On the Identification of the Synchronous Machine Parameters Using Standstill DC Decay Test

L. Vicol, M. Tu Xuan, R. Wetter, J.-J. Simond, I. A. Viorel

***Abstract* – This paper presents a refined approach to obtain the parameters of synchronous machine equivalent circuits from standstill DC decay tests. A dedicated program for the time-constants and reactances identification was developed and applied for both d- and q- axis, as well as for a random position of the rotor, with good results.**

***Index Terms* – standstill DC decay test, parameters, synchronous machine.**

I. INTRODUCTION

Usually, the characteristic values of a synchronous machine are obtained from a short-circuit test at no-load. This test requires substantial equipment and is therefore expensive, it implies risks and it can not be always carried out for levels of voltage higher than 50% to 60% of nominal voltage. This DC decay test is an interesting alternative since only light equipment is needed. It delivers the characteristic values of synchronous machine for the two axes in function of the saturation state of the leakage paths. In general, the DC decay test is done for the two extreme positions of the rotor, d- and q- axes. This contribution proposes a solution for a DC decay test extended for a random position of the rotor. This extension is important because, at standstill, it is almost impossible to fix the rotor of a large synchronous machine in a particular position.

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L. Vicol is with the Department of Electrical Machines, Technical University of Cluj-Napoca, Romania (phone: (+40)-264-401-828; e-mail: liliana.vicol@mae.utcluj.ro).

M. Tu Xuan is with the Laboratory for Electrical Machines, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland (e-mail: mai.tuxuan@epfl.ch).

R. Wetter is with the Laboratory for Electrical Machines, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland (e-mail: roland.wetter@epfl.ch).

J.-J. Simond is with the Laboratory for Electrical Machines, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland (e-mail: jean-jacques.simond@epfl.ch).

I.-A. Viorel is with the Department of Electrical Machines, Technical University of Cluj-Napoca, Romania (e-mail: ioan.adrian.viorel@mae.utcluj.ro).

II. IDENTIFICATION PROCEDURE

The standstill DC decay test consists in cutting off the constant DC supply, allowing the current from the coils to reach zero and keeping the rotor in a fix position. Initially, the switch K_2 is closed, K_1 is open. The DC source is supplying two phases of the stator with a known current i_o, whereas the excitation is short-circuited. Once the switch K_2 is opened and K_1 is closed simultaneously, the decreasing of the current is acquired and using a dedicated program, the reactances and time constants of the synchronous machine can be obtained.

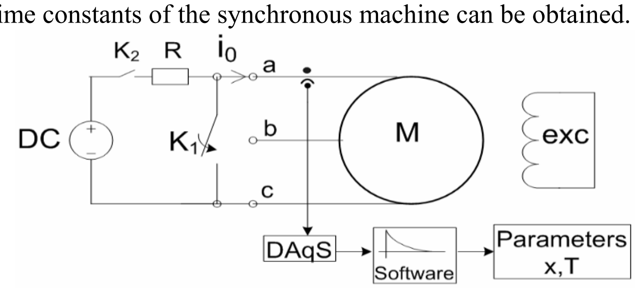


Fig. 1. Standstill DC decay test setup

The classical DC decay test requires also that the rotor at standstill to be either in transversal axis, either in longitudinal one. This work treats this case in particular, as well as, a general case, when the rotor is in a random position. The validation is done for a small laboratory machine. After this, the procedure is developed and applied for a simulated large machine with the rotor in various positions. The simulations are computed using the SIMSEN software package (http://simsen.epfl.ch).

A. Identification procedure for d- and q- axis

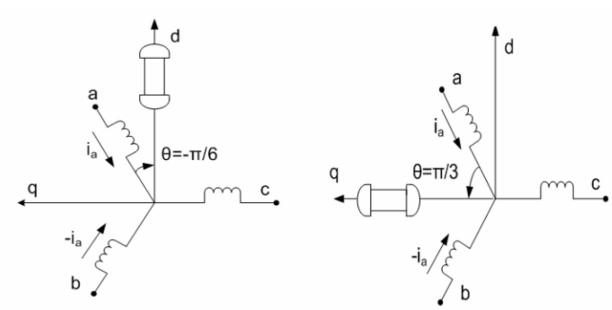


Fig. 2. d- and q- axis diagram

The identification procedure starts from a mathematical model, which consists of the machine voltage equations for the d- and q-axis. In the transient period of time, the voltage input becomes zero, r_s is the resistance of two series connected phases (in Fig. 2 – a and b phases), i is the resultant current of the two windings, ψ is the resultant flux coupled with the two phases, L stands for the inductance and p expresses the operator *d/dt.*

$$\begin{cases} 0 = r_S i + p\psi \\ \psi = L(p)i \end{cases} \tag{1}$$

For writing the expression of the current variation *i'* in the transient interval of time, Laplace transformations and operational inductances are used:

$$i'(p) = -\frac{r_s i_0}{p} \frac{1}{r_s + pL(p)} \tag{2}$$

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,

$$\begin{aligned} i_d(t) &= A_d e^{\alpha_{1d} t} + B_d e^{\alpha_{2d} t} + C_d e^{\alpha_{3d} t} \\ i_q(t) &= A_q e^{\alpha_{1q} t} + B_q e^{\alpha_{2q} t} \end{aligned} \tag{3}$$

where the coefficients A, B, C and α are functions of time-constants and reactances for each of the axis [2].

The developed identification program is based on the MATLAB curve-fit procedure. Starting from the expressions of the currents, the identification is applied on parts of the curves. Estimated data are used as initial values [3].

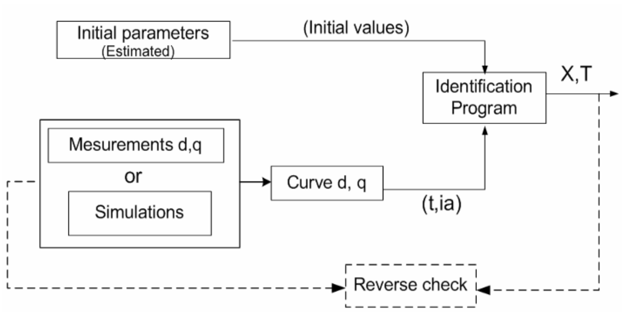
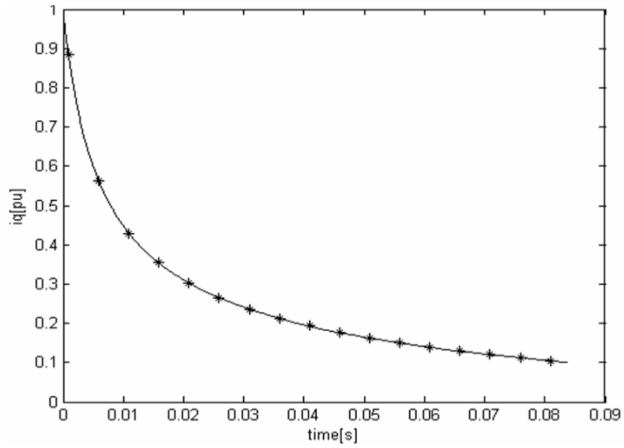


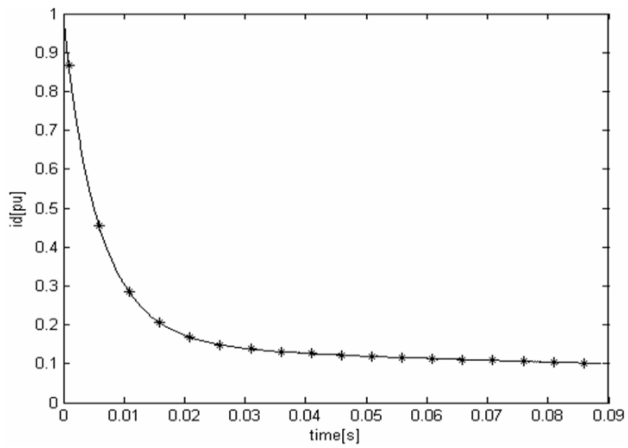
Fig. 3. Procedure lay out – case A

1) Procedure's validation

Firstly, the procedure was tested by using known values for simulating a small machine with SIMSEN. The results of the simulation are fed to the identification program, Fig.3. The identified parameters were afterward compared to the input values used in SIMSEN. There was a very good accuracy. A difference between known values and identified ones of less then 0.01% was obtained. The identification was made for both axes, Fig.4.



4a. q-axis identification



4b. d-axis identification

Fig. 4. Simulated currents identification (1 p.u.)

The identified constants A, B, C and α, obtained by curve-fitting, are directly used to calculate the time constants T and reactances X.

Table 1. d - axis parameters for simulated files

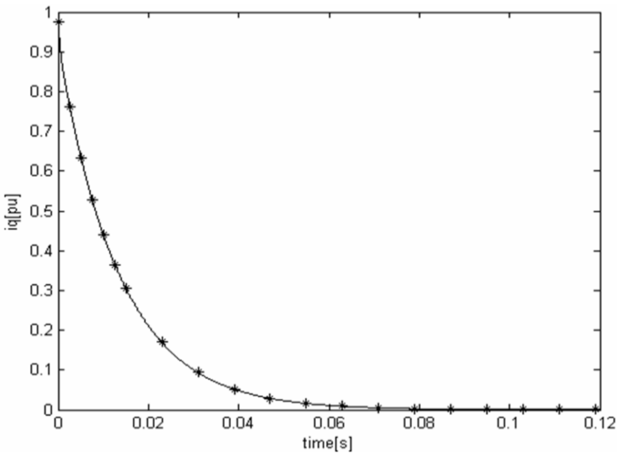
Parameters	Simulation values [p.u.]	Identified Parameters [p.u.]
x_d	1.1390	1.1390
x_d'	0.2543	0.2543
x_d''	0.1480	0.1480
T_d	2.0031	2.0031
T_d'	1.7789	1.7789
T_d''	0.0440	0.0440
T_{d0}'	7.9661	7.9661
T_{d0}''	0.0756	0.0756

Table 2. q - axis parameters for simulated files

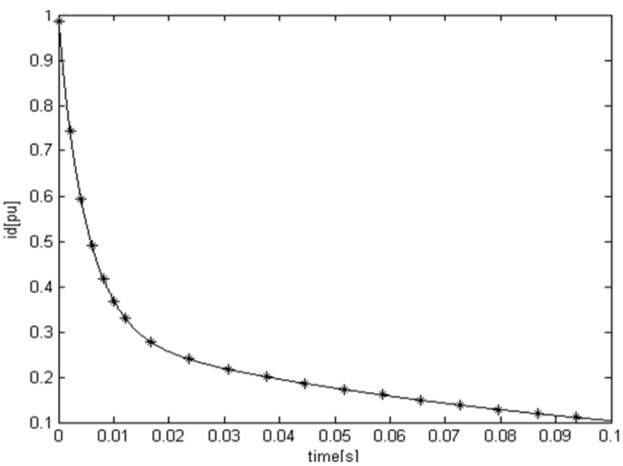
Parameters	x_q	x_q''	T_q	T_q''	T_Q
Simulation values [p.u.]	0.714	0.1809	1.2556	0.0339	0.1341
Identified parameters [p.u.]	0.7139	0.1808	1.2556	0.0338	0.1338

2) Application to a small laboratory machine

A synchronous machine with the following rated values: $S_N = 3kVA$, $U_N = 380V$, $I_N = 3.5A$ was tested. The test was performed for three different values of the current (1 p.u., 2 p.u., 3 p.u.). The obtained parameters were used afterwards in (3) and new currents were calculated. In Fig. 5, some values from the measured currents and the resulting ones are illustrated.



5a. q-axis identification



5b. d-axis identification

Fig.5. Measured currents' identification (1p.u.)

Table 3. d - axis parameters for 1p.u.

Parameters	Identified parameters from measurements [p.u.]
x_d	1.1938
x_d'	0.2194
x_d''	0.1903
T_d	0.0420
T_d'	0.0382
T_d''	0.0049
T_{d0}'	0.2078
T_{d0}''	0.0056

Table 4. q - axis parameters for 1 p.u.

Parameters	x_q	x_q''	T_q	T_q''	T_Q
Identified from measurements [p.u.]	0.8049	0.2795	0.0275	0.0147	0.0420

As expected, a normal decreasing of reactance values with the increase of the saturation level can be observed. In Fig. 6, the values of the transient reactances obtained for the small machine using the standstill DC decay test at different values of the current (1 p.u., 2 p.u., 3 p.u.) are illustrated.

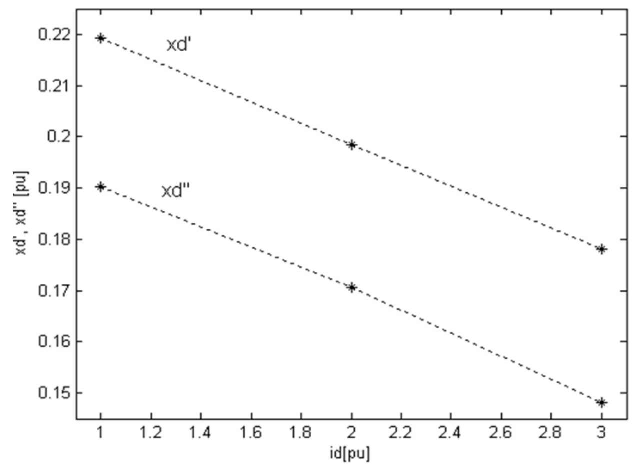


Fig. 6a. d-axis transient reactances

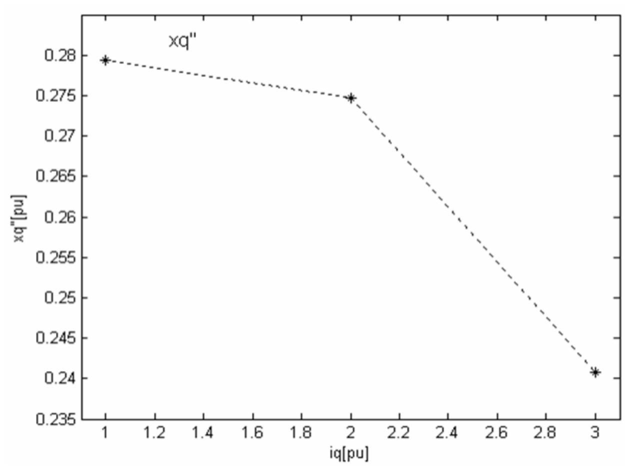


Fig. 6b. d-axis transient reactances

Fig. 6. Transient reactances for three different values of the current

B. General case – any rotor position

This case is solved starting from three sets of measurements, which will be used to determine first the rotor position *(θ)*. With three resultant currents and θ, the transversal and longitudinal currents can be separated *(i_d, i_q)*. Now, this case is an application for the first identification procedure. The same program will be used to identify the parameters of the synchronous machine.

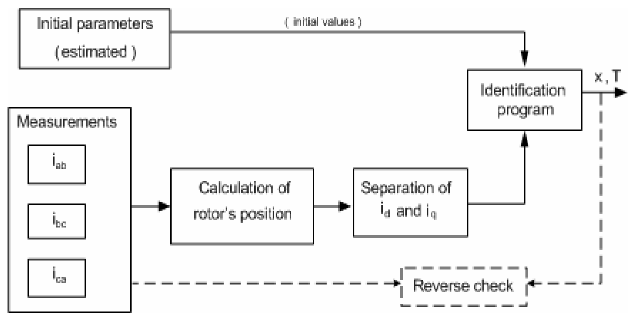


Fig. 7. Procedure lay out - case B

1) Determining rotor position

Keeping the rotor in the fix, initially unknown position, first phases ***a*** and ***b*** are supplied with continuous current, next the other 2 pairs of phases, ***b*** and ***c***, ***c*** and ***a,*** will be supplied with the 'same' value of the current. In practice, we can not have exactly the same value for the supplied current. Therefore, we try to have almost the same value and a normalization of the currents is made.

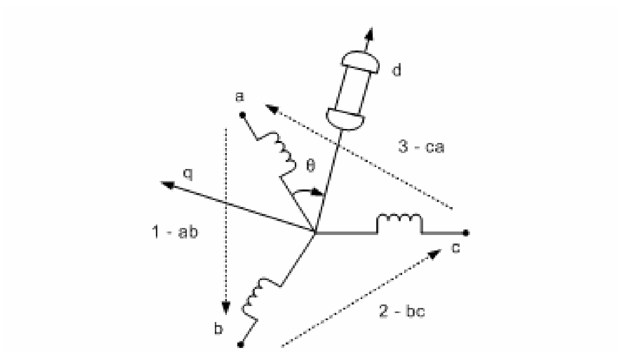


Fig. 8. Random position diagram

Knowing that the stator flux produced by one of these three resulted currents is:

$$\psi_s = \int_0^\infty u(t)dt - r_s \int_0^\infty i_s(t)dt \tag{4}$$

for this short transient period the inductance l_s will be:

$$l_s = \frac{\psi_s}{i_{s0}} \tag{5}$$

Each resulted current (i_s) is integrated and three inductances are determined. Angle θ' is the angle between i_s and d-axis (Fig. 9) and it is:

$$\theta' = \theta + \frac{\pi}{6} \tag{6}$$

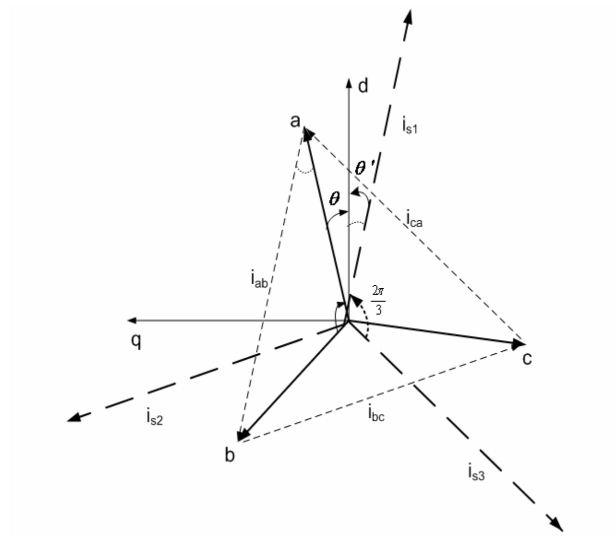


Fig.9. Currents' diagram

The stator inductance of two phases in series is given by the well known relation [1]:

$$l_s(\theta') = l_m + \Delta l \cos 2\theta' \tag{7}$$

where l_m is the median value, Δl the half difference of the transversal and longitudinal inductances

$$l_m = \frac{l_d + l_q}{2}, \qquad \Delta l = \frac{l_d - l_q}{2} \tag{8}$$

We have now a system of three equations, from (7), for each pair of phases, with the difference between the three currents of 120° and three unknowns l_m, Δl, θ'.

Transversal and longitudinal impedances (l_d, l_q) can be calculated and for a chosen angle, the impedance $l(\theta)$.

Next, the d- and q- inductances are calculated and angle θ' is found:

$$\theta' = \frac{1}{2}\arccos\left(\frac{l_i - l_m}{\Delta l}\right) \tag{9}$$

where l_i is one of the three inductances and θ' is the correspondent angle. In Fig. 10 are illustrated the three inductances for the rotor at 20° referred to d-axis. L_t is the theoretical impedance from (7).

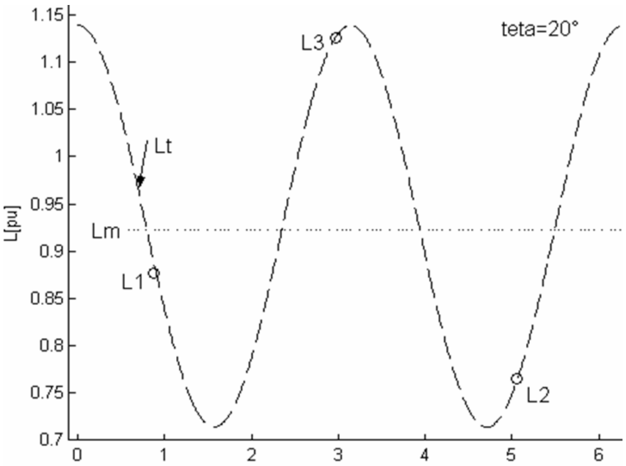


Fig. 10. Determining the rotor position

Having the rotor position, the three measurements and relations (1), we obtain 3 resultant currents. i_{dmax}, i_{qmax} are the currents obtained for the rotor in d-axis, respective q-axis**.** If we rotate the corresponded vector i_{max}, for the other two positions, equivalent as for *AB, BC, CA*, we obtain i_{s1}, i_{s2}, i_{s3}.

$$i_{si}(t) \cong \frac{3}{2}\left[i_{d\max}(t)\cos^2\theta_i' + i_{q\max}(t)\sin^2\theta_i'\right] \tag{10}$$

2) Separating d- and q- currents

Now, from the 3 resulted currents, d- and q- currents can be separated

$$\begin{cases} i_{d\max} \cong \dfrac{2}{3}\dfrac{i_{s1}\sin^2\theta_2' - i_{s2}\sin^2\theta_1'}{\cos^2\theta_1'\sin^2\theta_2' - \cos^2\theta_2'\sin^2\theta_1'} \\ i_{q\max} \cong -\dfrac{2}{3}\dfrac{i_{s1}\cos^2\theta_2' - i_{s2}\cos^2\theta_1'}{\cos^2\theta_1'\sin^2\theta_2' - \cos^2\theta_2'\sin^2\theta_1'} \end{cases} \tag{11}$$

Similar expressions are found for the other pairs of phases.

Finally we have i_{dAB}, i_{dBC}, i_{dCA} *and* i_{qAB}, i_{qBC}, i_{qCA}.

When the angle is a multiple of 30°, two of the i_{si} currents are symmetrical referred to d- and q- axis, the numerator and the denominator are 0. Equations (11) for this situation will not be accepted and the other two will be used. A procedure is written for choosing the appropriate currents used to identify the parameters.

3) Parameters identification for a random position

The i_d and i_q currents obtained before are introduced in the same main program. In Table 5 the results for a simulated machine are given. The same parameters as in Table 1 are used, but now, the rotor is positioned at 40°. The obtained parameters are compared with the ones used for simulation. Other simulations were made for different positions with the same good results.

Table 5. d-axis parameters

Parameters [p.u.]	Simulation 40°	Rotor's position 38.82°
x_d	1.139	1.1392
x_d'	0.2543	0.2607
x_d''	0.148	0.1483
T_d	2.0031	2.0034
T_d'	1.7789	1.8202
T_d''	0.044	0.0445
T_{d0}'	7.9661	7.9524
T_{d0}''	0.0756	0.0782

Table 6. q-axis parameters

Parameters [p.u.]	Simulation 40°	Rotor's position 38.82°
x_q	0.7140	0.7248
x_q''	0.1809	0.1789
T_q	1.2556	1.2747
T_q''	0.0339	0.0328
T_Q	0.1341	0.1329

III. CONCLUSIONS

The experience has shown that the d-axis current is more difficult to calculate accurately than that on the q-axis, because of the three time constants. But, with this method of identification (in different intervals) the problem can be solved with good accuracy and consistency of the results. A special attention must be given, in the interpretation of the results, to the current values because of saturation level.

This identification method is quick and easy to perform. Precise values for transient and sub-transient parameters are obtained with adequately chosen initial conditions. Having identified the parameters, the equivalent circuits are easily calculated using a specific program.

It is an attractive alternative to other tests because of the equipment simplicity and because of the short simulation and identification time.

REFERENCES

[1] Concordia, C., "Synchronous machine", Wiley, New York, 1951

[2] Groza,V., Biriescu, M., Liuba, Gh., Cretu, V., "Experimental determination of synchronous machines reactances from DC Decay at standstill", *IEEE Instrumentation and Measurements Technology Conference*, Budapest, Hungary, May 21-23, 2001

[3] Vicol, L., Simond, J.-J., Tu Xuan, M., "The identification of synchronous machine parameters by standstill DC decay test", *diploma project*, EPFL-UTCN, 2004 - unpublished