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Adaptive Identification of Induction Drive

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***Abstract*—Because not well known exact parameters of induction motor, on this production used different materials and their nonlinearity the simulation and experimental results differs. Experimental measurements of induction drive are performed. Drive parameters measurements methods are observed. Adaptive identification model including algorithm, comparison of simulated and experimental results is created and presented.**

***Index Terms*—Variable speed drives, DC machines, adaptive algorithm, power system simulation.**

I. INTRODUCTION

In the industry an electrical drive is one of the most important and responsive elements. From all of the electrical drives mostly used are the induction drives. Those drives are mainly used in the some production lines; in the fire extinguishing systems (for ex. automated valves) and the other equipment where the controlled motion is required. In many cases inexpensive drives can be used, whose durability is not so important, but in some critical cases it can impact all processes or other people lives and health. Similar important places and mechanisms like a “bottle neck” in technology need very reliable drives to save money and reduce production costs. Therefore diagnostic online remains the main aim in exploitation of these drives.

The paper discusses problem how to find changes in the drive as soon as possible it deals with identification of electric drive. If it is possible to identify an operating drive, for example, in its control of frequency converter, then it is possible to create its programmable model in it and afterwards, when drive is in use, measure and compare currents and voltages of real drive with those of model and get some information from a real drive about its torque and rotational speed. Those parameters can identify some problems with bearings, vibrations, bandages, short-circuited windings or cause of overheating. Secondly, this information is very important in diagnostics of electrical drives. From diagnostic history results engineers can get a lot of data to generate some solutions before something has happened with the drive and prepare to repair it when is possible or manipulate with an operating drive (for example, to change speed, to go away from resonance frequencies) and avoid the consequences. This can save a lot of money for companies in maintenance and availability in “bottle neck” machinery [1]–[5].

The resistance and inductance of the stator can be acquired from simple measurements, currents and voltages feed into drive and with sensor possible to read torque and speed. As it is known, elaborating of the induction drive model requires values of rotor resistance, its leakage inductance and mutual inductance of stator and rotor windings. It is possible to get some data from a data plate on a drive – moment of inertia, number of pole pairs, rated current, power, rated speed and others.

Some parameters are not linear and at the motor starting they change in real motor, but it is difficult to implement this phenomenon in the model. If measured parameters are entered to the model of the drive, the output signals of this model will differ from the real measurements.

In real drive the rotor and stator resistance are not linear and change with temperature of the motor. Some non-linearity’s are seen at the drive speed or load (on transients) changing.

II. DRIVE IDENTIFICATION TESTS

A. Direct Current (DC) Test

The DC test is performed to compute the stator winding resistance R_1. A DC voltage is applied to the stator windings of an induction motor. The resulting current flowing across the stator windings is a dc current; thus, no voltage is induced in the rotor circuit, and the motor reactance is zero. The stator resistance is the only circuit parameter limiting current flow. A 230 V DC power source is applied to the two phases of a Y-connected induction motor. A load is installed in the circuit as a resistive load in order to adjust DC current to the rated value. The current in the stator windings I_{dc} and voltage across the two phases of the motor V_{dc} are measured.

The stator resistance obtained from the DC test is an approximate value of the actual one since the skin effect observed when an AC voltage is applied to the stator windings and temperature effects are not taken into consideration. However, this approximation is reasonable enough for teaching purposes.

B. No-Load Test

The no-load test on an induction motor is conducted to measure the rotational losses of the motor and to determine some of its equivalent circuit parameters. In this test, a rated, balanced AC voltage at a rated frequency is applied to the stator while it is running at no load, and input power, voltage, and phase currents are measured at the no-load

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condition. Fig. 4 illustrates the experimental setup of the conducted no-load test. Where a three-phase balanced Y-connected ac source whose per-phase voltage is 230 V/50 Hz is applied to the stator terminal of the induction motor.

The measurements enable to approximate computation of the sum of the magnetizing reactance X_M and the stator leakage reactance X_l as follows [3]:

$$\left|Z_{n.load}\right| = \frac{V_f}{I_f} \approx X_l + X_m, \tag{1}$$

$$\left|Z_{n.load}\right| = X_l + X_M = \frac{Q_a}{I_f^2}, \tag{2}$$

where V_f is the per-phase voltage $V_f,= V_a = V_b = V_c$. Q_a is reactive power measured in the phase A, and I_f is the measured average phase current $I_f= (I_a + I_b + I_c)/3$. Using measured input power and the stator resistance obtained from the DC test, rotational losses of the motor given by the sum of the friction, ventilation and core losses can be found, as follows

$$P_{rot} = 3P_a - 3I_f^2 R_1. \tag{3}$$

C. *Locked-Rotor Test*

The locked-rotor test on an induction motor is performed in order to determine some of its equivalent circuit parameters. In this test, the rotor of the induction motor is locked, and a reduced voltage is applied to the stator terminals so that the rated current flows in the stator windings. The input power, voltage, and current are measured. For some design-class induction motors, this test is conducted under a test frequency, usually less than the normal operating frequency so as to evaluate the rotor resistance appropriately [3]. The experimental setup of the locked-rotor test is similar to that of the no-load test the only difference is that a synchronous generator coupled with a dc motor and auto transformer were installed in the circuit in order to perform the locked-rotor test at various frequencies and to control input voltage to the stator.

The measurement data from the locked rotor test enables one to determine approximately the locked-rotor resistance and reactance at the test frequency

$$\left|Z_{l.r.}\right| = R_{l.r.} + jX'_{l.r.} = \frac{V_a}{I_f}, \tag{4}$$

where $R_{l.r.}$ is the locked-rotor resistance and $X'_{l.r.}$ is the locked-rotor reactance at the test frequency [3]:

$$R_{l.r.} = \frac{P_a}{I_f^2}, \tag{5}$$

$$X'_{l.r.} = X'_1 + X'_2 = \sqrt{\left|Z_{l.r.}\right|^2 - R_{l.r.}^2}\ , \tag{6}$$

$$X'_{l.r.} = X'_1 + X'_2 = \frac{Q_a}{I_f^2}. \tag{7}$$

If the test frequency is different from the rated frequency, one of those can compute the total equivalent reactance at the normal operating frequency as follows since the reactance is directly proportional to the frequency

$$X_{l.r.} = \frac{f_{rated}}{f_{test}} X'_{l.r.} = X'_1 + X'_2. \tag{8}$$

When the three tests are completed, equivalent circuit parameters can easily be computed:

1) The stator resistance R_1 is directly computed from the DC test;

2) The no-load test gives the sum of the magnetizing reactance X_M and the stator leakage reactance X_1;

3) The locked-rotor test gives sum of the stator and rotor leakage ractances.

One needs to refer to test codes to find out the empirical proportions for stator and leakage reactance given for three-phase induction motors by class [3], [5]. When the classification of the motor is not known, one assumes that $X_1=X_2=0{,}5X_{l.r.}$.

The magnetization reactance X_M can now be evaluated using (1) and (2), as follows

$$X_M = Z_{n.load} - X_1. \tag{9}$$

As for the rotor resistance R_2, a better approximation is required since it has a more significant effect on the motor performance when compared with the other circuit parameters. Using the equivalent circuit under locked-rotor condition, the following expression achieves the desired approximation [4]

$$R_2 = \left(R_{b.r.} - R_1\right)\left[\frac{X_2 + X_M}{X_M}\right]^2. \tag{10}$$

III. EXPERIMENTAL INVESTIGATION

Two induction motors coupled with one shaft like shown into Fig. 1 were tested experimentally. Parameters of only one of those motors were measured. For current and speed measurements the power analyzer was used and for speed and torque measurements digital oscilloscope was used. All gathered data are transferred to Matlab. Matlab standard model of induction drive was used to simulate a mathematical model. A comparison of model simulation results with experimental ones is shown in Fig. 4.

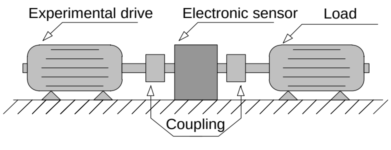

Fig. 1. System block diagram.

Simulation results indicate clearly the speed error between real model and the simulated. Therefore similar model hardly can be used in the diagnostic and monitoring processes.

In order to find correct value of the drive parameters we need to adapt model characteristics to the real measurements.

Some measured induction drive parameters from datasheet or data plate.

IV. ALGORITHM OF ADAPTIVE IDENTIFICATION

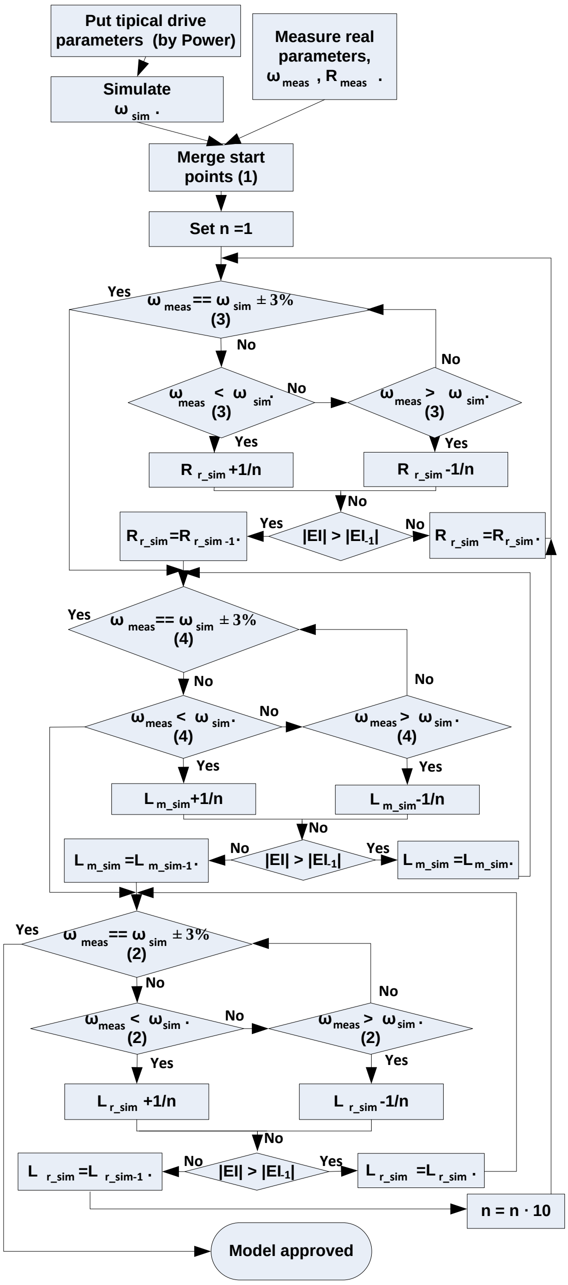

Fig. 2. Algorithm of adaptive simulation: here: *ω* – speed; *L* – inductance; *R* – resistance; *n* – variable; Index *-1* – mean what it is previous simulation value; Index *sim* – mean what it is simulated value; Index *meas* – mean what it is measured value.

Algorithm of adaptive simulation is shown in Fig. 2.

Elaborated algorithm needs to enter motor power, phase number and frequency and inertia moment (the other parameters set default for the first simulation). The first start of real drive is made with no load (if somebody is coupled to the drive it needs to sum approximately of inertia moments). Speed transient of starting is measured and recorded into the analyzing system. Number of pole pairs can be calculated from steady state speed. The stator windings reactance is measured and its average value is entered into simulation model. Model for adaptive identification is prepared.

After the first simulation is done, the program starts to compare transients of real measurements and simulation results at 4 main points. The first selected point (1) (shown in the Fig. 3) needs to set constant n to 1. In this way the numbers of digits after coma one after another are checked to select required value of parameter. After that the first comparison is done at the point (3) and ±3 % error is permissible because of measurement noises (it can be set less if measurement is done with sensors of higher quality). If transient's error is greater than ±3 % then it is necessary to check is the simulated ω_{sim} greater or smaller than measured one. Depending on the answer coefficient R_{r_sim} is increased or reduced. Afterwards checked errors in the third point gives information about simulation $error_{sim}$: is it smaller comparing with the simulation, which was done before ($error_{sim-1}$). If error is not greater in this point than error of calculation done before, then sum/integral of errors is checked. If integrated error *EI* module is greater than integrated error EI_{-1} of simulation done before then its mean that R_{r_sim} matches better model, which was calculated before with R_{r_sim-1} and it is used in further calculations. If not, then the cycle is repeated.

Next three cycles are similar just mutual inductance L_m and rotor inductances L_r are calculated. Sometimes if stator inductance L_s is not entered it can be calculated in the same way.

V. EXPERIMENT INVESTIGATION

First of all it is needed to enter into model as many known parameters as it is possible. Matlab allows possibility of choosing just the motor power. Using the entered power, number of phases and the number of pole pairs (it can be calculated from measured speed) it is possible to choose typical drive parameters (from table) for the first simulation.

When the simulated speed response is obtained it is possible to compare it with measured one. For comparison some points, shown in Fig. 3 were used.

After that model parameters were changed using an elaborated algorithm of matching parameters. It was assumed algorithm variable parameters are those that are not manually entered into the model. In the most cases algorithm variables are mutual induction L_m, rotor inductance L_r and rotor resistance R_r. Since the right parameters are chosen to fit in asked frames (impossible to fit in 100% because always will by some disturbances in the measured signal) it is possible to improve the model by using integration of simulated models errors. For simulated model comparison used integration of error *IE* (or possible to sum all errors IE_{mp} – useful for microprocessors) and on the end of transient just chose model with close to the zero.

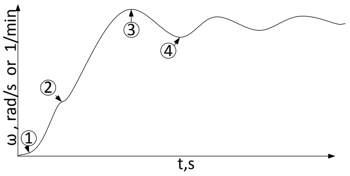

Fig. 3. Speeds comparison points.

$$error = \frac{(\omega_{meas} - \omega_{sim}) \cdot 100}{\omega_s}, \tag{11}$$

$$IE = \int |error|, \tag{12}$$

$$IE_{mp} = \sum |error|. \tag{13}$$

For this type of identification it is not so important to find real constructed motor parameters, but just to find parameters giving the model simulation results the same like a real drive results.

The experimental speed results their and comparison with adaptive simulation results are shown in Fig. 4.

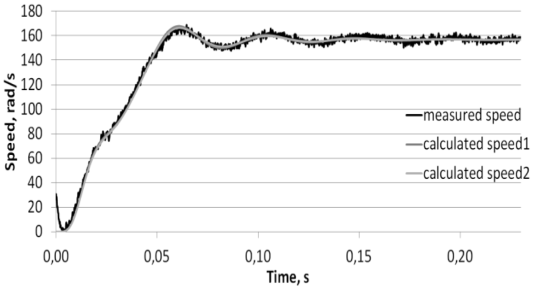

Fig. 4. Experimental measurements of speed in comparison with adaptive simulation

VI. CONCLUSIONS

Proposed adaptive identification system can be implemented in frequency controllers for protection of the drives and drive on-line monitoring.

Proposed type of identification best fits for simple models, because it finds not real parameters, but those which best match the current model.

This method can be implemented in microprocessor system by using a co-processor for a model calculation, when the main processor is used to store only typical drive parameters tables and parameters of an identification process.

At the initial stage of starting the speed error in real measurements is observed because of the stress on sensor. Because of that the comparison to second point (1) in Fig. 4 was used, but this greater peek is used to find starting point parameters of the motor.

Now and in the future all drives will come more efficient and in the same housing or with same parameters drives can have different dynamics of the transients, depending on materials used in production (such like ferromagnetic materials).

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