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Dynamics of a Slip Power Recovery Scheme

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Abstract

This research paper mainly focuses on the simulation of Static Scherbius Drive Scheme for efficient speed control using Inverter firing angle control method. A slip ring induction motor (SRIM) which is an asynchronous type is used, since the rotor does not run in synchronous speed with the stator poles. It is employed in high power, narrow range of speed applications and the slip power is regulated to yield the adjustable speed drive system. The slip energy recovery scheme is carried out using power electronic based converter technique in the power recovery and energy saving via thyristor control. It was observed that the torque of the drive varies linearly with the dc link current. Moreover, the increase in efficiency has been observed as compared to rotor resistance method of speed control. The simulation is carried out in MATLAB environment.

***Keywords:** Doubly fed, firing angle, recovery, slip power, static scherbius*

INTRODUCTION

Speed control of Induction motor drives is currently blowing air waves in the present day industries. More than 75% of the day to day load of any industrialized country consists of induction motor drives. The accessibility of slip power and the feasibility of employing a scheme that would utilize it has promoted to a large extent a 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 [1]. Currently, the Static Scherbius system or the slip energy recovery drives (SERD), appears to be ideal for the narrow speed range implementation as found in big pumps and drives of fans, inconstant speed wind energy systems, ship-board variable speed cum constant frequency systems. Some papers [2− 4] have looked at the stability analysis and the dynamic analysis of SERD. The slip power recovery scheme analysis using thyristors, the mitigations of the harmonics even up to that associated with the inverter systems were duly reported in [5−7]. The main lacing factors of this scheme has been inferred as the poor system power factor due to excess of reactive power drawn out of the source both by the motor as well as the line commutated inverter. For the purpose of overcoming the drawbacks of poor power factor, several methods have been reported in literature. In N Rao et al. (1983) [8], capacitive compensation approach was discussed. In Bose K Bimal (2002) [9], static scherbius drive with chopper was presented. The required speed control in this method was obtained by time ratio control of the chopper unit for fixed value of inverter firing angle. It re iterated that a reasonable extent of harmonic would follow non availability of transformer. A minimization of losses of a doubly-fed induction motor by using optimal control techniques was introduced in W Leonharn (1985) [10]. The optimal control vector voltage leads to the improvement of overall drive performance and a method of energy saving for industrial processes operating with variable loads in the low speed range [11]. Also, a simple modeling approach that can predict the operation of a slip recovery drives in detail both in the steady state and in the transient state was presented in R Krishnan (2001) [12]. The hybrid model retained the actual rotor states and the algorithm used a 4th order Runga Kutta integration method.

In JE Brown (1986) [13], slip recovery drive performance, adaptive fuzzy techniques for improving the performance were given. Starting transients in slip energy recovery induction motor drives was given in GD Marques [14]. In J Soltani, A Farrokh Payam (May 2006) [15], the stability of slip power recovery system was shown. The detailed analysis of slip energy recovery induction motor along with a step-down chopper control technique was given in P Jiang, B Shu Wang, X Hui Dua (12−15 July 2009) [16]. In N Rehman Malik, C Sadarangani, A Cosic, M Lindmar (2012) [17], a slip power recovery scheme arrangement using decoupled control of two different variables at the same time was presented. PWM voltage converter used on the line side is useful in controlling a wide range of reactive power and also lower than the current harmonic contents. Here in, a field and current space vectors appraisal of slip power recovery system was carried out. The advantages of the circuit were low cost, the simplicity which allow the quasi optimum exploration of the induction motor, the method developed had the disadvantage of increasing the switching stresses of the switching devices, dissipative commutation and complex control of the duty cycle [18]. Adaptive Fuzzy-neuro controller used for speed control of wound rotor induction motor is utilized for slip power recovery and it is presented in V Verma, S Maiti, C Chakraborty (2009) [19].

METHODOLOGY

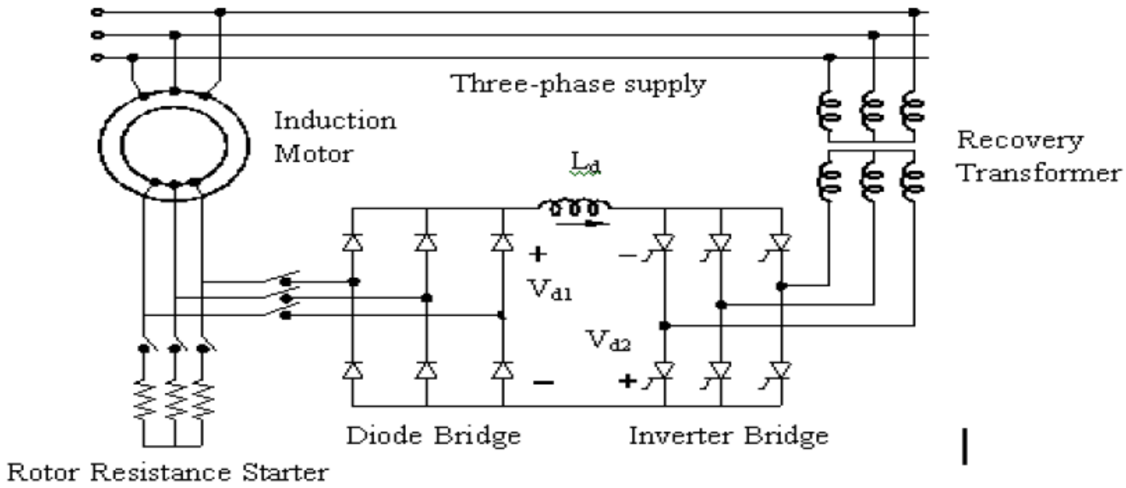

Figure 1: *Basic slip power recovery scheme.*

Performance Analysis of the Scheme

The basic slip power recovery scheme of a static Scherbius drive is as shown in Fig. 1. Throughout this scheme a voltage V_{iR} is applied to the connective terminals, in section with the rotor current through recovery device; line commutated converter. The effective equivalent circuit of the drive is described as shown in Fig. 2:

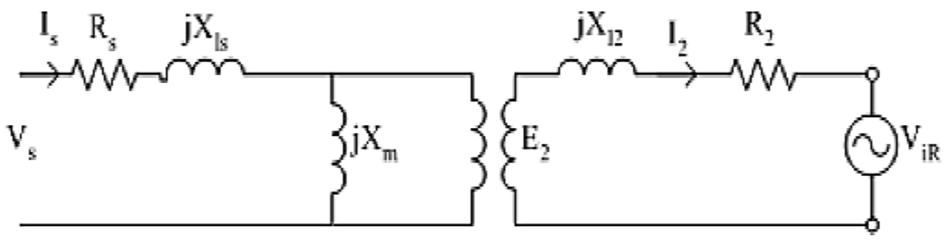

Figure 2: *Voltage injection in rotor circuit.*

The injected voltage can be referred to the stator as:

$$V_i = \frac{V_{iR}}{a_{eff}} \quad (1)$$

Above equation gives the following equivalent circuit:

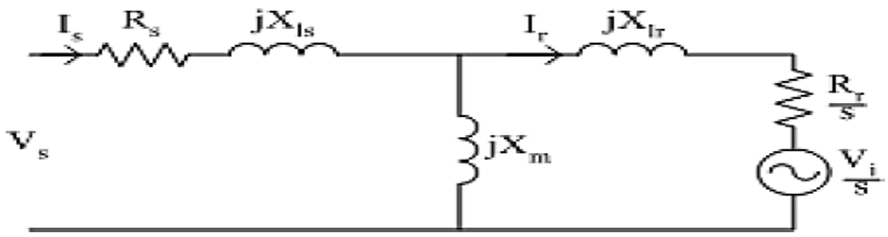

Figure 3: *Equivalent circuit referred to the stator.*

Considering the given equivalent circuit as shown in fig. 3, if the injected voltage Vi/s is increased, the rotor current Ir is reduced, resulting in a reduction at intervals the on the mechanical torsion generated by the motor. As machine receives load the tendency is for it to increase in slip so as to overcome an expected stall. As slip can increase, the effective voltage equivalent to the actual voltage physically induced at intervals on the rotor will increase. As a result, rotor current will increase. This permits the machine to hunt out a fresh steady state position where the induced rotor current produces enough torsion to equal the load torsion but consequently at a reduced speed.

Exploration of Operation

To carry out the analysis, it is with the assumption that the magnetizing physical phenomenon is affected at the terminals of the equivalent circuit as shown in Fig 4. The physical phenomenon and magnetizing physical phenomenon are replaced by a Thevenin equivalent.

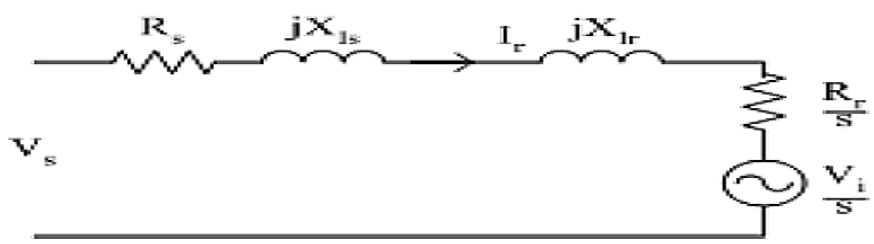

Figure 4: *Approximate equivalent circuit referred to the stator.*

The phase of the injected voltage being in accordance with the current of the rotor implies that the voltage of the equivalent circuit is additionally written as:

$$V_s = \overrightarrow{I_R}\left(R_{s+}\ \frac{R_R}{S}\right) + \frac{\vec{V_i}}{s} + j\vec{I_R}(X_{Is} + X_{I\gamma}) \tag{2}$$

$$V_s = \frac{I_\gamma R_\gamma + V_i}{s} \angle\, \theta_\gamma + I_\gamma\big(X_{Is} + X_{I\gamma}\big)\angle\,(\theta_\gamma + 90^\circ) \tag{3}$$

$$V_s^2 = \left(I_\gamma R_s + \frac{I_\gamma R_\gamma + V_i}{S}\right)^2 + I_\gamma^2\ (X_{Is} + X_{I\gamma})^2 \tag{4}$$

Re-arranging, the slip may be found as:

$$S = \frac{V_i + I_\gamma R_\gamma}{\left(V_s^2 - I_\gamma^2 (X_{Is} + X_{I\gamma})^2\right)^{1/2} - I_\gamma R_s} \tag{5}$$

Analysis of Power and Torque

Expression for the machine’s air-gap power is:

$$P_{gap} = 3I_\gamma \frac{(I_\gamma R_\gamma + V_i)}{S} \tag{6}$$

Breaking this equation into components, it will be seen that the air gap power is the total of rotor resistive losses, power recovered through the slip rings and therefore the mechanical power made.

$$\mathrm{P_{gap}} = 3\mathrm{I^2}_\gamma\, \mathrm{R}_\gamma + 3\mathrm{I}_\gamma \mathrm{V_i} + 3\mathrm{I}_\gamma\big(\mathrm{I}_\gamma \mathrm{R}_\gamma + \mathrm{V_i}\big)\frac{(1-\mathrm{s})}{\mathrm{s}} \tag{7}$$

From equation 7, the torque becomes:

$$\tau = 3I_\gamma\ \frac{(I_\gamma R_\gamma + V_i)}{s\omega_s} \tag{8}$$

Now, solving for the slip expression into the torsion expression offers the result that torsion is barely a fraction of rotor current, not slip or injected voltage:

$$\tau = \frac{3\mathrm{I}_\gamma}{\omega \mathrm{s}}\ [(\mathrm{V_s^2} - \mathrm{I_\gamma^2}(\mathrm{X_{Is}} + \mathrm{X_\gamma})^2)^{1/2} - \mathrm{I_\gamma R_s}] \tag{9}$$

The expression above means that for a given force, the rotor current is always constant irrespective of speed. The voltage at the input to the diode rectifier is given by:

$$V_{LLiR} = \sqrt{3}\frac{V_i}{a_{eff}} \tag{10}$$

The dc link voltage V_{DC} can be found from the diode input line-line voltage V_{LL} as:

$$V_{DC} = \frac{3\sqrt{2}}{\pi} V_{LLiR} \tag{11}$$

Considering the thyristor device, this circuit may be thought of as a thyristor rectifier connected in reverse, and therefore the DC link voltage is expounded to the line-line electrical converter voltage as:

$$V_{DC} = -\frac{3\sqrt{2}}{\pi} V_{LLix\gamma} \cos\alpha = \frac{3\sqrt{2}}{\pi} V_{LLix\gamma} |\cos\alpha| \tag{12}$$

Where α is the firing angle, the injected voltage V_i in the rotor on substitution becomes:

$$V_i = \frac{a_{eff}}{\sqrt{3}} V_{LLinv} \mid \cos\alpha \mid \tag{13}$$

In the case, that the electrical converter line-line voltage is connected to the availability through an electrical device, the injected voltage is involving the availability voltage as:

$$V_i = \frac{a_{eff}}{\sqrt{3}} \frac{N_{inv}}{N_{Line}} V_{LLS} \mid \cos\alpha \mid \tag{14}$$

Using this simplified analysis alongside the slip power recovery force equations, the thyristor firing angle needed for a selected force at a selected speed may be found.

Analysis of No Load Condition

Consider again the expression for slip:

$$s = \frac{V_i + I_\gamma R_\gamma}{\left(V_S^2 - I_\gamma^2 \left(X_{Is} + X_{I\gamma}\right)^2\right)^{1/2} - I_\gamma R_s} \tag{15}$$

If the torque is zero, then the rotor current will also be zero and at zero torque, the slip at that point s_0 is therefore given by:

$$s_o = \frac{V_i}{V_s} \tag{16}$$

The Efficiency

Ordinarily, the efficiency is to be the ratio of the output power to the input but for the control dynamics occurring at the rotor. As a result, the component of the recovered power is considered. Hence, the efficiency η is given as:

$$\eta = \frac{P_{out}}{P_{in} - P_{recovered}} \tag{17}$$

Here, $P_{recovered}$ is the effective recovered power at the stator coil terminals. A higher drive strength is expected because of the attendant energy that is feed back to the stator on being recovered from rotor.

SIMULATION OF THE SCHEME

To study the performance of the drive, a simulation block-set in Matlab/Simulink has been implemented as shown in Fig. 5. In this work, a two horse power machine with specifications as detailed in Table 1 was simulated upon taking into cognizance structures for measuring the associated machine force, current and speed. The active and reactive power input of the motor, the recovery device and additionally the availability are measured by exploiting the P-Q block. Provision has jointly been created to measure fully different voltages and currents of the scheme wherever required; the data has been saved to the area for any analysis.

Table 1: Wound rotor induction motor specifications.

Parameter	Rating	Parameter	Rating
Phase	3 Phase	Stator Resistance	0.7384 Ω
Input Capacity	2 Hp	Stator Inductance	0.003045H
Supply Voltage	400 Volts	Rotor resistance	0.7402 Ω
Frequency	50 Hz	Rotor inductance	0.003045H
Poles	4	Inductance of Smoothing Inductor	0.039H
Input Current	4.5 Amps	Resistance of Smoothing Resistor	0.2 Ω
Stator to Rotor turn ratio	5	Resistance of Smoothing Resistor	2 Ω

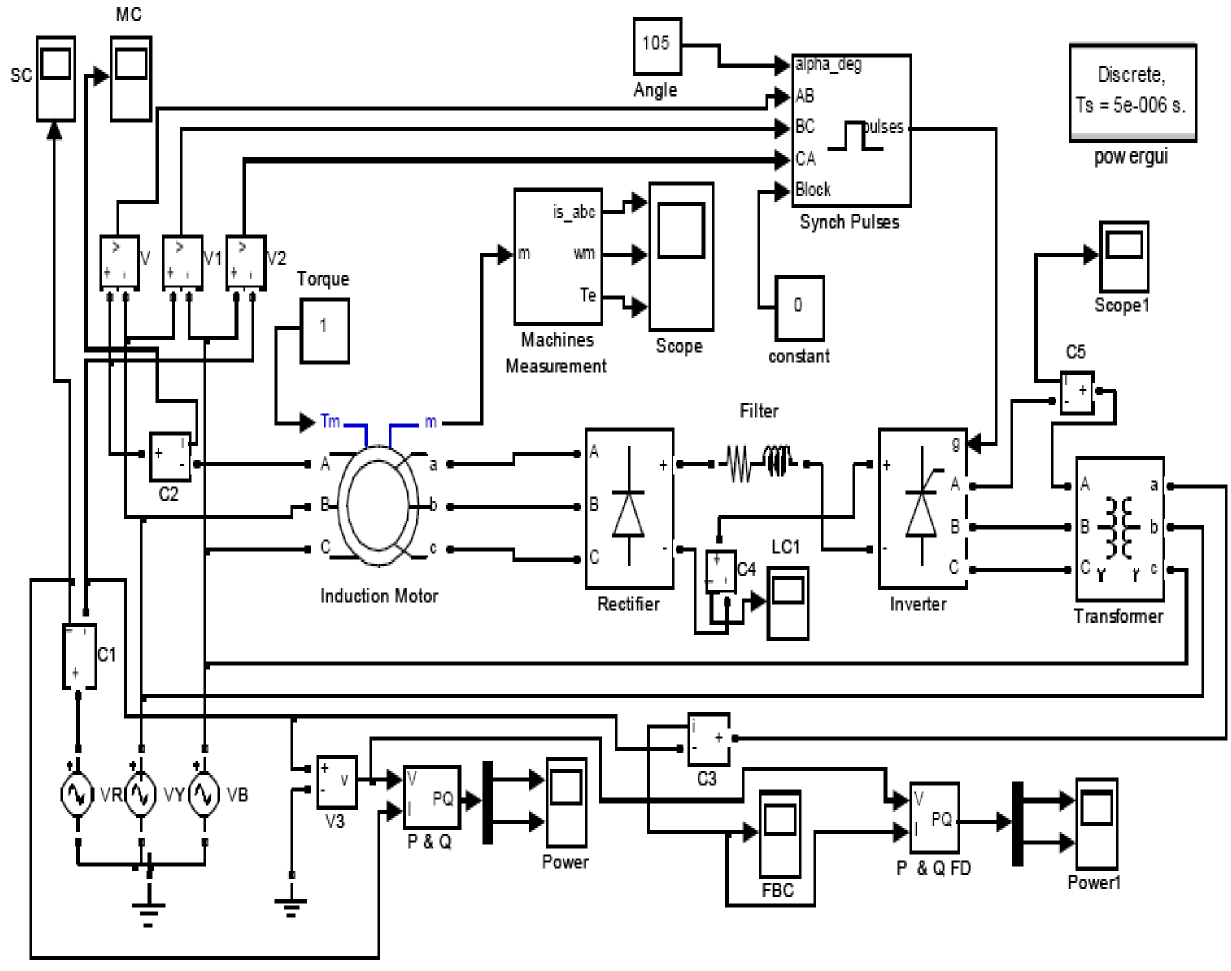

Figure 5: Simulation model of slip power recovery scheme on Simulink [1].

SIMULATION RESULTS

With incremental value of the firing angle beyond 90°, the machine speed is regulated within the adjustable range. The motor speed versus time characteristics at two different firing angles have been shown in Fig. 6. The speed for steady state associated with the smaller firing angle is higher than that of the greater firing angle. The torque, feedback and source currents characteristic plot are presented in Fig. 7.

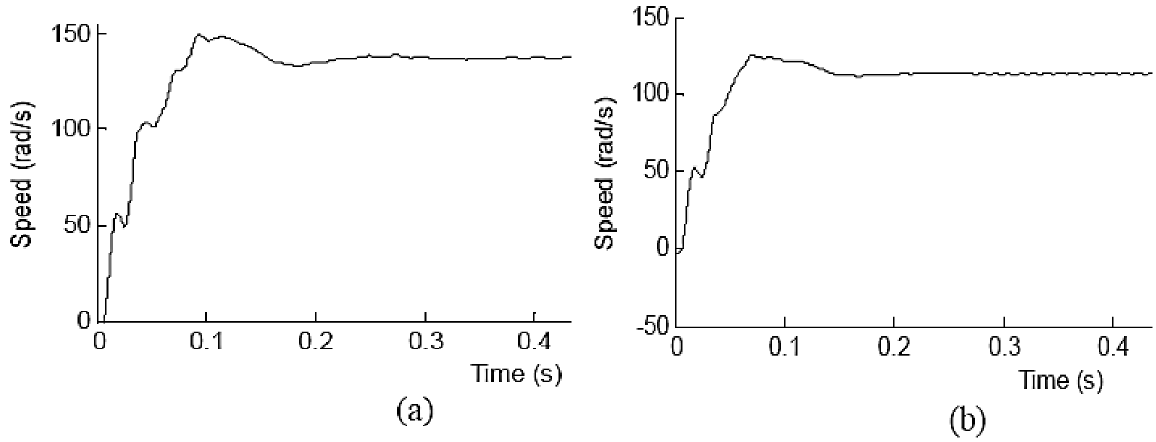

Figure 6: *Motor speed at (a) 93 degrees (b) 100 degrees firing angle.*

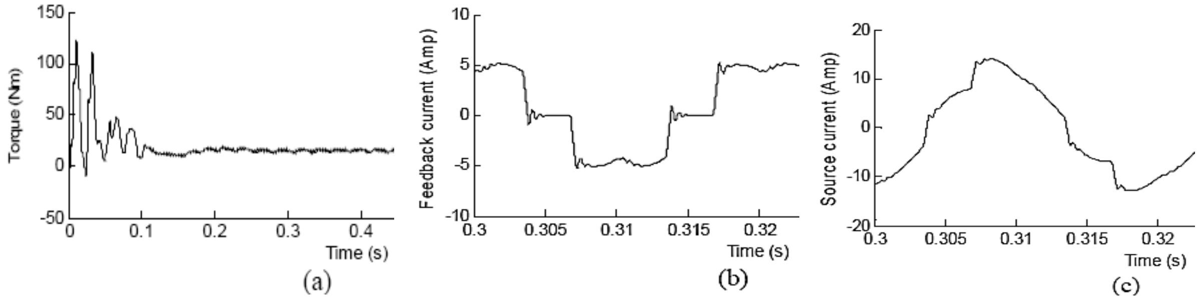

Figure 7: *(a) Motor torque (b) Feedback current (c) Source current.*

CONCLUSIONS

This paper, has considered the speed control of three-phase SRIM via the slip recovery energy scheme. The performance equations have been presented and a simulation block-set model in Matlab/Simulink has been implemented. These enabled for a good performance of the system. A microcontroller based open-loop speed control experimental set-up may be developed in the laboratory for the purpose of comparison and further analysis. However the following conclusions have been drawn from the study: There is an attendant overall reduction in the power factor of the drive. There is associated harmonic injection on the source side as a result of the converter and line commutated inverter. These current harmonics in stator and rotor windings cause further heating of motor which is not required as it brings about aging and may give rise to thermal degradation.

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