Modeling for the Calculation of Overvoltages Stressing the Electronic Equipment of High Voltage Substations due to Lightning

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Abstract: The High and Low Voltage networks of a High Voltage Substation are modeled and simulated with the numerical code ATP - EMTP, in order to calculate stimulated overvoltages occurred in the Low Voltage auxiliary network and stressing electronic equipment, due to lightning strokes that strike overhead power lines connected at the High Voltage part. Lightning currents from 10kA to 100kA have been considered and four representative scenarios are presented and analyzed. The most of the cases examined result to overvoltage stressing of the electronic equipment of the substation from 1kV to 2,5kV.

Key-Words: Modeling, Substation, Lightning, Overvoltages, Low Voltage Network

1 Introduction

Overvoltages in high voltage power systems may cause dangerous electromagnetic interference problems to low voltage systems and especially to electronic devices. High Voltage Substations are equipped more and more with electronic equipment and other L.V. auxiliary systems for operating, control and measuring purposes, like data acquisition devices, telecommunication equipment, protective relaying, measuring instruments, as well as other control and monitoring systems. Since the consequences of interference on such equipment may be critical for the operation of the whole High Voltage System, special care is paid to the design, specification, testing and installation of electronic equipment, from the immunity point of view. However, Electromagnetic Interference (EMI) control in a H.V. system must start from the emitter, i.e. the H.V. substation design and equipment. The EMI sources in high voltage substations, which most often seriously affect the operation of the secondary circuits are lightning strokes and switching in primary circuits. A detailed categorization of these sources is referred in [1].

Predicting the interference of a power system coupled with an other system, is quite complicated. Almost no case can be calculated without proper modeling of the coupled circuits and application of a numeric computational code. Several computational codes have been proposed for the calculation of electromagnetic fields caused by high voltage power systems during transient state conditions. Among them ATP-EMTP has a dominant position for transient overvoltage calculation.

2 ATP – EMTP Simulation

Modeling can be easily obtained using ATPDraw for later simulation with the ATP – EMTP program. ATPDraw is a graphical pre-processor for ATP-EMTP under Ms-Windows. The user can built a schematic of the network by selecting network predefined components from the menus of the program and enters the appropriate parameters for each element of the equipment. The user has also the ability to build new components.

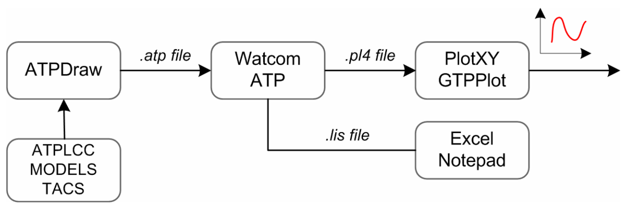

Figure 1: ATP – EMTP Simulation Procedure

ATPDraw creates the .atp file, which is the text file that the ATP-EMTP program handles. This .atp file is generated automatically at all from ATPDraw in correct ATP-EMTP format with automated node name generation. The user could ask from ATP-EMTP to plot the desired quantities by entering voltage or current probes in the circuit, in the ATPDraw shell. Watcom ATP reads the .atp file and outputs two files, one .pl4 and one .lis file. After the simulation, the user could see with various programs, like GTPlot or PlotXY, the requested quantities, reading the .pl4 generated file [3].

3 Network representation

In order to obtain simulation results close to reality, simple circuit models of coupling modes is not enough. The influence of frequency to network components has to be considered.

Various parameters have different influences on the representation of the system components, depending on the frequency of the transient study. The models of the network elements must correspond to the specific frequency range. According to CIGRE, four groups of frequency ranges, with overlapping frequencies, are specified for the representation of network components (table 1). Among them, Group III has a frequency range from 10kHz to 3MHz and includes fast front surges with time to peak $0.1\mu s \le T_p \le 20\mu s$ and tail duration $T_2 \le 300\mu s$. This representation is mainly used for lightning overvoltages. Group IV, respectively, has a frequency range from 100kHz to 50MHz, includes very fast front surges with time to peak $T_p \le 0.1\mu s$ and it is suitable for restrike overvoltages studies.

Table 1: Groups of frequency ranges for the representation of network components

Group	Frequency range	Time domain characteristic	Representation for
I	0.1 Hz – 3 kHz	low frequency oscillations	temporary overvoltages
II	50 Hz – 20 kHz	slow front surges	switching overvoltages
III	10 kHz – 3 MHz	fast front surges	lightning overvoltages
IV	100 kHz – 50 MHz	very fast front surges	restrike overvoltages

4 Application

The modeling of the high voltage network and the auxiliary low voltage power network of a high voltage substation is analyzed. Overhead lines, switches, surge arresters, transformers, grounding grid and low voltage network have been considered in the modeling, for calculating the overvoltages in the low voltage network, in case of lightning strike on the incoming overhead line, as illustrated in figure 2.

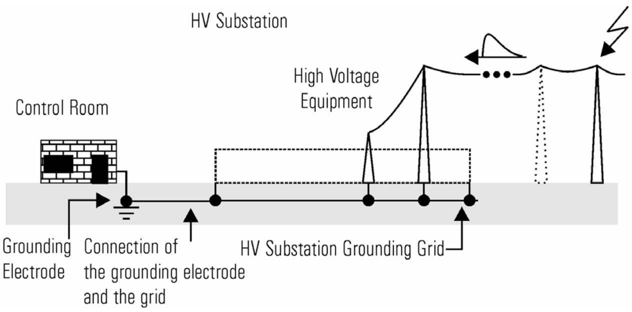

Figure 2: A lightning strike on an incoming line of a HV substation

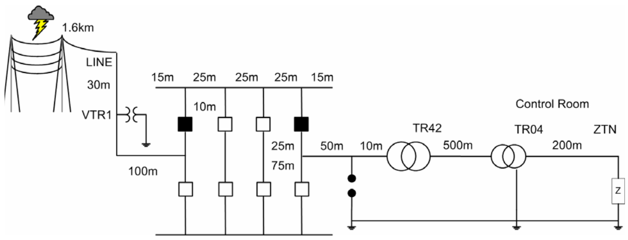

Figure 3: Schematic circuit of the substation

The modeling of the equipment is related to fast front overvoltages, so models for the frequency spectrum of Groups III and IV have been considered.

4.1 Case

The circuit of the substation under consideration is illustrated in figure 3. The 400kV overhead line is modeled with the frequency depended Jmarti line. The circuit breakers, drawn as black squares are closed, while the empty squares represent open circuit breakers. The length for each section is given next to the bus ducts. The high voltage transformer is protected with conventional gapped arresters. No further surge protection exists. The VTR1 is a capacitive voltage transformer.

The surge propagation of the lightning current along the transmission tower is modeled by distributed parameters elements and R-L branches. Non-linear resistors with sparkover voltage model the gapped surge arresters, before the transformer. The two transformers are modeled with π-equivalents capacitive coupling. Grounding is modeled with simple resistors, 10Ω for the control room, 5Ω for the distribution transformer and 1Ω for the surge arresters grounding. All conductors and bus ducts have been modeled with distribution parameters elements.

A detailed description for modeling equipment of high and low voltage power network using ATP – EMTP and ATPDraw is included in reference [5].

4.2 Scenarios and simulation

Following the modeling, several scenarios have been considered for lightning strokes from 10 kA to 100 kA, which hit the 5th tower away from the substation, where is the highest exposed point. Four representative scenarios of all examined are:

- 20 kA lightning current hits the top of the 5th tower away from the substation (case 1).
- 20 kA lightning current hits the phase a, at the 5th tower away from the substation (case 2).
- 50 kA lighting current hits the top of the 5th tower away from the substation (case 3).
- 50 kA lighting current hits the phase a, at the 5th

tower away from the substation (case 4).

4.3 Results

Calculations are made with the Watcom/EEUG ATP-EMTP Version, distribution 2003. The plots have developed with Plot XY Program.

As illustrated in figure 6, the lightning stroke of 20kA to the protection conductor at tower 5 causes

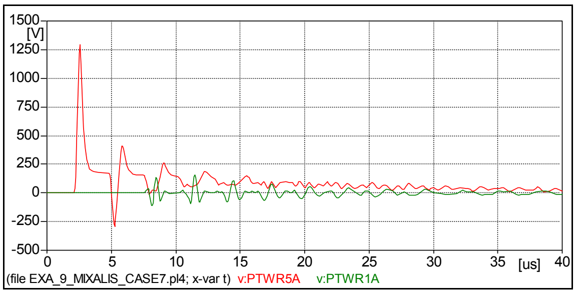

Figure 4: Protection conductor voltage for 20 kA lightning stroke (case 1). Red line is the voltage at the 5th tower, while green line is the voltage at the 1st tower, near to the substation.

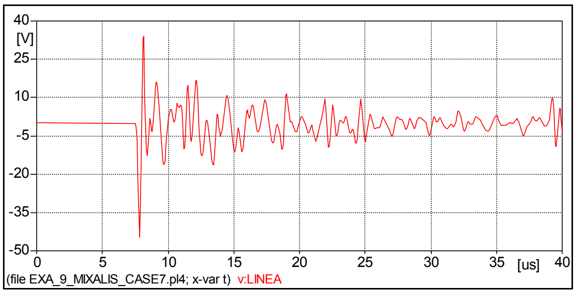

Figure 5: Overhead line voltage close to the substation, for 20 kA lightning stroke (case 1).

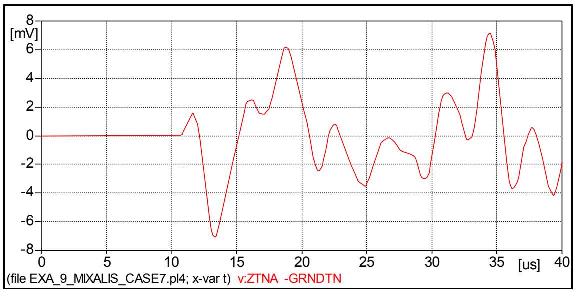

Figure 6: Low voltage network, phase to ground line voltage, for 20 kA lightning stroke (case 1).

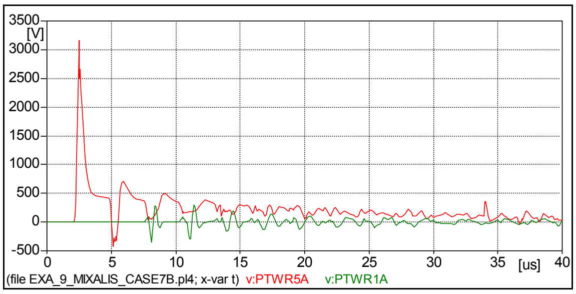

Figure 7: Protection conductor voltage for 50 kA lightning stroke (case 2).

negligible overvoltages at the low voltage network. However, the same lightning current hitting the phase a of the overhead line at the same tower, causes overvoltages of about 1,1 kV in the low voltage network (figure 12). A 50 kA lightning current on the top of the 5th tower, as illustrated in figure 9, causes overvoltages of about 1,3 kV, while if the same current hits the phase a at the same tower, overvoltages of 1,8 kV appear (figure 15).

Please note that all voltage values in the waveforms illustrated in figures 4 to 15 **must be multiplied with 10^3**.

The overvoltages calculated for the cases 2, 3 and 4 may be dangerous for the electronic equipment of the substation. So, a properly designed protection system must be provided for the avoidance of hazard to this equipment.

Some further remarks according to table 2 values:

- The voltage of the protection conductor in tower 5 is arised, according to the lightning current considering. For the same lightning current, a reduction is noticed when the lightning current hits not the conductor but the phase of the overhead line. The overvoltages appear then, come from either induction (for relatively small lightning currents) or flashover from the line to the tower.
- The voltage of the protection conductor at tower 1 arises also, according to the lightning current considered. The voltage is the same for cases 3 and 4, because of the flashover at the tower, but

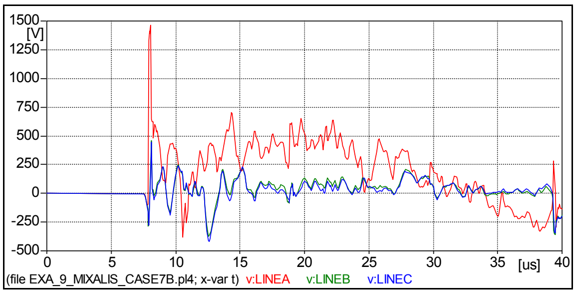

Figure 8: Overhead line voltage close to the substation, for 50 kA lightning stroke (case 2).

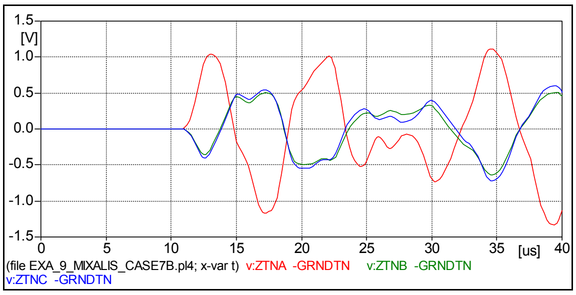

Figure 9: Low voltage network, phase to ground line voltage, for 50 kA lightning stroke (case 2).

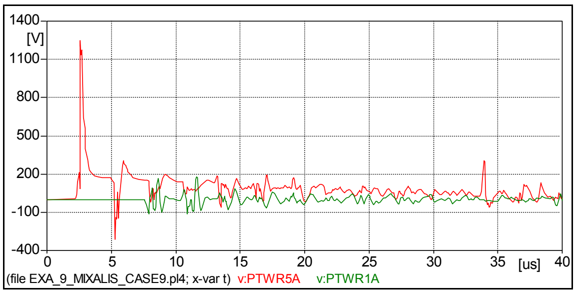

Figure 10: Protection conductor voltage for 20 kA lightning stroke on the phase a of the overhead line (case 3).

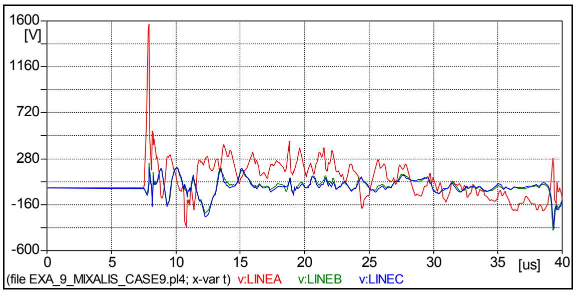

Figure 11: Overhead line voltage close to the substation, for 20 kA lightning stroke, on the phase a of the overhead line (case 3).

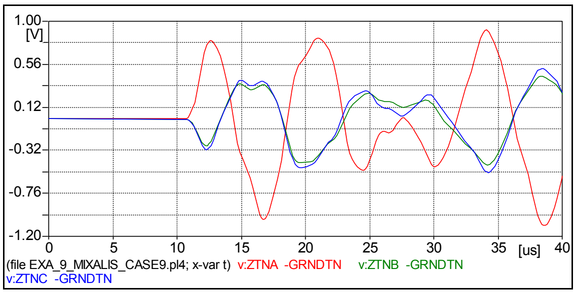

Figure 12: Low voltage network, phase to ground line voltage, for 20 kA lightning stroke, on the phase a of the overhead line (case 3).

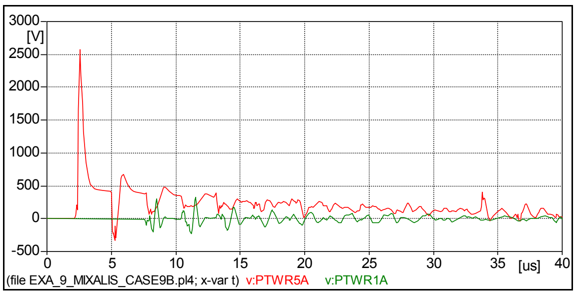

Figure 13: Protection conductor voltage for 50 kA lightning stroke, on the phase a of the overhead line (case 4).

not for cases 1 and 2, where no flashover occurs.

- In case 1, the voltage due to lightning current is only 33kV and the overvoltages at the low voltage part negligible.
- In opposite, from case 2, the overvoltages at the line have significant value, about 1,5 MV, so the overvoltages occur at the low voltage part may be destructive for the equipment, unless special care is taken. The voltage for phase hit with 50 kA is lightly lower than with 20 kA. This happens because of the flashover in the first case.

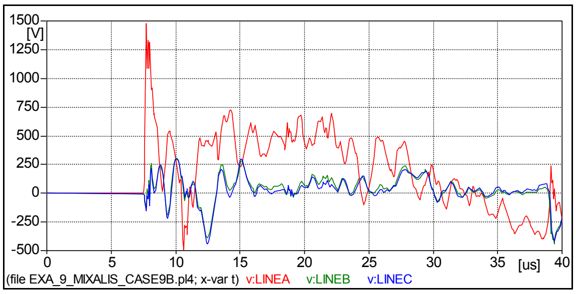

Figure 14: Overhead line voltage close to the substation, for 50 kA lightning stroke, on the phase a of the overhead line (case 4).

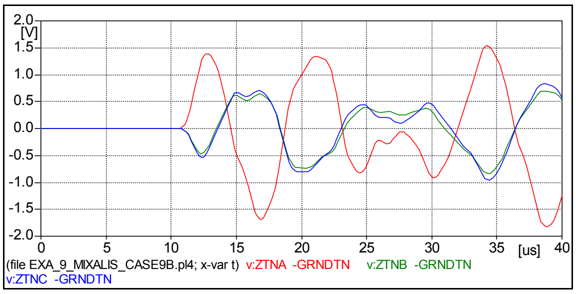

Figure 15: Low voltage network, phase to ground line voltage, for 50 kA lightning stroke, on the phase a of the overhead line (case 4).

The maximum lightning current considered is 100 kA. If this lightning current of hits the protection conductor at the 5^{th} tower, overvoltages of 2,5 kV to the L.V. network are caused. Also, if this lightning current hits the phase conductor, the overvoltages are lower and about 2 kV.

From the analysis presented it is concluded that overvoltages may occur at the L.V. auxiliary networks of a H.V. substation when a lightning strikes a H.V. overhead line entering the substation. These overvoltages may result to danger stressing of

Table 2: Overvoltages based on the simulated scenarios

Voltage (kV)	**20 kA tower**	**20 kA phase hit**	**50 kA tower**	**50 kA phase hit**
Protection Conductor tower 5	1300	1250	3200	2500
Protection Conductor tower 1	125	190	350	350
Line, close to the substation	33	1550	1450	1500
Low Voltage Network	0,007	1,1	1,3	1,8

the electronic equipment connected to the L.V. network of the substation, so properly designed surge protection must be provided at the L.V. network.

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