LIGHTNING SIMULATION STUDY ON LINE INSULATORS (Surge arresters) (110kV Overhead Power Line "Fierze F. Arrez – HC Dardhe")

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Abstract

During the designing phase of the line of a private power plant was made a study of how the atmospheric discharges from lighting impulses could affect the working regime of a new power Hydro Power plant under construction in the Dardhe Puke Area.
The line under study is a short 110kV double circuit overhead power line composed of 3 steel latticed towers with a 120mm2 ACSR conductor and 66mm2 OPGW. The insulation of the line is with 8 CAP PIN insulators type U120B and according to IEC 60071 (standard for insulation levels from 1 to 245kV) a 110kV power line should have a standard lighting impulse withstand voltage of 520kV.
The insulation of the line has been modeled in the ATP software for each tower of the line.
Standard lighting impulses of 10kA, 15kA, 60kA, and 120kA have been applied and we have seen the behavior of the line for each set of insulators on the towers to understand which lighting impulse would result in a flash over of the line insulation. The results of the viewed overvoltage traveling waves on the line and of the overvoltage's induced on the towers structure showed that the flash over of the insulation happened on the first tower which has the highest, grounding resistance for an impulse current of 15kA.
Alternative Transients Program (ATP) is computer software used by the electric power industry for simulation of electrical systems transients. This program develops subject "Platform for Overvoltage Calculation & Insulation Coordination "in Department of Electrical Systems of Power.

Keywords: *Lightning simulation, Power line transmission, Surge arrester, Overvoltage, ATPDraw.*

Introduction

In the following project has been studied a short 110kV double circuit overhead line which cuts the existing 110kV line Fierze-Fushe Arrez for connecting it to the substation gantry`s of a new private hydro Power Plant in the Dardhe village Puke Area. The line is composed of 3 steel latticed towers which mean only two spans. In the left circuit of the double circuit line is connected the existing line that comes from the Fierza Substation and in the right circuit is connected the existing line which goes to the Fushe Arres Substation.

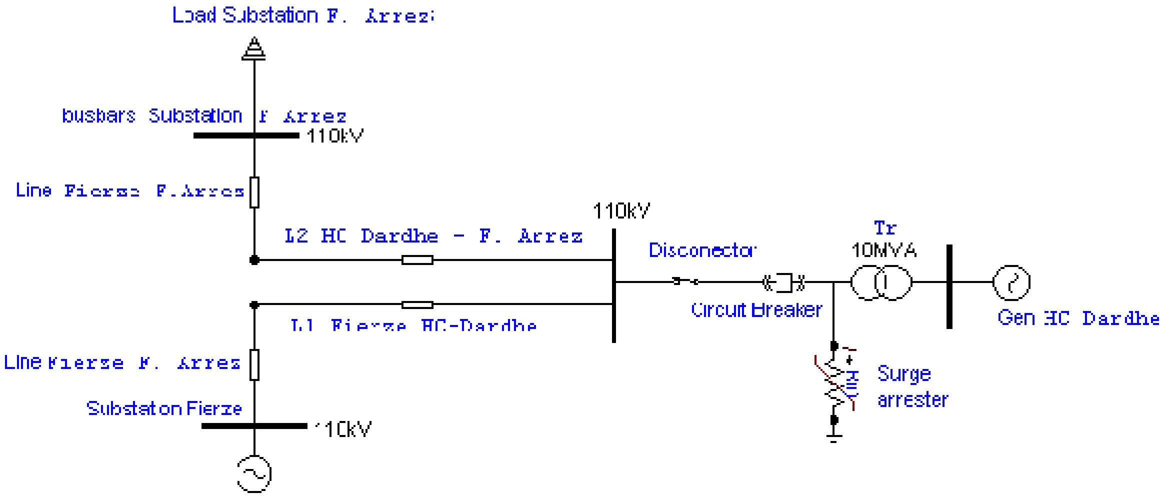


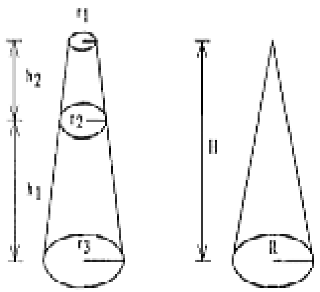
Fig.1 Line Diagram

In this project are made the following calculations:

1) **The tower model is modeling as a line with constant distributed parameters in base of the real tower dimensions**
2) **Calculation of the line parameters based on the tower cross arms dimension and the technical specification of the conductor and the OPGW steel wire.**
   The above calculations made by hand have been compared with the results from the line Check command with the ATP software
3) **After the modeling, the whole system has been simulated in the ATP software, Applying different currents simulating the lighting strokes in the OPGW steel wire of the line. In this simulation has been studied the flashover of the line insulators and the propagation of the overvoltage wave front till to the substation gantry. For these atmospheric discharges has been monitored also the state of the surge arresters in front of the power transformer**

1. Tower modeling as a line with constant distributed parameters

The steel towers are modeled as an ideal line with constant distributed parameters. The propagation velocity of a traveling wave along a tower is taken to be equal to the light velocity 300m/µS and also to the model sections are added parallel *RL* circuits at to represent traveling wave attenuation and distortion. The tower model used during the calculation can be represented as a cone divided in two parts or a trapezoid with an equivalent radius which is applied to find the surge impendence that the structure applies to the overvoltage wave with speed a of 300m/μS



Fi.g 2 Tower structure Equivalent radius

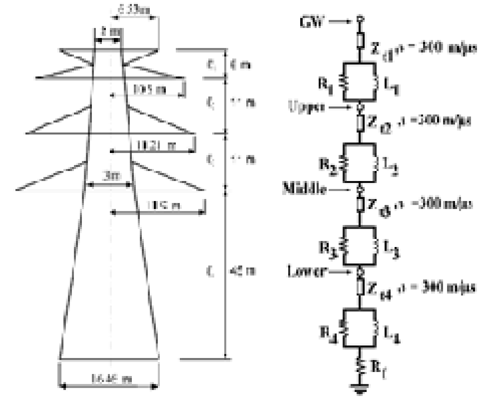


Fig. 3 Tower model with constant distributed parameters

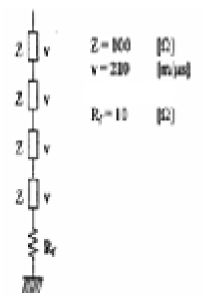


Fig. 4 Tower model according to " KAWAY" model

While the parallel *RL* sections are added to the circuit to represent the traveling wave attenuation from the steel structure. Another older method according to the "Kaway" tower model is to take the propagation speed of the overvoltage wave with a speed of 210 till to 240m/μS and to eliminate the inductances and resistances on the tower sections. This can be seen applied on the examples of the ATP software **Let us now calculate the surge impendence of the line towers for the tower top which is the same for all the towers and the tower bottom which differs according to the tower height.** According to the IEE and CIGREE (8) recommendations for the for the "wasted tower shape" the tower according the structure dimensions is represented by a trapezoid with an equivalent radius given by the formula

$$R = \frac{r_1 h_2 + r_2 h + r_3 h_1}{h} \tag{1.1}$$

And after having the equivalent radius and the tower height we can define the tower surge impedance with the formula

$$Z_t = 60 \ln\left[\cot g 0.5 \cdot tg^{-1}\left(\frac{R}{H}\right)\right] \tag{1.2}$$

The wave propagation velocity is taken that of the light $C=3x10^{-8}$ m/s or $3x10^{-5}$ Km /s. According to the above calculations the tower top has a characteristic impedance $Z_{T1}=214.04$ Ω which mean that the tower top structure has linear resistance according to the (1.3) formula and the specified section has a total resistance according to the (1.4) form.

$$r_1 = \frac{-2 \cdot Z_{T_1} \cdot \ln \gamma}{l_1 + l_2 + l_3} \quad (\Omega / m) \tag{1.3}$$

$$R_1 = r_1 \cdot l_1 \quad (\Omega), \quad R_2 = r_1 \cdot l_2 \quad (\Omega), \quad R_3 = r_1 \cdot l_3 \quad (\Omega) \tag{1.4}$$

The tower model is divided into sections according to her structure, in which except wave impedance are placed the RL sections representing the overvoltage traveling wave attenuation.

Let`s calculate the inductances in each tower section which is related to the time it takes to the traveling wave to cross the total tower height. At the beginning we find the traveling time **τ** and the inductances. This calculation is made for the tower top and is repeated for each separate tower according to his length.

$$\tau = \frac{2 \cdot H}{V} \quad [\mu s] \tag{1.5}$$

$$L_1 = R_1 \cdot \tau \quad (mH), \quad L_2 = L_3 = R_2 \cdot \tau \quad (mH) \tag{1.6}$$

For the tower bottom we calculate:

$$R_4 = \frac{-2 \cdot Z_{T_4} \cdot \ln \gamma}{l_4} \cdot l_4 \quad (\Omega) \tag{1.7}$$

$$L_4 = R_4 \cdot \tau \quad (mH) \tag{1.8}$$

Table 1. Summary table of the line towers parameters

Tower parameters	**Tower No.1 h=17m**	**Tower No.2 h=19m**	**Tower No.3 h=21m**
Time constant τ	0.2233μs	0.21 μs	0.1967 μs
Resistance R	Ω		
R1	20.153	20.153	20.153
R2	14.146	14.146	14.146
R3	14.146	14.146	14.146
R4	42.5	40.256	39.228
Tower inductance	mH		
L1	4.5	4.232	3.963
L2	3.1587	2.97	2.7825
L3	3.1587	2.97	2.7825
L4	9.49	8.454	7.716
Grounding resistance Ro and soil resistivity	9 Ω δ=400Ω·m	8.5 Ω δ=400 Ω·m	3.3 Ω δ=5 Ω·m
Grounding resistance taking into account soil ionization Rf	8.175	7.796	2.019
The tower surge impedance			
Tower top (is equal for both the 3 towers)	**Tower top surge impedance** 217.04 (Ω)		
Tower bottom which changes according to the tower height	**Tower bottom surge impedance Z (Ω)**		
21 (m)	182.40 (Ω)		
19 (m)	180.35 (Ω)		
17 (m)	175.75 (Ω)		

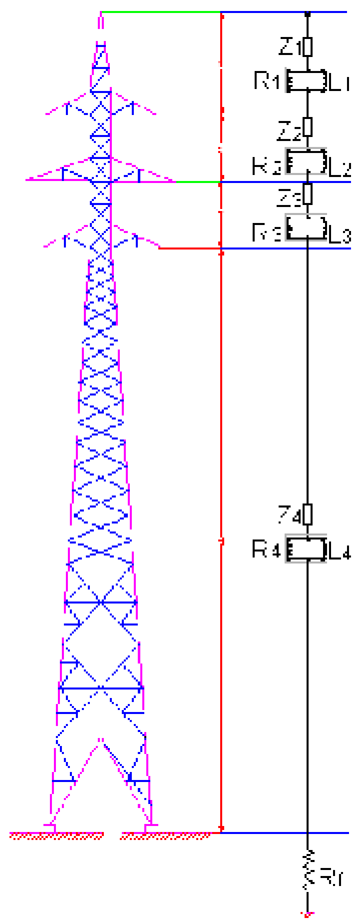


Fig. 5 Tower model with constant distributed parameters

2. Calculation of tower parameters and reactances

In the beginning are givenn the contuctor and opgw earth wire characterirctic

Conductor ACSR 120/20mm^2		**OPGW 60mm^2**	
Aluminum cross Section	120.05mm^2	Total cross section	64mm^2
Total cross section	141.4mm^2	Diameter	10.8mm
Diameter	15.5mm	Unit weight per Km	385Kg/Km
Rated tensile strength	44500N	Module of elasticity	162kN/mm^2
Resistance at 20ºC	0.2376Ω/Km	DC resistance (T=20ºC)	0.93Ω/Km

***After performing the calculations we are comparing the results of the handmade calculations with the ones from the line check command with the ATP Software*:**

a) **First span ρe=400Ωxm L=178m**

Line Parameters for the first span ρe=400Ωxm		**Results taken from the handmade Calculations**	**Result taken from the line check command in ATP** (J Marti) Method
Z Self impedance	Positive sequence impedance	Z1=0.0423+i0.077 Ω	L1: 0.0221+i0.0736 Ω L2: 0.0224+i0.0744 Ω
	Zero sequence impedance single circuit without earth wire	Z0=0.0386+i0.247 Ω	L1: 0.0386+i0.247 Ω L2: 0.0386+i0.2466 Ω
	Zero sequence impedance of earth wire	ZEE=0.0423+i0.077 Ω	0.0618+i0.1442 Ω
Z.mutual imp.	Mutual impedance between circuit and earth wire	ZCE=0.088+i0.0595 Ω	L1L3: 0.007+i0.04 Ω L2L3: 0.007+i0.04 Ω
	Mutual impedance between line circuits	ZC1C2=0.0112+i0.0614 Ω	L1L2:0.0165+i0.1502Ω

b) **Second span ρe=5Ωxm L=307.3m**

Line Parameters for the first span ρe=400Ωxm		**Results taken from the handmade Calculations**	**Result taken from the line check command in ATP** (J Marti) Method
Z Self impedance	Positive sequence impedance	Z1=0.0841+i0.133 Ω	L1: 0.0365+i0.127 Ω L2: 0.036 +i0.1172 Ω
	Zero sequence impedance single circuit without earth wire	Z0=0.1185+i0.367 Ω	L1: 0.072 +i0.3394 Ω L2: 0.0386+i0.2466 Ω
	Zero sequence impedance of earth wire	ZEE=0.3+i0.252 Ω	ZEE 0.101+i0.2274 Ω
Z. mutual impedance	Mutual impedance between circuit and earth wire	ZCE=0.01515+i0.06045 Ω	L1E: 0.004+i0.0461 Ω L2E: 0.006+i0.0434 Ω
	Mutual impedance between line circuits	ZL1L2=0.0193+i0.06373 Ω	L1L2: 0.0348+i0.1733 Ω

3. Simulations of the line insulation applying different lighting strokes on the line.

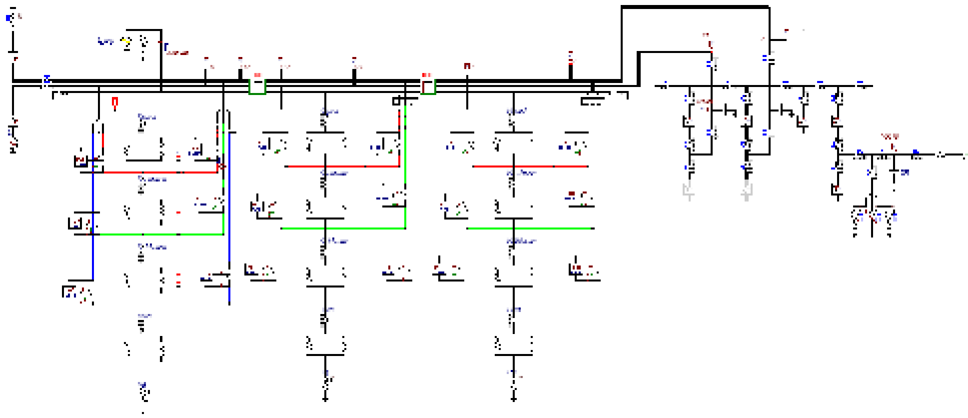


Fig. 6 Double circuit overhead line modeled in ATP software

After the whole system (lines, generators, insulation and other elements) had been modeled in ATP we start making simulations on this system.

First we apply a current of 10kA in order to simulate a lighting stroke in the earth wire of the first tower. In our insulation model that we have created we have put a minimal flashover voltage of 520kV so in order to happen this flashover the voltage applied in the phase insulator must be more than 520kV, and from the graphics (Fig. 7) of the voltage applied on the line insulators, created by the ATP software we see that the flashover did not happened because the conditioned implemented in the flash model was not fulfilled.

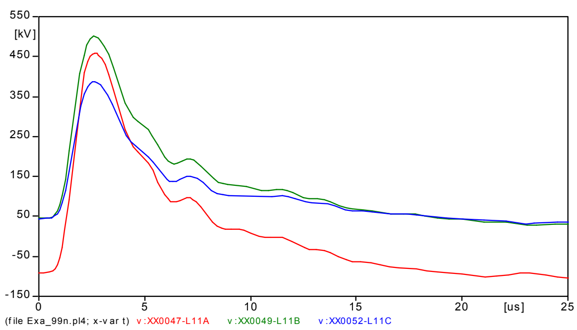


Fig.7 Applied voltage on insulator strings 10kA

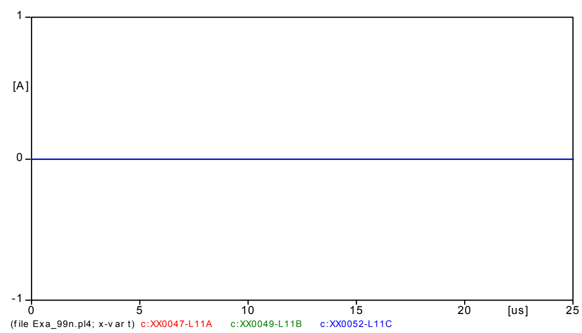
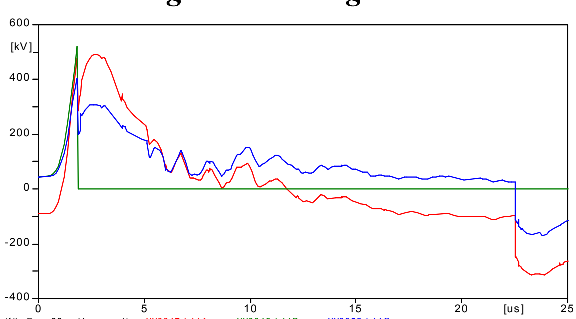
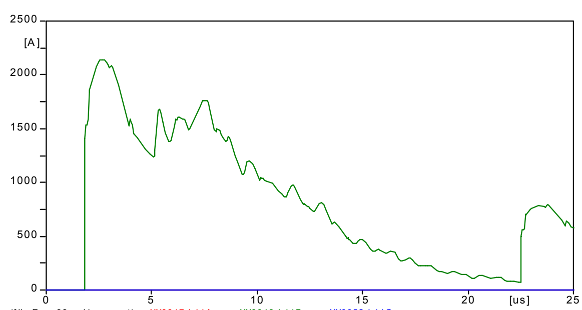


Fig.8 Current Values on insulator strings. 10kA

In the second simulation we apply a current of 15kA for simulating a stronger lighting stroke and we see again the voltage and current on the line insulators



Fi.g 9 Applied voltages on insulator strings 10kA



Fi.g 10 Current Values on insulator strings 15kA

As was predicted before from the initial conditions the flashover happens in the insulators of the B phase (Fig. 9) of the first circuit with a flashover current of 2140A (Fig. 10).

Now let us apply a current impulse of 60kA and see the behavior of the elements on the circuit. In the line insulators we will have the following voltages and currents:

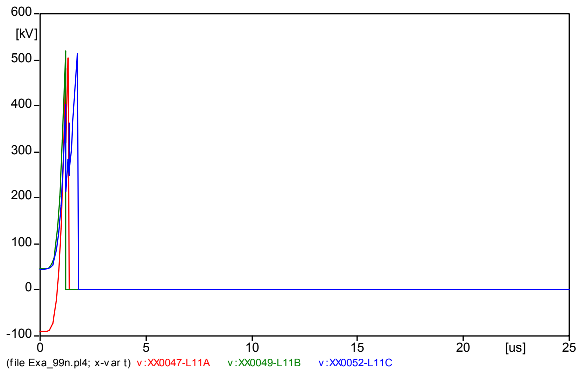


Fig. 11 Applied voltage on insulator strings 60kA

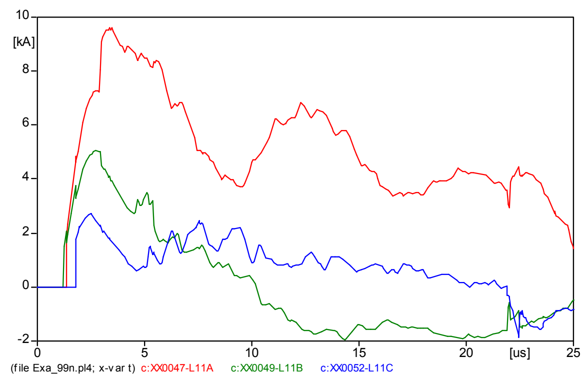


Fig. 12 Current Values on insulator strings 60kA

Watching the voltages and the currents on the line insulators we notice that the flashover has happened on all the insulators of the first circuit of the line (Fig. 11 and Fig. 12).
By monitoring the surge arrester in front of the transformers we see that also the surge arrester of the A phases has flashed with a discharging current of 14kA. (Fig.13)

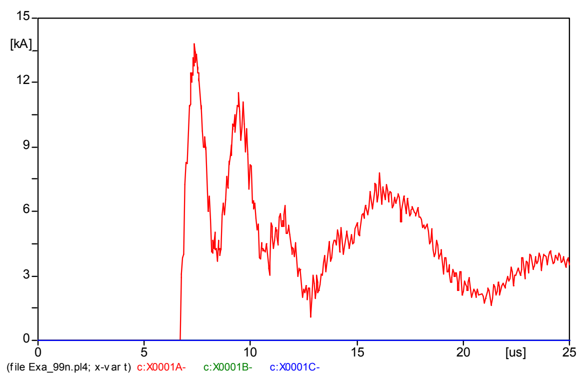


Fig. 13 Current on transformer surge arresters

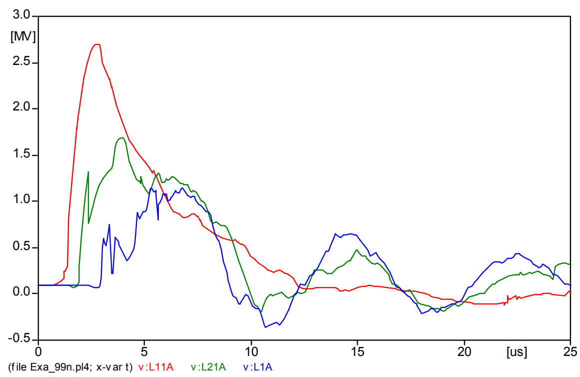


Fig. 14 Traveling wave during the overhead line

We also look at the overvoltage traveling wave (Fig. 14) where we see the decrease in amplitude of the overvoltage wave approaching to the substation gantry.
We see that in the A phase where the current impulse is applied the voltage value is 2.7MV and in the third tower before the gantry this overvoltage amplitude has decreased to 1.15MV.
While the B phase has an amplitude of 600kV only, this explains why has flashed only the A phase of the surge arrester in front of the transformer.

We are making a summary table of the results from the simulations made above and the results from the graphics of the ATP software:

Simulation Case	Did the flashover happen?	Did the surge arrester flashed?	Voltage values at the substation gantry`s form the first circuit L1			Voltage values at the substation gantry`s form the second circuit L2		
			Phase			Phase		
			A	B	C	A	B	C
Lighting stroke of 10kA in the earth wire of the first tower	No	No	67.4 KV	286 KV	-58.1 KV	74.6 KV	209 KV	-46.9 KV
Lighting stroke of 15kA in the earth wire of the first tower	Yes. In the B phase of the first circuit of the first tower	NO	308 kV	78.9 kV	-45.5 kV	87.5 kV	221 kV	-34.4 kV
Lighting stroke of 60 kA in the earth wire of the first tower	Yes. In the first Circuit Phase A, B, C at tower No1 and Phase A and B at tower No2 and also in the second circuit phase A at tower No 2.	Yes. Only the Surge arrester of the A Phase	1.14 MV	0.71 MV	0.263 MV	1.14 MV	0.3 MV	0.584 MV

CONCLUSIONS:

1- For small currents of lighting strokes applied in the earth wire because of the initial conditions happens first the flashover of the insulators of the B phase.
2- The surge arresters installed in front of the transformers start working for lighting strokes of currents near 60kA
3- The minimal Value of the current of the lighting stroke for which the insulators flashover happens is 15kA

REFERENCES:

1- Masaru Ishii, Tatsuo Kawamura, Teruya Kouno, Eiichi Ohsaki, Kazuyuki Shiokawa Kaneyoshi Murotani and Takemitsu Higuchi, "Multistory transmission Tower Model For Lightning Surge Analysis", IEEE Transactions on Power Delivery ,Vol. 6, No. 3, July 1991

2- J. A. Martinez, and F. Castro-Aranda, "Lightning Performance Analysis of Transmission Lines Using the EMTP", IEEE Transmission,2003

3- M. Kizilcay, C. Neumann, "Back flashover Analysis for 110-kV Lines at Multi-Circuit Overhead Line Towers, "Presented at the International Conference on Power Systems Transients (IPST'07) in Lyon, France on June 4-7, 2007