13th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2009, Hammamet, Tunisia, 16-21 October 2009

DYNAMIC ANALYSIS OF TORSIONAL TORQUE DURING THE START OF LARGE SQUIRREL CAGE INDUCTION MOTORS

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ABSTRACT
In the paper is presented a study of the starting process of a large squirrel cage induction motor driving an inertia load through an elastic shaft. The analysis of the electromagnetic torque of the motor has revealed that there are variable frequency components which interact with the torsional mode of the chanical system and produce hazardous shaft torque. The nature of the problem is explained trough mathematical modeling of large induction motors drives the pump in power plant. The Matlab was used for simulation.
Keywords: Large induction motors, starting process, torsional torque.

1. INTRODUCTION
Electrical induction motors when are started direct on-line they generate a considerable pulsating torque. This start up torque can create problems when the motor is connected to mechanical loads such pumps and there are reported cases in the coal fire plant of the interconnecting shafts having been sheared on start-up. The starting process of large induction motors has been extensively investigated [1-3] since they impose a severe burden on the power supply. These investigations provided several solutions and techniques for alleviating the problems encountered during the starting period. However, most of the attention has been given to limit the heavy starting current and to counteract its impact on the system and the motor. To cope with this objective, most of the models, assumptions and approximations are arranged to suit this purpose. This paper gives mathematic modeling of the inter-relationship between the electric motor and the mechanical system which is effectively a multi-mass oscillatory system.. The model include mathematical modeling of electrical part and mathematical modeling of mechanical system. These two models and connected to each other with angular velocity of rotor of electrical machines. Thus, we have two very accurate models to describe both electro-magnetic and the mechanical properties of the whole systems. The obvious advantage of such an

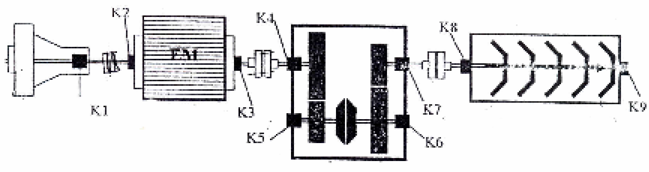

Figure 1. Layout of the system: EM –large induction motor, Power transmission system, pump

approach is the possibility to simulate complex drive systems with their transient behavior, which is common problem in practice. The derived model is used for calculation of dynamic currents and moments. It can be shown that large transients of both torque and speed occur immediately on start-up due to excitation of the oscillatory system. Figure 1 shows the layout of the system considered for the analysis conducted in this paper, which depicts a large squirrel cage induction motor driving a pump through an elastic shaft.

2. MODELING OF THE AC MACHINE

The dynamic analysis of ac machines is usually based following assumptions: stator and rotor winding (bars) are symmetrical and so distributed that the magneto motive forces (MMF's) are sinusoidal, the coefficient of mutual inductance between any stator and rotor winding is cosine function of the electrical angle between axes of the two windings, and self–inductance independent of the rotor position, that is physical inductance matrix is symmetrical, linear magnetic are assumed and the effects of the magnetic saturation and hysteresis, are neglected, space harmonics of the flux linkage distribution are neglected, slot harmonics are not considered, the motor parameters are independent of temperature and frequency, the motor is switched to a rigid supply system, all switching take place instantaneously. The approach eliminates the redundancy of poly-phase windings, substituting these by their two-axes equivalent. This reduce a poly-phase winding to a set of two phase-winding having their magnetic axes arranged in quadrature as shown in Fig.2. The two axes representation eliminates the mutual magnetic coupling of the phase windings, rendering the magnetic coupling of the phase-winding independent of the current in the other winding. In a second step, both poly-phase windings in the stator and the rotor of an ac machines are viewed from a common frame of reference which is either fixed to the stator, or to the rotor. More generally, the reference frame can be considered rotating at any arbitrary angular velocity ω_k. The common coordinate system is further interpreted as the complex plane, its real axis being denoted as the direct axis (d), and the imaginary axis as the quadrature axis (q-axis). According to Kron [1], a general ac machine is symbolically represented by the equivalent circuit Fig.3.The general k-coordinate system rotates at the angular velocity ω_k. with respect to the stator windings. The stator voltage equations referred to the k-coordinate system , are expressed in terms of normalized quantities:

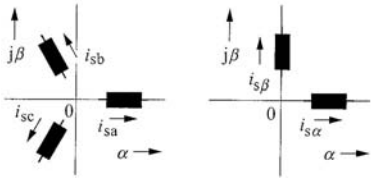

Figure 2. Poly-phase winding and two-axes equivalent

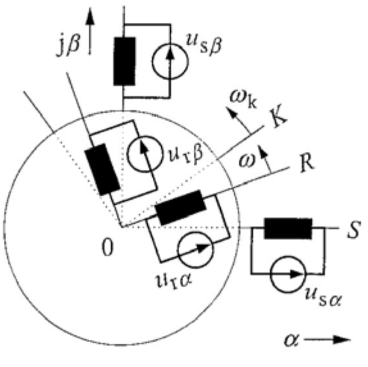

Figure 3. Two-axes representation of an ac machines. S,R,K, denote the real axes of the stationary, the rotor-fixed, and the general coordinate system.

$$
\begin{aligned}
\frac{d\psi_{d_s}}{dt} &= u_{d_s}\frac{R_s}{\sigma L_s}\psi_{d_s} + \omega_1\,\psi_{q_s} + \frac{R_sL_m}{\sigma L_sL_r}\psi_{d_r}\\
\frac{d\psi_{q_s}}{dt} &= u_{q_s}\frac{R_s}{\sigma L_s}\psi_{q_s}\omega_1\,\psi_{d_s} + \frac{R_sL_m}{\sigma L_{sL_r}}\psi_{q_r}\\
\frac{d\psi_{d_r}}{dt} &= \frac{R_r}{\sigma L_r}\psi_{d_r} + (\omega_1 - \omega)\,\psi_{q_r} + \frac{R_rL_m}{\sigma L_sL_r}\psi_{d_s}\\
\frac{d\psi_{q_r}}{dt} &= \frac{R_r}{\sigma L_r}\psi_{q_r}(\omega_1 - \omega)\,\psi_{d_s} + \frac{R_rL_m}{\sigma L_sL_r}\psi_{q_s}
\end{aligned} \tag{1}
$$

Electromagnetic moment is:

$$
M_{em} = \frac{3}{2}\,p\,\frac{L_m}{\sigma\,L_s\,L_r}(\psi_{ds}\psi_{qr} - \psi_{qs}\psi_{dr}) \tag{2}
$$

3. MODELING OF THE MECHANICAL SYSTEM

The mechanical system will be treated with n-stage coordinates and based on equations of **Lagrange**-it [5], o second order

$$\frac{d}{dt}\left(\frac{\partial W_k}{\partial \dot{q}_r}\right) - \frac{\partial W_k}{\partial q_r} + \frac{\partial W_p}{\partial q_r} + \frac{\partial \phi}{\partial \dot{q}_r} = Q_r, \quad (r = 1,2,3,...,n). \tag{3}$$

The dynamic model of mechanical system of electrical drives with induction motor and n-stage transmission systems: the mass of the shafts are negligible and they acting as elastic element; the torsional deformation of the shafts behaves according to the nonlinear elastic laws; joints in rotor shaft and in load shaft are not consider as separate rotary mass, but their torsional stiffness is taken in account through the total torsional stiffness of the shafts; in all shafts the dissipations, in connection with external load is include (friction in the bearing, etc.), the torque of the dissipation behave according to the nonlinear proportionality with speed of deformation of the elastic shafts, the inner friction of material (hysteresis looses of energy caused by non-ideal elasticity of material is not taken into account) are neglected; the gearbox is cylindrical with incline teeth; gearing of the pair of teeth behave according to the nonlinear elastic laws; during the gearing of the teeth the stiffness remains constant; the biased air gap of the teeth pair are neglected; the dissipation of energy of pair gearing teeth of gearboxes is taken in account through the dissipation torque, which are linear proportional with speed of deformation of teeth and gearboxes behave according to the function of rotary angle; the friction of work mechanism during the rotation is representing with torque of cosine-type function. The mechanical system treated and based on equations of **Lagrange**-it, finally will find a set of differential equations which describe the non-stationary motion of mechanical system in the matrix form:

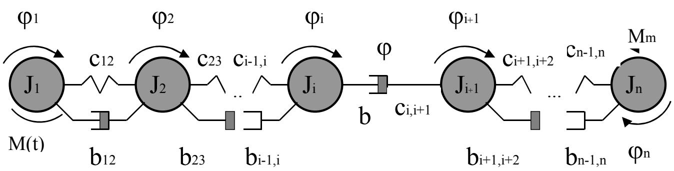

Figure 4. Mechanical model of adopted machinery set

$$[J^*][\ddot{q}] + [b^*][\dot{q}_1] + [c^*][q_2] = [M^*] \tag{4}$$

where is: [J*] is matrix of moment of inertia, [b*] is matrix of dumping coefficients, [c*] is matrix of stiffness coefficients, $[\ddot{q}]$ is column matrix of generalised acceralation, [M*] is matrix of perturbation torque, $[\dot{q}_1]$ column matrix are deference of generalised speed, and $[q_2]$ column matrix of difference generalised coordinates: Matrix equation (2) together with system of differential equation of induction motor (1) represent the general mathematic model of electric drives system with induction machines set pump with n-stage power transmission with elastic members involving the dynamic characteristics of the induction motor and moment of inertia of the working mechanism. .The developed numerical model permits to simulate the induction motor starting process and takes in account skin effect, transformation and rotational electromotive forces. In addition, this model is the same for both transients and steady-state analysis. Figure shows the behavior of the induction machine as it is switched over from the speed control to torque control mode at 0.5 second following the start of the simulation. The data of the: 6100 kW; 6300 V, 50 Hz, Y-stator windings, 2p=4, 1488 pmr/min, rate of current short circuit/nominal currents = 5.93, $\cos\varphi_n=0.8$; m=1680 kG, $r_s=0.16\ \Omega$; $r_R=0{,}138\ \Omega$, $X_{\sigma s}=1.26\ \Omega$;

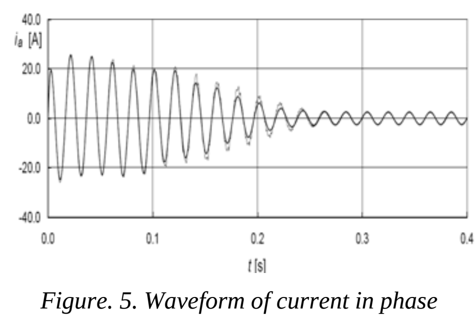

Figure. 5. Waveform of current in phase "A" during start-up

$X_{\sigma rk}$=0.84 Ω, R_m=22 Ω, X_m=39.97 Ω, [10]. The results for the dynamic model of the mechanical aggregate are graphically presented for time interval $t \in [0,5]$ s, representing work of such a system at transitional regime.

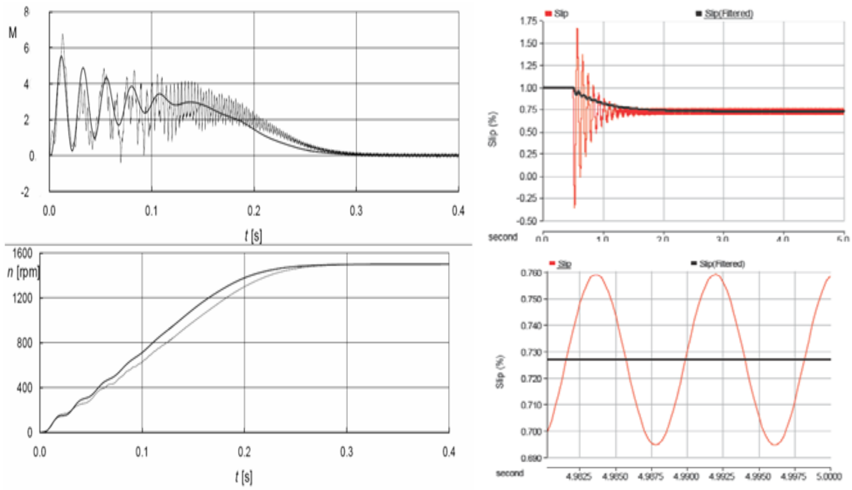

Figure 6. Left top: Waveforms of torque and rotational speed during start-up; right-Induction motor slip as a function of time -(top right) for the entire simulation period, and (bottom right) enlarged

4. CONCLUSION

Electrical induction motors at start processes generate a considerable pulsating torque. This start up torque can create problems when the motor is connected to mechanical loads such as pumps and there are reported of the interconnecting shafts having been sheared on start-up. A time domain model of the intercoupled electromechanical system is presented. On the basis of electromagnetic and mechanical theory is formed an mathematical model of electric drives system with induction machines. The derived model is used for calculation of dynamic currents and moments of electrical for different mechanical constant of the induction motor. The computer program package is developed in Matlab.

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