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Intersystem faults in the coupled high-voltage line working on the same tower construction

Abstract. *This paper describes the transient analysis in high-voltage transmission line systems with the specially stress of the overvoltage analysis occurring during system operation or fault conditions. The analysis is concerned with the effect of the various factors which influence fault-transient waveforms in the different coupled high-voltage line working on the same tower construction.*

Streszczenie. *W artykule przedstawiono analizę stanów przejściowych w systemach wysokonapięciowych linii przesyłowych, ze szczególnym uwzględnieniem przepięć występujących podczas pracy w warunkach normalnych i awaryjnych. Analiza dotyczy różnych czynników, które skutkują przejściowymi zakłóceniami przebiegów napięć w różnych liniach wysokiego napięcia pracujących na tych samych konstrukcjach wsporczych. (**Zwarcia wewnątrzsystemowe w liniach wysokiego napięcia pracujących na tych samych konstrukcjach wsporczych**).*

Keywords: electromagnetic transients, multi-voltage lines, energy and environment, power system.
Słowa kluczowe: stany przejściowe, linie wielonapięciowe

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Introduction

More and more often multi-voltage (two or more) lines will be used for the environmental protection, what will bring primarily limitation of forest belts needed to conduct electricity transmission routes. For a typical 400 kV line the required forest belt is with a width of 24 m.

One double-system line 400 kV is able to transfer as much energy every 4 simply lines 220 kV or 15 single line 110 kV. Building a higher voltage lines in the two-way instead of one-track system is reduced: lines nuisance to the environment, the area occupied by the line, material-line.

One four-system dual voltage line is able to send as much energy as one double-system line 400 kV and one 220 kV double system. Using multi-line dual voltage reduces to: onerousness to the environment, the area occupied by the line (more than double – see Figure 1).

Such solutions may, however, pose a risk of hazardous transient phenomena, which may be a consequence of inter-system interference. Such distortions are particularly severe for systems with lower voltages which may occur and overcurrent surges with values far in excess of the limits for devices operating at these voltage levels.

The lack of identification of interference and malfunction protection automation devices - cascading off the transmission lines, which can even cause system crashes – blackout, may be another dangerous phenomenon.

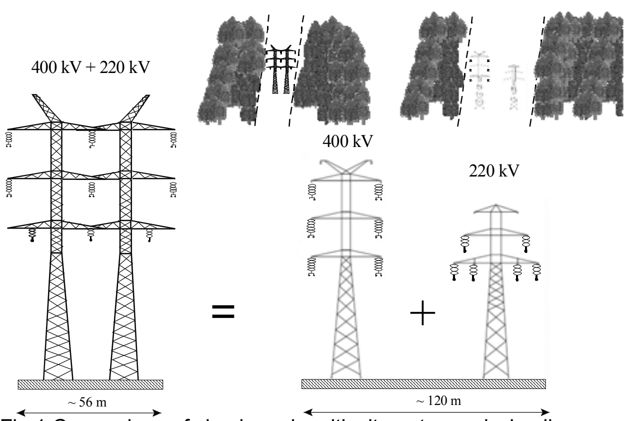

Fig.1.Comparison of simply and multivoltage transmission lines

Intersystem faults on such multiple-circuit lines can be caused by different factors, among others by broken conductors, line galloping due to wind influences or icicles, etc. Overcurrent and overvoltage stresses may occur, in consequence, in the lower voltage line, which should be removed by the respective power system protections systems. It is evident that the protection performance depends upon the current and/or voltage signals provided to the protection-inputs. Therefore the determination of current/voltage quantities, both in steady state and transient fault conditions is inevitable.

Transient voltages will be needed accurately in the area of high-speed distance protection and in the area of system insulation design. For any given fault condition there are various factors which influence the transient response by fault conditions. One very important point which emerges is that the sound- and the faulted phase can contain very significant traveling wave components. The magnitude of the transients voltage components are significantly affected by the magnitude of the zero-sequence system impedance. The overvoltage in the sound transmission line is represented as the superposition of the transients produced due the coupling parameters of both lines.

In the presented paper the extended fault the analysis for typical multi-circuit lines is shown. Various types of faults, line and power system parameters fault resistances etc. are taken into account.

Overvoltage in Transmission Line

Short-circuit faults occurring in high-voltage transmission lines will result in surge waves extending from the fault location till the ends of the fault line - the nodes, which are points of discontinuity. Multiple reflections at nodes cause transient appearance of high frequency components in the instantaneous voltages and currents waveforms. These components can be recorded on the ends of the line during faults easily. The ability to accurately determine the amplitude and frequency of these components in the past has allowed the idea of use these high-speed components in the algorithms for automatic protection systems [1, 2]. Rapid withdrawal from this trend as a result of many factors that may cause malfunction protection and locators based on the measurement of these components, however, cannot diminish interest in the consequences of their occurrence. Overlapping of reflected surge waves in the multi-wire systems gives rise to phenomena which can cause unnecessary action of protection system.

The investigation was made for the 400 kV transmission line and 220 kV working on the same supporting structures in the transmission system (as shown in Figure 1). The analysis was performed using the program MicroTran [3] with the line model with distributed parameters depend on the frequency.

The remaining part of system was replaced by equivalent (see Figure 2), for which the structure and parameter were determined by using standard methods for optimization [4, 5].

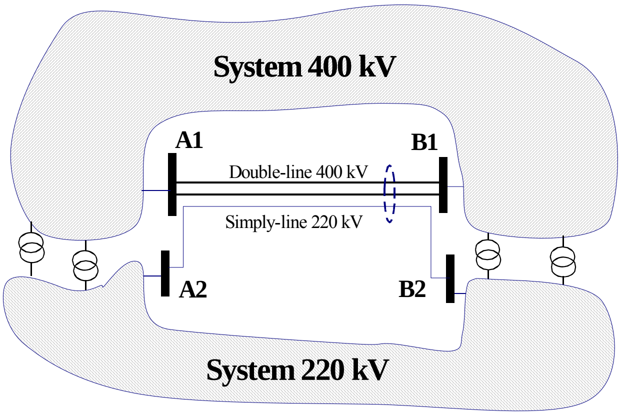

Fig.2. Stucture of investigated system

The model was verified by comparing the measurement results with the results of attempts to short-circuit calculations carried out for the same conditions. Surprisingly high accuracy of the measurement results allowed the use of numerical models in order to perform the calculations for the other fault conditions. The optimal parameters of equivalent system were obtained after about 100 iterations. It should be noted that for the analysis of transient phenomena in the areas of second (test stability, balance, etc.), the final replacement model can be given after only a few iterations. Verifiable analysis confirms the accuracy of models used [6].

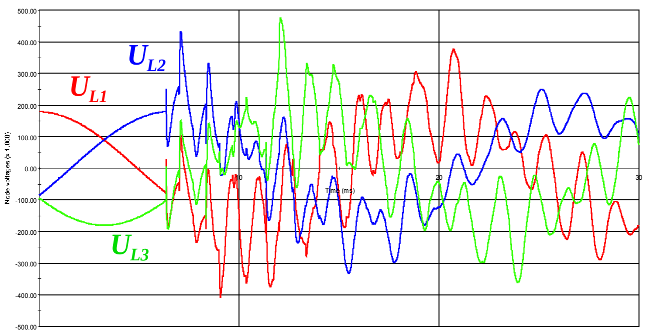

Fig.3.Voltage waveforms in 220 kV line (A2), during three-phase non-simultaneous fault at the end of 400 kV line (B1)

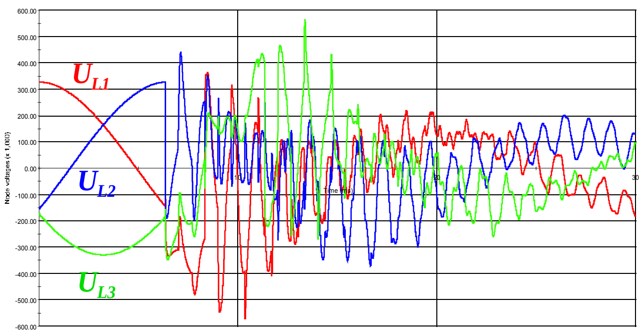

Fig.4. Voltage waveforms in 400 kV line (A1), during three-phase non-simultaneous fault at the end of 400 kV line (B1)

Transient phenomena occur in the "sound" lines as a consequence of short circuits occurring in other circuits operating on the same support structure, but with different voltage levels. These phenomena may lead to unnecessary cascaded disconnection of sound line. In addition, due to the fact that these circuits are connected to different system, the location of faults and their clearing may be very difficult.

Examples of voltage transients shown respectively, in Figures 3 and 4 have been calculated at the beginning of the line 220 kV and 400 kV (point A1 and A2), during three-phase non-simultaneous short-circuit at the end of a 400 kV line (point B1).

In the opposite case - that is, fault in the 220 kV line does not result in the overvoltages in the 400 kV line but only at 220 kV, what illustrate exemplary waveforms shown respectively in Figures 5 and 6.

The impact of individual parameters and operating conditions on the peak of the surge in the system during simultaneous faults is well developed in the literature. The conclusion of these results cannot be directly transferred to non-simlutaneous faults. The combination of delays closing phases in circuit braeker may result in overlapping of the high-frequency free components and the possibility of the creation of conditions conducive to the maximum value in each phase.

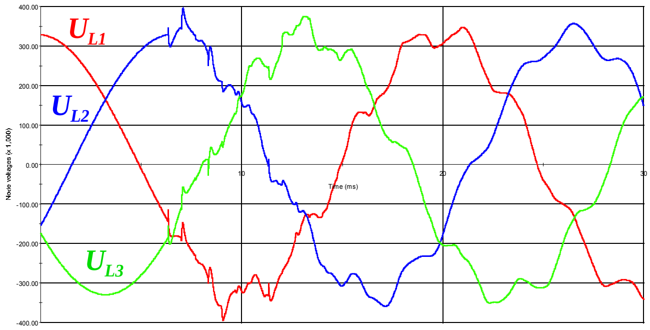

Fig.5. Voltage waveforms in 400 kV line (A1), during three- phase short-circuit at the end of 220 kV line (B2)

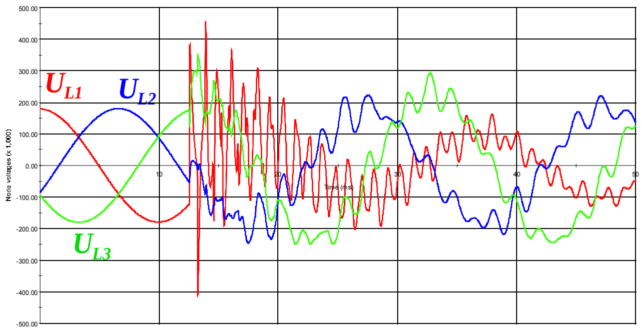

Fig.6. Voltage waveforms in 220 kV line (A2), during three-phase short-circuit at the end of 220 kV line (B2)

Correctness relating to simultaneous fault that the maximum overvoltages occur at the moment of maximum value of the faulted phases is not valid during non-simultaneous faults. This is due the fact that high frequency components are added to the base voltage value what causes that the relationship between components can significantly impact on the peak value of the resultant voltage.

The frequency of components is dependent on the location and type of circuit and is inversely proportional to the length of the line. For very short lines and the faults located close to the measurement point exists greater possibility that the maximum value component of the pulsations of higher amplitude will be added to the basic voltage. On the other hand, these components are attenuated more rapidly than during faults in the long lines.

Studies have shown a huge amount of factors that affect the rates surge, but often the change of individual parameters for a given system configuration does not cause a significant change in the values of these coefficients, and only change 'facts', such as the timing of the peak voltage during the ongoing transition process. For this reason, numerical analysis for determination of time delay closing phase, angle switching ranges, where there may be a maximum of overvoltages, is very tedious and time consuming. This is probably the reason for the total neglect of nonsimultaneous faults, while numerous studies transient. It is very surprising that exist the big number of publications according transient analysis of fault, with the mistaken assumption simultaneity of its creation.

Among other factors affecting the maximum value of the overvoltage are local and general phenomena. Local factors determine the general level of rates surge, which may occur in this system, are deterministic. These are:

- structure and parameters of the system. The main role have the parameters of transmission lines as well as power systems - mainly the relationship between zero and positive sequence impedance, and the resistance and reactance,
- the impact of the lad and operating conditions of the system (in normal mode) before the fault is negligible.

General factors are probabilistic:

- type of fault. During short circuit without earth, the high frequency components occur, giving rise to virtually only in the affected phase, in contradiction to short-circuit with the ground, in which the amplitude of components of the healthy phases may be larger than the in the phase affected during fault,
- the distance from fault. However, this is a factor associated indirectly with the local parameter, which is the length of the line. The time that 'needs' a surge wave to cross the road from the place of fault to the first point of discontinuity causing the reflection of the wave, determines the amplitude and damping time of frequency components,
- moment of short circuit. The maximum amplitude of the components are at the phase in which at time of fault the voltage reaches the maximum value. During non-simultaneous short circuit can cause inaccuracy of this statement. For example, in phase with delayed fault the components may be of substantial amplitude at the time of the voltage phase shift by zero (for simultaneous short-circuit there is the absence of the component under such conditions).

Intersystem Faults in Transmission Line

Very dangerous, although rare, are non-typical faults such as grounding wire or broken phase, which could affect the formation of surges in neighboring systems. As result of this multi-phase short-circuit may occur without or with ground. Very important is the fact that during such fault the extremely value of current occur - especially in lines with lower voltage. The short-circuit currents can have values much higher as compared to the short-circuit currents flowing in one system.

The results of simulation are compared for the extremely fault conditions, with faults close to voltage maximum (the worst cases from the point of view of overvoltage's) and faults close to voltage zero (the worst cases from the point of view of overcurrent).

The value of overvoltages can occur extremely high which is not allowed for the job of both lines. The voltage waveform in 220 kV transmission line are shown in Figure 7 during event: broken conductor in phase L3 of 400 kV line (point B1) touch to conductor in phase L2 of 220 kV line (point B2). It is evident that the momentary voltage in phase L3 of 220 kV line reaches even almost 4.5 times the value greater than the rated voltage.

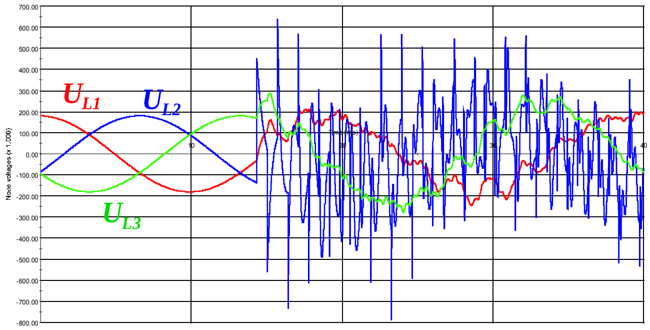

Fig.7. Voltage waveforms in 220 kV line (B1), during intersystem two-phase short-circuit ($L3_{400}$+$L2_{220}$) at the end of lines (A2+B2)

Even in the 400 kV transmission line during intersystem faults the overvoltages can occur. It is evident in Figure 8, where are results of simulation of voltage waveforms at the beginning of 400 kV line (A1) during intersystem fault: phase L3 of 400 kV line with L2 of 220 kV line. The maximum value of voltage can occur 1,8 times the rated voltage.

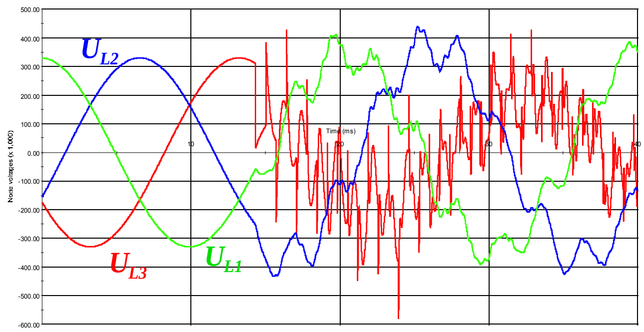

Fig.8. Voltage waveforms in 400 kV line (A1), during intersystem two- phase short-circuit ($L3_{400}$+$L2_{220}$) at the end of lines (A2+B2)

More dangerous is value of currents flowing during intersystem faults. The current waveforms during intersystem fault between phase L3 in 400 kV line and phase L1 in 220 kV line at point A2+B2, are shown in Figure 9. Transient current are plotted for each phase in both systems at the beginning of lines and for short-circuited conductors at fault location. It is evident than the amplitude of current can achieve extremely value which can be very danger first of all for 220 kV line and devices connected to this line.

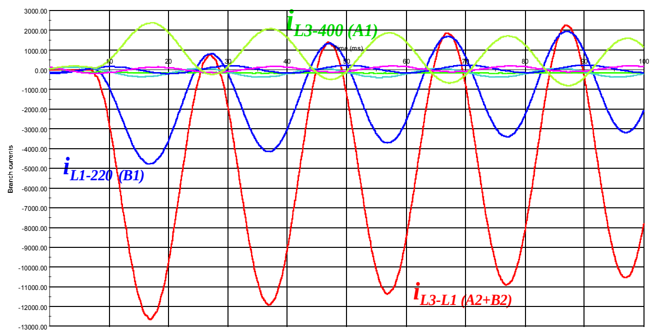

Fig.9. Current waveforms in both 400 kV (A1) and 220 kV lines (B1), during intersystem two-phase short-circuit ($L3_{400}$+$L1_{220}$) at the end of lines (A2+B2)

Final Remarks

The increasing number of multiple voltage transmission lines enables efficient management of routes and increase the power transferred over long distances. However, there is a danger of the occurrence of the high-value overvoltages due to coupling of electromagnetic interference in the 'sound' lines. The worst case could be a intersystem fault - a break in the wire and the short of the line with a different voltage level. Simulation research has shown that this phenomenon is very dangerous both for the job of line and for how consistent the possible failure of the system - blackouts.

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