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INDUCTION MOTOR EQUIVALENT CIRCUIT IDENTIFICATION FROM FINITE ELEMENT RESULTS

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Abstract – This paper describes a new method to identify the equivalent circuit parameters from finite element modelling. This new method will make it possible to split stator and rotor leakage inductances.

I. INTRODUCTION

The induction machines are more and more used in variable speed drives, like in electric cars (Tesla and Renault Twizi). In the industry as in France, 70% of the electric energy consumption is due to rotating machines [1], it highlights the importance of the speed variation to reduce losses and to adapt the machine to the load. Today, the electric machine is not considered alone, but as a part of a complex system like an electric car for instance. Co-simulation between system software and finite element software exists, but it can be time consuming. Co-simulation between system software using tables offers a good compromise between time and precision, but this method is not adapted for induction machines. Equivalent circuit is more suited for this kind of study. The classical equivalent circuit with grouped leakage inductances $N\phi$ can be determined with no-load and short circuit tests. Since the saturation is changing for each working load [2], [3], this circuit can be used only for the linear part the curve which gives the torque variation with speed. For the starting working point and the maximum torque, it is necessary to adapt the equivalent circuit parameters to the magnetic state of the machine for a given working load.

Method using FEM to extract equivalent parameters is already used in [2; 6] but, in some cases, the method seems to be laborious to setup and it allows to extract only for one working point. The proposed method has two points of originality. First, the used quantities can be extracted either from modelling or from measurements. The second interesting point is the splitting of stator and rotor leakage inductances. This separation is also used in [2] [6] using finite element computation and measurement but the method are heavy to apply.

In the following, the proposed method is described, as well as the used machine and the FEM model. The results obtained with the proposed method will be compared to the FEM results.

II. USED MACHINE AND FINITE ELEMENTS MODEL INFORMATIONS

The results presented in the paper concern to a 4 kW

induction machine. Its characteristics are: 230/400V - 15.3/8:8A - 1435 rpm - $p=2$ pole pairs – 36 stator slots and 28 rotor bars. The induction machine is modelled using the commercial software Flux® 2D. The computations are done in steady state AC application. As shown in figure 1, only one pole is taken into account in order to reduce time computation. The stator outer and inner radius are respectively 86 mm and 54.3 mm. The outer rotor radius is 53.85 mm. The used mesh contains 26735 of nodes. It is a 2nd order mesh.

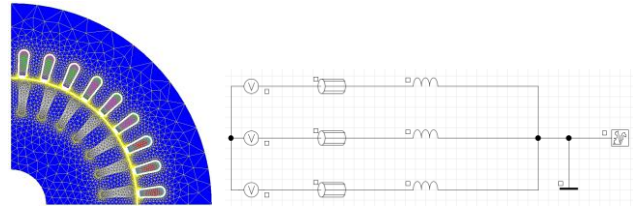


Fig.1. Meshed 2D geometry & Electric circuit

The used materials are M800-100A for stator and rotor lamination. Copper for stator winding and aluminium for rotor bars. There are 78 turns per stator phase whose resistance is 1.6 Ω , the stator end winding inductance is computed analytically and it is equal to 1.5 mH. Rotor end ring short circuit portion is computed analytically with Trickey formulas, the temperature is not variable according to the slip. The supply voltage is 230 V rms and the used circuit is given in figure 1.

III. IDENTIFICATION METHOD DESCRIPTION

A. Classical method

The determination of the equivalent circuit scheme 1 shown in figure 2 is based on no-load and short circuit tests. Table 1 gives measurement and modelling results of these two tests.

Test	Measurements		Flux 2D
	Measurements	Flux 2D	
No Load	U10 (V)	391	
	I10 (A)	5.7	6
	P10 (W)	436	261
	S10 (VA)	3860	4071
	Q10 (VAR)	3835	4063
Short circuit	Vcc (V)	35.57	
	Icc (A)	6.27	5.21
	Pcc (W)	307	215
	Sc (VA)	669	556
	Qcc (VAR)	594	513

Various reasons can explain the differences between measurements and modelling results, like the analytical computation of end winding inductance and end ring

impedance, the iron losses that are not taken into account during the solving process of Flux® 2D, ...etc. The finite element results will be taken into account as reference in this paper.

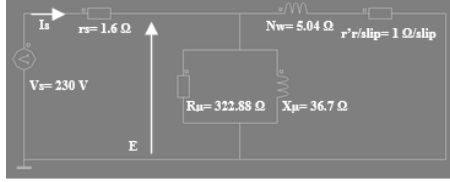


Fig.2. Scheme 1 – Equivalent circuit

B. Identification method description

The extracted results from FEM are the electromagnetic torque $\Gamma_{e,ref}$, the total consumed reactive power $Q_{tot,ref}$, the stator phase current $I_{s,ref}$. The magnetic flux computed from the integral of normal flux density component on a path in the air gap is called ϕ_{ref} .

The used equivalent circuit scheme 2 is shown in figure 3. This scheme allow us to split the stator and rotor leakage inductances. Since, in Flux® 2D, the iron losses are not taken into account during the solving and computed once the computation is achieved, the resistance R_{μ} is not represented in this circuit. The magnetisation voltage E_{ref} is computed from the magnetic flux ϕ_{ref} according to expression (1). The factor k is computed from the no load test.

$$E_{ref} = k \phi_{ref} \quad (1)$$

The factor “k” is computed from the no load test.

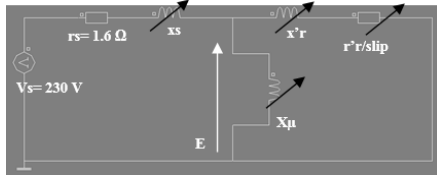


Fig.3. Scheme 2 - Used equivalent circuit for parameter identification

The parameters x_s , x_r' , r_r' and X_{μ} depends on the magnetic state of the machine. It means that, for each slip value, we will identify these parameters to minimize the difference between the FEM results and the analytical results. The constraints are:

$x_s \geq 0$ & $x_r' \geq 0$; $x_s + x_r' \leq N\omega$; $0 \leq X_{\mu} \leq 36.7$ and arbitrarily $0 \leq r_r' \leq 1.25 r_s$.

To answer the identification objective with the previous constraints, HyperStudy® is used to make identification by optimization. The optimisation is done for each slip value, which leads, in our case, to 15 iterations. For each iteration, we compare analytical computations with the scheme 2 to FEM computation of I_s , Q_{tot} , Γ_e and E .

C. Results comparison

Figure 4 shows the variation of the equivalent circuit parameters versus slip. Figure 5 shows the comparison between reference results from FEM computation and analytical computation with and variable equivalent circuit parameters found by identification method.



Fig.4. Equivalent circuit parameters variation versus slip

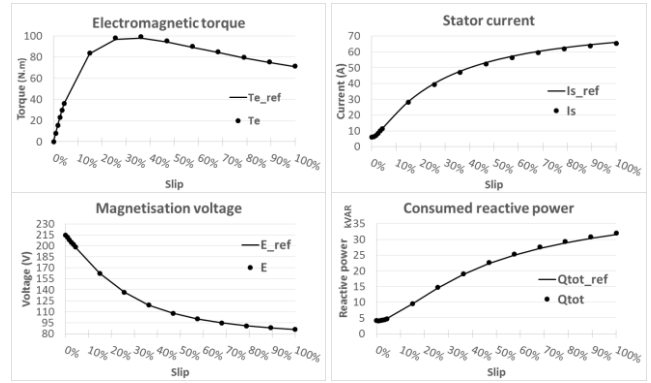


Fig.5. Comparison between reference results and analytical computation

IV. PERSPECTIVE AND CONCLUSION

In this paper, a new method to identify equivalent circuit parameters circuit of induction machine has been presented. This method allows to split leakage reactances and to take into account magnetic state of the machine with sufficient precision. This circuit can be used for system analysis or for studying transient behaviour of induction machines, especially high power machines. Future work will consist in using this method to extract the parameters versus frequency and voltage supply, by the way a 3D matrices to cover all the working loads can be obtained.

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