Simulation of Atmospheric Overvoltages on 400kV Power Lines in Transmission System

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Abstract: - External overvoltages are unambiguously caused by atmospheric overvoltages on overhead lines an emerges during storms. The paper presents simulation results of atmospheric overvoltages in slovak transmission system, which were realized in purpose of 400kV power lines surge arresters electrical parameters verification. Overvoltages in power network can cause devices faults, in which interruption of electricity supply and stability loss threat and safety of power system can arise. For overvoltage simulation detailed mathematical model of whole SR transmission system was created in ATP, which includes precise models of substations, transformers, towers, power lines, isolators and other devices.

Key-Words: - overvoltages, power system, surge arrester, overhead power lines.

1 Introduction

Overvoltage is voltage of any kind, which is higher than amplitude of highest system voltage.
External overvoltages are unambiguously caused by atmospheric overvoltages on overhead lines and emerges during storms:

- indirect strikes (induced overvoltages),
- direct strikes to phase conductors,
- direct strikes to ground wires,
- direct strikes to towers.

Internal overvoltages can be distinguished into two categories:

- switching overvoltages,
- temporary overvoltages.

Into class of switching overvoltages falls that effects, which originate in sudden changes of system parameters, as e.g. planned or emergency switching of power lines, transformers and other components (generators, rotating machines) and also in ground faults and short circuits. Transient phenomena are of oscillating character. Overvoltages arise usually during these processes:

- ground faults in 3-phase systems,
- short circuit disconnection,
- inductive currents disconnection,
- capacitive currents disconnection,
- energizing or auto reclosure of unloaded lines,
- arc ignition, or repeated arc ignition in breakers.

Attention is dedicated to overvoltages mainly for this three reasons:

- higher strain of isolating systems of all components and devices,
- subsequent faults of devices, which can cause interruption of power supply and endanger stability and safety of power system,
- electromagnetic disturbance, EMC.

2 Atmospheric overvoltages

State of atmosphere over Slovak republic shows Izokeraunic maps, which were created on basis of many years storm activity observation in individual regions of Slovak republic by Slovak hydrometeorological institute. From the point of view of power devices projecting, operation and placing on our area are this dates very important not only in transmission system, but also in distribution systems (Fig. 1).
Lightning discharge on stroked objects causes damages, which follow from its thermal, mechanical and electromagnetic effects.
In stroked location a current impulse is injected into power line in direct lightning strike. Voltage and current waves propagate from this place to both sides of line, which reflects in every place where change in surge impedance appears. If ground wire is stroked by lightning reflections appear also in places of connection with tower or on earthing of tower.

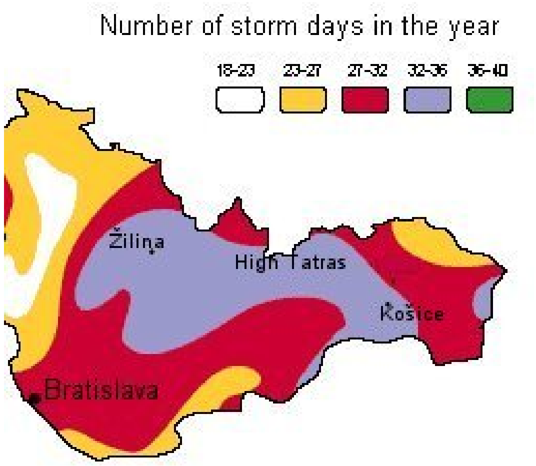

Fig.1.: Izokeraunic map of SR II

Lightning current propagates on line to both sides from stroked place, where in some simplifying we can determine value of overvoltage in this place as voltage drop caused by lightning current flow through parallel combination of line surge impedance.

Probability of direct lightning strike to phase conductor is decreased by using of ground wires. In case of ground wire strike current and voltage waves propagate along ground wire. However their behavior is influenced by reflections on connections with tower. Steel towers bears as surge impedance approximately of hundreds of ohms depended on tower configuration and dimensions.

3 ATP Models of devices in power system

For reason of electrical parameters verification it was necessary to execute mathematical simulations, which helped to determine real values and behaviors of overvoltages and also values of accumulated energies in arresters.

Mathematical models of individual elements of power system had to be created for reason of simulations. All devices were needed to model to represent physical relation of wave propagation phenomena.

For this reason models of individual elements distinguishes from generally are used models in field of system frequency.

3.1 Tower electrical model

For simulation of atmospheric overvoltages it was necessary to create tower models, mathematical models characterised by homogenously distributed electrical parameters.

Tower model includes:

- model of steel construction,
- model of isolators,
- model of tower earthing.

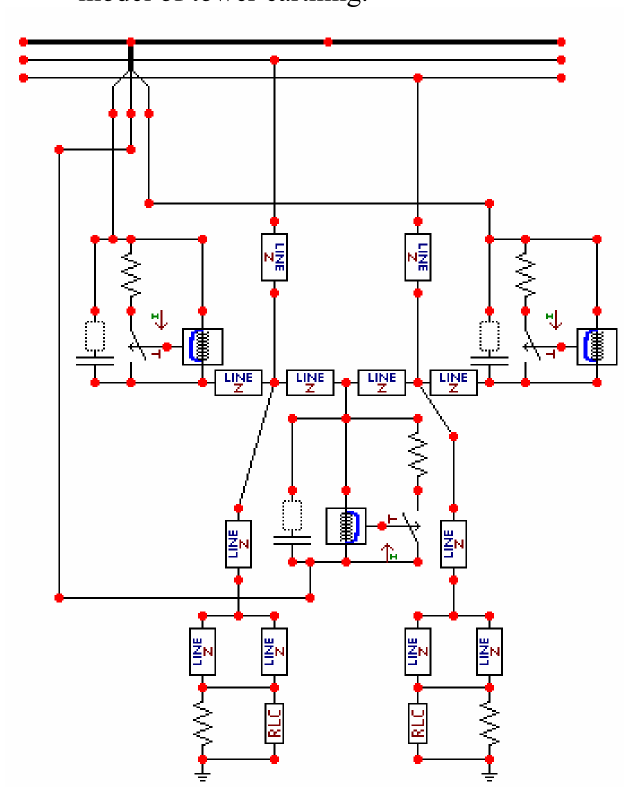

Fig.2.: 400 kV anchor portal tower

3.2 Power line electrical model

Overhead lines were modeled on basis of true dimensions of individual towers and used conductors with proper transpositions using LCC utility of ATP which takes into consideration also frequency dependency of electrical parameters of positive and zero sequence symmetrical components.

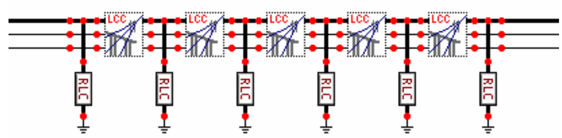

Fig.3.: Power line electrical model with individual ground wires for lightning strike study

3.3 Surge arrester electrical model

For simulation of atmospheric overvoltages, with reference to very fast wave processes, it was necessary take into consideration detailed model of surge arrester with respect to way of mounting and detailed model of earthing.

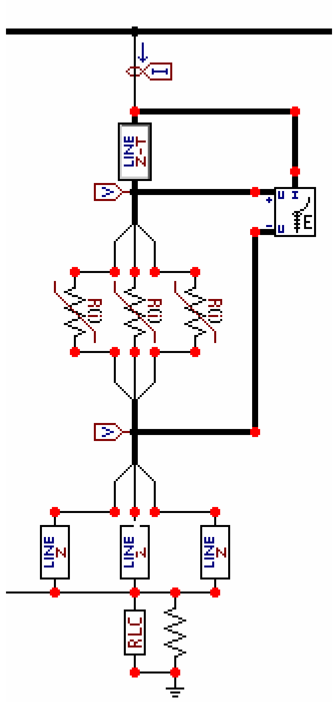

Fig.4.: Surge arrester electrical model

In all surge arresters were used identical VA characteristic of ZnO nonlinear material parametrized on basis of nominal rated voltage U_r.

3.4 Transformer model

Power transformer has to be modeled except electrical parameters as resistance and inductance of windings and magnetising branch also with parasitic capacitances of windings to ground and capacitances between windings for overvoltage simulation.

3.5 Electric network model

For overvoltage simulation on power lines and in electrical substation, was needed to create model of rest of power system – by using of electric network.

Parameters of electrical network are voltage of given system voltage level and inner impedance of power source in positive and zero sequence symmetrical components.

Value of short impedance in symmetrical components was calculated from short circuit conditions – values of short circuit powers for 3-phase and 1-phase shorts.

3.6 Substation electrical model

Detailed model of electrical substation includes:

- model of pipe bus bars,
- model of wire connections,
- model of breakers and disconnectors,
- model of current and voltage transformers.

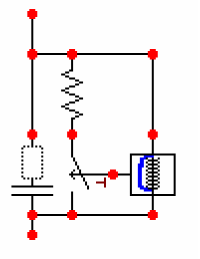

Fig.5.: Insulator model

4 Atmospheric overvoltage simulation on power lines

Simulation results of atmospheric overvoltages are influenced mainly by location of lightning strike and by value of lightning current.

Dependence of surge arrester accumulated energy value on lightning strike location on power line for direct strike to phase conductor is on fig. 6.

From shown behavior is clear that the most unpropitious place for strike is direct lightning strike to phase conductor in place of surge arrester installation.

With respect to this there was no need to execute other simulations (for other tower and line types). Differences in overvoltage values are dependent only on value of lightning current.

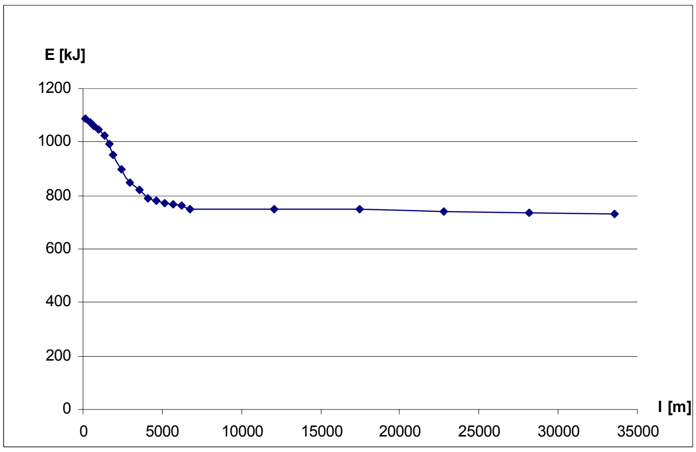

Fig.6.: Dependence of surge arrester accumulated energy value on lightning strike location on power line

4.1 Atmospheric overvoltage simulation results on power lines

Simulation of atmospheric overvoltages was executed for several values of lightning current (from 5 kA up to 100 kA).

As the most unpropitious place for lightning strike (as was mentioned in previous text) is direct lightning strike to phase conductor in place of surge arrester installation.

Even if this event is in reality of very low probability (for reason of lines and substations protection by ground wires), it is necessary to take this case into account for reason of obtaining the most unpropitious values of overvoltage and accumulated energy by surge arrester.

Results of atmospheric overvoltages on 400kV power lines are in tab. 1. and on next behaviors.

Surge arrester with parameters U_r/U_C - 360/255 was connected in place power line input to substation.

Current wave of lightning was modeled by parameters 8/20 μs for lightings up to 65 kA and 4/10 μs over 65 kA.

Limiting of overvoltage in case of simulation without surge arrester is caused by flashover of protective spark gap of insulator string on portal tower (Fig. 7).

For lightning currents higher than 53 kA arrester limits overvoltage on value higher than flashover voltage of spark gap and flashover appears what can be seen from energy accumulated in arrester.

Table 1: Atmospheric overvoltage simulation results – direct lightning strike to phase conductor in surge arrester installation

Lightning current [kA]	5	20	50	80	100
U_{max} without arrester [MV]	1,42	1,78	1,93	1,99	2,02
U_{max} with arrester [MV]	0,77	1,06	1,42	1,67	1,7
$I_{arrest-max}$ [kA]	3,79	18,2	46,3	39,5	39,1
E [kJ]	43	300	920	92,8	116

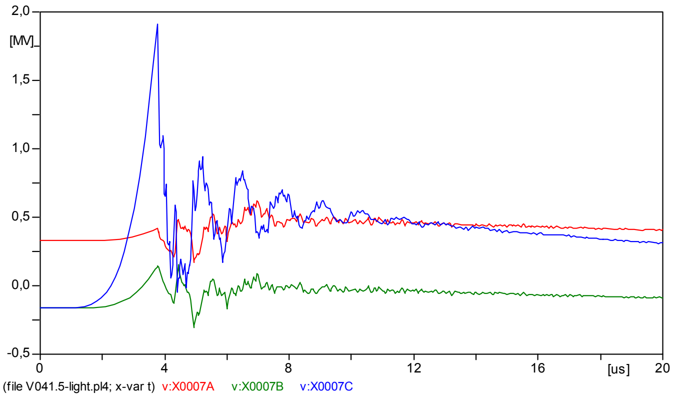

Fig. 7: Overvoltage limited by insulator spark gap – lightning current 40 kA, no surge arrester

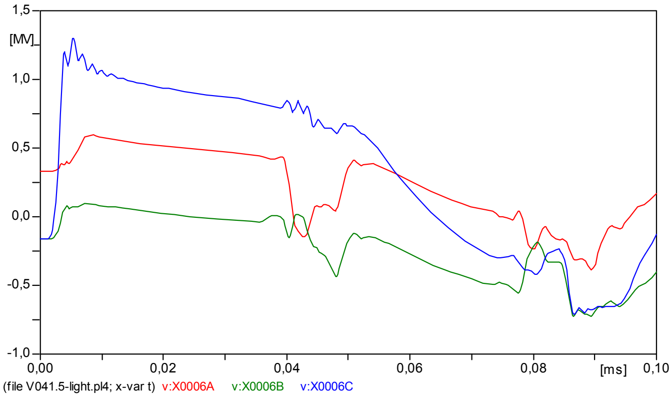

Fig. 8: Overvoltage time behavior on substation input in direct lightning strike to surge arrester 360/255 by lightning current 40 kA

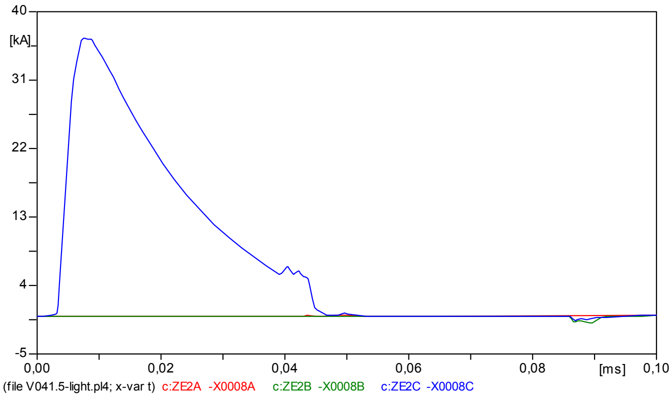

Fig. 9: Time behavior of arrester current for direct 40 kA lightning strike

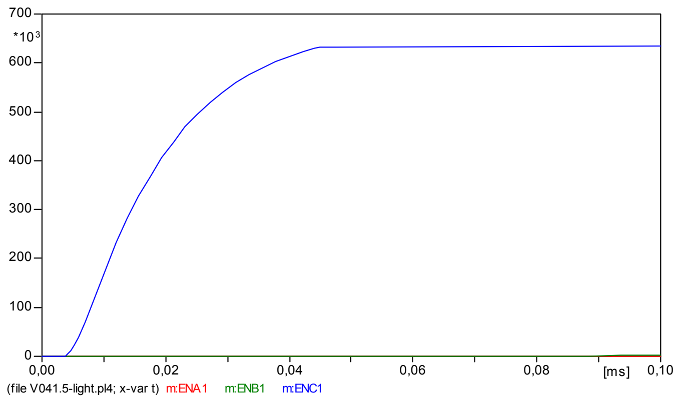

Fig. 10: Time behavior of absorbed energy in arrester for direct 40 kA lightning strike

Next simulations were executed for lightning strike to ground wire. Flashover through spark gap to phase conductor was reached for lightning currents from 90 kA and higher. Simulation results are shown in tab. 2.

Table 2: Atmospheric overvoltage simulation results – lightning strike to ground wire

Lightning current [kA]	5	20	50	80	100
U_{max} without arrester [MV]	0,34	0,36	0,39	0,42	2,1
U_{max} With arrester [MV]	0,34	0,36	0,39	0,43	1,4
$I_{arrest-max}$ [kA]	6E-04	0,003	0,01	0,01	11,0
E [kJ]	0,002	0,01	0,02	0,04	35,2

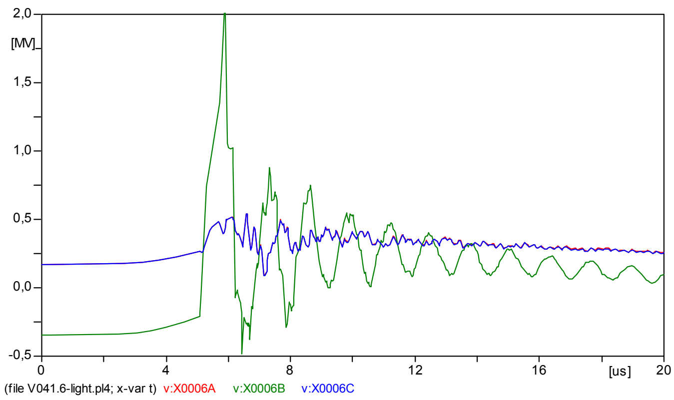

Fig. 11: Overvoltage limited by insulator spark gap – lightning current for lightning strike to ground wire by lightning current 100 kA, no surge arrester

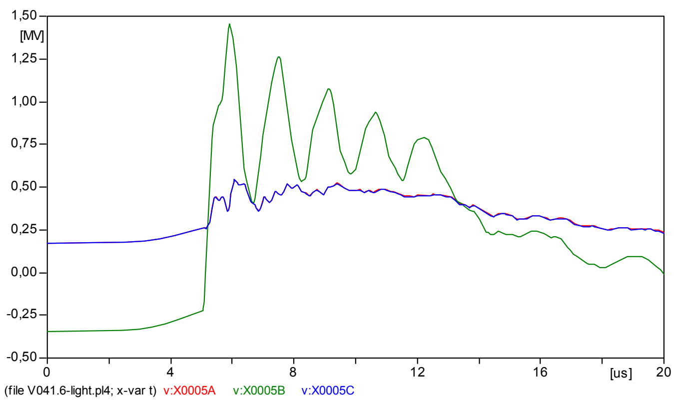

Fig. 12: Overvoltage time behavior on substation input in lightning strike by lightning current 100 kA to ground wire and flashover to phase conductor – surge arrester 360/255

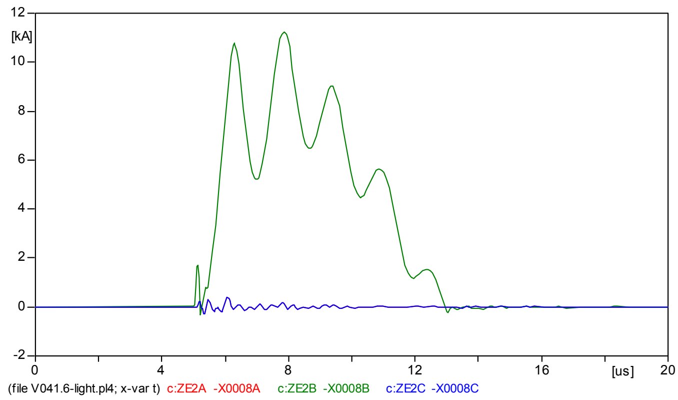

Fig. 13: Time behavior of arrester current for ground wire strike by 100 kA lightning current and flashover to phase conductor

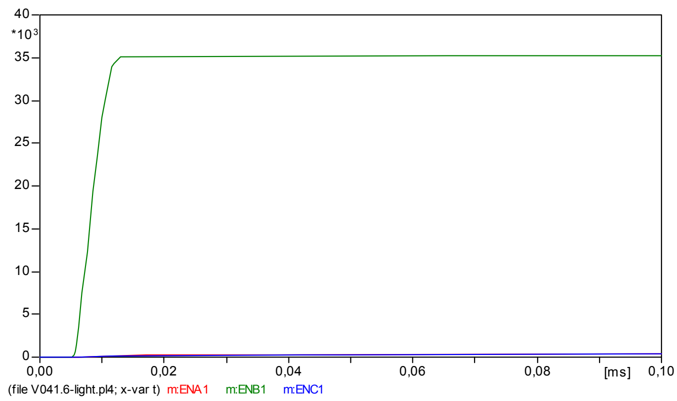

Fig. 14: Time behavior of absorbed energy in arrester for ground wire strike by 100 kA lightning current and flashover to phase conductor

5 Conclusion

Correctness of 400kV line surge arresters electrical parameters in transmission system was verified by realized simulations of atmospheric and switching overvoltages on detailed models of electrical power system parts. Absorbtion capacity of surge arresters was verified and value of normalized withstand voltage of individual devices installed on given voltage level was fulfilled. Correct protection of power system devices against overvoltages can decrease probability of serious faults origin in power system and by that improve safety, electricity supply reliability and stability of power system.

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