

ASSESSMENT OF THE ELECTROMAGNETIC COUPLING BETWEEN LINES OF DIFFERENT VOLTAGES SHARING THE SAME STRUCTURES

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ABSTRACT

With the increasing demand in densely populated areas and the consequent lack of space for exclusive transmission line corridors, sharing structures between transmission and distribution lines has become a commonly used solution, especially in emerging countries. This practice causes the electromagnetic interaction between these lines. This paper evaluates the effect of the electromagnetic coupling between a conventional 69 kV line and a compact overhead distribution line (spacer cable system) rated 11.4 kV sharing the same structures. Simulations were performed using the software ATPDraw (Alternative Transient Program) considering steady state conditions, the occurrence of faults on the high voltage line and transmission line energization.

INTRODUCTION

The expansion of the power transmission industry requires an intelligent use of available space to build new lines. An efficient solution used in areas of high population density is to carry more than one circuit with different rated voltages on the same tower. This solution has great potential in the reduction of investments during the construction of new feeders, once the transmission structures already exist. Due to the electromagnetic coupling between these lines high overvoltages can appear on the distribution line during switching and fault conditions on the high voltage line. Induced overvoltages in the medium and low voltage networks may not provide adequate security to the maintenance staff. In addition, the overvoltages transferred to the low voltage network may exceed the dielectric withstand limits. [1]

This study refers to a 69 kV transmission line that connects the Julius Arp (JAP) and Conselheiro Paulino (CPA) substations, both owned by the Energisa Group and located in the city of Nova Friburgo – RJ, Brazil. This line shares its structures with both medium voltage (11.4 kV) and low voltage (220/127 V) networks.

This paper analyses the magnitudes of the overvoltages induced on the medium and low voltage distribution lines under some switching and fault transient conditions. As a result of this study this paper proposes a procedure to be adopted by the maintenance staff to ensure their safety as well as protective devices to be installed in the low voltage grid to increase the security to customer's devices. This research is sponsored by the Brazilian distribution utility ENERGISA as part of the Brazilian Electricity Regulatory Agency (ANEEL) Research and Development Program.

NETWORK DESCRIPTION AND CASE STUDIES

The simulations refer to a network composed of a conventional 69 kV line, a spacer cable distribution line rated 11.4 kV, a 220/127 V line and a communication system, all of them sharing the same structure for approximately 3.8 km. The distance between two subsequent high voltage structures is equal to 70 m and the distance between the high voltage structure and the medium voltage pole is 35 m.

Fig. 1 and Fig. 2 show some details of the line and the high voltage structure.

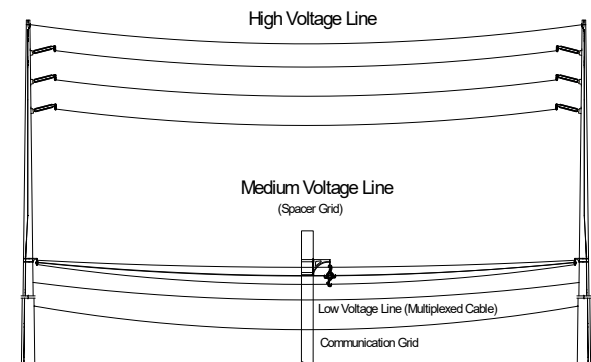


Figure 1 - Line configuration.

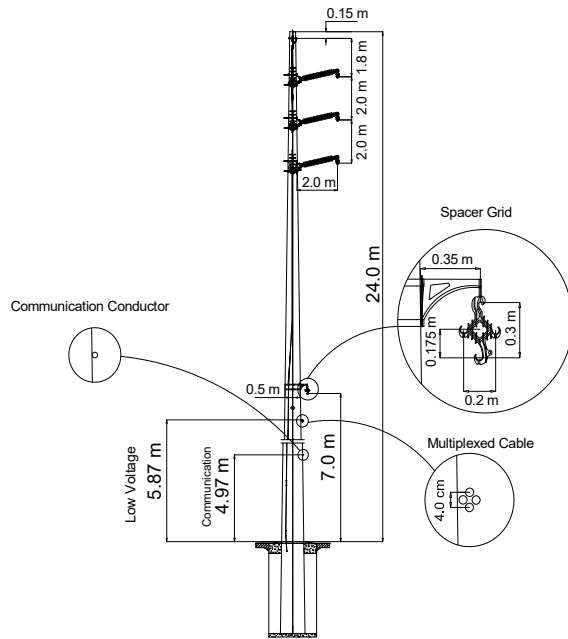


Figure 2 - High voltage structure.

MODEL PARAMETERS

Suitable models were used to simulate the main components of the transmission and distribution systems under switching and fault transient conditions. The details of the models are described below:

Loads – the RLC 3-phase branch with Y-coupling and independent values per phase. Three loads with 20 kVA and six loads with 15 kVA were considered. The loads were modeled as constant impedance (Fig. 3) and they were distributed between two distribution transformers rated 75 kVA and 112.5 kVA.

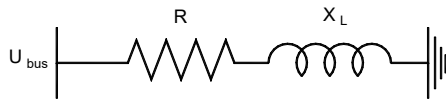


Figure 3 - Single phase equivalent circuit of a three-phase load.

Groundings – the average value of ground resistivity is 1000 Ωm . Based on the value of resistivity and on the grounding project, a 20 Ω resistor was adopted for the simulation of the grounding system.

Network equivalent – an equivalent model for the original

power system was developed, retaining buses of the network that has its structures shared and eliminating buses of the external network resulting in a source followed by an impedance (positive and zero sequences) to represent the influence of the external network with maximum precision.

Transformers – a 3-phase, two-winding transformer model was used to represent the transformers in the system. Due to the phenomena involved in the simulations, it was necessary to model the stray capacitances between windings and from winding to ground using typical values as shown in Fig. 4 and Table 1.

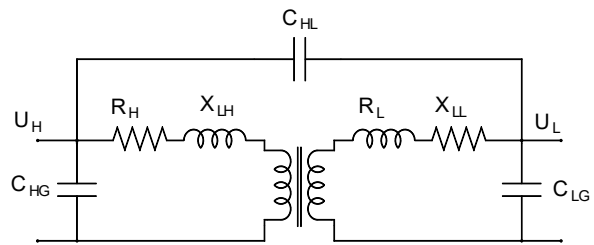


Figure 4 - Single phase equivalent circuit of a three-phase transformer.

Table 1 - Transformers Electrical Characteristics.

U_H/U_L (kV)	S (MVA)	X (%)	X/R	C_{HG} (nF)	C_{HL} (nF)	C_{LG} (nF)
69/11.4	25	14.6	30	3.5	10.3	12.6
11.4/0.22	0.075	3.0	6	-	-	-
11.4/0.22	0.112	3.0	6	-	-	-

Transmission and distribution lines – the LCC module (Bergeron methodology) from ATP was used to model the lines with shared structures. The other lines were simulated using distributed parameters.

Surge arresters – modeled by an exponential current-dependent resistor (Type 92), with the characteristics indicated in Table 2.

Table 2 - High voltage surge arrester characteristics.

Voltage Level	Rated Voltage (kV _{rms})	Nominal Discharge Current (kA _p)
High Voltage	60	10
Medium Voltage	10	10

The complete system modelled using ATPDraw [2] is depicted in Fig. 5.

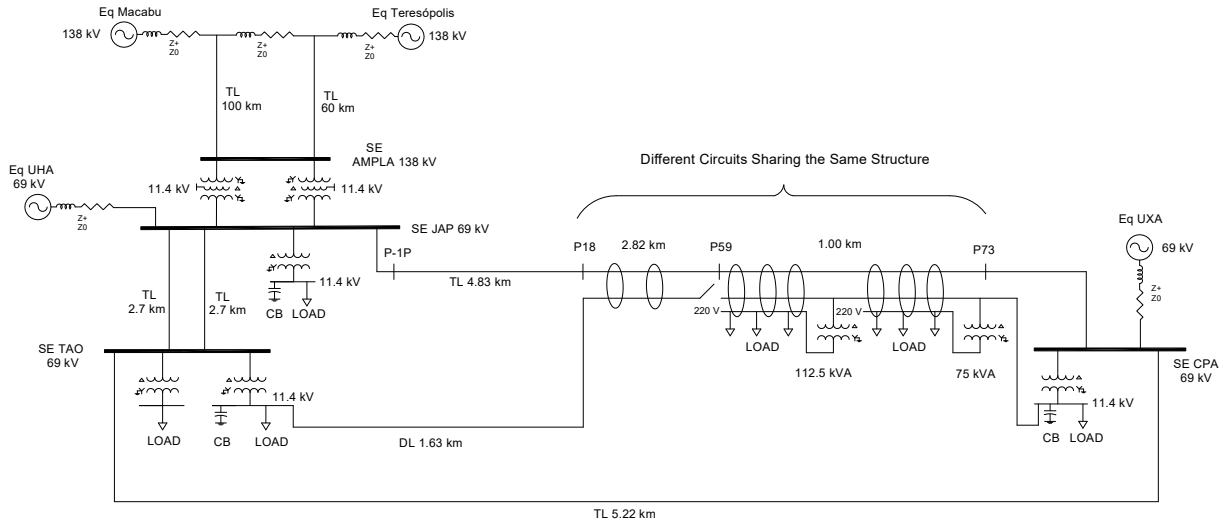


Figure 5 - Single line diagram of the system.

As shown in Fig. 5, the high voltage line connects the Julius Arp substation, which is located in rural area, and the Conselheiro Paulino substation, located in urban area. The latter is newer and it was built to meet the growing energy demand of the city.

SIMULATION RESULTS

In all the simulated cases the voltage was calculated at structure P59, since the highest overvoltages were observed at this point.

First Case

Transmission line condition: steady state.

Distribution line condition: de-energized.

Fig. 6 shows the induced voltages calculated on the medium voltage line.

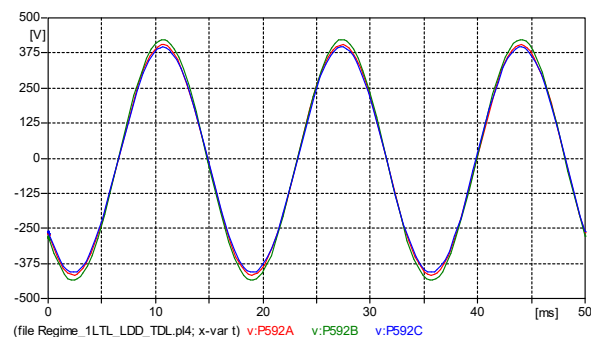


Figure 6 - Induced voltages on the medium voltage line during its maintenance.

Second Case

Transmission line condition: steady state.

Distribution line condition: steady state.

Contingency : single-phase-to-ground fault applied at the 69 kV bus on the Conselheiro Paulino substation.

Fig. 7 shows the induced voltages calculated on the medium voltage line, while the induced voltages on the low voltage line are shown in Fig. 8.

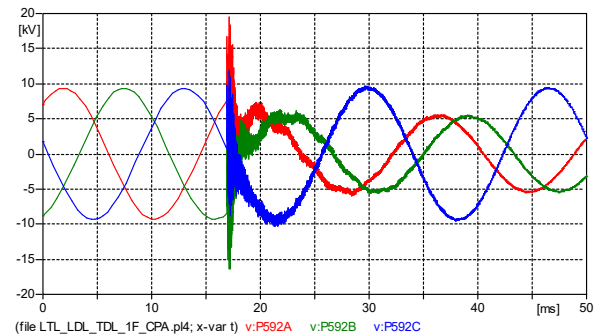


Figure 7 - Overvoltages at the medium voltage line during the occurrence of a single-phase-to-ground fault on the high voltage line.

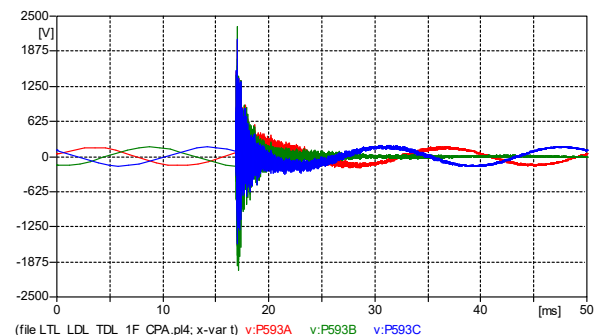


Figure 8 - Overvoltages on the low voltage line during the occurrence of a single-phase-to-ground fault on the high voltage line.

Third Case

Transmission line condition: steady state.

Distribution line condition: de-energized, grounded and under maintenance.

Switching: grounding clamp removal during the occurrence of a single-phase-to-ground fault at the 69 kV bus on the Conselheiro Paulino substation.

Fig. 9 presents the overvoltage calculated at the terminals of the grounding clamp during its removal. The short-circuit occurred at 16 ms and the grounding clamp was removed at 27.4 ms.

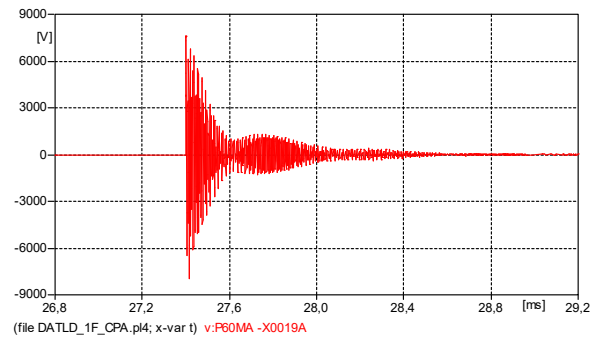


Figure 9 - Overvoltages between the terminals of the grounding clamp.

Fourth Case

Distribution line condition: steady state.

Transmission line condition: energization process.

Fig. 10 shows the overvoltage calculated on the low voltage line during the energization of the transmission line.

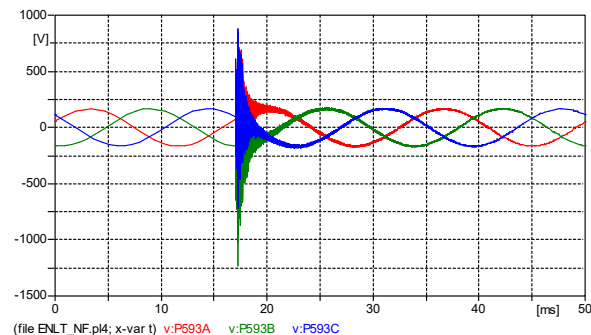


Figure 10 - Overvoltages on the low voltage line during the energization of the transmission line.

ANALYSIS AND RECOMMENDATIONS

First case

During normal maintenance conditions of the medium voltage line, just before the grounding clamp be installed, the peak value of the induced voltage on the line conductors will be about 420 V (Fig. 6).

Therefore the maintenance staff must use personal protective equipment (PPE) that withstand this voltage level.

Second case

When a short-circuit occurs at the Conselheiro Paulino substation, a high transient overvoltage appears on the distribution line, reaching peak values of 19.5 kV (Fig. 7) and 2.3 kV (Fig. 8) on the medium voltage and low voltage lines, respectively. The amplitude of the overvoltage induced on the medium voltage line is below the transformer withstand limit and therefore it will not cause damage to the transformers or other device installed in the medium voltage line. On the other hand, the overvoltage induced on the low voltage line may exceed the dielectric withstand limits.

Third case

If a single-phase-to-ground fault occurs on the high voltage line during distribution line maintenance, the overvoltage that appears between the terminals of the grounding clamp during its removal reaches approximately 8 kV, as shown in Fig. 9. This situation should definitely be prevented, once this voltage level can be fatal. Although this case corresponds to an unlikely situation, the maintenance staff must use appropriate devices and tools to ensure safety.

Fourth case

During transmission line energization, a transient overvoltage with magnitude of about 1.25 kV appears on the low voltage line. Although fast, such transient may cause insulation failures.

INSTALLATION OF SURGE PROTECTIVE DEVICES ON THE LOW VOLTAGE LINE

The second case was simulated again, but now the low voltage line was equipped with seven surge protective devices (SPDs) in order to limit the overvoltage caused by the short-circuit. The SPDs were placed 100 m far from each other and the voltage was monitored in seven points of the feeder.

The simulation results are shown in Table 3, where points "1" and "7" are the farthest and the nearest, respectively, from the 112.5 kVA distribution transformer, as shown in Fig. 11.

Table 3 - Peak values of the overvoltages at points 1 to 7 of the low voltage line considering or not the installation of SPDs.

Point	1	2	3	4	5	6	7
Voltage on the line without SPDs (V)	2300	1950	1440	1250	1050	800	600
Voltage on the line with SPDs (V)	1350	1000	790	680	630	570	520

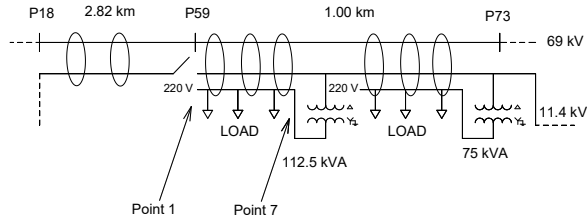


Figure 11 - Indication of the points of voltage calculation on the low voltage line.

Table 4 presents the characteristics of the SPDs used in the low voltage line.

Table 4 - Characteristics of the SPDs.

Nominal Discharge Current (I_n)	5 kA _p
Maximum Continuous Operating Voltage	280 V _{rms}
Voltage Protection Level at I_n	1100 V _p
Energy Absorption Capability	1800 J

After the installation of SPDs, the maximum overvoltage caused by transmission line energization reaches only 550 V (peak value), which indicates that this measure is a solution also for the fourth case. [6]

CONCLUSIONS

The sharing of the same structure by transmission and distribution lines is a very efficient solution for the lack of space in highly populated areas. However, the electromagnetic coupling between the lines can cause high transient overvoltages in the distribution line, which requires some analysis. Countermeasures must be adopted to ensure safety to costumers' devices. Maintenance staff must use proper personal protective equipment, which must guarantee safety even during the highest overvoltage levels. The installation of properly selected surge protective devices on the low voltage line can limit the overvoltages caused by short-circuits and transmission line energization.

The analysis showed that an extra care must be taken for loads located far from the transformer, as the farther the load is from the transformer, the higher the overvoltage amplitude will be between its terminals.

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