Transients Simulation in Low Voltage Power System

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Abstract— **Transients in low voltage power system are generally unknown. Facing to lightning overvoltages, a lot of people just consider standards and take into account voltage surges of 1.2/50µs type or current surges of 8/20µs type. Measurements and simulations show us that reality is quite different. Modeling and simulating transients in low voltage cables can be difficult : geometry of the grounding system, missing information about high frequency behaviour of cable and transformer for example. Moreover, the right simulation of the system requires a validity of each model of the several parts of the network. Arresters allow you to have a more secured power system, but design and location remain in question. This paper is a contribution to answer these questions.**

Keywords : Low voltage, power system modeling, high frequency, ATP, EMTP, arrester, line and cable modeling

I. INTRODUCTION

Optimizing the power system is becoming the major current trend. A better knowledge of phenomena, a rising competition between electricity actors make reduce the security margin of products in general. At the same time, electronic devices are introduced more and more in equipments, what involves some questions about the withstands to meet in order to insure an acceptable power quality.
From a system point of view, three main points have to be managed : which constraints occur where product is installed without protection, what is done by protection devices and what is the out-of-work limit for the product installed. Standard on product allows one to have a minimal information about the withstands for the two last points : protection devices, product. For the first point many cases can been encountered, what justifying a general simulation approach.
This paper deals with high frequency transients as lightning overvoltages. Modeling and simulation are done with ATP-EMTP. Two points are more thoroughly developped : arrester model and cable model. High frequency entails to use a distributed parameters model for the cable : JMarti is successfully used but a frequency dependant parameter need to be set well, the distributed conductance.
Some results of real recorded signals and simulations on low voltage power system are finally given.

II. MEASUREMENT / MODELING

A. *arrester model*

A 8/20 generator has been used to characterize the protection devices. The arrester (Imax=8kA) has been tested for the following range of current [0.5kA-8kA].

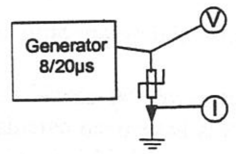


Fig. 1 : Electrical diagram

These measurements allow one to determine the value of the stray inductance L and to identify the U-I curve of the varistor . The stray (a few nF) capacitance was determined by using an impedance analyser

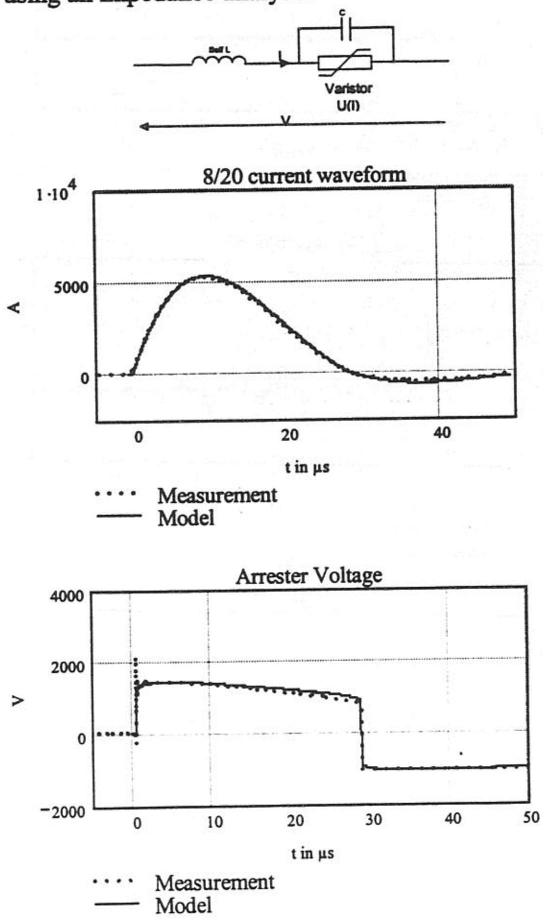


Fig. 2 :ATP-EMTP arrester model and simulation

B. *cable model*

Wave propagation tests have been recorded on typical 2.5mm² low voltage cable (four-wires system with phase, neutral, ground-wire and one sheath).
Characteristic frequency observed due to the signal injected and the length of the cable is around 500 kHz.
Cable parameters (CP) and JMarti setup have been used to define the model (convergence troubles occurred when using Noda Setup).
Fig. 3 shows the electrical diagram of the measurements and simulation.

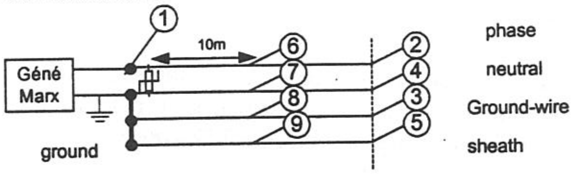


Fig. 3 : electrical diagram 50m cable

For the Cable Parameters model alone, the frequency at which the line parameters have been calculated is 500kHz. Fig.4 shows the comparison between measurement and simulation (arrester is modeled as indicated before).

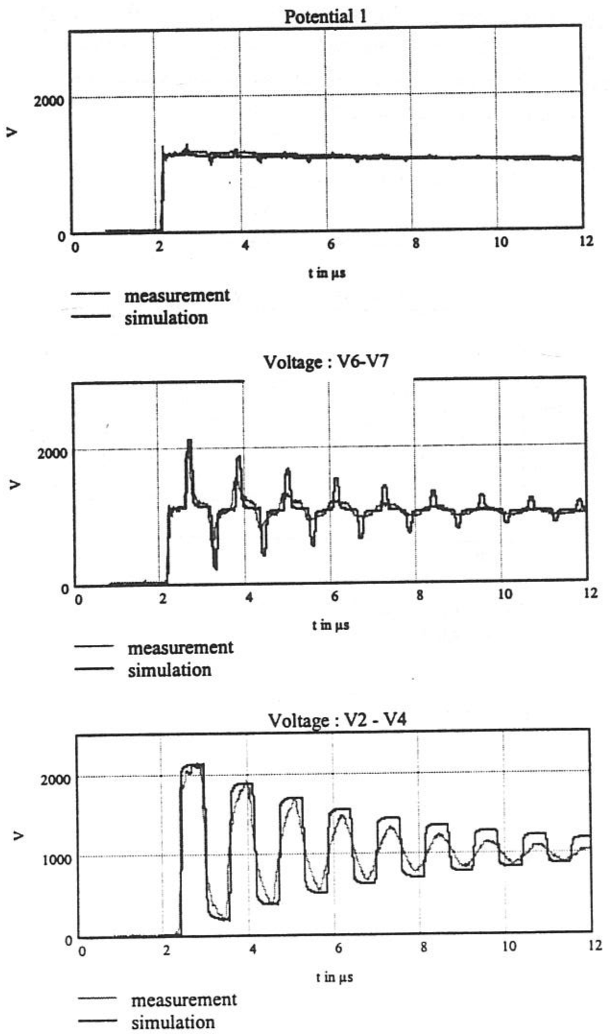


Fig. 4 : Simulation using Cable Parameters alone

For the three internal conductors (R = radius) :
R1=0
R2=0.000892 ρCu=1.95*10^{-8}
R3=0.001892 εr=2.5(PR)
For the sheath (pipe using cable parameters) :
RP1=0.004784 εr=4 (PVC)
RP2=0.004884 ρ_sheath=1*10^{-6}
RP3=0.006584 εr=4 (PVC)
Low voltage cable :

In addition, using the JMarti setup which brings a frequency dependant model, the results are shown below.

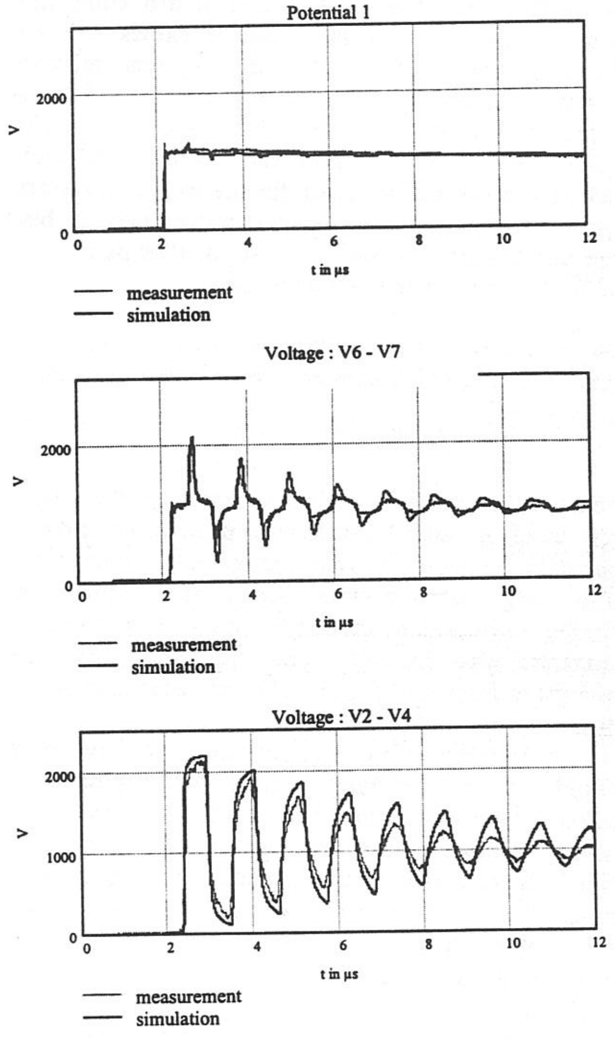


Fig. 5 Simulation using CP and Jmarti setup

The arrester keeps the voltage under 1.1kV at the sending-end. The length is long enough according to the slope of the input voltage to involve a wave propagation, and so to imply a double voltage at the receiving-end.

The results for the two models at each point of interest can be considered as correct especially regarding the first peak voltage at the receiving end. But thanks to the frequency dependence which flattens the steep front, the JMarti model is quite better if we concentrate in the waveforms.

However, the attenuation remains still too low and we need to take into account the effect of the conductance Gmode in the cable.

Gmode parameter is set from the following formulation :

$G = C.2.\pi.f.tg\delta.10^{-9}$ S/m C: capacitance in nF/m
f: frequency in Hz
δ: loss angle of the dielectric

The capacitance measured by using an impedance analyser is 0.4nF/m, the tgδ for a PVC insulator is about 0.1.
For a frequency of 1MHz, the calculated value of G is then 0.025 S/m (the typical value at 50Hz in the model is 3.10^{-8} S/m).

Using the value of 0.04 S/m, the results between simulation and measurement seem very good (slightly better than with 0.025 S/m).

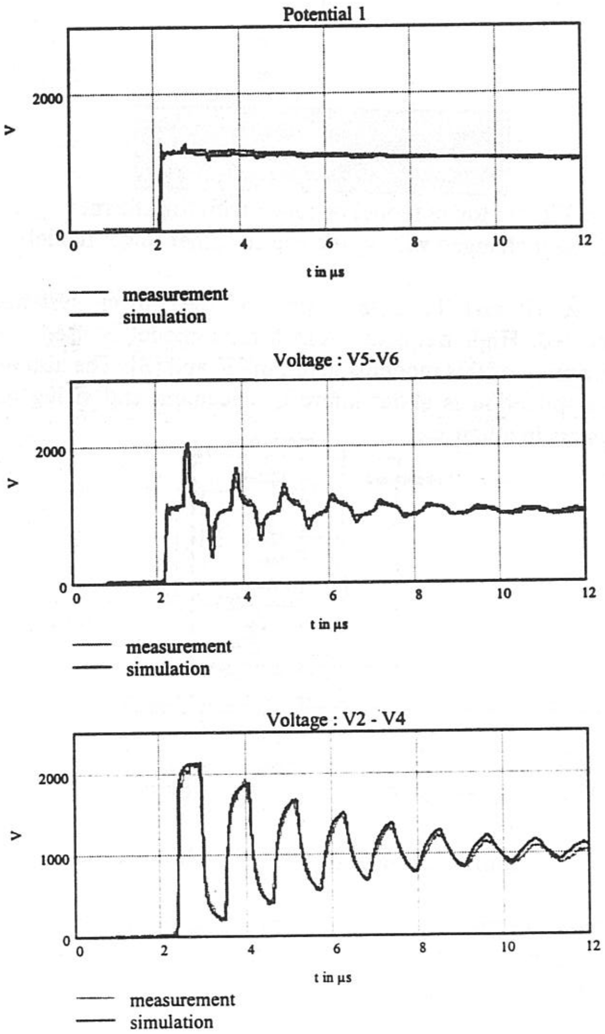
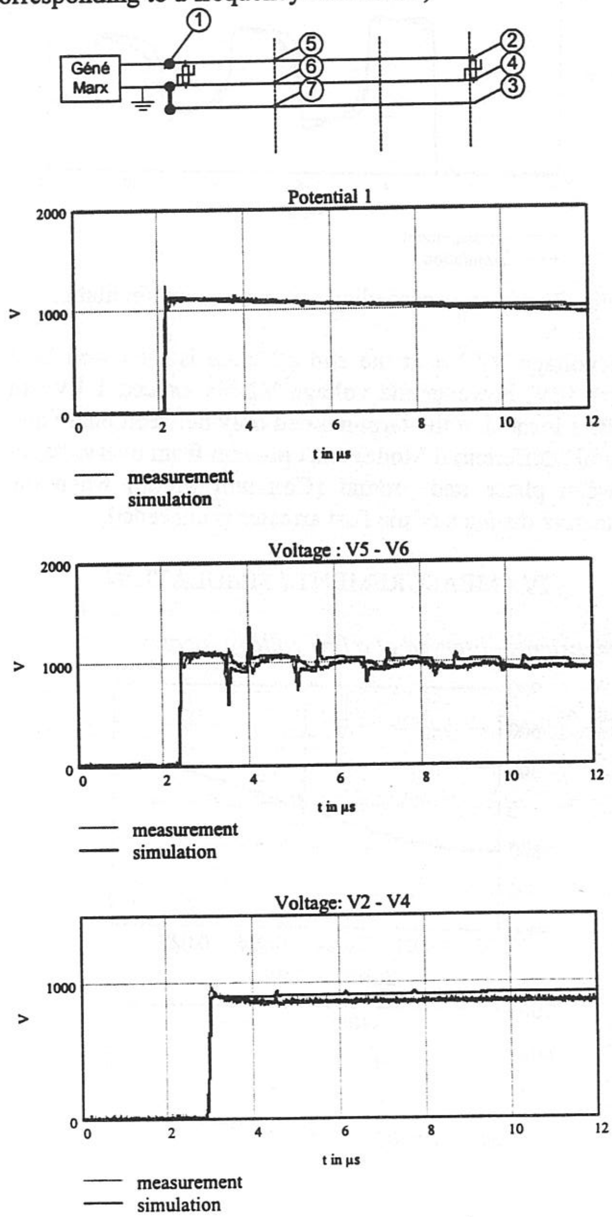


Fig. 6 : CP with JMarti setup and G=0.04 S/m

III. SURGE ARRESTERS CASCADING

To avoid such reflection phenomena when the protective distance of the arrester is exceeded and to keep the voltage at the receiving end under 1kV, one way is to use the cascading of two surge arresters. Fig 7 shows the electrical diagram and the comparison between measurement and simulation of the test of a cascading with a 3 conductors cable of 150m long (three piece of 50m) without sheath (same geometry and cable data as before but without sheath).
The cable was modelled with JMarti and the value of the conductance Gmode was chosen at 0.005 S/m (corresponding to a frequency of 250kHz)



Voltages (V5 – V7) and (V2 - V3) are on the following page (ending Fig. 7 serie) .

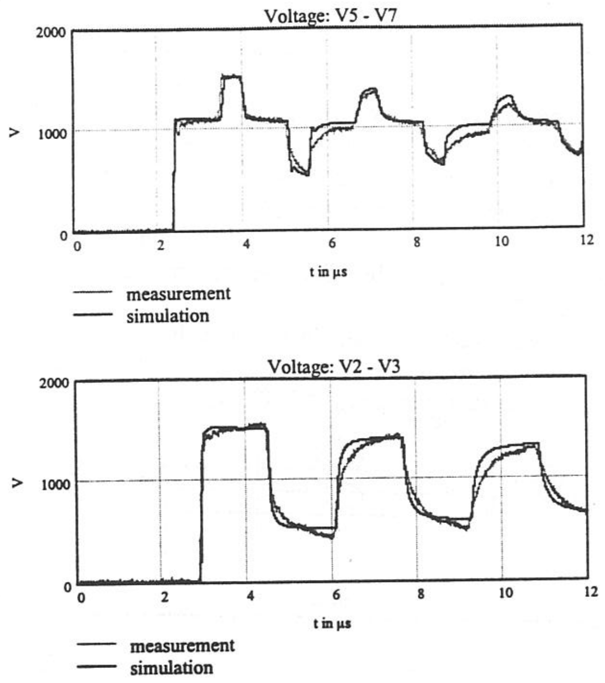


Fig. 7 : arresters cascading : measurement/simulation

The voltage V2-V4 at the end of cable is then well kept under 1kV, however the voltage V2-V3 exceed 1 kV: an arrester located at the terminal end only between phase and neutral (Differential Mode) can't prevent from overvoltages between phase and ground (Common Mode) when the protective distance of the first arrester is exceeded.

IV. MEASUREMENT / SIMULATION

A. *transients observed at a low voltage location*

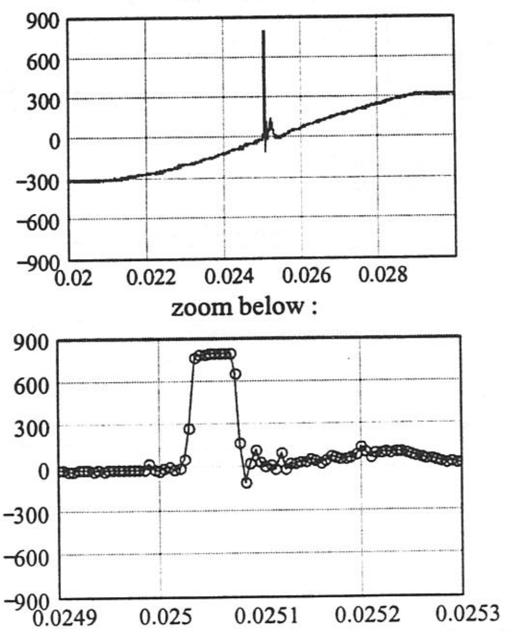


Fig. 8 : phase to ground voltage (V) versus time (s)

Measurements have been performed in a LV installation which is frequently perturbed when thunders appear. Several records as Fig. 8 was observed.

An arrester is installed at the measurement location what explain the limitation at around 800V. This arrester was previously installed here and in addition allowed us to protect the voltage probe.

B. *simulation for a domestic low voltage system*

The typical french power system is composed of :

- MV line : 3 phases - 10 spans from the MV/LV transformer to the line surge impedance matrix
- LV line : 3 phases and neutral
- Residential cables : a phase, a neutral and a ground wire
- LV neutral direct to ground near the MV/LV transformer and earth installation to ground
- MV/LV 100kVA transformer

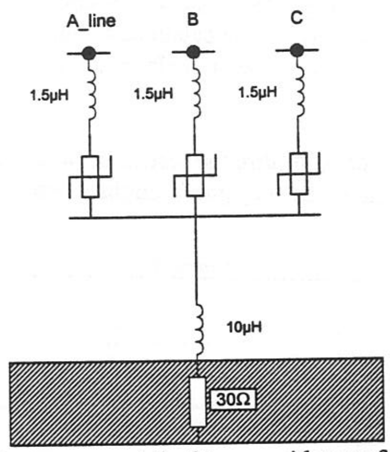


Fig. 9 : tower model of tower with transformer (arrester changed with spark-gap for other tower model)

Fig. 9, 10 and 11 give a part of the power systems simulated. High frequency transformer model is used : a description of this model is given in [2] and [3]. The aim of this application is about interest, placement and sizing of arresters in a house.

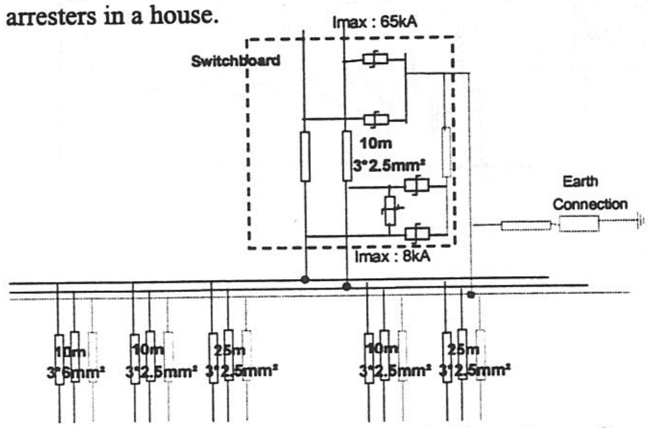


Fig. 10 : domestic power system : switchboard cascading

Surge protection is done by a cascading of arresters, both located in the switchboard but separated thanks a 10m long cable to allow enegetic coordination.

Several cases have been simulated : direct strike on the medium voltage line, on the house protective structure or induced voltage on lines. It appears that the worst case considering overvoltages and steepness of the front is a direct stroke on the MV line.

Ligthning surge is modeled with Heidler source (recommanded by CEI 1024-1 and 1312-1), that is 15 card in ATP. A 2/50µs (for direct strike) and a 10/350µs (for a strike on the structure) current wave form were chosen.

Direct stroke on the MV line : 80kA

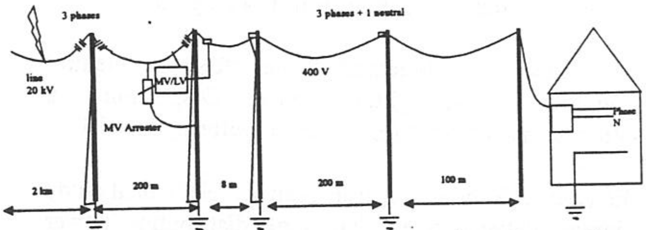


Fig. 11 : domestic power system : switchboard cascading

The stroke causes many insulators breakdown on the MV line. The lightning current flows then trough the towers to the ground. The overvoltage is then the addition of several peaks and of a low-frequency wave corresponding to the potential rise.
As shown in Fig 12, only the high frequency parts of the overvoltage is transferred to the LV power system via the capacitances of the transformer.

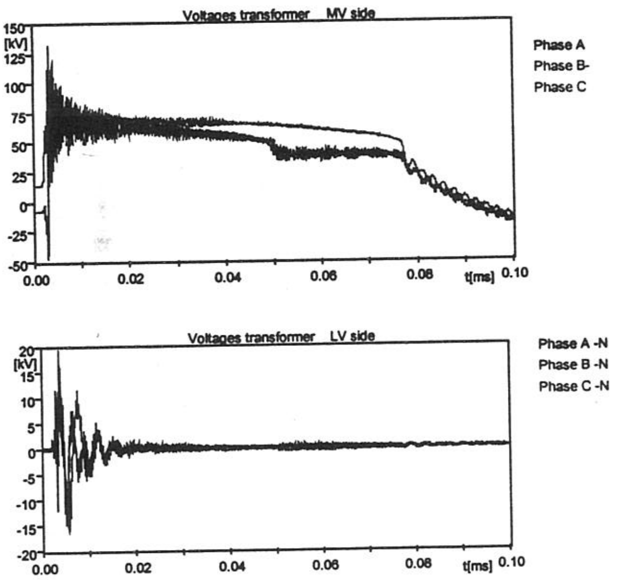


Fig. 12 : Simulation of a 80kA direct stroke on the MV line

Incoming steep fronts voltages are registered about 15kV/µs and lead to reflection on open ended cables of 25m long in the installation . Over 25m, protection of electronic devices may not be satisfied with overvoltages above 1.2kVas shown in Fig. 13.

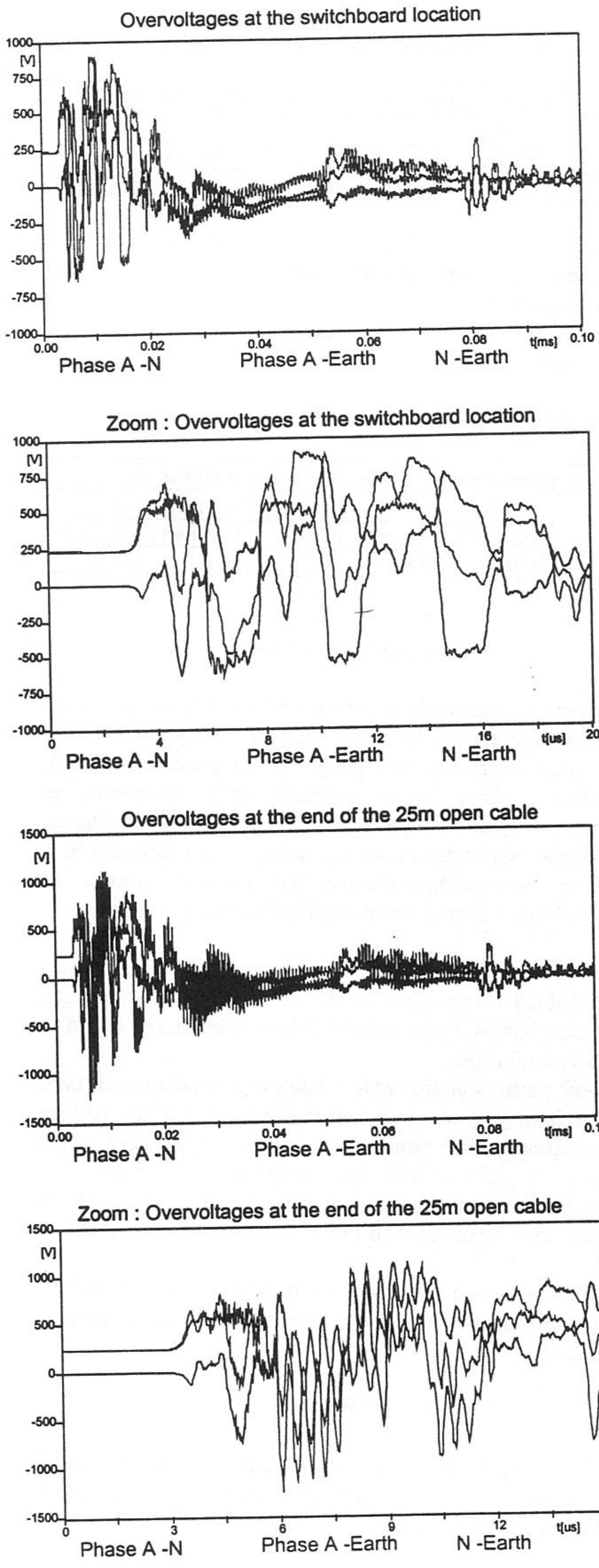


Fig. 13 : Simulation of overvoltages in the domestic installation (at switchboard location or at the receiving-end 25m cable)

Table 1 : overvoltages without terminal arrester

Overvoltages at the end of opened cables (kV)					
10m			25m		
Ph-N	Ph-Earth	N-Earth	Ph-N	Ph-Earth	N-Earth
0.86	0.98	0.90	1.25	1.12	0.94

In those cases, surge-arresters (Imax=4kA) should be installed at the terminal end of the cable, close to the load to be protected.
Voltages are then well kept under 1kV as shown in the table below.

Table 2 : overvoltages with terminal arresters

Overvoltages at the end of opened cables (kV)					
10m			25m (protected)		
Ph-N	Ph-Earth	N-Earth	Ph-N	Ph-Earth	N-Earth
0.82	0.91	0.88	0.78	0.82	0.76

V. CONCLUSION

From measurements in laboratory on low voltage arresters, transformers and cables, some high frequency models have been implemented in ATP program. The positive results of simulation allow us to simulate some transients, as lightning surges, in order to forecast possible overvoltages. Protection with arresters or cascading of arresters can be a right solution but the protective distance of the arrester has to be taking into account to avoid reflection phenomena.

An unexpected result is that cable parameters associated with JMarti Steup gave us the best results in simulating transients propagation, even if JMarti is commonly used to model aerial lines.
A weak point is about cable modeling if simulation of both power frequency and transient is expected in a low voltage power supply. The conductivity taken into account in the JMarti model should be frequency dependant. A formulation is proposed according to some data sheet. Values have been checked in part by our measurements.

Measurements on site allow us to observe some transients in low voltage power system. The interest of the arrester is verified.

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