A NEW PARAMETER IDENTIFICATION METHOD FOR INDUCTION MACHINES

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Abstract

The present paper describes a new parameter identification method for induction machines. This method requires only a start-up test during which speed as well as stator currents and voltages are measured. The processing of these quantities by an identification procedure allows the computation of the parameters of the equivalent circuits of different types of induction machines.

Keywords

Parameter identification, induction machine, optimization.

1 Introduction

The prediction of the behavior of rotating machines in steady-state or transient conditions by numerical simulation as well as the control of variable-speed drives need a precise knowledge of the parameters of the equivalent circuits of those machines.

Classical standard methods using several tests allow to obtain the parameters of the equivalent circuits of different types of induction machines with a relatively important time investment. The new method presented in this paper is based on a **single start-up test** and can be used for all types of induction machines.

A test-bench has been developed to realize the start-up test and the measurements of different quantities: stator voltages and currents, power factor, rotor speed and electromagnetic torque.

An identification procedure allows the computation of the parameters of the equivalent circuit with up to 3 rotor circuits. This procedure is based on an optimization method called 'gradient method'. The definition of an objective function J permits to obtain a mathematical expression which characterizes the quality of the identified parameters.

The choice of the number of rotor circuits permits the modeling of different types of induction machines such as double-cage or deep-bar machines in which skin effect is important.

2 Start-up test

The equivalent circuit-diagram of an induction machine is represented in figure 1. The number of the considered rotor circuits depends on the type of the induction machine. It is equal to 1 for wound rotor types, and to 2 or 3 for squirrel-cage or double cage types, in order to consider the skin effect.

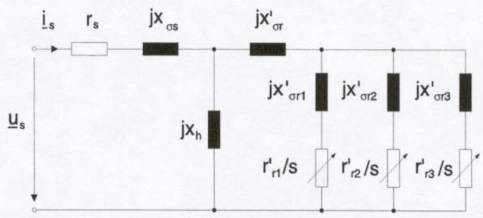

Fig 1 *Equivalent circuit-diagram of an induction machine with 3 rotor circuits.*

In steady-state conditions, one has:

$$\underline{Z} = \underline{U} \cdot \underline{I} \tag{1}$$

$\underline{Z}$ represents the total phase impedance of the machine. The number of parameters to determine depends on the number of rotor circuits. During a start-up test the speed, the stator voltages, the currents, the torque, and the power factor are stored. In order to remain in steady-state conditions, the starting time may be increased by supplying the stator with reduced voltages, and, if necessary, by increasing the inertia of the rotor with a flywheel.

By writing equation (1) for different speeds or slips during the start-up test, one obtains an equation system which permits to identify the parameters of the equivalent circuit-diagram.

3 Description of the test-bench

The following elements are used in the experimental setup (see figure 2):

- induction machine
- device for data acquisition and computation of the transient air-gap torque

- position sensor
- PC

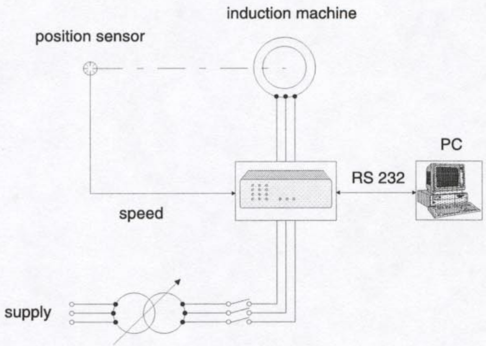

Fig 2 *Test-bench*

The main element of the test-bench is the data acquisition and processing system. It contains three acquisition cards for voltages and currents [2, 3], a calculation unit with a DSP and a memory card (Figure 3). The calculated values as well as the speed are stored on the memory card. An algorithm implemented in the DSP calculates in real time the effective values of the armature currents and voltages as well as the power factor of the three phases.

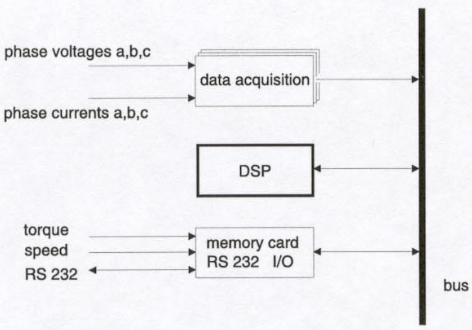

Fig 3

The instantaneous values of the phase currents and voltages are sampled at a frequency of 100 kHz and transferred to the DSP, which transforms the phase values into Park values and calculates the air-gap torque [4].

An optical absolute sensor using the Gray code permits to calculate the speed.

4 Measurement procedure

Once a constant voltage is applied at the terminals of the induction machine the data acquisition and processing unit starts working. The effective values of the voltages and the currents, the power factor and the electromagnetic torque are calculated in real time and stored on the memory board. Once the starting-up is finished, the DSP writes the data to the PC and the identification procedure starts.

5 Description of the identification procedure

The identification procedure allows the computation of the equivalent circuits with up to 3 rotor circuits. This procedure is based on an iterative optimization method called 'gradient method' [5]. The definition of an objective function J permits to obtain a mathematical expression which characterizes the quality of the identified parameters.

The identification procedure has been developed with MATLAB. This guarantees a good compatibility between different systems (Windows, Mac OS, UNIX).

All calculations are made in per unit *[p.u.]*. The impedance of the machine may be expressed in per unit as:

$$\underline{i}_{model} = \underline{z}_{model}^{-1} \cdot \underline{u} \tag{2}$$

The electromagnetic torque $t_{em,model}$ of an induction machine is proportional to the i^2r losses in the rotor and is given in per unit by:

$$t_{em,\,model} = \frac{P_{cu,\,r}}{s} \tag{3}$$

The optimization algorithm is shown in figure 4.

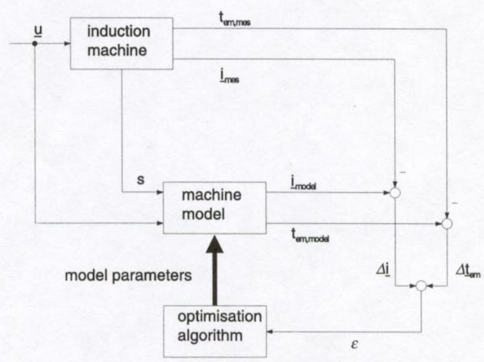

Fig 4 *Scheme of the algorithm of optimization.*

The problem is to find a set of parameters of the equivalent circuit (put together in a vector $\underline{\theta}$) which minimize, for the whole range of speed, the differences $|\Delta \underline{i}|$ and $|\Delta \underline{t}_{em}|$. The objective function J depends on the set of parameters $\underline{\theta}$, the slip s, the applied voltage $\underline{u}$, the measured current $\underline{i}_{mes}$ and the measured torque $t_{em,mes}$. One has:

$$J(\underline{\theta}, s, \underline{u}, \underline{i}_{mes}, t_{em,mes}) = \sum_s \varepsilon = \sum_s (|\Delta \underline{i}| + |\Delta \underline{t}_{em}|) \quad (4)$$

The identification procedure described above leads to an equivalent circuit diagram which takes into account the skin effect as well as the saturation effects relative to the leakage and magnetizing reactances during the start-up test. The influence of the saturation effect on the magnetizing reactance is obtained by a no-load test released automatically after the start-up test.

The parameters of the equivalent circuit are submitted to constraints. Therefore, it is possible to fix lower and upper limits for the variation range of these parameters.

For each type of induction machines initial values are defined by default. Nevertheless, the user can modify these initial values. For example the stator resistor, which can be measured manually, can be introduced. The initial values allow the identification procedure to converge faster to an acceptable solution. It is also possible to define constraints, e.g. that the leakage inductance in the first rotor circuit has to have a higher value than the one in the second rotor circuit.

A graphical interface allows the user to introduce all the parameters needed for the identification parameters: number of the rotor circuits, the constraints, the initial values of the parameters and curves to display.

6 Examples of applications

In order to show the possibilities and the advantages of this approach, tests on three machines of different types and power are presented in Table 1.

type	wound rotor motor 1	double cage motor 2	deep bars motor 3
connection	Y	Y	Y
rated voltage U_n *[V]*	220/380	220/380	220/380
rated current I_n *[V]*	8.7/5	11.9/6.9	63/36.5
rated active power P_n *[V]*	2200	2200	18500
rated speed n_n *[rpm]*	1405	1435	1460
rated frequency *[Hz]*	50	50	50
power factor $cos\varphi_n$ *[1]*	0.8	0.79	0.85

Table 1 Characteristics of tested machines

6.1 Wound rotor type induction machine

A wound rotor type induction motor is used for this example (see table 1 motor 1). In this case, the geometrical locus of the current calculated from the equivalent circuit diagram for the applied voltage is represented by a semicircle. Figure 5 shows a very good agreement between measured and calculated values.

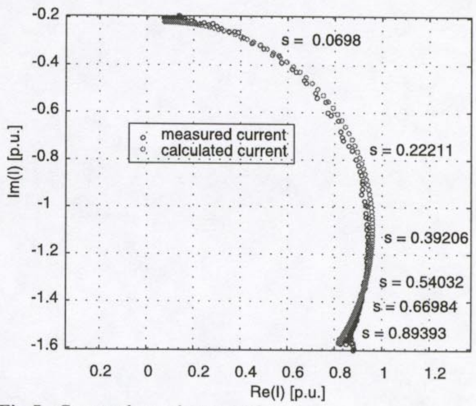

Fig 5 *Current locus for motor1.*

Figure 6 shows that the calculated torque is slightly higher than the measured one. The maximal relative difference between the values of the torque is $\Delta = 8\%$, and it is lower than $\Delta = 4\%$ for the other points.

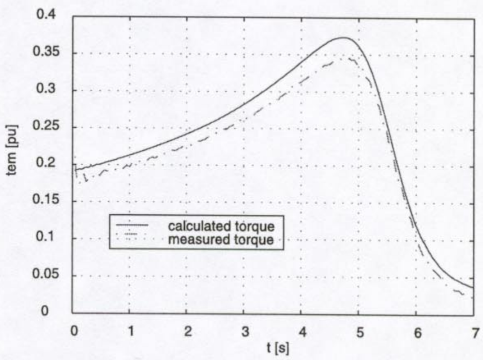

Fig 6 *Measured and calculated torque for motor 1.*

6.2 Double cage induction machine

For the second example a double cage induction machine is used (see table1 motor 2). The equivalent circuit diagram is constituted by 2 rotor circuits. The skin effect is important for this type of machine for slip values close to 1. Consequently, the geometrical locus of the current is no more represented by a semicircle, but by a part of circle for high values of slips (upper than 0.4).

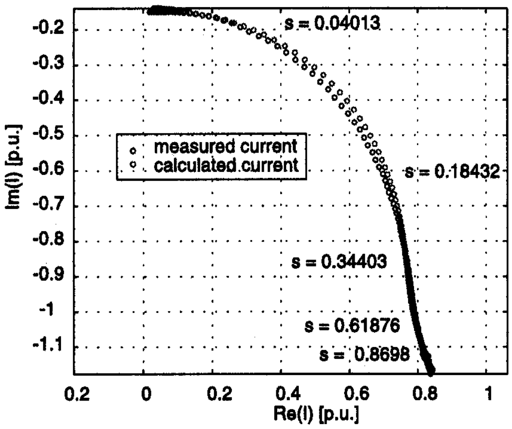

Fig 7 *Current locus for motor2.*

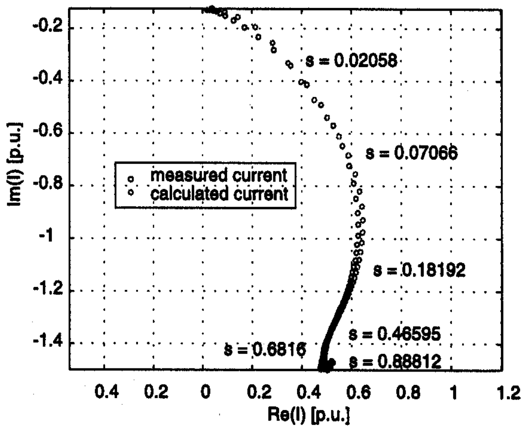

Fig 9 *Current locus for motor3.*

Figure 7 represents the loci of the calculated and measured currents. The maximal relative difference between measured and calculated torques is Δ = *8%* (see figure 8).

Figures 9 and 10 represent respectively the loci of calculated and measured currents, and torques. The relative difference between maximal values of the torque is Δ = *9%*.

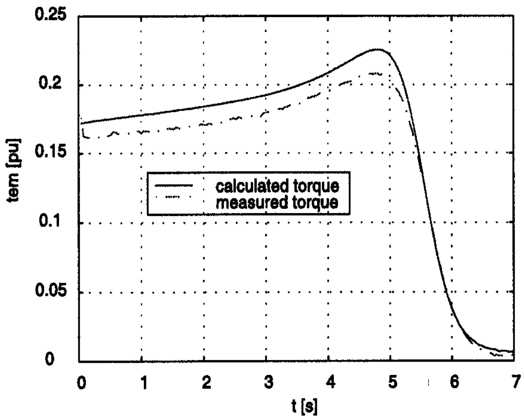

Fig 8 *Measured and calculated torque for motor 2.*

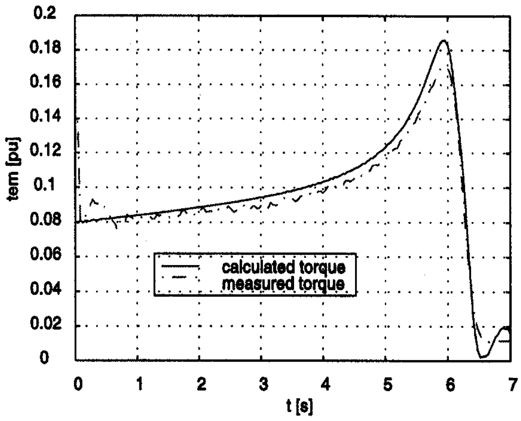

Fig 10 *Measured and calculated torque for motor 3.*

6.3 Deep bar induction machine

To validate the method also for larger machines, the third motor of table 1 has been utilized for this example. The skin effect is also important in this case. A modeling of the rotor with 2 circuits did not lead to good results. For this reason we use a rotor model with 3 rotor circuits.

6.4 Induction motor fed by a frequency converter

The elements of the equivalent circuit (obtained in the described way) can be used to simulate the machine in different operating conditions. Figures 11,12 and 13 show the simulation results for motor 3 at constant load [7]. The machine is fed by a frequency converter (see figure 17).

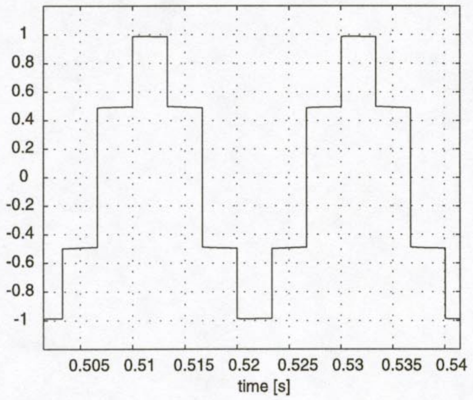

Fig 11 *Simulated phase voltage.*

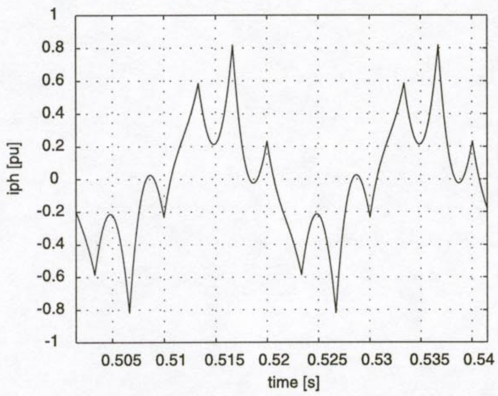

Fig 12 *Simulated phase current.*

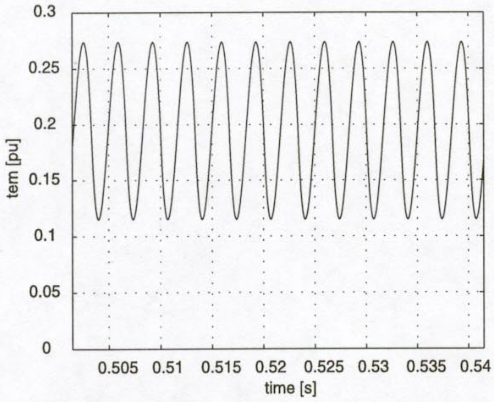

Fig 13 *Simulated torque.*

Figures 14, 15 and 16 show the measured voltage, current and torque for the same steady-state operating point at constant load.

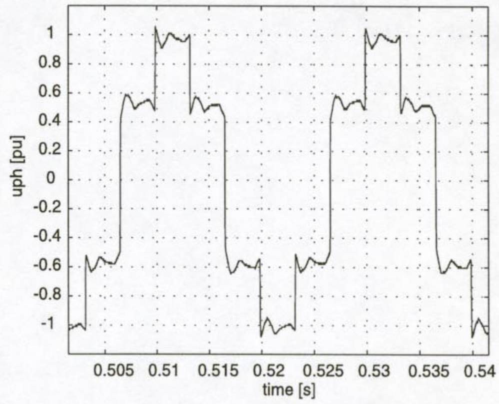

Fig 14 *Measured phase voltage.*

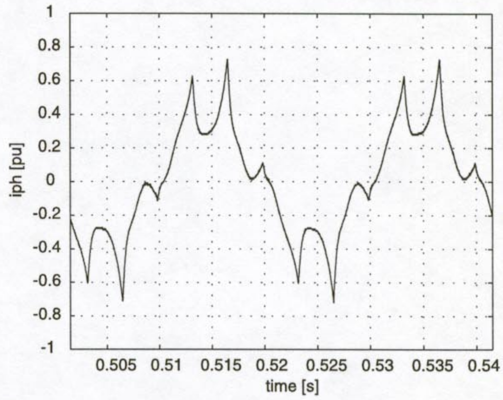

Fig 15 *Measured phase current.*

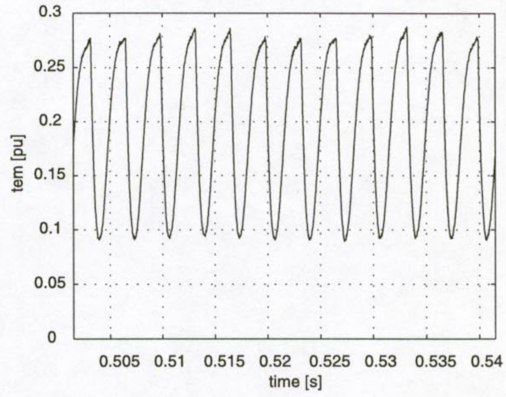

Fig 16 *Measured torque.*

The simulation results and the measured values are in good agreement and confirm the validity of the identified elements of the equivalent circuit.

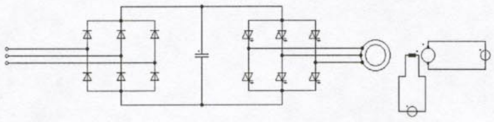

Fig 17 *Induction machine fed by frequency converter.*

7 Conclusions

The method presented in this paper for the determination of the parameters of the equivalent circuits is based on a **single start-up test** and can be used for all types of induction machines.

A test-bench has been developed to realize the start-up test and make the measurements of the different quantities: stator voltages and currents, power factor, rotor speed and electromagnetic torque.

In order to show the advantages of this method, three examples are presented. The equivalent circuits of wound-rotor, double-cage and deep-bar induction machines with different rated powers are identified.

A system composed of a supply, a voltage inverter, an induction machine and an electrical load has been simulated. The results of this simulation are compared to direct measurements of this system in order to show the accuracy of the identified parameters.

The developed test-bench and the identification procedure allows the **automatic and fast** determination of the parameters of the equivalent circuits of induction machines.

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