THE EFFECT OF THE CAPACITANCES ON THE WAVE PHENOMENA IN POWER TRANSMISSION SUBSTATIONS

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1. Introduction

The importance of the analysis of the overvoltages due to lightning surges is increasing with the increase of the voltage level of the transmission systems. These overvoltages cause damages in the apparatuses and thereby they are injurious to the reliability of the network. With the knowledge of the arising overvoltages a proper overvoltage protection can be chosen. The increase of the voltage levels results in an increase of the dimensions of the power transmission substations, therefore from the aspect of the occurring residual voltages, the wave reflections within the substations must not be neglected. The transient phenomenon going on as superposition of elementary waves can be influenced by the capacitances of the apparatuses in the substations. The determination of the overvoltages taking into consideration the busbar branches and the capacitances of the apparatuses needs the application of a computer for the calculations.

In this study, transient phenomena will be analysed by means of digital computer method. The effect of the capacitance of the apparatuses on the shape and magnitude of the overvoltages in substations will be shown, numerical results will be given for the case of a 400 kV substation. The results show that from the point of view of the surge protection it is desirable to carry out exact calculations for every individual case in consideration of the substation topology and the capacitance of the apparati.

The results are obtained by using a digital computer program based on Bergeron's method. The program was written in ALGOL computer language. The computations were carried out in the computing Centre of the Research Institute of Electric Energy Industry (VEIKI), on a RAZDAN-3 computer, the diagrams were obtained by using an off-line plotter.

2. The calculation method

The digital computer program used in this study for the analysis of wave reflections in substations, is applicable for the calculation of transient phenomena on any looped network of N node. The network treated by the program is supposed to be built up of distributed parameter lines with lumped resistive shunt elements in the nodes. The program calculates the instantaneous values of the node voltages and the branch currents for each time step. The algorithm permits to consider an incident wave of arbitrary time function by using a current generator simulation.

For choosing the time step of the computation, several aspects have to be taken into account. On the one hand, the time step Δt must be small enough to follow the form of the incident wave with a sufficient accuracy, and the length corresponding to the time Δt has to be the larger common quotient of the length of the lines in the network studied with sufficient accuracy as well. On the other hand, by decreasing the time step Δt both the needed computer storage capacity and the computation time increase.

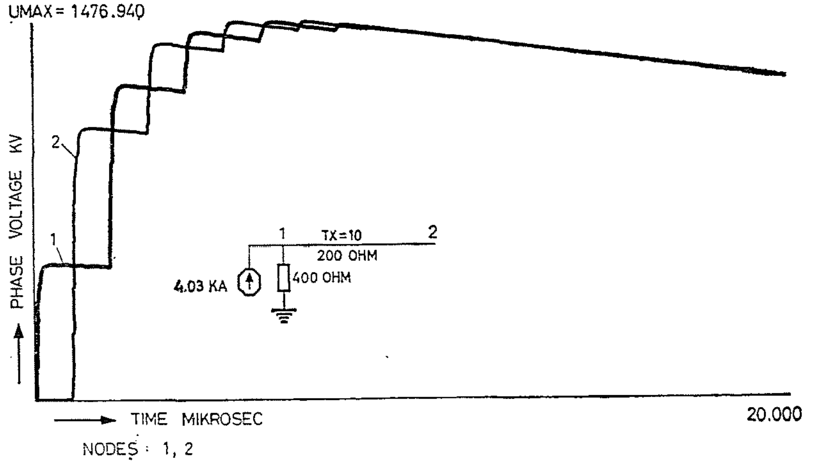
In this study the effect of the capacitance of the apparatuses was taken into consideration. The lumped capacitances were dealt with as distributed elements transformed to short lines. The smaller the length of the equivalent line, the higher is the accuracy of this method. The length of the substituting line must be necessarily smaller than that of the adjacent lines. So it is obvious to take the length of the substituting line equal to the length corresponding to the computation time step Δt. The choosing of the time step Δt is influenced by this circumstance, too. The line substituting the lumped capacitance can be characterized by a characteristic impedance

$$Z = \frac{\Delta t}{C} .$$

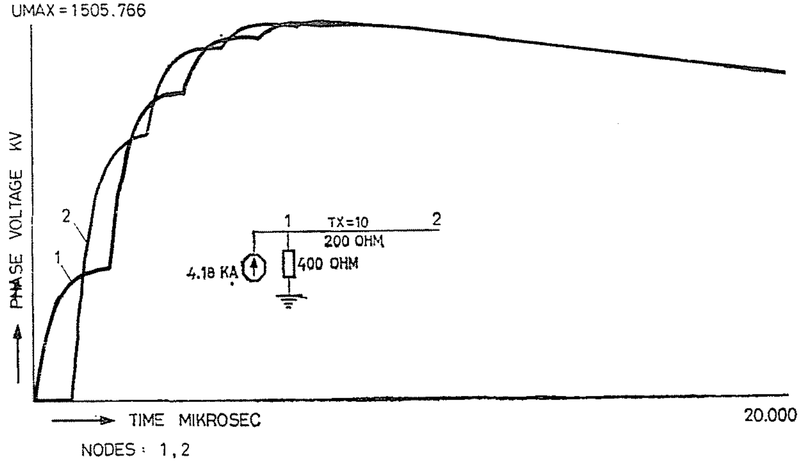
To improve the calculation accuracy, Δt has to be chosen for a small value, so this characteristic impedance will be small as well. This fact is in accordance with the theory of the transformation of lines into lumped elements [3]. According to this, a line behaves in a transient phenomenon as a capacitance if its characteristic impedance is much lower than that of the adjacent lines (provided that its length is shorter than that of the adjacent lines).

3. Analysis of basic cases

As a first step of the study of the surge phenomena in substations, some simple cases concerning the effect of the capacitances were analysed. An incoming wave of 800 kV crest was applied and was simulated by a double exponential time function. The surge was supposed to arrive from a line of infinite length and of 400 ohms characteristic impedance in the substation busbar of 300 m length having a characteristic impedance of 200 ohms. The overvoltages were calculated without capacitances (Fig. 1), with a capacitance in the junction point (Fig. 2) and with a capacitance on the end of the busbar (Fig. 3). The capacitance considered was 4000 pF corresponding approximately to the value of a 400 kV voltage transformer capacitance. The computations were made for different front times and different values of time to 1/2 maximum



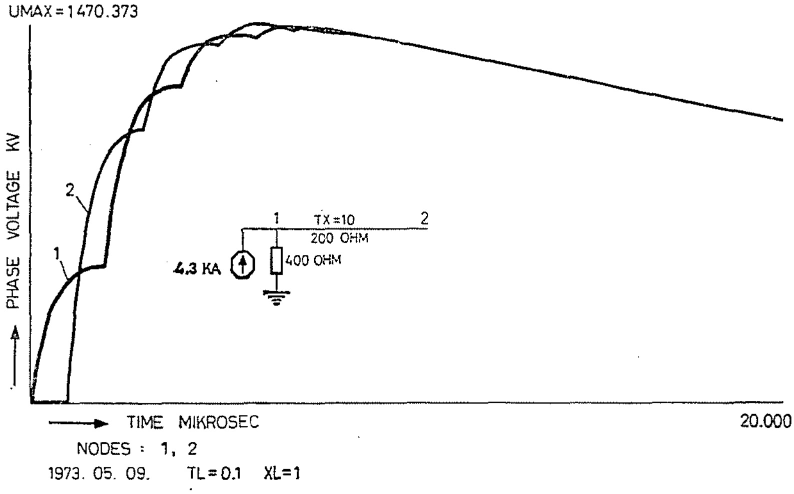
1a)



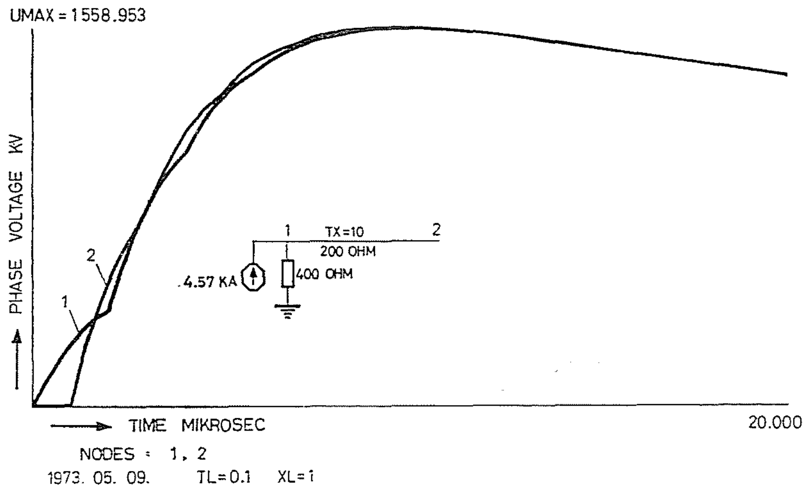
1b)

voltage: 0.1×50 μs, 1×50 μs, 1×30 μs, 3×50 μs waves were considered. The time step Δt was chosen to be 0.1 μs (Figs 1 to 3) being the travel time of a 30 m long line. It is 1/10 of the length of the busbar analysed. This rate was modified to a rate of 1/20 for having a control over the accuracy (Fig. 4).

In Fig. 1, the superposition of the elementary waves is to be seen. The length of the busbar is 300 m, so 2 μs is the double travel time of this line, and



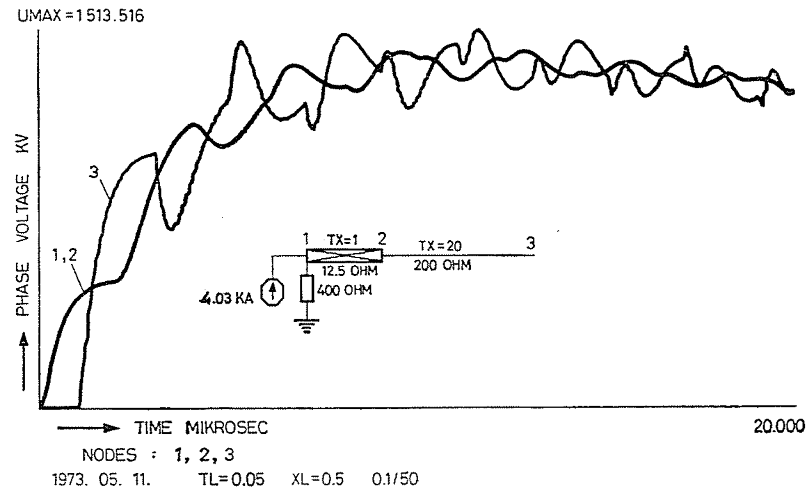
1c)



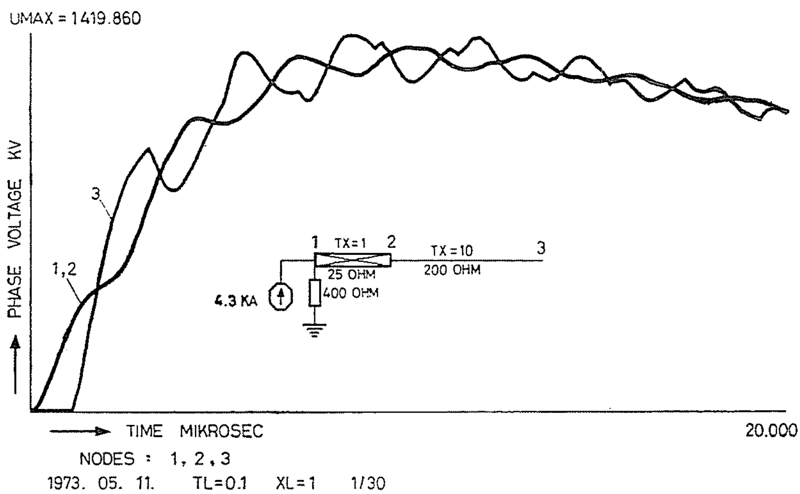
1d)

Fig. 1. Overvoltages in substation considered by simplified scheme without capacitance with different incoming waves: a) 0.1×50 μsec; b) 1×50 μsec; c) 1×30 μsec; d) 3×50 μsec

the superposition occurs in every 2 μs according to the reflexion coefficient of $\varrho = 1$ at the open end. In the case of 0.1×50 μs wave the reflected wave arriving from node 2 is superposed on the decreasing tail of the incident surge. The highest value is obtained in the case of a 3×50 μs wave, when the reflected wave was superposed on the front of the incident surge, near to the crest. The peak value of the first step of the resulting wave in node 1 is about 500 kV, which corresponds to the refraction factor $\beta = 0.66$. The front of the 0.1×50 μs surge is not quite smooth, not because of the character of the physical phenomenon but of the drawing technics of the plotter used.



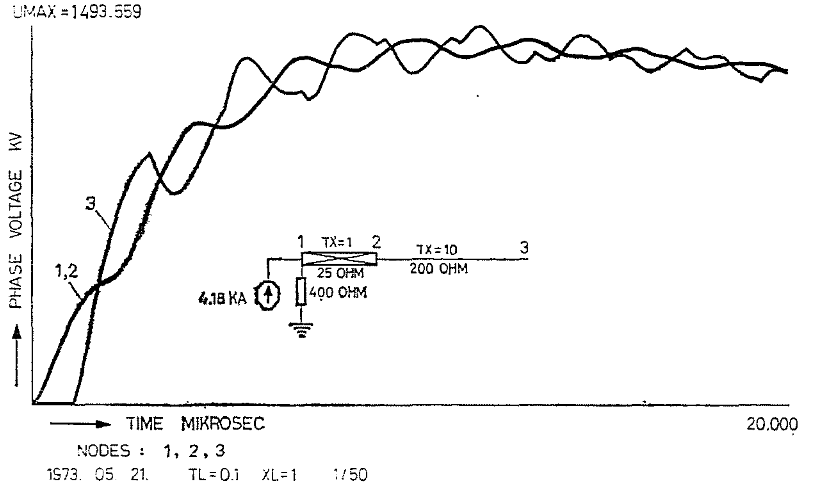
2a)



2b)

Comparing the curves of Fig. 1 with that in Fig. 2, it is seen that the wave phenomenon is modified by the presence of the capacitances:

- oscillations appeared;
- the overvoltage is lower in the most part of the time interval analysed than that without capacitance;
- the average rate of rise of the resulting wave decreased;
- the initial part of the front flattened.



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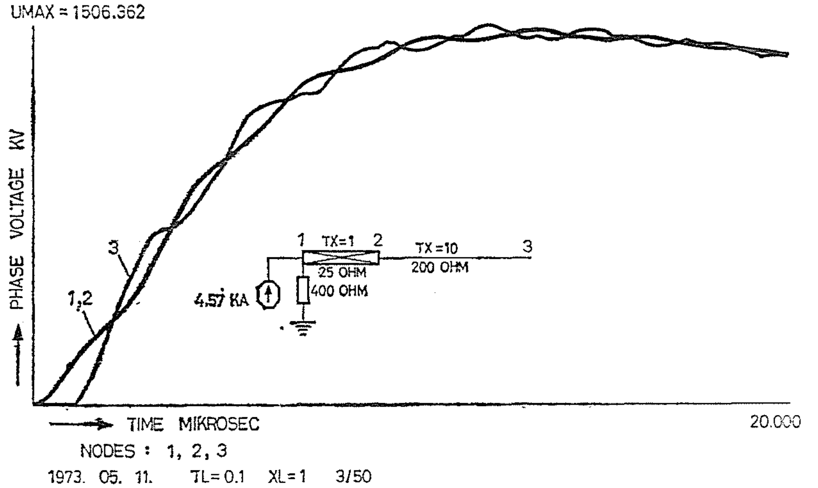


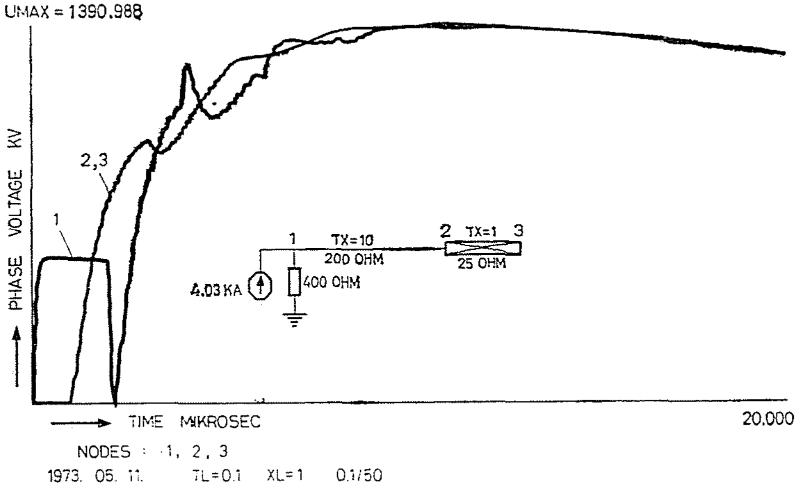
2d)

Fig. 2. Overvoltages in substation considered by simplified scheme with capacitance at the junction point. Incoming waves: a) 0.1×50 μsec; b) 1×50 μsec; c) 1×30 μsec; d) 3×50 μsec

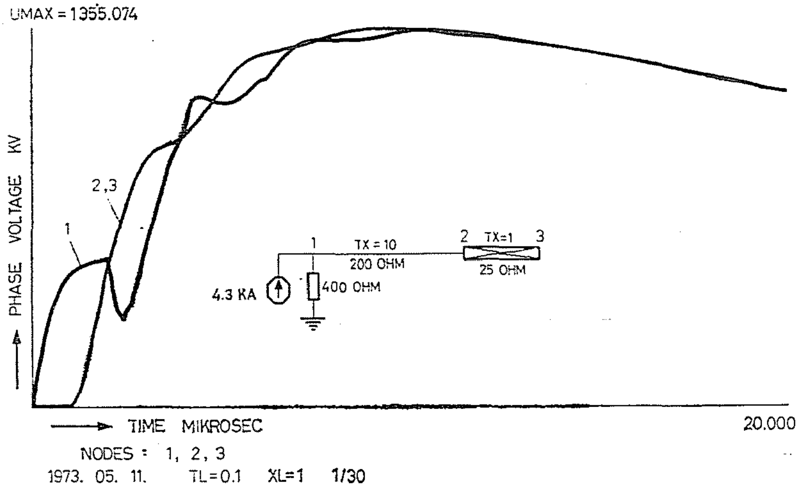
The frequency of the dominant oscillation is equal to $1/4\tau = 1/4\ \mu s$. In Fig. 2a it is seen that by taking the capacitances into consideration higher peak values may occur than that of the peak value in Fig. 1, in spite of the fact that the average value is lower than that of the case in Fig. 1a. The amplitude of the oscillations depends:

— on the rate of the front time of the incoming wave to the travel time of the line;

— on the characteristic impedances of the network.



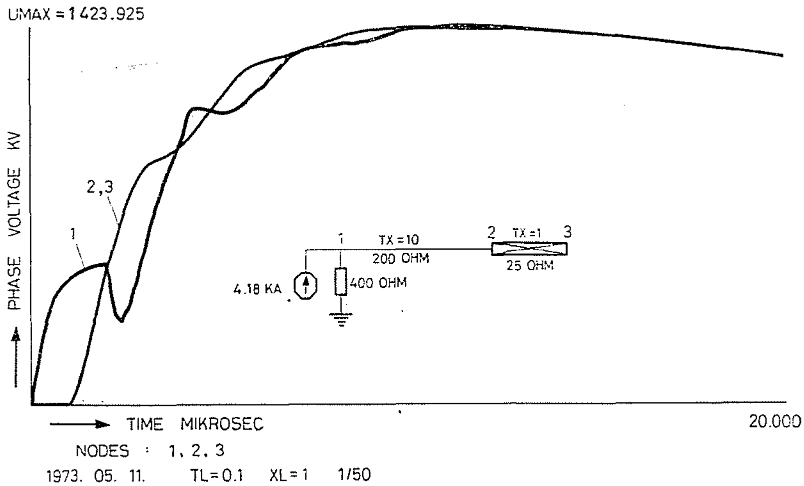
3a)



3b)

The statements above are valid for the case of Fig. 3 where the capacitance is on the end of the line, the average value of the overvoltage decreased more than in the previous cases. The maximal values are lower than in the case without capacitance.

The voltages on both ends of the equivalent line (nodes 1 and 2) are coincident in the figures, proving that the length of the equivalent line was chosen for a value low enough (0.1 μs). This was also proved by the control



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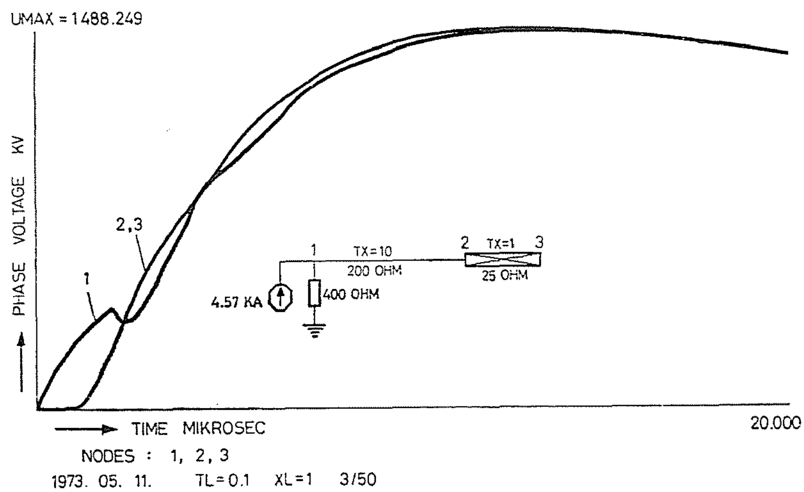
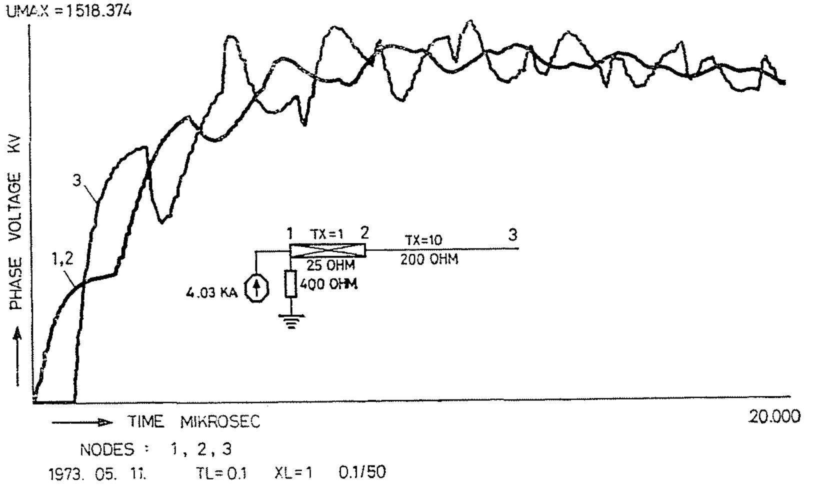
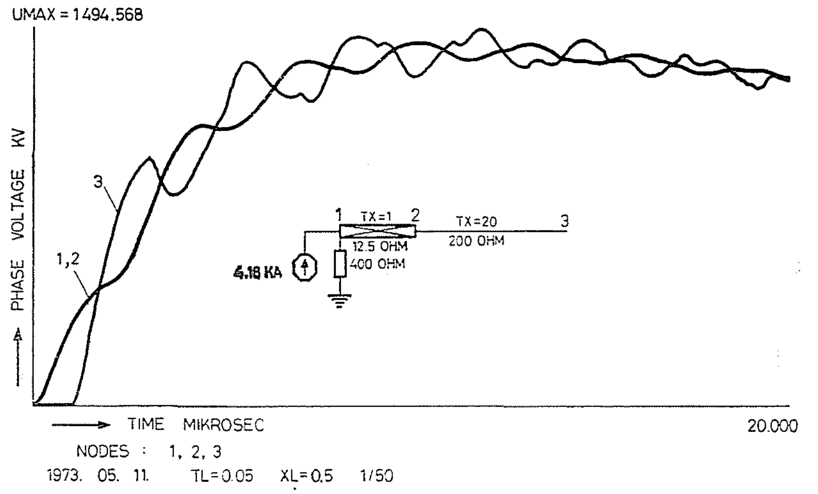


3d)

Fig. 3. Overvoltages in substation considered by simplified scheme with capacitance at the end of the busbar. Incoming waves: a) 0.1×50 μsec; b) 1×50 μsec; c) 1×30 μsec; d) 3×50 μsec



a)



b)

Fig. 4. See Fig. 2a and b but calculated with increased accuracy

calculation with a lower time step (0.05 μs) shown in Fig. 4a (0.1×50 μs) giving an incident surge of identical peak and shape with that in Fig. 2a only the curves are smoother. The curve in Fig. 4b (1×50 μs incoming wave) is quite identical with that in Fig. 2b.

4. Analysis of a given substation

In the following the analysis results on the overvoltages of the 400 kV substation Göd will be given. The incoming wave was supposed to arrive from a line of infinite length and to be a 1×50 μs wave with a crest of 900 kV corresponding to the surge flashover voltage of the overhead line insulators. The topology of the substation analysed is shown in Fig. 5. The characteristic impedance of the overhead line is 347 ohms, that of the busbar is 365 ohms and that of the connections to the apparatuses is 336 ohms (they are supposed

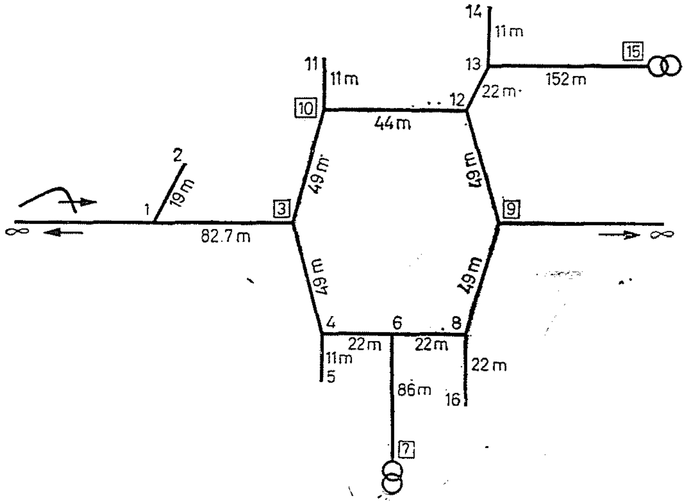


Fig. 5. Topology of the substation analysed

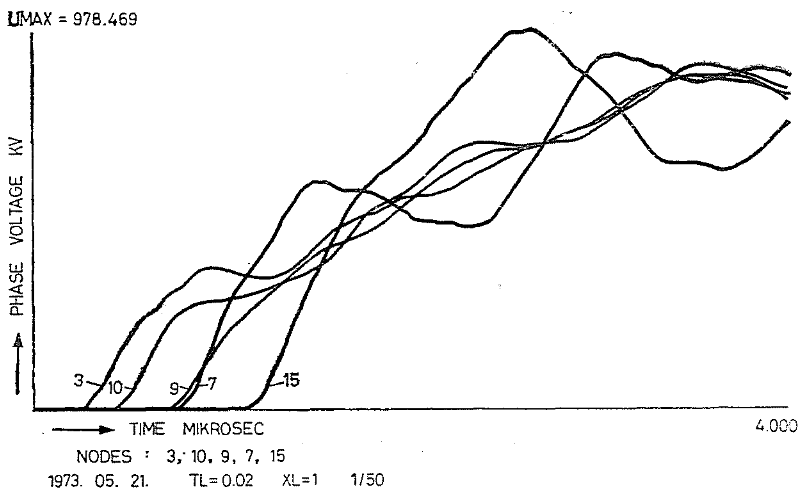


Fig. 6. Node voltages in the substation of Fig. 5 without the consideration of capacitances

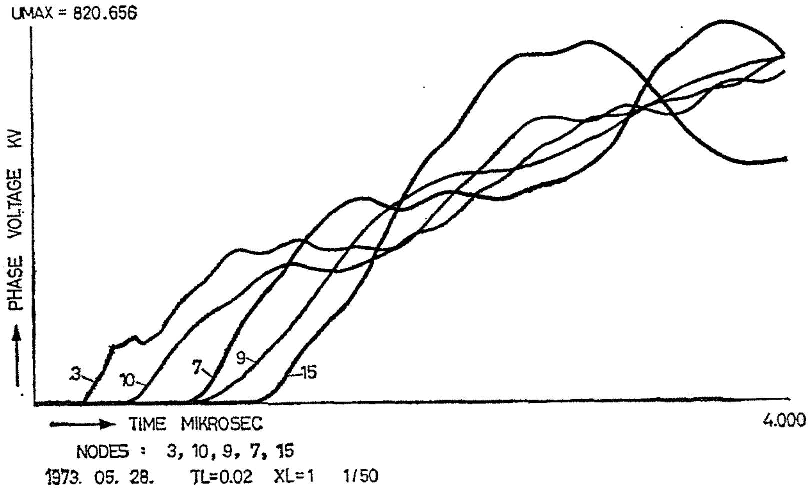


Fig. 7. Node voltages in the substation of Fig. 5 with the consideration of the capacitances of apparatuses

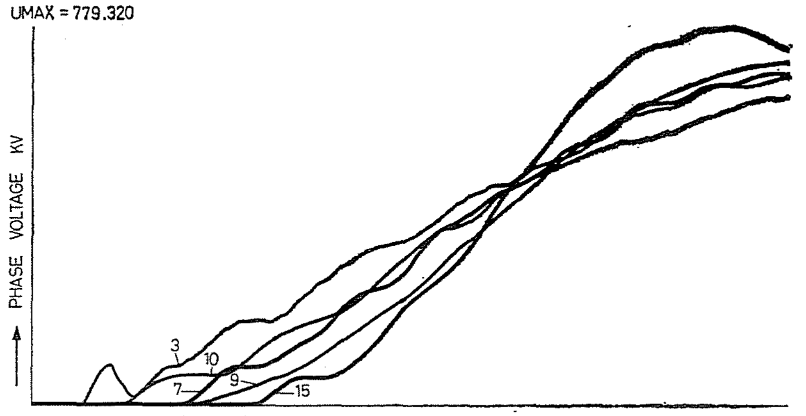


Fig. 8. Node voltages in the substation of Fig. 5 with the consideration of increased capacitances of apparatuses

to be horizontal throughout). The substation is of polygon connection having four apparatuses in each branching: two disconnecting switches, a current transformer and a circuit breaker. The capacitance of these four elements was considered as a single concentrated capacitance of 1200 pF because of computer storage problems. So in the calculation the characteristic impedance of the equivalent line was $Z = 16.7$ ohms at the used time step of 0.02 μs.

In Fig. 6 the voltages in the substation nodes are seen for the case without taking into consideration the capacitances. The numbers of the nodes given on the curves correspond to the topology of Fig. 5. The highest voltages occurred at the transformers (nodes 7 and 15).

The curves in Fig. 7 were computed and plotted with taking into consideration the capacitances of the circuit breaker, disconnecting switches and current transformer. As it is seen on the curves, here too the highest voltage values occur at the transformers (nodes 7 and 15), but the maximal value is lower by about 16 per cent. The initial part of the curves flattened, the average rate of rise decreased and the imaginal average curves were lower than that of the curves in Fig. 6. Taking into consideration the capacitance of the voltage transformers in the nodes modifies in the same manner the node voltages, so there is a reduction of 20 per cent in the maximal values of the voltages compared with the curves in Fig. 6.

Acknowledgements

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Summary

The study deals with overvoltages on high voltage power transmission networks due to lightning surges. The effect of substation capacitances on the wave phenomena in substations was analysed by means of a digital computer program based on Bergeron's method.

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