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MODELING AND SIMULATION FOR TRANSFORMER RATIO CONTROLLED SLIP POWER RECOVERY SCHEME

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Abstract: This research paper mainly focuses on the simulation of Static Scherbius Drive using transformer ratio controlled method. Previously there are many methods already for recovery of reactive power which is being wasted normally without using a feedback network circuit. This is an attempt to find an alternative method for recovering slip energy with better performance of the overall circuit. As harmonics are the main concerned here which offers difficulty for employing this scheme, this work aims to get better overall harmonics distortion with better speed control of the rotor through changing the turns ration of the transformer.

***Index Terms*— PWM inverter, Slip Power Recovery Scheme and Static Scherbius Drive.**

I. INTRODUCTION

THERE has been remarkable research innovations in the field of energy saving as it had become a necessity with the widespread of industrial development all around the world. Induction motors covering the major area of energy consumption has attracted many researchers for better utilization and management of the energy resources. Many high performance controlling methods for induction motors have been derived and are substantially used in order to get maximum energy benefits.

A simple and primitive method for induction motor control was rheostatic control done mechanically. Although the entire rotor power in this case was wasted but this method have advantages of smooth starting, maximum torque with no in-rush current and no harmonics. Instead of wasting this power which is in the form of slip power, it can be controlled through a rectifier with power then fed back to the line and eventually improving the overall efficiency of the system. This schematic approach is given the name of slip power recovery scheme. This scheme is mainly used in wind turbines for producing energy out of wind by harnessing most of its power and converting it to usable form.

Conventionally induction machines which used are squirrel cage motors. The reason for this preference is its robustness, low cost, safer, lower operating temperatures and can operate at constant speed even when overloaded. Slip ring induction motors on the other hand offer higher starting torque with 5 to 9 times inrush current with wide range of speed control. As all the industrial applications cannot be performed with almost same speed all the time, that's why slip ring induction machines found their use in places where variable speed applications were required such as hoists, elevators, printing presses, large ventilating fans, etc.

A method to evaluate harmonic distortion in slip power recovery drives was presented in [1], while taken into account commutation overlap and dc current ripple. This method predicted the voltage and current waveforms accurately and computed the individual harmonic components efficiently. In [2], an attempt was made to recover the slip energy to the part of the stator winding to avoid use of recovery transformer. The major problem with this concept was the rotor neutral, must now be isolated if grounding was assumed at supply transformer neutral.

In [3], an adaptive fuzzy technique for improving performance of slip recovery drive was presented. A technique for starting of a slip energy recovery induction motor drive from standstill position was given in [4]. This approach used a hybrid model which retained the actual rotor phase variables but transformed those of the stator, to examine the starting transients of a slip recovery drive system. In [5], an analytical technique on the rectifier output voltage in the slip energy recovery induction motor drives was introduced. Since, this technique used hybrid dq/abc model, it was found to be a suitable method for harmonic analysis of current waveforms.

[6] proposed the harmonic analysis of the system that provided significant reduction in the current harmonics contents torque which was superimposed on the average electromagnetic torque and de-rating of the percentage of machine. The use of the proposed induction machine, resulted in a complicated detailed mathematical model. [7] presented a neural network based tracking control system for slip energy recovery drive-in adaptive control, this model could be very complicated especially for the slip-energy recovery system. In [8], the analysis of Static

Scherbius Drive with two IGBT sinusoidal current converters in the rotor circuit using hybrid model was given. The analysis was based on a transformation of stator variables only to a frame of reference stationary with respect to the rotor but the performance was achieved at significant reduction in the electromagnetic torque developed by the machine.

[9] introduced a novel compact type slip-power recovery system having sinusoidal waves of rotor currents and solved the problem due to the distorted stator and rotor currents but the proposed topology and the control algorithm was more complicated than the conventional compact type system.

In [10], a numerical simulation method using dq induction-machine model for the slip power recovery system. [11] presented the DC Link Series Resonant Converter based Slip Power Recovery Scheme for Variable Speed Drive for Wound Rotor Induction Motor. It also provided a procedure to integrate the three single phase ac to dc converters for connection to three-phase mains. The visible drawback of this new scheme was voltage and current stresses on the devices. In [12], a vector controlled inverter fed wound rotor induction motor for high power applications was proposed.

[13] presented Simulation of PWM inverters using MATLAB. The simulation time for PWM inverters using MATLAB was more than a hundred time shorter than that using PSPICE.

A different circuit configuration in which a boost up chopper connected the rotor rectifier to a dc link of voltage controlled line commutated inverter connected in parallel with a capacitor was given in [14]. It increased the penalty factor for not using the field-orientation control method and more complex control system was added to the VSI controller. [15] presented adaptive Fuzzy-neuro controller for speed control of wound rotor induction motor with slip energy recovery. In [16], the presence of sub harmonics of line frequency and simulated harmonics content of waveforms in various points of the drive at different speeds, based on hybrid model (dq/abc) was investigated to improve the power factor of the drive but complicated inverter circuit.

The design of microprocessor based slip power recovery scheme using Intel 8085 microprocessor was proposed in [17]. The motor converter system was modeled in s-domain and was simple, flexible and straight-forward. A methodology for the rotor side control of a doubly-fed induction machine was given in [18] to reduce the converter cost without any major sacrifice in the performance of the system.

[19] presented Fuzzy Logic Controlled Inverter-Chopper for High Performance of Slip Energy Recovery System, which introduced the modified slip energy recovery system in order to improve its power factor. A double winding induction machine and its speed control methods were proposed in [20]. It has the disadvantage of its larger physical size, less efficient and the reduction of maximum torque when the machine speed was decreased.

[21] presented a different approach in which three-phase ac supply was taken as input to the stator of the wound rotor induction motor and by further using a three-phase rectifier, ac supply was converted into dc. In [22] it was found that the performance of Slip Energy Recovery Devices used for speed control of large induction motors adversely affected by instantaneous power-supply failures of a few cycles duration. [23] presented the performances of a linear control technique implemented on a state feedback to control speed of wound rotor induction motor using dSPACE along with the MATLAB/SIMULINK tool. [24] proposed the simulation study using a matrix converter to replace the line commutated cyclo-converter as a static frequency changer in a slip power controller for induction motor speed control from power quality point of view. [25] presented Standard PWM drive power converters that applied to slip power recovery applications with appropriate control modifications. Using the modern PWM drive technology for SPR applications eliminated the disadvantages of the older current source-type SPR drives which included low power factor operation at high load and torque pulsations in the motor shaft. It might also be cost effective for new wound rotor motors when speed control was necessary.

Thus, slip power recovery scheme needs through investigation in terms of its performance validation and also its control mechanism. In this paper, the modeling and simulation of turn ratio controlled slip power recovery scheme is revealed for its speed, active and reactive feedback power by varying transformer turn ratio.

II. BACKGROUND

Slip ring induction motors unlike squirrel cage induction motors can be controlled from both stator and rotor sides. The various methods of speed control of induction motor are classified as follows,

1. From the stator side

   i. Stator voltage control: The speed can be controlled by controlling the three phase input voltage. This is done through switches in the rectifiers which are nothing but thyristors. As torque developed in the motor is directly proportional to the square of the voltage, this method also serves the purpose of controlling rotor torque.
   ii. Pole changing control: This is one of the basic methods of speed control used for motors. Changing polarity of the poles alters the rotation of the rotor hence controlling its speed. Being a three phase induction motor, there number of pole changing combinations that can be done to serve the purpose.

iii. Supply Frequency control: The speed and torque of induction motor can be controlled by controlling the supply frequency but keeping stator voltage constant. When supply frequency is decreased, air gap flux saturation takes place. At low frequencies, rotor current may increase too high and torque developed decreases abruptly. That's why this method is rarely used.

2. From the rotor side

From the rotor side the speed control can be accomplished by using the following methods:

i. Rotor resistance control: The rheostat which is connected externally to the slip ring induction motor can be used to perform speed control of the rotor. The resistance value is set at its highest at the starting and then its value is reduced gradually so that rotor could build up speed. Thus speed can be controlled by increasing or decreasing rheostatic value.
ii. Slip power recovery control: The methods discussed above concerns only about the real power from the source input power fed to the induction motor. All the reactive power is wasted in these methods. This power is also called the slip power can be harnessed and can be put to use to increase overall efficiency of the system.

III. METHODOLOGY

A. Conventional Slip Power Recovery Scheme

This is done by simulation our main scheme and controlling the firing angle of the pulse generator which controls the duty cycle of the thyristor switches in the inverter section. For positive feedback to our main bus bar, firing angle of thyristors must be greater than 90 degrees. As the value of firing angle is increased rotor speed is reduced. The rotor runs at maximum speed when the firing angle is set to 90 degrees.

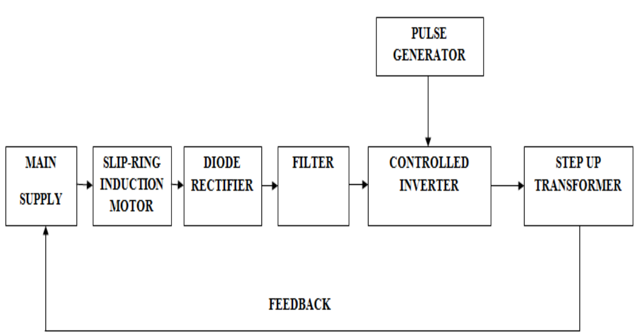

Figure 1 Block Diagram of Conventional Slip Power Recovery Scheme

B. Slip Power Recovery Scheme with Variable Transformer Turn Ratio

This is done by replacing normal transformer with variable transformer so that we can control the speed of rotor by changing the amount of voltage being fed back to the main bus bar.

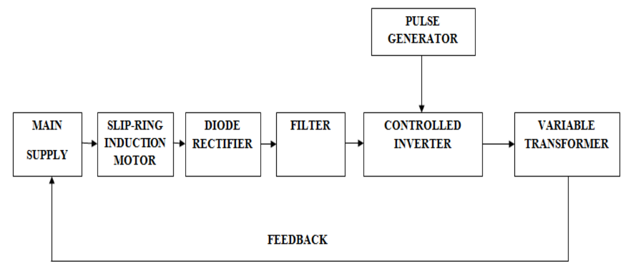

Figure 2 Block Diagram of Slip Power Recovery Scheme with Variable Transformer Turn Ratio

C. Modeling and Simulation Process for Transformer Ratio controlled SPR Scheme

a) Initially, the firing angle of the synchronized 6-pulse generator has been selected as 90°.
b) T-ratio is kept as 100/400 and Mosfet based chopper can be removed or duty ration can be kept as 100%.
c) By changing the turn's ratio of the transformer on the inverter side, change in speed and other parameters have been observed.
d) Turn's ratio will be changed from 100/400 to 400/400 where 100/400 means inverter to line side turn's ratio of the transformer.

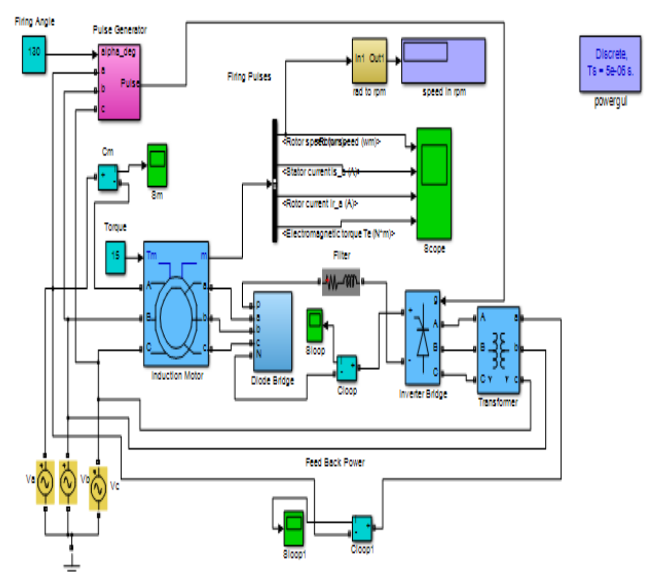

Figure 3 Simulation Model of SPR Scheme with Turn's Ratio Control

IV. RESULTS AND DISCUSSIONS

Results of Transformer Turn Ratio controlled SPR Scheme

Table I. Results of Transformer Ratio Controlled SPR Scheme

SN	T-Ratio	Speed (RPM)	THDa (%age)	THDfb (%age)	FBP (W)	FBQ (VAR)
1	100/400	1450	5.14	29	1	-227
2	150/400	1435	6.81	29.55	9	-357
3	170/400	1436	7.7	29.25	13	-389
4	250/400	1416	9.96	28.69	20	-538
5	300/400	1395	10.9	28.29	31	-651
6	350/400	1372	11.53	27.95	42	-771
7	400/400	1345	12.44	27.57	60	-882

Table I gives the tabular analysis of the SPR Scheme with transformer control.

Figure 4(a) shown below gives the effect of change in t-ratio over the speed of the drive. It is clearly seen that increase in t-ratio over 100/400, the speed of the drive reduces linearly. But change in speed is very limited as compared to inverter control.

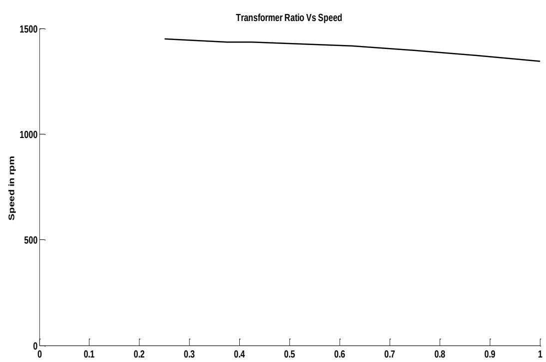

Figure 4(a) Graph between T-Ratio and Speed

The figure 4(b) shown below is the graph between t-ratio and feedback active power which is again almost linear i.e. increase in t-ratio results in increase in feedback power and decrease in rotor speed.

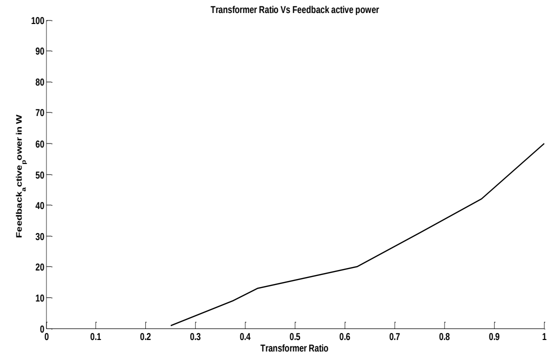

Figure 4(b) Graph between T-Ratio and Feedback Active Power

Figure 4(c) below shows the reactive power requirement of the scheme at various t-ratios. It is seen that the reactive power required for the scheme increases as the T-ratio increases (or as the speed decreases. Hence overall power factor of the scheme decreases with decrease in speed.

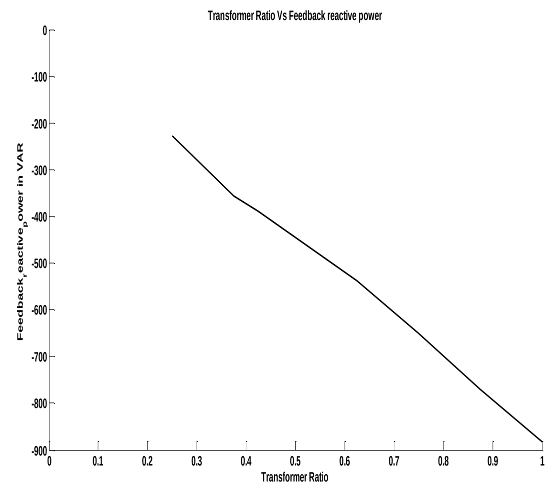

Figure 4(c) Graph between T-Ratio and Feedback Reactive Power

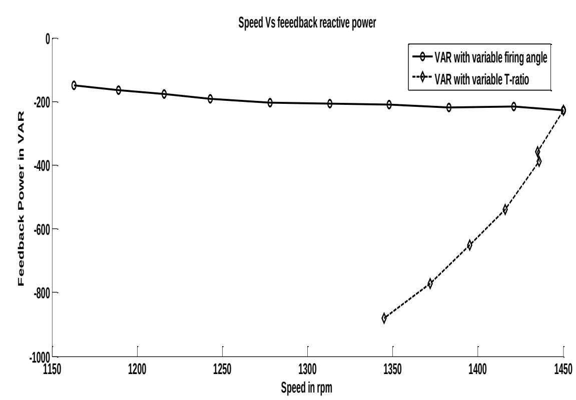

Figure 4(d) Comparison between speed and Feedback Reactive Power

A comparative graph between speed and reactive power requirement of the scheme is for both the topologies i.e. firing angle control and t-ratio control is plotted in figure 4(d). It is seen that for the given speed, reactive power requirement is high in case of t-ratio control as compared to firing angle control.

V. CONCLUSION

The simulation of the Static Scherbius Drive is able to achieve the speed control for Transformer ratio (T-ratio) controlled method. A comparison is also drawn between speed and reactive power. Reactive power fed to the scheme is high whereas limited range speed control is obtained using transformer ratio control. Total harmonic distortion (THD) of the source current is also high in case of transformer ratio controlled slip power recovery scheme.

Latest technology of multi-level inverter can be used to meet the requirement of operation of motor at variable speed with reduced reactive power and lower value of THD. It can provide a variable speed at maximum power factor and lower THD levels.

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