INFLUENCE PARAMETERS OF STEP AND TOUCH VOLTAGES IN THE VICINITY OF HV POWER LINE TOWERS UNDER NORMAL AND FAULT OPERATING CONDITIONS

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ABSTRACT

In the case of electrical faults with earth return currents, during normal operating condition, as well as in the case of lightning strokes into the tower or the ground wire(s) of a HV power line, the grounding system of the affected tower and, if ground wires exist, also the neighbouring towers and grounding systems are electrically influenced by the currents flowing in the phase and ground wires of the line. Load and fault currents form mainly inductively and conductively coupled electric circuits via the phase and ground wires, the tower and its grounding system, as well as the ground itself and other connected grounding systems.

In the planning and operating phase of HV power lines, step and touch voltages at each tower of the power line as well as in the vicinity of the towers have to be controlled both during normal and fault operating condition to avoid electrically dangerous situations for people.

In this paper, the results of a study [1] at Graz University of Technology are presented, showing that the intensity of the currents and therefore also the (prospective) intensity of the step and touch voltages in the grounding system of HV power lines with 2 three-phase systems not only depends on the intensity of the load or fault currents and the fault location, but also additionally on other parameters of the line.

The influences of the most relevant parameters in this context – the phase configuration, the conductor arrangement, the operation mode (both systems in operation, only one system in operation, one system grounded), the grounding resistance of each tower, the impedance of the coupled lattice network (tower, wires, grounding systems, ground return, ...) and the overall length of the line – are presented by depicting simulation results and measurements.

METHOD

All investigations were done using MATLAB and Simulink with its Toolbox 'SimPowerSystems'. A specialised blockset was developed, allowing the concurrent calculation of both the electrical behaviour (e.g. the currents flowing in the phase and ground wires) of all types of overhead power lines carrying 6 phase wires or bundles and 1 ground wire, and the currents flowing into the grounding systems of all towers and stations belonging to this line. Particular attention was paid to the accurate electrical representation of the phase and ground wires and their ohmic, inductive and capacitive couplings by using the 'Distributed Parameters Line'-Block of SimPowerSystems and parameter matrices optimised for the operating frequency of 50 Hz. Based on the current flowing through the pylons and considering the grounding resistance of each grounding system the prospective touch voltages can be calculated in consequence.

Using the described blockset, a generic model of a HV overhead power line was created, consisting of 30 spans, 2 transpositions (one after every 10 spans) and 31 towers (the first and the last one being treated as substations with comparatively low grounding resistances).

Next, a set of 13 different parameters was defined (see Table 1). As all of these parameters could be set completely independent of each other in the model, accurate traceability of the results was given in every case. That is, the parameter causing a difference between 2 simulation results could always be exactly pinpointed.

The pursued strategy in the analytic process was to investigate the particular influence of each parameter separately, determining its relevance in the overall outcome, and arranging parameter values causing similar influences into classes. The results of this parameter variation and the parameters with the highest relevance are discussed in the following chapters.

Parameter Name	Relevance
Transposition method	high
Phase configuration	high
Conductor arrangement	high
Operation mode	high
Tower grounding resistance	high
Substation grounding resistance	high
Total load current	high
Span length	medium
Soil resistivity	medium
Ground wire distance	medium
Tower height	low
Neutral point treatment	low
Operating voltage	low

Table 1: Investigated parameters and their relevance

RESULTS

Transposition Method

To give a HV power line more symmetric transfer characteristics, transposition of the phase wires is applied at regular intervals. This can be done in a homogeneous or in an inhomogeneous way (see Figure 1), which both lead to the desired balancing of the power line impedances, but vary significantly in terms of grounding system influence.

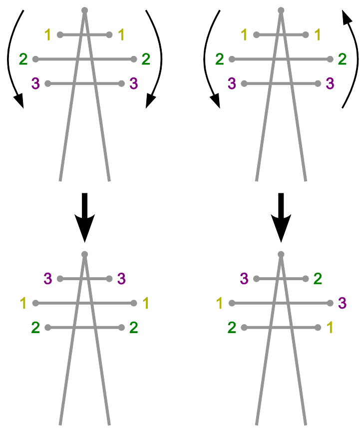


Figure 1: Homogeneous (123/123 → 312/312) and inhomogeneous (123/123 → 312/231) transposition of the phase wires

If the phase configuration of the line changes after every transposition, the shape of the grounding system magnitude curves is different for every geometric tower and phase configuration (i.e. coming and going ground wire currents, currents into the tower grounding system, prospective touch voltages, see Figure 2). This makes comparisons and general conclusion practically impossible and each configuration has to be calculated and evaluated separately. Inhomogeneous transposition of the phase wires comprises the danger of higher imbalanced system impedances and should therefore be avoided.

The following figures depicting the currents in the grounding system (current in the ground wire coming from the left side, current in the ground wire going to the right side and the current through the grounding system of the pylons) and the prospective touch voltage (grounding voltage to the reference potential) are based on a symmetrical total load current of 1000 A_{RMS} (2 x 500A).

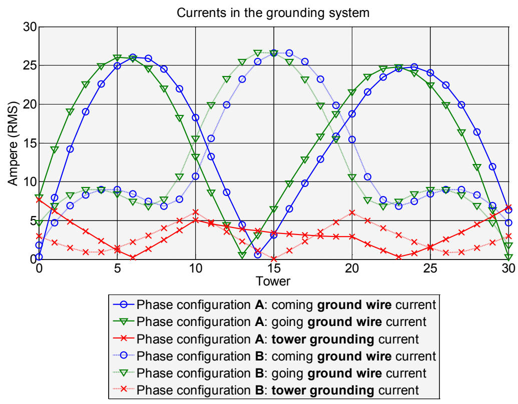


Figure 2: Currents in the grounding system Inhomogeneous transposition method
Phase configuration A: (123/132)
Phase configuration B: (123/231)

If, however, the phase configuration remains unchanged after every transposition, different geometric configurations cause only a proportional scaling of the mentioned curve shapes (see Figure 3).

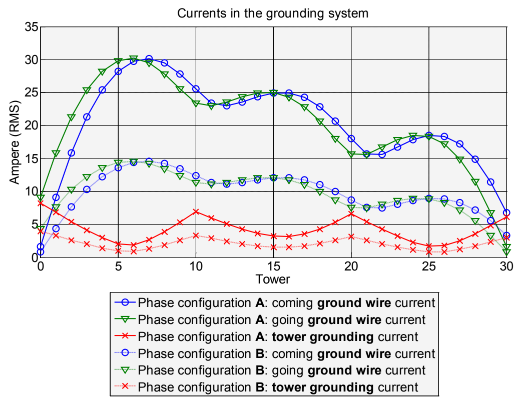


Figure 3: Currents in the grounding system Homogeneous transposition method
Phase configuration A: (123/132)
Phase configuration B: (123/231)

The transposition method in Figure 3 is therefore called homogeneous, while the former (Figure 2) is called inhomogeneous. It is important to keep in mind that all findings described in the following subchapters are only valid for lines with homogeneous transposition.

Phase Configuration and Conductor Arrangement

Provided that the homogeneous transposition method is applied and the 2 three-phase systems are separated to the left and the right side of the tower respectively, the 3 phases of one system can face the corresponding phases of the other system in 6 different ways, out of which 2 are identical in terms of resulting current and voltage magnitudes in the grounding system. Each of the 5 distinct phase configurations proportionally scales these magnitudes by a certain factor (as already shown in Figure 3), which is dependent on the conductor arrangement, the tower height, the ground wire distance and the soil resistivity, but independent of all other parameters, including the overall length of the HV power line.

In [1], the equivalent phase configurations of different conductor arrangements are organized in so called "Phase Opposition Classes" (POC), ranging from highest grounding system influence (POC 1) to lowest grounding system influence (POC 5). Table 2 shows the phase configurations of POC 1 and POC 5 (i.e. worst and best case) for the 3 investigated conductor arrangements.

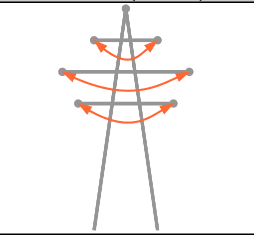
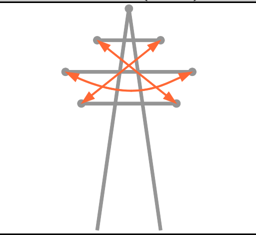
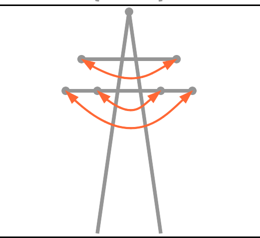
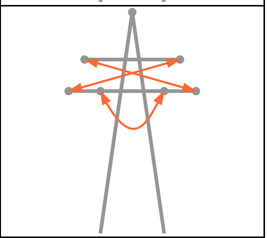
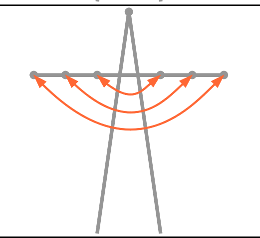
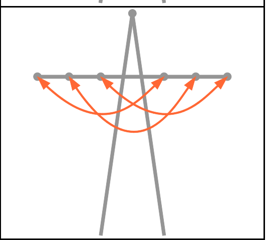
	POC 1 (worst)	POC 5 (best)
3-lvl.		
2-lvl.		
1-lvl.		

Table 2: Best and worst phase configurations

By arranging the phase opposition classes and their corresponding geometry scaling factors in table form, comparison of and mathematic conversion between different geometric configurations can be done in an easy way. Table 3 shows such an arrangement for the POCs 1 and 5. All factors are valid for grounds having a soil resistivity of 100 Ωm.

		3-lvl.		2-lvl.		1-lvl.	
		POC 1	POC 5	POC 1	POC 5	POC 1	POC 5
3-lvl.	POC 1	**1**	5.4	2.1	11.6	1.4	30.1
	POC 5		**1**	0.4	2.1	0.3	5.6
2-lvl.	POC 1			**1**	5.5	0.6	14.2
	POC 5				**1**	0.1	2.6
1-lvl.	POC 1					**1**	21.8
	POC 5						**1**

Table 3: Geometry scaling factor table

Some of the figures in this table are quite noticeable. For example: The resulting current and voltage magnitudes in the grounding system of HV power lines with three-level towers are always around 2.1 times higher than the corresponding magnitudes of lines with two-level towers belonging to the same POC. The comparison of POC 1 with POC 5 of three-level and two-level towers respectively shows that there is a difference by about factor 5.4 in both cases, i.e. a simple swapping of 2 phases on one side of the tower (see Table 2) immediately lowers all currents and voltages in the grounding system of the line to less than one fifth. This decrease is even more significant in the case of lines having single-level towers, as the resulting magnitudes differ by nearly factor 22 here.

Operation Mode

As, like explained in the previous subchapter, a simple change of the phase configuration brings significant improvements to the electrical influence of the grounding system, it is tempting to switch to POC 5 and not ground each tower too excessive in order to save costs. This, however, can lead to danger if the facilities in the substations allow the operation of just one three-phase system of the line. If one system is tripped and left open, the grounding system is influenced exactly as if the line had a phase configuration belonging to POC 1. Even if the total load current is then only 50 %, all current and voltage magnitudes in the grounding system are still higher (around 2.7 times in the case of two-level and three-level towers and nearly 11 times in the case of single-level towers) than those occurring at 100 % load current with both systems being in operation. Grounding the tripped system at both endpoints brings only minor improvements to these magnitudes.

Grounding Resistance of Towers and Substations

Higher grounding resistances lead to lower currents in the grounding system (Figure 4), but this decrease does not compensate the simultaneous increase of the prospective touch voltages (Figure 5) in consequence. As can be seen in Figure 4, the resulting currents in the grounding system vary in the course of the HV power line, showing inhomogeneities at those points where the wires are transposed.

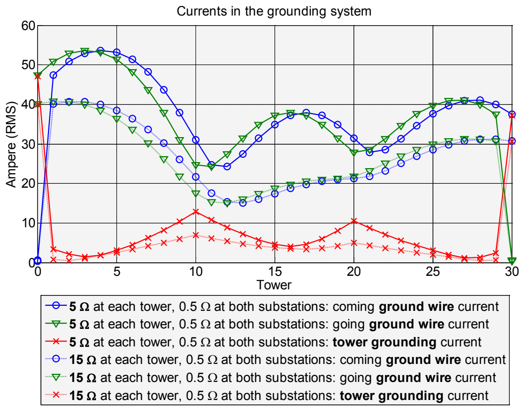


Figure 4: Currents at different grounding resistances

As can be seen in Figure 5, the resulting prospective touch voltages vary too in the course of the HV power line, also showing high inhomogeneities and values at those points where the wires are transposed.

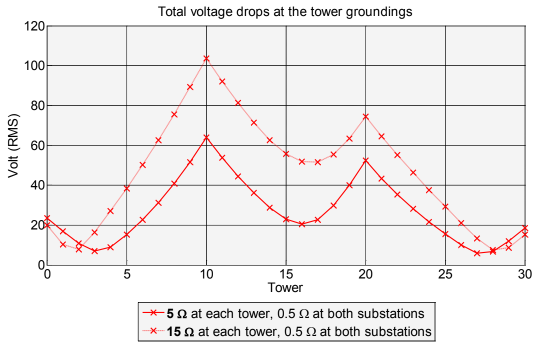


Figure 5: Voltages at different grounding resistances

Total Load Current

The currents and voltages in the grounding system of the line – except those in the substations – change directly proportional with the total load current flowing over the phase wires. This relation is only valid though if no other parameters of the line change at the same time. For example: If the ratio between the load current values of both systems also varies, effects as described in subchapter "Operation Mode" will occur.

Overall Line Length

The overall length of a HV power line is determined by its number of spans and the span length. Only variations of the span length have been thoroughly investigated in [1], but the results are also applicable to variations of the number of spans. Increasing the span length, i.e. elongating the line, generally raises the currents and voltages in the grounding system and vice versa. The extent of this change significantly depends on the values of the grounding resistances, but is independent of the phase configuration and the conductor arrangement.

CONCLUSIONS

Based on a numerical model, which was evaluated in several measurement campaigns, the relevant structural and operational characteristics of HV overhead power lines affecting the currents in the grounding system (ground wires, pylons) and the prospective touch voltages occurring at the pylons where discussed.

If in the case of normal operation the load currents in the HV Power line are low, no great requirements for the grounding resistances of pylons have to be obeyed to meet the permissible touch voltages. General measures to keep the touch voltages in case of normal operation in permissible limits are increasing the operating voltage of the HV system, limiting the load currents and optimising the grounding resistance of the pylons especially of the pylons where the lines are transposed. In case of an earth-to-ground fault or a lightning stroke the low total impedance of the grounding system of the HV overhead power line (ground wire(s), grounding system of the affected pylon and the neighbouring pylons and stations) contribute to lower the prospective touch voltages. Furthermore, special attention must be paid for repair work on a HV power line system and the grounding or not grounding of this system to consider the resulting unbalanced situation. A usually good balanced system can change to a severe unbalanced system leading to high currents in the grounding system.

Enlarging the distance of the ground wires and the phase wires leads to a significant reduction of the induced currents and the currents into the grounding system of the pylons, and the lightning protection effect increases, but it must be considered that measures concerning phase geometry also affect the magnetic and the electric field in the vicinity of the line, in some cases witch contradictory effects. The value of the grounding resistance always plays a significant role. The smaller it is the higher is the current occurring in the grounding system. This can be reduced by increasing the resistance values, thereby increasing the prospective touch voltages in return. An efficient design of the grounding system and the currents in normal and fault operation help to keep to the standards for protection against dangerous touch and step voltages; however the grounding resistance should be kept as low as reasonable to reduce the dangers resulting from touch voltages on the one hand and back flashovers in case of lightning strokes on the other hand.

REFERENCES

[1] H. Breitwieser, 2010, *Numerical analysis of the electrical influence on overhead line-earthing systems*, Graz University of Technology, Graz, Austria.

[2] HD 637 S1: 1999, *VDE 0101/HD 637 S1:1999 Power installations exceeding 1 kV (ÖVE/ÖNORM E 8383)*.

[3] ÖVE/ÖNORM E 8384, *Earthing in AC installations with rated voltage higher than 1 kV*, 2007.