AN ACCURATE HIGH-FREQUENCY MODEL OF INDUCTION MOTOR

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Abstract. In this paper, an accurate high-frequency model of induction motor is presented. The proposed mode l allows analyzation at the same time both the high-frequency phenomena up to some megahertz due to the static supply and the low-frequency phenomena usually analyzed by means of the dq motor model.

Introduction. Electrical drives with PWM (Pulse Width Modulation) static power converters and induction motors are commonly used in a large number of industrial applications due to their interesting performances and flexibility. The effects of the high-frequency voltage components introduced by the PWM technique are usually neglected when the electromechanical performance of the motor are analyzed. On the contrary, the high dV/ dt applied to the motor introduce a non-negligible amount of high-frequency leakage currents, which flow through the stray distributed capacitance between the stator winding and the motor frame. Since the motor frame is usually connected to the ground by means of the ground circuit, the high-frequency leakage currents are present in the power mains and can cause electromagnetic interference. In the last years the problems due to the high frequency components and the related leakage currents have been analyzed by other researchers. In this paper, high-frequency model of induction motor is presented. In particular, the main goal of the present work is to show that a global model which allows us to consider at the same time the electrical machine's behaviors at high and low frequency has been found, and it can be useful for a wide spread of system analysis. The proposed high-frequency model is based on lumped parameters, and, connected to the classical dq model, it is accurate in the frequency range from a few hertz up to some megahertz, the model presented at picture 1. This kind of model avoids the use of distributed parameter, and consequently every network simulation program can be used without problems. In particular, in the present work good results have been obtained using Simulink MatLab programs [1].

Main part. Two main capacitive effects are involved in the high frequency phenomena:

1) winding to ground capacitance;
2) winding turn to turn capacitance.

It is obvious that both capacitances are inherently distributed, but, as previously mentioned, the proposed approach is based on lumped parameters. Figure 1 shows the high-frequency phase circuit used as first approach with the following lumped parameters:

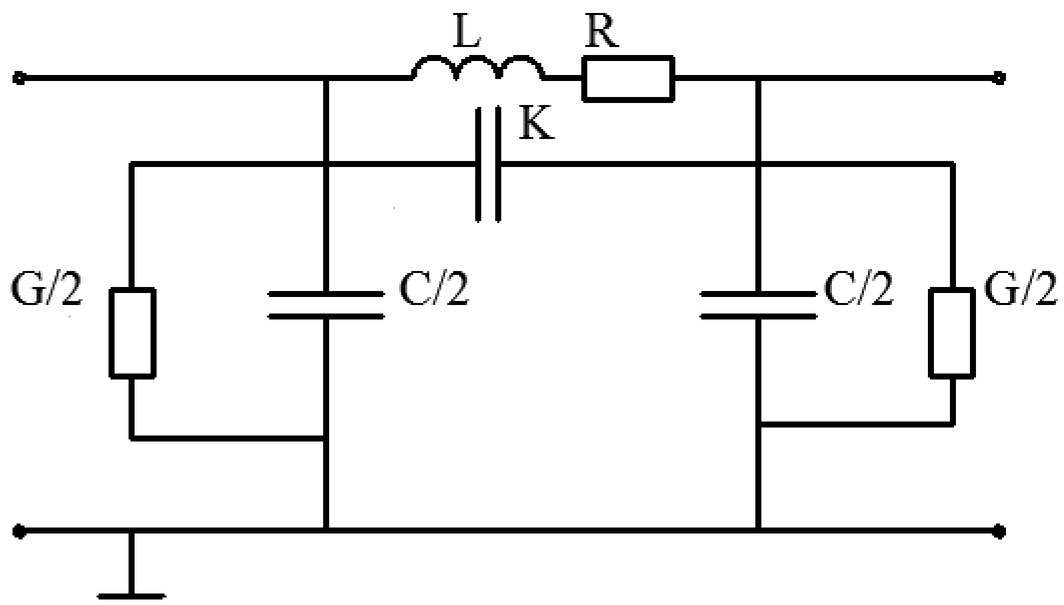

Figure 1 – Equivalent circuit with lumped parameters

R – stator and rotor phase resistance;

L – phase leakage inductance;

C – capacitance representing the turn-to-turn distributed capacitive coupling;

K – capacitance representing the winding-to-ground distributed capacitive coupling;

G – resistance representing eddy currents inside the magnetic core and the frame.

It is important to underline that al the values have to be considered as values referred to a single star-connected phase. The winding to ground-distributed capacitance has been represented by two lumped capacitances of the same value, the first one connected between the phase terminal and the ground, and the second one connected between the motor neutral and the ground. A motor star connection has been assumed, but a motor delta connection obviously does not change the model validity. The phase resistance R and the phase inductance L are the usual 50 / 60 Hz parameters obtained by the locked rotor test. As shown by the experimental results, the time-domain response of the motor is well damped. The typical values of the resistance R are too low to explain the observed damping [2].

An analysis of the physical phenomena leads to consider that the damping factor must be linked to the dissipated energy by the high-frequency eddy currents. As a consequence, a resistance R representing the eddy currents has to be connected in parallel with the leakage inductance. In order to characterize the motor in the high-frequency range, it is possible to evaluate the frequency response of the two impedances defined in Figure 2(a, b):

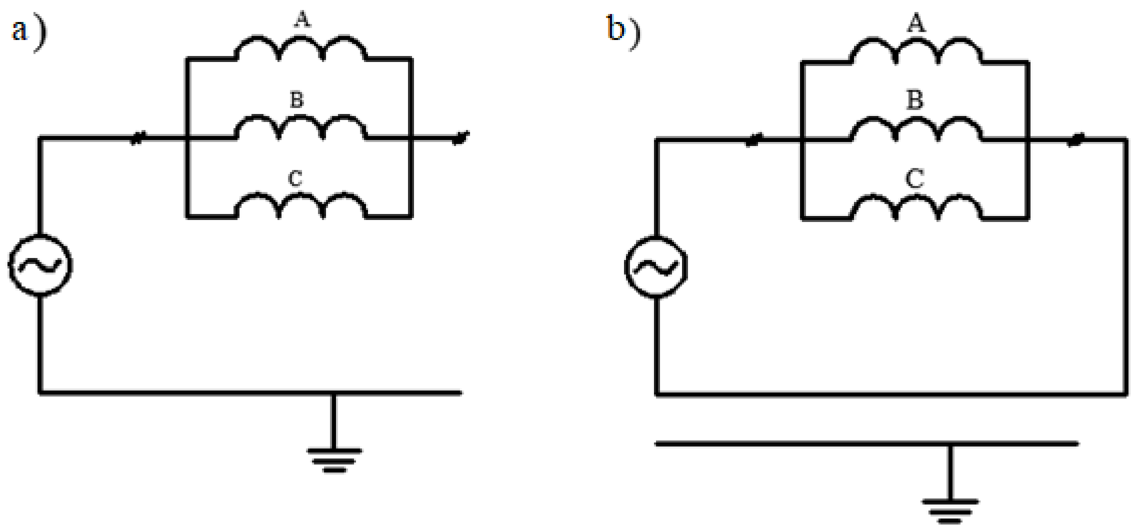

Figure 2 – Connections and impedances for the frequency analysis

- The impedance Zwn measured between the three phase terminals connected together and the motor neutral, with floating ground terminal (a).
- The impedance Zwg measured between the three phase terminals connected together and the ground terminal, with floating motor neutral (b).

Model Development and Experimental Results. In the considered frequency range, the phase resistance R is much smaller than the reactance of the leakage inductance Ld [3]. In the following considerations the stator resistance will be always neglected. The impedances of the circuit of Figure 2 (a, b) can be easily evaluated using simulation in Matlab. The following circuits, for simulation, are shown below.

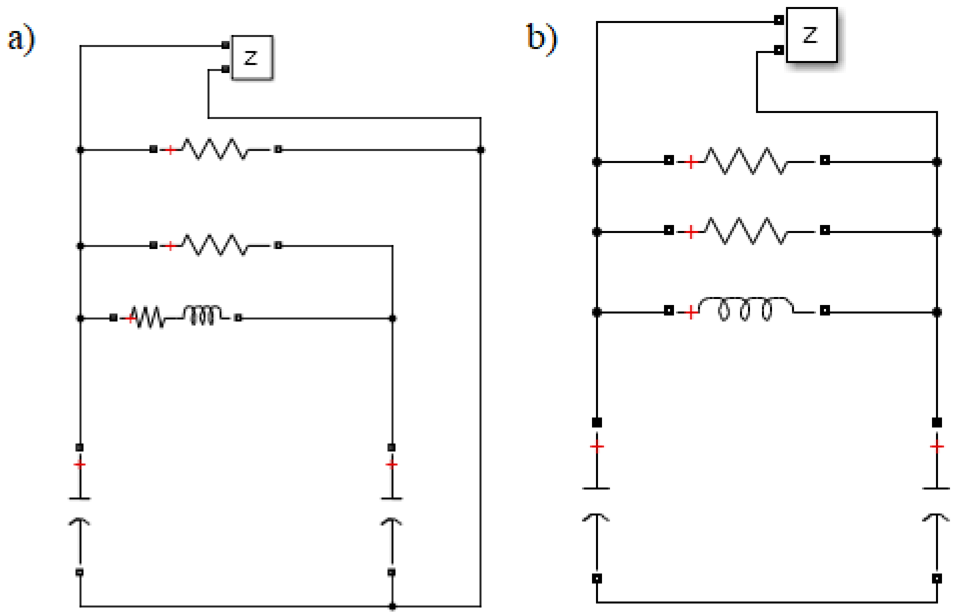

Figure 3 – Electrical circuits for Matlab: a) – impedance Zwn b) – impedance Zwg.

In Figure 4-5 the comparison between the simulation and experimental results on the frequency response of the impedance Zwn.

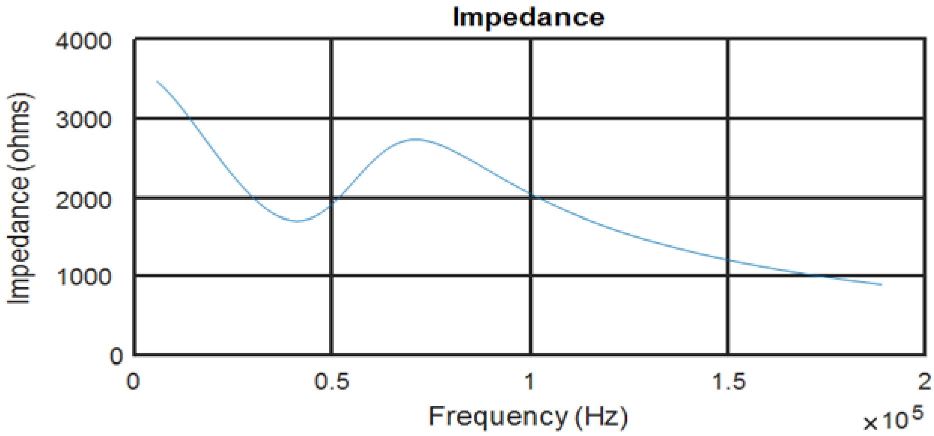

Figure 4 – Simulation results on the frequency response of the impedance Zwn using the skin effect parameters

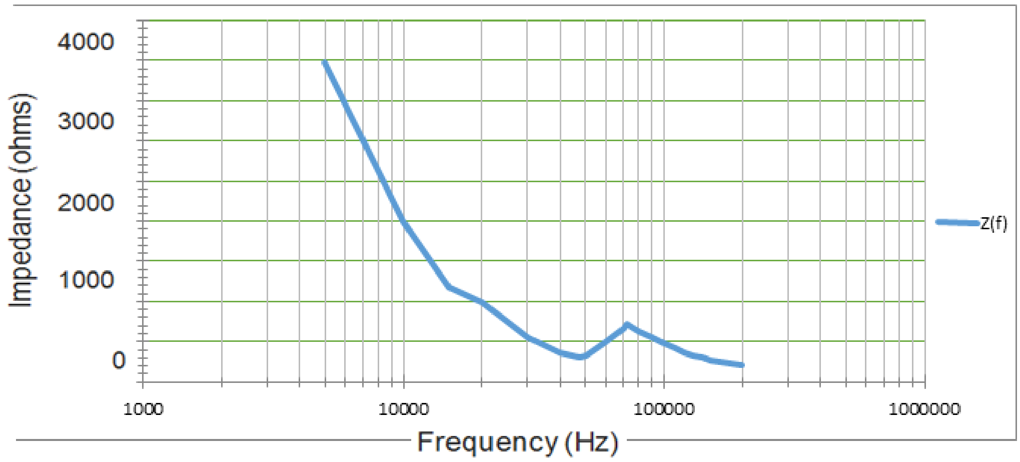

Figure 5 – Experimental results on the frequency response of the impedance Zwn using the skin effect parameters

Conclusions. In the paper a high-frequency model for induction motor based on lumped parameters has been proposed and a measure procedure to obtain model parameters has been identified. The experimental and the simulation results on motors of different size are in good agreement both in frequency and in time domain. The influence of magnetic saturation on model parameters has been deeply discussed [4]. The proposed high-frequency model can be added to the wel-known dq dynamic model, and it is possible to get a comprehensive model which allows the analysis of high- and low-frequency phenomena with standard simulation software.

References

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