

Identification of network models parameters for simulating transients

D. Cavallera, J-L. Coulomb, O. Chadebec, B. Caillault, F-X. Zgainski and A.Ayroulet

Abstract—In case of electrical black-out, one of the first critical operations consists in reenergizing power transformers on weak networks. The temporary harmonic over-voltages, that occur during the switching of the transformers, depend on the frequency resonance of the network composed by the power source and the EHV lines.

The use of field test measurements appears to be the best way for the identification of electrical parameters needed to model these transients, but, due to the high number of parameters and the few number of switching operations measurements, the methodology has to be improved.

The present work deals with the identification of network parameters from the EHV lines switching, in order to use them in the simulation study of the transformer switching.

Keywords: identification, simulating transients, EHV lines.

I. INTRODUCTION

In the process of overvoltage studies realised, the last step of validation is to compare simulations and real measurements. The data used to realise the comparison are the voltages and the currents measured when the transformer is switched on. The following figure gives an example where a target transformer is energized after the lines (Fig. 1)

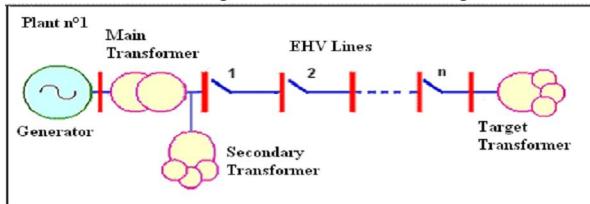


Fig. 1. Network configuration studied in the cases of lines and transformer switching

The EMTP-RV (ElectroMagnetic Transient Program) software is basically used to simulate the network and

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MATLAB is used to : execute EMTP, modify the network parameters in their uncertainty domains and finally to do the comparison between EMTP simulation results and the real data [1].

During sudden re-energization of a transformer (typically at 400 kV), hypothesis are done to model the network components [2]. The main difficulty is the modeling of the following components of the network : the generator, the line capacitance and the magnetic characteristic of the transformer (residual flux, magnetization curve). Simulations are done taking in account uncertainty domains on these parameters and variability on initial conditions i.e. the switching times of the circuit breaker and the resistive part of these elements in harmonic resonance .

The comparison results show that it is very hard to converge on a single solution. In the present work, the study has been simplified in order to understand the different phenomena that are visible on the recorded signals. This paper concerns the previous EHV line energization from a single generator. Allowing to identify the parameters of the generator and of the lines, the number of variable parameters of the study is thus reduced. Then the simulations of the transformer switching can be done with reduced uncertainties.

The first part of this paper describes a very simplified mathematical model for the computation of the switching overvoltages. The second part shows the identification of network model parameters (application with EMTP-RV and sensitivity study) and methods using signal processing. The last part presents an identification of models parameters with real measurements.

II. DESCRIPTION OF NETWORK MODELS PARAMETERS

A. Description of the modeling of the network

The system studied is composed by a generator, a step up transformer and a short EHV line. A very simplified single line phase diagram is used. The generator is modelled by an electromotive force, a resistance and an inductance. The transformer is characterized by a fixed resistance and inductance. The line is modelled by a capacitance. This hypothesis is acceptable in our case because the length of the lines is inferior to 50 km. These elements are presented in Fig. 2.

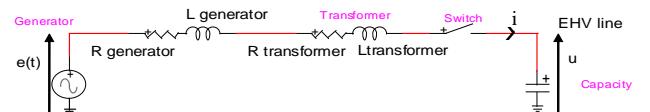


Fig. 2. Simple modelling in the case of a short EHV line

In order to work with a real system, the components data are computed and then extracted from a real case. Value Parameters are presented in the Table I. The different network components values are calculated at 400 kV RMS voltage level.

TABLE I
NETWORK DATA FOR CALCULATION

	Units	Values
E	V	215640
Lgenerator	mH	137
Rgenerator	Ω	22.3
Ltransformer	mH	68.7
Rtransformer	Ω	0.75
Capacitance	μFarad	0.548

The differential equation that describes the system in Fig. 2 is (1):

$$\frac{d^2u(t)}{dt^2} + 2\lambda \cdot \frac{du(t)}{dt} + \omega_0^2 \cdot u(t) = e(t) \quad (1)$$

Where: $R = R_{\text{generator}} + R_{\text{transformer}}$,

$$L = L_{\text{generator}} + L_{\text{transformer}},$$

$$\lambda = \frac{R}{2L} \quad \text{and} \quad \omega_0 = \frac{1}{\sqrt{L \cdot C}}$$

The term λ is the damping factor of the signal and ω_0 is the resonance frequency. The expression of the electromotive force is done by the following expression, (2):

$$e(t) = E \cdot \sqrt{2} \cdot \cos(\omega \cdot t + \psi) \quad (2)$$

In this equation, ω is the angular frequency of the electromotive force and ψ is the voltage angle of the line energizing, supposed done at $t=0$. The voltage, $u(t)$, at the end of the line and the current, $i(t)$, that circulates through the line are linked between the simple capacity equation. At the beginning, there are no residual voltage, no current and no electrical charge on the line.

The differential equation is solved. The mathematical time dependent equation for the voltage is exposed hereafter, (3):

$$u(t) = \frac{(E\sqrt{2})}{Z} \times \frac{1}{(C \cdot \omega)} \left[\cos(\omega \cdot t + \psi) - \cos(\psi) \times e^{a_1 \cdot t} + \left(\frac{\omega}{\omega_0} \right) \times \sin(\psi) \times e^{a_2 \cdot t} \right]$$

The terms a_1 and a_2 depend on λ and ω_0 . A mathematical model was built for the computation of the switching overvoltages in the 400 kV network with fixed and variable parameters [3-4].

B. Illustrations of voltage and current signals

Sometimes, when a line is energized, overvoltages can appear, system exist to minimize these phenomena [5]. The main factor that we can control is the voltage angle of the line energizing (ψ). For example, if $\psi = 0$ (rd), the voltage value in (2) at the switching time $t=0$ (s) is a maximum [6]. The

different equations exposed before are scripted using MATLAB and computed signals are presented in Fig. 3.

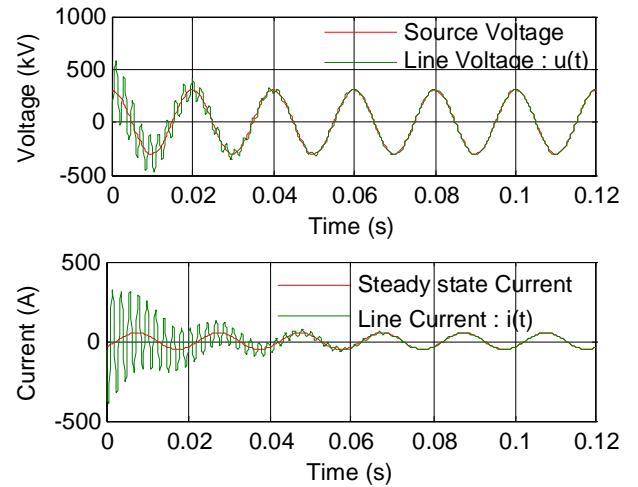


Fig. 3. Voltage and Current signals for a single line energizing

III. IDENTIFICATION OF NETWORK MODELS PARAMETERS

The main variable parameters in the studied modelling are the generator inductance and resistance, line capacitance and the voltage angle of the line energizing. In this part, two methods are established in order to determine the network variable parameters.

In the first analysis, the reference signal is obtained by simulation. The first one does the identification of the variable parameters using the time signals (currents, voltages) with a genetic algorithm.

The second one applies signal processing methods on simulated data. MATLAB is used to program the script and for its optimization algorithms.

A. Identification from time signals with a genetic algorithm

The identification of variable parameters is based on a genetic algorithm. It is known that the main performance is to find the global optimum of the system instead of the local ones. The time signals are generated by mathematical equation solved with MATLAB. This process is very fast and so the utilization of a genetic algorithm, that uses the objective function a great number of times, is not a problem. The objective function is based on the least square method. The formulation of the method is (4), within the function on MATLAB, (5).

$$\text{Error} = - \frac{\text{Norm2}(\text{Signal}_{\text{reference}} - \text{Signal}_{\text{simulation}})}{\text{Norm2}(\text{Signal}_{\text{reference}})} \quad (4)$$

$$\text{where} \quad \text{Norm2}(V) = \sqrt{\sum |V|^2} \quad (5)$$

The genetic algorithm goal is to maximize an adaptation, that is why the equation of the objective function is negative. The comparison between the reference signal and the computed

signal is realised point to point. Consequently the sampling frequency choice is very important and has a real influence on the computed error (objective function of the identification algorithm). Fig. 4 presents a schematic view of the identification method.

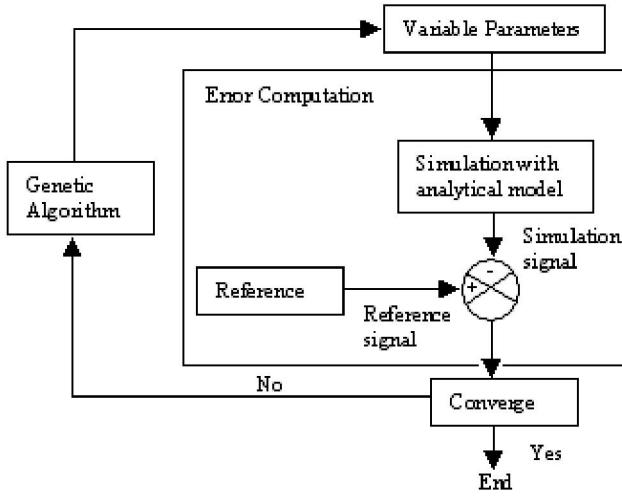


Fig. 4. Schematic algorithm of identification parameters

The input data of the genetic algorithm are the following: the number of populations is set to 10, the number of generations is set to 500 and the parameters uncertainty interval is $\pm 20\%$ for each parameter.

In order to implement and validate the identification methodology, a simple research of one variable parameter have been firstly done. The reference case is a computed time signal exposed in Fig. 3, obtained with data presented in Table I. The comparison is realised on a window including the transient and the beginning of the steady state, that represents 120 ms and 1200 comparison points because the sampling period is 10 kHz. Despite the overestimated choice of input data of genetic algorithm, the simulation time for one identification is less than 10 seconds. For example, with a comparison based on the voltage signals, the algorithm converges, with a maximum error of 0.05% after the first 100 generations.

The same identification method is then applied with four variable parameters: the inductance and the resistance of the generator, the line capacitance and the voltage angle of the line energizing.

The voltage angle of the line energizing, ψ , the damping factor of the signal, λ and the resonance frequency, ω_0 are obtained with a high precision with this method.

Despite a perfect superposition of the voltage signal, the resistance, the inductance of the generator and the line capacitance do not match the reference values.

Another strategy is used to find the three last variable parameters. When the steady state is reached, the exponential terms, in (3), disappear. Taking into account a phase shift of $\pi/2$ between the signals of current and of voltage and using the ratio I/U , the line capacitance value can be obtained. This line capacitance and the resonance frequency allow us to obtain the

inductance of the generator. The inductance value of the generator and the damping factor allow us to obtain the resistance of generator. In this way, an identification method is established but we can notice that uncertainties can spread along these parameters calculations. In order to validate the identification tools, we now use them with simulated data generated by the software EMTP-RV.

B. Application with EMTP-RV

In this part, the reference case is generated by the software EMTP-RV. The data of the reference case and the results obtained by identification with four variable parameters are presented in Table II.

TABLE II
THE DATA FOR THE REFERENCE CASE, THE SYSTEM BOUNDS AND THE RESULTS

Variable parameters	Reference Case	Inferior limit	Superior limit	Obtained results (Error %)
Capacitance (μF)	0.5	0.4	0.6	0.54 (8%)
Inductance (mH)	140	100	200	123 (12%)
Resistance (Ω)	20	2	50	18.33 (8%)
Voltage angle of the line energizing (rd)	0	0	$\pi/10$	0 (0%)

The results obtained from a single identification show once more that it is not possible to perfectly find the resistance, the inductance and the line capacitance. Nevertheless, the parameters ω_0 and λ obtained after the identification match the reference case (Table III).

TABLE III
STUDY CONSTANTS: REFERENCE CASE/ IDENTIFICATION RESULT

Constants	ω_0 (rd \cdot s $^{-1}$)	λ (s $^{-1}$)
Reference case	3085	49.4
Identification result	3085	49.4

The goal is reached because the study constants allow to find all variable parameters.

In order to check the link between the initial parameters, the following part proposes a sensitivity study.

C. Sensitivity study on representative model parameters

The objective of this sensitivity study is to show if there is a link or not between parameters. The reference case parameters and the limits variable parameters are exposed in the Table IV.

TABLE IV
DATA FOR THE REFERENCE CASE, BOUNDS OF THE SYSTEM

Variable parameters	Reference Case	Inferior limit	Superior limit
Capacitance (μF)	0.57	0.528	0.612
Inductance (mH)	143	121	164
Resistance (Ω)	14	2	30
Angle of the line energizing (rd)	$0.73*\pi$	$0.63*\pi$	$0.83*\pi$

The reference case is simulated on 100 ms, keeping only the transient perturbation. The sampling frequency is fixed to 10 kHz and the voltage signal is used to realise the study. The method principle is to fix 2 parameters therefore the other two

parameters remain free. The parameters values are expressed in p.u.

The objective function computes the errors between the computed and the reference signals, when varying the parameters in their uncertainty domains.

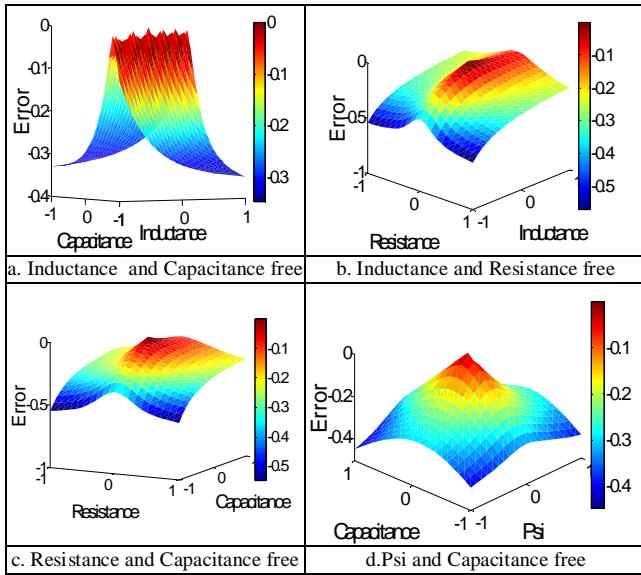


Fig. 5. Results of simulation study with different configurations

The correlation between the capacitance and the inductance values is highlighted by a “crest” form variation in Fig. 5a. This link can be explained by the fact that we can have different value of the capacitance and the inductance for the invariability of the frequency resonance variation, ω_0 .

In Fig. 5b the “crest” form variation shows the link between the resistance and the inductance values. This time the variation gradient is smaller. The damping factor of the signal, λ , contains this physical link. An of one of this two parameters variation has a smaller influence to the system. The link between capacitance and resistance is presented in Fig. 5c. This link is explained by the appearance of inductance in both expressions of λ and of ω_0 . Finally, the peak form in Fig. 5d. is the perfect example of no physical link between the voltage angle of line energizing and the capacitance.

This analysis confirms the links between the variable parameters of the model in the equation. The amplitude of the objective function for different couple of parameters allows us to measure the sensitivity of the model.

D. Methods using signal processing analysis in order to find variable parameters of the model

In order to determine more precisely the variable parameters of the model, a method using signal processing is developed in this part. The voltage and current signals, obtained during the switching of the line, have lots of harmonics. That is why the tools based on signal processing can allow us to determine the model parameters.

The time signals are generated by the mathematical model developed in §IIA. The data used are exposed in Table I.

The first step is to determine the signal fundamental frequency for two reasons. First reason is to obtain precisely the capacitance using the ratio I/U . The second reason is that it allows us using subtraction of the fundamental component of the signal afterwards.

Indeed, deleting the fundamental component allows to improve the transient characterization.

There are two possibilities: the use of filters or the use of subtraction. The filter type used is a butterworth highpass with cutoff frequency set at 300Hz. The voltage signal filtered is illustrated in Fig. 6.

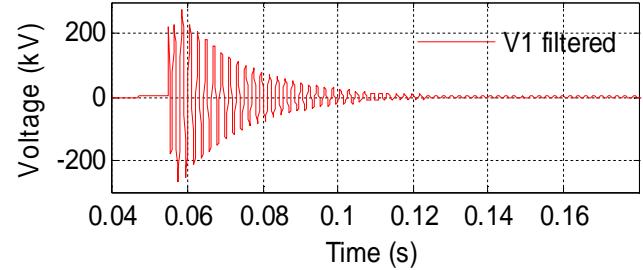


Fig. 6. Voltage signal filtered

The 50 Hz component has thus completely disappeared, but the disadvantages of the filter are the delay introduced and the data loss, for the first two periods of ω_0 . The subtraction method allows to delete perfectly the fundamental component of the signal and we avoid the delay introduced by the filter.

The second step consists in evaluating the resonance frequency of the signal. The spectrum is computed using the pwelch MATLAB function. With a signal sampling frequency of 10kHz, the precision obtained is of 2.5 Hz. To improve artificially this precision by ten, a frequency interpolation is realised. The calculated frequency resonance is 474 Hz and the precision is improved.

The inductance value is obtained as the previous method, by using the ω_0 and the capacitance value calculated with the final established values of $u(t)$ and $i(t)$.

Then the determination of the damping factor of the signal is needed in order to obtain the resistance value.

First the absolute values of the signals is used. Then the maximum signal amplitude is found. Then the next maximum is determinate for the next semi-period of ω_0 . Iteratively each semi-period maximum is obtained. The curve equation is shown in (6), where A is the signal amplitude and λ is the damping factor.

$$E(t) = A e^{-\lambda t} \quad (6)$$

To determine the damping factor, the signal logarithm is computed point by point.

The found damping factor is of $53.7 (s^{-1})$, therefore the error is of 4%. To improve this result, the reference signal must have a sampling period greater than 10 kHz. The results obtained with other sampling frequency values are presented in Fig. 7 on voltage and current signals.

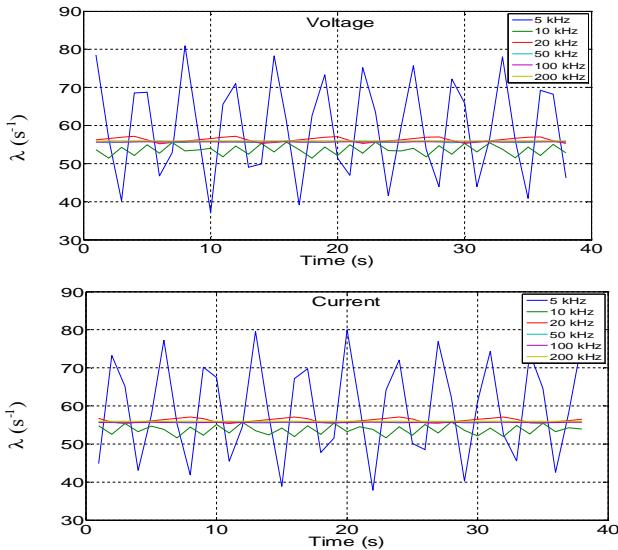


Fig. 7. Damping factor for different sampling period

The resistance can be precisely calculated if the precision on the damping factor is sufficient.

The network parameters are determinated using two methods. The first one is based on the identification of the time signals (current, voltage) by the use of genetic algorithm toolbox in the MATLAB environment [7]. The second one is using signal processing methods applied on the simulation data. The signals have often a rich harmonic resonance as case transformer re-energization [8].

IV. IDENTIFICATION OF MODEL PARAMETERS ON REAL MEASUREMENTS

After these theoretical applications, a few comparisons with on site tests measurements have been done. Generator and transformer parameters are typically the same as those illustrated in Table I.

In Fig. 8 the result of identification parameters with genetic algorithm is illustrated.

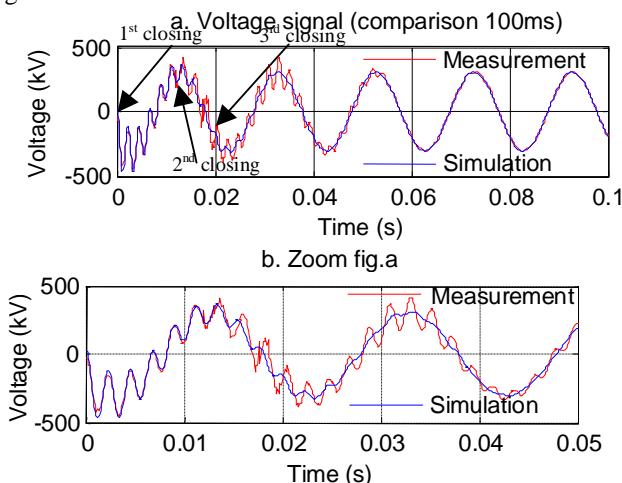


Fig. 8. Comparison between voltage measurement and simulation (phase 1)

The comparison between the signal simulations and the signal measurements on the first 100 ms (Fig. 8a. and Fig. 8b.) shows the good determination of the resonance frequency on the first simulation instants. But differences remain between the signals amplitudes, the damping effect is not well estimated. The best amplitude correlation is done in the first 15 ms.

Between the 1st and the 2nd closing of the circuit-breaker (CB) poles, the signals correlations are acceptable. After the second CB pole closing the signals are not correlated. The problem is due to the coupling with the other lines supplied on the interconnected network and to the differences of the specifically parameters of the capacitance values on each phase. The simple mathematical model is not adapted for the computation of a three phase network because of the variation of the resonance frequency on each phase.

The real measurement in Fig. 9.a and real measurement without the zero sequence component in Fig. 9.b. illustrate the identification results applied on the 3rd phase after the 3rd CB pole closing (comparison on the first 60 ms).

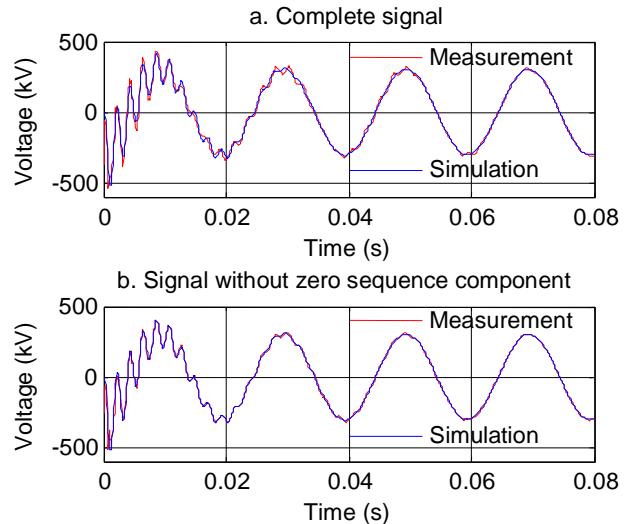


Fig. 9. Comparison between voltage measurement and simulation (phase 3)

The best signals superposition is obtained using the signal without zero sequence component (Fig. 9b). The parameters determination is exposed in the Table V, with the following color code: complete signal in blue and signal without the zero sequence component in red.

TABLE V
IDENTIFICATION RESULTS BASED ON DIFFERENT TIME INTERVALS

Time intervals (ms)	Resonance frequency (Hz)	ω_0 (rd s ⁻¹)	λ (s ⁻¹)	ψ (rd)	Error
1 to 10	471	2959	77.75	0.4*π	-0.193
1 to 10	469	2946	122	0.4*π	-0.165
1 to 30	471	2957	105	0.4*π	-0.155
1 to 30	469	2948	113	0.4*π	-0.104
1 to 60	470	2953	105	0.4*π	-0.122
1 to 60	469	2946	111	0.4*π	-0.081

For every time interval, the error between simulation and real measurement appears smaller in the case of signal without zero sequence component. The instant of line energizing can be determinated. The resonance frequency and the damping factor can be identified using the proposed method.

The identification of parameters using current signal is more difficult because the real current measurements are very small and less precise than the voltage measurements due to the low value of the current of the unloaded lines.

Furthermore, the identification method shows that the resonance frequency is different for each phase (signal without the zero sequence component). The results using the signal processing method are the same as the results using identification method. The voltage and the current spectrum are illustrated in Fig. 10.

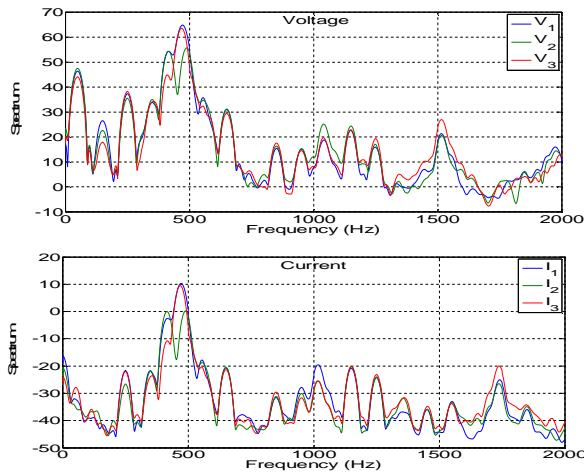


Fig. 10. Voltage and current spectrum

The maximum of the spectrum gives the resonance frequency. The resonance frequency values are: 472 (Hz) for the 1st phase, 490 (Hz) for the 2nd phase and 468 (Hz) for the 3rd phase. The resonance frequency depends mainly on the capacitance of the conductors that depends on the topological location of the conductor on the pylon. These frequencies are different for each phase.

The comparison between the simulations based on the mathematical model and the real measurements shows the limits of the tool and the complexity of parameters identification and thus of three phase network studies.

V. CONCLUSION

Parameters identification appears essential in order to validate overvoltages studies. The comparison between a reference signal obtained by simulation allows us to understand the sensitivity of the numerous parameters of the equations. A parameters identification method using genetic algorithm and a method using signal processing have been presented in this paper. The line energizing is firstly used in order to minimize the number of variable parameters. It shows the theoretical possibility of using these signals to reduce the uncertainty considered on the parameters. The application on a real case of a short line energizing shows the limits of the

mathematical model and of the signal processing methods, on a three phase network. A practical conclusion is that it is necessary to increase the sampling frequency during line energizing in order to improve the parameters determination with signal processing.

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