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Matlab/Simulink Model of a Slip Energy Recovery System in a Cement Plant

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Summary

A subsynchronous converter cascade system, also known as "slip energy recovery system", presents some problems associated with the power electronics converter, namely its effects on the electromagnetic torque.

To analyse these effects, a model of the slip energy recovery system was developed in MatLab/Simulink software, using the Power System Blockset (PSB) library. The results show disturbances on the electromagnetic torque, which can be reduced introducing a DC link coil.

Introduction

Induction motors are widely used in industrial applications. The speed control applied to the same, the ones that allow the recovery of the slip energy, have been developed by researchers for many years.

In those studies it was verified that the recovery of slip energy using electronic converters presents some inconveniences to the global performance of the system, in spite of its enormous advantages in energy terms. The inconvenients that are known are the low power factor, the low efficiency, and harmonic current generation and torque oscillation.

Several studies contributed to the minimization of these problems. Lavi and Polge [1] studied the behaviour of a slip energy recovery system using a synchronous inverter in the rotor. They concluded that the speed of the motor was independent of the linearity between torque and the current. The system has the characteristic of a separately excited DC motor.

The study performed by Takeshi Tsuchiya [2] for a super synchronous Sherbius system, shows the analysis of the system through state equations with speed control accomplished using modern control theory and microprocessor control.

Franz and Mayer [3] developed a mathematical model for the recovery of the rotor slip energy using a 6-pulse rectifier, a 12-pulse inverter and two smoothing inductances.

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Brown et al. [4] developed an analytical model to analyse the performance of the Kramer system in transient conditions. This model was validated through the analysis and comparison of the results obtained for four different types of thyristor bridges, with the same motor, diode bridge, and smoothing inductance.

Akpinar and Pillay [5] using a hybrid model with the stator refereed to the rotor, analysed the transient behaviour and the characteristics of the system.

Shepherd and Stanway [6] presented a study showing that the efficiency is improved if the slip energy is recovered through rectification and inversion and presented a study for operation at low speeds.

Zahawi et al. [7] have analysed the behaviour of slip energy recovery systems with three different non-conventional inverter schemes and found a better performance than the normal.

The problems related with the low power factor and high consumption of reactive power were significantly reduced.

Rao et al. [8] developed a system with a semi-controlled inverter, obtaining better power factor, efficiency and reduction of the alternating component of the DC link current.

With the motivations for energy-economy, a cement plant decided to recuperate energy from the rotor of an induction motor that powered a big rotating ventilator. Instead of the conventional diode bridge, DC coil, thyristor inverter and adapter transformer, it was selected a set consisting of a thyristor bridge, no DC coil, thyristor inverter and adapter transformer.

The motor and power electronic converter set, although recuperating energy, had frequent motor problems, requiring the rewinding or substitution of the motor, which was not the case previously, without using power electronics.

The goal of this paper is to study the electromagnetic torque using simulation implemented in MatLab/Simulink, Power System Blockset.

Proposed Slip Energy Recovery System Model

Fig. 1 shows the model developed in MatLab/Simulink, which is composed by the following modules: mains (M), asynchronous motor (AM), adapter transformer Y_gY_0 (AT), starter rheostat (RS), rectifier bridge (RB), inverter bridge (IB), inverter adapter transformer (IAT), circulation current controller (CCC), mechanical load (blower - ML), rotor slip frequency calculator (RSFC), rotor voltages adaptive filter (RVAF), rectifier pulse generator (RPG), main voltage signal filter (MVSF), inverter pulse generator (IPG), rectifier controller (RC), inverter controller (IC), and inverter activation controller (IAC).

The asynchronous motor uses the model available in the PSB library. In this model the rotor is referred to the stator.

The adapter transformer is modelled with three linear single-phase transformer models, also available in the PSB library.

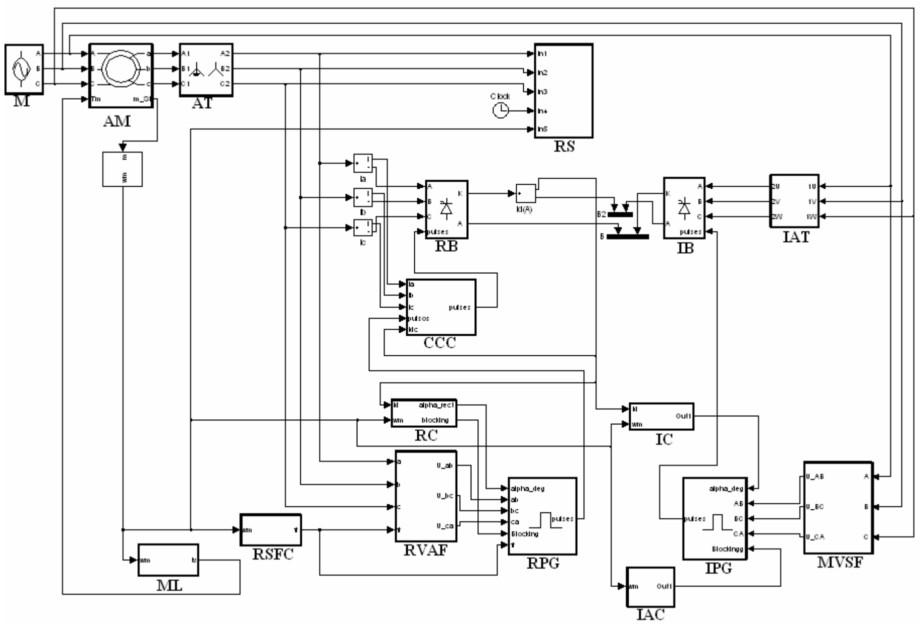

Fig. 1 Model developed in MatLab/Simulink, using PSB.

The measured rotor voltages together with the slip frequency are the inputs of the adaptive filter (RVAF). This module consists of a specially designed 3-phase-locked generator outputting three voltages with the successive 120º phase shift and phases locked with the corresponding unfiltered rotor voltages. The amplitudes of the generated voltages are limited in order to obtain a more stable system. These voltages, V_ab, V_bc and V_ca are inputs to the rectifier pulse generator. In this pulse generator, V_ab, V_bc and V_ca, are processed in order to obtain the zero–crossing positive-going instants and a time-delay is computed according to the running values of the slip frequency and delay angle computed by the rectifier controller (RC). With these values of time, are generated pulses in order to be applied to the thyristors if they do not cause inconveniencies.

The blocking output of the rectifier controller module (RC), allows the simultaneous blocking of the rectifier pulse-generator outputs (RPG). The output

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of the rectifier pulse generator is one 6-way input to the circulation current control module, being the other inputs signals proportional to the rotor currents and to the output direct current of the rectifier bridge. The CCC module detects the occurrence of circulation current, if it occurs, and in this case blocks the ignition of the adequate thyristor in order to go out of the circulation current mode.

The inverter controller and the rectifier controller, both have rectified bridge current (Id) as input. The rectifier controller uses it for overcurrent protection, the inverter controller for imposing the current level of Id, in normal operation.

Some detailed aspects of the simulation modules are following presented in this paper. The converter is simulated with two thyristor bridges and no DC coil.

Simulation Results

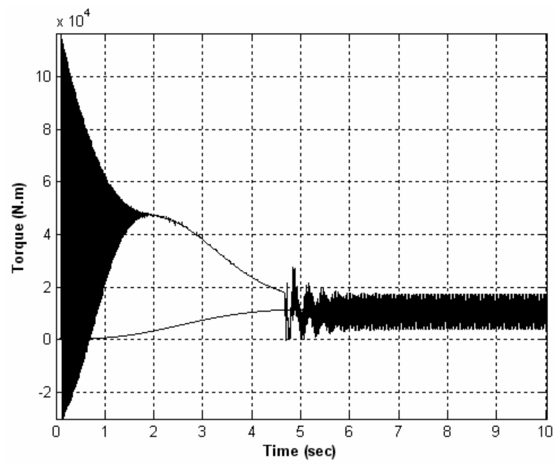
The results obtained, with the model developed and implemented, are present in Fig. 2, corresponding to the electromagnetic and load torques, with these parameters and conditions of simulation: method of integration; ode23tb (stiff /TR- BDF2); variable step, with maximum step $2x10^{-4}$; relative and absolute tolerances of 10^{-2}; simulation time of 10s; $90^o \leq \alpha_I \leq 150^o$ and $5^o \leq \alpha_R \leq 90^o$. The slip reference is 0.1.

During rheostatic starting, the torque oscillates between 11.8 $x10^4$ N.m and -3$x10^4$N.m with decaying oscillations, which is the normal starting behaviour.

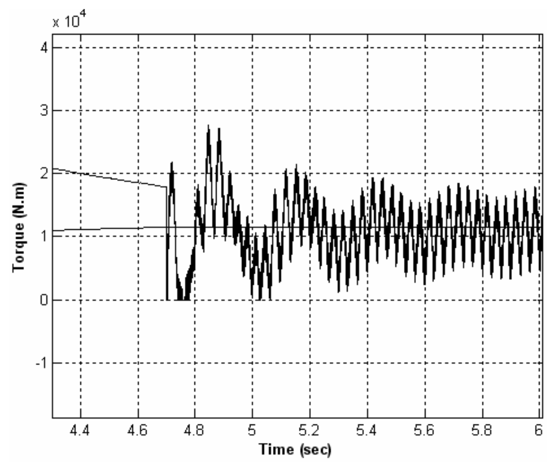
At about 4.7s the current start flowing through the bridge converters and the electromagnetic torque tends to a steady state oscillating behaviour, with a maximum of 1.8$x10^4$ N.m and minimum of 0.4$x10^4$ Nm. This corresponds to an alternating/average value of (1.8-0.4)/(1.8+0.4)=0.64 for the steady state, which is much worse than the equivalent value when a DC link coil is used.

The load torque is almost constant in steady state, and corresponds to the average value of the electromagnetic torque. The peak-to-peak value of the steady-state electromagnetic torque (1.4 x 10^4 N.m) is much lower than the peak –to-peak value during rheostatic starting (14.8 x 10^4 N.m).

Although lower, it constitutes a strong nuisance, because it occurs during most of the working time and strongly contributes to the loss of mechanical life.



(a)



(b)

Fig.2 Load and electromagnetic torques.

Conclusion

This paper analyses the influence of the power electronics converter, of a slip energy recovery system, on the electromagnetic torque. To perform this analysis, a model of the slip energy recovery system was developed using MatLab/Simulink software. The simulation results showed a strong disturbance in the electromagnetic torque in the steady state, caused by the power electronics converter. To reduce this disturbance, and consequently to increase the mechanical life of the motor, a DC link coil must be used.

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