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Design of an Induction Motor with Torque and Position Control

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ABSTRACT

The steady state equivalent circuit of the induction motor will not give satisfactory result when the rate of variaton of shaft torque is comparable to the shaft speed. This paper shows how MATLAB and SIMULINK can be used to simulate the dynamics of an induction motor when the shaft torque varies as a function of shaft position. As an example of such a load, a reciprocating compressor is considered. Simulation of the induction motor is carried out by using two different methods that have been suggested in literature, viz. the dq or 2-axis method and the hunting network method. Both methods enable the instantaneous values of current, power, power factor and slip of the motor to be calculated.

Keywords: ***induction motor simulation, dq method, hunting network***

I .INTRODUCTION

The 2-axis or dq method [1] of analysis is used to predict the performance of an induction machine with arbitrary shaft torque variations. It is a time domain method and when shaft torque is periodic, it gives results during the transient as well as steady state. It requires numerical integration of simultaneous state variable differential equations. Middlemiss [2] had proposed this method to calculate the current pulsations in a reciprocating compressor drive.

The hunting network method [3] is applicable only when the shaft torque varies periodically and the final steady state dynamics alone are of interest, as in case of an induction motor driving a reciprocating compressor. It is a frequency domain method and yields solution for one complete cycle of variation during the steady state, bypassing the transient state. It avoids integration and uses algebraic expressions instead. Cummings [4] had proposed this method to calculate power and torque pulsations in a reciprocating compressor drive.

Both methods enable the instantaneous values of current, power, power factor and slip to be calculated in the steady state when the shaft torque is periodic.

II SIMULATION THROUGH D-Q METHOD

It is well known that all time-varying inductances in the voltage equations of an induction machine due to electric circuits in relative motion can be eliminated by transforming both the stator variables and the rotor variables to a reference frame that may rotate at any angular velocity or remain stationary. For a symmetrical induction machine working under balanced conditions, it is easier to work with the synchronously rotating reference frame, since dealing with power frequency quantities is avoided and one has to deal only with the much slower torque-frequency quantities. This results in faster simulation but yields only the envelopes of all the quantities. This is sufficient since it is known that the electrical quantities are sine waves modulated by this envelope and so the envelopes are proportional to their rms values.

The stator supply voltage is represented in the field reference frame by constant values of d axis and q axis voltages vsd and vsq such as vsd = 0 and vsq = peak

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phase voltage. The SIMULINK 2-axis model is depicted in Fig. 2, which is self-explanatory. Although the machine in the example is a squirrel cage one, d axis and q axis rotor voltages vrd and vrq are also carried in the equations for generality. Since transients are of no interest, they are made to die down faster by reducing the inertia J to a small value initially by using a step block. The load torque is applied only after steady state is nearly reached under no load condition. Fig. 3 shows the result.

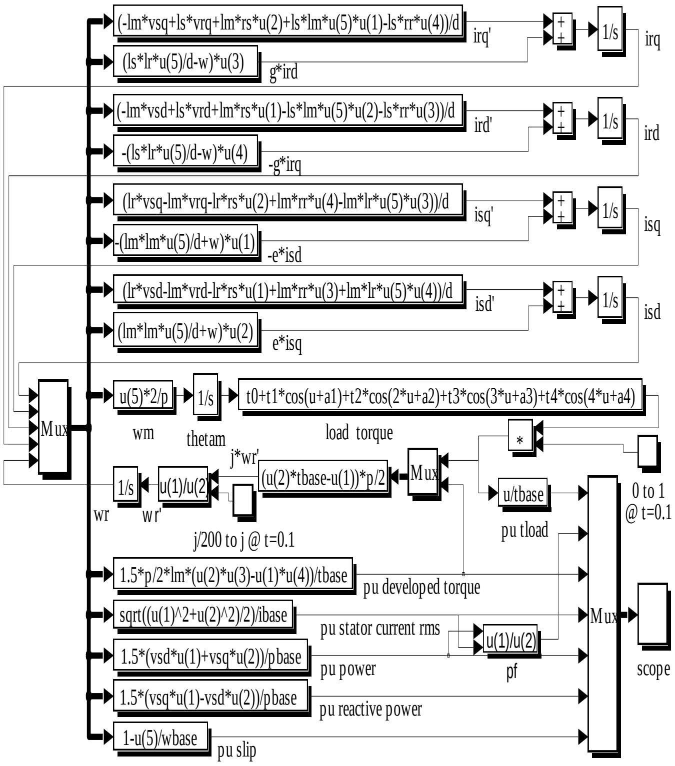

Fig. 1 SIMULINK model for analysis through dq method

SIMULATION THROUGH HUNTING NETWORK METHOD

Dynamic analysis through the hunting network approach is implemented through the corresponding steady state and hunting network equivalent circuit representations of the induction machine [3] as shown in Fig. 4. The derivation of the relevant equations is given in Appendix B. The algorithm is depicted in Table I and implemented using the MATLAB program given in Appendix C. The result is shown in Fig. 5.

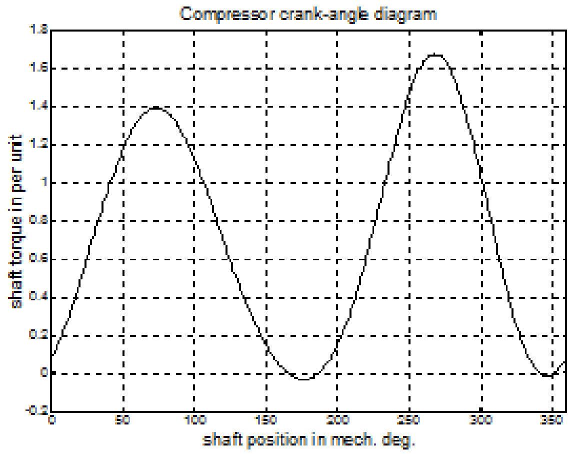

Fig. 2 Crank angle diagram of reciprocating compressor

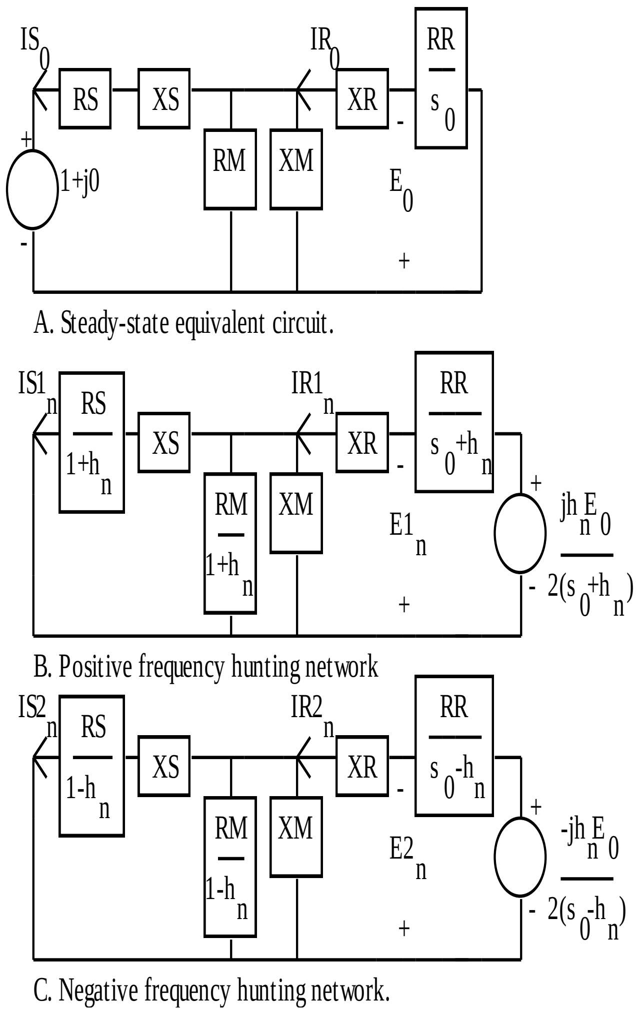

Fig. 3 Equivalent-circuit representation of induction machine for dynamic analysis through hunting-networks

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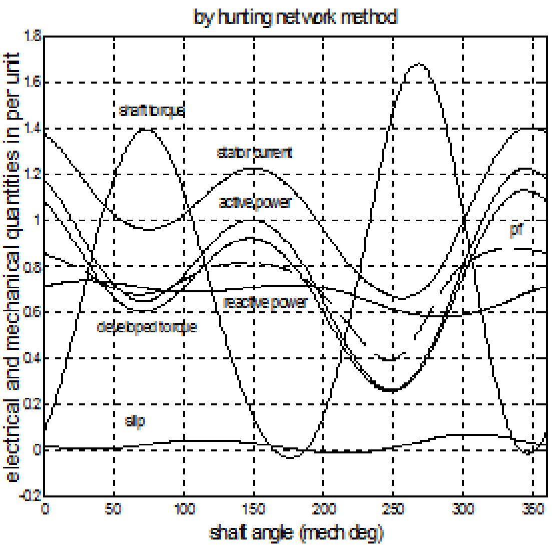

Fig. 4 Predicted steady state operation through hunting network method

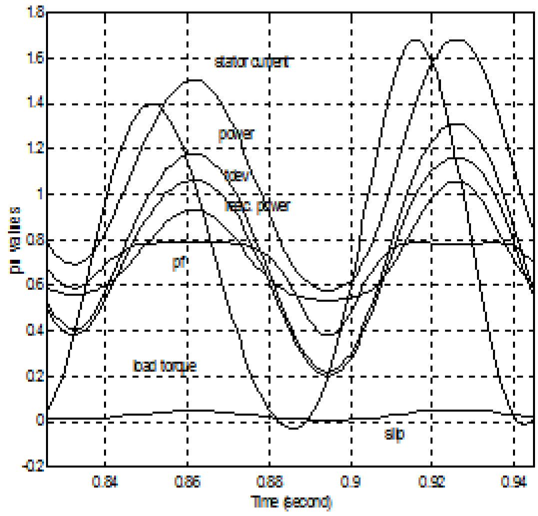

Fig. 5 Predicted steady state performance through the steady state equivalent circuit

RESULTS AND CONCLUSION

Comparison of Fig. 3 with Fig. 5 shows that the results are identical in steady state. The horizontal axis for the hunting network method is the shaft angle, whereas that for the dq method is time. They also agree with the experimentally measured data of Cummings[4]. The result of analysis using the steady state equivalent circuit is shown for comparison in Fig. 6. As expected, the result is unsatisfactory. A 3-phase 200 hp induction motor driving a reciprocating compressor, whose parameters are taken from Cummings [3] is considered for this paper. The crank-angle diagram (shaft torque vs. angular shaft position in mechanical degrees for one cycle of operation) of the reciprocating compressor is shown in Fig. 1. Fourier analysis is carried out on it to obtain the average value and harmonic components (upto fourth order) both in magnitude and in phase. The harmonic magnitudes and phase angles are loaded into the MATLAB workspace together with the parameters and ratings of the induction machine, the supply voltage and frequency, the moment of inertia of the system and the base values used for converting to per unit notation, using the MATLAB code in Appendix A. This code must be executed in the MATLAB command window before carrying out simulation by either method.

The first term on the left hand side is the inertia torque and the remaining two terms add up to the generated torque, which opposes the prime mover torque. δ_n is the nth harmonic rotor displacement in electrical radians. The nth harmonic synchronising and damping torque coefficients may be calculated using the following formulae obtained from Concordia[2]:

$$Ts_n = \mathrm{Re}(IR_0(E1_n + E2_n)^* + (IR1_n + IR2_n)E_0^*)$$
$$Td_n = \mathrm{Im}(IR_0(E2_n - E1_n)^* + (IR1_n - IR2_n)E_0^*)/h_n$$
(3)

where the currents and voltages are as depicted in Fig. 4

$$\text{and} \qquad h_n = \frac{-n}{\omega_s}\frac{d\theta}{dt} = \frac{n}{\omega_s}\frac{d(\omega_T t)}{dt} = \frac{n\omega_T}{\omega_s} = \frac{nf_T}{f}$$

is the hunting torque coefficient, where ωs is the synchronous speed in electrical rad/s = $2\pi f$, f is the supply frequency in Hz, f_T is the frequency of the shaft torque waveform in Hz and $\omega_T = 2\pi f_T$. The steady-state solution of equation (2) is

$$\delta_n(\theta) = |\delta_n|\cos(n\theta + \angle\delta_n)$$

where

$$|\delta_n| = \frac{|TT_n|}{Ts_n\sqrt{X_n^2 + Y_n^2}}, \qquad \angle\delta_n = \angle TT_n + \tan^{-1}\frac{Y_n}{X_n},$$
(4)

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$$X_n = \frac{h_n^2 J}{Ts_n} - 1 \quad \text{and} \quad Y_n = \frac{h_n T d_n}{Ts_n}. \tag{5}$$

The total rotor displacement is obtained by adding all the harmonic displacements to an average displacement of zero to give

The above methods can be readily extended to generator mode (e.g. an induction generator driven by a reciprocating engine) by allowing the average shaft torque to become negative. This has been reported in Yegna Narayanan et al [5].

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