Simulation of Slip Power Recovery

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Abstract—This paper consists of Numerical simulation method of Slip Power Recovery System of wound rotor induction motor. In the industry most of the motors used are induction motor, in that squirrel cage induction motor are mostly used. But for the blowers and fans which required higher power ratings Wound Rotor Induction Motors are used. In these motors the most of the power is wasted at the rotor resistance circuit. If we save some of the power and fed back to circuit then the efficiency of the motor is increases.

Slip power recovery system is the composed of wound rotor induction motor and static frequency converter. Here the modelling of induction motor in the d-q frame is explained which is advantageous from other method. At the same time modelling of Diode Bridge with inductor circuit is also done. The operations performed to model the system are equivalent to assuming that the diode bridge rectifier and the DC circuits are transformed into a non linear circuit connected to the rotor terminals. MATLAB/Simulink is used to integrate the equations.

Index Terms—Slip power, Diode Bridge, rectifier, inverter, MATLAB/SIMULINK.

I. INTRODUCTION

The electricity becomes the need of the common person and the heart of the Industries, use of electrical energy increases very rapidly day by day. Because of heavy increased in demand of electrical energy, the generation companies are unable to fulfil the demand of all customers. As a market rule of demand and supply, the rate of electrical energy is also increases. Moreover one cannot store the electrical energy. So it’s our duty to save the electricity, as the “Saving electricity means generating electricity”. This having other advantages, like reduction in electricity bill amount and reliability of power supply will be more.

Slip power recovery system (SPRS) is a variable speed drive for slip ring induction motors. It recovers and delivers the slip dependent rotor power from the motor to the grid. It is composed of a wound induction machine and a static frequency converter on the rotor.

II. WHAT IS SPRS?

The basic concept is that the power wasted in the rotor resistance of the wound rotor induction motor is to be utilized for increasing the efficiency and performance of induction motor, speed control is also achieved. In many industries high rating induction motor is used for running the fans and blowers. The slip power, which has been wasted in rotor resistance, can be conveniently returned to the main or the mains or the used in useful manner making the drive more efficient. This is achieved by means of slip energy recovery scheme widely known as Kramer and Scherbius drives.

III. INDUCTION MACHINE MODELING

A. Equivalent circuit of Induction Motor

From equivalent circuit of induction motor the following equations we can write

\[
\begin{align*}
v_{ds} &= R_s i_{ds} + \frac{di_{ds}}{dt} - \omega_s q_{qs} \\
v_{qs} &= R_s i_{qs} + \frac{di_{qs}}{dt} + \omega_s p_{qr} \\
v_{dr} &= R_i i_{dr} + \frac{di_{dr}}{dt} - (\omega_s - p\omega_m) q_{qr} \\
v_{qr} &= R_i i_{qr} + \frac{di_{qr}}{dt} + (\omega_s - p\omega_m) q_{dr}
\end{align*}
\]

Where \(v_{ds}, v_{qs}, v_{dr}, v_{qr}\) are instantaneous stator and rotor voltages, \(i_{ds}, i_{qs}, i_{dr}, i_{qr}\) are instantaneous stator and rotor currents, \(\omega_s\) = synchronous speed, \(\omega_s - p\omega_m\) speed of
the referential relative to the rotor, \( R_s = \) stator resistance, 
\( R_r = \) rotor resistance

Flux linkages:

Flux linkages are calculated by using following matrix

\[
\begin{bmatrix}
\varphi_{ds} \\
\varphi_{qs} \\
\varphi_{dr} \\
\varphi_{qr}
\end{bmatrix}
= 
\begin{bmatrix}
L_s & 0 & M & 0 \\
0 & L_q & 0 & M \\
M & 0 & L_r & 0 \\
0 & N & 0 & L_r
\end{bmatrix}
\begin{bmatrix}
i_{ds} \\
i_{qs} \\
i_{dr} \\
i_{qr}
\end{bmatrix}
\tag{5}
\]

\( \varphi_{ds} = L_s i_{ds} + \eta \) \hspace{1cm} \tag{5-a}
\( \varphi_{qs} = L_q i_{qs} + \eta \) \hspace{1cm} \tag{5-b}
\( \varphi_{dr} = M i_{dr} + \eta \) \hspace{1cm} \tag{5-c}
\( \varphi_{qr} = N i_{qr} + \eta \) \hspace{1cm} \tag{5-d}

Where \( \varphi_{ds}, \varphi_{qs}, \varphi_{dr}, \varphi_{qr} \) are flux linkages.

Flux linkage derivates:

From the voltage equations shown in equation number (1-4) we can calculate the flux linkage derivatives, which are as follows.

\[
\frac{d\varphi_{ds}}{dt} = v_{ds} - R_s i_{ds} + \omega_s \varphi_{qs}
\]
\tag{6-a}

\[
\frac{d\varphi_{qs}}{dt} = v_{qs} - R_s i_{qs} - \omega_s \varphi_{ds}
\]
\tag{6-b}

\[
\frac{d\varphi_{dr}}{dt} = v_{dr} - R_r i_{dr} + (\omega_s - p \omega_m) \varphi_{qr}
\]
\tag{6-c}

\[
\frac{d\varphi_{qr}}{dt} = v_{qr} - R_r i_{qr} - (\omega_s - p \omega_m) \varphi_{dr}
\]
\tag{6-d}

For building the stator flux block diagram of an induction motor equation no. 6-(a) and 6-(b) are used. With this block diagram we are getting flux linkages for stator in the d-q format. These block diagram are shown below.

Fig. 3 Model of Flux linkage for stator

Similarly rotor flux block diagram can be constructed from the equation 6-c and 6-d.

Fig. 4 Model of Flux linkage for Rotor

The electromagnetic torque \( T_e \) of the induction motor is given by:

\[
T_e = p \left( \varphi_{ds} i_{qs} - \varphi_{qs} i_{ds} \right)
\]
\tag{7}

Fig. 5 Model of Electromagnetic Torque

By combing the entire above small model diagram we form a block diagram for Induction Motor, which is shown in the following figure.

Fig. 6 Model of Induction Motor
IV DIODE BRIDGE MODELLING

While doing diode bridge rectifier modelling following assumptions has been considered
1) All switches are ideal.
2) The total losses in the diode bridge can be represented by lumped resistor \( R \) that can be added to the DC resistance \( R_{dc} \).

Figure 7 shows the representations of a three-phase diode bridge. The modelling of the diode rectifier is done with the help of three Heaviside functions. These Heaviside functions determine if the diode is conducting or in blocking state.

![Fig. 7 Three phase Diode Bridge](image)

The voltage on the ac arms are given by:

\[
e_1 = g_1 \times U_{dc} \quad (8) \\
e_2 = g_2 \times U_{dc} \quad (9) \\
e_3 = g_3 \times U_{dc} \quad (10)
\]

The phase voltages can be computed by:

\[
u_1 = f_1 \times U_{dc} \quad (11) \\
u_2 = f_2 \times U_{dc} \quad (12) \\
u_3 = f_3 \times U_{dc} \quad (13)
\]

where,

\[
f_1 = \frac{(2g_1 - g_2 - g_3)}{3} \quad (14) \\
f_2 = \frac{(2g_2 - g_3 - g_1)}{3} \quad (15) \\
f_3 = \frac{(2g_3 - g_1 - g_2)}{3} \quad (16)
\]

The DC current is given by:

\[
I_{dc} = g_1 i_1 + g_2 i_2 + g_3 i_3 \quad (17)
\]

V RESULTS

Torque Vs Time characteristics: -

Theoretically, initially the torque of slip ring induction motor is very high and then after some time it settles down to a constant value. That we can observe in the following graph.

And the result from the simulation of slip power recovery system is as follows: From this graph we observe that initially the torque is very high whose value is around 19 N-m. And after sometime the torque is settles down to a constant value of 11 N-m.

![Fig. 10 Graph of Torque Vs Time Experimental Result](image)

Speed Vs Time characteristics: - Next result is for the \( \omega_0 \) i.e. angular speed of the motor under no-load condition. Theoretically as we know that, the speed starts from zero and increases to its rated value and remains constant at this value. The expected results are shown in the following figures.

![Fig. 11 Graph of Torque Vs Time (Simulation Result)](image)
And result which is obtained from simulation is shown in Figure 13. The speed starts from zero then increases to value of 300 rpm and remains constant at this value.

![Graph of ωr Vs Time (Simulation Result)](image)

**Fig. 13 Graph of ωr Vs Time (Simulation Result)**

**Torque Vs Time characteristics (Under load condition) TL = 5 units:** Torque should be increase initially and settled down to some specific value. When sudden load is applied torque should increase by some value and then afterwards it should be constant. The graph is as shown below.

![Graph of Torque Vs Time (Simulation Result TL = 5 unit)](image)

**Fig. 14 Graph of Torque Vs Time (Simulation Result TL = 5 unit)**

**Speed Vs Time characteristics: Under load condition- TL = 5 units:** As we know that at the starting speed is zero, then it increases slowly and settles down to one particular value. And if apply the load on the motor, then speed get decreases to some value and settled down that new value. This is shown in the graph below.

![Graph of ωr Vs Time (Under load) (b)](image)

**Fig. 15 Graph of ωr Vs Time (Under load) (b) Simulation result TL = 5Unit**

### VI CONCLUSION

As we know that in the wound rotor induction motor during the speed control the power is wasted in the rotor resistance. The result of this is losses are increase and efficiency of the motor is decreased. So to improve the efficiency of such motors “Slip Power Recovery System” is used.

In this system the power which is wasted in the rotor resistance is fed back to the network.

In this paper the simulation of the induction motor and diode bridge rectifier/Inverter is done to achieve the results. The model presented used Park’s variables in a common reference frame for the stator and rotor variables. The diode bridge and DC circuit can be interpreted as a nonlinear load that is connected to the rotor terminals.

The simulation was achieved using Simulink graphical block diagrams to represent the elements of the SPRS. Simulation and experimental results are presented showing good accuracy.

### REFERENCES


