IDENTIFICATION OF THE SYNCHRONOUS GENERATOR PARAMETERS BY STANDSTILL TESTS

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Abstract **– The identification of the synchronous machine parameters via standstill DC decay test is the purpose of this work. The method is simple, without any risk and much less expensive than other methods. A dedicated data processing program for the time-constants and reactances identification was developed and some given examples based on lab tests are fully discussed.**

Keywords: *synchronous machine, parameters identification, standstill tests*

1. INTRODUCTION

From the early days of the energy distribution, which means late twenties of the last century, the grid engineers understood how important is an accurate model of the synchronous machine in calculating the stability, or in general, the dynamic behaviour of the network. Since the synchronous machine model is based on its parameters, the need for a reliable set of electrical parameters is obvious. The parameters can be calculated analytically or via a magnetic field analysis procedure during the design stage of the machine. The parameters can be obtained also by tests at the factory or on site.

Many papers have been published on synchronous machine parameter identification, [1, 2, 3, 4]. Most papers address standstill frequency response (SSFR) methods following the protocols of IEEE Standard 115-1995, [5].

Generally, the parameter estimation process consists of two parts. First, the time constants are extracted by applying a curve-fitting procedure to measured data. Next, the equivalent circuit parameters are determined by solving a set of non-linear equations through numerical optimisation. The weakness of this approach is that the order of the model must be known before the parameters can be determined and that numerical optimisation is a process full of numerical difficulties.

Off-line standstill tests (e.g. DC-decay test) are preferred over online and off-line running machine tests, because off-line test results with good signal to noise ratio due to the absence of disturbance signals (electromagnetic interference) and at standstill there is no coupling between d- and q-axis, [6, 7, 8].

A quite classic test used to calculate the synchronous machine parameters is the short-circuit one even if it weakness consists mostly in less adequately treating the case of higher order models, [9, 10].

The DC decay test is simple, without any risk and less expensive. In this work a dedicated data processing program for time-constants and reactances identification is developed. The parameter identification procedure is well defined and the results are accurate. Some examples are given too and the results are fully discussed.

It was tested a synchronous machine with the following rated values: S_N =3kVA, U_N = 380V, I_N = 3.5A. A second set of measurements were performed on a different synchronous machine, a salient pole synchronous one, with the following rated data: S_N = 4.5KVA, U_N = 400V, I_N = 6.5A

This identification method is quick and easy to perform once the equations are written, and with carefully chosen initial conditions can give good values for transient and sub-transient parameters. It is an attractive alternative to other tests due to the equipment simplicity and to the time required for simulation and identification.

2. IDENTIFICATION PROCEDURE

The identification procedure starts from a mathematical model, which consists of the operational equations for the d- and q-axis. The d- and q- axis current time-variation is considered as being given by a sum of exponential functions, which means, in a per-unit variant,

$$\frac{i_d(t)}{i_{d0}} = Ae^{\alpha_1 t} + Be^{\alpha_2 t} + Ce^{\alpha_3 t} \qquad (1)$$

$$\frac{i_q(t)}{i_{q0}} = De^{\beta_1 t} + Ee^{\beta_2 t} \tag{2}$$

where the initial conditions are:

$$u_{d0} = r_s i_{d0},\ u_{q0} = r_s i_{q0}$$

and the final conditions are:

$$u_d = 0,\ u_q = 0$$

Since the measured current is the phase one, *ia*, Fig.1, than

$$\frac{i_a(t)}{i_{a0}} = \frac{i_d(t)}{i_{d0}} \tag{3}$$

and the relation between phase current and *dq0* equivalent current is:

$$i_{a0} = \frac{\sqrt{3}}{2} i_{d0} \tag{4}$$

The developed identification program based on MATLAB curve-fit procedure was tested first by using a simulation. The dynamic regime, specific for a standstill DC decay test, was simulated for a machine with given parameters. The phase current was fed to the identification program and the resulted parameters were compared with the initial given parameters.
It resulted a quite good identification for the q-axis current, (fig.1), but it was not the case for the d-axis one (fig.2).

ia2q= measured current; iaq= identified current

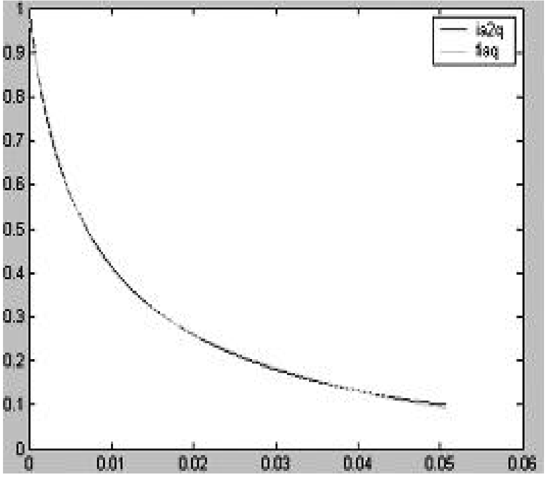

Fig.1.a. Identification **axe q**
Synchronous machine 3 kVA, Ia0= **10 A**

ia2= measured current;
ia_Sq= simulation of the current starting from the identified parameters

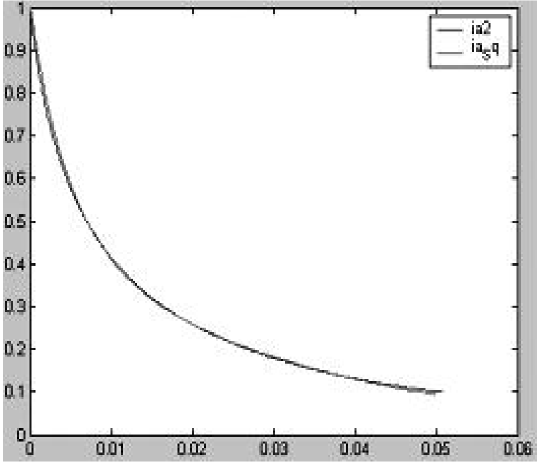

Fig.1.b. Identification **axe q**
Svnchronous machine 3 kVA. Ia0= **10 A**

ia2= measured current;
ia_S= simulation of the current starting from the identified parameters

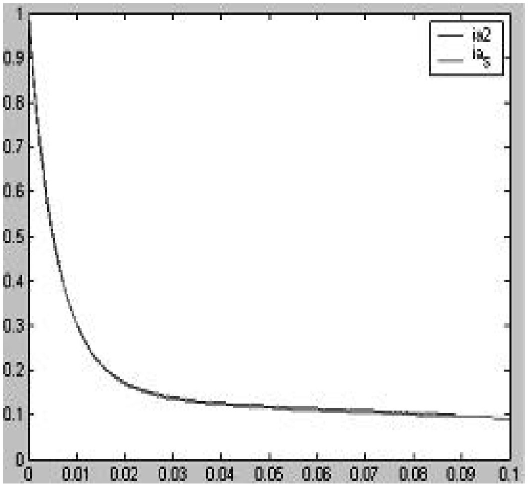

Fig.2.a. Identification **axe d**
Synchronous machine 3 kVA, Ia0= **3.5 A**

Then the identification program was developed and it was applied on parts of the phase current curve first. This way results a first estimation which was used for a new run on as initial values. After three steps quite a good accuracy was obtained. The final form of the identification program was used to determine the reactances and the time constants for some synchronous machines from the laboratory.

ia2= measured current;
ia1= identified current (I); ia2= identified current (II)

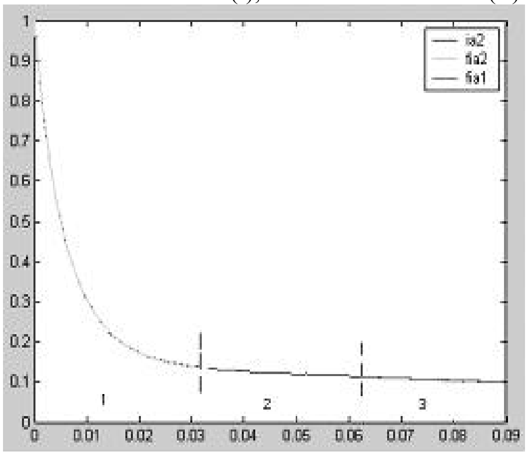

Fig.2.b. Identification **axe d**
Synchronous machine 3 kVA, Ia0= **3.5 A**

The test lay-out for the DC standstill decay test is given in Fig.3

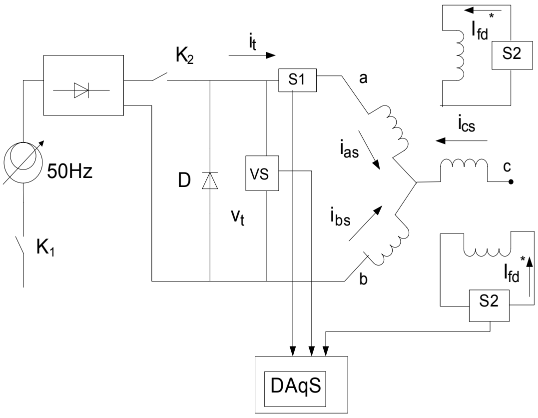

Fig.3 SSCD test set up

The results were checked via different tests and the obtained accuracy was quite a good one.

The obtained values for one machine, when the initial current has the rated value are given, in per-unit, in Table1:

x_d = 1.1938	x_q = 0.8049
x_d' = 0.2194	
x_d'' = 0.1903	x_q'' = 0.2795

Table 1. Calculated reactance (p.u.)

For the same machine, via a no-load and a steady state three-phase short-circuit test combination, was obtained for the d-axis reactance the per unit value x_d = 1.1120, which is in a quite good agreement with the DC standstill decay test result.

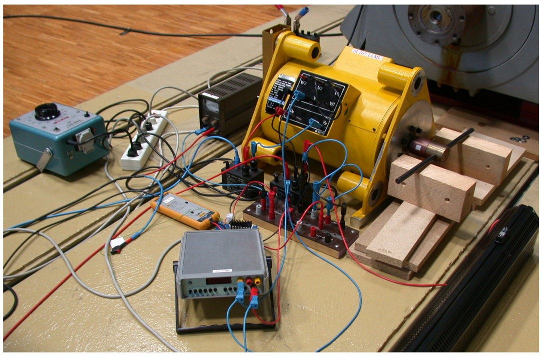

Fig.4. The test bench set-up, machine M1.

A second set of measurements was performed on a different synchronous machine. This machine, a salient pole synchronous one, has the following rated data: S_N = 4.5KVA, U_N = 400V, I_N = 6.5A.

In order to verify/compare the results, some classic tests were performed too. The no load and symmetrical steady state short-circuit test allow for unsaturated d-axis reactance calculation. The q-axis reactance was computed after performing a low slip test on the machine

The values of the sub-transient reactances were obtained via a steady-state test which models the transient regime

The values of the second machine, M2, reactances obtained through conventional steady-state tests, are given, in per-unit, in Table2.

x_d = 0.9471	x_q = 0.4455
x_d'' =0.1210	x_q'' = 0.3356

Table2. Machine M2 per-unit reactances
(Conventional tests)

The per unit values of the machine M2 reactances, computed via the proposed identification method, based on the DC standstill decay test are given in Table 3. The test was performed at different initial I0 current values, in the Table 3 being given the per unit values of the reactances obtained for the rated current value.

x_d = 1.0520	x_q = 0.5770
x_d' = 0.3304	
x_d'' =0.2500	x_q'' = 0.4671

Table3. Machine M2 per-unit reactances
(DC standstill decay test)

The results are quite different from the ones obtained through conventional tests due to the fact that the iron core remanent flux density of this, quite old, machine is important and it was not possible to make the final flux value zero within DC standstill decay test.

In figure 5 the values of the transient reactances obtained for the machine M1 using the standstill DC decay test at different values of the current (3,5A, 7A, 10A) are illustrated.

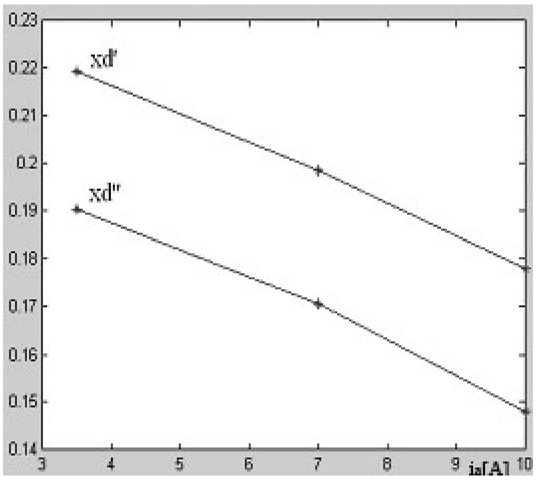

Fig.5 Transient reactances for machine M1

3. CONCLUSIONS

In this paper, a method and an algorithm of synchronous machine parameters identification is proposed.

This approach has been successfully applied in the laboratory on two synchronous machines. The calculated values of the reactance and time constants by this approach have been found to be in a quite good agreement with the measured ones.

This identification method is quick and easy to perform once the equations are written, and with some carefully chosen initial conditions can give good values for transient and sub-transient parameters. It is an attractive alternative to other tests because of the equipment simplicity and because of the simulation and identification required time.

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