Stability studies with parameter uncertainties

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***Abstract*—The aim of this paper is to present how EDF deals with the generator parameter uncertainties when performing stability studies. These uncertainties mostly affect the Park's generator model. The presented methodology consists in two steps: firstly, a reference set of the parameters is computed from several time-domain field measurements on one generator unit; secondly, generic stability studies are performed with uncertainties associated to these reference parameters in order to account for the variability among units of the same type; this allows to draw conclusions for all the units of the same type. Both steps involve the use of transient parametric simulation, which is carried out with EMTP-RV and PAMSUITE.**

***Keywords*: Transient stability, parametric simulation, Monte Carlo simulation, EMTP-RV, PAMSUITE**

I. Introduction

WHEN performing transient stability simulation studies, it is crucial that the numerical models used for simulation are representative of the measurements obtained during tests. As most utilities, EDF is indeed periodically carrying out performance checks and field measurements of the synchronous machines of its fleet, which consists in a number of units of several types.

Section II deals with the parameter determination for one type of generators, a 150 MVA – 18 kV. Differences between the tests measurements and the simulation results were found. After investigation it was shown that these differences were due to the synchronous machine and more precisely to the poor identification / knowledge of the model parameters. This is the reason why EDF has carried out an optimization study to fit more accurately the measurements that have been carried out on that plant.

For the power plants of the type considered in section II, the section III evaluates the risks of stability loss following a three-phase fault on the network. The goal is to perform a generic study that allows to draw conclusions for all the units of the same type (for example all the hydro units of the same site), not only one unit. However, the model parameter values determined in section II are correct for the generator unit involved in the measurements, but not necessarily for any other unit of the same type. Indeed, significant variations of the parameter values can occur among units of the same type due to a number of factors such as manufacturing variations and differences in ageing. For this reason, the type stability study of section III is performed by introducing parameter uncertainties that account for the variability among units of the same type.

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II. Generator parameter determination for the lead unit of the family

The purpose of this section is to define a set of parameters that provide minimum error compared to field measurements performed on a given generator unit, here the lead unit of the family.

A. Initial model from standard tests

The machine models used in electromechanical stability studies are based on the classic Park transformation. EDF uses the IEC 60034-4 [1] standard for determining synchronous machine electrical parameters. The procedure exploits several tests, such as the no-load, short-circuit and three-phase short circuit tests in which the machine is operated at the rated speed.

However, these tests are time consuming and costly, and performing short-circuit tests may be risky taking into account the age of the test machine. Therefore they are generally done before the first use of the machine, by the manufacturer or by EDF, and they are performed only on the lead unit of the same family.

The current study case involves the 150 MVA – 18 kV synchronous generator fleet. For this generator, the computed parameter values for the lead unit are shown in Table I.

With these parameter values, the model of the plant is checked against three field tests on the lead unit, for which measurements have been performed:

- No-load test
- Permanent three-phase short-circuit test
- Three Load tests
    1. Reactive power step test
    2. Machine overexcitation at T ≈ 20°C
    3. Machine overexcitation at T ≈ 40°C

The first two tests allow to verify that the machine model input data give an accurate solution in steady-state conditions.

The model check is performed by comparing the simulated results to the measured values for several important quantities. The simulations are performed with EMTP-RV [3].

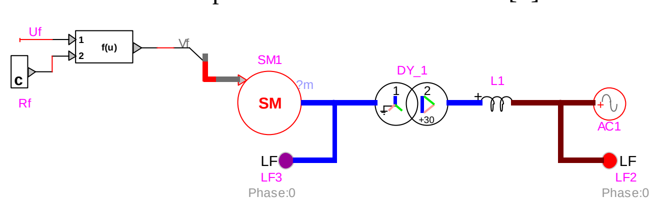

Fig. 1. Study case

The Fig. 2 compares the simulated and measured rotor current I_f for the three test configurations: from top to bottom, the reactive power step test, the machine overexcitation test at T ≈ 20°C and the machine overexcitation test at T ≈ 40°.

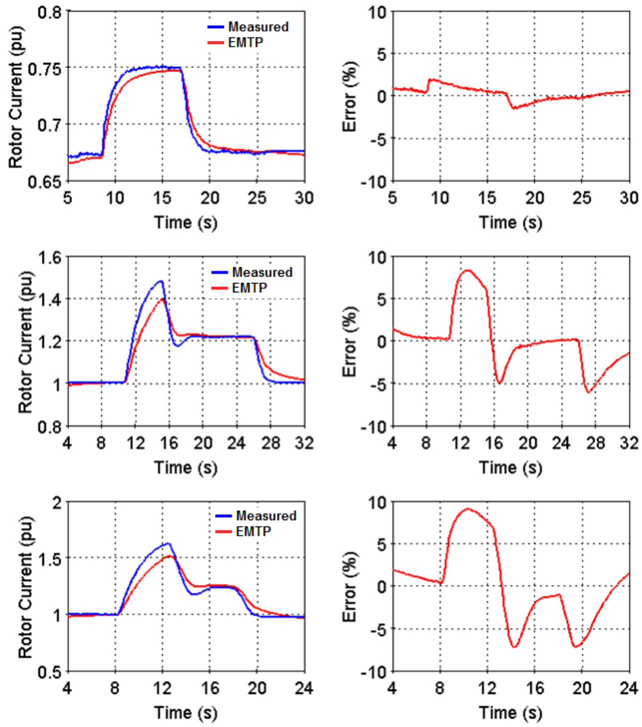

Fig. 2 Time domain rotor current If comparison between calculation and measurement

In the case of the rotor current, the maximum absolute difference between simulation and measurements are the following depending on the case considered: 2%, 8.5% and 9%.

These differences between simulation and measurements, which are considered too high, are due to two reasons: first, the referred IEC parameter determination procedure has limited accuracy; second, the unit characteristics may have slightly changed over time since the standard tests were performed.

B. Parameter determination from field measurements

The aim of this paragraph is to reduce the gap between simulations and measurements for the lead unit.

In order to compute more accurate parameter values, an optimization study is performed to finds the values that allow to match the field tests.

According to §4.19 of [2], 15% tolerance must be considered for several of the generator parameters. Similarly, a 15% uncertainty range will be considered during the optimization procedure for the parameters x'_d, x''_d, T'_{d0}, T''_{d0}, x''_q and T''_{q0}.

TABLE I
GENERATOR PARAMETER VALUES FOR THE LEAD UNIT

Parameter	**From standard tests (IEC procedure)**	**Optimized values from field tests**
x'_d	0.4 pu	0.34 pu
x''_d	0.25 pu	0.22 pu
T'_{d0}	10.8 s	9.34 s
T''_{d0}	0.22 s	0.2 s
x''_q	0.32 pu	0.28 pu
T''_{q0}	0.55 s	0.55 s

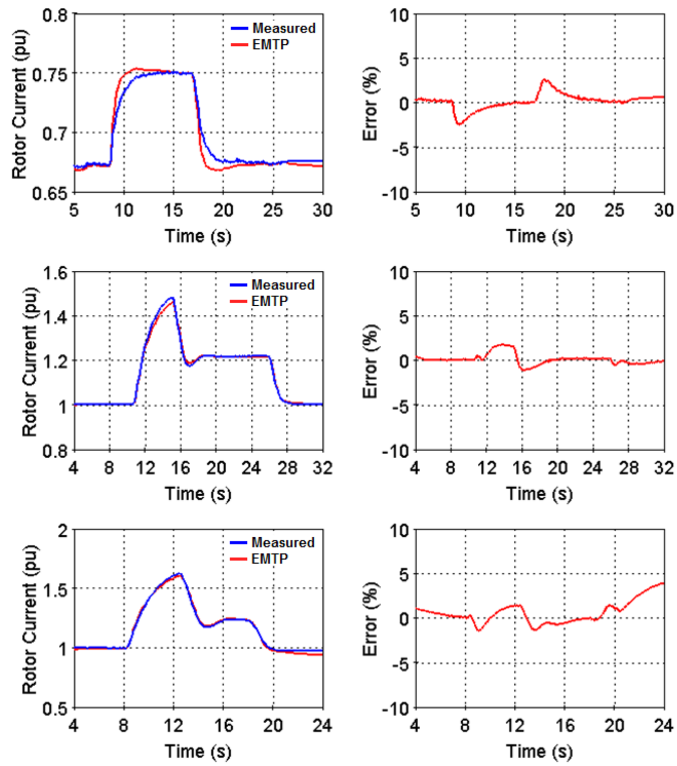

Fig. 3 Time domain rotor current If comparison between calculation and measurement after the model calibration

The Monte Carlo optimization process is carried out by PAMSUITE [5], a parametric simulation tool for EMTP-RV that allows to perform studies with parameter uncertainties, sensitivity analysis, contingency scenarios exploration, optimization and data matching.

The optimized parameter values are shown in Table I. The maximum absolute difference between simulation and measurements are now below 4% for the three tests considered. This better matching is shown in Fig. 3.

III. GENERIC STABILITY STUDY ACCOUNTING FOR GENERATOR VARIABILITY IN THE SAME FAMILY

The goal of this section is to check the stability of the power plants equipped with generators of the same type as the one in the section II. As an example, one particular condition will be investigated, the short circuit stability test.

The goal here is to draw conclusions for all the units of the same type (for example all the hydro units of the same site), not only for the lead unit.

However, the parameter values determined in section II cannot be considered correct for all the units of the same type. Indeed, the parameters that characterize the behavior of a generator family can vary from one unit to another because of variations during the manufacturing process and differences in ageing over time.

Therefore, the generic stability study (i. e. for all the units of the same type or family) must consider parameter uncertainties that account for this variability among units of the same type.

A. Short circuit stability test

The objective of this test is to evaluate the risks of stability loss of a power plant following a three-phase fault on the grid which should be eliminated by the protection systems.

According to the French TSO rules [4], the short-circuit stability study is carried out with a simplified grid circuit. The synchronous machine is connected to the grid through a step-up transformer and four lines in parallel, of reactance 3b (see Fig. 4).

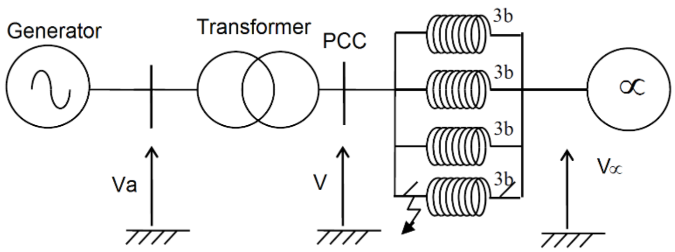

Fig. 4. Simplified circuit used for the study of stability on short circuit [4]

The value of the b reactance to use in the short circuit stability test is imposed by the TSO [4] and is a function of the power plant rated power.

TABLE II
REACTANCE VALUE FUNCTION OF THE INSTALLED MAXIMAL POWER

Nominal power of the power plant	**b value (p.u.)**
Pmax ≥ 800 MW	b = 0.6
250 MW ≤ Pmax < 800 MW	b = 0.54
Pmax<250 MW	b = 0.3

This test is done for a single operating point:

- The delivered power at the Point of Common Coupling (PCC) must be the maximum power that the group can provide.
- The reactive power must be 0 Mvar at the PCC.
- The voltage value at the PCC is 405kV (according to the French TSO rules).

The three phase fault is simulated by earthing (for a time T = 85ms) one of the lines at a distance from the PCC of 1% of the total length line.

The conformity criteria defined by the French TSO are:

- The power plant must be stable (with a maximum of 3 revolutions of rotor angle);
- The power plant does not trip;
- The damping time of the active power at the PCC must be within ±5% ($T_{SP5\%}$) of its final value in less than 10 seconds.

The power plant is isolated from the network if one of the following criteria is reached:

- 4 revolutions of rotor angle
- 20 power inversions

B. Determination of the maximum acceptable line reactance

In order to determine the maximum acceptable line reactance, b, an iterative method based on the short-circuit stability test is used. The iterative procedure is described in the Fig. 5. The identification of the reactance starts from a maximum value fixed by the nominal power of the power station (a margin of 10% is taken).

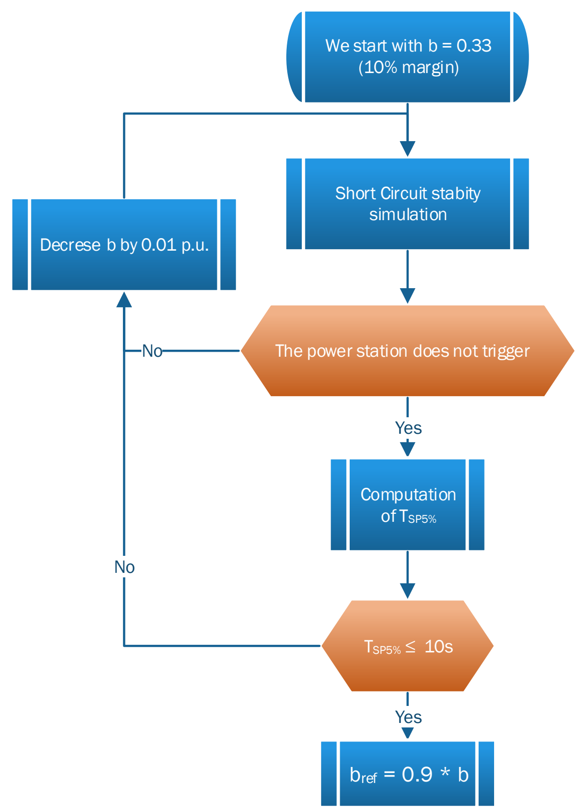

Fig. 5 Iterative method in order to determine the b reactance and $T_{SP5\%}$

$T_{SP5\%}$ and b_{ref} are the final values that will be transmitted to the grid operator for the studied power station.

For the plant at study, at the end of the described iterative procedure a short-circuit reactance of b=0.26 pu is obtained. The active power damping time at the PCC point is $T_{SP5\%}$ = 7.6 s.

The time-domain curves of interest are shown in figures 6 to 8.

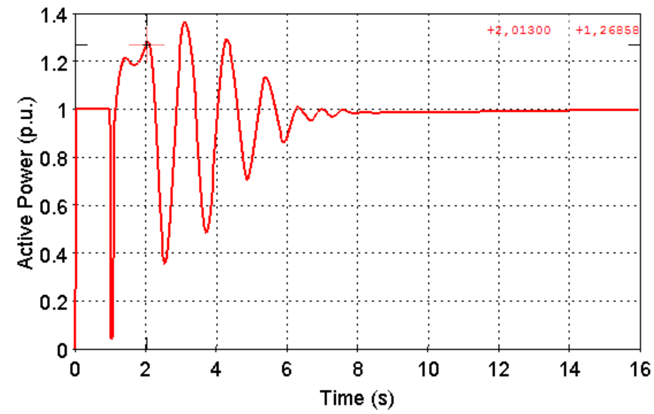

Fig. 6 Active power at PCC for b = 0.26 pu

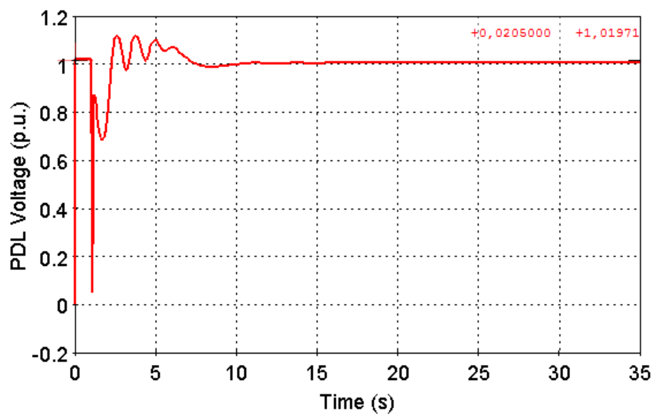

Fig. 7 RMS PCC Voltage for b = 0.26 pu

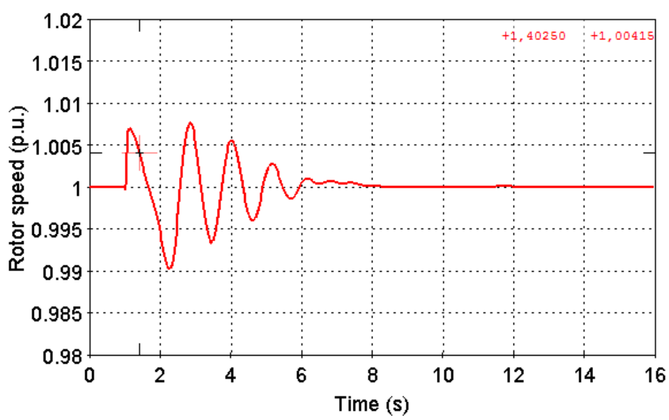

Fig. 8 Generator speed for b = 0.26 pu

Taking into account these results, the final values are computed with a 10% safety margin: b=0.26 x 0.9 = 0.23 pu.

C. *Uncertainty assessment: parametric study*

A parametric study was conducted in order to make sure that the 10 % margin is enough to take into account the uncertainty that exists on the generator parameters due to the variability among different units of the same type/family.

The uncertain parameters are x_d, x_q, x_l, x'_d, x''_d, T'_{d0}, T''_{d0}, x''_q and T''_{q0}. Given the 15% tolerance associated to several of the generator parameters in §4.19 of [2], a slightly higher value of 20% will be considered here to account for variability among units and evolution in time.

The interest quantities defined are:

- The damping time $T_{SP5\%}$
- Maximum and minimum frequency values
- Maximum and minimum SM power angle
- Time-domain signals of P_{PCC}, Q_{PCC}, V_{PCC}, V_a.

With the parametric tool 10 000 Monte Carlo simulations have been performed that cover the range of variation of the uncertain parameters. From these results, the following conclusions have been derived. The cumulative density function (CDF) of $T_{SP5\%}$ in Fig. 9 shows that among the performed simulations there is a 100 % probability that the active power damping time at the PCC is less than 7 s, which is below the criteria of 10 s.

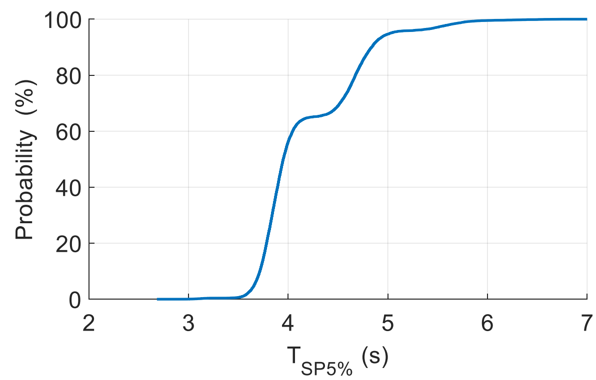

Fig. 9 Cumulative distribution function of $T_{SP5\%}$ after 10 000 simulations

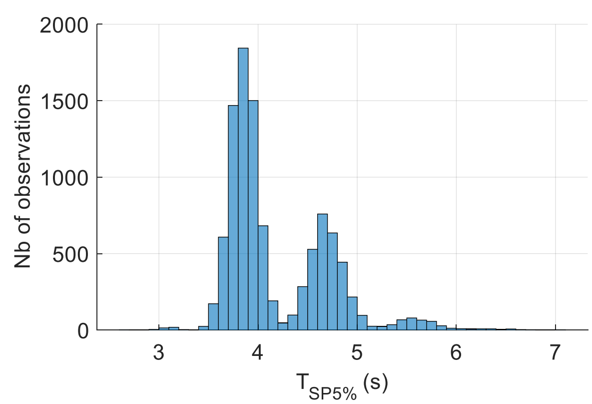

Fig. 10 Probability distribution function of $T_{SP5\%}$

Furthermore, the high and low values of some other key quantities are:

- The frequency varies between 49.45 and 50.45 Hz;
- The maximum PCC voltage reaches 1.13pu for a duration of less than 3 s;
- The power angle of the synchronous machine varies between 16.5 and 83 degrees.

The Figures 11 and 12 show the active power and voltage oscillations for each of the 10 000 simulations.

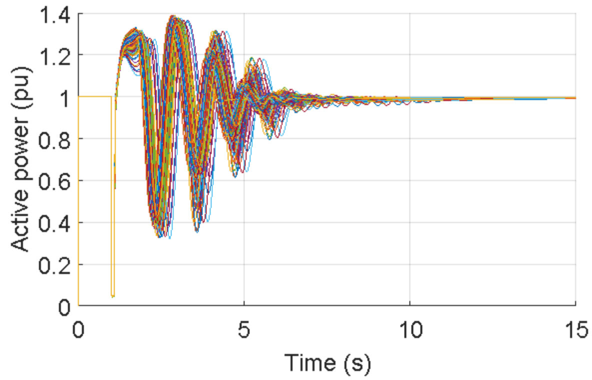

Fig. 11 PCC active power

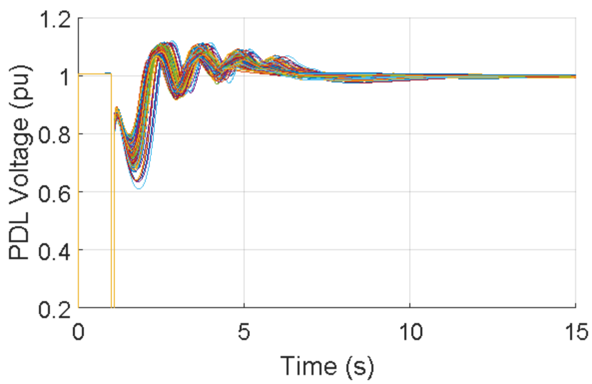

Fig. 12 PCC voltage

Finally, as a further analysis, Fig. 13 shows a cobweb plot for sensitivity analysis. In this type of plot, the parameter values are normalized for better readability. The values that give a $T_{SP5\%}$ over 5.7 s are shown in red. The rest of the simulations are showed in blue.

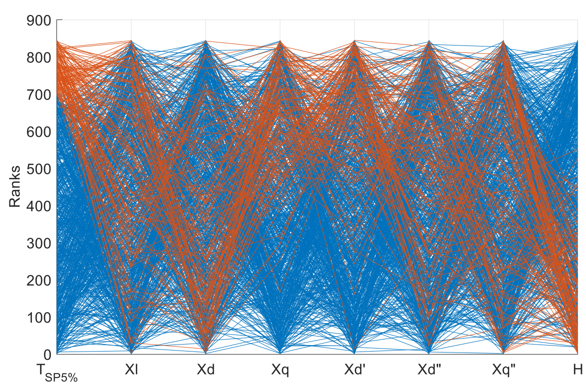

Fig. 13 Alternator speed for b = 0.23 pu

One can observe that the higher x_q, x'_d the higher the $T_{SP5\%}$. The same kind of conclusion can be made for the rotor inertia H. For small values of the inertia constant H we get an increase in the damping time of the PCC active power.

IV. CONCLUSIONS

This paper presented a parametric approach to the synchronous machine parameter determination and transient stability studies. This approach takes into account parameter uncertainties due to the determination procedures accuracy, ageing and variability among units of the same type.

First, it has been shown how parametric studies allow to fit generator models more accurately to match actual measurements. Second, that they allow to provide generic stability conclusions for all the generators of the same type. In particular, this approach ensures that the TSO conformity criteria are met for all the units of the same type.

To do so, EMTP-RV used with its parametric toolbox PAMSUITE can be of great help.

V. REFERENCES

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