An electromagnetic-mechanical modeling of an induction motor and rotor shaft coupled to angular approach

Aroua. FOURATI[ab], Adeline. BOURDON[a], Didier. REMOND[a], Nabih. FEKI[b], Fakher. CHAARI[b], Mohamed. HADDAR[b]

a. LaMCoS UMR5259, CNRS, INSA-Lyon, University of Lyon, France
{aroua.fourati,adeline.bourdon,didier.remond}@insa-lyon.fr
b. La2MP, National School of Engineers of Sfax – BP 1173-3038, Tunisia
{arwafourati,fekinabih,fakher.chaari}@gmail.com
mohamed.haddar@enis.rnu.tn

Résumé:

Ce papier présente un modèle électromécanique pour simuler le comportement dynamique d'une machine asynchrone / arbre du rotor. Le modèle décrit dans ce travail combine un modèle de réseau de perméances d'un moteur à induction à cage d'écureuil et un modèle dynamique simple de son arbre de rotor. Un échantillonnage angulaire est utilisé pour permettre d'investiguer les variations de vitesse angulaire instantanée et de couple. Le système rotatif est décrit en se référant à la position angulaire de l'arbre. La méthodologie de couplage électromécanique est bien détaillée. En se basant sur un certain nombre de simulations, on montre l'influence des variations de couple provenant de la machine à 'induction sur le comportement dynamique du système mécanique.

Abstract:

This paper present an electromechanical model to simulate the dynamic behavior of induction motor/ rotor shaft. The model detailed in this work combines a permeance network model of a squirrel cage induction motor and a simple dynamic model of its rotor shaft. Angular sampling is used to allow investigation of instantaneous angular speed and torque variations. The rotating system is described referring to the angular position of the rotating shaft. The methodology for electro-mechanical coupling is well detailed. Based on a number of simulations, it is shown the influence of torque variations derived from the induction machine on the dynamic behavior of the mechanical system.

Mots clefs: Induction machine, electro-mechanical modeling, Instantaneous Angular Speed, condition monitoring

1 Introduction

Induction machines connected to mechanical devices are frequently integrated in industrial applications. In these conditions, diagnosis is crucial in terms of fault monitoring to ensure optimal performance. However, these systems are operating under non-stationary conditions. This reality has been the catalyst to the development of surveillance techniques for machines under variable operating conditions. In numerical domain, several sophisticated models were proposed in the literature for modeling industrial components [1], [2]. In the other hand, the angular approach is developed to reproduce varying operating conditions [3]. In this paper, an electromechanical model of an induction machine coupled to its rotor shaft in angular domain is proposed in order to extend modeling to varying angular speed. Coupling between the electrical and the mechanical subsystems is dealt by dual interaction via torque, angular speed and air-gap. A number of numerical results are presented to illustrate electrical-magnetic and mechanical subsystems interactions in order to highlight the importance of angular sampling for diagnosis of rotating machines in non-stationary conditions.

2 Angular background

In the framework of rotating machinery modeling, angular approach is well developed to investigate in modeling of rotating machinery in the case non-stationary rotational speed. It consists on sampling variables in reference to an angular step rather than a time step.

A system of n degrees of freedom is represented in angular domain via angular sampling by the following system [1]:

$$\frac{dt}{d\theta_R} = \frac{1}{\omega(\theta_R)}$$
$$\left\{\frac{dQ(\theta_R)}{d\theta_R}\right\}_{2n} = \frac{1}{\omega(\theta_R)}\Big(\left[A(t,\theta_R)\right]_{2n\times 2n}.\left\{Q(\theta_R)\right\}_{2n} + \left[B(t,\theta_R)\right]_{2n\times 2n}.\left(\left\{U_t(t)+U_{\theta_R}(\theta_R)\right\}\right)_{2n}\Big) \tag{1}$$

Where the variable used for the integration is the rotational degree of freedom θ_R and time is resulting from the relationship between angle and time through the instantaneous angular speed function. This angular approach allows to highlight angular periodicity of a rotating system.

3 Electro-mechanical coupling

3.1 Electrical modeling: permeance network model

The permeance network model offers a detailed representation of an induction machine. It makes possible to consider winding distribution, stator and rotor slotting and rotor eccentricity. It consists in discretizing the induction machine on a finite number of nodes. The induction machine is represented by a permeance network model (Fig.1) and a classic electrical circuit (Fig.2).

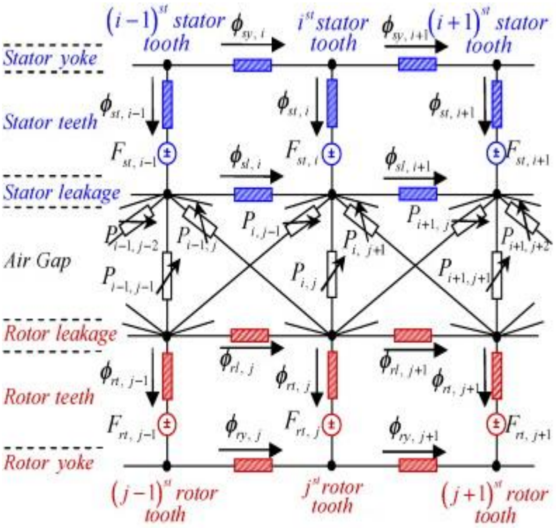

Fig.1.A part of the permeance network model

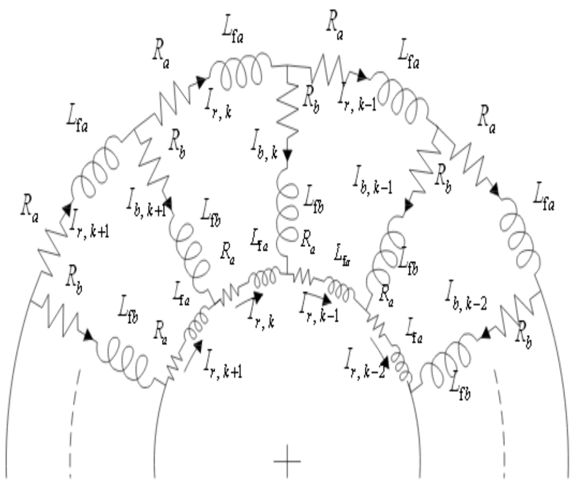

Fig.2. Rotor squirrel cage electrical circuit

Considering magnetic and electrical models, electromechanical behavior of an induction machine can be modelled using a differential equation in the angular domain:

$$\left([L]+[GXZ(\theta_R)]\right).\frac{d\{I\}}{d\theta_R}.\omega(\theta_R)+\left([R]+\frac{d\left([GXZ(\theta_R)]\right)}{d\theta_R}.\omega(\theta_R)\right).\{I\}=\{V(t)\}$$
$$\frac{d\theta_R}{dt}=\omega(t) \tag{2}$$

Where θ_R the instantaneous angular position of the rotor shaft. $\{I\}$ is the generalized stator and rotor currents vector, $\{V(t)\}$ is the power supply vector, $[R]$ and $[L]$ are respectively matrices of inductances and resistances of the stator and the rotor and $[GXZ(\theta_R)]$ is the matrix describing electrical-magnetical coupling in the induction machine.
It is important to notice that being modeled in angular domain, results of simulation of the induction motor can be extended to manage non-stationary rotational speed conditions.

3.2 Mechanical modeling: simple rotor shaft model

The mechanical model of the rotor shaft is simulated by a simple 3-nodes Timoshenko beam elements whereas bearings are introduced by additional lumped stiffness elements as shown in Fig.3. The mechanical system dynamic behavior is therefore accounted for by 3 nodes with 2 degrees-of-freedom per node: axial rotation and radial displacement.

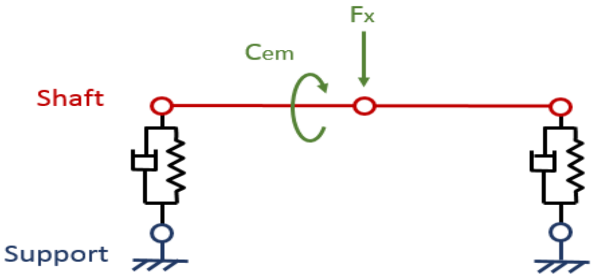

Fig.3. 3-nodes dynamic rotor shaft model

The general equation of motion of the rotating shaft may be written in angular domain as following:

$$\left\{\frac{dQ(t)}{dt}\right\}=[A(\theta_R)].\{Q(t)\}+[B(\theta_R)].\left(\{U_t(t)+U_{\theta_R}(\theta_R)\}\right)$$
$$\frac{d\theta_R}{dt}=\omega(t) \tag{3}$$

Where θ_R is the rotational degree of freedom of the shaft. $\{Q(t)\}$ is displacement and velocity vector, $\{U_t(t)\}$ and $\{U_{\theta_R}(\theta_R)\}$ external forces vectors depending respectively from time and angle, $[A(\theta_R)]$ and $[B(\theta_R)]$ are matrices representing the dynamic characteristics of the shaft.

3.3 Coupling electrical and mechanical models

The electromechanical coupling is realized by defining a global state vector including electrical and mechanical outputs. In each iteration, magnetic, electric and mechanic models are solved while ensuring input/output relationships between subsystems. In order to take into account dynamic variations of the system, the rotor angular position, the electromagnetic torque, the rotor eccentricity, the rotational speed and the time are up-dated at every step. Electromagnetic torque generated by the induction machine is applied as an external force at node 2 of the shaft. In another hand, instantaneous angular speed and radial displacement of the same node of the mechanical model are used to feed the electrical model of the rotational speed and the air-gap eccentricity as shown in Fig.4.

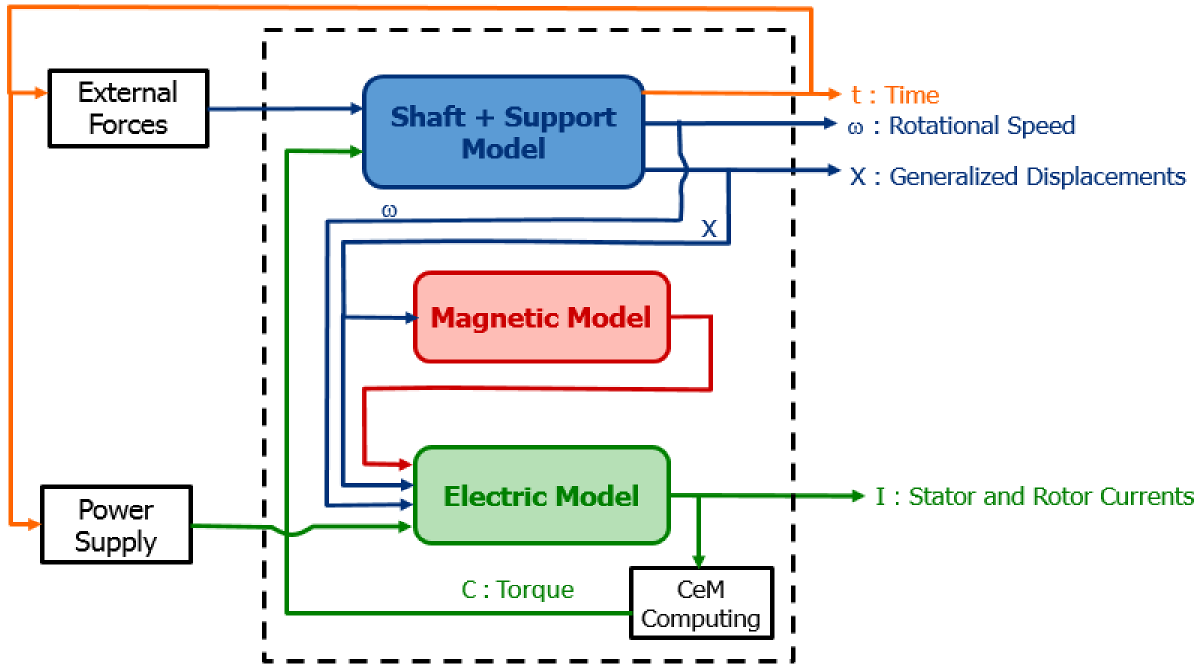

Fig.4. Electric-magnetic-mechanical coupling

4 Results

The proposed electromechanical system is used to simulate the influence of the interaction between electrical and mechanical models on the dynamic of the whole system. Fig.5 illustrate angle variations of the first-phase stator current. Fig.6 shows air-gap eccentricity amplitude. In Fig.7, instantaneous angular speed response is represented. Torque variations are shown in Fig.8.

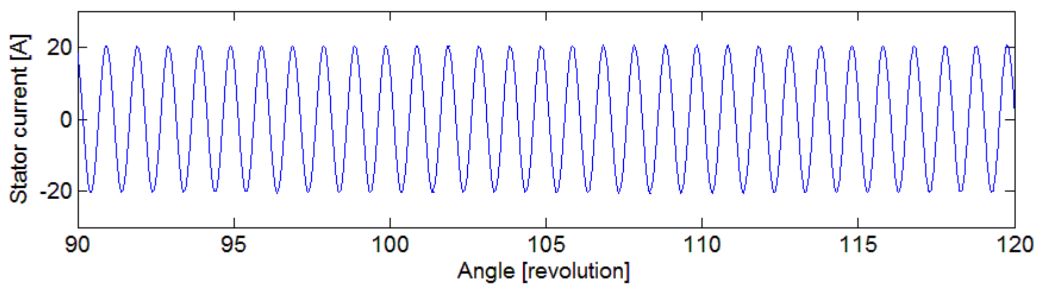

Fig.5. First phase stator current

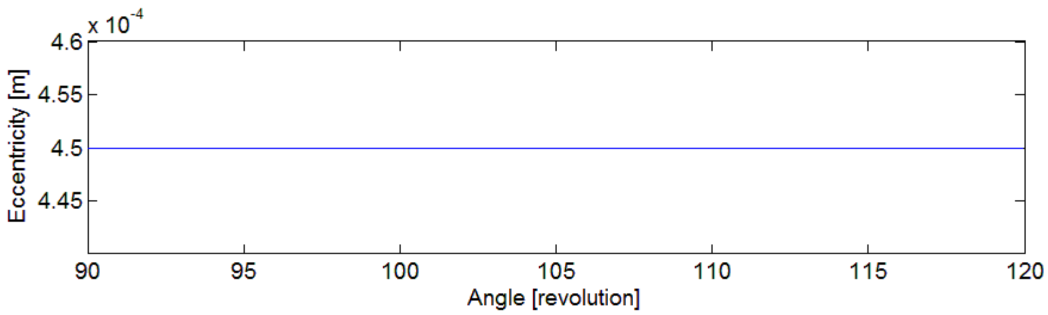

Fig.6. Air-gap eccentricity amplitude

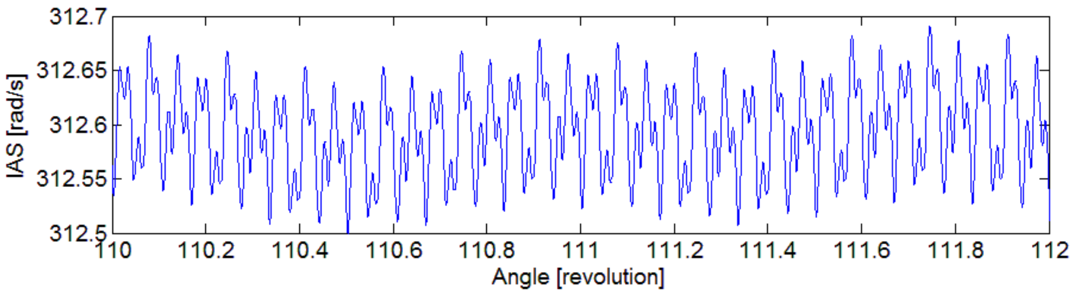

Fig.7. Instantaneous angular speed

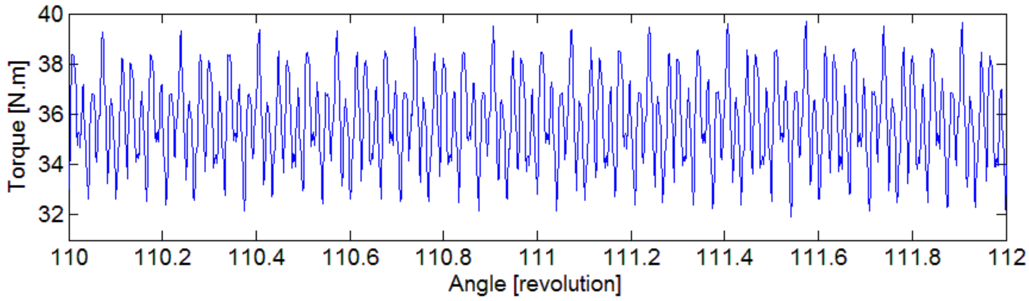

Fig.8. Motor torque

It is important to notice that results presented in this paper are simulated for a constant macroscopic angular speed. However, analysis can be extended to varying speed. Influence of this variable on the other dynamic variables of this system (eccentricity, torque, currents …) may be investigated.
Finally, to show the potential of the angular approach, a comparison between simulations of the model using time and angular sampling in the same conditions has shown that simulations in angular domain provide a gain of 70% of the computing time.

5 Conclusion

The proposed electromechanical model makes possible to simulate behavior of an induction machine and a simple rotating shaft dynamically connected. The electrical model, based on the permeance network model was modified by coupling with angular approach to be suitable to non-stationary operating conditions. A simple mechanical model of the rotor shaft was sampled in angular domain to make access to angular speed variations. Results presented in this paper shows the interconnection between subsystems. Further works will present the combination of this resulted system with more complex mechanical systems (bearing …) that add angular periodicities able to influence the dynamic of the whole system.

Références

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