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MODELING AND SIMULATION OF INDUCTION MOTOR FOR DYNAMIC BEHAVIOUR TESTING USING SPECIFIED LOAD

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Abstract: In this paper model for testing induction motor dynamic behaviour using direct current (DC) generator as discontinuous load is presented. Basic mathematical formulation which describes induction motor and DC generator is given. Existing laboratory model is described. Simulation model of induction motor, DC generator and model of alternating current source is made in Matlab-Simulink. Essential parameters for starting simulation of used induction motor and DC generator are given. Dynamical characteristics of induction motor as results of simulation are shown.

Key words: motor, dynamic, load, model, simulation.

1. INTRODUCTION

The main problem of this paper is building simulation model which is based on real laboratory model. Laboratory model (Fig. 1) consists of induction motor (AM), DC generator, power source for motor and generator. Simulation model will be used for testing induction motor dynamic behaviour during motor load. Before model building the experiment is done on three phase induction motor. DC loading generator is in solid mechanical connection with induction motor. While changing resistance on the resistor for loading the generator, behaviour of induction motor is observed. This is necessary for understanding dependence of motor main parameters such as: motor current, torque, slip, power, power factor, efficiency and motor losses. The analysis is done with assumption of constant sinus voltage and constant frequency of induction motor power source. Simulation model is made by the mathematical model. Modeling and simulation are performed in Matlab Simulink in program part called Simpower System Blockset which is used for simulation of electrical drives. Similar simulation of dynamic behaviour of induction (asynchronous) motor is done by (Ertugrul, 2002) in LabVIEW program. Basic equations which describe induction motor and DC generator are given in (Bose, 2002), (Leonhard, 2001) and (Jadric, Francic, 1995). The dynamic behaviour of electric motors is a difficult topic to study without a computer-aided tool (Ertugrul, 2002). With analysis of mathematical model expensive and unwanted testing of original can be avoided (Jovic et al., 2006).

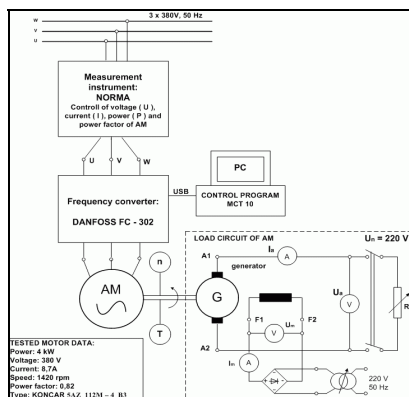


Fig. 1. Laboratory model for testing induction motor.

2. MATHEMATICAL MODEL

Mathematical model consists of differential, algebraic and logic equations. They present the starting point before simulation on computer. That provides experimenting on mathematical model instead original. The mathematical model to be used is tailored to the needs of controlled drives (Leonhard, 2001).

2.1 Induction motor

One of the most fundamental principles of induction machines is the creation of a rotating and sinusoidally distributed magnetic field in the air gap (Bose, 2002). The speed difference between rotating magnetic field of stator and rotor speed is needed for creation of electromagnetic torque. The mathematical model derives from equivalent scheme of induction motor (Fig. 2a) which consists of resistances, self inductances and mutual inductances. The induction machine may be viewed as a system of electric and magnetic circuits which are coupled magnetically or electrically (Boldea & Nasar, 2002). The mathematical model consists of several groups of equations in matrix and differential form as given in (Jadric, Francic, 1995):

- Voltage equations for stator and rotor:

$$\begin{aligned} \mathbf{u}_{abc s} &= \mathbf{R}_s \mathbf{i}_{abc s} + \frac{d\boldsymbol{\psi}_{abc s}}{dt} \\ \mathbf{u}_{abc r} &= \mathbf{R}_r \mathbf{i}_{abc r} + \frac{d\boldsymbol{\psi}_{abc r}}{dt} \end{aligned} \quad (1)$$

where $\mathbf{u}_{abc s}$ and $\mathbf{u}_{abc r}$ are voltage vector matrixes of three phase system for stator and rotor, \mathbf{R}_s and \mathbf{R}_r are resistance matrixes of stator and rotor, $\boldsymbol{\psi}_{abc s}$ and $\boldsymbol{\psi}_{abc r}$ are flux vector matrixes of stator and rotor, $\mathbf{i}_{abc s}$ and $\mathbf{i}_{abc r}$ are current vector matrixes of three phase system for stator and rotor.

- Flux equations for stator and rotor:

$$\begin{aligned} \boldsymbol{\psi}_{abc s} &= \mathbf{L}_{abc s} \mathbf{i}_{abc s} + \mathbf{L}_{abc sr} \mathbf{i}_{abc r} \\ \boldsymbol{\psi}_{abc r} &= (\mathbf{L}_{abc sr} \mathbf{i}_{abc s})^T + \mathbf{L}_{abc r} \mathbf{i}_{abc r} \end{aligned} \quad (2)$$

where $\mathbf{L}_{abc s}$ and $\mathbf{L}_{abc r}$ are induction sub matrixes of stator and rotor, $\mathbf{L}_{abc sr}$ is mutual inductivity sub matrix.

- Mechanical (motion) equation:

$$J \frac{d\omega_m}{dt} = M_m - M_l \quad (3)$$

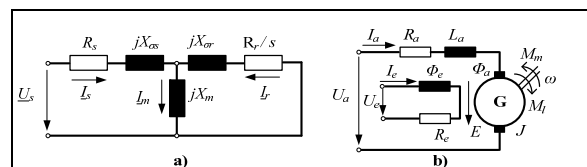


Fig. 2. Equivalent scheme of AM a) and DC generator b).

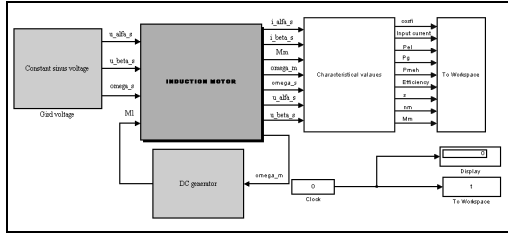


Fig. 3. Simulation model of induction motor load circuit.

- Electromagnetic torque equation:

$$M_m = \frac{1}{2} (\mathbf{i}_{abcs})^T \frac{d\mathbf{L}_{abcsr}}{d\vartheta_m} \mathbf{i}_{abcr} + \frac{1}{2} (\mathbf{i}_{abcr})^T \frac{d(\mathbf{L}_{abcsr})^T}{d\vartheta_m} \mathbf{i}_{abcs} \quad (4)$$

where J is moment of inertia, ω_m is angular motor speed, M_m is electromagnetic torque, M_l is load torque, and ϑ_m is difference angle between rotor and stator position.

2.2 DC generator

Functioning of DC generator can be explained by using two electrical circuits (Fig. 2b). Exciting (field) circuit creates magnetic flux and in armature circuit voltage is induced. DC generator can be described by using following equations for armature and field circuit as given in (Leonhard, 2001):

$$\begin{aligned} U_a &= R_a I_a + L_a \frac{dI_a}{dt} + E \\ U_e &= R_e I_e + N_e \frac{d\Phi_e}{dt} \end{aligned} \quad (5)$$

where U_a is armature voltage, R_a is armature resistance, I_a is armature current, L_a is armature inductance, E is induced voltage, U_e is field circuit voltage, R_e is field circuit resistance, I_e is current of field circuit, N_e is number of field windings, Φ_e is field flux. Motion equation of DC generator is similar to equation (4) of induction motor.

3. SIMULATION MODEL AND PARAMETERS

Simulation model of induction motor load circuit consists of model of power source, induction motor model, model of DC generator and model of discontinues resistance connected with DC generator which represents load for induction motor (Fig. 3). The simulation model of separately excited DC generator is determined by explicit equations and in this way directly implemented in the model. Usage of Park transformation, on the equations mentioned in mathematical model of induction motor, provides creation of simulation model (Fig. 4). This new explicit equations are directly implemented in the simulation model. In Fig. 3 the block which presents characteristic values provides information of all main motor values (current, torque, speed, etc.) needed to display wanted characteristics. Main

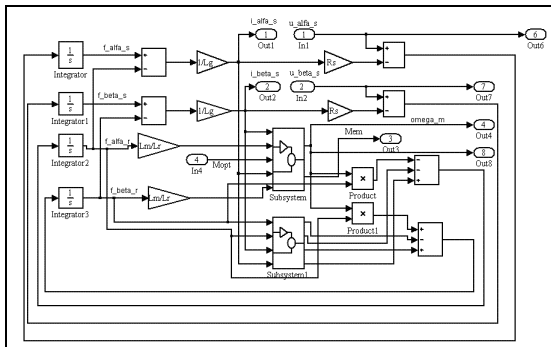


Fig. 4. Simulation model of induction motor.

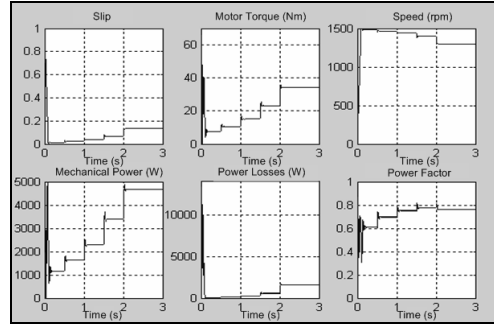


Fig. 5. Dynamic characteristics of induction motor.

parameters of induction motor and generator are determined by measuring and using manufacturer catalogues. Before simulation start, a wide offer of numeric integration algorithms are available. Integration methods are determined by the model of electromotor drive. User evaluates which method will suit him the best. After creation the Simulink models, and before simulation starting it is necessary to determine characteristic simulation parameters (tolerance, integration step, etc.).

4. RESULTS

Some results of simulation are shown on Fig.5. They present all important variables necessary for understanding motor dynamics during motor starting and loading in four steps (each step presents load of 1,5 kW). Instant values of characteristics variables (slip, motor torque, speed, etc.) are possible to monitor during the simulation performance. From given results motor static characteristics can be derived.

5. CONCLUSION

Usage of different kinds of programs, such as Matlab, provides complete dynamic state analysis and testing of induction motor by using simulation model instead original. Programming in Matlab Simulink represents a relatively simple task which consists of combining “in” and “out” ports of different subsystems which make the system. This model can be used for testing different motor types. The used model shows considerable accuracy in the area of nominal point. The largest deviation occurs in determination of motor slip. Further research will include complete evaluation of real and simulation model, testing of model for different types of load and motor and determination of dynamical parameters. For analysis of some tasks M-files will be used. It should be mentioned that usage of simulation model without good understanding of actual physical model gives wrong results.

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