MEĐUNARODNO REGIONALNO SAVETOVANJE O ELEKTRODISTRIBUTIVNIM MREŽAMA

REGIONAL CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION

Crna Gora, Herceg Novi, 5 - 8. oktobar 2004. / ***Montenegro, Herceg Novi, October 5 - 8, 2004***

POSSIBILITY OF COMPUTER APPLICATION FOR SWITCHING OVERVOLTAGES CALCULATION BY TAKING INTO CONSIDERATION REAL CIRCUMSTANCES AND INFLUENCES THAT CAN BE PRESENT IN DISTRIBUTION SYSTEM EXPLOITATION

S. Škuletić, Faculty of Electrical Engineering, Montenegro
P. Mijajlović, Electric power industry of Montenegro, Montenegro

ABSTRACT

In the paper, the results of switching overvoltages calculation for real overhead lines in one part of power system of Montenegro have been presented. Program for calculation of switching overvoltages is written in Microsoft FORTRAN PowerStation 4.0. Lines energizing and disconnection of unloaded lines - by means of normal commutation, forced-manual commutation and with arc re-ignition have been observed. Within this analysis, influence of breaker's "current chopping" has been simulated, as well as calculation with normal process of current disconnection with arc extinguishments in the moment when current passes through zero value. Graphical presentation, analysis and comments of the obtained results also have been given.
For the purpose of verification, obtained results have been compared with experimental results from switching overvoltages explorations on the observed real lines.
By using these analysis, advantages, disadvantages, possibilities and recommendation for practical application of used program have been given in shape of conclusions.

INTRODUCTION

Exact calculation of overvoltages in real power networks, from both technical and economical point of view, is very important task in the cases of designs and analysis of power systems. This is particularly important in the phase of determination of insulation level in high voltage distribution networks. Besides lightning overvoltages, it is very important that switching overvoltages, caused by normal switching operations and switching operations in the cases of faults, should be also calculated.
Experimental researches of switching overvoltages request very expensive equipment and interruption in normal operation of power system during measurement periods. These explorations can be performed only within new-built system, so they cannot be involved in design's processes.
At the other side, development of numerical methods and development of digital computers are enabled calculations and analysis of overvoltages states that are exact enough, so overvoltages that appear in real power systems can be calculated with larger accuracy, analyzed and controlled even in phases of system planning (design).

[1] *University of Montenegro, Faculty of Electrical Engineering, Cetinjski put bb, 81000 Podgorica, Montenegro. Tel. +381 81 243 638. Email: skuletic@cg.ac.yu*

Program, which is used for calculation of switching overvoltages in real 110 kV lines in one part of power system of Montenegro, is written in Microsoft FORTRAN PowerStation 4.0. By its origin, this program [3] was divided into three parts because of lack of memory on PC computers with 640 kB RAM memory. Now, program is united and it is changed and readjusted so it can be used on new PC computers.
Program enables calculation of transient processes such are: energizing and disconnection of unloaded lines, energizing and disconnection of customers, appearance and disconnection of short circuit faults, disconnection of lines with automatic reclosing system and energizing and disconnection of unloaded transformers.
Multiple nonsymmetrical commutation as well as changes of failure states can be also simulated. On this way, successful and unsuccessful disconnections with automatic reclosing system can be simulated. Breaker disconnection can be done in advance-preset moment or in the moment when current passes through zero value. Also, normal process of disconnection with arc extinguishments in the moment when current passes through zero value can be observed.

BASIC PRINCIPLES OF PROGRAM'S WORK AND CALCULATION MODEL

By using program, transient process in networks with concentrated or distributed parameters can be observed and analyzed. Part of the network represented with concentrated parameters is analyzed in phase's coordinates. On that way, nonlinear elements such transformer magnetic branch and electric arc between breaker's contacts have been taken into consideration. Part of the network represented with distributed parameters is analyzed in symmetrical component's coordinates. A technique of sparse matrices is used for matrices creation. By using only nonzero elements, this technique enables faster calculation and saving of computer memory.
For regular work of program, it is necessary to create basic directory. This directory consists of file paths that program uses for input data, and file paths in which program puts inter results and final results.
First part of program represents user's interface for input parameters data and for calculation of transient process. All input parameters are written in textual files format, which represent input data. It is necessary that these files exist before of program's start because they content input data for calculation. Basic data define calculation and additional data define network model on which calculation should be done. These data are: network configuration, type of elements in network branches, length and characteristic impedance of lines, nodes and branches, electromotive forces of generators and nodes in which they exist.
Second part of program represents analysis of calculation results in Excel and their graphical representation. All examples of calculation are done on the basis of simplified three phase model that is given on figure 1.

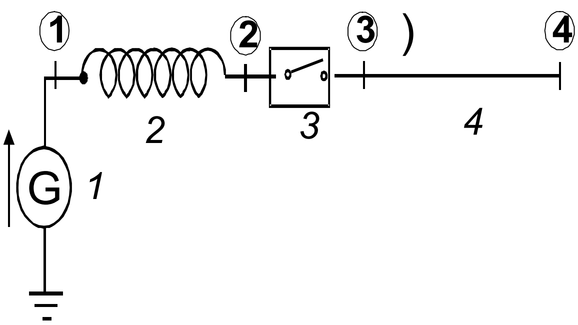

Figure 1. Model for calculation of switching overvoltages

On the figure 1, it can be observed that system has four nodes (which are marked with numbers in circles) and four branches (which are marked with numbers below model elements). Second branch is inductance with initial conditions because it is connected on generator and because it is necessary that system has inductance in order that current can be calculated. Breaker is without shunt and it performs energizing and disconnection operations. Line connected after breaker has initial conditions because it is connected on the source before of commutation's start.

All element marks are defined by program. This model is chosen because energizing and disconnection of unloaded 110 kV overhead lines are analyzed by using experimental explorations. By using the mentioned model these cases can be represented; [1].
Any element of network model is defined on characteristic way and it has special indicator. Concrete data for any element of network model have to be read by algorithm procedure. For example, coordinates of drawing are first on list that is read for breaker. Code number of nodes between which breaker is placed are next in this process. Within next steps, number of points with which dielectric withstand level between contacts is defined, breaker operation (energizing and disconnection) and shunt existence are specified. Program by itself has ability to control big errors in input data. In these cases, textual messages indicate errors.
In the paper, mathematical model and results for calculation of switching overvoltages on real overhead lines in one part of power system of Montenegro have been presented. Line energizing and disconnection of unloaded lines have been observed. By using these examples, analysis and graphical representation of the obtained results and comments of performed simulation have been given.
For the purpose of verification, obtained results have been compared with experimental results from switching overvoltages explorations on the observed part of power system of Montenegro.

RESULTS OF CALCULATIONS OF SWITCHING OVERVOLTAGES ON THE REAL LINES

Program is applied for calculation for calculation of switching overvoltages in one part of power system of Montenegro on overhead lines DV 110kV Podgorica1 - Budva and DV 110kV Podgorica1 - Bar. These cases are taken into consideration because they have worst results within performed experimental explorations (re-ignition of electric arc between contacts of low oil breaker with maximal measured values of overvoltages, [2]).
It is assumed that the observed line was in the unload state. Frequently depended parameters, as well as surge arresters, aren't taken into consideration. Also, in the network there aren't nonsymmetrical states and there haven't failures before of commutation. Value of 108kV is taken for magnitude of phase to neutral voltage. Value of zero degree is taken for start phase of this voltage. Constant values are taken for characteristic impedances and lines lengths. For time step of calculation in all calculations is taken value of 0.001s.
Also it is possible to select another values for number of calculation points as well as for number of points that are used for drawing in order to desire resolution of graphical presentation can be accomplished. On that way it is possible that one part of the obtained diagram can be presented with more details.
Simulation of breaker disconnection is performed in preset moment (manual commutation) or in the moment when current passes through zero value. On that way, influence of breaker's "current chopping" is simulated as well as calculation with normal process of current disconnection with arc extinguishments in the moment when current passes through zero value. Dielectric withstands level between breakers contacts is modeled with linear segments (in reality U-t curve is ascending in the case of disconnection, while it is descending in the case of energizing). Values for dielectric withstand level is taken in segments which coresponds with the values for the observed voltage levels.
Calculations are performed for node 4 in model and all diagrams are obtained with existence of manual commutation and taking into consideration of one network change in step 25 in which there aren't nonsymmetrical states. Frequently depended parameters aren't taken into account. Dielectric withstand level between breaker's contacts is modeled with two pints of U-t diagram: first 0s and 900kV, and second 0.01s and 0kV. For time of process delay i.e. for arc extinguishments after the moment when current passes through zero values for last time value of 1s is taken.
On figure 2, transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Budva in the case of line energizing in TS Budva are given. Value of obtained voltages in node 4 are: u_{max0}=143kV, u_{max4}=195kV and u_{max8}=174kV, i.e. overvoltages coefficients are k_{f0}=1.32, k_{f4}=1,8 and k_{f8}=1.61.

PRETRAŽIVANJE / SEARCH
ŠTAMPANJE / PRINT
IZLAZ / EXIT

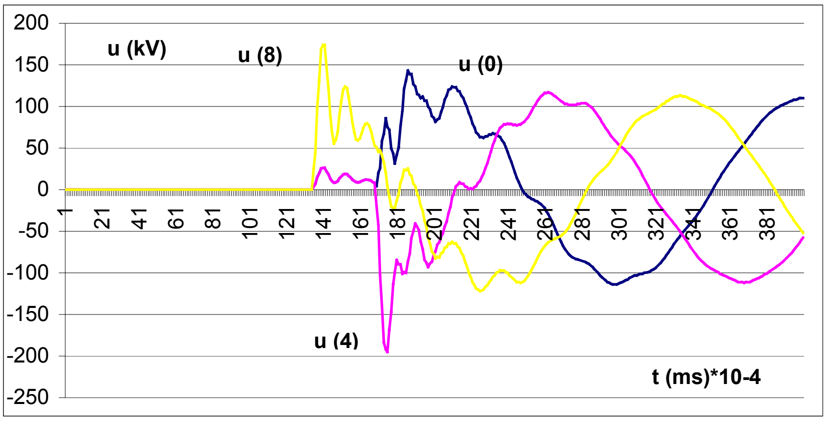

Figure 2. Transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Budva in the case of line energizing in TS Budva

On figure 3, transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Bar in the case of line energizing in TS Bar are given. Value of obtained voltages in node 4 are: u_{max0}=114kV, u_{max4}=120kV and u_{max8}=111kV, i.e. overvoltages coefficients are k_{f0}=1.05, k_{f4}=1,11 and k_{f8}=1.02.

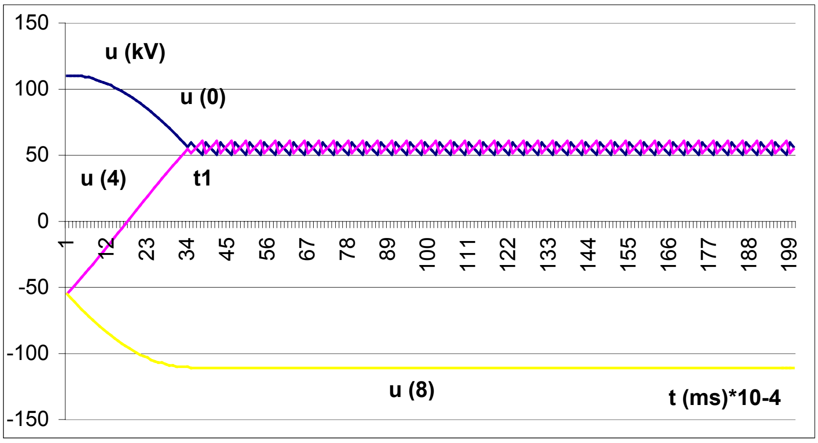

Figure 3. Transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Bar in the case of line energizing in TS Bar

It can be observed that simulation of commutation in the moment when current passes through zero value isn't performed in all three phases. Instead of that, "current chopping" in two phases is simulated. This is because manual commutation is simulated and because multiple reflected components of voltage appears in phases 0 and 4 (reason for this are saw shaped voltage in these two phases after moment of commutation). In order to commutation in the moment when current passes through zero value be achieved it is necessary to disconnection of manual commutation be simulated.

On figure 4, transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Bar in the case of switching off in TS Bar by taking into consideration moment when current passes through zero value are given. Calculation is performed in 200 points and steps of calculation and it is consider on node 4 in model. Diagrams are obtained with taking into account disconnection of manual commutation. Values of the obtained voltages are: u_{max0}=111kV, u_{max4}=120kV and u_{max8}=112kV, i.e. overvoltages coefficients are k_{f0}=1.02, k_{f4}=1,11 and k_{f8}=1.03.

By means of comparison of figures 3 and 4, on figure 3 it can be observed that multiple reflected components of voltage appears in two phases because simulation of commutation in the moment when current passes through zero value isn't performed. On the figure 4, in the case of commutation in the moment when current passes through zero values natural shaped sinusoids of voltage are obtained.

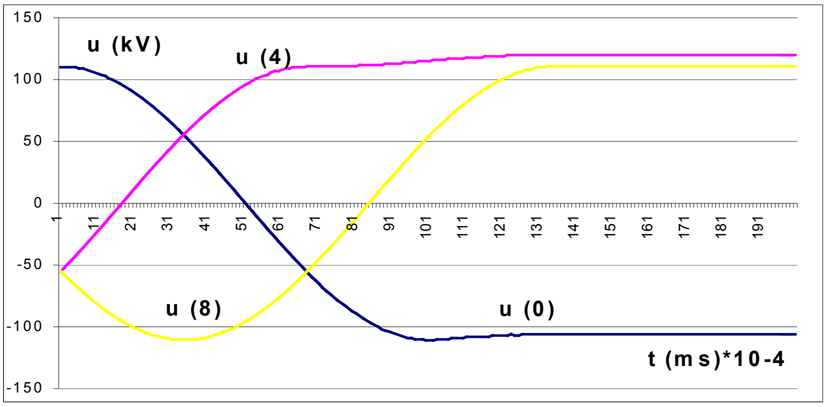

Figure 4. Transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Bar in the case of switching off in TS Bar

In order to re-ignition of electric arc can be taken into analysis, it is necessary to insufficiency dielectric withstand level between breaker's contacts be simulated. For example, on the figure 5, transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Budva in the case of line energizing in TS Budva by taking into consideration re-ignition of electric arc. Voltages in node 4 are: u_{max0}=157kV, u_{max4}=164kV and u_{max8}=117kV, i.e. overvoltages coefficients are k_{f0}=1.45, k_{f4}=1,52 and k_{f8}=1.08.

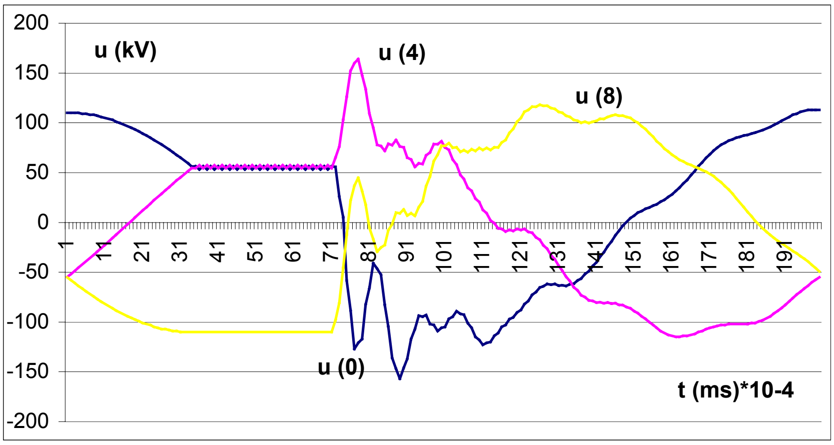

Figure 5. Transient phase to neutral voltages u_0, u_4 and u_8 on the end of overhead line Podgorica1 - Budva in the case of line energizing in TS Budva by taking into consideration re-ignition of electric arc

ANALYSIS OF THE OBTAINED RESULTS

By using calculation of switching overvoltages on the overhead lines DV 110kV Podgorica1 - Budva and DV 110kV Podgorica - Bar, 56 diagrams in four configurations are obtained. The cases of line energizing and disconnection of unloaded line (by means of natural commutation, manual commutation and with taking into consideration of arc re-ignition) have been analyzed.

Simulations of breaker's work are performed on the following way:

- Resistance between breaker's contacts in the observed phase is zero until the moment of arc extinguishments. Arc extinguishments occur in the moment when current passes through zero value. Numerically it is accomplished with the moment when current changes its sign. When current changes its sign, it is considered that breaker's contacts in that phase are disconnected and that the value of resistance between contacts is infinity large.
- From that moment, calculation of voltage between contacts of the observed phase starts as well as difference of voltages on the beginning and the end of line on another side of breaker. In the same

time, withstand values of voltage between contacts, which linearly grow with time because of growing distance between contacts, also are calculated.

- The speed of dielectric withstand level establishment is changed in order to disconnection of breaker with re-ignition of electric arc and bad state of insulation system of active breaker's part in real cases, be simulated.
- Relationship between overvoltage coefficient and speed of dielectric withstand level establishment couldn't be determined because overvoltage coefficient only indirectly depends on speed of dielectric withstand level establishment. Overvoltage coefficient mostly depends on values of voltage between breaker's contacts in the moment before arc re-ignition. From that reason lower values for dielectric withstand level are taken (usually 300kV and 600kV).
- Because real 110kV lines haven't surge arresters for protection against switching overvoltages, they haven't taken into calculation.
- Highest value of overvoltage coefficient obtained is 1.96 p.u, and that in the case of energizing of 110kV overhead line Podgorica1 - Budva (this coefficient is obtained by taking into consideration manual commutation and one change of network configuration in step 25 with dielectric withstand level between breaker's contacts modeled with two points on U-t diagram: first point 0s and 600kV and second point 0.01s and 0kV).
- Highest value of overvoltage coefficient obtained is 1.74 p.u, and that in the case of disconnection of unloaded 110kV overhead line Podgorica1 - Bar (this coefficient is obtained by taking into account re-ignition of electrical arc, one change into network configuration in step 25 and with dielectric withstand level between breaker's contacts modeled with two points on U-t diagram: first point 0s and 0kV and second point 0.01s and 300kV)

COMPARISON OF EXPERIMENTAL EXPLORATION RESULTS AND CALCULATIONS OF SWITCHING OVERVOLTAGES

For the purpose of verification, obtained results have been compared with experimental results from switching overvoltages explorations for real lines (1).
For example, on figures 6 and 7 direct comparison between results of experimental explorations (a) and calculations (b) of switching overvoltages on lines DV Podgorica1 - Budva and DV Podgorica1 - Bar are given.
Transient phase to neutral voltage u_4 on the end of overhead line Podgorica1 - Budva in the case of its energizing in TS Budva obtained by experimental explorations is given on figure 6 a). Transient phase to neutral voltage u_4 on the end of overhead line Podgorica1 - Budva in the case of its energizing in TS Budva obtained by calculation is given on figure 6 b).
From the diagram on the figure 6 a) it can be observed that measured value of switching overvoltages in phase 4 is 1.82 p.u, i.e. maximal value of measured overvoltage was 196.5kV. Duration of transient process was 5.2ms.
From the diagram on the figure 6 b) it can be observed that measured value of switching overvoltages in phase 4 is 1.79 p.u, i.e. maximal value of measured overvoltage was 193.3kV. Duration of transient process was 4.9ms.
Very good correspondence by means of shape and magnitude can be noticed.

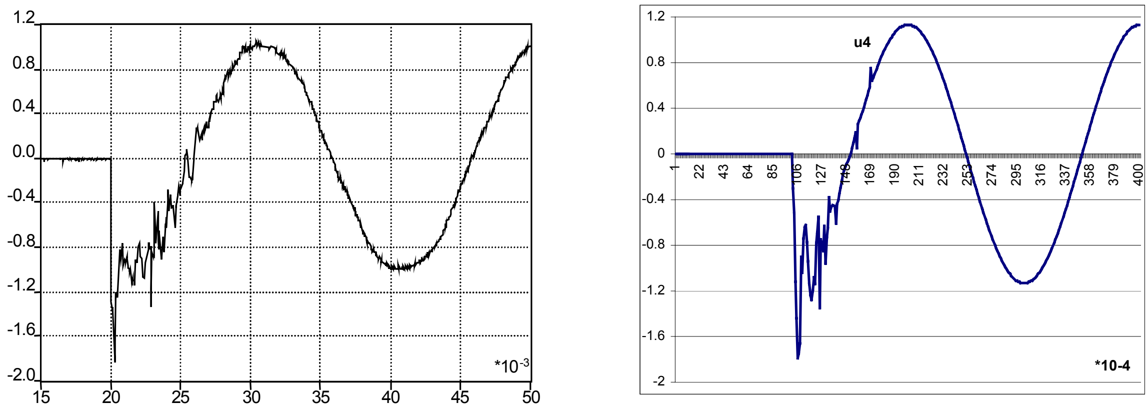

Figure 6. Transient phase to neutral voltage on the end of unloaded overhead line Podgorica1 - Budva

a) Experimental explorations

b) Calculations of switching overvoltages.

Transient phase to neutral voltage u_0 on the end of unloaded overhead line Podgorica1 - Budva in the case of its disconnection in TS Budva obtained by experimental explorations is given on figure 7 a). Transient phase to neutral voltage u_4 on the end of unloaded overhead line Podgorica1 - Budva in the case of its disconnection in TS Budva obtained by calculation is given on figure 7 b).

From the diagram on the figure 7 a) it can be observed that measured value of switching overvoltages in phase 0 is 2.33 p.u, i.e. maximal value of measured overvoltage was 252kV. Duration of transient process was 9.5ms with appearance of repeated breakdown (19ms) after first arc extinguishments (11ms) and triple repeated arc re-ignition (in moments 24ms, 27ms and 29ms) until final arc extinguishments (31ms).

From the diagram on the figure 7 b) it can be observed that measured value of switching overvoltages in phase 0 is 1.71 p.u, i.e. maximal value of measured overvoltage was 184.7kV. Duration of transient process was 5.6ms with appearance of double repeated arc re-ignition (in moments 5.2ms and 6.4ms) after first arc extinguishments (moment 3.7ms).

Significant deviations by means of magnitude and wave shape of transient phase to neutral voltage on the end of unloaded overhead line Podgorica1 - Budva in the case of its disconnection in TS Budva obtained by calculation of switching overvoltages can be noticed.

These deviations can be explained with fact that result of experimental exploration is consequent of multiple re-ignitions of electric arc between contacts of low oil breaker in TS Budva. These effects are caused by bad states of complete insulation system of active breaker's parts [1].

Deviation in magnitudes obtained by calculation of switching overvoltages is less than 10% in all explored configurations. Correspondence between wave shapes of switching overvoltages obtained by experimental explorations and those obtained by calculation is quite good [2].

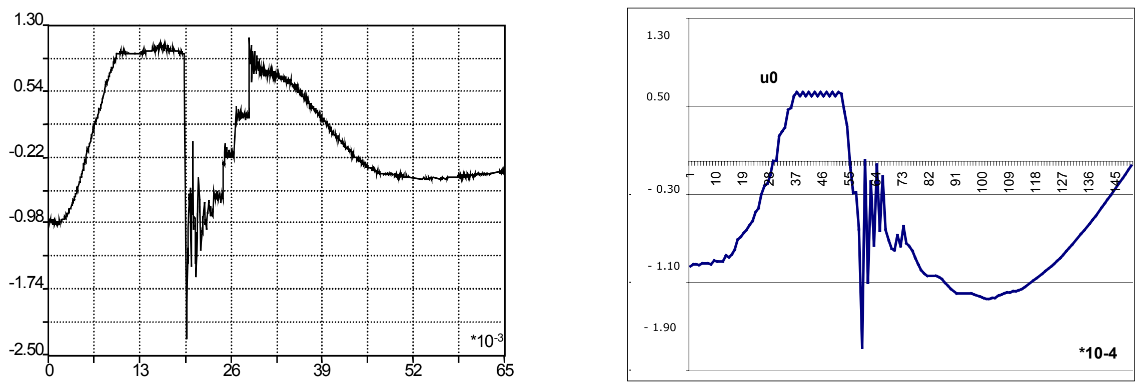

Figure 7. Transient phase to neutral voltage on the end of unloaded overhead line Podgorica1 - Budva

c) Experimental explorations

d) Calculations of switching overvoltages.

CONCLUSION

By using obtained results of switching overvoltages calculation on the overhead 110kV lines in one part of power system of Montenegro, it can be concluded that used program enables fast and easy calculation of switching overvoltages.
Preparation of data is simple, so final user can easily perform direct simulations for desired configuration, work regime and simulation model.
This program is very flexible and it enables wide range of calculations. From these reasons application of this program for the practical purposes is indisputable.
Further efforts within this course will be additional development of created program by means of its algorithm and graphical interface, as well as its testing on real problems.

LIST OF REFERENCES

1. Mijajlovic P., 2004., ″Sklopni prenaponi u mrezama visokih napona″, magistarski rad, ″Univerzitet Crne Gore″, ETF Podgorica, 54-90
2. Skuletic S, Mijajlovic P.,2003, ″“Eksperimental Investigations of Switching Overvoltages in 110 kV Network of Power System of Montenegro″”, ″IEEE Bologna PowerTech Proceedings″, BPT03-58
3. Savic M., 2004., "Program za proracun sklopnih prenapona", ETF Beograd.