Analysis of Coordination between Surge Protection Devices in Low Voltage Electric Networks

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Abstract – Low voltage Surge Protection devices (SPDs) are one of the most important electrical equipments to protect the electric networks against transient destructive electrical waves. Using only one SPD, in general, is not enough due to either large distances between SPDs and electric loads or high sensitivity of the electric networks' apparatuses. In practice, to make conditions better, several SPDs are used simultaneously and in due order. In this case, right technical selection of each of the SPDs and the electrical distance between each pair play an important role to achieve an effective protection system to keep the electrical equipments safe; this is specifically important since having not taken into account the SPDs specifications and the distance between each pair would lead into destructions of electric equipments and even SPDs themselves. In this paper, though modeling and simulation of a complete low voltage network, coordination's between a two-stage protection systems will be analyzed; modeling and studies have been implemented in EMTP-RV software package and results extracted and investigated. The outcomes of this study have pointed out that when SPDs are selected technically rightfully, an increase in the cable between two SPDs would increase the absorbed energy and current discharge in the upstream SPD and decrease the voltage of the SPD near to the load.

Keywords: Transient over voltages, Low voltage surge protection, Surge protection coordination
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1. Introduction

Transient waves caused by switching and/or lightning are among the main destruction and malfunction of sensitive electrical equipment and electronic systems in the low voltage networks. The ever increasing developments of low voltage and low insulation strength of electrical and electronic systems justifies due attention to their effective protections against these switching or lightning phenomena. Employing the low voltage Surge Protection Devices (SPDs) is one of the prevalent methods to prevent destruction of electrical equipment against the transient waves. Generally, to make protection system more efficient, there is a need to use more than one SPD in protection scenarios. In such cases, paying appropriate attention to the coordination between SPDs to perform best are of much importance to achieve an effective protection system. Here, the coordination refers to the technical specification of each SPD and the electrical distance between each pair of them in order to effectively secure the system under protection with respect to voltage and current.

Generally speaking, when manufacturing technology between two SPDs are different, coordination between them are more important. This is because of the higher current capacity of the upstream SPD makes their internal structure different from the voltage SPDs. In current SPDs (class 1), when the input voltage exceeds the Maximum Continuous Operating Voltage (MCOV), they start to discharge the lightning current. Since the continuous operating voltage (COV) of the voltage SPDs (classes 2 and 3) is lower than that of COV of the current SPDs, the voltage SPD would discharge the current sooner and thus, it makes the current SPDs unable to perform as their voltage is already lower than the needed one for them to operate. Therefore, if these SPDs (voltage and current ones) are installed in a line and less distant from the appropriate one, there is a possibility that all the lightning current discharges through the voltage SPD and thus makes it damaged.

The most prevalent method to make coordination between SPDs is using those suggested in the standards. The standard IEC 62305-3 (as depicted in Fig. 1) suggests using a separating inductance between SPDs in order to create coordination between them (two-stage protection system). One important disadvantage of using this method

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is that the inductive impedance is limited to only 32 and 63 amperes [2]. Moreover, when usage of the separating impedance is not possible, performance of the two SPD will face problems.

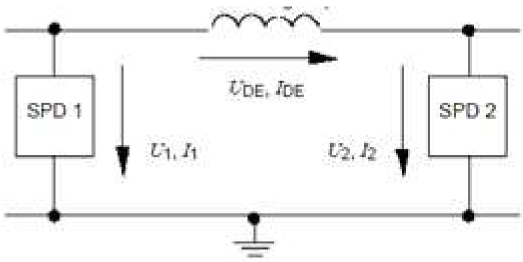


Fig 1: Using the inductance in order to coordinate the two SPDs [1]

The related papers in this context generally discuss the usage of separating impedance for coordination between SPDs [3-5]. Others have analyzed technical specifications and distance determination of the SPD from the equipment under the protection for a given network configuration and equal distances between SPDs [6-8].

In this paper, having modeled a low voltage network with more exact specifications of the equipment, the coordination between SPDs have been studied; more specifically, it has been tried to derive some rules for better coordination between SPDs and taking care of the equipment under protection in the absence of the separating impedance.

2. The Network under Study

In order to study the coordination between the low voltage SPDs in a given electrical network, each part of the network should be modeled exactly.

Here, to model the lightning as well as a mixed 6kV/3kA waveforms, the circuit depicted in Fig. 2 have been used [8]. This circuit is able to produce voltage waveforms with 12.5 micro seconds and current waveforms with 8.2 micro seconds, respectively. More details of the model are as follows: a single stranded copper cable with 1.6mm diameter and insulated with a PVC layer of 0.6mm thickness and 4.55 dielectric constant. More on the cable, the specific resistance is 1.724e-8 Ωm, capacitance 452.3pF/m and inductance 3.0685μH/m; the characteristic impedance of the cable is equal to 82.4Ω; the supply circuit has been modeled as π segments separated from each other with Δx=5m.

In order to model the upstream SPD (farthest one from the device under the protection), due to its high current and inclusion of the sparking branch, Pinceti model (Fig. 3) has been used [9].

For the upstream SPDs (input to the networks), SPDs of class 1 (current SPDs) are typical, while for the downstream (nearest to the equipment under protection) SPDs are chosen based on the v-i characteristic curve as given in table I.

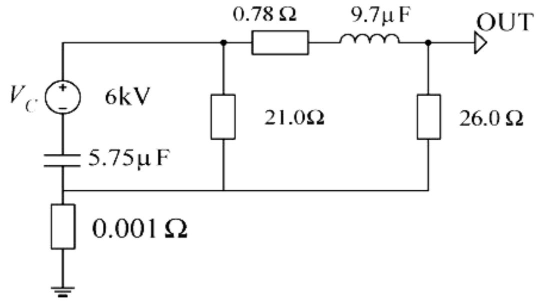


Fig. 2: The simulator circuit of voltage and current of lightning waves

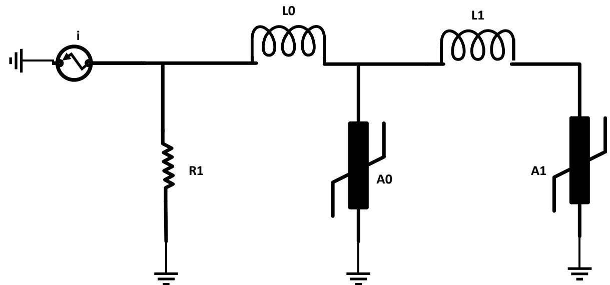


Fig.3: The Pinceti SPD

Table I: The v-i characteristic curve of the SPD

Voltage(Pu.)	*Current(A)*
10^{-8}	1.78455
10^{-7}	2.31807
10^{-6}	2.63083
10^{-5}	2.75961
10^{-4}	2.98038
10^{-3}	3.12756
10^{-2}	3.42191
10^{-1}	3.76043
1	4.50000
1.5	5.45666

3. The studied Network for SPDs' Coordination

The single phase equivalent circuit of the network under study, as depicted in Fig. 4, include a generator for production of the voltage-current waveforms, cables for connections of equipment and protection SPDs.

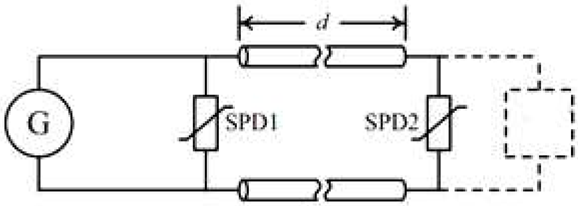


Fig.4: The single phase low voltage network under study

In order to model the transient behavior of the lightning, a mixed 6kV/3kA wave has been adopted [10]. The first protective SPD (SPD1) is the next device after the lightning waveform generator. This SPD is connected to the over-voltage SPD (SPD2) using a cable of the length d. The other details of the simulated scenario are given in table II.

The simulations have been done in the absence of the electrical load; since the performance has been improved in the absence of the load, the results can also been used for the SPDs in the presence of the electrical loads such as residential.

Table II: Technical specifications of the SPDs

Surge Arrester	*MCOV*	U_P	$I_{Max}(8/20\mu s)$
SPD275v	275	710	2
SPD320v	320	810	2
SPD660v	660	1650	4.5

4. Simulations and Analyses

4.1. Determination of the appropriate configuration and technical specifications of SPDs

Figs. 5-6 demonstrate voltages and currents of the two SPDs for 6 different configurations. The simulations are done in the absence of the loads; the length of the connection cable is also d=10m.

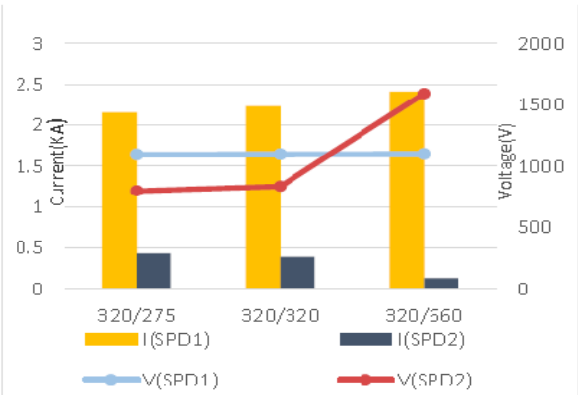


Fig. 5: Discharge voltages and currents of the SPDs (SPD1:SPD320v

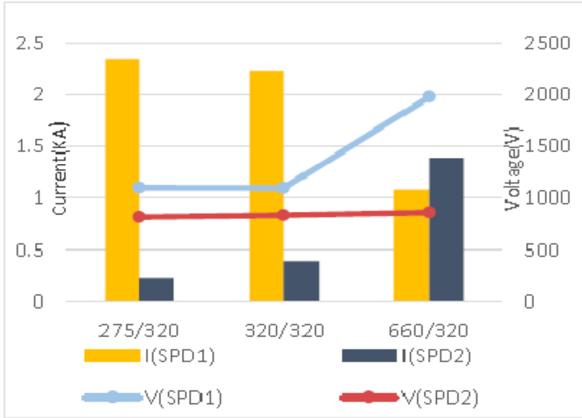


Fig. 6: Discharge voltages and currents of the SPDs (SPD2:SPD320v)

In the case of using SPD320V as the upstream SPD, any changes in the specifications of the downstream SPD would have no effects on the voltage of SPD1. Furthermore, with an increase on the protection voltage of SPD2, its surface voltage increases and the discharge current and absorbed energy decreases.

When SPD320V is used as the downstream SPD, changes of the upstream SPD, approximately, have no effect on the SPD2. In this case, voltage of SPD2 as compared with the one in which it had been used as the upstream SPD, is decreased. Also, increasing the protection voltage of SPD2 would result in lowering the discharge current and absorbed energy of the downstream SPD, while increasing them for the upstream SPD.

As it has been observed, when the two-stage protection configuration are applied, the voltage of each SPD can be well estimated with the protection voltage level of that SPD. Moreover, the discharge currents and absorbed energies of SPDs are dependent upon the configuration of the network. Besides, increasing the protection voltage of each SPD would cause the discharge currents of other SPDs to increase (still, for any scenarios, the role of upstream SPD on the current discharge of the lightning would be higher than the one for the downstream SPD).

The voltages' waveforms on the SPDs for different configuration have been illustrated in Figs. 7-9.

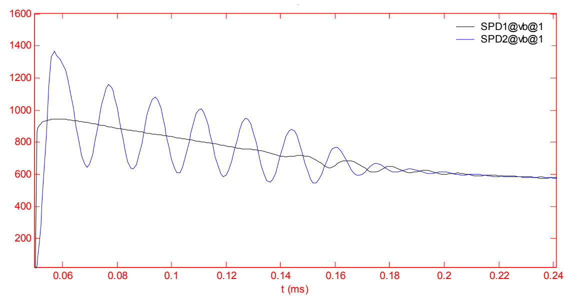


Fig. 7: the voltage's waveforms of the SPDs;

SPD1:320V- SPD2:660V

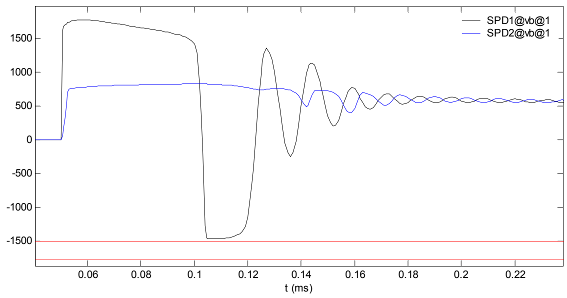


Fig. 8: the voltage's waveforms of the SPDs;SPD1:660V- SPD2:320V

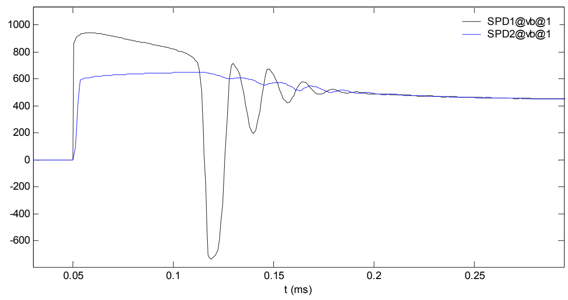


Fig. 9: the voltage's waveform of the SPDs;SPD1:320v SPD2:275v

The results of simulations when using SPD660V and SPD320V, respectively are demonstrated in Figs. 7-8. As it can be seen, when SPD320V is used as the upstream SPD (SPD1), the voltage waves reach the downstream SPD (SPD2) while experiencing intensive oscillations. In fact, since the downstream SPD has larger impedance, some portions of the incident voltage waves would reflect and cause the corresponding oscillations. The oscillations will reach the equipment under protection if they are connected. On the other hand, when using SPD660V as the upstream SPD, first, energy of the primary lightning wave would be absorbed by the SPD1 and then, it will be controlled with no oscillations involved when reaching the downstream SPD. Similar results have been observed as in Fig. 9, when SPD320V and SPD275V are used for the upstream and downstream, respectively.

It can be observed that in all of the cases, the upstream SPD has an effective role in primary decreasing the energy of the lightning waves and the corresponding discharge of its current; thus, the SPD with higher capability in absorbing energy and discharging current must be used for the upstream SPD; On the other hand, the downstream SPD which is located near the equipment under the protection, must be capable of effectively decreasing the transient voltage waves and taking them to the point where they are tolerable for the equipment. In addition, the SPD near the load must have lower protection voltage.

4.2. Effect of Length of Cable Connecting SPDs on Coordination

As it has been mentioned already, the SPD with higher current discharge should be employed for the first SPD and the one with the lower protection voltage for the SPD next to the load. When there is a better configuration between SPDs, distribution of the discharge current and control of the voltage for each SPD will be done better. Nevertheless, the simulation results show that the suitable configuration between SPDs, alone, is not enough for coordinated performance of SPDs. Therefore, from now on, the length of the connection cable, d, will be varied and the corresponding discharge currents and voltages of each SPD will be studied. Fig. 10 demonstrates the current discharged of protection SPDs for two configurations and for a variable cable from 1m to 50m.

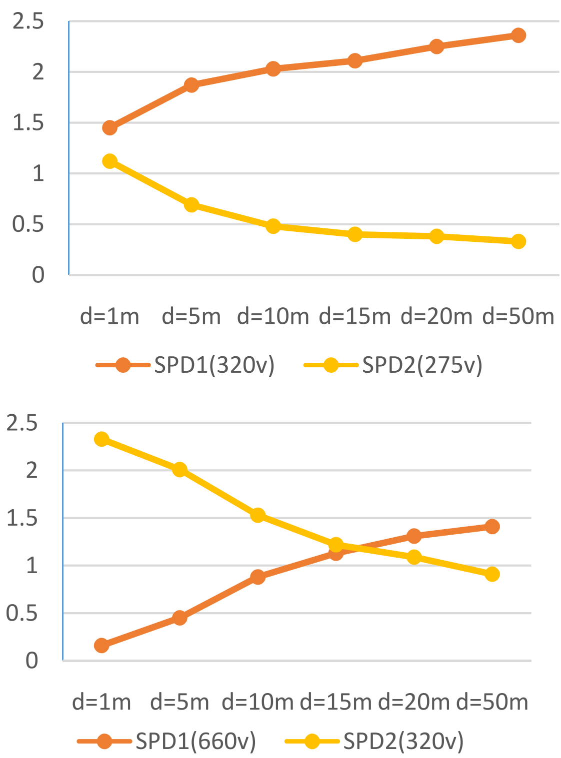
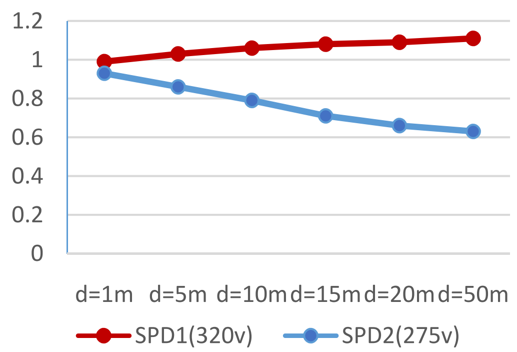


Fig. 10: The discharged currents of protection SPDs against variation of the cable length from 1m to 50m

The driven results in Fig. 10 show that the discharged currents of protection SPD are distributed better when the electrical distance between two SPDs is increased. In fact, the discharge current and the absorbed energy of SPD1 have been increased; conversely, when distance between two SPDs is increased, the discharge current and absorbed energy of SPDs near the loads are decreased. This sequence of results would be saturated when distance between SPDs is increased farther. As a result, in two-stage protection systems where current SPD in located at the upstream and voltage SPD in downstream in the neighborhood of the equipment under protection, increasing the length of the connecting cable between SPDs would be more suitable from the viewpoint of distribution of lightning discharge currents between SPDs. Therefore, in order to create harmony and coordination among SPDs, length of the connection cable should be more than some given distance.

Fig. 11 illustrates voltage of SPDs for two different configurations as distance between them varies from 1m to50m; results of this analysis show that increasing the distance between SPDs would increase voltage of SPD1 and decrease voltage of SPD2. Indeed, when the distance between SPDs is increased, distribution of the voltages over SPDs is more desirable.

The farther the distance between SPDs, the closer of the voltage of SPDs to the Up.



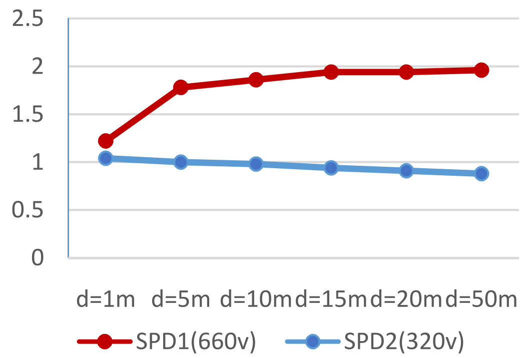


Fig. 11: Voltages of SPDs vs the variations of distance between them

4.3 Calculation of the separating Inductance for Coordination of two SPDs

In the previous section, effect of the distance between two SPDs on the coordination between them has been analyzed. In the cases where increasing the distance between two SPDs is not possible practically, and furthermore, the existing distance between feeders on which the SPDs are installed is lower than the minimum distance requirements, using a separating inductance to improve the performance of SPDs is necessary. In the followings, effect of the inductance values on the improvement of SPDs performance would be studied. The inductive impedance has been connected using two 2m cables to the two SPDs on the either sides. Fig. 12 shows values of discharges' voltages and currents against different values of the inductive impedance. In this scenario, SPD660V has been used for the upstream SPD (current SPD) and SPD320V for the downstream SPD (voltage SPD), accordingly.

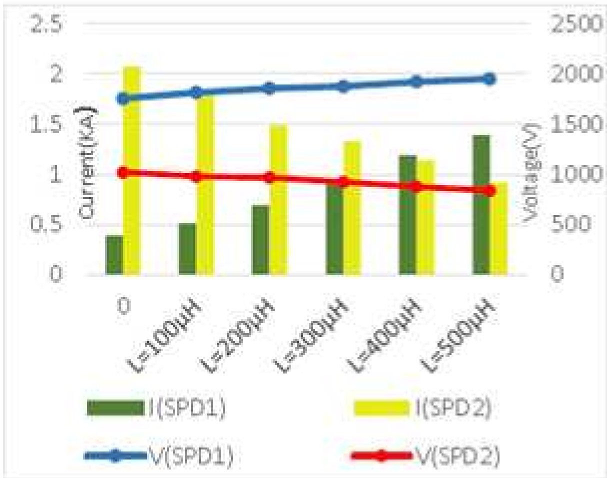


Fig. 12: Variations of the discharges' voltages and currents vs. different values of the inductive impedance

As it can be seen, the discharge current of SPD next to the load would exceed the tolerable ones when the inductive impedance has not been employed in the circuit. Also, voltages of the downstream SPD would be more than the tolerable ones of the electrical and electronic systems in the low voltage network. As a remedy to this problem, when the inductive impedance is added to the circuit, SPDs perform better and distribution of the discharged lightning currents between the two SPDs is more suitable. The results of the simulations has noted that for inductive impedance larger than 300µH, the upstream SPD discharges a notable portion of the lightning current, the voltage of the downstream SPD as well as the equipment to protect is within the suitable limits, and SPDs perform well.

5. Conclusions

One of the main challenges in Surge Protection Devices (SPD) selection in low voltage sensitive electrical and electronic systems is determination of the technically appropriate SPD and proper electrical distance between them. In this paper, through modeling and simulation of a low voltage electric network specified with two-stage protection SPDs, effects of different factors on the coordination between SPDs have been tried to be studied.

Results of the simulations and studies have pointed out that for better coordination the SPDs' performance, it is better off to place the SPD with higher capacity level at the upstream. Also, voltages of protection SPDs would be determined according to the voltage level to be protected at, as well as the configurations between SPDs. Therefore, technical specifications of any SPD would affect other SPDs negligibly.

The ability of SPDs to absorb energy and discharge currents of lightning depends on the configuration between the two SPDs; any increase in the voltage protection level of either of SPDs leads to the increased absorbed energy and discharging of lightning currents of other SPDs.

On the other hand, analyses have shown that even with an appropriate configurations, there are possibilities of inappropriate functioning and of coordination. Hence, in order to set up the coordination between SPDs, besides the proper configuration and right technical specifications, the electrical distance between SPDs should be taken into account. As a general conclusion, thus, increasing length of the connection cable between two SPDs is in company with increasing the discharge currents and absorbed energy of the upstream SPD. Also, the voltage of the downstream SPD would decrease with increasing the distance between the two SPDs.

Last but not the least, when the distance between two SPDs is lower than the minimum requirement, addition of an inductive impedance valued between 300μH and 500μH could improve performance of the SPDs.

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