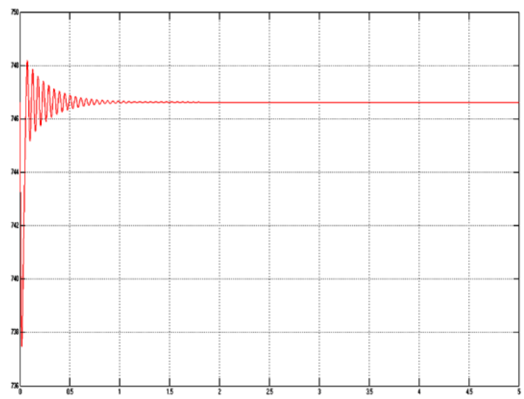

Figure 9 Speed (R.P.M.) of motor at firing angle (45^0)

At angle of 130^0 speed of motor will decrease, thyristors block the current and act as variable resistance change in firing angle change in blocking in current also feedback power to the bus bar.

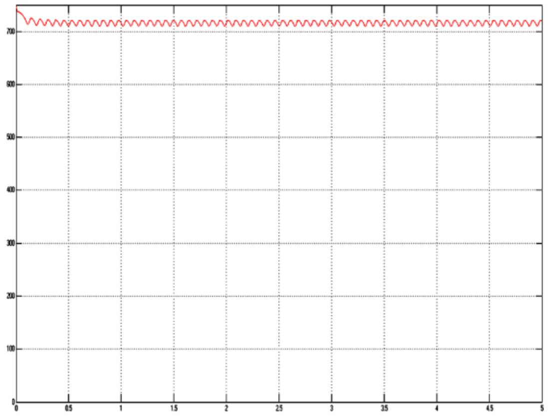

Figure 10 Speed (R.P.M.) of motor at firing angle 130^0

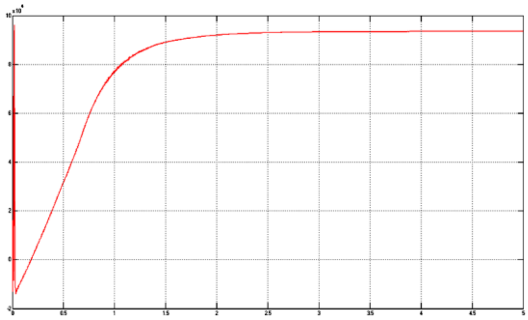

Figure 11 Feedback power (W) at firing angle 45^0

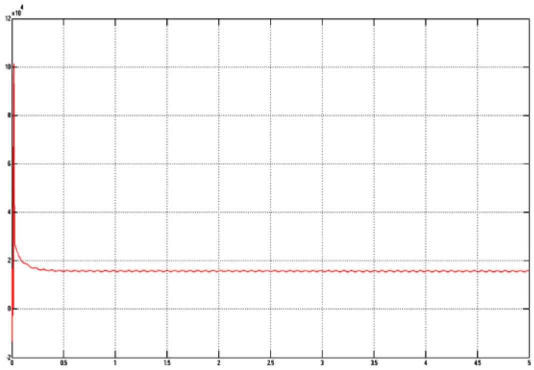

Figure 12 Feedback power (W) at firing angle 130^0

The data of feedback power and speed at various firing angle is given below.

Table 4 Feedback power and Speed at different firing angle

Firing Angle (Degree)	Feedback Power(W)	Speed (R.P.M.)
40	III. 9.4 * 10^4	IV. 746.5
70	8.3*10^4	746.0
100	2.9*10^4	730.0
130	1.6*10^4	715.0
145	0.4*10^4	705.0

By considering the rotor resistance we can control the speed of the motor but loss of system is increase as shown in table 3, whereas in slip power recovery system speed of motor can control and system loss is also minimize as shown in the table 4

V. CONCLUSIONS

In this paper power loss analysis of slip ring induction motor is presented and from the result it is conclude that by using slip power recovery system we can control the speed of the motor and minimize the loss which is present in the speed control of slip-ring induction motor using rotor resistance. This method is also useful in high starting torque and speed control below synchronous speed of slip-ring induction motor.

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