U.P.B. Sci. Bull., Series …, Vol. …, No. …, 2009 ISSN 1454-23xx

INFLUENCE FACTORS ON THE TRANSMITTED OVERVOLTAGES FROM HIGH VOLTAGE TO LOW VOLTAGE NETWORKS

Marian COSTEA[1], Bogdan NICOARĂ[2]

***Abstract**: In the high and medium voltage networks a large variety of overvoltages can occur. These are produced by lightnings, switching operations or insulation faults. Normally, the protection against overvoltages, based of surge arresters and relay protection of the equipment, act to eliminate or reduce the insulation stress. The transients occurred in the high or medium voltage networks are then transmitted by different mechanisms to the low voltage networks. The paper analyse the influence factors and their weights to the transmitted overvoltages from a superior voltage networks to the low voltage one considering a proper action of the protection against overvoltages in the first network. The study was performed on a real configuration of network subjected of different shape and amplitude of lightning overvoltages.*

Keywords: electric power installation, full lightning impulse, chopped lightning impulse, lightning induced overvoltage.

1. Introduction

Transient events which occur in the high or medium voltage installations produced by switching operations or lightning are transmitted to the final low voltage user by propagation along the transmission or distribution lines and through inductive and capacitive couplings between the windings of transformers.

The parameters of lines and transformers have a major influence to the transmitted overvoltages. But the behaviour of the lines, transformers, arresters and other equipment of the network depend of the frequency and voltage level and, consequently, of the shape and the amplitude of the initial transient overvoltage. An accurate modelling of the elements of network and overvoltage source parameters permits by mean of numerical simulations the determination of the transmitted overvoltages [1]. In order to highlight the influence factors to the overvoltage received by the final low voltage user, an existing network was modelled and different transient events were simulated in some points. The simulations were performed using EMTP – ATP software package.

---

[1] Assoc. prof., Power Engineering Faculty, University “Politehnica” of Bucharest, Romania
[2] Prof., Power Engineering Faculty, University “Politehnica” of Bucharest, Romania

2. The main features of the network and the modeling of their elements

The Figure 1 presents the studied network which include a 110 kV overhead line connected to the national system, a high voltage/medium voltage (HV/MV) step down transformer which supply the 20 kV busbar of a substation, and many overhead distribution lines, one of them supplying two transformer substations namely TS1 and TS2. The length of high voltage line is 18 km.

Each transformer substation contains a single 20/0.4 kV, 250 kVA power transformer with Dyn winding connections; the first transformer substation is connected close to the 20 kV busbar by a cable line having 70 m length, and the second by mean of a 31 km overhead distribution line. The medium voltage terminals of transformers are protected by gapless arresters with 10 kA rated current and 81.6 kV residual voltage. Local low voltage (LV) networks are supplied by TS1 and TS2 respectively.

All power lines, except those of local low voltage were modelled by their distributed parameters, the input data being rigorously known. For the step-down transformers was adopted a three leg core saturable power transformer model completed with a capacitor network. The capacitances in the equivalent circuit of transformers were provided by low frequency measurements during maintenance operations. An adequate metal oxide arrester model was introduced in the equivalent diagram of the network. The ground of transformer substations was considered by mean of a ($R_g = 4\ \Omega$) invariable resistance.

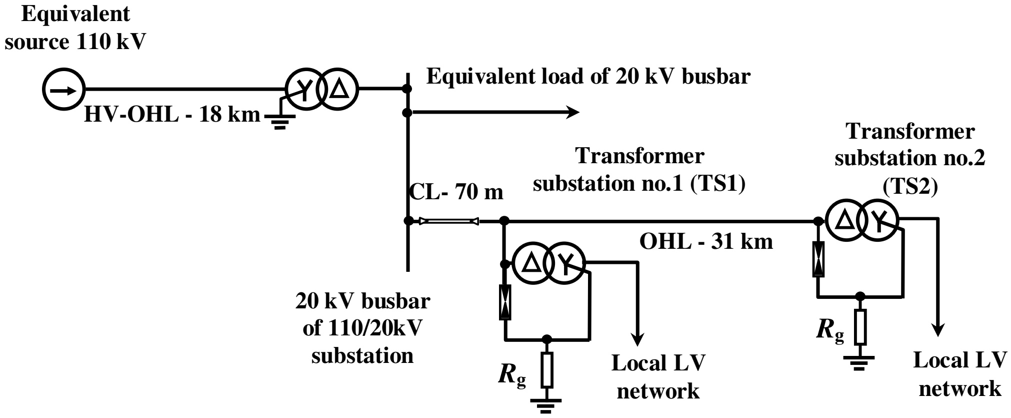

Fig.1. The analyzed network.(HV-OHL – 110 kV high voltage overhead line; MV-OHL – 20 kV medium voltage overhead line; CL – cable line; TS – transformer substation).

In order to evaluate the parameters of overvoltages transmitted to the inferior voltage networks, overvoltages with different shape and amplitude were applied in different locations.

3. The response of the network to the different overvoltages

The events which produce the transients in the high and medium voltage network were considered as follow: full and chopped wave lightning overvoltages and lightning induced overvoltages (with short tail). The strokes were considered to be located both on the 110 kV overhead line and on 20 kV medium voltage network.

In the first simulation, a full lightning impulse voltage having standardized testing shape (1.2/50 µs) and 600 kV amplitude was injected at the beginning of 110 kV overhead line, on the A phase. The overvoltages which act at the high voltage terminals of 110/20 kV transformer are presented in the Fig.2.

It can observe that on the phase A, the maximum recorded peak value of the voltage does not change substantially comparing with amplitude surge injected at the beginning of the line (in the first stage, due to propagation along the line, the amplitude of voltage arrived at the terminals of high voltage transformer is reduced to approx. 525 kV but the reflexion that occurs restore it, practically, to their initial value after about 30 µs). On the phases that were not directly affected (B and C), identical induced voltages occur reaching peak values about 50% of phase A. An oscillatory regime in the primary windings of transformer is triggered. The voltage occurring at the medium voltage terminals present a slow time variation with an amplitude about 50 times lower compared with those of the primary one, the reduction being with one order of magnitude greater than rated transformer ratio (which is 5.5) (Figure 3).

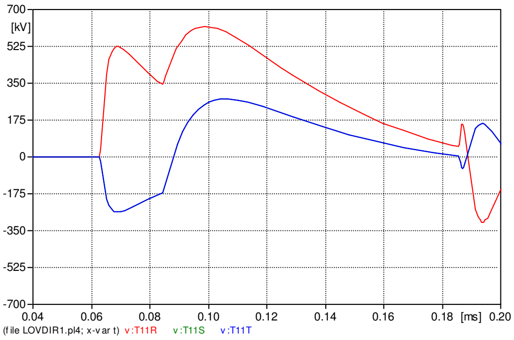

Fig.2. The voltages at high voltage terminals of 110/20 kV transformer, after the propagation of the surge along 110 kV line.

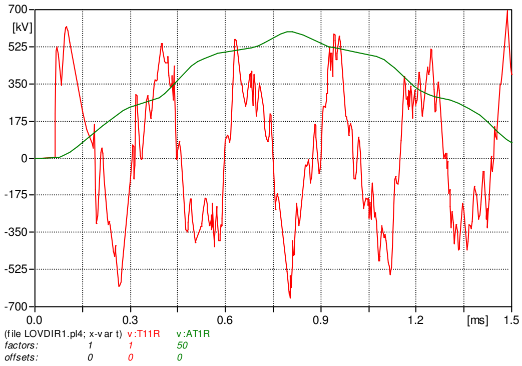

Fig.3. The voltages at primary and secondary (values multiplied by 50) terminals of 110/20 kV transformer due to the lightning stroke.

An expanded time diagram of the voltage variations between MV terminals and earth of the two MV/LV transformers in the transformer substations TS1 and TS2 is presented in the Figure 4. The oscillatory regime has a basic frequency of about 33 Hz and amplitude of 12 kV. It can be remarked that the overhead distribution line does not modify, practically, the shape and the amplitude of the transmitted overvoltage arrived to the far away transformer substation (TS2). As a result of slow variation of the input overvoltage, in the low voltage network a reduced value is injected, according to the transformer ratio (see Fig.5), and the final user is not affected (the maximum peak voltage reaches only 240 V).

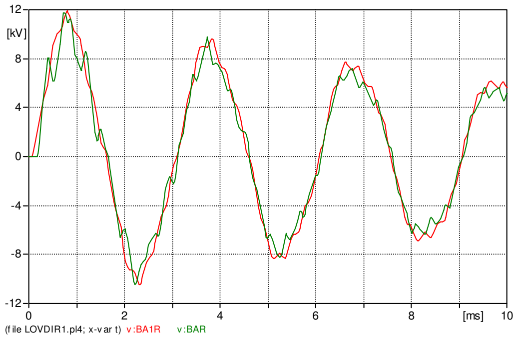

Fig.4. The voltages recorded at medium voltage terminals of the two transformers (TS1 and TS2).

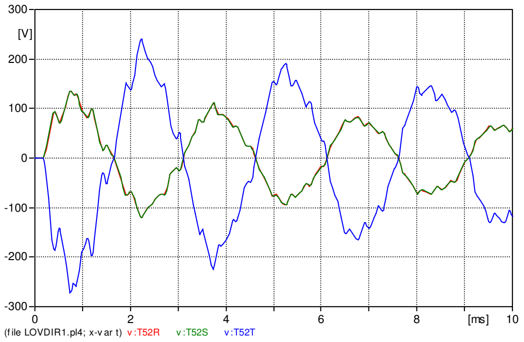

Fig.5. The voltages recorded at low voltage terminals of TS2 transformer.

Another set of simulations was performed using a tail chopped lightning overvoltage injected in the high voltage line, on the phase A and having also the amplitude of 600 kV. The voltages in the primary of 110/20 kV transformer are presented in the Figure 6, the maximum peak being recorded on phase A, which was directly affected by the lightning. Despite the rapid time variation of the voltage across primary winding of transformer, in this case a very important decrease of overvoltages transmitted to the medium voltage network was observed and the voltage reaches only 2 kV on MV busbars. It can conclude, taking into account even the network modelling imperfection that a lightning stroke, full or chopped, injected in the 110 kV line, have practically no effect to the final low voltage users. Other simulations were performed, considering that the lightning acts directly or indirectly on the 20 kV distribution network.

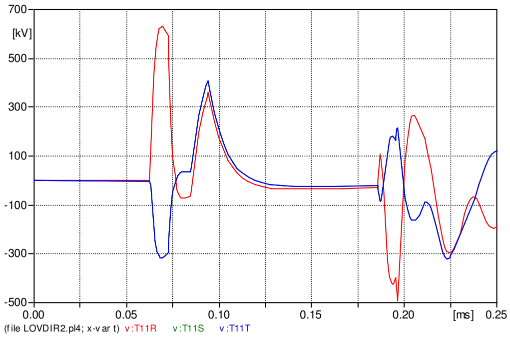

Fig.6. The voltages at high voltage terminals of 110/20 kV transformer, after the propagation of the chopped lightning overvoltages along 110 kV line.

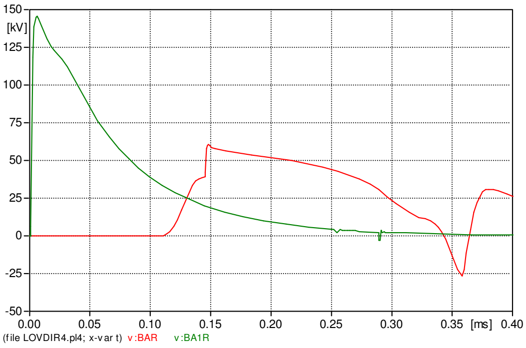

Fig.7. The primary voltages at 20/0.4 kV terminals of transformers connected in TS1 and TS2 (for the last, the delay due to the propagation can be observed).

In the first case, a full lightning overvoltage having 165 kV peak value is injected in the MV busbar of substation. As consequence, an important overvoltage occurs in the low voltage network. At the medium voltage terminals the peak voltage reaches about 145 kV for TS1 – the closer transformer to MV busbars – and about 60 kV for TS2 – the remote transformer (Figure 7). Rate attenuation due to the medium voltage line of about 2.7 kV/km can be remarked. At the low voltage terminals of these transformers, the amplitude of overvoltages reaches about half of the primary voltages (transmission ratio 2:1), a very serious stress for low voltage insulation and the final user, even if their duration is short. This stress duration is about 50 μs for TS1 and about 20 μs for TS2. The necessity to install voltage arresters to LV terminals of transformer is consequently proved. The other simulations, with increasing amplitude of overvoltages occurring on MV busbars, reveal that the voltages recorded at secondary terminals do not increase directly proportional with the primary ones because of surge arrester intervention. Keeping the amplitude of lightning and the affected phase (A) but changing their shape (at 1/5 μs) the amplitude of overvoltage in the secondary windings of transformers located in TS1 and TS2 remains at a high level (for example, about 50 kV for TS1) but the stress duration become under 10 μs. Also reducing the coupling capacitances between MV and LV windings (from 5 nF to 1 nF) of transformers has a reduced influence to the peak and time duration of transmitted overvoltage.

In the last series of simulations, lightning induced overvoltages (LIOV) were considered to be injected in the medium voltage network.

The coupling mechanism between the lightning channel and a medium voltage overhead line is not discussed in this paper. It has been treated in numerous works such as [2...5]. The main conclusions which can be found about the features of this type of overvoltage are the following:

- the amplitudes reached by the lightning induced overvoltages (generally, under 300 kV for medium voltage overhead lines) are dangerous only for the distribution systems because their relatively reduced basic insulation level;
- the shape of LIOV can be described such as short tail lightning impulse (the front duration about 1 μs and the tail –few microseconds);
- because of reduced distances between the phases of the medium voltage overhead lines, the LIOV have identical amplitudes on all phases.

In our simulations a shape of 1/5 μs of the induced overvoltages was considered with the amplitude equal to basic line insulation (125 kV), all three phases being equally stressed. The point of overvoltage injection was considered the 20 kV busbar of substation. While the medium voltage terminals of the transformers are protected by surge arresters, no low voltage arresters at secondary terminals of 20/0.4 kV transformer were considered in the first simulation.

The notations used to describe the results are: U_1 – the amplitude of the voltages between the medium voltage terminals and ground of the transformer substation; U_{10} – the amplitude of the voltages between the medium voltage terminals and reference ground; U_2 and U_{20} the amplitude of the voltages between the low voltage terminals and ground and, respectively, reference ground. The main results of this simulation are presented in the Table I.

Table 1

The amplitudes of transient voltages without arresters at low voltage terminals of transformer substations

Transformer substation	U_1	U_{10}	U_2	U_{20}
	kV			
TS1	72.0	111.0	14.1	34.9
TS2	51.0	52.8	4.1	5.6

The differential voltage peak at TS1, between a phase conductor and the neutral (connected to the common ground of the substation) reaches about 14 kV, with a rise time shorter than 1 μs and the total duration of transients about 10 μs. The transient ground potential rise (above 30 kV) is transmitted to the neutral conductor of low voltage system. It must be noted that in the transformer substations in Romania the usual case is that a single ground exist for medium and low voltage parts. Regarding TS2, located far away from the MV busbar, the amplitudes of the overvoltage at the primary terminals of transformer are reduced about 2.1 times comparing to the similar stress of TS1 (the rate attenuation due to the medium voltage line is now about 1.9 kV/km, lower than the corresponding value for the shape 1.2/50 μs, as seen previously), the amplitude of the phase to ground voltage being limited at 4 kV. The duration of the transient process has the same order of magnitude as for TS1.

For the TS1 the ratio between the primary and the secondary amplitude of the overvoltages is about 5.1, while for TS2 this ratio increases up to 12.4. Greater ratio means a diminished coupling between the primary and the secondary windings of the transformer. No association with the rated transformer ratio (50, for power frequency voltage) can be found in the case of fast transient voltage applied to the primary windings. The average steepness of the overvoltage decreases by propagation along overhead line from 95 kV/μs at medium terminals of TS1 to about 17 kV/μs at TS2 equivalent terminals. In order to avoid great disturbances or insulation faults in the low voltage network supplied by 20/0.4 kV transformer, LV arresters must be connected at their secondary terminals. For subsequent simulations low voltage arresters (having clamping voltage U_p=1.8 kV and rated current 10 kA, 8/20 μs) were connected to low voltage terminals of transformer. Even in the case of the most exposed equipment (TS1), the secondary voltages, for the same dielectric stress is reduced up to 1.3 kV (and about 1 kV for TS2). The presence of LV arresters has no influence, of course, to the potential difference between secondary terminals and reference ground which remain very high for the transformer closest to the origin of lightning induced overvoltage. Then, adequate measures must be taken to low voltage consumer (such as the achievement of own ground and the use of surge protection devices in the point of coupling to the network).

4. Conclusions

During the lightning storms numerous disturbances in the low voltage networks occur, even if this network in not directly affected, i.e. the lightning activity is far away from the network. The paper analyze how a lightning overvoltage occurred in a superior voltage level (high or medium) could be transmitted to the inferior voltage network. Different shape of overvoltages (defined as full impulses 1.2/50 µs or 1/5 µs and 1.2/50 µs chopped impulses) were injected in a model of real network existing in Romania, and the response of power lines and transformers which connect the networks with different rated voltage was analyzed. The main interest was to record the disturbance level to the low voltage final user.

For the case of overvoltages assumed to have a full standardized lightning impulse shape or tail chopped impulse occurred in a high voltage overhead line (rated voltage 110 kV), the transmitted transients to the medium voltage network through step down transformer show no significant amplitudes. On a relatively short line (having 18 km) the attenuation due to the propagation is reduced. Also the chopped impulse was stronger attenuated than the full one. At the same amplitude of lightning overvoltages (full or chopped) the behavior of transformer is different, the greater amplitude characterizing the full impulse.

The final low voltage consumer can be affected only if the overvoltage is initiates in the medium voltage network. In this case great values of amplitudes at secondary terminals were recorded both for a full impulse 1.2/50 µs acting on single phase and for full impulse 1/5 µs acting to all three phases. The greatest values were obtained for a single phase insulation stress. But the probability of occurrence of this last kind of overvoltages (due to a direct lightning stroke) is reduced. More probable for MV overhead line is the occurrence of induced lightning overvoltages acting to all three phases. An interesting result is the identically response of MV/LV transformer at primary terminals single phase excitation comparing with all phase excitation, but only for the transformers located in the vicinity of injection point of overvoltage. For this reason, the reduced values were followed to the final user in order to conclude about disturbance level and protective measures to be adopted.

The propagation along the MV distribution line reduces the steepness of the overvoltage more for the shape of 1.2/50 µs compared with the shape of 1/5 µs. The most exposed low voltage network is that supplied by the nearest transformer to the striking point, particularly in the case when no load is connected. The simple existence of a ground at the low voltage consumer does not solve the problem of overvoltage transmitted to him even if adequate low voltage arresters are connected in the transformer substation. And this because of the resistive coupling path existing between the ground of the substation and ground of consumer by neutral conductor which transmit the potential ground rise. A combined set of measures (own ground and surge protection device at the connection point) must be adopted to protect the low voltage consumer and reduce their insulation stress to the level prescribed by representative standards such as [6].

REFERENCES

[1]. * * * – CIGRE WG 02 SC 33 – Guidelines for representation of network elements when calculating transients Brochure CIGRE no. 39, 2000.

[2]. *C.A. Nucci, F. Rachidi* – Lightning-Induced Overvoltages, presented at the IEEE Transmission and Distribution Conference, Panel Session "Distribution Lightning Protection", New Orleans, USA, April 14, 1999.

[3]. *V. Cooray, V. Scouka* – Lightning-Induced Overvoltages in Power Lines: Validity of Various Approximations, IEEE Trans. on Electromagnetic Compatibility, vol. 40, no. 4, pp. 355-363, Nov.1998.

[4]. *C.A. Nucci, F. Rachidi, M.V. Ianoz, C. Mazzetti* – Lightning-induced voltages on overhead lines, IEEE Trans. on Electromagnetic Compatibility, vol. 35, no. 4, pp. 75-86, Feb.1993.

[5]. *A. Borghetti, F. Napolitano, C.A. Nucci, M. Paolone, M., A.S. Morched* – Lightning-induced overvoltages transferred from medium-voltage to low-voltage networks, Proc. PowerTech 2005, St. Petersburg, Russia, 27-30 June 2005, pp.1-7.

[6]. Insulation coordination for equipment within low voltage systems. Part 1: Principles, Requirement and Tests, IEC 60664-1/2000.