OSCILLATION PHENOMENA IN ISOLATED HIGH VOLTAGE NETWORKS CAUSED BY LIGHTNING STROKES

Georg Achleitner
Austrian Power Grid AG (APG)
Austria
georg.achleitner@apg.at

Lothar Fickert, Christian Raunig,
Institute for Electrical Power Systems
TU Graz- Austria
lothar.fickert@tugraz.at
christian.raunig@tugraz.at

Stephan Pack, Jürgen Plesch
Institute for High Voltage
Engineering and System Management
TU Graz- Austria
pack@tugraz.at, juergen.plesch@tugraz.at

ABSTRACT

Isolated networks are common practice for operating high voltage networks up to a small earth fault current defined by standards. The reason for choosing this type of network are the saving of the arc suppressing coils by coexistence of a self-healing grid in case of an earth fault. During the starting up of a 110-kV-isolated network long-time measurement were installed. During these measurements several unexpected voltage oscillation phenomena were detected. Investigations show that lightning strokes in the area around the high voltage line are the sources of the voltage oscillation. Comparisons between the measurement of the voltages and currents of the high voltage line and the detection protocol of the Austrian Lightning and Detection System (ALDIS) proofed this hypothesis. This paper describes the phenomena based on measurement, the correlation with lightning strokes and will confirm the measurement with simulation examples.

INTRODUCTION

Under the aspect of the continuous growing electric energy consumption, the goal of the electricity supply is to provide electricity in high quality for every consumer.

In order to meet the rising current consumption, besides establishing adequate power station reserves above all, the networks must be enlarged. In order to allow further extensions of these networks without endangering humans and animals in case of ground faults, considerations regarding the neutral point treatment of these networks in the sense of precaution are absolutely necessary [6,7].

One possibility of neutral point treatment for electrical networks up to a small earth fault current is the operation with an isolated neutral point [1,2,3,4,5]. One major advantage of isolated neutral point is the high power quality, because most of single line-to-ground fault, mainly lightnings, self- extinguish in a short period of time and does not require any switching activities on the operation side. Because of this outstanding feature grids with an isolated neutral point treatment can be classified as self-healing grids.

During a start-up of such a network, measurements were performed because in isolated networks ferro resonance oscillation can occur and it should be proofed, that no ferro resonance oscillation cause problems. During these measurement no ferro resonance oscillation were measured but unexpected voltage oscillation phenomena.

MEASUREMENTS

As mentioned before, transient voltage measurements at the isolated network were performed in the first months of operation of a small 110-kV-network. During these measurements unexpected voltage oscillation phenomena, were detected. These oscillations were damped very well.

It was interesting to observe that all three phases were affected in the same way and as a consequence the step could be seen also at the zero sequence voltage U_0. These measurements show a step of all three voltages and a step of the zero sequence voltage up to 60kV. Several steps right after the step before were accumulating and voltage rises higher than 100kV were detected. Figure 1 shows the measured line-to-ground voltage.

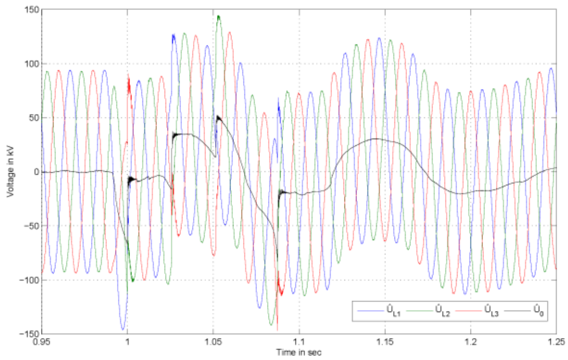

Figure 1: Measurements of the phenomena

These measurements were discussed between several experts but no reason for these phenomena could be given.

Energy of the voltage step

One of the first steps was to calculate the energy of the voltage step, to get knowledge about a possible source.

With the use of the zero sequence capacitance of the transmission line, 240nF, the energy of the voltage step can be calculated:

$$W = \frac{CV^2}{2} \qquad (1)$$

The following parameters were derived, see Table 1:

	Energy (Ws)	Time difference
1	114	-
2	100	26ms after 1.
3	16	25ms after 2.
4	100	36ms after 3.

Table 1: Energy necessary for the step and time difference between following steps

The results show, that only a little energy consumption is necessary to trigger such a voltage step of approximately 60 kV.

LIGHTNING

The next step was, that observations show, that the phenomenon were detected during bad weather. First investigations have shown that a direct lightning impact is not the tripping event.

Due to the observations, a correlation between the recordings of the Austrian Lightning and Detection System (ALDIS) and the recordings of the measurement system could be found. The time delay between one and another lightning stroke from ALDIS were accurate identically with the time delay of the measurement. This was the proof of the root for the hypothesis of these phenomena.

In the next step the location of the lightning impact position were print in a map (see Figure 2)

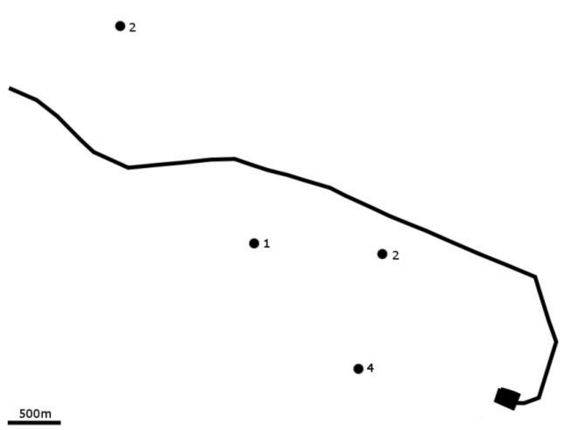

Figure 2: Location of the lightning strokes

The distance between a lightning stroke and the line were between 500m and 2km. The current of the strokes were higher than 20kA. Oscillations caused by strokes under this level could be detected.

It was an interesting fact that a lightning, even it does not directly hit a high voltage line, can cause these "jump" phenomena (voltage oscillation phenomena).

From the operation point of view these lightning can cause troubles due to voltage limits. The fact cannot be excluded, that more than 3 to 4 strokes hit the ground in some ms and lead to a violation of the permissible voltage limits.

CALCULATION OF THE INDUCED VOLTAGE

Lightning discharges near overhead transmission lines generates an induced voltage to the line. The induced voltage could be calculated with the help of the scalar potential φ and the magnetic potential A. For the numerical calculation of the induced voltage to the overhead line the basic formulae form [11] were used.

$$\boldsymbol{E}_i = \boldsymbol{E}_{ei} + \boldsymbol{E}_{mi} = -\nabla\phi - \frac{\partial \boldsymbol{A}}{\partial t} \qquad (2)$$

$$V_i = -\int_0^h \boldsymbol{E}_i dz = V_{ei} + V_{mi} \qquad (3)$$

The induced voltage, caused by the two potentials, may influence the behaviour of the line-to-ground voltage. As the measurement shows, the lightning stroke to ground, leads to oscillate the line-to-ground voltage.

SIMULATION MODEL

A simulation model of the mentioned network was created with the help of the transient simulation program EMTP – RV. Figure 3 shows the simulation model, consisting out of two substations (A and B) and an overhead line connection with an approximately length ca. 10 km. This model is created in EMTP – RV. The network consists of 4 transformers with the voltage level 220/110 kV and 110/30 kV. The power supply is represented through a voltage source and the grid impedance.

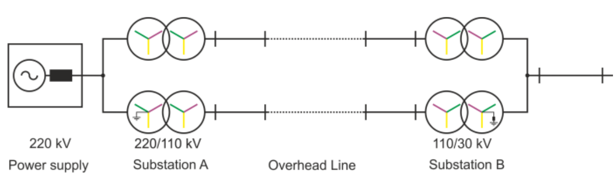

Figure 3: Complete simulation model in EMTP – RV with the isolated 110 kV overhead transmission line

The overhead line connection between the two substations consists of two circuits with 3 phase wires and one earth wire and was separated into 13 elements.

The induced voltage, caused by a lightning stroke into the ground, is represented through an impulse voltage wave shape. Figure 4 shows an example of the induced voltage into the overhead line. Due to the small distance between the phase wires, it was assumed that in all phase wires the same induced voltage appears.

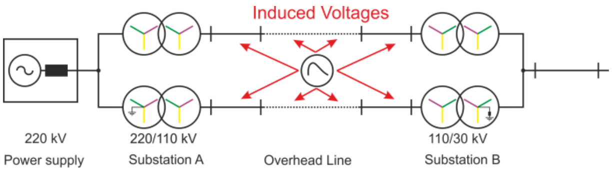

Figure 4: Induced voltage into the overhead line

Figure 1 shows the measured voltage in substation A at the voltage instrument transformer. To compare measurement and simulation, the simulated voltages in substation A were evaluated. For the evaluation of the simulated voltage, a simple model of a voltage instrument transformers was created.

To simulate the behaviour of the isolated network, some assumptions were made:

- Distance: Phase wire – phase wire << transmission line – lightning stroke position
- Transformers without hysteresis
- Same grounding conditions for every tower
- Only one lightning discharge will be analysed
- Measured and simulated voltage below the BIL → surge arresters were neglected

Figure 5 shows the evaluated voltage in substation A. With the assumption it could be said that the induced voltages has the same behaviour like the measurements. The calculated voltages show that a jump of the voltage level appears. After the voltage jump, the network returns to the steady state operation. The energy stored in the voltage jump can only be discharged by voltage instrument transformers.

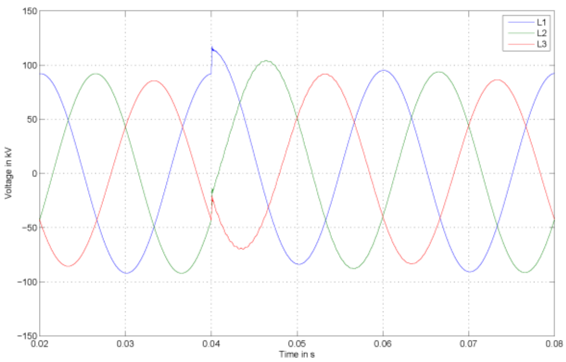

Figure 5: Evaluated voltage in substation A

LOW OHMIC AND RESONANT GROUNDED NETWORK

Operational experiences show that nearby lightning strokes cause no problem in these types of networks. The reason is, because of the neutral point treatment, the influenced charges are levelled fast and cause no problems due to unallowed voltage limits. The small amount of energy, which cause voltage rises in isolated networks, is discharged by the neutral point treatment.

Figure 6 shows the grounded secondary side of the transformer. The assumptions made the section before are also valid for the grounded circuit.

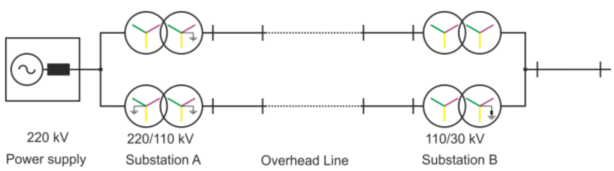

Figure 6: Grounded secondary side of the transformer

The simulation result shows that a change in the grounding conditions can change the behaviour of the transmission network – see Figure 7. In this case, no voltage jump appears, but a transient oscillation is the result after the same induced voltage. The neutral point of the transmission network is fixed through the grounding conditions.

Also in resonant grounded networks the induced voltages are levelled very fast and no problems occur. Also in practise no "voltage jump" problems with nearby lightning strokes are reported in directly or resonant grounded networks.

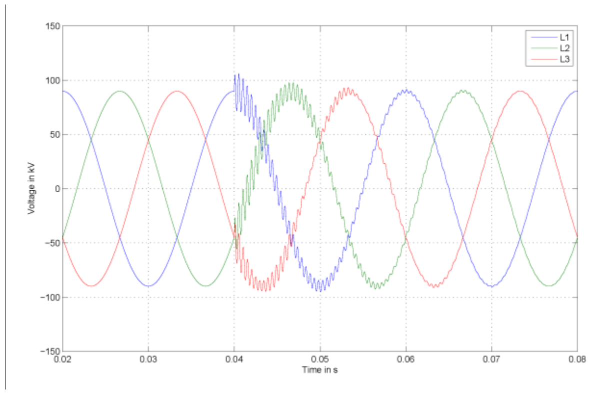

Figure 7: Evaluated voltage in the grounded circuit

SUMMARY

This paper show voltage rise caused by nearby lightning, and not, as everybody expected, direct strokes.
The concept of the isolated grounded grids is a known operation possibility in high voltage networks. Under the aspect of the standards, isolated networks are allowed

only to a certain size depending on the earth fault current.
Measurements in an isolated network have shown unexpected und unknown voltage oscillation phenomena with high voltage steps, which can cause violation of the permissible voltage limits. It could be shown that indirect lightning strokes were the source of these oscillations and can cause voltage steps of several thousand.
Simulations were performed to confirm the correlation between lightning and voltage steps on the isolated power high voltage line and for simulations different network types were analysed. Further simulations have shown that in low ohmic and resonant grounded networks the effects of a nearby lightning is minimized due to the good grounding conditions.
Based on a long time duration measurement of an overhead line connection in Austria, the authors could show for the that indirect lightning strokes could trigger an oscillation of the phase voltages.
This paper shall show that not only the well knows direct lightning strokes, but also nearby or indirect strokes can cause problems with high voltage in power lines. These problems are more or less eliminated in low ohmic or resonant grounded grids.

REFERENCES

Standards:
[1] HD 637 S1:1999, “*Power installations exceeding 1 kV a.c.*”, CENELEC, Brussels
[2] EN 50522:2008, “*Earthing of power installations exceeding 1 kV a.c*.”, CENELEC, Brussels
[3] EN 50160:2005, “*Voltage characteristics of electricity supplied by public distribution systems*”, CENELEC, Brussels
[4] [9] EN 60909-0:2001, “*Short-circuit currents in 3-phase a.c. systems*”, CENELEC, Brussels

Dissertations:
[5] Obkircher Clemens, „*Ausbaugrenzen gelöschter Netze*“, Dissertation, TU Graz, 2008

Papers from Conference Proceedings (Published):
[6] Fickert Lothar, Achleitner Georg, Obkircher Clemens, „*Innovative Neutral Point Treatment in Compensated Networks*”, 19th International Conference and Exhibition on Electricity Distribution, CIRED 2007, Vienna, Austria
[7] Fickert Lothar, Achleitner Georg, Ernst Schmautzer, Christian Raunig, Clemens Obkircher,„*Resonant grounded grids - quo vadis!?*”, 20th International Conference and Exhibition on Electricity Distribution, CIRED 2009, Prague, Czech Republic
[8] Zec Mladen, Gacanovic Mico, “Overvoltages caused by indirect lightning strokes” CEMBEF 2009, Nis, Serbia
[9] P.Chowdhuri “Parametric effects on the induced voltage on overhead lines by lightning strokes to nearby ground, 1989

Books:
[10] Khalil Denno “High Voltage Engineering in Power Systems”
[11] Pritindra Chowduri “Electromagnetic Transients in Power Systems”
[12] P.L. Kalantarow, L.R. Neumann “Theoretische Grundlagen der Elektrotechnik”
[13] Allan Greenwood „Electrical Transients in Power Systems“