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OVERVOLTAGE INVESTIGATIONS OF CABLE SHIELDINGS AND PROTECTION METHODS

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Abstract: Due to the fact that there is a special high alpine situation in Austria, different earthing systems and shielding concepts are in practical use. The aim of this paper is to review a current project at the Institute of High Voltage Engineering and System Management which deals with medium voltage cables that are used for the internal power supply of a substation, where the handling of overvoltages at cable shieldings are researched. The investigation includes computer simulations of several types of faults based on local earth resistance measurements. The focus was set on single-phase faults as well as the transient behaviour of the cable shield. Therefore, a cable-model consisting of RLC-elements had to be set up. The entire simulation has been carried out using a numerical simulation software based on EMTP/ATP. Those numerical calculations include the overvoltages occurring on the cables shield, the stray current and the energy absorption capacity of the surge arresters. According to the simulation results, a strategy for the dimensioning and application of several surge arresters was drawn up, in order to avoid contact and step voltages. Additionally, the paper shows the influence of the propagation impedance as well as the dependence on the fault current amplitude.

1. INTRODUCTION

Whenever an earth fault occurs in electric power systems or when lightning strikes, a voltage is impressed on the faulted object resulting to earth potential rises, voltage inductions, voltage surges and transients. The voltage to which this object rises depends largely on the voltage of the faulted transmission line, lightning, or the earth resistance. Depending on the ground conditions, the higher the earth resistance, the higher the impressed voltage. This can damage equipment and injure working staff unless proper isolation and protection devices are provided. In addition, it is vital to provide good earthing measures.

Nevertheless, even in well earthed substation structures and transmission towers a dangerous potential difference can result out of a fault. How dangerous the voltage is, depends on the magnitude of the fault current and the time of exposure. Therefore special protection equipment and measures are necessary to ensure a safe operation of power systems [1].

2. STEP AND TOUCH VOLTAGES

2.1. Voltage-gradient distribution curve

A voltage funnel occurs around an energized earthed conductor or at the place of a lightning stroke. Due to the fault current flowing through an earthing electrode and earth, a voltage drop occurs in the resistance zone. The voltage distribution is equivalent to the resistance distribution and looks funnel-shaped in case of an earth rod. This means, that the voltage funnel is spatially expanded because the current leaves the electrode in all directions. Persons or animals in this resistance zone bridge with each step a part of the voltage gradient distribution curve, which is known as step voltage [1].

2.2. Step voltage

The term step voltage refers to a voltage between the feet of a person or an animal standing near an energized earthed object. It is equal to the voltage difference between two points at different distances from the earthing electrode given by the voltage distribution curve. During a fault, a person could be at risk of injury, simply by standing near the earthing point [1].

According to the Austrian engineer’s standards OVE/ONORM E 8383, the step voltage is that part of the earthing voltage which is tapped by a step size of 1 m, with the current flowing from foot to foot [4].

2.3. Touch voltage

The potential difference between an energized object and the feet of a person in contact with the object is called touch voltage. The touch voltage is equal to the difference in voltage between the faulted object and the person some distance away [1].

3. PROTECTION METHODS

3.1. Protection from hazards of earth-potentials gradients

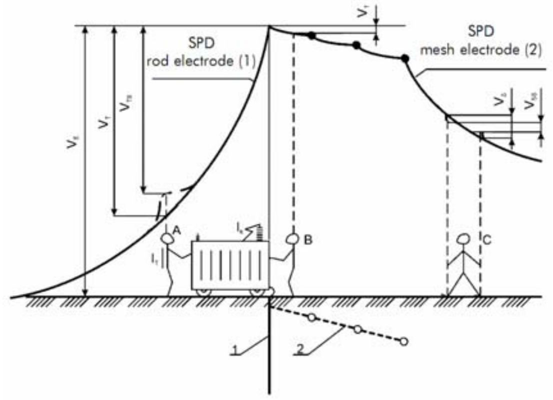
A numeric simulation of electrical power systems under fault conditions can be used to find out whether or not hazardous step and touch voltages arise. Out of the simulation results protective measures and appropriate precautions can be taken.

Several methods are applicable to protect persons from dangerous voltage potentials, such as equipotential zones (1), insulating equipment (2) and restricted work areas (3).

(1) A person "B" standing within an equipotential zone will be protected by step and touch voltages. This zone can be created by a metal mat or a close-meshed grid. Standing partly or fully outside the equipotential zone will not protect the person "C".

The rod electrode (1) has an unfavourable potential distribution while the meshed electrode (2) has a much flatter one. Therefore the touch voltage at person "A" is considerably larger for the rod electrode than for the meshed one at person "B".

Bonding conductive objects inside the work area can be applied to reduce the voltage potential between the objects and from object to earth. However, in some cases a bonded object outside the work area can increase the touch voltage to that object.



1	rod electrode
2	meshed electrode
V_E	earthing voltage
V_T, V_{TS}	touch voltage and shocking touch voltage respectively
V_S, V_{SS}	step voltage and shocking step voltage respectively
I_T	shocking touch current
I_K	short circuit current equal the current flowing to the earthing system
A, B, C	persons at various earth surface potentials

Figure 1: Comparison of earth surface potential distribution (SPD) during the current flow in the earthing system, for two earth electrode constructions [2].

(2) During switching operations and handling electrical conductors, insulation equipment, for instance rubber gloves, can protect employees from touch voltages. Therefore the insulating material must be rated for the highest voltage under fault conditions that can be impressed on the earthed object.

(3) Due to performed operations, even at restricted work areas employees cannot be protect directly from hazardous touch and step voltages. Employees should be kept at a certain distance where step voltages would be insufficient to cause harm. Engineers should not operate on earthed conductors in order not to become energized except they are within an equipotential zone or are protected by proper insulating equipment [1, 2].

3.2. Earth potential rise

Each time an earth fault occurs, the fault current flows back to source using different ways such as metallic and earth paths. Metallic return paths include overhead earth wires, station earth grid, protective multiple earthing, bonding conductors, messenger wires, metallic cable shielding, and other conducting materials.

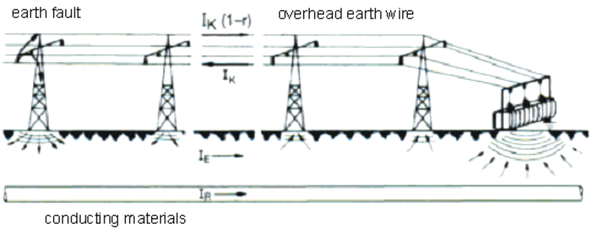


Figure 2: Earth fault of an overhead line [5].

In Austria, the engineer standards OVE/ONORM E 8001-1 and OVE/ONORM E 8383 are in practical use [3, 4]. Out of these engineer standards we can take the following values:

Table 1: Touch voltages depending on the fault current duration time.

Fault current duration [sec]	Touch voltage [V]
0,2	500
0,4	285

Allowable values for step voltages are much higher than for touch voltages. If the requirements for the earthing system regarding the touch voltages are fulfilled, in general no hazardous step voltage can occur [4].

4. NUMERICAL SIMULATION

4.1. Local situation at the substation

All plant components of the substation are arranged on 4 levels (A, B, C and D) in different altitudes. The substation area has a circumference of 160 m times 80 m at hillside situation.

This substation is supplied by a 220-kV and a 110-kV overhead line. A 25-kV cable with the length of about 300 m is used to assure the internal power consumption.

The overhead earth wires of the 220-kV and 110-kV towers are connected to the equipotential bonding system, as well as the shielding of the 25-kV internal power supply cable.

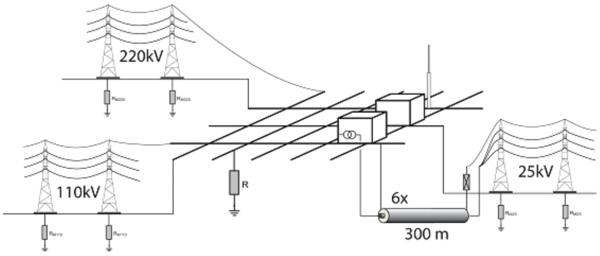


Figure 3: Schematic configuration of the electrical energy system.

The soil conditions in the substation area are the following:

- approximately 30 cm humus,
- approximately 30 cm loess, and
- schist.

While the basement was built, the schist-layer was removed. All earth measurements were evaluated in detail and represented tabularly:

Table 2: Specific earth resistance measurements.

	test series 1		**test series 2**	
probe spacing	**earth resistance**	**specific earth resistance**	**earth resistance**	**specific earth resistance**
a [m]	**R_E [Ω]**	**ρ_E [Ωm]**	**R_E [Ω]**	**ρ_E [Ωm]**
0.5	37,9	119	42,8	134
1	30,7	193	28,4	178
2	20,2	254	9,9	125
3	14,3	269	11,2	211
4	10,9	274	9,5	237
5	9,1	285	8,5	267
6	7,7	291	7,6	287
7	6,5	287	6,9	305
8	5,8	291	6,5	325
9	5,2	295	5,8	327
10	5,4	337	5,4	336

Test series 1 was carried out horizontally to the substation area whereas test series 2 was carried out vertically to the substation area.

Note: It is probable that the measurements in 2 meter depth were affected by the near concrete shaft.

4.2. Earth potential simulation

To simplify the simulation, a mesh of 10×10 m was chosen for the equipotential bonding within the substation, without losing any accuracy but saving calculation time. According to a measurement report, the specific earth resistance for a ground consisting of two layers, is 150 or rather 250 Ωm.

For the simulation a relative single-phase earth-fault of 1000 A was taken as a basis. An extrapolation can be assumed to be linear.

The needed input parameter for the simulation program OBEIN-2S are the following: ground plan of the earthing system, fault current, specific earth resistance of the different ground layers, the thickness of each ground layer.

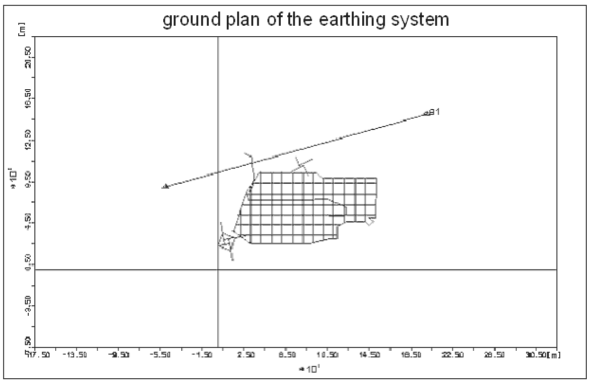


Figure 4: Ground plan of a substation, 110-kV and 220-kV-towers connected to the earthing system, earthing strip of 25-kV cable connected, two-layer ground.

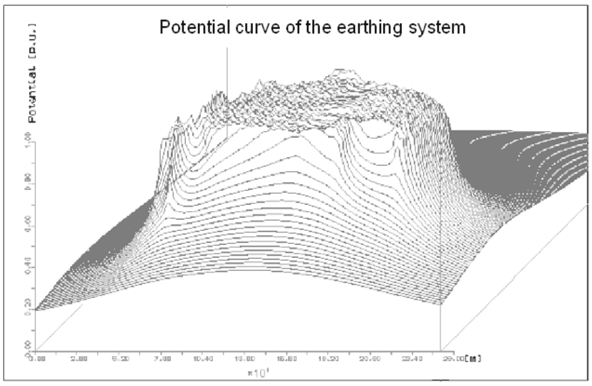


Figure 5: Potential curve of the earthing system.

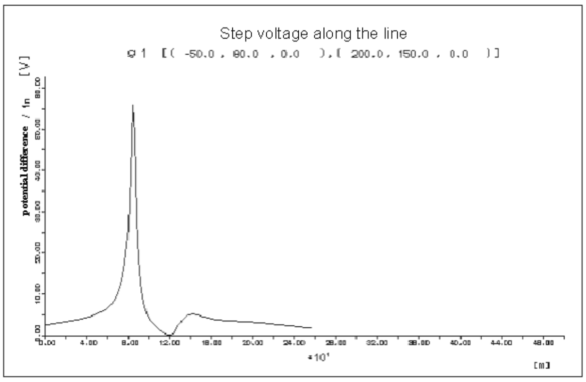


Figure 6: Step voltage along the line g1 (projection 25-kV cable) as shown in figure 4.

4.3. Potential rise of the cable shielding

To determine the potential rise of the cable shielding, a numerical simulation software based on EMTP/ATP has been used.

For the simulation we have taken the following values:

- earth resistance of the substation: 1.14 Ω
- overhead earth wires of the 220-kV and 110-kV lines, the first 5 line sections were modelled. The tower earthing resistance was assumed to be 5 Ω.

- measurements for the tower earthing resistance of the 25-kV towers yield to 1.42 Ω.
- the 25-kV cable shielding was simulated with an equivalent π circuit, based on experienced data. All six cable shielding were protected by separate surge arresters at the same tower earthing resistance.

A range for the input parameters had to be chosen:

- single-pole sustained earth short-circuit 1 ÷ 100 kA, 50 Hz
- lightning impulse current 1 ÷ 100 kA, 1.2/50 µs.

Surge arrester

The surge arresters characteristic V-I-curve is shown in figure 7.

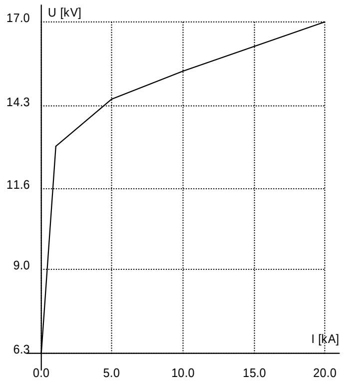


Figure 7: V-I-curve of the surge arrester (ATPDraw)

If the voltage at the chosen surge arrester exceeds 6.3 kV, it will switch over into a conducting state. Thereby the resistance has a non-linear characteristic.

A representative overview of fault currents at working frequency with according voltages and currents of the surge arrester can be gathered from figure 8.

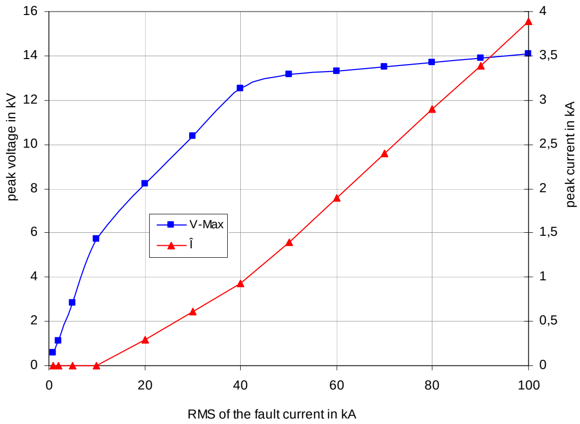


Figure 8: Voltage and current at the surge arrester at an earth fault (effective values 1 ÷ 100 kA) at working frequency.

To use the surge arresters full capacity, it is recommended to use a low inductive conductor for earthing. If every of the six cable shieldings has its own arrester, the current would be divided by six for each one. Figure 9 clearly shows the voltage limiting behaviour of the surge arrester.

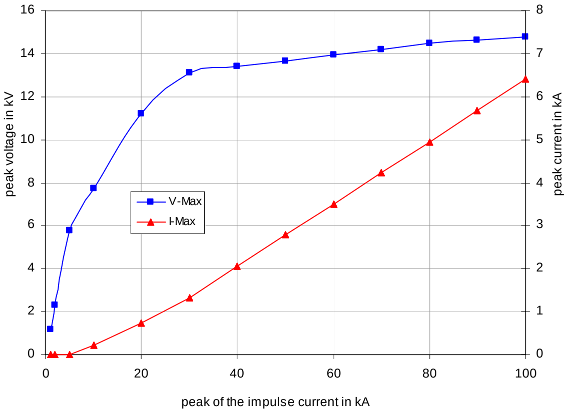


Figure 9: Voltage and current at the surge arrester at an atmospheric discharge (1 ÷ 100 kA, 1.2/50 µs).

Energy absorption capacity of surge arresters

A surge arrester does not only have to cope with impressed currents and voltages, it also has to deal with the energy absorption. To make an estimation, the power was calculated by graphical integration out of the simulated currents and voltages.

Due to the fact that atmospheric discharges have a very short duration, the energy release compared to a fault at working frequency is lower by the factor 1000. Thereby the interruption duration of the earth fault is assumed to be 0.4 seconds.

Due to the graphical integration and numerical simulation, the energy absorption diagrams have to be understood as guideline values, which are supposed to show the order of magnitude.

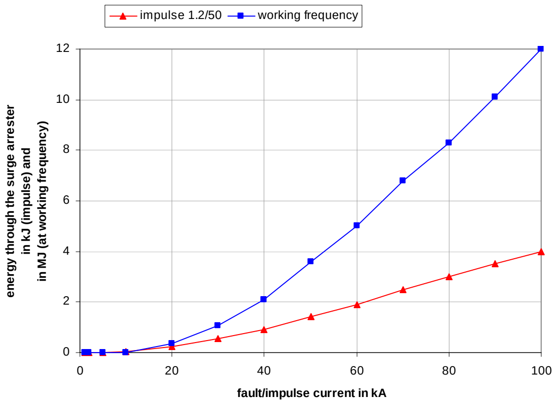


Figure 10: Energy absorption of the surge arrester in dependence of earth fault currents (working frequency) and atmospheric discharges (1.2/50 µs).

5. CONCLUSION

Our investigations include the potential curves of the whole earthing system, including the towers earthing, the boundary fence and the 25-kV cable. Different protection measures were suggested so as to avoid possible step and touch voltages.

Within the substation, the numerical simulation shows an evenly potential curve, no significant potential differences could be observed graphically. If the mesh width would have been chosen more closely, the potential curve became more even. Therefore within the substation no measures have to be taken.

At the boundary fence the earthing system has its end, therefore touch and step voltages are increasing. Therefore, the potential curve could be enhanced by a so-called potential grading earthing electrode.

For the 220-kV and 110-kV towers a connection to the earthing system of the substation should be carried out. Furthermore a potential grading earthing electrode should be placed, which slopes downwards for grading the potential.

The calculated step voltages above the earthing strip of the 25-kV cable have comparable values with the step voltages at the towers earthing due to an earth fault so that there is need to take action in protection measures. Following protective measures can be recommended:

- one-side earthing of the cables shielding at the switch house,
- protection through surge arrester at the other end of the cable,
- the use of surge arresters for the cables conductors, as well as
- the examination of the earthing system of the 25-kV tower concerning the crossover between cable and overhead line.

Furthermore expected overvoltages of the 25-kV cable shielding concerning earth faults at working frequency and atmospheric discharges at the equipotenial bonding system were investigated. A surge arrester for the 25-kV cable shielding, protecting it from voltage surges and transients, can be recommended.

During an earth fault of 23 kA, the simulation yields to a voltage of 8.9 kV and a current of 385 A trough the surge arrester. The energy consumption was 560 kJ.

At lightning discharge with a peak value of 100 kA leads to an impressed voltage at the arrester of 15 kV and a current of 6.5 kA through it. Although those values are much higher, the energy consumption is much lower due to the short duration time, namely 4 kJ.

6. ACKNOWLEDGMENTS

The project described in this paper is the result based on a scientific cooperation between the Austrian utility TIWAG, department of Electrical and Control Systems, Ing. R. Hetzenauer and his team, and Dr. E. Schmautzer, Institute of Power Systems at Graz University of Technology. Therefore, the authors would like to thank all involved partners for enabling this research project, their support and the assistance during the performance of the numerical simulations.

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