PARAMETER ESTIMATION OF A SYNCHRONOUS MACHINE BY MEANS OF LabVIEW ENVIRONMENT

***Szabó L.*[1] *- Biró K.Á.*[2] *- Barz V.*[3] *- Hedeşiu H.C.*[1]**

[1]Lecturer, Ph.D., [2]Professor, Ph.D., [3]Ph.D. student
Technical University of Cluj, Electrical Machines Department
P.O. Box 358, 3400 CLUJ, Romania
E-mail: Lorand.Szabo@mae.utcluj.ro

1. INTRODUCTION

Synchronous machines are frequently used both as generators and motors. Synchronous generators, the most popular energy conversion devices, produce virtually all the electrical energy used in the world. The synchronous motors are also widely used in various industrial drive systems not only for their energy saving possibilities, but also for their high control performances.

The classical 3-phase synchronous machine typically consists of the stator, a stack of laminated ferromagnetic core with internal slots, having distributed three-phase winding placed in the core slots. The turns of the stator windings are equally distributed over pole-pairs, and the phase axes are 120 electrical degrees apart. The cross-section shape of the rotor can be salient or cylindrical. On the rotor are placed the field winding and one or more equivalent rotor body (damper) windings. The d.c. excitation to the field winding can be supplied through a pair of insulated slip rings mounted on the rotor shaft. An outer framework completes the machine's structure with end shields and bearing for the rotor shaft. Although this construction is relatively more expensive than that of induction machines, the higher efficiency of synchronous machines is an advantage especially at higher power rating.

Knowledge of the synchronous machine’s parameters is essential in many fields, as in designing a control algorithm, in automated fault diagnosis or in precise simulations [1]. The most common parameters required in such cases are the simplified model parameters: stator winding resistance (R_S), d-axis reactance (X_d) and transient reactance (X'_d), q-axis reactance (X_d) and transient reactance (X'_q)

Several papers have been published that study different techniques used to estimate the parameters of synchronous machines. One of these estimation methods consists of fixing the rotor of the machine in a specific position, applying a simple d.c. voltage source and evaluating the parameters using experimental techniques. This method is called standstill time-domain test or d.c. decay test [2, 3].

A powerful test bench was utilised in order to carry out the necessary measurements. A virtual instrument (VI) was created in LabView environment in order to process and analyze the acquired data from the transducers.

The measured current variations were approximated by a sum of four exponential components. Using the parameters of these exponential components and the stator resistance determined by the classical A-V method the synchronous reactances of the machine in study were computed.

The results are perfectly in accordance with the theoretical expectations and with some results of an earlier made slip test. The results were validated also by means of simulation of the synchronous machine.

2. TEST BENCH

The experimental measurements were made on an intelligent test bench (see Fig. 1).

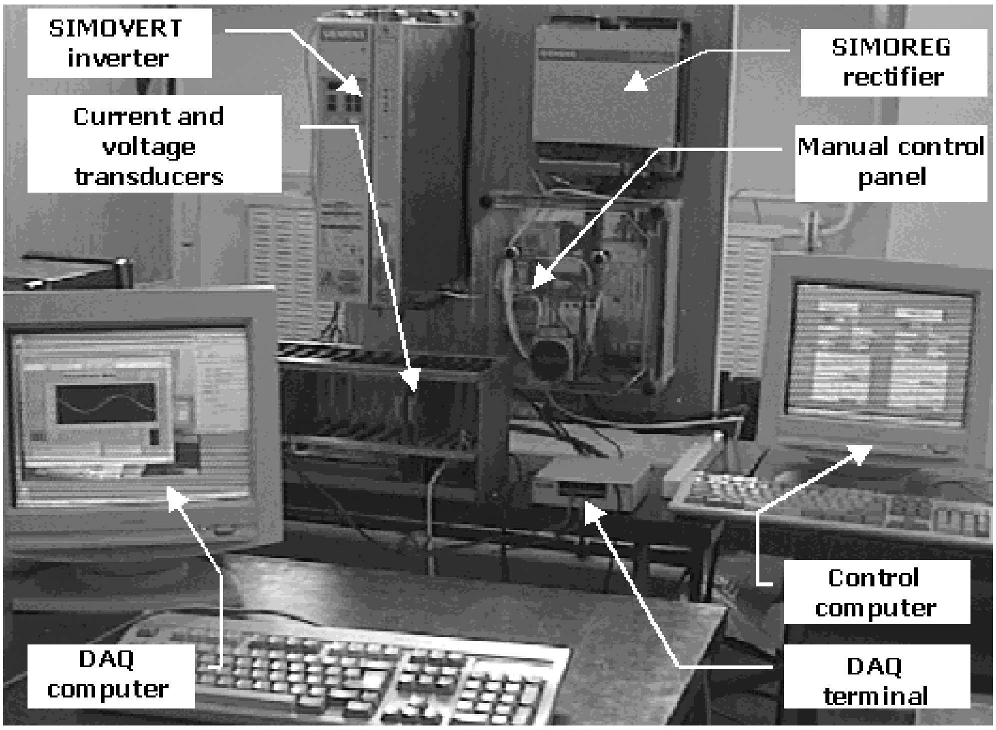


Fig. 1. The test bench

The mechanical part (not shown in figure) of the bench consists of two mechanically coupled electric motors, a PC computer controlled rectifier (SIMOREG) fed d.c. motor for breaking and loading purposes and the motor to be tested, supplied from a PC controlled SIMOVERT frequency converter. SIMOREG and SIMOVERT are products of Siemens.

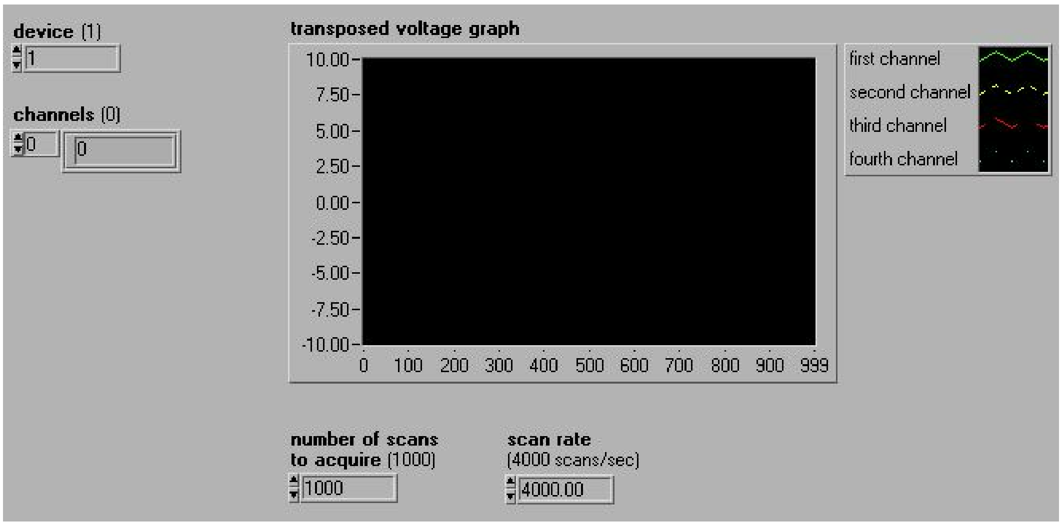
Several sensors measure parameters such as voltage, current, speed or angular incremental position and torque in order to give signals to the data acquisition unit.

The measurement part of the bench consists of a usual Pentium processor based PC having a National Instruments PCI-MIO-16E-1 type acquisition board [4]. This delivers high performance and reliable data acquisition capabilities, having 1.25 MS/s sampling rate, 16 single-ended analog inputs. It features both analog and digital triggering capability, as well as two 12-bit analog outputs, two 24-bit, 20 MHz counter/timers and eight digital I/O lines.

The electrical signals generated by the transducers must be optimized for the input range of the DAQ board. The SCXI signal conditioning accessory amplifies the low-level signals, and then isolates and filters them for more accurate measurements.

Several programs written in LabVIEW 5.3 coordinate all the data acquisition and the test measurement processes. This is a powerful graphical programming development for data acquisition and control, data analysis, and data presentation. LabVIEW gives the flexibility of a powerful programming language without the associated difficulty and complexity because its graphical programming methodology is inherently intuitive to the users. The LabVIEW programs are simply made by assembling using drag-and-drop methods software objects called virtual instruments (VIs) [5].

The virtual instrument created for the purpose of processing and analyzing the acquired data from the test bench is easy to use and flexible. The front panel user interface elaborated (shown in Fig. 2a) assures an interactive control of the entire acquisition software. The assembled block diagram presented in Fig. 2b ensures its functionality. The acquired data are stored in simple ASCII-type text files in order to be easy imported in any other program.

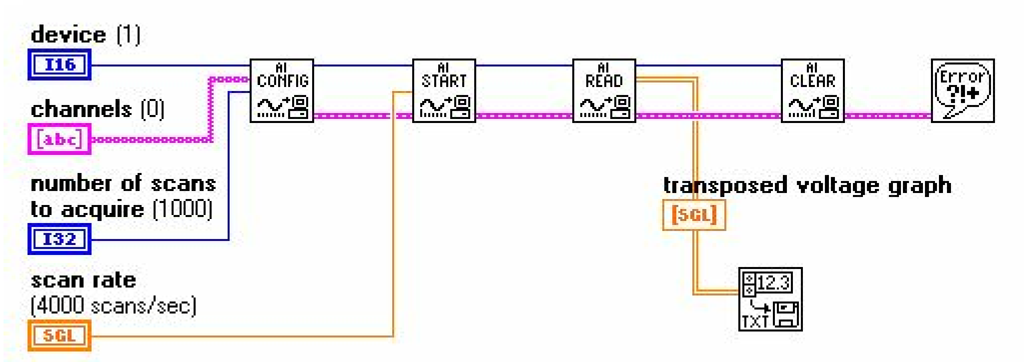

device (1): 1

channels (0): 0, 0

number of scans to acquire (1000): 1000

scan rate (4000 scans/sec): 4000.00

a) The front panel



b) The block diagram

Fig. 2. The data acquisition program

The program provides a powerful interface between the operator who co-ordinates the tests and the test bench because it can be manipulated easy and simply.

3. TEST SETUP

The test setup composed for identifying the synchronous machine's parameters is presented in Fig. 3.

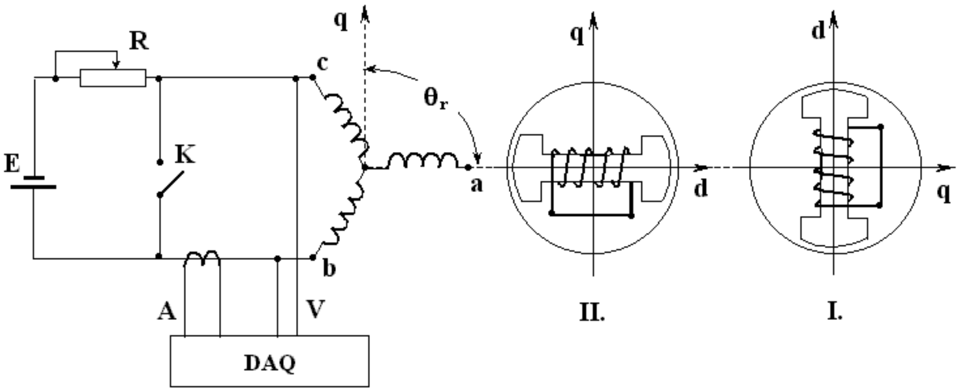


Fig. 3. The test setup

The test setup beside the investigated machine (a 4.5 kW ASEA synchronous machine) consists of a very well filtered d.c. voltage source (E), an adjustable resistor (R) and a switch (K).

4. TEST RESULTS

The direct and quadrature positions (marked with II. and I. in Fig. 3) of the rotor must be determined first. For this the field winding must be short-circuited with an ammeter and on two of the stator winding terminals (*b* and *c*) a reduced a.c. voltage must be applied. When the rotor is in a direct position, the measured current in the rotor circuit is at maximum. When the ammeter indicates a very low voltage, it means that the rotor is in a quadrature position.

During the test the rotor must be in standstill in the required position. Its field winding will remain short-circuited. Two measurements will be carried out (for the direct position, respectively for the quadrature position). When the switch is switched on, a transient current can be observed like that presented in Fig. 4.

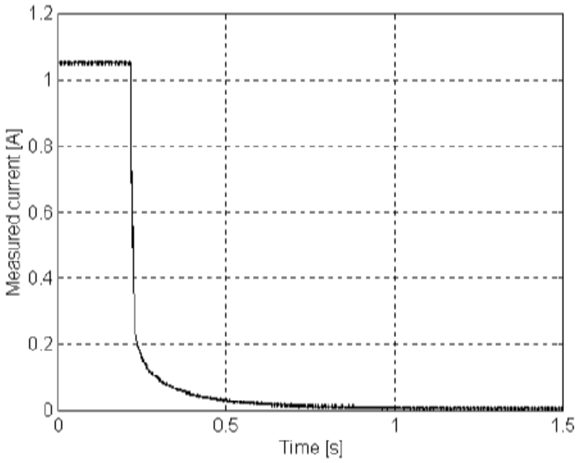


Fig. 4. The measured current

The stator winding resistance needed for the computation of the parameters is R_s=1.657 Ω, and it was obtained by applying the classical V-A method.

The variation of the measured current must be processed first. The moment of the switching must be detected first. After this the initial (I_0) and the remaining steady state (I_∞) values of the current response must be determined.

The d and q axis synchronous reactances may be computed simply by integrating the measured transient current [2]:

$$X_{d,q} = \frac{R_s \omega_s}{I_{d,q0}} \int_0^\infty i_{d,q}(t)dt \qquad (1)$$

where ω_s is the supply frequency given in rad/s.

The variation versus time of the measured current $i_{d,q}(t)$ was approximated by a sum of four exponential components:

$$i_{d,q}(t) \approx \sum_{k=1}^{4} I_k e^{-t/T_k} \qquad (2)$$

Using a special program (TableCurve of Jandel Scientific) a curve was fitted very accurately to the measured current's variation function of time. The coefficient of determination in all the cases was over 0.99.

The synchronous reactances can be computed using the following relation:

$$X_{d,q} = \frac{R_s \omega_s}{I_{d,q0}} \sum_{k=1}^{4} I_k T_k \qquad (3)$$

Next the results of estimating X_q will be presented. The eight parameters of the fitted curve and the limits of the measured current response are given in Table 1. The accuracy of the approximation can be easily observed in Fig. 5, where the measured current is plotted together with the curve that approximates it. As it can be seen the two curves are difficult to differentiate in the graph, because the errors are very small.

Table 1

I_k [A]	T_k [s]	i_{q0} [A]	$i_{q\infty}$ [A]
0.8566	0.0058	1.0518	0.0088
0.0763	0.0634		
0.0763	0.0620		
0.0740	0.3066		

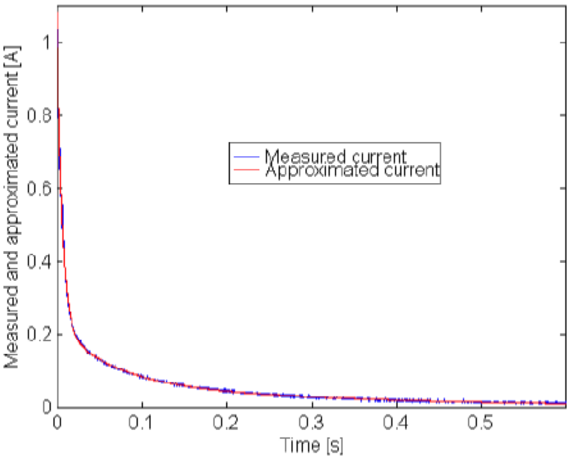
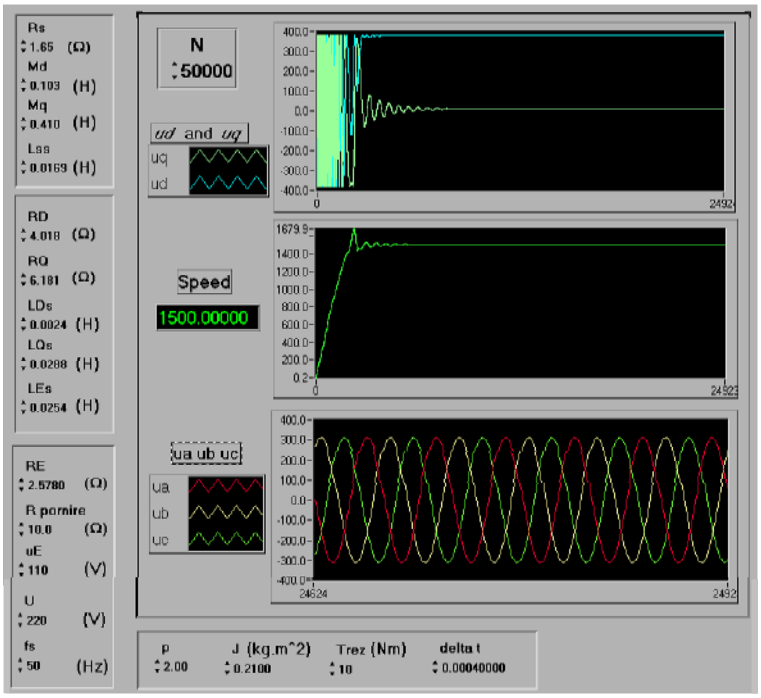


Fig. 5.
The measured and approximated current

The q-axis reactance obtained this way is X_q=18.6 Ω. In a same manner was estimated the d-axis reactance: X_d=33.04 Ω. The two reactances in per unit values are X_d=0.93 and X_q=0.52. These meat the requirements for the two reactances to be in the interval of 0.9÷1.2, respectively 0.5÷1. The obtained results are also in accordance with the results of some earlier made slip tests with the same machine (X_d=37.825 Ω and X_q=18.38 Ω). These last results are only for informing purposes, because these slip tests were not performed using accurate data acquisition systems.

The estimated results were validated using simulation. The applied model of the machine was that based on the winding equations written in the rotor's orthogonal *dq0* reference frame with all rotor quantities referred to the stator [6]. Based on this a simulation program was written also in LabView. The front panel of this program figuring the results of simulating the starting of the machine is shown in figure 6.



Rs
1.65 (Ω)
Md
0.103 (H)
Mq
0.410 (H)
Lss
0.0169 (H)
RD
4.018 (Ω)
RQ
6.181 (Ω)
LDs
0.0024 (H)
LQs
0.0288 (H)
LEs
0.0254 (H)
RE
2.5780 (Ω)
R pornire
10.0 (Ω)
uE
110 (V)
U
220 (V)
fs
50 (Hz)
N
50000
Speed
1500.00000
p
2.00
J (kg.m^2)
0.2100
Trez (Nm)
10
delta t
0.00040000

Fig. 6.
The front panel of the simulation program

The results of simulations are in accordance with the measurements carried out and with the theoretical expectations. So these results validate the estimated parameters of the synchronous machine in study.

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