Application of Program Packages EMTDC and Matlab in the Analysis of Impact of Neutral Point Operating Regime on the Magnitude of Touch Voltage

Nadil Berbić, Rizah Memišević, and Jože Voršič, *Member, IEEE*

***Abstract*—This paper introduces a method for power system modeling during the earth fault. The possibility of using this method for selection and adjustment of earth fault protection is pointed out. The paper also contains the comparison of results achieved by simulation with the experimental measurements.**

***Index Terms*—Earth fault, electromagnetic transients EMTDC, Matlab, touch voltage.**

I. INTRODUCTION

ELECTROMAGNETIC transient phenomena that occur in electric power networks during an earth fault have theoretically already been analyzed in detail.

Nevertheless, the problem of dangerous touch voltage during the transient process still remains an open question, as well as the impact of the method of earthing and the earthing resistance in medium voltage network on this voltage. The current engineering practice is to select and size the earth electrode on the basis of an analysis of steady-state fault currents. These magnitudes are obtained on the basis of analytical or numerical solutions, based upon the steady-state analysis.

The steady-state analysis of the earth fault cannot provide a realistic insight into the entire electromagnetic transient phenomenon. This is why have the authors of the present paper, on the basis of an analysis of the actual network, generated simulation systems, and performed simulations for the 6-kV part of the network.

II. DESCRIPTION OF EXPERIMENTAL SYSTEM

Experimental measurements have been performed in a 6-kV network of the surface mine "Gračanica" in Gacko. Fig. 1 shows a simplified system diagram of the GTS-35/6 kV-5 × 4-MVA network of the mine, presenting the section of 6-kV network in which the measurements have been performed. A direct, "purely metal" earth fault is presented in the Section VI of this paper. During the measurements, a galvanic separation of other four MVA transformers has been secured. Thus, according to Fig. 1, only the transformer bay B1 supplying the measured part of the network, and the transformer bay A1 supplying the measurement equipment have been in operation. This has been necessary to secure an independent supply of measurement equipment and consequently an impact of deliberately created earth fault on the accuracy of measurement. Fig. 2 shows a single-line system diagram of 6-kV switchgear system that is supplied through the transformer bay B1. The switchgear consists of one incoming feeder, one measurement unit, one low-voltage functional unit, and five outgoing feeders.

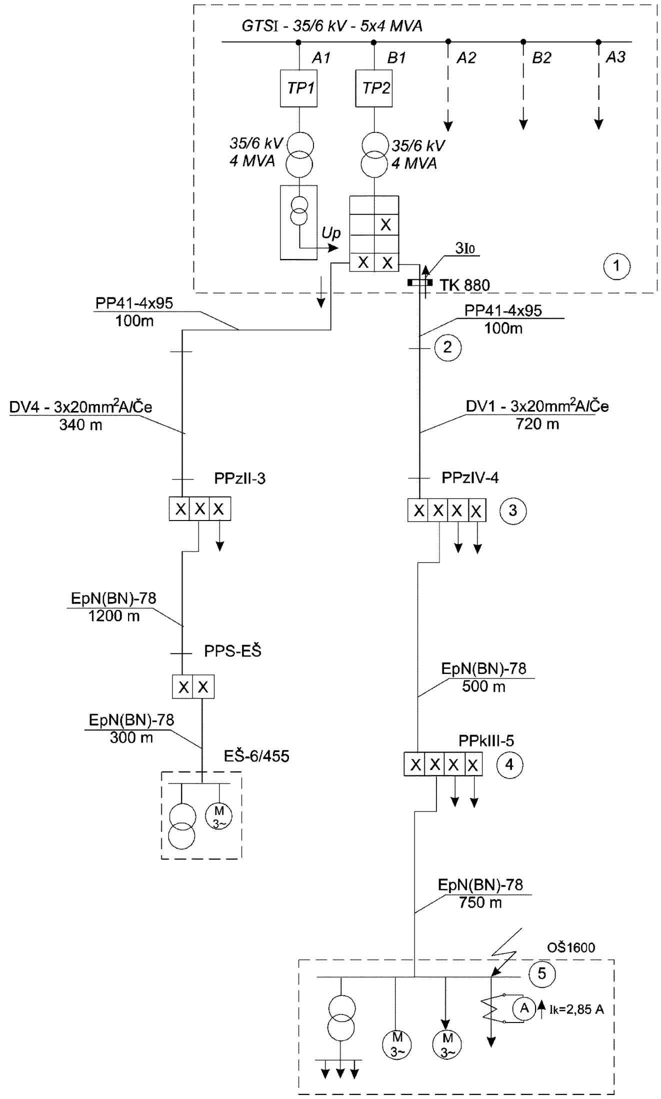


Fig. 1. Simplified system diagram of 6-kV network.

Manuscript received February 27, 2003. Paper no. TPWRD-00087-2003.

N. Berbić is with the Faculty of Mining and Geology, University of Tuzla, Tuzla, Bosnia and Herzegovina (e-mail: bnadil@untz.ba).

R. Memišević is with the Faculty of Electrical Engineering, University of Tuzla, 75000 Tuzla, Bosnia and Herzegovina (e-mail: benjo@bih.net.ba).

J. Voršič is with the Faculty of Electrical Engineering and Computer Science, University of Maribor, 2000 Maribor, Slovenia (e-mail: vorsic@uni-mb.si).

Digital Object Identifier 10.1109/TPWRD.2004.839185

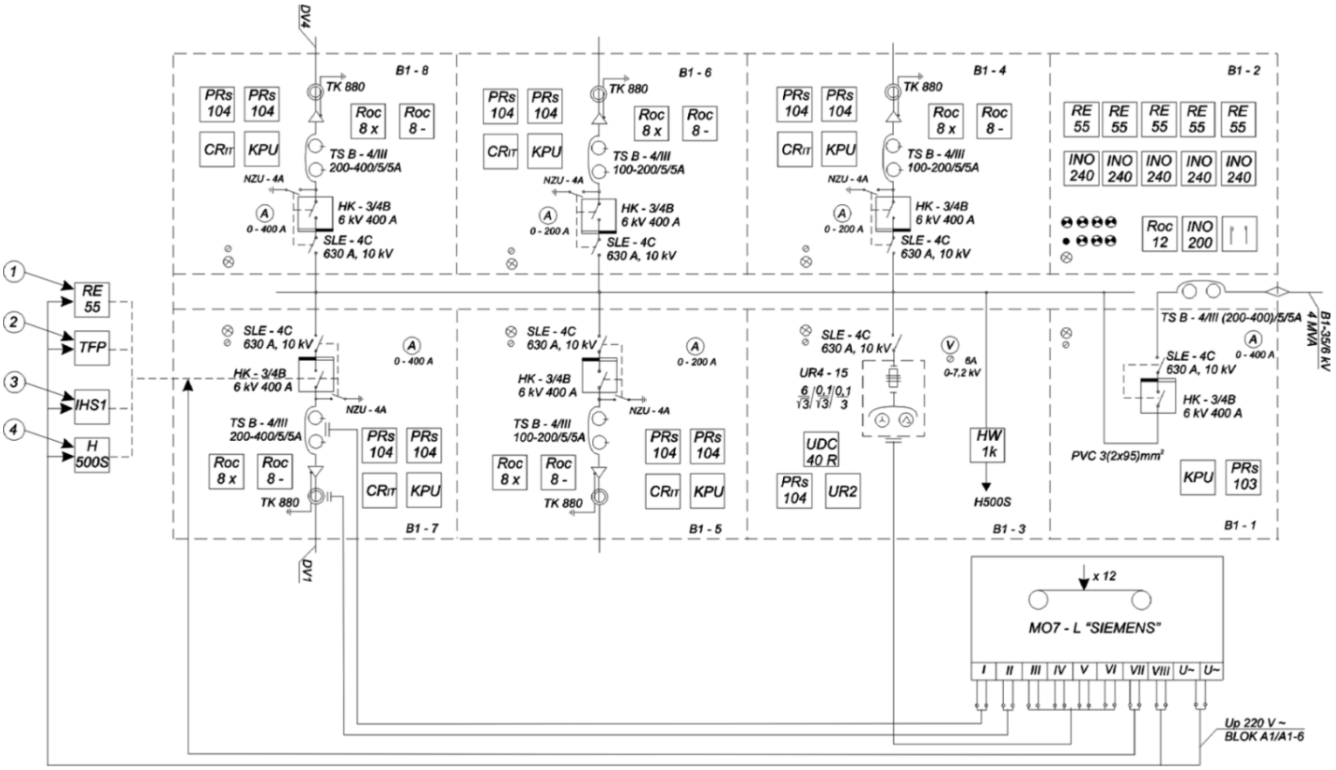
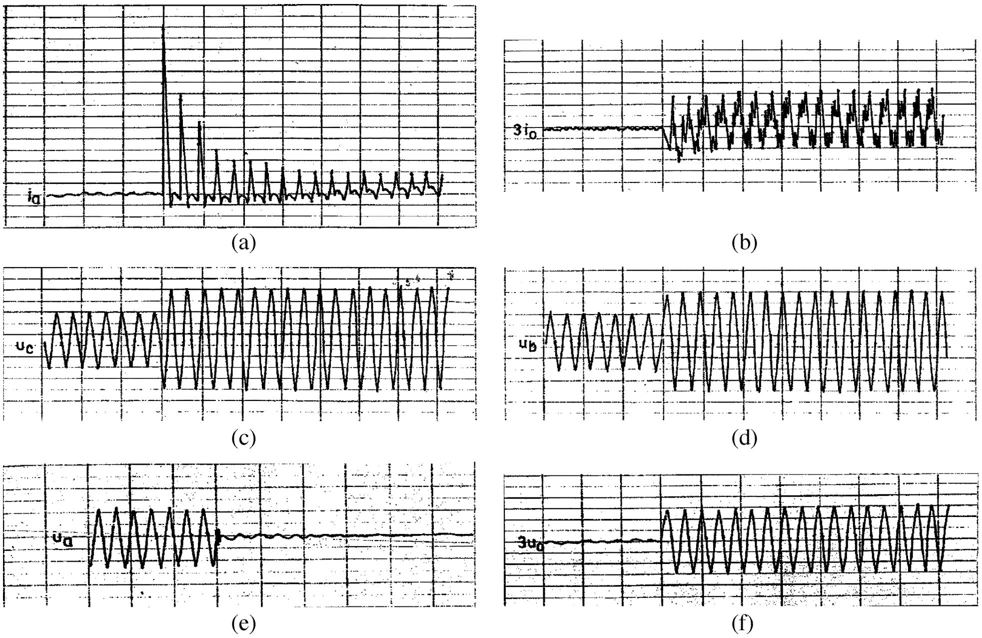


Fig. 2. Single-line system diagram of 6-kV switchgear.



(a) (b)

(c) (d)

(e) (f)

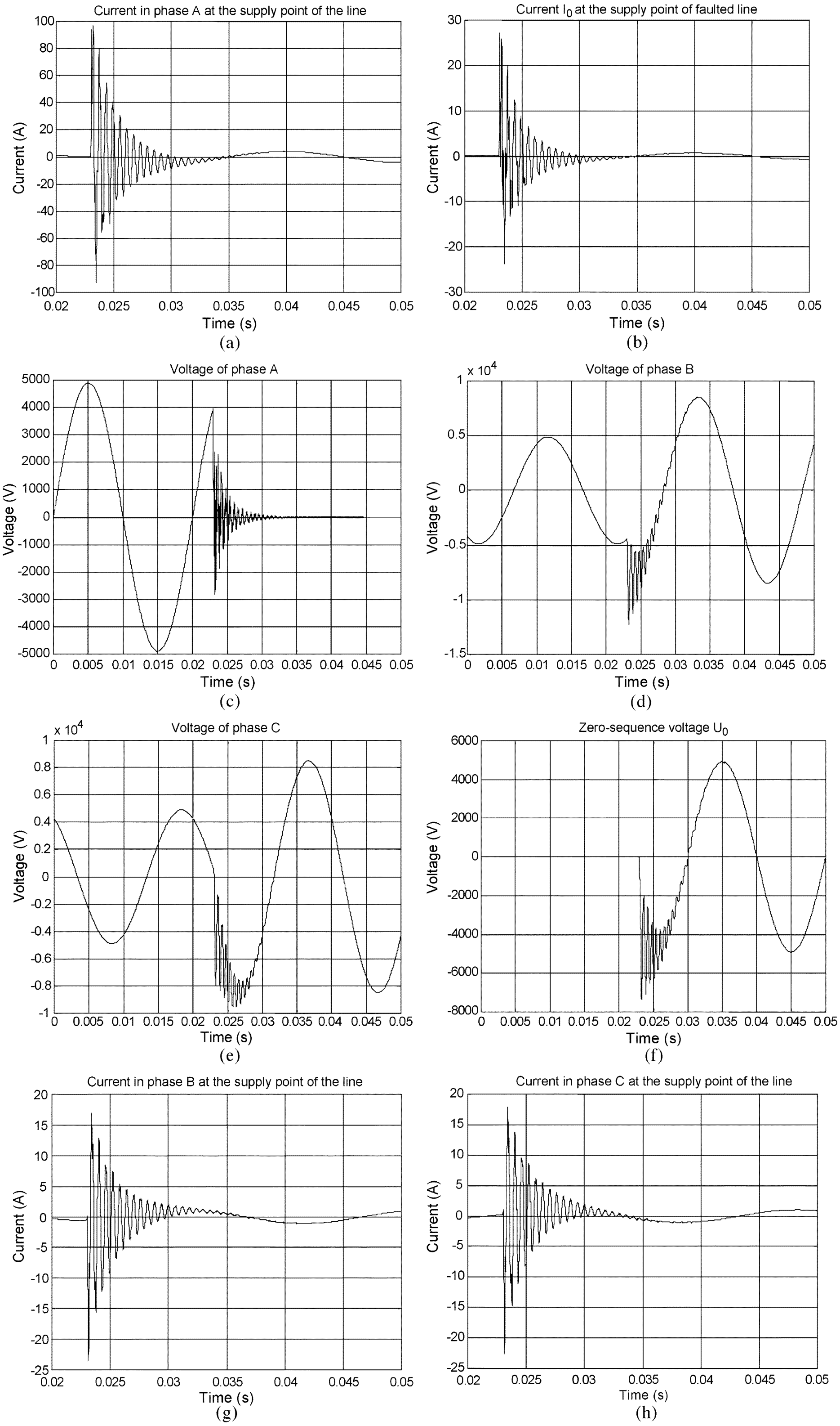
Fig. 3. Experimental measurements.

The measurements have been performed using 12-channel oscilloscope M07-L "Siemens". Three channels (III, IV, V) have been used for the connection to the secondary winding of voltage transformer UR-4/15 in the measurement unit B1-3.

Thus phase-to-neutral voltages U_a, U_b and U_c, have been measured, while the zero-sequence component $3U_0$ has been measured using a separate channel (VI), as seen in Fig. 2.

The current in the phase with earth fault (phase A) has been measured with the connection of the secondary winding of the TSB-3/III-200/5/5A cl. 0.5 current transformer to the channel I of the oscilloscope.

Channel II has been used for registering the zero- sequence component of current $3i_0$ of the cable transformer TK 880, which is located in the 6-kV outgoing feeder B1-7.



(a) (b)

(c) (d)

(e) (f)

(g) (h)

Fig. 4. Oscillograms of characteristic physical quantities.

III. EXPERIMENTAL RESULTS

The results, obtained with measurements of fault currents and voltages in the above described system are shown in Fig. 3.

The symbols a, b, and c are used for denotations of phases.

IV. RESULTS OF EARTH FAULT SIMULATIONS

All lines (aerial and cables) are in the model simulated as four poles. Equivalent values of resistance, inductance and capacitance have been determined on the basis of data, provided by the manufacturers of cables and overhead lines, while the values of leakage capacitance of 6-kV switchgear devices have, on the other hand, been calculated on the basis of the unit value capacitances for this kind of equipment, taken from the literature.

Oscillograms of characteristic physical quantities for this process are shown in Fig. 4.

The process simulation has been developed in the Matlab environment, using the Matlab program tools, including Simulink and Power System Blockset. As it is well known, the MathWorks Company has purchased the rights of using the EMTDC program package for electromagnetic transient analysis. This package has been implemented in Matlab as Power System Blockset tool. Since this tool is completely identical with EMTDC, only the results of simulations with Matlab are presented in this paper.

V. Comparison Analysis of Experimental and Simulational Results

The comparison of voltage oscillograms shows that before the fault occurrence the voltages U_a, U_b, and U_c are perfectly symmetrical. After the occurrence of earth fault in the phase a the voltage of this phase falls to zero after a few periods of the voltage sinusoid. During the same period of time the voltages of "healthy" phases U_b and U_c increase and reach the value of phase-to-phase voltage, while the neutral point reaches the potential of phase-to-neutral voltage $3\underline{U}_0 = -\underline{U}_a$.

Identical changes of phase voltages U_a, U_b, and U_c, as well as changes of zero-sequence voltage U_0 can be seen in oscillograms in Fig. 4, which are obtained by the simulation of the described 6-kV network.

The current in the phase with ground fault i_a has a very high amplitude that reaches, during the first few periods after the fault occurrence, up to ten times higher values than the steady-state value $(\sqrt{2} \cdot 2,85\text{A})$.

Comparison of the oscillograms of I_a, obtained by the simulations, with those obtained by measurements and shown in Fig. 3, shows that they are almost identical.

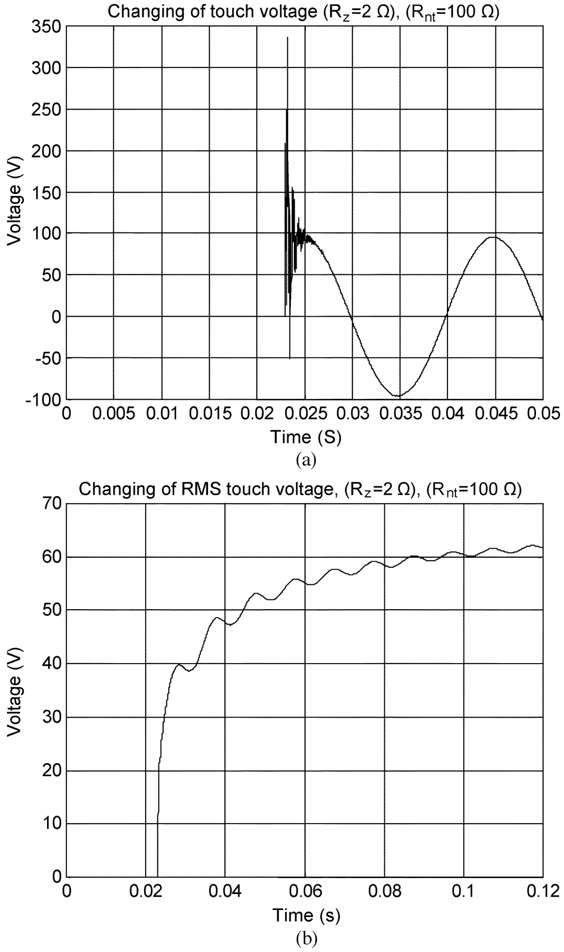
Oscilograms of currents I_a, I_b, and I_c from Fig. 4 are completely in line with generally known theory about earth faults. The current I_a has the opposite direction than the currents I_b and I_c, which is just another verification of adequacy of the above described model for simulation of transient phenomena during single line earth faults in electric power networks.

The model therefore completely supports the experiment, not only as regards the absolute values of currents and voltages, but also regarding their mutual phase shifts.

A confirmation of the above stated conclusions becomes obvious with comparison of oscillograms in Fig. 3 with those in Fig. 4, i.e. by comparing the phase shift of $3I_o$ with the phase shift of $3U_0$. This phase shift amounts exactly to one fourth of the power frequency period.

VI. Analysis of Neutral Point Operation Regime on the Magnitude of Touch Voltage During Transient Process

A broad range of EMTDC's capabilities has been used for the analysis of the touch voltage magnitude as a function of the mode of neutral point earthing and of the earthing resistance in the tested 6-kV network.



(a)

(b)

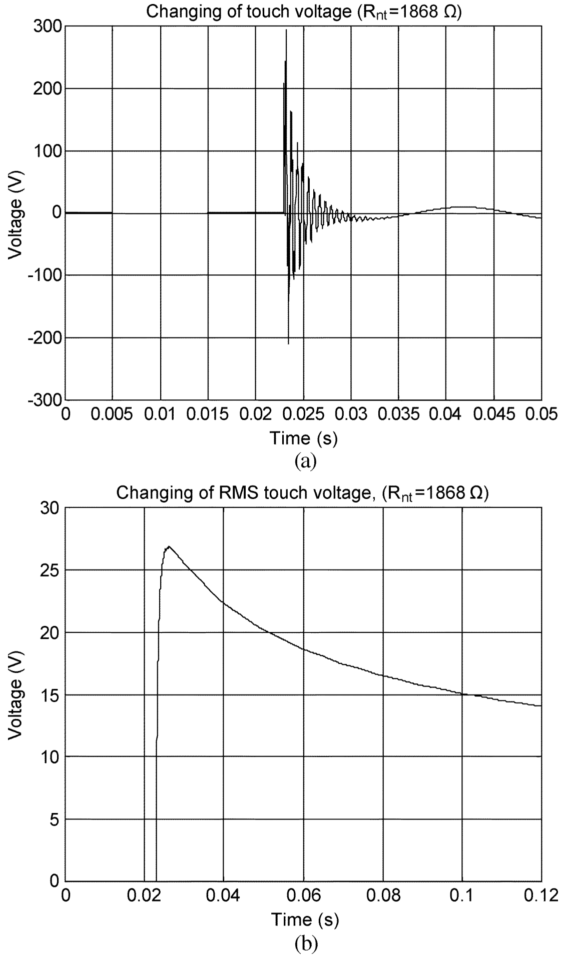
Fig. 5. (a) Changing of touch voltage for the 6-kV network, earthed through a relatively low resistance $R_{nt} = 100\ \Omega$. (b) Rms values of touch voltage

In principle, it is an analysis of a contact of human beings with metal parts that are in normal operation not energized, but can become energized in the case of a failure, such as an earth fault. Touch voltage (as well as step voltage) is determined by the magnitude of earth fault current I_Z and earthing resistance R_Z, i.e. $u_d = R_Z \cdot i_Z$.

The model of the network from Fig. 1 has been used for the analysis. The model enables a simulation of conditions in the real network.

It has been analyzed how changing R_{nt}, which is connected between the neutral point and the earthing electrode, influences the changing of touch voltage. The resistance has been varied from $R_{nt} = 100\ \Omega$ to $R_{nt} = \infty$ at the constant values of transient resistance and earthing resistance, $R_{prel} = 0,01\ \Omega$ and $R_{uz} = 2\ \Omega$, respectively.

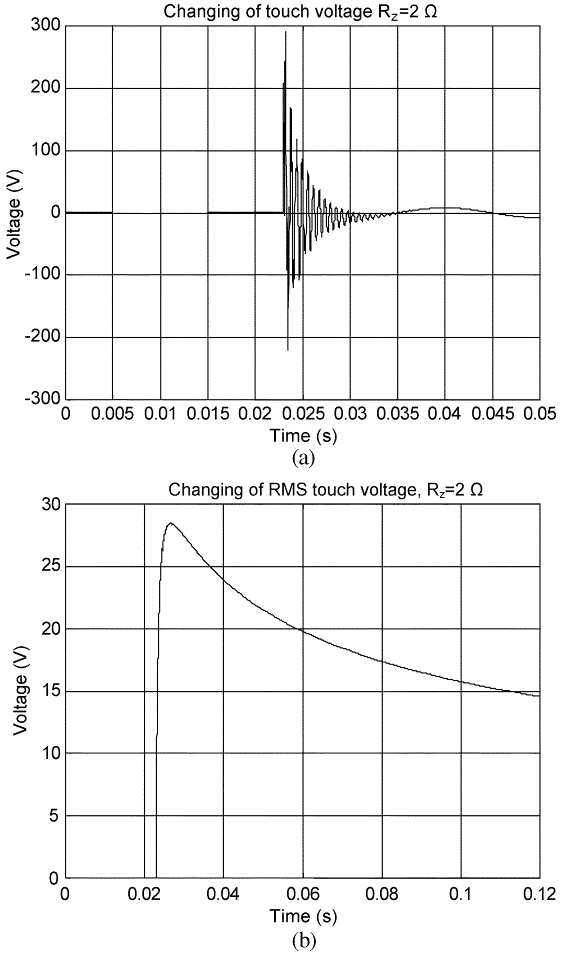
Three characteristic oscillograms of changing of touch voltage as a function of time, as well as oscillograms of the rms voltage of these touch voltages, have been selected for the analysis. Fig. 5(a) shows changing of touch voltage for the 6-kV network, earthed through a relatively low resistance $R_{nt} = 100\ \Omega$. Observing the mentioned graph it can be seen that the transient process has a relatively short duration of a few milliseconds, and that the touch voltage is very high with



(a)

(b)

Fig. 6. (a) Changing of touch voltage for the 6-kV network, earthed through resistance R_{nt} = 1868 Ω. (b) RMS values of touch voltage.



(a)

(b)

Fig. 7. (a) Changing of touch voltage for the 6-kV network with insulated neural point. (b) RMS values of touch voltage.

amplitude in the steady-state reaching 100 V. Rms values of touch voltage are shown in Fig. 5(b).

Increasing the resistance R_{nt} decreases touch voltage. Thus, in the case of $R_{nt} = R_{\text{opt}} = 1868\ \Omega$ touch voltage, under the same conditions as in the previous case, amounts only to 20 V, and the transient process lasts less than 10 ms. During this transient process, touch voltage reaches values of more than 50 V [Figs. 6(a) and 6(b)].

Analyzing Fig. 7(a), showing changing of touch voltage in the case of a network with insulated neutral point, one can conclude that the transient process lasts a few milliseconds longer than in the case of earthing through R_{opt}.

During the transient process there are "leaps" of touch voltage exceeding 200 V. After a little more than 10 ms, the steady-state condition with the maximum voltage change of 15 V is reached.

Graphs in Figs. 5(a)to 7(b) have been obtained for the resistance of connecting wires of $R_{pr} = 0,01\ \Omega$, i.e. $R_{pr} \approx 0\ \Omega$, and for the earthing resistance of 2 Ω. Analyzing graphs in Figs. 6(b) and 7(b), showing changes of rms touch voltage, it becomes obvious that touch voltage conditions in the case of earth failure are more convenient in the networks with small capacitive current than in the insulated networks. The optimum value of the resistance between neutral point and earthing electrode amounts to $R_{\text{opt}} = R_{nt} = 0,6X_C$, where $X_C = 1/\omega C$ represents the total capacitive reactance of the network.

In selecting the measures for protection against dangerous touch voltage during earth faults, the time of activation of protective system should be set with respect to the magnitude of touch voltage, as required by the technical regulations.

The use of so developed models for studying transient and steady-state conditions in medium voltage networks offers a valuable support in selecting the most adequate set of protective measures and in determining necessary parameters of protective devices against electric shock caused by a contact of human beings with parts that are in normal operation not energized.

Such an analysis is of special importance for mining and industrial medium voltage networks, since earth faults in these networks represent the most common cause of equipment damaging, as well as human injuries or fatalities due to electric shock.

The analysis has been, as mentioned earlier, carried out on the network model from Fig. 2. The model is universal and can be used for analysis of much larger medium voltage networks.

VII. CONCLUSION

Earth faults are, in principle, stochastic phenomena. This is why conditions and parameters of specific earth faults vary considerably from case to case. The research work presented in this paper clearly shows the applicability of the developed model in studying transient phenomena in electric power networks as a part of fault analysis, sizing the earthing system, and setting the protection against faults.

REFERENCES

[1] N. Berbić and R. Memišević, "Korištenje programskih paketa EMTDC i MATLAB za simulaciju prelaznih procesa pri zemljospoju u elektroenergetskim 6 kV mrežama na površinskim kopovima," . Neum, Serbia, 2001.

[2] J. Nahman, *Uzemljenje neutralne tačke distributivnih mreža* Beograd, Serbia, 1980.

[3] R. Horvat, *Elementi analize električnih kola*. Beograd, Serbia: Gradevinska knjiga, 1983.

[4] C.-M. Ong, *Dynamic Simulation of Electrical Machinery Using Matlab/Simulink*. Upper Saddle River, NJ: Prentice-Hall, 1998.

[5] M. Aredes, J. Häfner, and K. Heumann, "Three-phase four-wire shunt active filter control strategies," *IEEE Trans. Power Electron.*, vol. 12, no. 2, Mar. 1997.

Nadil Berbić was born in Derventa, Bosnia and Herzegovina, in 1953. He received the B.S. degree from the Faculty of Electrical Engineering, Sarajevo, in 1977, the M.S. degree from the Faculty of Electrical Engineering, University of Sarajevo, in 1989, and the Ph.D. degree in 1999.

In 1977, he began work as a Researcher at the Mining Institute. In 1982, he was engaged as an Assistant at the Faculty of Mining and Geology, University of Tuzla, Bosnia and Herzegovina, and later was elected to Higher Assistant in the same faculty. In 2000, he was elected to Assistant Professor at the University of Tuzla. His area of research interest is theoretical and applayed electrotechnics in mining.

Dr. Berbić is a member of BH K CIGRE.

Rizah Memišević was born in Bosnia and Herzegovina on October 9, 1964. He received the B.S. and Ph.D. degrees from the Faculty of Electrical Engineering, University of Tuzla, Bosnia and Herzegovina, in 1988 and 2000, respectively, and the M.S. degree from the Faculty of Electrical Engineering, Sarajevo, in 1992.

In 1994, he was engaged as a Lecturer at the Faculty of Electrical Engineering, University of Tuzla, responsible for teaching power electronics and control, high-voltage techniques, power system analysis, power system control, and electrical drives. Since September 2000, he has been an Assistant Professor in power electronics and electrical drives control at the Faculty of Electrical Engineering, University of Tuzla. As a Project Coordinator, he worked on the Tempus Joint European Project (JEP) on the upgrade of teaching in power electronics and related fields.

Dr. Memišević is a member of BH K CIGRE.

Jože Voršič (M'82) was born in Maribor, Slovenia, on November 24, 1946. He received the B.S. degree from the University of Ljubljana in 1972, the M.S. degree from the University of Zagreb in 1982, and the Ph.D. degree from the University of Maribor in 1983, all in electrical engineering.

In 1972, he was engaged at the University of Ljubljana as a Research Assistant, where his work focused on the research of the quality of electrical energy. In 1974, he joined the University of Maribor as an Assistant. At present, he is a Professor of Power Systems Engineering. Since 1976, he has been an active member of the self-managerial governing bodies of the Faculty of Technical Sciences, and later at the Educational Community of Slovenia and the Ministry of Science and Technology.

Dr. Jože Voršič is a member of CIGRE.