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Modelling and Analysis of Lightning Overvoltage Protection of MV Cable Laterals Connected with Overhead Lines

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Introduction

The lightning strokes and switching actions taking place in electricity distribution networks result in overvoltages, which most of the times cannot be avoided. The most common type of fault is the single-phase earth fault, however, short circuits may represent a considerably higher share of experienced faults during lightning, which are stressful and causing in addition to interruptions, sags [1, 2]. Three types of overvoltages are essentially distinguished as temporary, switching, and lightning overvoltages [3]. Temporary overvoltages occur during load rejection or because of earth connection faults and the duration of such operating frequency oscillating overvoltage lies between 0.1 seconds and several hours with the surge magnitude not exceeding above 3 p.u. Switching overvoltages occur during switching actions and consist mostly of heavily damped oscillations with frequencies up to several kHz and a magnitude up to 3 p.u.

Lightning overvoltage originate in atmospheric discharges. They reach their peak value within a few µs and subsequently decay very rapidly. The magnitude of these uni-polar overvoltages in a MV network can reach well over 10 p.u. and they are considered the greatest threat to the MV networks. The lightning can touch a power line by striking either a conductor or a tower or an earth wire, causing the significant overvoltages classifies like the most dangerous constraints for the electric systems [3,4]. Overvoltage protection must be arranged in such a way as to confine the overvoltage to non-damaging values. The earth wire protection in MV networks is generally not very effective. Due to the small distance between the earth wire and the line wires, a direct lightning stroke hits usually the line wires as well. In addition, induced overvoltages in the line wires (indirect effects of the lightning strokes) cannot be avoided by the earth wires. The most effective protection against overvoltages in a MV network is therefore the use of surge arresters in the vicinity of the electrical equipment [5-9].

Overvoltage protection in cable laterals

The essential difference between the electrical data of overhead lines and cables is the surge impedance of their conductors to earth. Values for overhead distribution lines are approximately 300 Ω to 450 Ω and for cables in the 20 Ω to 60 Ω range. First of all, this difference causes a marked decrease of the lightning overvoltage as soon as the traveling wave reaches the cable entrance. The reduced voltage wave flows through the cable and it is reflected at the end so that the voltage is nearly doubled. Subsequently the wave returns to the cable entrance and is once more reflected, etc. In this way, the overvoltage in the cable is built up gradually although the overvoltage slope in the cable is actually lower, the peak value is near that of lightning overvoltage on the line.

Longer cables require arrester protection at both ends. For short cables sections, one-sided protection is in some cases, sufficient. This is because an arrester at only one end can still offer sufficient lightning overvoltage protection to the other end. A cable which connects the overhead line with the substation is often only endangered by lightning on the line. The arrester must therefore be mounted to the line at the cable junction. The most of the incidence lightning wave hitting overhead line will reflect back from the interconnection of overhead line and cable with negative polarity and reduce the effect of incidence wave. But the situation reverses as the surge travels ahead to a transformer, thus raising the incidence wave to double magnitude. Then, there will be multiple reflections between the junctions until the reflected surges will attenuate naturally. It is therefore essential to protect the cable against surges at both ends, particularly when the traveling wave is likely to be a higher value than the basic impulse level (BIL) ratings of the cable. It is advisable to take cognizance of all such reflections and refractions while carrying out the engineering for a surge protection scheme and deciding the location for the surge arresters. Naturally, cables in overhead lines are lightning endangered on both sides. Therefore it must be taken into account that in cables with one-sided protection, overvoltage can also come from the unprotected side. In this case, the protection effectiveness of the arrester at the other end would be strongly reduced. The allowable length of cables in overhead lines with one-sided protection is therefore smaller.

The single-line diagram of the electricity distribution network under analysis is shown in Figure 1. The overhead line and underground cable are combined in the network. A lightning impulse is struck on the overhead line and is injected into cable through the cable junction. A surge arrester is installed near the cable junction. The lightning impulse in the cable will be doubled due to its reflection from the other end near the transformer, therefore, it is normal practice to protect the cable from surges at both ends (by installing surge arresters at cable injection as well as at other end of cable near transformer). However, it is noticed that there is a natural damping of the traveling waves as they travel ahead through the network due to the lumped capacitances and inductances of the system. The investigations have been carried-out by installing single surge arrester (SA-1) near the cable junction to protect cable from lightning surges as well as installing second surge arrester (SA-2) on the other side of the cable (near to transformer). Following investigations have been carried out during this work:

- Is it enough to install single surge arrester (SA-1) near the cable junction to protect cable from lightning surges? If yes, what would be the minimum length of the cable in this situation?
- Is it essential to install second surge arrester (SA-2) on the other side of the cable (near to transformer), If yes, what should be its rating?

The above investigations have been considered for different lengths of the cable and different number and lengths of the sub-laterals to decide the optimal location of the surge arresters under various network arrangements.

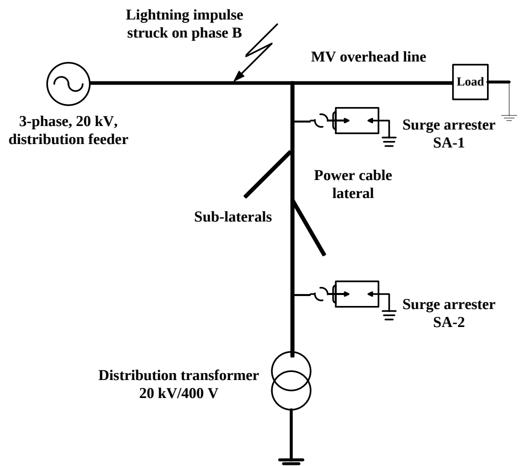

Fig. 1. Electricity distribution network used to analyse the effect of lightning overvoltages

Simulating lightning overvoltages

The simulations have been carried out using electromagnetic transient program-alternative transient program (EMTP-ATP). ATPDraw is used as a graphical interface to model the lightning overvoltage protection scheme for distribution network of Figure 1. The models for MV overhead line, lightning impulse, MOV, and cables are drawn. The distribution transformer model is used for high frequency applications [10]. The following use-cases have been investigated during simulation: (a) There is no surge arrester installed in the network, i.e. no lightning protection, as well as there are no sub-laterals in the network. (b) There is no surge arrester installed in the network, i.e. no lightning protection, however, sub-laterals are connected within the network. (c) The lightning overvoltage protection scheme by installing one surge arrester (SA-1) at the junction of overhead line cable and sub-laterals are connected within the network. (d) The lightning overvoltage protection scheme by installing two surge arresters (SA-1 ands SA-2) at both ends of the cable and sub-laterals are connected within the network.

A lightning surge (see Figure 2) is struck on phase B of the overhead line and the resulting overvoltages are investigated at the junction of overhead line and cable and at the far end of the cable (near the transformer). The lightning overvoltage protection is carried out using MOV. [6,11]. The simulation results for the above mentioned use-cases (only for a and d) are given in the next sub-sections.

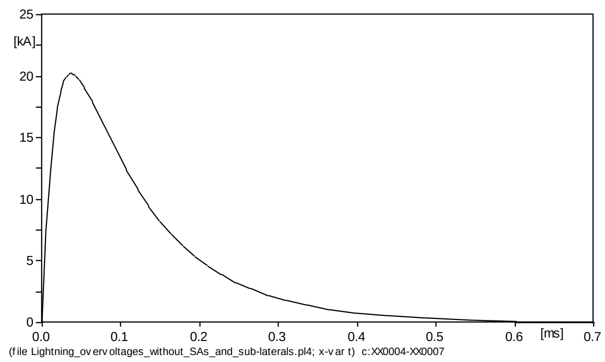

Fig. 2. Lightning surge (current pulse)

Simulations with no surge arrester installed, no sub-laterals connected. The ATP model for use-case (a) is drawn in Figure 3 and is simulated. The length of the cable is kept 6 km for instance, and no surge protection is provided in the cable network. The phasor voltages at the junction of overhead line and cable and at far end of the cable are given in Figures 4 and 5, respectively. The amplitude and wave-shaping of phasor voltages in these Figures are quite similar because the attenuation of the cable does not have any significant effect due to very high voltages. There might be difference observed between the magnitudes of lightning overvoltages at junction of overhead line and cable and at far end of cable while considering longer lengths of the cable. The similar overvoltages are observed for smaller lengths of cables (e.g. 3 km) because there is no lightning protection provided for the entire cable network.

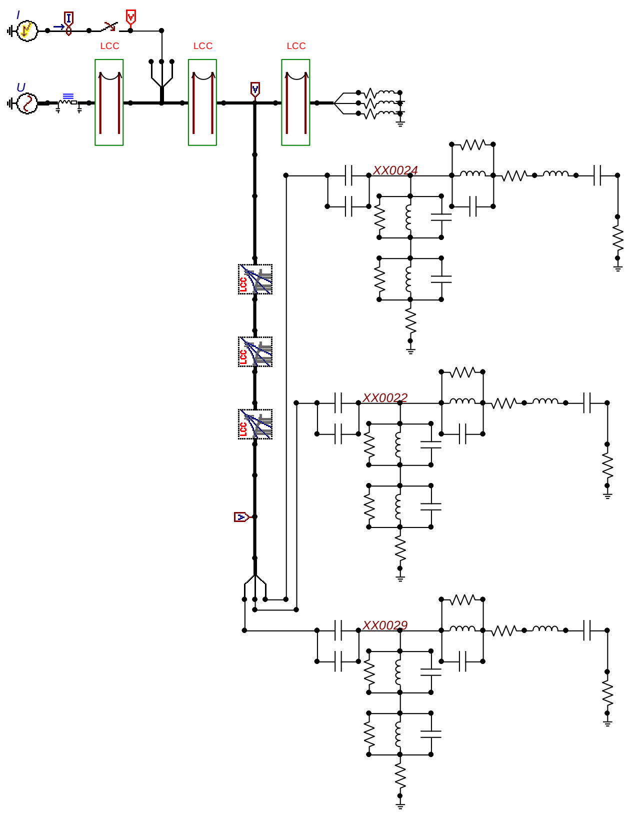

Fig. 3. ATP model of the MV network shown in Figure 1 for use-case (a)

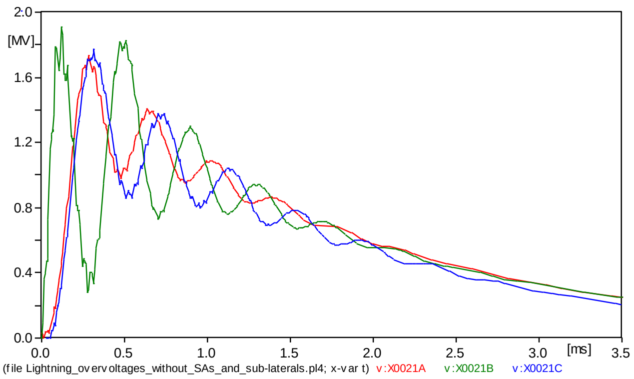

Fig. 4. Lightning overvoltages at junction of overhead line and cable for use-case (a), cable length is 6 km

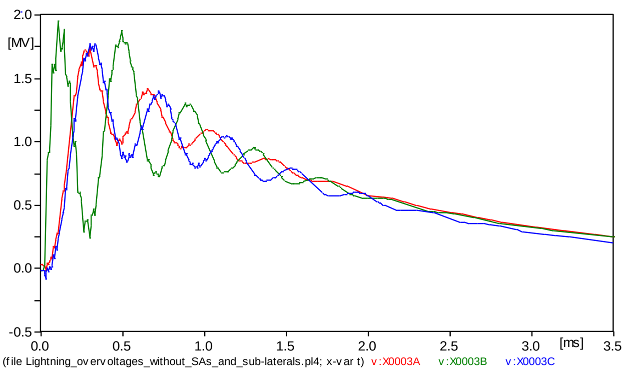

Fig. 5. Lightning overvoltages at far end of cable for use-case (a), cable length is 6 km

Simulations with two surge arresters installed, sub-laterals are connected. The length of the cable is kept 6 km, and surge protection is provided in the cable network by installing two surge arrester (SA-1 and SA-2) at both ends of the cable. The two cable sub-laterals each having length 1 km, are also connected in the network. The phasor voltages at the junction of overhead line and cable and at the far end of the cable are given in Figures 6 ad 7, respectively.

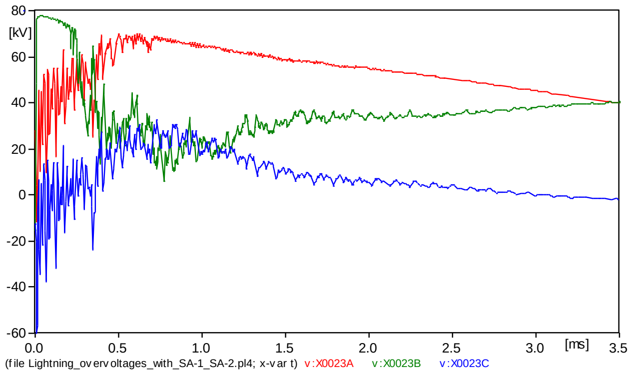

Fig. 6. Lightning overvoltages at junction of overhead line and cable for use-case (d), cable length is 6 km

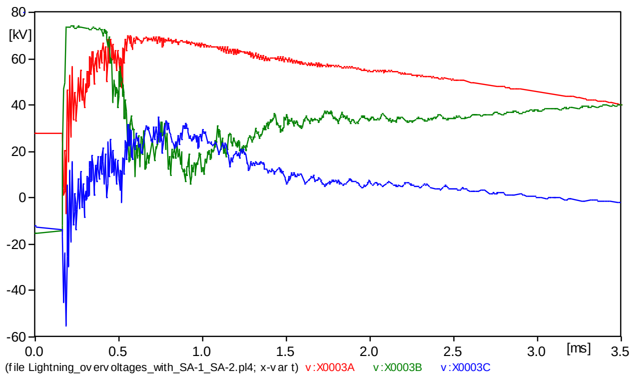

Fig. 7. Lightning overvoltages at far end of cable for use-case (d), cable length is 6 km

It has already been mentioned that by installing only one surge arrester (SA-1) for cable lengths below 29 km, the overvotlage surges at the cable end are higher in magnitude than BIL ratings of the feeder equipment. It is now clear from Figure 7 that by installing two surge arresters (SA-1 and SA-2) at both ends of the cable, the lightning overvoltage surges have been reduced to values less than BIL ratings.

Conclusions

The lightning overvotlage protection of cable laterals connected with MV overhead line has been investigated using EMTP-ATP simulation environment. The lightning surge is struck on one of the overhead line phases and overvoltage effects are investigated in the cable connected to overhead line. It is revealed that very high overvotlage surges are experienced if the cable lateral is not protected by surge arresters. The length of the cable has not shown any significant effect in reducing overvoltages magnitude because limited dimensions of the cable length are used in the simulation. However, the lengthy cables might have effect in reducing the overvotlages magnitude because the attenuation of the cables is frequency-dependent and it increases significantly at higher frequencies in the range of frequency bandwidth carried by lightning impulses.

The surge voltages are reduced to some extent if sub-laterals are connected to the cable laterals in the network having no surge arrester installed. However, the magnitude of overvoltages is still higher than BIL ratings, and the network is not safe for operations. By installing single surge arrester at the junction of overhead line and cable, the minimum length of the cable that attenuates the overvoltage surges so that there is no need to install another surge arrester at the far end of the cable is 29 km. Therefore, it is possible to protect a cable having length of 29 km or more with one surge arrester installed at the junction of overhead line and cable. However, if the length of cable is shorter than 29 km, it is need to install two surge arresters at both ends of the cable. The investigations carried out in this research work will be useful to analyse the existing lightning protection schemes of the distribution cable networks connected with overhead lines and developing various mitigating techniques to protect MV cable laterals on the basis of surge arresters locations, sub-laterals connections, and cable length in the distribution network.

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This paper describes the lightning overvoltage protection schemes of cable laterals connected with MV overhead line. The various protection schemes are modelled and investigated are carried out on the simulation results. The simulations are performed using EMTP-ATP simulation environment, which is a strong tool to analysis transient behaviour of MV network components. The simulated lightning surge is struck on one of the overhead line phases and overvoltage effects are investigated down the cable connected with overhead line. The cable laterals are consisted of sub-laterals which are also simulated in this study. Generally, the surge arresters are installed at the junction of overhead line and cable and at far end of the cable. The various mitigation methods and protection schemes for protecting MV cable laterals are proposed on the basis of surge arresters locations, sub-laterals connections, and cable length. Ill. 7, bibl. 11 (in English; abstracts in English and Lithuanian).

M. Hashmi, M. Lehtonen, S. Hanninen. Apsaugos nuo žaibo viršįtampių modeliavimas ir analizė vidutinės įtampos tinkluose su kabelinėmis orinių linijų atšakomis // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 7(123). – P. 49–52.

Straipsnyje aprašomos apsaugos nuo žaibo viršįtampių schemos, naudojamos vidutinės įtampos tinklų kabelinių oro linijų atsišakojimų apsaugai. Atliktas įvairių apsaugos schemų modeliavimas ir gautų rezultatų analizė. Modeliavimui buvo panaudota AMTP-ATP modeliavimo platforma, kuri yra geras pagalbininkas analizuojant pereinamuosius procesus vidutinės įtampos skirstomuosiuose tinkluose. Sumodeliuota žaibo iškrova į vieną oro linijos fazę ir ištirta jos sukeltų viršįtampių įtaka tinklo kabelinei oro linijos atšakai. Kabelinės linijos turi atšakas, kurios taip pat buvo modeliuojamos šiame darbe. Dažniausiai viršįtampių ribotuvai yra montuojami prie jungties su oro linija ir kabelinės linijos gale prie transformatoriaus. Pasiūlyti įvairūs viršįtampių slopinimo metodai ir apsaugos nuo viršįtampių schemos vidutinės įtampos sudėtingos konfigūracijos kabeliniams atsišakojimams su skirtingai išdėstytais ribotuvais ir įvairiaus ilgio kabeliais. Il. 7, bibl. 11 (anglų kalba; santraukos anglų ir lietuvių k.).