# Special Features of Transient Processes at Ground Faults in Long-Distance Transmission Lines

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***Abstract*--Mathematical model for analysis of transient processes at ground faults in the ungrounded long-distance transmission line is developed. Calculations show that along the transmission line there are areas having overvoltage ratios more than in the fault area. Results are in good agreement with experimental data obtained at ground fault experiments in different areas of the long-distance transmission line.**

***Index Terms*--Long-distance transmission lines, overvoltage level, single phase-to-ground fault, ageing of transformer magnetic core, harmonics in fault current.**

## I. Introduction

USUALLY, 35 kV power transmission lines are long-distance lines having tens or even hundreds kilometers lengths. During the operation of an overhead transmission power line at single phase-to-ground faults, damages of 35 kV circuit breaker bushings are observed. For example, for the period of last 24 years there were 25 damages of circuit breaker bushings on the 161-km-length transmission power line connected Sosnovka Substation and Orlovskaya Substation owned by KirovEnergo (KirovEnergo is a regional branch of Joint Stock Company “Interregional Distribution Grid Company of Centre and Volga Region”). Special features of transient processes in long-distance transmission lines are not fully covered by technical literature and publications. In the present paper, we make an attempt to clarify this issue.

In summer and autumn of 2011, we carried out experiments on the transmission power line connected Sosnovka Substation and Orlovskaya Substation. Oscillography of processes at single phase-to-ground faults (arcing and solid) was done; a computer model of 35 kV network is developed using EMTP (ElectroMagnetic Transients Program); methods of detection of the transformer having an aged magnetic core is proposed.

The model includes:

- The model of equivalent generator
- The model of supply transformers
- The model of the transmission power line
- The models of intermediate substations (i.e. power takeoffs)

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For more detailed investigation of transient processes, non-linear saturation curves of magnetic cores of transformers supplying the transmission line and transformers of intermediate substations are taken into account. When studying transient processes in long-distance transmission lines, wave processes and distributed and frequency dependences of main line parameters should be considered. For simulation, we choose JMarti transmission line model which most closely describes frequency dependence of main line parameters [1].

## II. Verification of the Model

The main problem at the development of the model is its debugging and verification [2]. The model is verified by the comparison of the curves of voltage distribution under normal operating conditions obtained from the model and from investigations on operational power lines. These curves are presented in Fig. 1. Having a transmission line of more than 100 km length and operating voltage of 35 kV, decreasing of voltage with increasing of the line length is observed. For example, real operating voltage at Sosnovka Substation is maintained to be 42 kV, while real operating voltage at Orlovskaya Substation is about 36.6 kV. The distance between two substations, as mentioned above, is 161 km.

Capacitance currents recorded at artificial single phase-to-ground faults are compared with calculated capacitance currents (see Fig. 2). Difference between recorded values and calculated values is no more than 10% that explained by surrounding environment near the transmission line and associated different line heights.

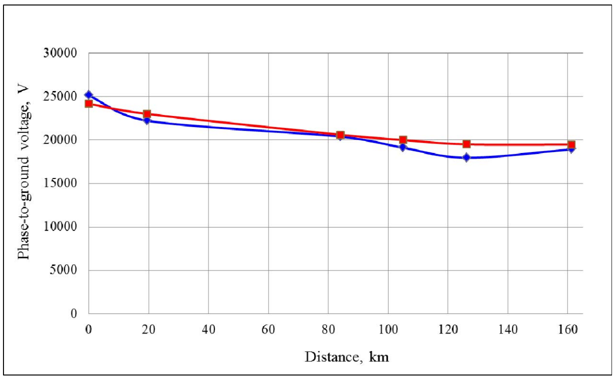


Fig. 1. Calculated (red curve) and recorded (blue curve) voltage distributions along the transmission line obtained from the model and from investigations on operational power lines.

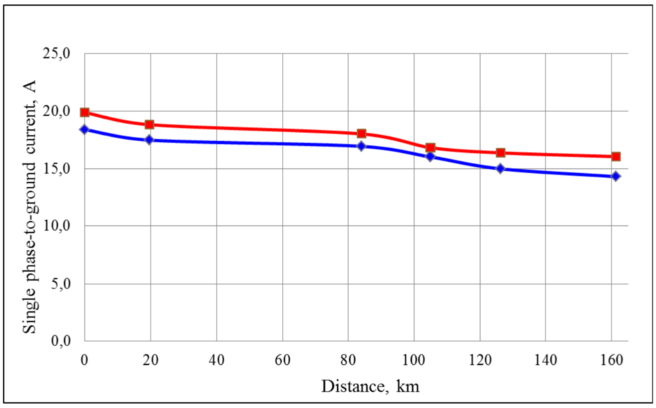


Fig. 2. Capacitance current distributions along the transmission line obtained from the model (red curve) and from investigations on operational power lines (blue curve)

## III. Transient Processes in the 35 kV Long-Distance Transmission Line at Solid Single Phase-to-Ground Fault

Measurements show the character of transient processes along the transmission line moving from a fault place. Figs. 3–5 present oscillograms of phase-to-ground voltages at artificial solid single phase-to-ground fault at Astrakhanovo Substation. Oscillography was done in a fault place and in the distances of 60 km and 105 km from a fault place.

Modeling in EMTP shows that processes at single phase-to-ground faults are similar to real oscillograms shown in Fig. 3–5 (see Figs. 6–8).

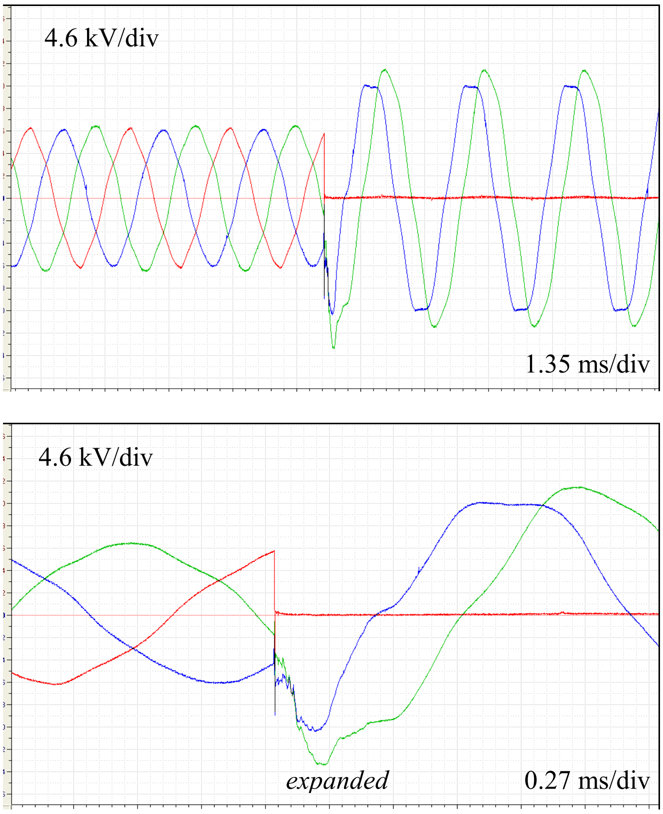


Fig. 4. Real oscillograms of phase-to-ground voltages recorded at Astrakhanovo Substation at single phase-to-ground fault at Astrakhanovo Substation.

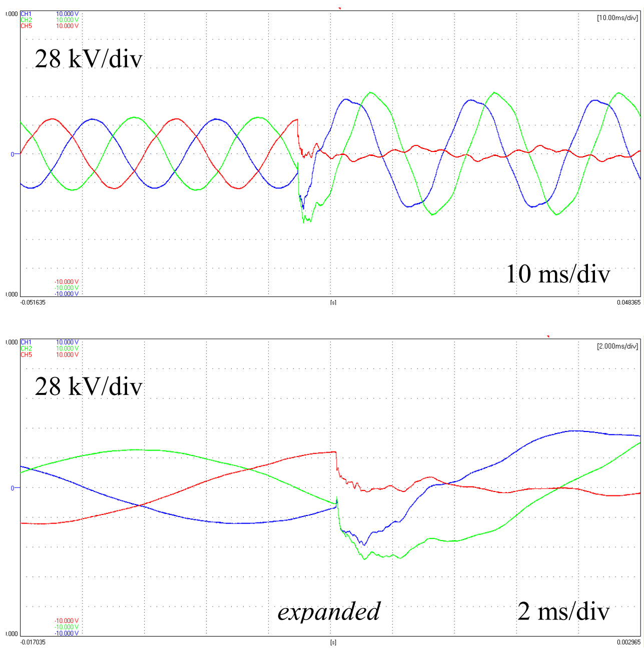


Fig. 3. Real oscillograms of phase-to-ground voltages recorded at Sosnovka Substation at single phase-to-ground fault at Astrakhanovo Substation.

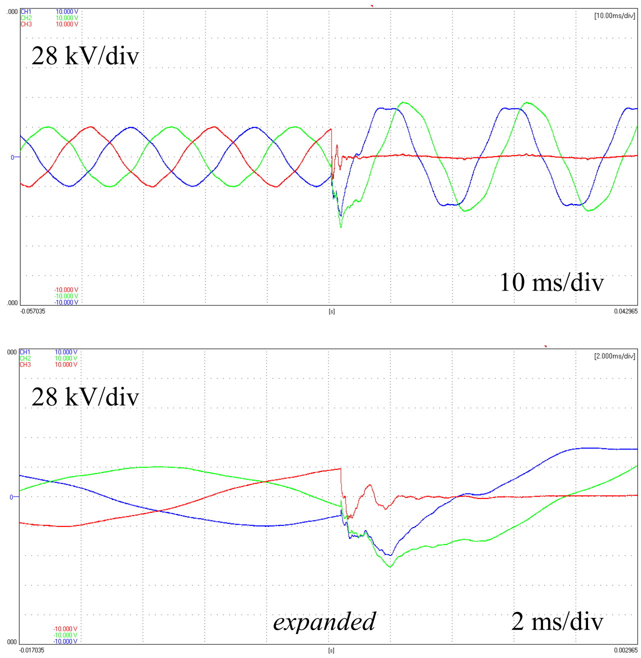


Fig. 5. Real oscillograms of phase-to-ground voltages recorded at Orlovskaya Substation at single phase-to-ground fault at Astrakhanovo Substation.

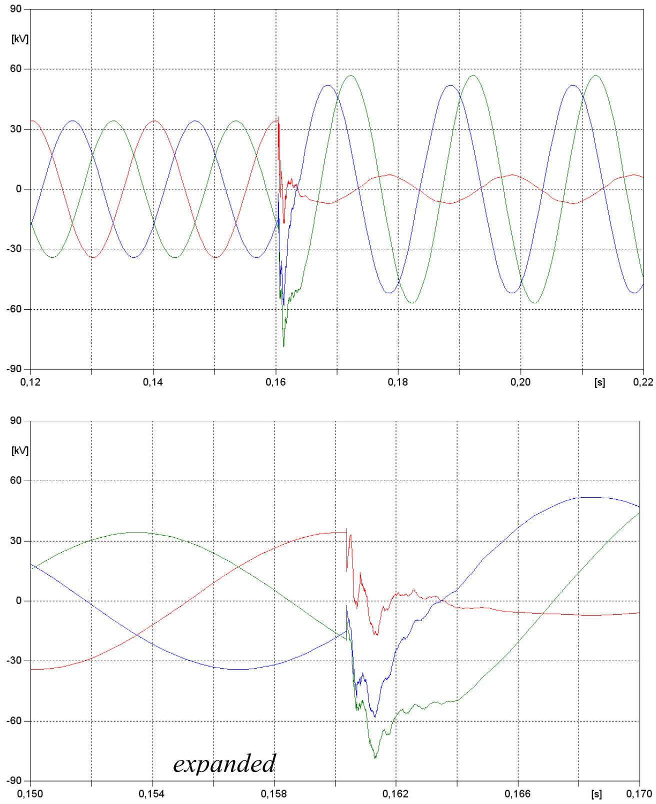


Fig. 6. Calculated oscillograms of phase-to-ground voltages recorded at Sosnovka Substation at single phase-to-ground fault at Astrakhanovo Substation.

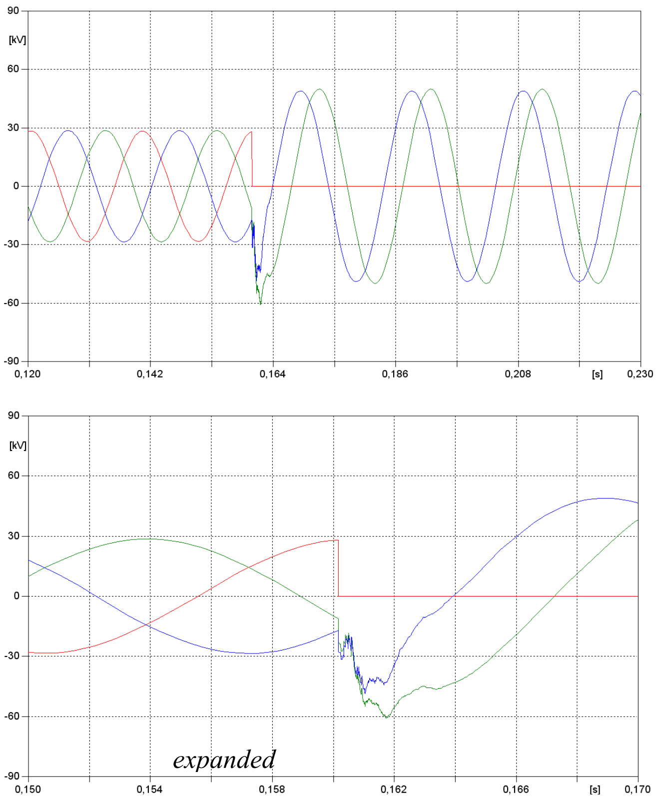


Fig. 7. Calculated oscillograms of phase-to-ground voltages recorded at Astrakhanovo Substation at single phase-to-ground fault at Astrakhanovo Substation.

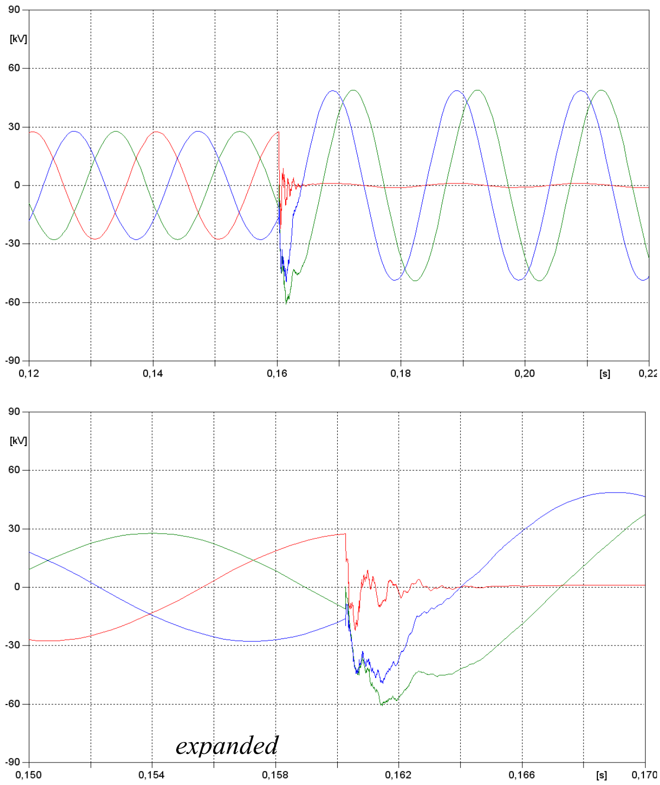


Fig. 8. Calculated oscillograms of phase-to-ground voltages recorded at Orlovskaya Substation at single phase-to-ground fault at Astrakhanovo Substation.

During calculations, we found out that overvoltage levels at solid ground faults depend on the distance between a fault place and a place of oscillography. Similar dependence is obtained from the model. Fig. 9 presents overvoltage levels moving from a fault place at Astrakhanovo Substation. Overvoltage levels increase with the move from a fault place that depends on changing of inductances and capacitances along the transmission line. We made an artificial ground fault at Astrakhanovo Substation at the distance of 89 km from the beginning of the line. Overvoltage level at Sosnovka Substation was 2.11, while overvoltage level at the end of the line at Orlovskaya Substation was 2.06. After that, we made an artificial ground fault at the beginning of the line. Overvoltage level at the end of the line reached 2.71.

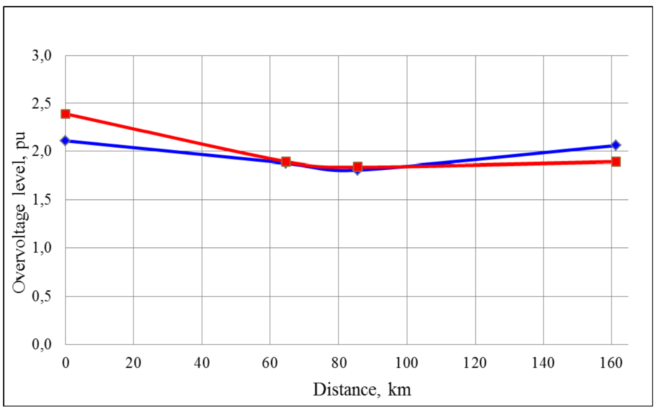


Fig. 9. Overvoltage levels along the transmission line at solid single phase-to-ground fault at Astrakhanovo Substation calculated from the model (red curve) and recorded during investigations on operational power lines (blue curve).

For prevention of dangerous consequences of ground faults, ungrounded networks should be redesigned into high-resistance grounded networks. For long-distance transmission lines, faults outside the protection area of a resistor are possible to happen. For choosing the right place of resistor installation, modeling of ground faults in various points of the transmission line is done. According to calculations, two 2000 Ω resistors were installed at the beginning of the line at Sosnovka Substation and at the distance of 126 km from the beginning of the line at Kilmez Substation.

## IV. Evaluation of Ageing of Transformer Magnetic Core

Fig. 10 presents real oscillograms of currents recorded in various points of the line at stable ground faults, while Fig. 11 illustrates calculated oscillograms.

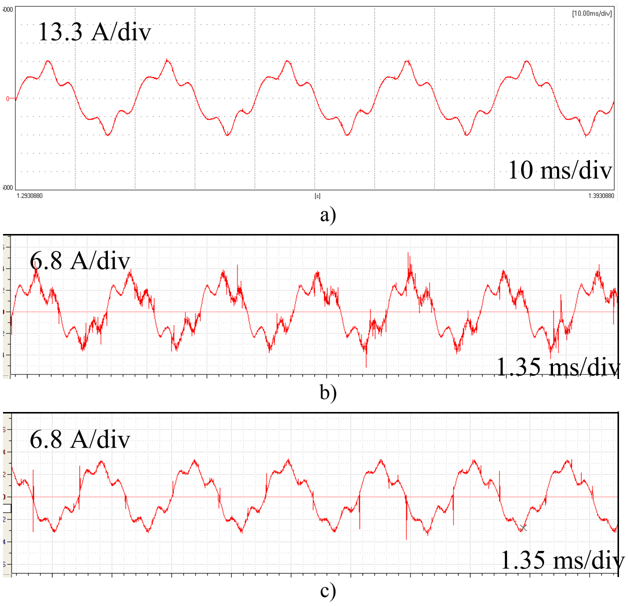


Fig. 10. Real oscillograms of single phase-to-ground currents recorded in various points of the transmission line: a) Sosnovka Substation; b) Satnur Substation; c) Kilmez Substation.

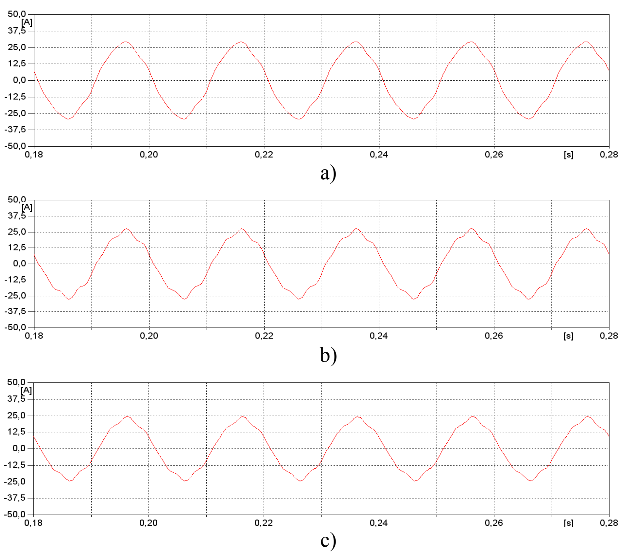


Fig. 11. Calculated oscillograms of single phase-to-ground currents in various points of the transmission line: a) Sosnovka Substation; b) Satnur Substation; c) Kilmez Substation.

Based on the analysis of harmonic composition of single phase-to-ground current, we make a hypothesis that somewhere there is a transformer with aged magnetic core. Most transformers have been operated for more than 20 years. During their operation, transformers are continuously exposed to mechanical and thermal stresses that can result in ageing of transformer magnetic cores and associated deformation of their saturation curves [3]. Transformers of the first intermediate substations are operated under higher than rated voltages that influences on harmonic composition of single phase-to-ground current [4].

For analyzing the influence of transformer magnetic core ageing on harmonic composition of single phase-to-ground current, we did calculations and obtained dependences of harmonic components of single phase-to-ground current on points of ground faults (see Fig. 12). Dependences are plotted in Fig. 12 for the most significant harmonic components (in % of the first 50 Hz harmonic).

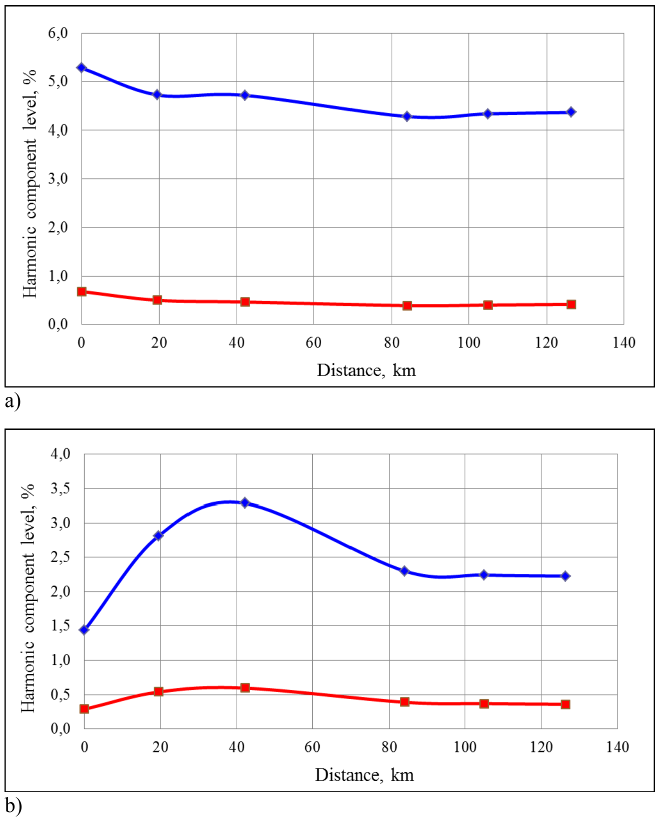


Fig. 12. Harmonic composition of calculated (red curve) and recorded during experiments (blue curve) single phase-to-ground current in various points of the transmission line: a – 250 Hz harmonic; b – 350 Hz harmonic

Based on the analysis of harmonic composition of single phase-to-ground current, we found out that a transformer with aged magnetic core is installed at Satnur Substation.

## V. Conclusions

1. Dependence of overvoltage levels on the distance from a fault place is shown.
2. Efficiency of resistance grounding inside the protection area of the resistor is evaluated.
3. For overvoltage limitation, neutral grounding through two 2000 Ω resistors with the distance between them of 120 km is implemented.

4. Analysis of harmonic composition of single phase-to-ground current allows detection of a transformer with aged magnetic core.

## VI. References


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## VII. Biographies

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