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SELECTION AND APPLICATION PRINCIPLES OF SURGE PROTECTIVE DEVICES CONNECTED TO LOW-VOLTAGE DISTRIBUTION SYSTEMS

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SUMMARY

In the paper selection and application principles of surge protective devices connected to low-voltage systems in accordance with IEC 61643-12/2002 standard are presented. First of all, some definitions about surge protective devices are outlined because they are very important for surge protection understanding. In the second part selection and application principles of protective devices are shown. The simulation model made by ATP-EMTP is presented in the third part of the paper, as simulation results are in the fourth part. Voltage and energy co-ordination of surge protective devices is done by this simulation model. It can be valuable tool in the selection of protective devices because all relevant data for surge protection design could be gained.

Keywords

Low-voltage, Low-voltage protection, Surge protection, Surge protection devices, ATP-EMTP, Protection coordination

1. INTRODUCTION: SOME DEFINITIONS ABOUT SURGE PROTECTIVE DEVICES

In this part of the paper some definitions about low-voltage surge protective devices are presented. Definitions are taken from [1] and [2]. These definitions are important to understand selection and application principles presented in the paper. Only few freely interpreted definitions are shown.

Surge protective device (SPD) is the device that is intended to limit transient overvoltages and divert surge currents. It contains at least one non-linear component.

Maximum continuous operating voltage (U_C) is the maximum r.m.s. voltage which may be continuously applied to the surge protective device. This is equal to the rated voltage.

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Voltage protection level (U_P) is the parameter that characterizes the performance of the surge protective device in limiting the voltage across its terminals. This value is greater than the highest value of the measured limiting voltages. Also, this voltage threatens the insulation of the protected equipment.

Measured limiting voltage is the maximum magnitude of voltage that is measured across the terminals of the surge protective device during the application of impulses of specified waveshape and amplitude.

Residual voltage (U_{res}) is the peak voltage that appears between the terminals of a surge protective device due to the passage of dischagre current.

Temporary overvoltage (U_T) is the maximum r.m.s. value that the protective device can withstand and that exceeds the maximum continuous operating voltage U_C for specified time duration.

Nominal discharge current (I_n) is the crest value of the current through the surge protective device having a current waveshape of 8/20. This is used for the classification of the device for class II test.

Impulse current (I_{imp}) is the current peak value (I_{peak}) and the charge (Q) tested according to the test sequence of the operating duty test. This current is used for the classification of the device for class I test.

Voltage switching type surge protective device is the device that has a high impedance when no surge is present, but can have a sudden change in impedance to a low value in response to a voltage surge. The examples are spark-gaps and gas discharge tubes.

Voltage limiting type surge protective device is the device that has a high impedance when no surge is present, but will reduce it continuously with increased surge current and voltage. The example is non-linear varistors.

Combination type surge protective device is the device that incorporate both voltage switching type components and voltage limiting type components.

Maximum discharge current (I_{max}) for class II test is the crest value of a current through the surge protective device having an 8/20 waveshape and magnitude according to the test sequence of the class II operating duty. To note, maximum discharge current is greater than nominal one.

Sparkover voltage of a voltage-switching surge protective device is the maximum voltage value before disruptive discharge between the electrodes of the gap of a device.

Specific energy W/R for class I test is the energy dissipated by the impulse current I_{imp} in a unit resistance of 1 Ω. It is equal to the time integral of the square of the current:

$$W / R = \int i^2 \cdot dt \ .$$

Lightning protective system is the complete system used to protect a structure and its contents against the effects of lightning. For the protection against surges the Lightning Protection Zones Concept described in [3] is applied. Here, a structure is subdivided in different risk zones:

- 0_A – Zone where items are subjected to direct lightning strokes, and therefore may have to carry up to the full lightning current. The unattenuated electromagnetic field occurs here.
- 0_B – Zone where items are not subject to direct lightning strokes, but the unattenuated electromagnetic field occurs.
- 1 – Zone where items are not subject to direct lightning strokes and where currents on all conductive parts within this zone are further reduced compared with zones 0_B.
- 2 – If a further reduction of conducted currents and electromagnetic field is required, subsequential zones shall be introduced.

In this paper it is analyzed what happens when the equipment is protected by one spark-gap at the entrance to the structure (main distribution board), and by one non-linear ZnO varistor in the vicinity of protected appliance. The spark-gap is at the boundary between 0_B and 1 zones, and ZnO varistor is between 1 and 2 zones. The spark-gap in this case is known as class I device, non-linear varistor is known as class II device. These equipment (class I and class II) are quite different by their currents and specific energies that they can bear.

For the spark-gaps (class I device) the testing by the current impulse 10/350 μs is prescribed. This surge is caracterized by very high energy and charge. Much lower values of energies and charges are employed for testing non-linear resistors if it is class II device because the waveshape of current impulse. The waveshape in the case of class II device is 8/20 μs. In practical cases it is easy non-linear varistor to be destroyed due to high energy stresses if co-ordination between devices is not achived.

2. SELECTION AND APPLICATION PRINCIPLES ACCORDING TO IEC 61643-12

Some application principles of low-voltage surge protective devices according to IEC 61643-12 are presented. Detailed informations can be found in [1].

Possible mode of protection and installation are dependent of types of systems. When the equipment to be protected has a sufficient overvoltage withstand or is located close to the the main distribution board, one surge protective device may be sufficient. In this case, the protective device should be installed as close as possible to the origin of the installation. The surge protective device should have sufficient surge withstand capability for this location.

The device should be installed between line and neutral, line and protection conductor (PE) and neutral and PE because neutral and PE are separated in this type of system. In the TN-C system there is the device between line and PEN (commom protection and neutral conductor). In the TN-S system the protective devices between line and neutral, line and PE and between neutral and PE conductor are required. Protection between phase and phase are possible in all cases, but is not generally used.

The influence of the oscillation phenomena on the protective distance is also very important. When an surge protective device is used to protect specific equipment or when the device located at the main distribution board cannot provide enough protection for some equipment, protective devices should be installed as close as possible to the equipment to be protected. If the distance between the protective device and the equipment to be protected is too large, oscillations could lead to a voltage at the equipment terminals which is generally up to two times higher than protection level but, under some circumstances, can even exceed this level. This can cause a failure of the equipment to be protected, in spite of the presence of the surge protective device.

In order to achieve optimum overvoltage protection, connecting conductors of protective devices shall be as short as possible. Long lead lengths will degrade the protection offered by the protective device.

The need for additional protection is also important. In some conditions one surge protective device is sufficient, for example, if the stresses at the entrance to the structure are low. It is then better to install the protective device close to the mains entrance. Additional protection close to the equipment to be protected may be necessary in some special cases, for example where very sensitive equipment (electronic, computer) is present, the distance between the protective device located at the entrance and the equipment to be protected is too long, or there are electromagnetic fields inside the structure created by lightning discharges and internal interference sources.

It is necessary to consider the voltage withstand U_W (defined by IEC 60664-1) of the most sensitive equipment to be protected. The protective device located closest to this equipment shall be selected with a voltage protective level of U_{p2} at least 20 % below the voltage withstand of this equipment. If the protective level U_{p1} of the entrance device combined with possible oscilations due to the distance between this device and the equipment leads to a voltage below $0{,}8\times U_W$ at the terminals of the equipment, then no additional surge protective device is necessary close to the equipment. This condition have to be analyzed. This analysis is presented in this paper. That analysis mainly can be done by special electromagnetic transients programs. Potentially damaging switching surges can be generated inside buildings. In this case, additional protective devices may be needed. When two protective devices are used on the same conductor, they shall be co-ordinated. There are some procedures for doing this task. One of them is presented in this paper.

At the point of entry depending on the incoming stress, surge protective devices tested according to class I, class II or class III may be used. The devices tested according to class II and class III tests are also suited for location close to the protected equipment.

The procedure of selection of the protective devices can be presented as follows:

- Selection of U_C, U_T and $I_n/I_{imp}/I_{max}/U_{OC}$ of the surge protective device,
- Protective distance (location of the protective device),
- Prospective life and failure mode,
- Interaction between protective devices and other devices,
- Choice of the voltage protection level U_p, and
- Co-ordination between the chosen surge protective device and other surge protective devices.

Some of these issues are explained.

Continuous operating voltage U_C in TN and TT systems have to be higher than maximum continuous operating voltage U_{CS} that may occur in the system:

$U_C > U_{CS}$.

The relationship between U_C and the nominal voltage of the system is presented in Annex B of the standard [1, page 109]. For example, when the nominal voltage of the system is 230/400 V, minimal U_C for surge protective device installed between phase and PE in the case of TN systems or between phase and neutral in the case of TT systems is 253 V.

U_T values shall be higher than the temporary overvoltage (TOV) that is expected to occur in the installation due to faults in the low-voltage system. This value is very important for thermal stability and the runaway of the non-linear protective devices, for example ZnO varistors. The choice of ZnO is based on the same principle as in the high-voltage systems in order to avoid the thermal runaway. The value of U_T have to be provided by manufacturer of surge protective device.

The choice of the of the surge protective device energy withstand (choice of either I_{imp}, I_{max} or U_{OC} depending on the class of test) shall be based on a risk analysis which compares the probability of occurence of surges, the price of the equipment to be protected, completed with a co-ordination analysis when more than one device is involved.

The protective distance is also important. To determine the location of device (at the entrance, close to the equipment, etc.) it is necessary to know the acceptable distance between the surge protective device and the equipment to be protected.

Co-ordination between the chosen surge protective device and other protective devices is of special importance in this paper. Some applications may require the use of two (or more) surge protective devices in order to reduce the electrical stress on the equipment to be protected to an acceptable value and to reduce the transient current inside the structure. To obtain an acceptable sharing of the stress between the two protective devices according to their energy withstand, co-ordination is needed.

Between two protective devices the impedance (in general an inductanse) may be needed in to the line to facilitate the sharing of the energy between the two devices. This can be an inductanse or is a cable of some length. In [1, page 93] it is proposed to calculate with 1 μH/m per cable length.

Co-ordination between protective devices is made to achive the energy criterion. This is based on the maximum energy withstand of the second device. This energy is dependent upon the waveshape and the tests, as described in IEC 61643-1. Two values are necessary to define satisfactorily the energy withstand of an surge protective device:

- $E_{max\ S}$ for short-duration current waveshapes, for example, 8/20 (class II test), and
- $E_{max\ L}$ for long-duration current waveshapes, for example class I test waveshapes.

It is necessary to co-ordinate devices 1 and 2 using their maximum energy withstand E_{max} for the relevant surge waveshapes. That means it is necessary to deal with two cases: co-ordination with long-duration and short-duration waveshapes. In this paper co-ordination is made using the long-duration waveshapes. The case of co-ordination between a gap-based surge protective device and a ZnO varistor based one is done. There is some inductance between them to achieve adequate co-ordination. At higher energy levels, non-operation of spark gap will allow excess energy to reach the downstream protective device and cause its destruction. Co-ordination is achieved by ensuring that there is sufficient series decoupling impedance to ensure gap operation at all energy levels above the limit of the downstream surge protective device.

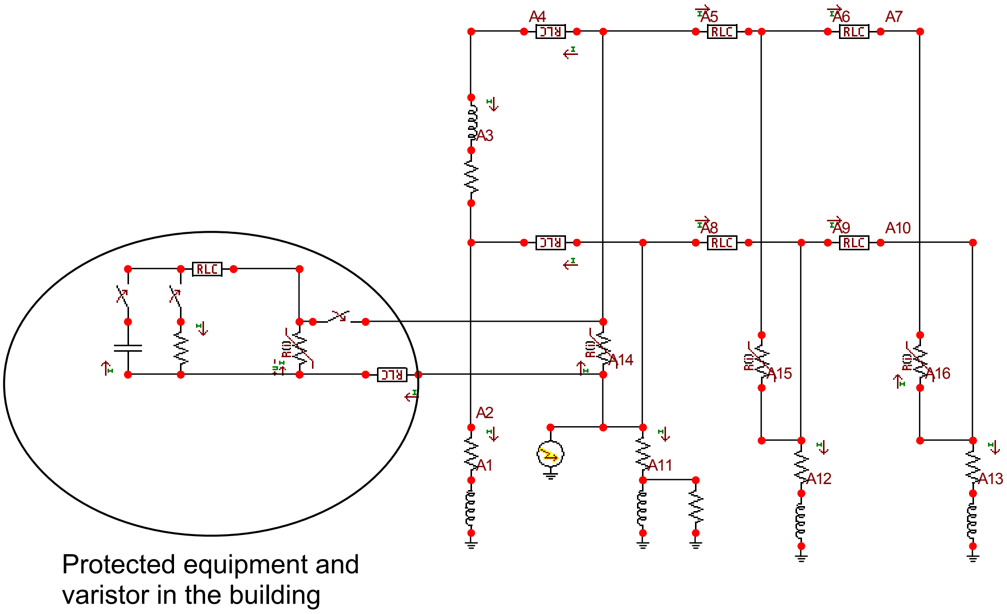
3. THE SIMULATION MODEL

In [5] the results of an analysis of a lightning current sharing between many surge protective devices (gas discharge tubes) are presented. It is supposed that there is only one device per building (structure). This lightning current arrester is mounted in the main distribution board. The striken structure is surrounded by two other structures and a transformer station 10/0,4 kV. But, in [5] there was no interest about current sharing into the building. On the contrary, in this paper the main issue is the current sharing and overvoltage limitation inside the building.

But, for the reason of simplicity, current sharing is analyzed only in one of the three buildings. It is supposed that there is one ZnO voltage-limiting device (surge arrester) close to the protected equipment. The varistor is 30 m far from lightning current arrester in the main distribution board. The TN system is supposed. For the sake of simplicity, only two conductors in the building are assumed – phase and PEN conductors.

The simulation model is taken from [5], but it is completed with internal installation in one of the building. Simulations are done by ATP-EMTP (Alternative Transients Program version of ElectroMagnetic Transients Program).

In the Figure 1 the simulation model is presented.



1. Figure 1: The simulation model

Analyzed network consists of a transformer 10/0,4 kV and three buildings in line. The first building is 20 m away from transformer. The second building is 100 m away from the first one, as the third building is 100 m far from the second one.

Rated primary and secondary voltage are 10 kV and 0,4 kV. Transformer is presented as R-L branch with resistance R_T=2,2 mΩ and inductance L_T=14 μH. Grounding of the transformer station is presented by resistance of 10 Ω and inductance of 5 μH.

Installations in the buildings are connected to transformer by the cable which phase and PEN conductors cross-section are the same (25 mm^2). The unit resistance of the cable is r=0,823 mΩ/m at 60°C and unit inductance l=0,2548 μH/m. The grounding of the building is R=10 Ω and L=5 μH.

The lightning is modeled as current generator with two exponential functions, as proposed in [3]:

$$i(t) = 104799{,}83 \cdot (e^{-2083{,}3 \cdot t} - e^{-250000 \cdot t}) \quad i(\mathrm{A}), t(\mathrm{s}) .$$

This generator, for example, will give the current which peak value is approximately 100 kA, with vaweshape 10/350.

In each building there is one lightning current arrester in the main distribution board. It is supposed that it is encapsulated creepage discharge spark gap with sparkover voltage of 2500 V and residual voltage 80 V. For the sake of simplicity, it is supposed that the impulse sparkover voltage curve is flat, in other words, the sparkover voltage is not dependent upon the rate of rise of the applied transient voltage. Rated voltage (maximum continuous operating voltage is 255 V/50 Hz. The spark gap is tested (class I) by 50 kA of vaweshape 10/350 μs. Charge Q (integral of current) or specific energy (W/R) is not given in the catalogue. But, simulation model is made in such a way to enables us to calculate these decisive values.

The residual voltage curve of one ZnO varistor installed close to protected equipment is taken from [7, page 382]. That curve is typical and is presented in Table I. For the sake of simplicity in the figure 1 one varistor with protected equipment is presented. The varistor is 30 m away from main distribution board.

Table I: Residual voltage curve of ZnO varistor

I [A]	0.001	500	2000	5000	14000	25000
U [V]	500	600	700	850	1250	1400

This device (class II) is tested by 8/20 maximum discharge current I_{max} of 5 kA. Lightning impulse current 10/350 is not given. It is necessary to co-ordinate two different class devices – one tested with 10/350 and the second by 8/20 μs vaweshape. That means that it is necessary to recalculate energy of vaweshape 8/20 to energy corresponding to vaweshape 10/350 because the lightning stroke is simulated with the current of vaweshape10/350. The proposed derating factor [1, page 165] is 4:1. Therefore, the peak current rating reduces from 5 kA to 1,25 kA.

The line conductor in the building is presented only by its inductance L=1 μH/m, as proposed in [1]. The resistance of this conductor can be neglected [1]. It is clear that length of this conductor will be very important for co-ordination of two protective devices.

In the figure 1 paralleled capacitance and resistance model protected equipment. But, equipment can be presented as infinite impedance.

4. SIMULATION RESULTS

In the figure 2 two current curves are presented. One is 5 kA 8/20, as the second is 1085 A 10/350 μs waveshape. The ZnO varistor is tested with current of 5 kA 8/20, but simulations are made with 10/350 waveshape. Specific energy W/R for these currents are equal, 304 A^2s. Calculation of energies is made by ATP-EMTP. That means that ZnO varistor may bear this energy stress. Derating factor calculated by ATP is 4,6:1, close to value 4:1, as proposed in IEC standard [1].

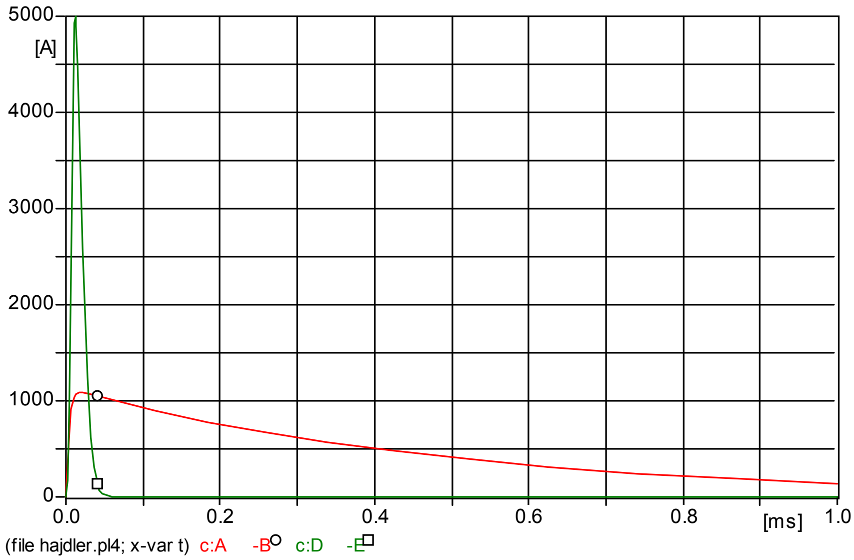


Figure 2: Waveshapes of currents 8/20 and 10/350

In the first simulation the crest value of 10 kA is proposed. At the first time (33 ns) the current flows through varistor, but not through spark gap. Inductance of conductor is 30 μH because its length is 30m. Voltage at inductance grows, as well as at ZnO varistor. About 33 ns from beginning spark gap ignites, and current start to flow through it. Because the spark gap is practically short-circuit, all current is diverted through spark gap. This is the method for energy coordination because varistor can bear much lower energy than spark gap. The essence element in this procedure is inductance.

In the figure 3 voltages on varistor (A16-A5), spark gap (A14-A5) and inductance (A18-A5) are presented. It is evident that spark gap ignites at t=33 ns and takes over the current from varistor. Specific energy in that case is negligible small (3,9· 10^{-8} A^2s).

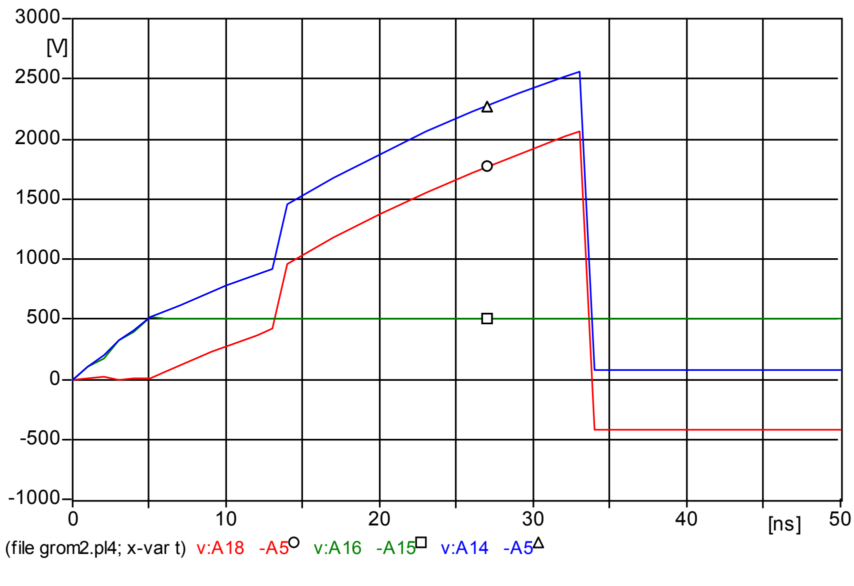


Figure 3 Voltages of the inductance (A18-A5), varistor (A16-A5) and spark gap (A14-A5)

The spark gap is placed in main distribution board where dielectric withstand is 4 kV (category III). Residual voltage at spark gap is 2,5 kV. Because residual voltage is much lower than 4 kV, the protection of installation of 4 kV is adequate. In accordance to standard [1], the protective device shall be selected with voltage protective level of device at least 20 % below the voltage withstand, in this case 4 kV.

If ZnO varistor is placed close to protected equipment, for example household appliances, portable devices etc, it can adequately protect equipment because for category II withstand voltage is 2,5 kV. Protective level of ZnO varistor is 1,5 kV (1,5/2,5=0,6).

In the figure 4 result of another simulation is presented. This is the case where varistor cannot withstand energy requirements due to very low inductance. The spark gap cannot ignite and all of the current flows through varistor. Energy coordination of two protective devices is not achieved.

Specific energy in this case is 1058 A^2s, much greater than 304 A^2s. The ZnO varistor would be destroyed easily. In any case, simulation by ATP can give us all answers about choice of protective devices. Also, we can get an answer about a value of needed inductance to achieve good energy coordination. Figure 4 shows that spark gap cannot ignite because voltage on it is about 1450 V, much lower than 2500 V.

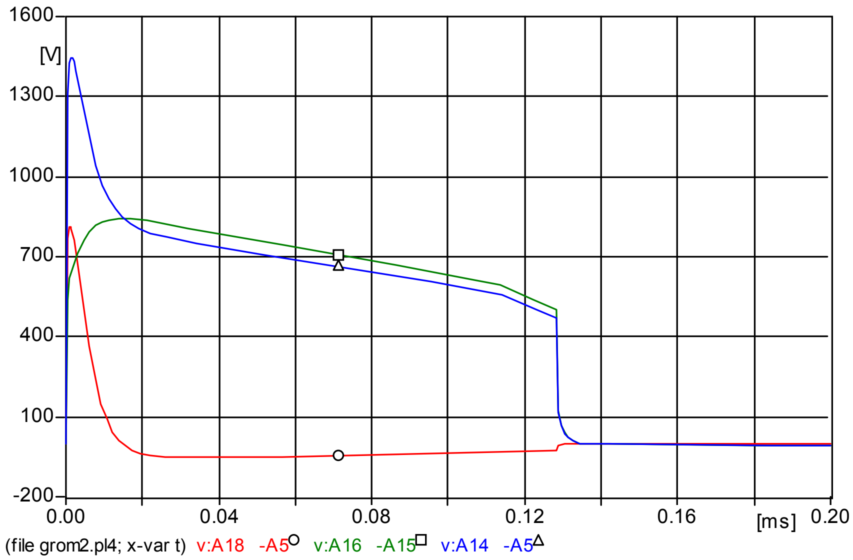


Figure 4 Voltages in the case of bad coordination
Voltages of the inductance (A18-A5), varistor (A16-A5) and spark gap (A14-A5)

In some conditions one surge protective device is sufficient, if the stresses at the entrance to the structure are low. It is then better to install the protective device close to the mains entrance. Let the ignition voltage of spark gap is 1300 V. Such devices are available in the market. There is no ZnO varistor close to the connected load. The load is 30 m away from main distribution board. Unit conductor inductance is L=1 μH/m and unit resistance is R=0,0115 Ω/m. If a load resistance is 10000 Ω, voltages at the spark gap (A14-A5), at the inductance (A18-A5) and at load (A15-A16) are presented in the figure 5.

In this way we can compare maximum voltage at the load with withstand voltage of equipment. But, voltage is dependent of the load resistance and value of lightning current, if load is not disconnected during current surge. In the Table II voltages at the load as function of surge current are presented. In the third row the time of spark gap ignition is shown.

Table II: Voltages at the load as a function of surge current

U (V)	186	851	781
I (A)	100000	10000	1000
t (ns)	1	8,2	Doesn't ignites

In the Table III influence of load resistance on maximum load voltage is shown.

Table III: Load voltage as a function of load resistance.

R (Ω)	100000	10000	5000	1000
U (V)	1194	851	631	215

Maximum load voltage have to be compared with withstand voltage of protected equipment. In this way the conclusion is the protection is adequate or not can be made.

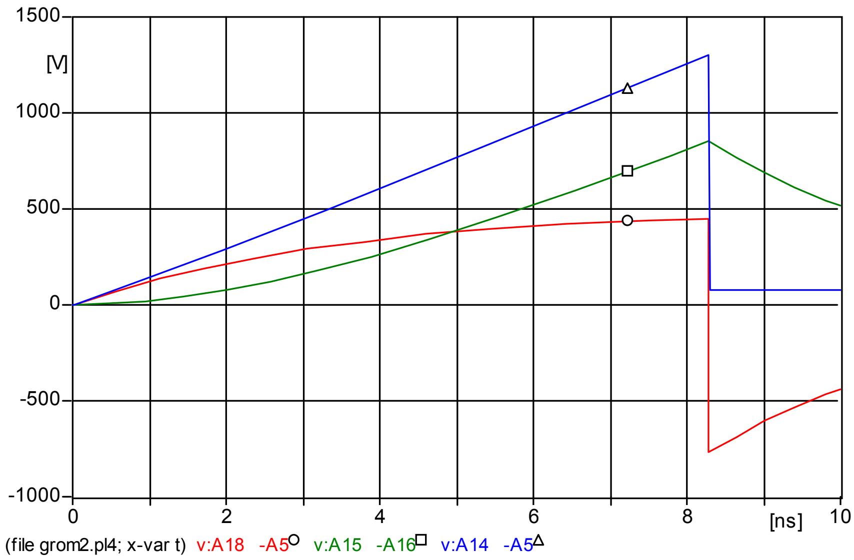


Figure 5: Load voltage (A15-A16)

5. CONCLUSIONS

Some conclusions can be made.

Selection and application principles of surge protective devices connected to low-voltage power distribution systems are not a simple matter. They are defined by IEC 61643-12 standard, published 2002. Some parameters of these devices have to be defined in accordance to the rules presented in this standard. In the paper some issues about this choice are presented.

Energy and voltage co-ordination of several protective devices are relativly hard task if the data are not given by manufacturer. The best way to coordinate two or several devices is to simulate the processes in real installation. This is done in this paper. In such a way all needed data for choice and coordination are obtained.

6. REFERENCES

[1] IEC 61643-12 Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles, First edition 2002-02

[2] IEC 61643-12 Low-voltage surge protective devices – Part 1: Surge protective devices connected to low-voltage power distribution systems – Performance requirements and testing methods, First edition 1998.

[3] JUS IEC 1312-1 Zaštita od elektromagnetskog impulsa atmosferskog pražnjenja, Deo 1: Opšti principi, 1997. (Protection against lightning electromagnetic impulse Part 1: General principles)

[4] Mansoor A, Martzloff F. D, Phipps K: 1998, “Gapped arresters revisited: A solution to cascade coordination”, 1998, IEEE Transactions on Power Delivery, Vol. 13, No. 4, October 1998. pages 1174-1180.

[5] Stojković S., 2002, “Izbor uređaja za zaštitu objekata od struja pražnjenja pri direktnom udaru groma" , JUKO CIRED Treće jugoslovensko savetovanje o elektrodistributivnim mrežama, Vrnjačka Banja 15-18. oktobar 2002., referat R 2.07

[6] Canadian/American EMTP User Group, 1987-92, ″Alternative Transients Program (ATP) Rule Book″,

[7] DEHN – Blitzplaner, 2001, Druckscrift Nr. DS 702/2001, prospektni materijal firme DEHN+SOHNE

[8] DEHN+SOHNE, 2002, Surge Protection, Main Catalogue, Publication No. DS 570/E/2002.