Electrical Machines and Converters

Modelling and Simulation

H. Buyse, J. Robert Editors

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Modelling and Simulation

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FOREWORD

The modelling and simulation of electrical machines and converters are topics which seem of great interest today, especially in view of the industrial needs and also due to the ever increasing potential of the digital computers.

The basic idea, however, is not new since the first modelling methods are the equations written at the beginning of the century. The main purpose of these equations was to describe various types of machines in order to predict essentially their steady state behaviour. Many refinements were added and, at the beginning of the twenties reasonable methods were available to calculate the performance of the machines and to help designers.

At that time a new trend began to emerge, due to the ever increasing constraints existing in the power systems. Transient, as well as subtransient reactances were defined, unbalanced operation was more deeply investigated. In some particular domains equivalent circuits were developed, matrix and tensor analyses were used.

A.C. and D.C. network analysers were expanded. In some cases mechanical differential analysers were used.

New electronic analog computers, which appeared essentially in the forties and fifties prompted many engineers to use such calculating machines to study the transient performance of various types of electric machines used either in power systems or in control applications.

With the advent of digital computers continuous simulation programs were evolved and a new trend appeared : the use of very sophisticated programs, such as E.M.T.P. to predict the transient performance of power systems, or, to analyse for example, the transient operation of large induction machines.

Some discrepancies between calculated and measured performances now lead many engineers to search for improvements of the methods which are available today. For example, new components were introduced in Park's models. Similarly new measuring techniques are needed to obtain the values of all the necessary parameters.

These efforts result in methods which could be named "third generation modelling".

This includes also advanced work in two particular domains.

The first is a direct result of the ever increasing use of semi-conductor devices associated with all types of electrical machines. This trend leads to the development of more and more simulation programs which include the machines and their electronic drives. In general these problems are very complicated for two main reasons : First, the number of possible configurations is high since it depends on the state of all semi-conductors. Secondly, the currents and voltages contain rather large harmonic components and the models of the machines should be designed to represent their effects.

The modelling of these systems is often believed to be the most practical way of predicting their performance. This, however, is not necessarily true, since global methods have been developed using the theory of electrical machines with sliding contacts. These methods are, in fact, the generalization of the old theories of D-C machines "seen from the outside", in which all transient effects in the rotor coils due to commutation are ignored. The results obtained by such approximations are very representative of the actual performance of the machines.

The other domain which has become more and more important is the study of electromagnetic fields in the machines.

Not too long ago the only practical way for calculating these fields was by using graphical methods and each calculation involved many hours of tedious work with a pencil and, principally, an eraser.

Rheographic devices were then used and consisted mainly of electrolytic tanks with automatically driven probes. They gave very interesting results but necessitated a good deal of experimental work.

With the advent of digital computers this domain of activity started to expand. Finite difference equations were used and the theory of finite elements was developed and we now have at our disposal very sophisticated programs which in seconds calculate all we need.

This is in fact very slow and for transient problems we would like to obtain solutions in milliseconds rather than in seconds.

And now, what is the future ? No doubt the computer improvements will help. Parallel processors will permit higher computing speeds, but the problems of stability of the solutions are to be mastered.

On the other hand one has always to search for more efficient methods of writing the equations and of solving them.

The non-linear properties of iron should also be more easily modelled.

The papers which are assembled in this book represent good samples of the efforts made in all the domains we have mentioned above.

If we work on new modelling and simulation methods we can with confidence say : "The future : we are working on that".

H. BUYSE J. ROBERT

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Session 1

IDENTIFICATION OF THE PARAMETERS OF ELECTRICAL MACHINES

Chairman: R. PONCELET

ELECTRICAL MACHINES AND CONVERTERS - Modelling and Simulation
H. Buyse and J. Robert (editors)
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EXPERIMENTAL DETERMINATION OF LARGE TURBOGENERATOR PARAMETERS

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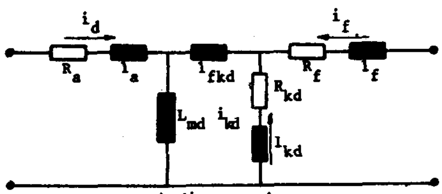
This paper is dealing with the experimental determination of large turbogenerator two axis model parameters (PARK's models).
After a general review of our works in that field, we particularly deal with DC decay test at standstill (step response) for determining d and q axis parameters.
We especially present theoritical aspects, results and comments about the DC decay test performed at the field side, for d-axis parameters determination.
Obtained values are used for reconstruction of experimental signals from tests performed in the network and at the manufacturer's testing bench.

TERMINOLOGY - SYMBOLS - UNITS

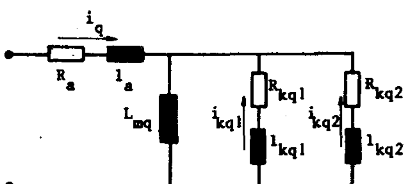
We use IEC terminology and symbols for the impedances and for the time constants [1][2]. For the elements of d and q axis equivalent circuits, we use inductances and resistances suffixed as shown in figure 1.

Suffixes : a : armature winding
d,q : direct, quadrature axis
m : magnetising
f : field winding
k : damper winding

All the impedances are expressed in per unit and time constants in seconds.



a) direct axis



b) quadrature axis

Figure 1 : Equivalent circuit notations
(a) : direct axis
(b) : quadrature axis

1. INTRODUCTION

This paper is dealing with the experimental determination of large turbogenerator models, in order to compute the dynamic behaviour of large power systems.

In practice, lumped element linear PARK's models are universally used with generally one damper circuit on d-axis and two in q-axis. These models are usually enhanced with CANAY's mutual leakage inductance [3][4].
However, there is no consensus about the methodology for parameters determination [3].
Numerous methods are propounded for the experimental determination of these parameters [1][2], but, in practice, the analysis of the corresponding signals and the interpretation of their results are still setting problems.
The application of IEC recommended methods can give large discrepancies between the values obtained by different methods [5].
For these reasons, we have entered upon a critic and systematic study of these experimental methods [6] - [10].
The purpose of this study is to optimize the experimental conditions and the analysis process, and to quantify the confidence which can be attributed to the results.

Presently, we are working on the following methods :

- sudden three-phase short circuit test;
- DC decay test in armature winding at standstill;
- DC decay test in field winding at standstill;
- field extinguishing test with armature on short or open circuit, machine running at rated speed;
- frequency response at standstill.

For each method, we systematically analyse the signals from both armature and field terminals. The experimentation is carried out in two steps : firstly, the tests are studied on three-phase

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micromachines (220 V, 2 kVA, 1500 r.p.m.), and after that, performed on large turbogenerators. We use systematically a computer aided analysis of the experimental data [7].

The experimental signals are identified to analytical expressions, where machine parameters appear; these expressions are deduced from the model.

We have performed and analysed DC decay test in armature winding at standstill on several large turbogenerators of the Belgian network (39.2 MVA, 337.5 MVA and 1330 MVA), and on the 1330 MVA turbogenerator sudden three-phase short circuit tests for five different initial voltages (0.1 - 0.2 - 0.3 - 0.4 - 0.5 U_N) [8].
Besides, all the mentionned methods have been performed on a 361.4 MVA turbogenerator at the manufacturer's testing bench (February-March 1983).
A comparative study of these last test results will be presented in a 1984 CIGRE report [10].

In the present paper, we are essentially dealing with DC decay test at standstill (step response method) for determining d and q axis parameters. Application limits of these methods are put forward. Discrepancies between obtained values are explained by considering signal shape and physical phenomena.
We show advantages to perform the DC decay test at the field side for d-axis parameters determination, in comparison with the test performed at the armature side.
Finally, we present a method for obtaining "compromise values" which allowed us to compute very satisfactory restitution of experimental signals.

2. DATA PROCESSING METHOD

For understanding purpose, we give hereafter the principle of our general data processing method (for more informations : cfr. [7]).

The experimental data processing is performed in two steps : an automatic analysis is realised following the usual methods (IEC recommandations). The results from this analysis are then used as initial conditions for the identification by least square algorithm. We identify experimental data with analytical expressions, which contain machine parameters, by means of regression computer programs. These programs, implementing the LEVENBERG-MARQUARDT's least square algorithm, use iterations on the JACOBIEN matrix of the function : sum of square deviations between experimental data and values given by the analytical expressions.
All the computer programs are implemented on a DEC VAX-11/780 (2.5 Mbytes central memory). These programs include several specific subroutines in order to analyse experimental signals automatically (starting time detection, offset detection, local quadratic curve fitting, parasite elimination, ...). From statistical informations, we also quantify the quality of the signal analysis, and determine the statistical confidence of the results [7].

3. DC DECAY TEST IN THE ARMATURE WINDING AT STANDSTILL (IEC 34-4-A, clause 59)

This test is particularly easy to perform, even in the power station [7][8]. It gives the step response in both axis and the recorded signals are therefore a sum of exponentials.
The method used for analysing the signals is the identification of the exponential terms, from which we determine the d and q axis parameters. The number of exponential components is equal to the number of required circuits for representing the machine in the considered axis. This test then allows to investigate the complexity of the mathematical model to be retained.
We have performed numerous such tests on turbogenerators and micromachines. They were analysed and we conclude the following [9][10] :

- This test is very sensitive to the influence of the magnetic phenomena. We have systematically obtained very low values of magnetising inductances L_{md} and L_{mq}, and also the open circuit time constants T'_{do} and T''_{do}. This is explained by the low permeability values during the test. These low values are characteristic of magnetic recoil curves of very low magnitude due to practical current limitations.

- The identification of the exponential terms is very sensitive to the signal shape, and besides the actual signals are unfortunately distorted by non linearity effects. Therefore, the recorded signals are not exactly a sum of exponentials. Difficulties are especially met for tests performed in the quadrature-axis where the iron effect of the rotor steel body is not masked by a field winding as for the direct-axis.

- The analysis of the sole field current leads systematically to inconsistent results. Simultaneous processing of both armature and field currents recorded in a direct-axis test is so sensitive to the weighting of these two signals that the test is very difficult to be applied.

- The magnetising inductances L_{md} and L_{mq} must be adapted to the magnetic level, anyway.

- The obtained values for the reactances X'_d, X''_d, and X''_q, and for the time constants T''_d, T''_{do}, T''_q and T''_{qo} are systematically excessive.

- In the q-axis, physically unexpected results have been obtained, such as a leakage reactance greater than magnetising reactance [7].

4. DC DECAY TEST IN FIELD WINDING AT STANDSTILL [9]

4.1. Introduction

To avoid problems met in the previous method (DC decay test in armature winding), we propose to carry out the DC decay test at the field side for direct-axis parameters determination.
This test is performed in two sequences : armature on open circuit and on short circuit. It brings more information than the previous test, for which it is not realistic to open the field winding.
The test applied at the field side brings several other advantages in comparison with the test performed at the armature side [9] :

- on a magnetic level standpoint, quasi normal values are reached because a large variation of the magnetic field can be imposed;
- more simple equations in order to calculate the machine parameters as showed hereafter;
- reduction of the requirement for the short-circuit contactor resistance (cfr. figure 2).

4.2. Principle and wiring diagram

The principle of this test is analogous to the previous one. It is also easy to perform in practice. DC voltage is applied to the field winding, machine at standstill. The rotor is placed so that the magnetic field axis be in quadrature with one armature phase-axis (phase A on the figure 2). Only one quantity must therefore be recorded at the armature side (a voltage for the test with armature on open circuit and a current for the test with armature on short circuit).
Hereafter, we present the theoritical aspects for the usual model, enhanced with the field-damper leakage reactance l_{fkd}. All the expressions can be generalised for models with more damper circuits [9].

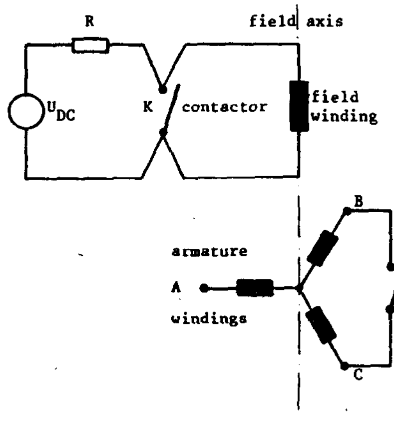

Figure 2 : DC decay test in field winding, machine at standstill - wiring diagram, armature on open circuit and on short circuit

4.2.1. Test with armature on open circuit

We record the whole process of field current decay and the armature voltage, after field winding has been short-circuited (K contactor closed).
Theoritically, from the analysis of these two signals, it must be possible to determine the following parameters :

$$T'_{do}\ ,\ T''_{do}\ ,\ X_{md}\ ,\ T_{kdo} \text{ and } T_x = l_{kd}/r_{kd}$$

From those parameters, we can compute directly all the elements of the direct-axis equivalent circuit for the model without the mutual keakage inductance l_{fkd} (R_a and l_a must be known).

4.2.2. Test with armature on short circuit

In this case, we record the whole process of the field current decay and the armature current. From the recorded signal analysis, it is theoritically possible to determine the time constants T'_d and T''_d.

Finally, from both previous test results and from the armature leakage inductance l_a, we are able to compute all the d-axis parameters of the PARK's model, enhanced or not with the field-damper mutual leakage inductance l_{fkd}.

4.3. Theory of the DC decay test in the field winding, machine at standstill

4.3.1. Test with armature on open circuit

From the general PARK's equations in Laplace transforms, we obtain the following expression for the field current Laplace transform after field winding has been short-circuited :

$$\begin{aligned} i_f(p) &= \frac{i_{fo}}{p} + i'_f(p) \\ &= \frac{i_{fo}}{p} - i_{fo} \cdot \frac{(1 + pT_{kdo})}{p(1 + pT'_{do})(1 + pT''_{do})} \\ &= i_{fo} \cdot \frac{T'_{do} + T''_{do} - T_{kdo} + pT'_{do} \cdot T''_{do}}{(1 + pT'_{do})(1 + pT''_{do})} \end{aligned} \quad (1)$$

where i_{fo} is the initial field current;
$i_{f'}$ is the surimposed field current change.

The recorded field current has thus the following form :

$$i_f(t) = i_{fo} + i'_f(t) = i_{fo} \cdot \sum_{i=1}^{2} A_i \cdot e^{-t/T_i}$$

or, in Laplace transform :

$$i_f(p) = i_{fo} \cdot \sum_{i=1}^{2} \frac{A_i \cdot T_i}{1 + pT_i}$$

$$i_f(p) = i_{fo} \cdot \frac{A_1T_1 + A_2T_2 + pT_1T_2(A_1 + A_2)}{(1 + pT_1)(1 + pT_2)} \quad (2)$$

Consequently, the time constants T'_{do} ($\equiv T_1$) and T''_{do} ($\equiv T_2$) are directly obtained from the field current analysis which gives the A_i and T_i parameters. We also obtain the value of T_{kdo} from the following expression :

$$T_{kdo} = T'_{do}(1 - A_1) + T''_{do}(1 - A_2)$$

The following condition holds :

$$A_1 + A_2 = 1$$

The armature voltage change is expressed by :

$$u_d(p) = i_{fo} \cdot L_{md} \cdot \frac{1 + pT_x}{(1 + pT'_{do})(1 + pT''_{do})} \qquad (3)$$

where $T_x = l_{kd}/r_{kd}$.

As the recorded voltage has the form :

$$u_d(t) = \sum_{i=1}^{2} A'_i \cdot e^{-t/T_i}$$

(notice the same time constants for field current and armature voltage), and

$$u_d(p) = \frac{A'_1.T'_{do} + A'_2.T''_{do} + pT'_{do}.T''_{do}.(A'_1 + A'_2)}{(1 + pT'_{do})(1 + pT''_{do})} \qquad (4)$$

from identification side to side of (3) and (4), we obtain :

$$L_{md} = \frac{A'_1 \cdot T'_{do} + A'_2 \cdot T''_{do}}{i_{fo}}$$

$$T_x = \frac{T'_{do} \cdot T''_{do} \cdot (A'_1 + A'_2)}{A'_1 \cdot T'_{do} + A'_2 \cdot T''_{do}}$$

From the armature voltage analysis which gives the A'_i and T_i parameters, we obtain thus :

$$T'_{do} \;,\; T''_{do} \;,\; L_{md} \text{ and } T_x = l_{kd}/r_{kd}$$

The d-axis parameters, l_f , l_{kd} , R_f and R_{kd} can be obtained from the four following equations for the model without mutual leakage inductance l_{fkd} ($l_{fkd} = 0$) :

$$T'_{do} + T''_{do} = \frac{L_{md} + l_f}{R_f} + \frac{L_{md} + l_{kd}}{R_{kd}}$$

$$T'_{do} \cdot T''_{do} = \frac{l_f \cdot l_{kd} + (l_f + l_{kd}) \cdot L_{md}}{R_f \cdot R_{kd}}$$

$$T_{kdo} = \frac{l_{kd} + L_{md}}{R_{kd}}$$

$$T_x = \frac{l_{kd}}{R_{kd}}$$

(cfr. analytical solution of those four equations with four unknowns on appendix 1).

4.3.2. Test with armature on short circuit

In this case, from the PARK's equation system, we obtain the following expression for the field current :

$$i_f(p) = \frac{i_{fo}}{p} - i_{fo} \cdot \frac{1 + p(T'_4 + T'_5) + pT'_5.T'_6}{p(1+pT'_1)(1+pT'_2)(1+pT'_3)} \qquad (5)$$

$$= i_{fo} \cdot \frac{T'_1+T'_2+T'_3-T'_4-T'_5+p(T'_1T'_2+T'_1T'_3+T'_3T'_2-T'_5T'_6)+p^2T'_1T'_2T'_3}{1+p(T'_1+T'_2+T'_3)+p^2(T'_1T'_2+T'_2T'_3+T'_3T'_1)+p^3T'_1T'_2T'_3}$$

where $T'_1,\ldots,T'_6$ are depending of the equivalent circuit elements (l_f , R_f , ...).

The recorded field current has thus the form :

$$i_f(t) = i_{fo} \sum_{i=1}^{3} B_i \cdot e^{-t/T'_i}$$

Or, in Laplace transform :

$$i_f(p) = i_{fo} \sum_{i=1}^{3} \frac{B_i \cdot T'_i}{1 + pT'_i} \qquad (6)$$

By identification side to side of equations (5) and (6), we obtain :

$$B_1 + B_2 + B_3 = 1$$

$$T'_4 + T'_5 = \sum_{i=1}^{3} T'_i(1 - B_i) \qquad (7)$$

$$T'_5.T'_6 = T'_1.T'_2(1 - B_1 - B_2) + T'_2.T'_3(1 - B_2 - B_3) + T'_3.T'_1(1 - B_1 - B_3) \qquad (8)$$

From (7), (8) and the identified time constants T'_1 , T'_2 and T'_3, it is then possible to determine five elements of the d-axis equivalent circuit from the five equations given in appendix 2 [9].

The armature current d-axis component has the following expression :

$$i_d(t) = \sum_{i=1}^{3} B'_i \cdot e^{-t/T'_i}$$

The same identification method as for the field current, leads to :

$$\sum_{i=1}^{3} B'_i = 0 \quad ; \quad \frac{L_{md}}{R_a} = \sum_{i=1}^{3} B'_i \cdot T'_i \qquad (9)$$

$$T_x = \frac{l_{kd}}{R_{kd}} = \frac{T'_1T'_2(B'_1+B'_2)+T'_2T'_3(B'_2+B'_3)+T'_3T'_1(B'_3+B'_1)}{\sum_{i=1}^{3} B'_i \cdot T'_i} \qquad (10)$$

From (9), (10) and the identified time constants T'_1 , T'_2 and T'_3, we can obtain five equations similar to those established for the field current (appendix 2) from which we can determine five elements of the direct-axis equivalent circuit.

In conclusion, from the analysis of the field and armature current of the DC decay test in field winding with short-circuited armature, it is theoritically possible to determine seven elements of the direct-axis equivalent model (seven equations for eight unknowns values : R_a , R_f , R_{kd} , l_a , l_f , l_{kd} , l_{fkd} and L_{md}).

4.4. Practical use

4.4.1. Test with armature on open circuit

The field current analysis leads systematically to excessive values of the subtransient time constants. This is due to the shape of the signal

conditionned principally by the large time constants.
The armature voltage, on the other hand, contains much more information about the subtransient phenomena [9]. The voltage is an induced one, directly depending of the flux variation. The subtransient time constants obtained from this voltage analysis are much smaller.
The reconstruction of experimental signals from tests performed in the network and at the manufacturer's testing bench showed us that these smaller values are those which give the best results [10].
The simultaneous identification of the field current and the armature voltage in order to use concurrently all the information, gives results extremely depending on the weighting of the two signals between each other.

4.4.2. Test with armature on short circuit

From this test, the field current analysis leads to acceptable results. Generally, the analysis of the armature current gives unacceptable time constants, as for the field current analysis from test in the armature side (section 3). This is due to the combination effect of the signal shape and the identification process.

4.4.3. Combination of the results of tests with armature on open circuit and on short circuit

In practice, to determine the direct-axis parameters, we propose to take account of both tests with armature on open circuit and on short circuit. The combination of the results of these two tests can be made as follows :

$$T'_{do} , T''_{do} \Rightarrow L_{md} , T_x$$

from the armature voltage analysis, test with armature on open circuit

$$T'_1 , T'_2 , T'_3$$

from the field current analysis, test with armature on short circuit

From these previous values, we determine T'_d, T''_d and L_d/R_a solving the following equations :

$$\frac{L_d}{R_a} = T'_1 + T'_2 + T'_3 - (T'_{do} + T''_{do})$$

$$T'_d + T''_d = \frac{T'_1 . T'_2 + T'_2 . T'_3 + T'_3 . T'_1 - T'_{do} . T''_{do}}{L_d/R_a}$$

$$T'_d . T''_d = \frac{T'_1 . T'_2 . T'_3}{L_d/R_a}$$

We can now determine l_f, l_{fkd}, l_{kd}, R_f imposing the value of armature leakage inductance l_a, by solving the equation system :

$$T'_d + T''_d = \frac{1}{R_f}\left(l_f + l_{fkd} + \frac{L_{md} . l_a}{L_{md}+l_a}\right) + \frac{1}{R_{kd}}\left(l_{kd} + l_{fkd} + \frac{L_{md} . l_a}{L_{md}+l_a}\right)$$

$$T'_d . T''_d = \frac{1}{R_f . R_{kd}}\left[l_{kd} l_f + (l_{kd}+l_f)\left(l_{fkd} + \frac{L_{md} . l_a}{L_{md}+l_a}\right)\right]$$

$$T'_{do} + T''_{do} = \frac{1}{R_f}(l_f + l_{fkd} + L_{md}) + \frac{1}{R_{kd}}(l_{kd} + l_{fkd} + L_{md})$$

$$T'_{do} . T''_{do} = \frac{1}{R_{kd} . R_f}\left[(l_{kd} l_f + (l_{kd}+l_f)(l_{fkd}+L_{md})\right]$$

$$T_x = \frac{l_{kd}}{R_{kd}}$$

These equations have an analytical solution without any approximation [9].
Nevertheless, there is a practical problem because of the sensivity of the results with respect to T''_{do} value, which is not determined with a good accuracy [9]. In order to circumvent this problem, we impose the value of the subtansient reactance X''_d. This one is determined with a good accuracy from the standstill test at rated frequency (IEC - 34-4, clause 44).

In the two equations for determining T'_d and T''_d values, we eliminate the product $T'_{do} . T''_{do}$ using the expression of the subtransient inductance :

$$L''_d = (L_{md} + l_a) \frac{T'_d . T''_d}{T'_{do} . T''_{do}}$$

It follows :

$$T'_d . T''_d = \frac{T'_1 . T'_2 . T'_3}{L_d/R_a}$$

$$T'_d + T''_d = \frac{T'_1 . T'_2 + T'_2 . T'_3 + T'_3 . T'_1 - \frac{T'_1 . T'_2 . T'_3}{L''_d} . R_a}{L_d/R_a}$$

4.5. Results and comments about DC decay tests in the field winding of a 361.4 MVA turbogenerator (3000 RPM - 20 kV)

Hereafter, we present results from DC decay tests performed in the field winding of a 361.4 MVA turbogenerator at the manufacturer's testing bench. Two initial field currents have been imposed, 0.1 p.u. and 0.3 p.u. For each one, the tests with armature on open and short circuit have been realised two times.

Test (-)	i_{fo} (pu)	T'_{do} (s)	T''_{do} (ms)	T_x (ms)	T'_1 (s)	T'_2 (ms)	T'_3 (ms)	X_{md} (pu)
I	0.1	6.51	24	2.5	8.19	264	15.2	2.43
I'	0.1	6.40	46	-	8.12	262	15.5	-
II	0.1	6.44	12	2.6	8.18	258	14.0	2.43
II'	0.1	6.35	34	-	9.02	262	14.5	-
III	0.3	7.45	19	2.5	9.26	266	16.7	2.46
III'	0.3	7.41	48	-	9.20	260	16.3	-
IV	0.3	7.44	22	2.6	9.01	275	15.7	2.46
IV'	0.3	7.35	34	-	9.02	262	14.5	-

Table I

Table 1 :
I', II', III' and IV':
results deduced from the analysis of the sole field current
I , II , III and IV :
results deduced from the simultaneous analysis of the signals from both armature and field terminals
"-" : means unacceptable identified value

Test (-)	T'_d (s)	T''_d (ms)	T'_{do} (s)	T''_{do} (ms)	T_x (ms)	X_d (pu)	X'_d (pu)	X''_d (pu)
I	1.09	15.4	6.51	24	2.5	2.69	0.46	0.29
I'	0.98	17.2	6.40	46	-	2.69*	0.42	0.15
II	1.06	13.9	6.44	12	2.6	2.69	0.45	0.49
II'	0.99	18.0	6.35	38	-	2.69*	0.42	0.20
III	1.18	16.3	7.45	19	2.5	2.72	0.43	0.37
III'	1.07	18.0	7.41	48	-	2.72*	0.39	0.15
IV	1.23	16.0	7.44	22	2.5	2.72	0.49	0.35
IV'	1.17	12.4	7.35	34	-	2.72*	0.43	0.16

* Imposed values

Table 2

This table 2 presents the turbogenerator parameters deduced from the table 1 values.

This last table shows the inconsistency of the results particularly for the subtransient reactance X''_d.
To circumvent this problem, we impose the value of the subtransient reactance X''_d as mentionned before, and we obtain the results of table 3.

Test (-)	T'_d (s)	T''_d (ms)	T'_{do} (s)	T''_{do} (ms)	T_x (ms)	X_d (pu)	X'_d (pu)	X''_d (pu)
(I)	1.06	15.9	6.40	23	2.5	2.69	0.45	0.31
(II)	1.02	14.3	6.35	20	2.6	2.69	0.43	0.31
(III)	1.15	16.6	7.41	23	2.5	2.72	0.42	0.31
(IV)	1.15	14.8	7.35	20	2.5	2.72	0.43	0.31

Table 3

(I) and (II) : results from tests at 0.1 p.u.
(III) and (IV) : results from tests at 0.3 p.u.

These last results show a very good consistency for all the parameters. They allow good reconstruction of experimental signals as showed below (section 4.6).
The results of the previous table 3 are uncorrected ones, directly deduced from the analysis process.
In order to compare the obtained values with the manufacturer's data, they have been adapted to the rating conditions of those last ones (temperature, resistance of armature and field circuits, magnetic level).

The corrected values are given on next table 4.

Test (-)	T'_d (s)	T''_d (ms)	T'_{do} (s)	T''_{do} (ms)	T_x (ms)	X_d (pu)	X'_d (pu)	X''_d (pu)
(I)	1.36	15.9	8.31	23	2.5	2.74	0.45	0.31
(II)	1.31	14.3	8.28	20	2.6	2.74	0.43	0.31
(III)	1.28	16.6	8.29	23	2.5	2.74	0.43	0.31
(IV)	1.29	14.8	8.25	21	2.5	2.74	0.43	0.31
(1)	1.34	57	7.27	84	-	2.74	0.50	0.34
(2)	1.21	50	6.83	57	-	2.74	0.48	0.42
(3)	1.04	35.0	7.98	43	-	2.74	0.40	0.32
(4)	1.43	11.0	9.52	15	2.7	2.74	0.41	0.29

Table 4

(1) : results from armature current analysis - DC decay test in armature winding at standstill
(2) : results from simultaneous analysis of field and armature current - DC decay test in armature winding at standstill
(3) : manufacturer's data - old method
(4) : manufacturer's data - new method

4.6. Reconstruction of experimental signals

The obtained values have been used for the reconstruction of experimental signals from sudden three-phase short-circuit tests performed at the manufacturer's testing bench and in the Belgium network.
All computations have been done by numerical integration of PARK's equations, with the use of EMTP program (Electromagnetic Transient Program).

A detailled comparative study of results from different methods will be presented in a 1984 CIGRE report [10].
In the present paper, short of space, we are only giving reconstruction obtained with the results from the DC decay test in field winding.

4.6.1. Sudden three-phase short-circuit test at the manufacturer's testing bench (0.1 initial voltage)

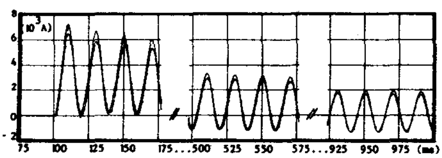

Figure 3 : Armature current (the computed current has been voluntary shifted from the measured one)

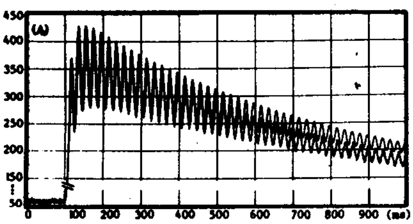

Figure 4 : Field current

These results are much beter than those obtained from the DC decay test in the armature winding, especially for the field current [10].

4.6.2. Three-phase short-circuit on the Belgian 150 kV network

We have computed the behaviour of an identical turbogenerator of the Rodenhuize power station during a voluntary effected short-circuit (metallic three-phase short-circuit on a tower 15 km from the turbogenerator; duration : 122 ms; generator at rated P and Q [11].

The comparison between computed and measured signals shown on the next figures 5 and 6, concerns the armature current and the mechanical torque between the generator and the low pressure turbine.
For all the computations, we have used q-axis parameters deduced from a DC decay test, except for X''_q deduced from a test at rated frequency at standstill.

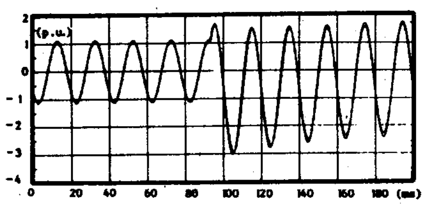

Figure 5 : Armature current

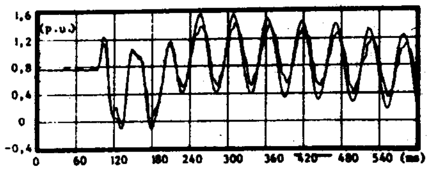

Figure 6 : Mechanical torque

These last results are very acceptable; they are similar to those obtained with parameters from other reliable methods of experimental determination [10].

5. CONCLUSIONS

The analysis of any experimental signal, sum of exponential terms, is a critical problem, and a great care must be taken in interpreting the results anyway.
For the synchronous machine test signals, non linear effects complicate this problem. A this standpoint, we have presented the results of a critic of the DC decay test in the armature winding which leads to excessive values for the subtransient parameters. Besides, this test is characterized by small incremental magnetic permeability, and requires consequently important magnetic corrections of the results.

DC decay test performed in the field winding permits to circumvent these problems :

- it works at quasi normal magnetic permeability and so requires only small magnetic corrections;
- it may be effected in two configurations, with armature on open and on short circuit; that increases the available information;
- the test with armature on open circuit brings an armature voltage signal very representative of the subtransient phenomena. The analysis of this voltage leads to better results of the subtransient parameters, quasi independent of the identification conditions.

Finally, very satisfactory parameter values have been obtained by imposing a reliable value of X''_d (obtained from a standstill test at rated frequency) and by an adequate combination. These parameters allowed good reconstructions of experimental signals from different tests performed at the manufacturer's testing bench and in the Belgian network.

REFERENCES

[1] Recommendations for rotating electrical mechinery.
Part 4 : Methods for determining synchronous machine quantities from tests (IEC, 34-4, 1967, 87 p.).

[2] First supplement to publication 34-4 (1967) : Unconfirmed test methods for determining synchronous machine quantities (IEC, 34-4-A, 1972, 96 p.).

Figure legend : ——— : measurement ; -x-x-x- : computation

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