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The Analysis of Lightning on Urban Railway Fed with Direct Current Overhead Power Supply

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Key words : Light Railway System, Lightning, Surge arrester, Over Voltage

Abstract

Lightning is one of the most important causes of over voltage disturbances in the DC Light Railway Transportation (LRT) system, which, its effect is not considered, would cause serious problems for devices, staffs and passengers. Lightning arrester is a useful device to eliminate and mitigate this problem. In this paper the effect of lightning strike on LRT is analyzed in two cases: including surge arresters installed in different locations of electrical DC supply and without arresters. Simulation results carried out with ATP software is presented for both cases. It is assumed in this paper that the lightning dose not strike the DC line, directly.

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1-Introduction

Overvoltage is one of the most significant factors in the design of electrical systems such as light railway transportation systems which if not considered, can result in serious hazards for passengers and staffs and interruption in transportation service. Over voltages in electrical systems, are caused by two important reasons: the switching and the lightning. Because of the low voltage used in urban railways (750 V DC) lightning overvoltage has more importance. Nevertheless, switching overvoltage is important, but is in the next priority after the lightning. Lightning phenomenon and its transient overvoltages can make undesirable effects on traction system and can damage them [1].

Charged clouds accommodating above the overhead DC supply system of train, also can change the voltage waveform and the effective value of the voltages which result in flash over in the insulations and could damage them. High voltage disturbances injected to the overhead lines follows in the transformers and to the ground that would damage the insulators quickly. If the resistance of ground path to the load be equal with the resistance of transformer grounding, no overvoltage would be created on the transformer terminals, so no serious problem will be caused. Otherwise serious damages to the insulations and wires would be happened [3].

In the railways which are in parallel with high voltage transmission lines, any fault in the transmission line can change the symmetrical conditions in magnetic fields surround them, which results in currents in the conductors around. Therefore, voltage inductions would be happened in the DC supply of the railways paralleled with high voltage transmission lines which can damage devices [2].

In this paper a short analysis of lightning over voltages is presented and after a glance on the model of direct current system, the simulation results strike of strike of lightning on the LRT is provided for both cases without and with surge arrester installed on different locations of network. Eventually a comparison between them and best point for installing surge arresters providing most protection and fewer costs is presented.

2- Lightning Overvoltage Analysis

The electric railway overhead conductor impedance Z is obtained by equation (1):

$$Z = \sqrt{(L/C)} \qquad (1)$$

which L and C are inductance and capacitance of line in Henries and Farads per length unit, respectively. Lightning waves propagate in the overhead line conductors with light speed and a half of light speed in the cable conductors. Because of different surge impedances in cable and overhead sections, reflection and propagation phenomenon would be seen in the junctions.

The voltage of the surge will be obtained by (2):

$$V_{FC} = 2V_I\left(\frac{Z_c}{nZ_{ocs} + Z_c}\right) \qquad (2)$$

that Z_c and Z_{ocs} are the cable and overhead line surge impedances, respectively. n is the number of parallel cables and V_I is the voltage of surge in the terminals of the transformer which, should be disconnected by appropriate switch.

Arresters used to protect DC power supply system of LRT systems should sustain the maximum switching and lightning DC transient overvoltage. The maximum amplitude of voltage is obtained by (3) and (4):

$$U_{50\%CZ} = \frac{1.05U_{b.p}.K_d}{(1-3\sigma_z)K_h} \qquad (3)$$

$$U_{50\%L} = \frac{1.1 \times 1.25K_d}{(1-3\sigma_L)K_h}U_{b.c} \qquad (4)$$

where $U_{50\%CZ}$ is half of the positive discharge voltage of switching impulse, $U_{b.p}$ is switching impulse limitation, $G_{Z=0.05}$ the constant coefficient for switching impulse of positive amplitude variations, $U_{50\%L}$ half of the positive discharge voltage of lightning impulse, U_{bc} the voltage limit for lightning impulse wave, $G_{L=0.05}$ the constant coefficient for lightning impulse of positive amplitude variations, k_d and k_h are the air density coefficient and air humidity coefficients, respectively [2].

Arresters used in LRT systems in addition to having nonlinear time and temperature invariant characteristics should be able to sustain the energy injected by lightning waves and carry its current to the ground. Thus the best appropriated arrester for railway system protection are the variable metal oxide resistance types.

3-Direct Current Power System Modeling

Usually, urban railway systems are supplied by direct current system with 750 V nominal voltage and maximum amplitude variation between -33% and +20% in the overhead lines [1]. The direct current fed to the locomotive using pantograph returns to the power supply through running rails. Overhead Contact System (OCS) lines consist of parallel tracks connected to each other at the end. Direct current is produced by rectifying AC 20kV waves. After decreasing the AC voltage level using transformer, it is rectified and delivered to the OCS by cable. The schematic diagram of electric railway system is shown in Fig. 1.

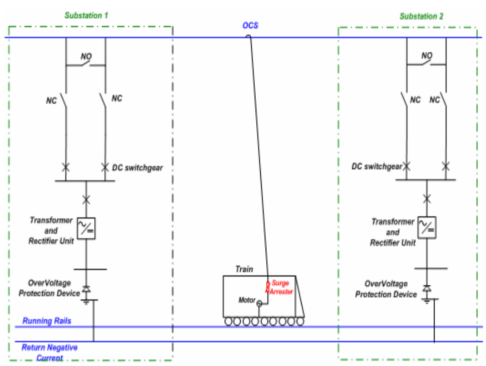

Fig. 1. Schematic diagram of electric railway system

As shown in the Fig. 1, OCS lines are fed using two lines with 500 meter distances from ends.

4-Numerical Simulations

In this section the simulation results for system analyzed in three different cases are presented:

- The system without any surge arresters
- The system with arresters installed at the junction of rectifier and the cable. this condition is shown in Fig .2 illustrated with number 1.
- The system with arresters installed in the junctions which the location of the arrester is shown in Fig .2 illustrated with number 2.
- In this case the arresters are installed both in the cable-rectifire junction and cable-current line junctions(locations 1 and 2 in fig.2)

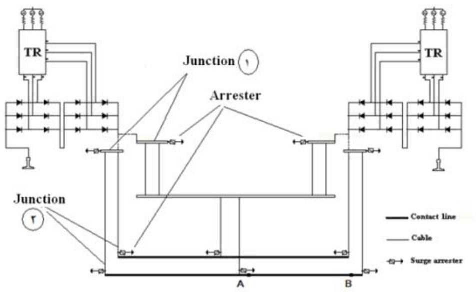

Fig. 2. Different locations for installing arresters

In all above mentioned cases, a 1Ω resistance is serried with surge arrester. Larger resistance leads to larger overvoltage and zero resistance is not suggested because of no control on short circuit currents. Arresters used in simulations have the rated voltage of system and act in 4.08 kV. In each case, the effect of strike of lightning at points A and B is analyzed (A is the contact point of pantograph and the OCS line and B is contact point between the overhead line and power supply cable)

A. First case

In this case the system is supposed to the surge without arrester. The results are shown in Fig. 3 to Fig. 6 for surges stroked to the point A and Fig. 7 to Fig. 9 for surges stroked to the point B.

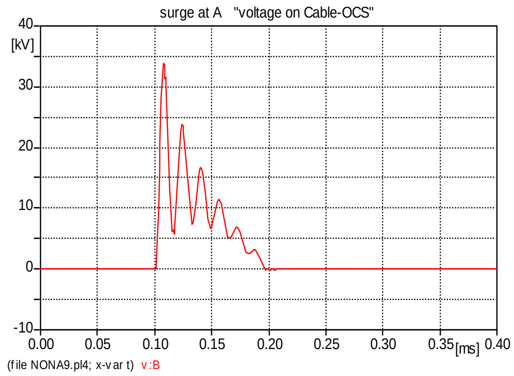

Fig .3. Voltage at cable-OCS junction without arrester and the surge at point A

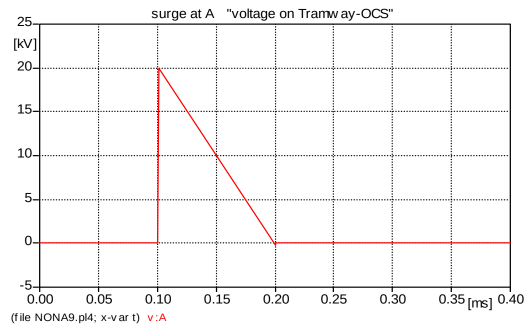

Fig . 4. Voltage on the junction of pantograph and OCS line without arrester and the surge at A

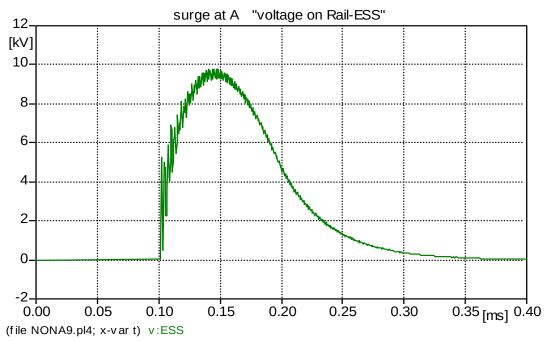

Fig.5. Voltage of rail to return cable junction, without arrester and the surge at point A

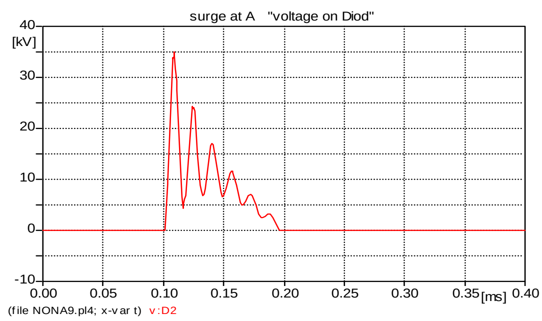

Fig. 6. The voltage of diode without arrester and the surge at point A

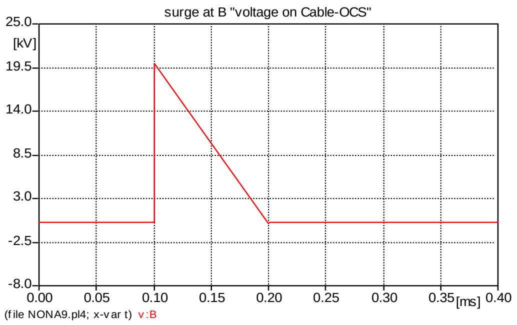

Fig. 7. Voltage at cable-OCS junction without arrester and the surge at point B

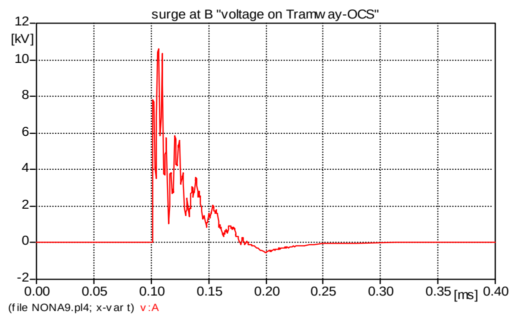

Fig .8. Voltage of junction of pantograph and OCS without arrester and the surge at point B

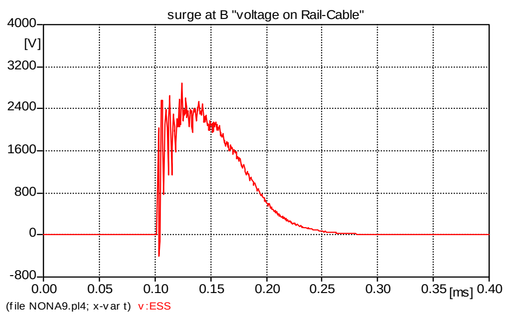

Fig. 9. Voltage at the junction of rail and return cable, without arrester and the surge at point B

B. Second case

In this case arresters are installed at cable to rectifier junction. The results of striking surge at point A are shown in Fig .11 to Fig .14 and at point B are shown in Fig .15 to Fig .18

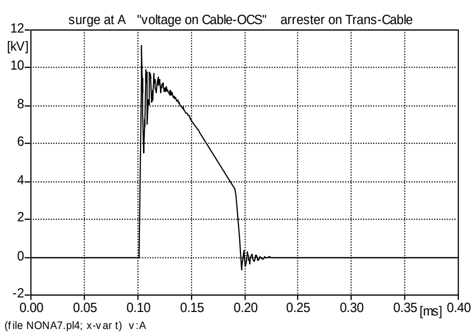

Fig .11. voltage on cable to OCS line junction with arrester at cable to rectifier junction and the surge at point A

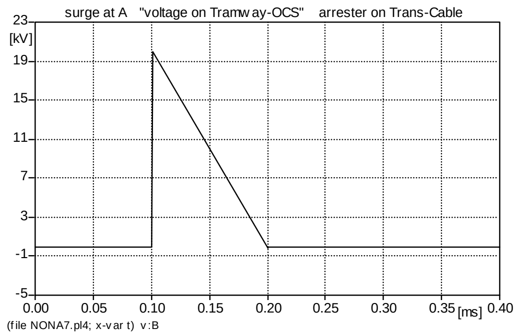

Fig .12. voltage on pantograph connection to OCS line point with arrester at cable to rectifier junction and the surge at point A

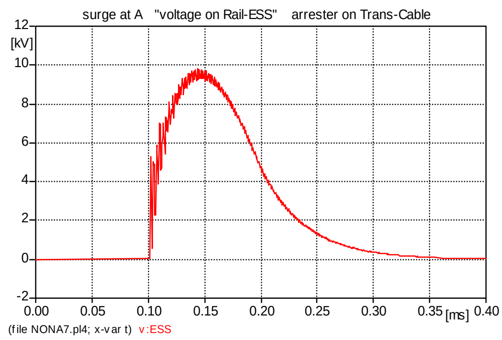

Fig .13. voltage at the rail junction to the return cable with arrester at cable to rectifier junction and the surge at point A

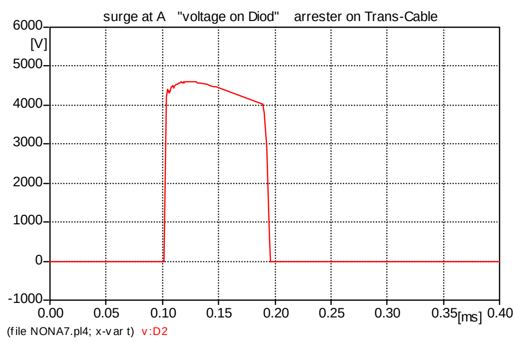

Fig .14. diod voltage with arrester at cable to rectifier junction and the surge at point A

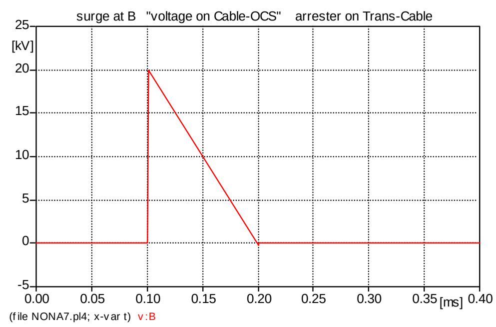

Fig .15. voltage at cable to OCS line junction with arrester at cable to rectifier junction and the surge at point A

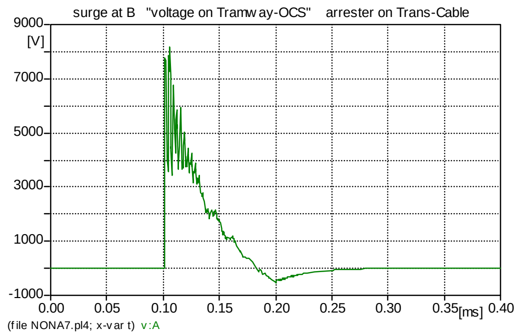

Fig .16. voltage on pantograph connection to OCS line point with arrester at cable to rectifier junction and the surge at point B

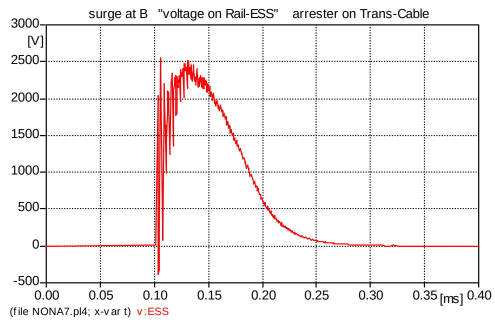

Fig.17: voltage at the rail junction to the return cable with arrester at cable to rectifier junction and the surge at point B

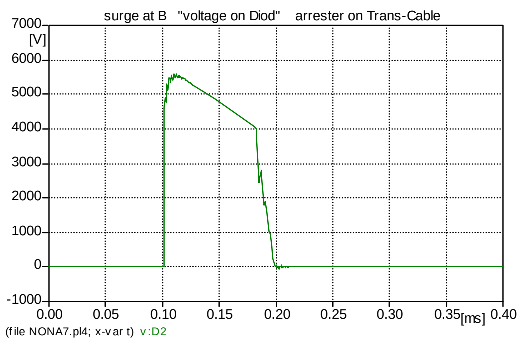

Fig .18. diod voltage with arrester at cable to rectifier junction and the surge at point B

C. Third case

This is the case of arrester installed at the cable to OCS line and the cable to rail junctions.the figs 19 to 22 are results for stricking the surge at point A and figs 23 to 26 for point B.

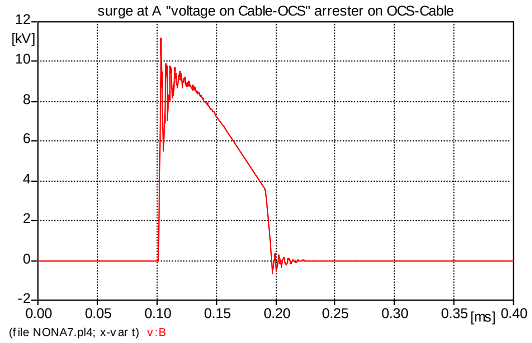

Fig .19. voltage at cable to OCS line junction with arrester at rail to cable and OCS to cable junctions and the surge at point A

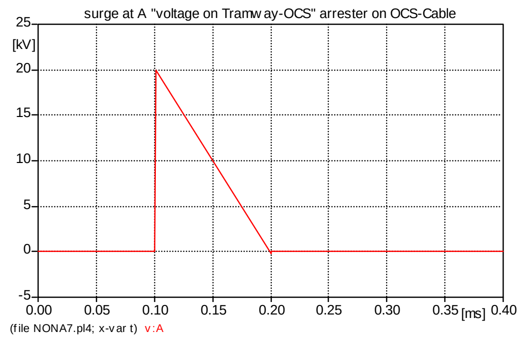

Fig .20. voltage on pantograph connection to OCS line point with arrester at rail to cable and OCS to cable junctions and the surge at point A

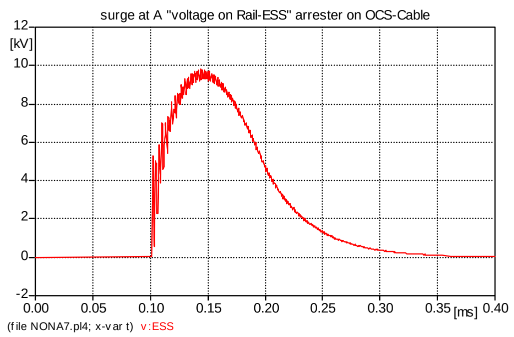

Fig .21. voltage at the rail junction to the return cable with arrester at rail to cable and OCS to cable junctions and the surge at point A

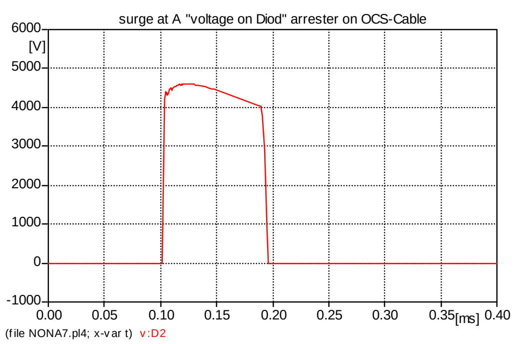

Fig .22. diod voltage with arrester at rail to cable and OCS to cable junctions and the surge at point A

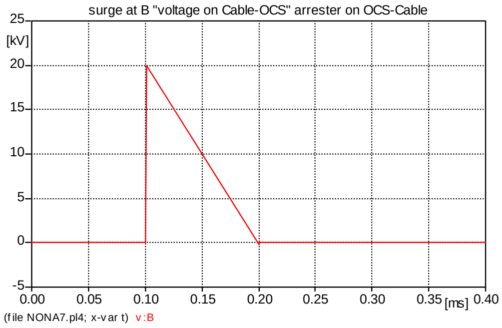

Fig .23. voltage at cable to OCS line junction with arrester at rail to cable and OCS to cable junctions and the surge at point B

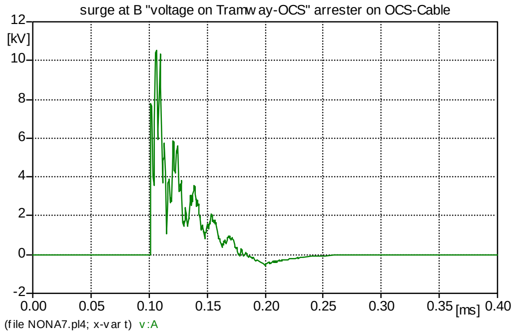

Fig .24. voltage on pantograph connection to OCS line point with arrester at rail to cable and OCS to cable junctions and the surge at point B

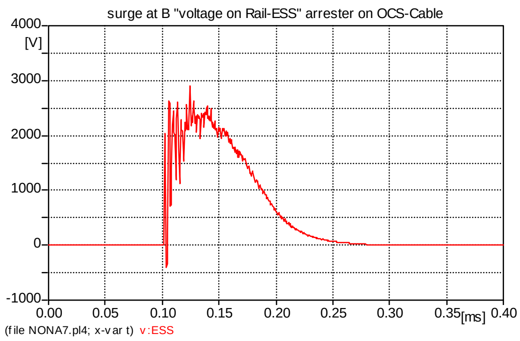

Fig .25. voltage at the rail to the return cable junction with arrester at rail to cable and OCS to cable junctions and the surge at point B

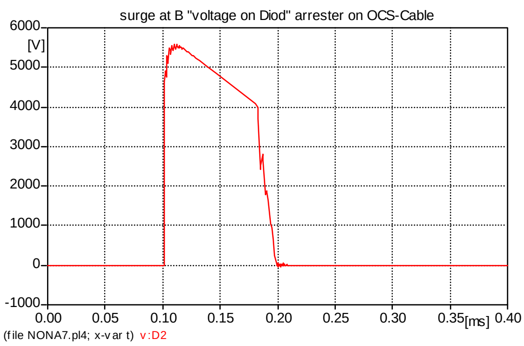

Fig. 26. diode voltage with arrester at rail to cable and OCS to cable junctions and the surge at point B

D. Case four

in this case the arrester is installed at two ends of cable (the cable to rectifier junction and the OCS junctions with rail and the line).although this case is too conservative and have desirable results,it spends a high cost.so the use of this method depends on protection importance,the system sencitivity and the essentially the costs.the results for this case are shown in figs 27 to 30 for surge stricking at point A and the figs 31 to 34 for surge stricking at B.

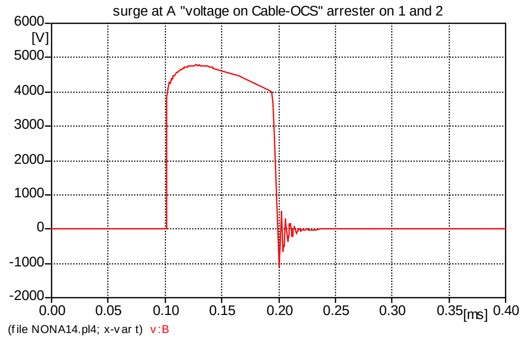

Fig .27. voltage at the cable to OCS line junction with the arresters in points 1 and 2 and the surge at point A

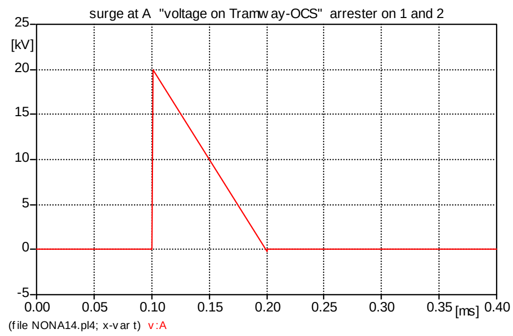

Fig .28. voltage on pantograph connection to OCS line point with the arresters in points 1 and 2 and the surge at point A

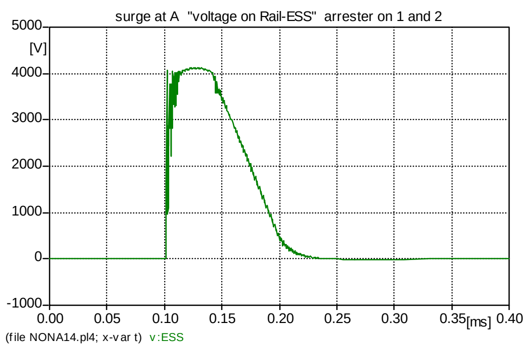

Fig .29. voltage at the rail to the return cable junction with the arresters in points 1 and 2 and the surge at point A

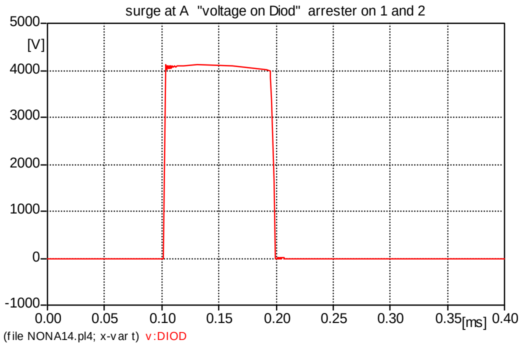

Fig.30: diod voltage with the arresters in points 1 and 2 and the surge at point A

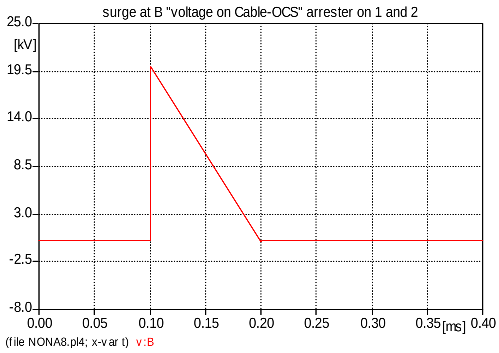

Fig .31. voltage at the cable to OCS line junction with the arresters in points 1 and 2 and the surge at point B

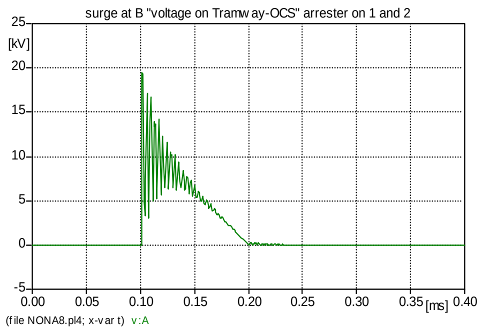

Fig .32. voltage on pantograph connection to OCS line with the arresters in points 1 and 2 and the surge at point B

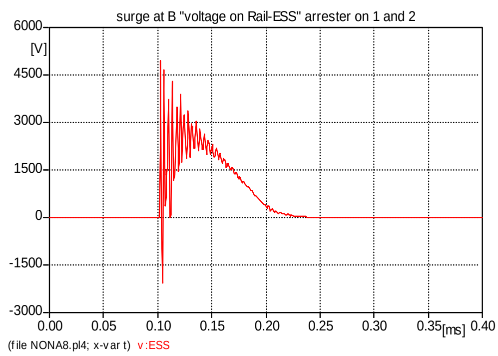

Fig .33. voltage at the rail to the return cable junction by the arresters in points 1 and 2 and the surge at point B

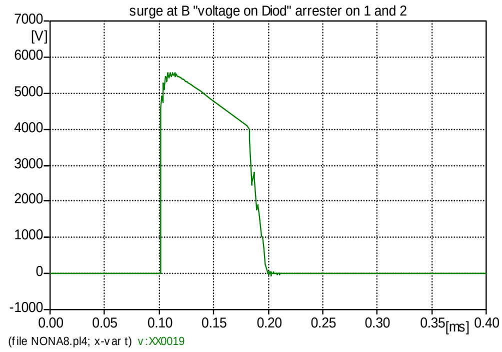

Fig .34. diod voltage with the arresters in points 1 and 2 , the surge at point B

5-Comparision

Considering the simulation results, as it was expected, it is not acceptable for the system to be without arrester(case 1).versus the last case is a reliable one and entirely acceptable but by spending the high cost, we prefer to use one of cases 2 or 3. A brief comparison is shown in Table 1.

Tabble .1. Voltage level comparison of cases 2 and 3

Dio	Rai	Pan	OC	Dio	Rai	Pan	OC	
5.5	2.5	8	20	4.5	9	20	11	1
5.6	2.8	10.5	20	4.5	9.4	20	11	2

It is observed that in all operational conditions, the lightning overvoltage in the second case is less than the third, so it is preferred.

6-Conclution

Considering the simulation results, it was observed that lightning strikes to the overhead current line of urban railway causes very high over voltages on equipments (first case). So it is obvious that in the lack of arrester in the system, serious problems and damages would be happened for devices and interruption in service operation. Although the results of the case 4 was the best, but a trade-off between the cost and protection with a little risk will be acceptable. By considering the insulation voltage limit of 8 kV for cables and 4 kV for rectifier unite [2] and 20 kV for OCS line insulators, in comparison with values of table(1) there is not a considerable difference between values of second case and the desirable values. So the optimum point to install arresters is the location of connecting cable to the rectifier system.

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