Network parameters identification using a comparison between on site tests and simulations

B. Zouch, F. X. Zgainski, B.Caillault

***Abstract*-- The EHV network and power plant restoration plan is a key process of a fast re-energization of customers. The first step after a black-out consists in re-energizing lines and transformers, both on the network and in power plants, as soon as possible, without running risks. A first evaluation of the taken risk is performed by using computation tools. The temporary harmonic overvoltages generated by the transformer re-energization is then evaluated and compared with transformers limits [1] in order to classify the risk of failure in the energization.**

The proposed paper presents a parameters identification methodology based on a comparison between on site tests and simulations with a given model taken from the state of the art [2]. A real case with measurements will be presented. The specific on site tests performed before the energization of the transformer are explored and detailed. The line energizing is firstly used in order to minimize the uncertainty domain firstly adopted. It shows the possibility of using these signals to get information on the frequency response of the studied network. The application on a real case of a long line energized can show the advantages and the limits of the numerical model identification, on the uncertainties on the measurements and of the signal processing methods, on a three phase network.

***Keywords*: Parameter identification - Line energizing - Field tests.**

I. INTRODUCTION

IN order to do this risk analysis, large uncertainties are used on the data taken from the TSO or the owner of the electrical devices used for the power restoration purposes. It can be very useful to reduce these uncertainties by doing specific on site tests able to increase the understanding of the frequential behavior of the studied network [2].

Firstly, this paper describes the modeling of the network. Secondly, the results of the study are presented. Thirdly, field measurements are analyzed in order to reduce the uncertainties on network parameters. The possibility of excluding the extreme case considered in the initial study where overvoltages exceed the withstand voltage is examined. In this case, the 100 Mvar shunt inductor used to compensate the line and limit the overvoltages is sufficient and the use of a second inductor can be avoided.

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II. DESCRIPTION OF NETWORK MODELS PARAMETERS

The electrical components of the network are modeled using EMTP-RV [3]. The generator is represented by a perfect voltage source with a resistance and an inductance (sub-transient).

This simplified model is well adapted for the interval of frequencies studied [100 Hz-500 Hz], that are the frequency range resonances of our network [1].

Taking into account uncertainties on the value of the inductance compensates this simplification.

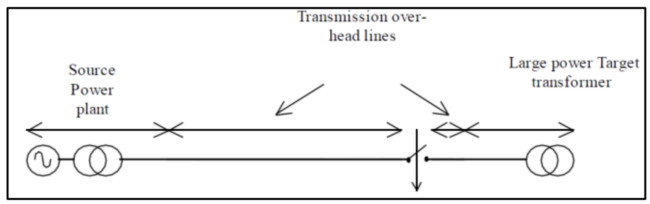

Fig. 1. Network configuration studied in the case of transformer switching

The line sections are modeled by using matrix PI section model that deals with both electrical and magnetic coupling between each electrical conductor [4], [5]. In order to represent the losses, parameters are calculated at the network resonance frequency. A good geometrical description of the over-head line towers is provided.

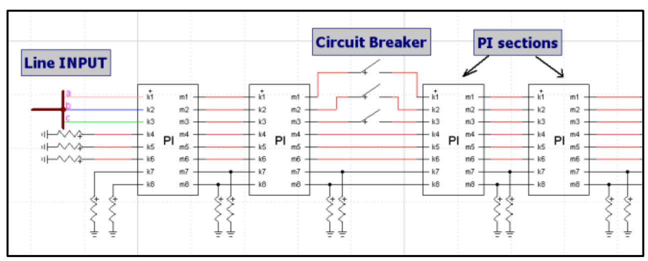

Fig. 2. PI section model

Uncertainties on the values of the line capacitances are also considered.

The circuit breaker is considered as an ideal switch with one switching time per phase that is to say three closing times defined.

The transformers are described by three single phase transformers, described by a classical model shown on the following figure that takes into account the iron losses, the resistances of each conductor, and the short circuits values of the transformer. The non linearity of the transformer magnetic core is modeled by a non linear inductance – characterized by a curve of the flux versus the current (flux(I)) – put in parallel with the iron loss resistance [6], [7].

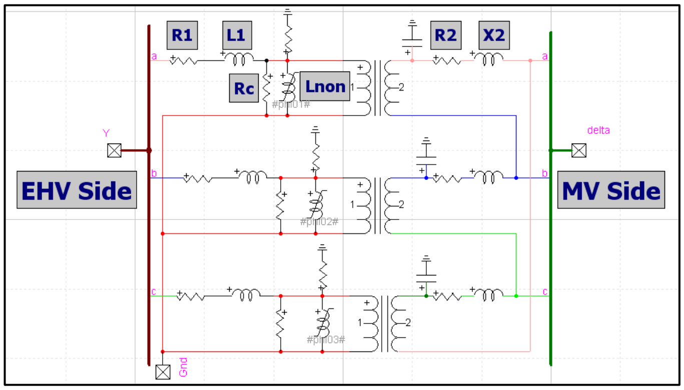

FIG. 3. Target transformer model

III. INITIAL STUDY

The first simulation consists in the computations of the overvoltages that happen at the power transformer energization.

In our case, the auxiliary transformer (96 MVA), located at 315 km of the 1300 MW source power plant, is switched on by a near circuit breaker.

The line is compensated by a 100 Mvar shunt inductor located at the end of the line.

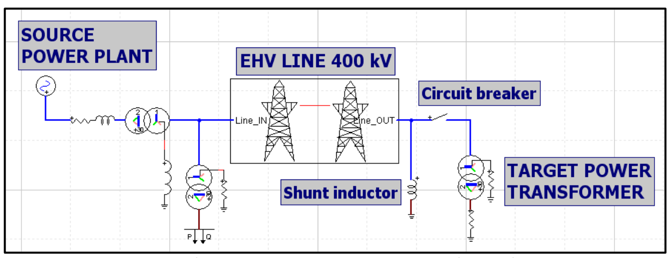

Fig. 4. Network configuration studied in the case of transformer switching

The simulations are made to check that the overvoltages levels and durations stay under the admissible limits given by the transformer manufacturer [1].

In order to take into account the uncertainties on the key parameters of the network, a large number of computations have to be performed [8], [9].

- First of all, the inductance of the generator is taken as a +/- 15% value around the direct-axis sub-transient reactance value (X"d).
- The phase-to-earth capacitance of the over-head lines (Cj/t) is supposed to be known at +/- 5%.

In order to consider the uncertainty domain corresponding to these two parameters, which have an influence on the network resonance frequency value, 25 couples of values are defined. Each couple has the same probability to fit with the real value, and is also associated with a network frequency value.

TABLE I
NETWORK RESONANCE FREQUENCY

Frequency (Hz)	ΔL=-15%	ΔL=-10%	ΔL=+0%	ΔL=+10%	ΔL=+15%
ΔC=-5%	170,1	168,4	165,2	162,1	160,6
ΔC=-2,5%	168	166,3	163,1	160,1	158,6
ΔC=+0%	166	164,3	161,1	158,1	156,7
ΔC=+2,5%	164,1	162,4	159,2	156,2	154,8
ΔC=+5%	162,2	160,5	157,4	154,4	153

Those frequencies correspond to the network studied (generator, source power transformers, EHV line and shunt inductor) without the target transformer.

We can underline that the proximity of this frequency with a harmonic of the 50Hz will lead to particular resonances.

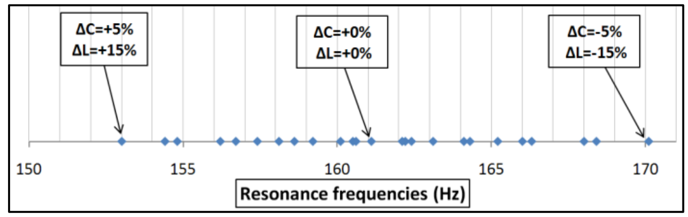

FIG. 5. Network resonance frequency

For each couple defined, in order to perform a Monte Carlo analysis, 200 computations are done statistically to deal with the random switching initial conditions: closing times of the three circuit breaker poles, and the three remanent fluxes in the transformer core.

These initial conditions are considered as random conditions because they cannot generally be imposed and controlled. We use our historical set of measurements in order to have an idea of their extreme values and apply random laws on these conditions.

- The closing times rules are the following ones: the first pole of the circuit breaker is closed anytime on one time period and the second and third pole are closed with a standard deviation of 20 ms (i.e. one period of 50 Hz).
- The remanent flux values in the three limbs of the transformer follow a uniform distribution, and are supposed to reach 0,8 p.u. [1]; due to the winding delta connection always present in the power plant or network transformers considered, the sum of the three remanent flux values is assumed to be equal to zero.

The saturation curve, and especially the air-core reactance (Lsat) i.e. the final slope of this curve, is a key point for the computation of the inrush currents but this value is not very easy to obtain. The transformer manufacturer provides a Lsat slope value with a dispersion usually considered of +/-20 % around a computed value. The lower value is taken in the simulations in order to make a conservative diagnostic.

The results of the computations are the estimated probability to get temporary overvoltages higher and longer than the limits prescribed given in [2].

The following figure gives the simulation results obtained in the 25 cases considered. The phase to phase and phase to earth voltages are compared to the withstand voltage of the power transformer insulation. Only the extreme case considered in the study (ΔC=+5% and ΔL=+15%), that corresponds to 153 Hz (near to a harmonic frequency) leads to overvoltages exceeding the withstand voltage.

The overvoltages are shown in the following figure where are plotted the phase voltages envelopes (for the case ΔC=+5% and ΔL=+15%). The red and blue horizontal lines correspond to the voltage limits.

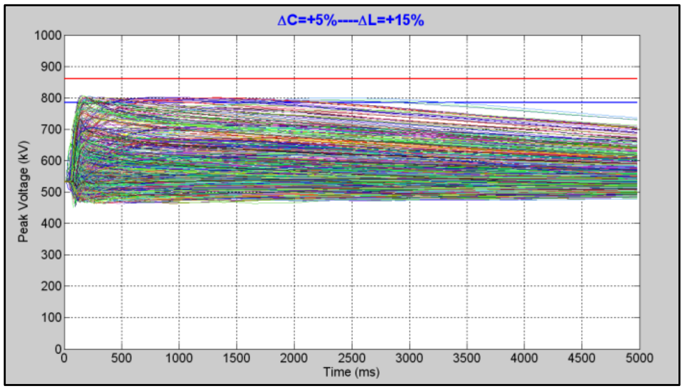

Fig. 6. Initial study results

To put it in a nutshell, in order to know if we run a risk in this switching, we have to reduce the uncertainties on the main parameters of our system. The first idea is to perform dedicated on-site tests in order to get information from the studies network.

IV. Field Tests and Measurements

Field tests are performed in order to reduce the uncertainties on parameters L and C.

Much of the open-ended line (290 km/315 km), without the target transformer and the shunt inductor, is energized by closing the circuit breaker located next to the source power plant.

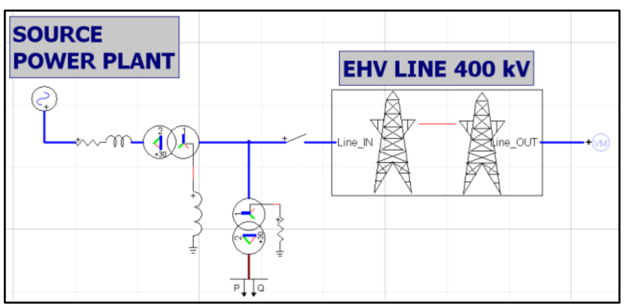

Fig. 7. Network configuration tested in the case of line energizing

The measurements of the voltages and the currents are performed during the tests at both ends of the line [10]. Furthermore, a dedicated recording system has been installed on both sides of the circuit breaker with a sufficiently high acquisition rate.

A. Reducing the uncertainty on the line capacitance value

On the one hand, the line capacitance is evaluated by using the voltages and currents measurements.

For an EHV line, the capacitive term is the main term in the expression of the impedance magnitude and we can neglect the other ones.

$$|Z| \approx \left| \frac{1}{C\omega} \right|$$

Thus, we can estimate the capacitance of the line by calculating the impedance |Z|=Vrms/Irms, where Vrms and Irms are the voltage and current measured at the beginning of the line.

The measured impedances of the three phases are not constant and can vary. The following figure shows the measured impedance as a function of time.

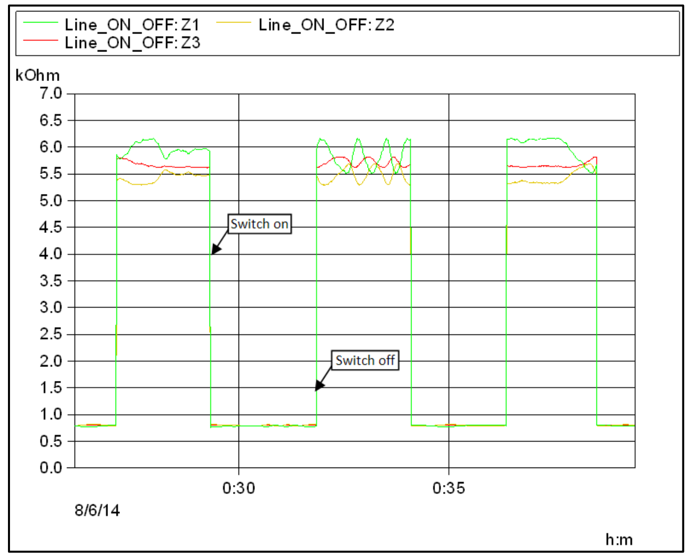

Fig. 8. Line impedance – measurements

The impedance varies as a function of the network configuration and also because we have coupling between the studied network and the interconnected network by the double-circuit lines.

For the comparison with the simulations, we use the average values of these impedances.

TABLE II
Line Impedance – Comparison Between Measurements and Simulations

Line Impedance (per phase) (measurements)	Line Impedance (per phase) (calculations)	Difference
$Z_{1measurement} = 789\ \Omega$	$Z_{1simulation} = 832\ \Omega$	$\Delta Z_1 = 6\%$
$Z_{2measurement} = 797\ \Omega$	$Z_{2simulation} = 813\ \Omega$	$\Delta Z_2 = 2\%$
$Z_{3measurement} = 800\ \Omega$	$Z_{3simulation} = 857\ \Omega$	$\Delta Z_3 = 7\%$

In order to check this hypothesis, we also use the reactive power measured at the source (AC generator) to estimate the average capacitance of the lines.

The reactive power measured is equal to -157 Mvar.

The reactive power calculated with our model is equal to -149 Mvar. Applying +5% to the capacitance of the line brings the reactive power to -157 Mvar.

B. Initial conditions

In order to be precise with respect to the closing times of the three poles of the circuit breaker we have installed a dedicated set of recorders on the both sides of the circuit breaker. Then, the switching times are obtained by superposing the voltages measured on both sides of the circuit breaker.

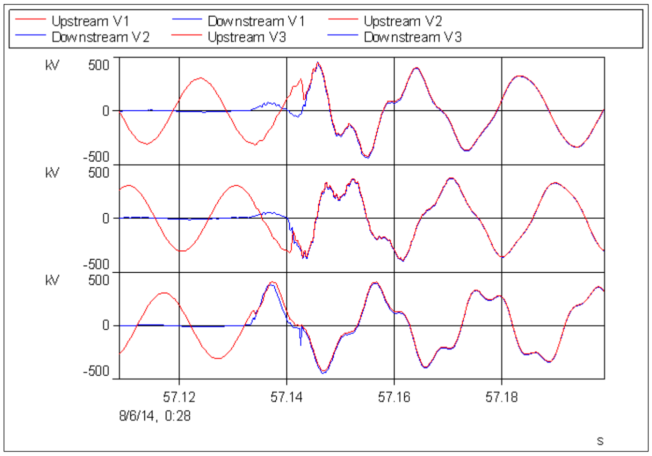

Fig. 9. Three phases voltages on both sides of the circuit breaker

The disturbance observed on the currents is also used to find the switching times. Those times are determined with an accuracy of +/-1ms and are then used in EMTP-RV to simulate the transient state that happens at the energization of the power line. We have made seven switchings in order to have a good understanding of the frequency response of the system.

The three closing times have the same reference to the zero crossing on phase A.

TABLE III
SWITCHING TIMES OBTAINED

Closing times (reference to the zero crossing on phase A)	t1 (ms)	t2 (ms)	t3 (ms)
Line energizing N°1	24	21	15
Line energizing N°2	15	12	7
Line energizing N°3	11	9	5
Line energizing N°4	16	15	10
Line energizing N°5	21	18	14
Line energizing N°6	17	16	12
Line energizing N°7	23	21	17

We can note that each closing time is different and that the maximum delay between the closing times is about 10 ms.

C. Spectral analysis – measurements

When energizing the line seven times, voltages do not resonate in the same way. We decided to retain only the first energizing where voltages resonate the most and where the voltages spectrum has the largest amplitude.

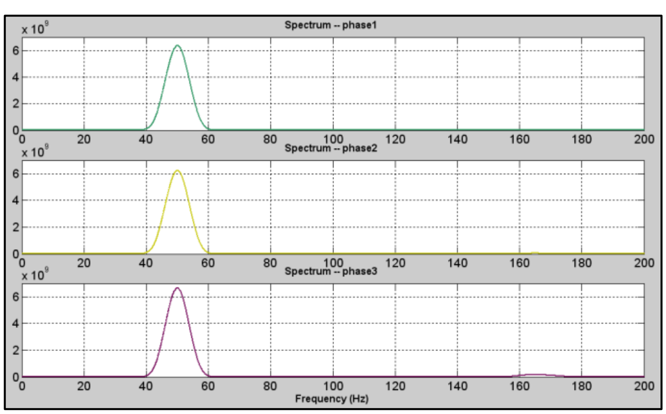

Fig. 10. Voltages spectrum (measurement) [0-200Hz]

The spectrum of the voltages measured at the end of the line is calculated to determine the natural frequency resonance of the line.

The spectrum of the figure 10 highlights two frequencies:

- The first at 50Hz represents the frequency of the voltage source.
- The second around 160Hz, represents the natural frequency of the studied line.

The natural frequencies of the voltages are determined by analyzing the spectrum of the measured phase-to-ground voltages measured at the line's end. Then, with our model, we look for the fitting values of L and C that lead to a similar frequency response.

We already have an idea about the value of C from the steady state comparisons; this frequency analysis helps us accurately determine the parameter L.

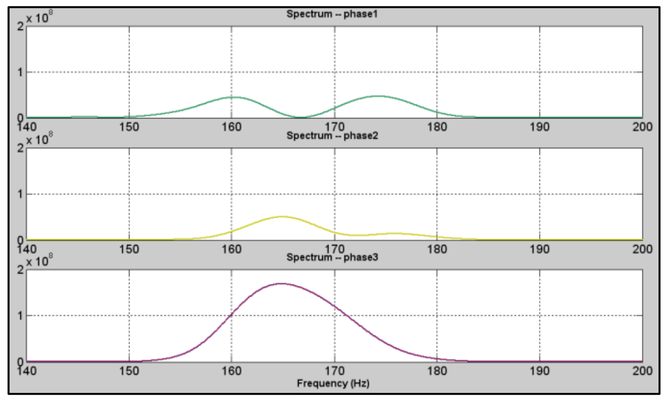

Fig. 11. Voltages spectrum (measurement) [140-200Hz]

We note that on the same spectrum two neighboring frequencies may occur. We filter the zero sequence voltage and work only on the filtered voltages of the three phases. The next figure illustrates the spectrum of the filtered voltages.

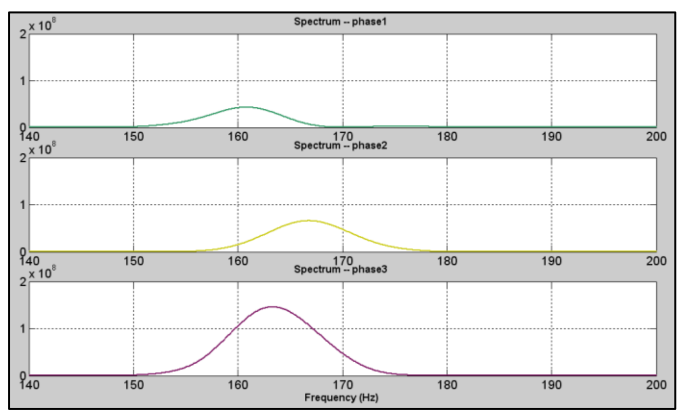

Fig. 12. Filtered voltages spectrum (measurement) [140-200Hz]

Each spectrum has one visible peak now. The maximum of the spectrum gives the resonance frequency which is different for each phase. The resonance frequencies values are: 161 (Hz) for the 1st phase, 167 (Hz) for the 2nd phase and 164 (Hz) for the 3rd phase.

TABLE IV
RESONANCE FREQUENCY (HZ) - MEASUREMENTS

Phase 1	Phase 2	Phase 3
161	167	164

Those frequencies correspond to the network tested with much of the line (290 km of 315 km) and without the 100 Mvar shunt inductor.

D. Spectral analysis - simulation

In simulation, the natural frequencies of each phase are relatively close contrary to what was observed with measurements.

The amplitudes of the spectrum are larger than those measured. This difference is not related to the inaccuracy of the switching times: we verified that a variation of +/- 1ms did not change the spectra.

The two case where we increase the three capacitances with the same coefficient (ΔC=5%) and with different coefficients ΔC_1=6%, ΔC_2=2%, ΔC_3=7% give the same resonance frequency.

The resonance frequencies calculated from simulations with ΔC=5% and different values of ΔL are shown in the following table.

TABLE V
RESONANCE FREQUENCY (HZ) - MODEL

ΔC (%)	ΔL (%)	Phase 1	Phase 2	Phase 3
5	-15	168	167	168
5	-10	166	166	166
5	0	162	162	162
5	10	158	159	159
5	15	156	158	157

Using this comparison between the calculated resonance frequency with measurements and simulations, we can conclude that we have the following values for our parameters: $\Delta C \approx +5\%$ and $\Delta L <= 0\%$.

The extreme case considered in the initial study (ΔC=+5% and ΔL=+15%) where overvoltages exceed the withstand voltage is excluded.

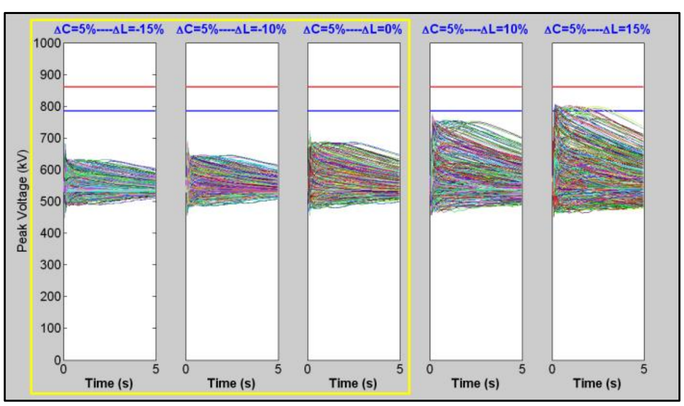

Fig. 13. Initial study results – cases selected

The cases selected (framed in yellow) correspond to resonance frequencies close to those measured.
The results of the initial study are thus refined by the use of measurements. The 100 Mvar shunt inductor used to compensate the line and limit the overvoltages is sufficient. The use of a second inductor is avoided.

V. CONCLUSIONS

This paper underlines the need of field tests in order to improve the modeling of transient overvoltages with EMTP.
It focused on the real case of an EHV line energization (290km).
The initial study of a power transformer energization (96MVA) shows that the extreme case considered (ΔC=+5% and ΔL=+15%) leads to overvoltages exceeding the withstand voltage.
It was then decided to perform field tests and measurements to reduce the uncertainties on the line parameters.
On the one hand, the line capacitance is evaluated by using the voltages and currents measures. On the other hand, with our model, we look for the fitting values of L and C that lead to a similar frequency response.
Using this comparison between the resonance frequencies calculated with measurements and simulations, we conclude that we have the following values for our parameters: $\Delta C \approx +5\%$ and $\Delta L <= 0\%$.
The extreme case considered in the initial study (ΔC=+5% and ΔL=+15%) is thus excluded.

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