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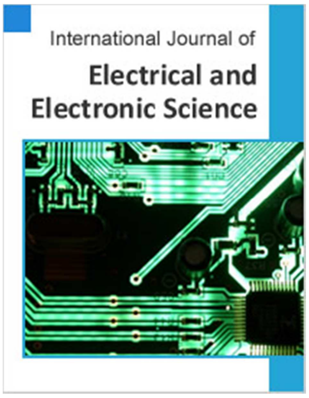

Influence of Physical Factors on Stability at Computer Simulation of Some Transients in Electric Power Systems

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Abstract
Results of studies of stability at computer simulation switching transients in electric power systems are presented in the paper. There are considered and investigated the key computational features of computer simulation transitional processes at switching-offs power capacitor banks and unloaded transformers (in the main) and power transmission lines (partly) by SF_6 and vacuum circuit-breakers at use different stiff ordinary differential equations' solvers and algorithms realized them (fast and robust ones). There is shown influence of some physical factors (free frequencies, attenuation and arc resistance, type of circuit-breaker) on the simulation process and solutions' stability. The simulation process covers wide range of initial step sizes and tolerances. There were given the possible interpretations for the reasons and phenomena being responsible for the worsening of stability at numerical research transients in electric power systems.

1. Introduction

Study of transitions in electric power systems has always had significant importance because that just in these regimes transitional voltages and currents reach their maximum values capable of being dangerous for insulation and conductive parts of electrical installations and apparatus [1]. The most important applications of transitions' study concern to co-ordination of electrical installations' high-voltage insulation, design and setup of relay protection and emergency control, option of switching equipment, electromagnetic compatibility etc.

It must be noticed that numerical modeling and computer simulation are ones of the most important and widely used ways to research transitions in electric power systems. Still B. Swanson noted at the end of the seventies of the last century that the numerical simulation is becoming the main tool for the study of transients due to the high cost of field studies and fundamental flaws of physical modeling of the problem under consideration [2]. It notably increases requirements to adequacy of numerical modeling and computer simulation to the physical processes.

The problem studied a priori has a complicated character. As it was shown in [3] numerical modeling of transitions in electric power systems belongs to the class of so called "stiff" problems [4, 5]. Computer modeling and simulation of such a class of problems usually face with the stability problem. Possible loss of stability is conditioned by accumulation of local errors leading to the growth of global error with subsequent "repulsion" of the solution from the stable one [5]. Successful computer simulation of the stiff problems requires primarily determination of appropriate method (ode solver) and simulation parameters (initial step size and tolerance) providing stability of solutions, e.g. see [6, 7] sometimes it may be required also determination of the best algorithm (fast or robust) concerned to the same method [7].

The concept of differential equations' stiffness and computational aspects of the stiff problems solution and stability were comprehensively studied in numerous works, in particular [4, 5, 8, 9].

2. Research Ground and Data

The electrical installations had been studied were power capacitor banks and unloaded transformers, all of rated voltage 110 kV (see chapters 2 and 3). Some research concerned to power transmission lines are considered separately in the chapter 4. All the parameters and switching (switching-off and arc repeated re-ignitions and re-strikes) conditions were presented in details in [6, 10]. The electric and equivalent schemes are presented in figure 1 and figure 2.

The following numerical methods from MATLAB R2013a set for solving stiff ordinary differential equations were used for simulation of transitional processes under study:

a. ode 23s, the Rosenbrock method of order 2;
b. ode 23tb, trapezoidal method, with backward differentiation;
c. ode 23t, trapezoidal method;
d. ode 15s method.

Both fast and robust algorithms (but the ode 23s method) were used for simulation. The research had been implemented in wide ranges of simulation parameters. The initial step sizes values changed between 10 nanoseconds and 100 microseconds, the relative tolerance values changed between 0.000001 and 0.0001.

Note that above-minded methods (solvers) were created just for solving stiff differential equations. Use of different methods and algorithms gives us an opportunity to evaluate the stiffness of problem.

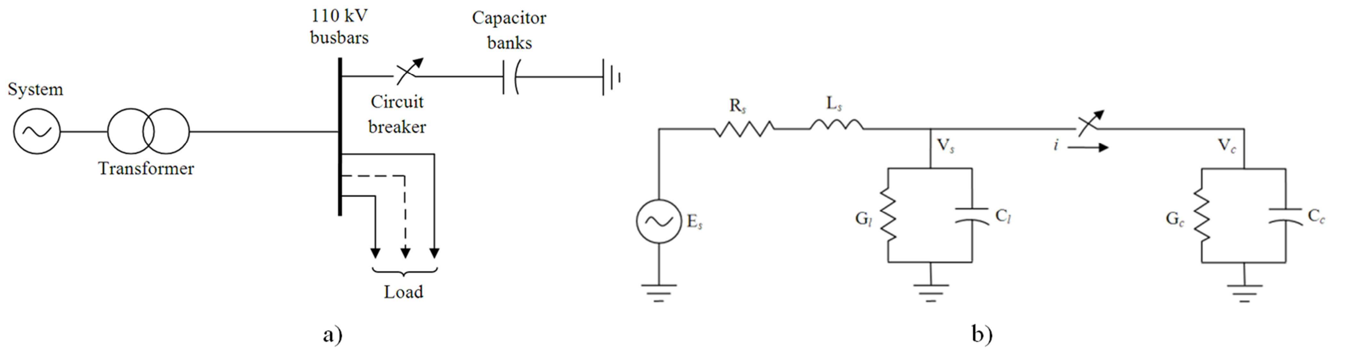


Figure 1. *Switching-off a capacitor bank: a) electric scheme; b) equivalent network (R, L, C and G are resistance, inductance, capacitance and conductance respectively. Index "s" concerns to the source parameters, "l"- to the load parameters, "c"- to the capacitor banks parameters, Es is e.m.f. ofthe voltage source).*

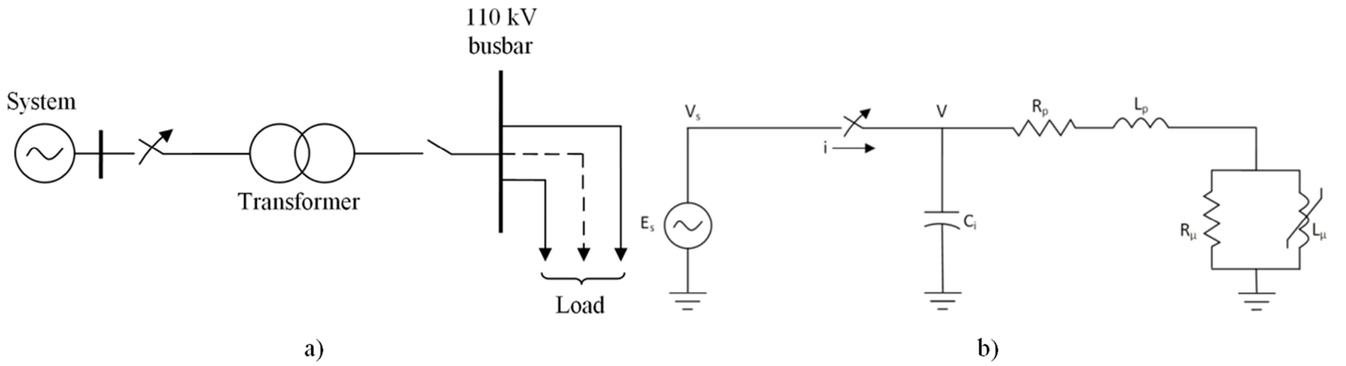


Figure 2. *Switching-off unloaded transformer: a) electric scheme; b) equivalent network (R, L, C and G are resistance, inductance, capacitance and conductance respectively. Index "s" concerns to the sourceparameters, "l"- to the load parameters, "c"- to the capacitor banks parameters, Es is e.m.f. ofthe voltage source).*

3. Physical Features That May Have Influence on the Results of Computer Simulation and Stability

There are some physical parameters and phenomena characterizing transients under consideration and affecting on results of computer simulation from the point of view of stability. Consider them successively.

3.1. Influence of Free Frequencies on Computer Simulation's Stability

As it was shown in [10] higher free frequencies may lead to worsening of stability via increasing of local errors. It takes place because of greater steepness of transitional functions at higher free frequencies. Note that at network transformations taken place at quenching and re-ignitions (re-strikes) of arc in inter-contact spaces of circuit-breakers there may appear free oscillations of more than one frequency. In general it may require use of significantly little values of initial step size at computer simulation. It must be noticed here that as a rule solutions for transitional functions obtained at simulation of switching-offs unloaded transformers has worse stability in comparison with ones got for switching-offs power capacitor banks [10, 11]. On our opinion, it is conditioned by very little value of transformers' (and autotransformers') input capacitance which is about 1 or 2 dozens of nanofarad [12]. By this reason, free frequencies in the circuit containing transformer's magnetization inductance and input capacitance reach high values. Thus, higher free frequencies lead to increasing of local and global errors and obstruct obtaining stable solutions. As it is seen from the figure 3 higher free frequencies conditioned by lesser input capacitances leads to worse stability both for voltage across the transformer's terminals and recovery voltage. Note that at lesser relative tolerances there have taken place significantly greater deviations of transitional voltages from their stable values.

The curves shown in the figure 3 were got at use the Rosenbrock method ode 23s, simulations were implemented at relative tolerance equaled 10^{-6}. The conclusions and explanations given are acceptable for all the stable methods. The same tendency has taken place for switching-off power capacitor banks. Stability of solutions is better for capacitor banks of greater (reactive) power since greater power corresponds to greater capacitance and less frequency of free oscillations.

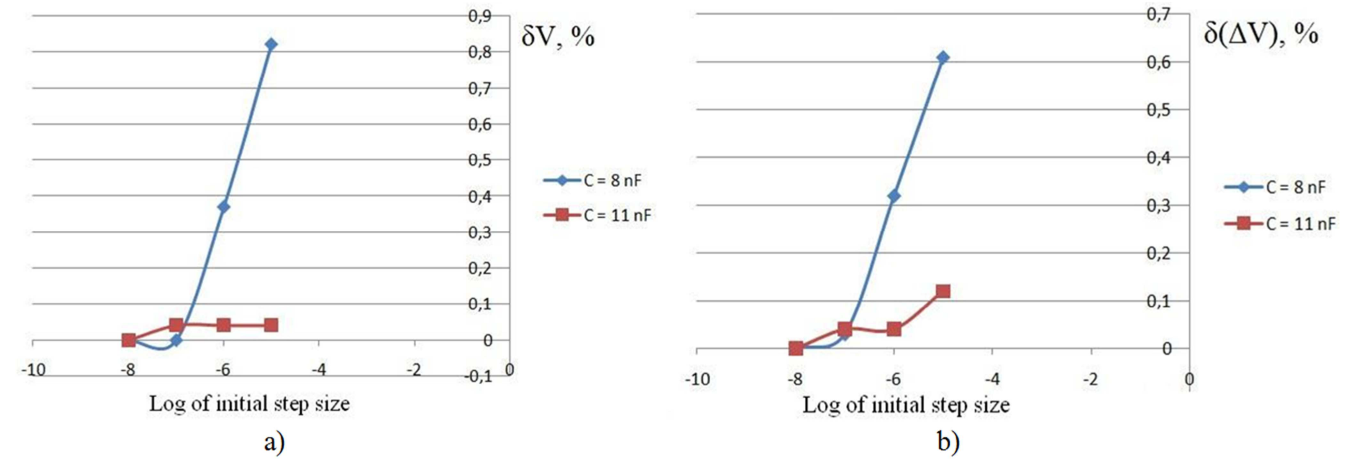


Figure 3. *Calculated deviations of transitional voltages from their stable magnitudes for different input capacitances of switched-off transformer: a) voltage across the transformer terminals; b) recovery voltage.*

3.2. Influence of Attenuation in Switched-off Circuit and Arc Resistance on Computer Simulation's Stability

It is known that resistive elements in physical systems may affect positively on asymptotic stability that is conditioned by attenuation of transitional functions due to energy losses [13]. The main attenuating factors in the problem under consideration are resistance of the switched-off transformer itself and resistance of arc in inter-contact space of circuit-breaker (note that values of the arc resistances depend on circuit breaker type [14]). Higher attenuation factors in the electrical circuits during the transitional process will lead to greater damping of free frequencies. In computational aspect it means that change of transitional functions as a result we get less local and global errors and in general, better stability of solutions.

These general suppositions and explanations are not unequivocally. So, as it was shown in [6] taking arc resistance seeming a priori a factor leading to the greater attenuation does not always improve stability. Moreover at use some ode solvers stability may be even worsened [6]. We suppose that it is conditioned by closer (due to additional attenuation) magnitudes of transitional functions of two consecutive points in areas of lesser steepness.

3.3. Influence of Circuit-Breaker's Type on Computer Simulation's Stability

Our previous researches showed that type of circuit-breaker can seriously influence on the flow of transition process and magnitudes of transitional functions of voltages and currents [11, 15, 16, 17]. The type of circuit-breaker (vacuum and SF_6 ones in our researches) can impact on the switching transitional process via value of chop (or chopping) currents, electric strength restoration law and full switching time [11, 18, 19].

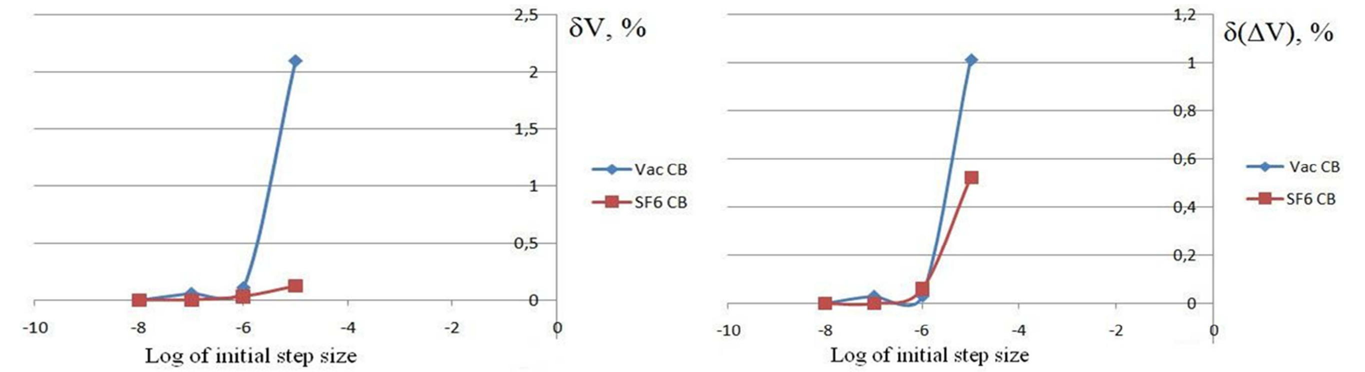
Here we are interested in influence of circuit-breaker type on computer simulation's stability. There we can note the following feature conditioned by circuit-breaker type we observed at the computer simulation. As a rule transitional functions at switching-off electrical installations (power capacitor banks, unloaded transformers and autotransformers, unloaded power transmission lines) have worse stability for the cases of switching by vacuum circuit-breakers. It is conditioned by higher magnitudes of overvoltages and recovery voltages taken place at use vacuum circuit-breakers [11, 18]. As a result in general we get higher instantaneous values of transitional voltages and currents and higher local errors affecting on global error and stability.

The given explanation is well illustrated in figure 4 and figure 5. As it is seen from these figures computer simulation of switching-off unloaded transformers (and autotransformers) and power capacitor banks by vacuum circuit-breaker is accompanied by higher deviations of transitional functions from their stable solutions (due to above given reasons). The curves concerned to the unloaded transformer switching-off (figure 4) were got at use the Rosenbrock method ode 23s, the curves concerned to the capacitor banks switching-off (figure 5) - at use the ode 23tb method, simulations were implemented at relative tolerance equaled 10^{-6}. The conclusions and explanations given are valid for all the stable methods of ones mentioned in the chapter 2.

Notice that conditions for option the initial step size taking circuit-breaker chop current into consideration given in [20] are easily satisfied because of its very little values needed to provide stability of solutions.

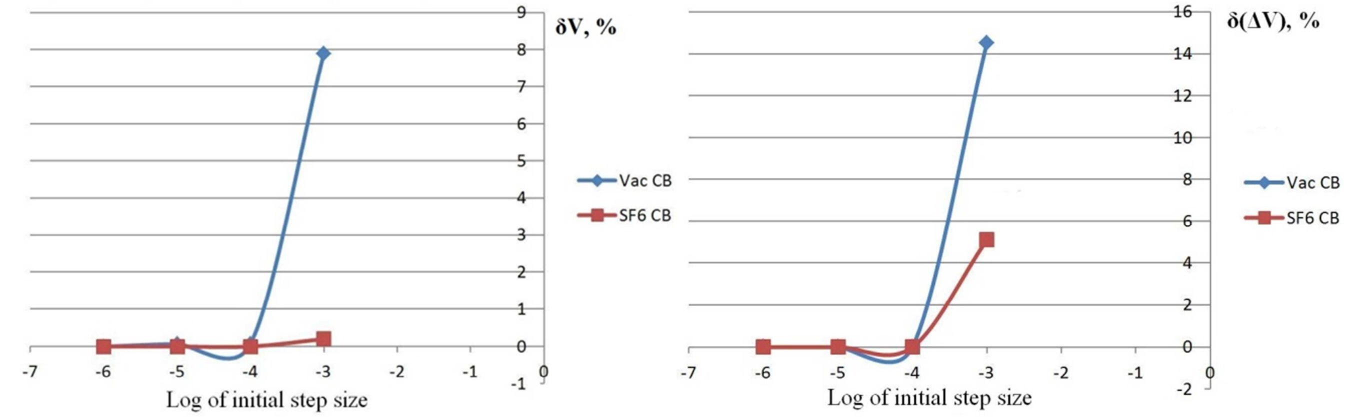
The examples of stable solutions are given in: figure 6 – for switching-off power capacitor banks; figure 7 – for switching-off unloaded transformer (see chapter 2).

As it is known stability of solutions of differential equations and their systems are closely related with so called stiffness concept [4, 5, 8, 21]. Our above presented researches showed once again that the stiffness is a complicated definition which must be estimated with taking into consideration methods (ode solvers) and simulation parameters.



a) b)

Figure 4. *Calculated deviations of transitional voltages at switching-off unloaded transformer from their stable magnitudes for different types of circuit-breakers: a) voltage across the transformer terminals; b) recovery voltage.*



a) b)

Figure 5. *Calculated deviations of transitional voltages at switching-off power capacitor banks from their stable magnitudes for different types of circuit-breakers: a) voltage across the capacitor banks terminals; b) recovery voltage.*

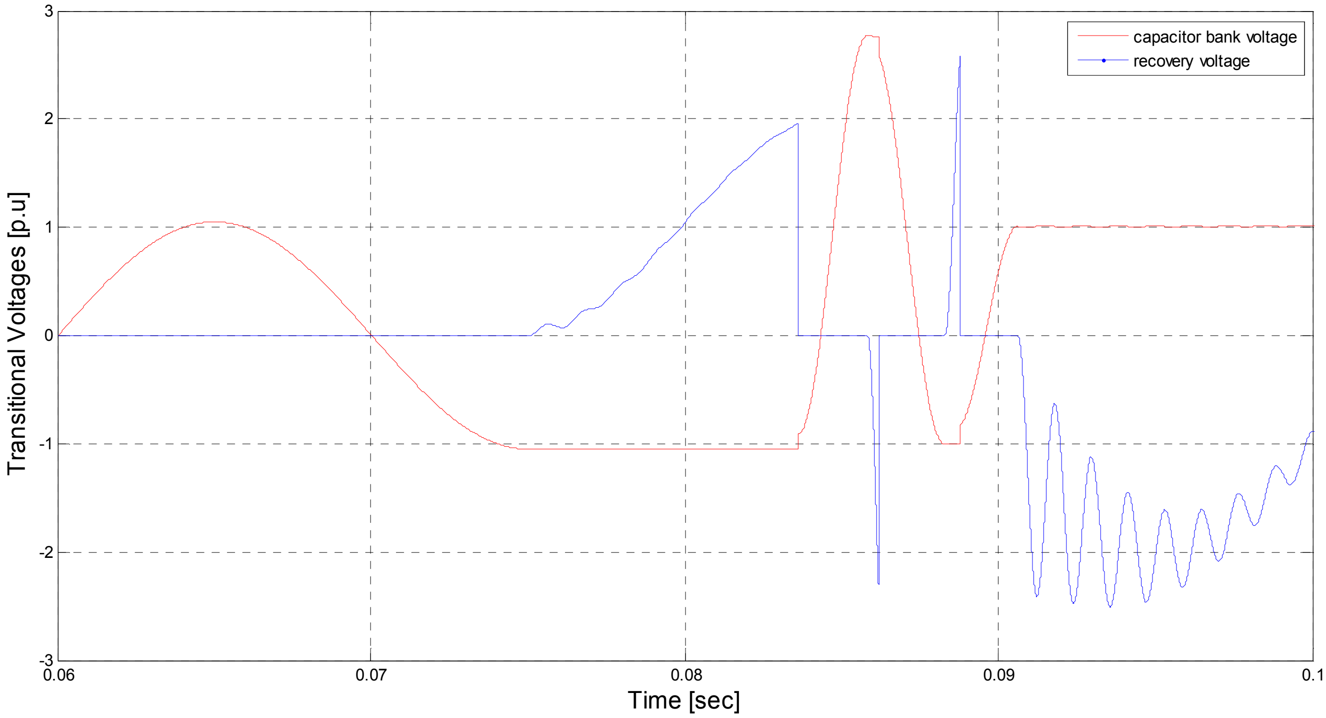


Figure 6. *Simulated transitional voltages (stable solutions) at switching-off power capacitor banks.*

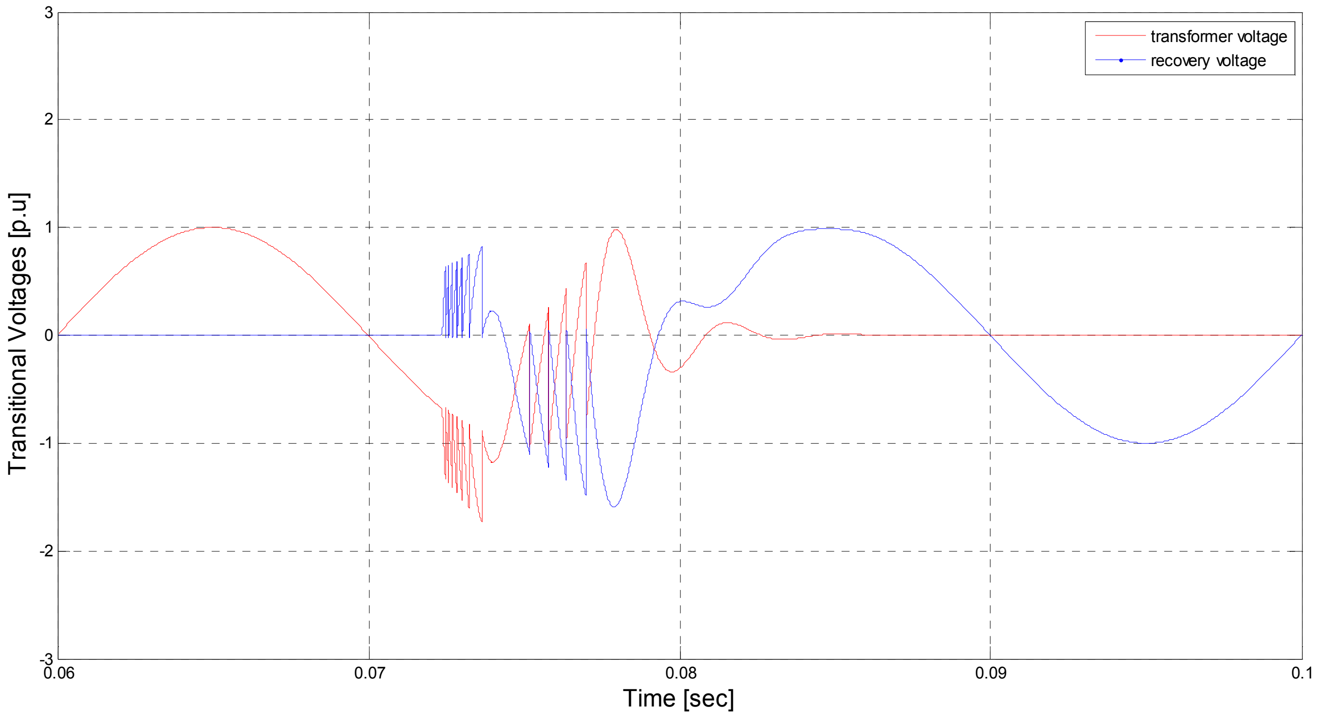


Figure 7. *Simulated transitional voltages (stable solutions) at switching-off unloaded transformer.*

Developing of numerical methods has led to change the evaluation of the problems and methods' stiffness. e.g. problem may be estimated as a stiff one at use some numerical method, may be considered as a non-stiff one at use the other method (ode solver in our case).

4. On Simulation of Switching-off Unloaded Power Transmission Lines

Some physical peculiar properties of no-load power transmission lines switching-off process are presented in [16, 22].

Our researches concerned to switching-off power transmission lines let us to reveal the main feature of computer simulation of this transient in comparison with switching-off power capacitor banks and unloaded transformers (auto-transformers). This is notably greater time required for obtaining stable solutions. In our opinion it is conditioned by higher free frequencies (about 1350 – 6000 Hz for 110 kV power transmission lines of length 20 – 90 kilometers, higher frequencies correspond to less lengths). It leads to the necessity of use very little initial step sizes (at most 1 nanosecond at relative tolerance no more than 10^{-6}) providing stability of solutions. Subsequently on smoother parts of solutions, this will lead to an unnecessarily larger amount of computation with a corresponding increase in the simulation time.

It must be noticed here that use the initial step sizes more than 1 nanosecond at relative tolerances less than 10^{-6} does not ease obtaining the stable solutions. In other words, stability of solutions is more sensitive to the value of initial step size rather relative tolerance.

5. Conclusions

1. Free frequencies of transitional processes in electrical systems have significant impact on stability of solutions for transitional functions. Higher free frequencies give greater contribution to numerical simulation's global error and worsen convergence of solutions and their stability. This should be taken into consideration at numerical research of transitions at switching-off unloaded transformers and autotransformers.
2. There is no definite influence of increased attenuation of the switched-off circuit on stability of solutions. It seems that the influence of attenuation on stability depends on the features of the methods (solvers) used, which problem requires additional research.
3. The type of circuit-breaker may have influence on magnitudes of transitional voltages, and impacts by this reason on stability of solutions. The circuit-breakers with steeper law of electric strength restoration (e.g. vacuum ones) worsen computational stability compared to circuit-breakers with a less steep restoration law (e.g. SF_6 ones).

References

[1] J. P. Bickford, N. Mullineux, and S. R. Reed, Computation of Power System Transients. Peter Peregrinus Ltd., England, 1976.

[2] Klaus Ragaller, Current Interruption in High Voltage Network, Plenum Press, New-York, 1978.

[3] T. Lazimov, S. Akhundov, "Peculiarities of transients' simulation in electrical circuits," in Proc. 2003 of the Republican Conference on IT, Baku, Azerbaijan.

[4] L. F. Shampine, Numerical solutions of ordinary differential equations, Chapman and Hall, New-York, 1994.

[5] E. Hairer, S. P. Norsett, and G. Wanner, Solving ordinary differential equations, Part 1, Springer-Verlag, Berlin, Heidelberg, New-York, London, Paris, Tokyo, 1987.

[6] T. Lazimov, E. Saafan, "Influence of Arc Resistance on Transitional Functions' Stability at Computer Simulation of Switching-off Processes," Proc. of the IEEE PES APPEEC Conference, Hong-Kong, 2014, pp. 1-4.

[7] T. Lazimov, A. Sadigov, and Sh. Mammadly, "Some Features of Computer Simulation Transitional Processes at Switching-off Unloaded Transformers," Balkan Journal of Electrical & Computer Engineering, 2017, vol. 5, 1, pp. 5-8.

[8] E. Fehlberg, NASA Technical Report, TR R-287, 1968.

[9] C. Moler, Numerical Modeling with MATLAB, Society for Industrial and Applied Mathematics, 2004.

[10] T. Lazimov, S. Imanov, "On stability while simulating the switching offs the capacitive and small inductive currents," in Proc. 2006 of MEPS International Symposium, Wroclaw, Poland, pp. 407-410.

[11] T. Lazimov, S. Imanov, and E. Saafan, "Transitional Recovery Voltages at Capacitive Currents Switching-off's by Vacuum and SF_6 Circuit-Breakers," in Proc. 2010 of MEPS International Symposium, Wroclaw, Poland, pp. 777-783.

[12] T. Lazimov, E. Saafan, "On interaction between circuit-breaker and network at small inductive currents' switching-offs," Present Problems of Power System Control, Wroclaw, Poland, vol. 1, No. 1, pp. 23-31, 2011.

[13] G. Nicolis, I. Prigogine, "Exploring Complexity. An Introduction", W. H. Freeman and Company, New-York, 1989.

[14] Shengwen Shu, Jiangjun Ruan, Daochung Huang, and Gaobo Wu, "Influencing factors of breaking capacity of double-break vacuum circuit-breakers," Telkomnika, Vol. 11, No. 6, pp. 2903-2911, 2003.

[15] T. Lazimov, S. Akhundov, "Modeling of electrical strength of high voltage circuit-breakers," in Proc. 2001 of the International Symposium SIEMA, Kharkov, Ukraine, pp. 112-114.

[16] T. Lazimov, S. Imanov, "Some results of unloaded line switching-offs' computer Simulation," Proc. of the 5-th International Conference ELECO'2007, Bursa, Turkey, Dec 2007, pp. 147-150.

[17] T. Lazimov, S. Akhundov, "Research on Influence of High-Voltage Circuit Breakers' Characteristics on Switching Overvoltages and Overcurrents," in Proc. 2003 of the III International Conference ELECO, Bursa, Turkey, pp. 1-4.

[18] H. Mammadov, T. Lazimov, and S. Imanov, "Improved model of circuit-breaker's dielectric strength restoration," in Proc. 2009 of the ELECO International Conference on Electrical and Electronic Engineering, Bursa, Turkey, pp. 354-356.

[19] H. A. Mammadov, T. M. Lazimov, S. V. Imanov, and A. Nayir, "Comparison of transients while switching-off capacitor banks by vacuum and auto-compression circuit-breakers," in Proc. 2008 of the Fourth TPE International Conference, 2008, Pitesti, Romania, pp. II. 9-II. 12.

[20] T. Lazimov, S. Akhundov, "Numerical modeling of current chopping in circuit-breakers," Power Engineering Problems", No 2, pp. 38-43, 2000.

[21] K. Dekker, J. G. Verwer, Stability of Runge-Kutta methods for stiff nonlinear differential equations, Elsevier Science Publishers B. V., Amsterdam-New York-Oxford, 1984.

[22] T. Lazimov, E. Saafan, "Transitional Processes at Switching-off Unloaded Power Transmission Lines by Modern Circuit-Breakers and their Computer Simulation," Present Problems of Power System Control, Wroclaw, Poland, vol. 3, No. 2, pp. 67-75, 2013.

Biography

Tahir Lazimov was born in Baku, Azerbaijan in 1955. He received the engineer qualification in electrical engineering from the Azerbaijan State Oil Academy, Baku, in 1977, Ph. D. degree in high voltage engineering from the Tomsk Polytechnic Institute, Tomsk, Russia, in 1989. From 1977 to 2004 he worked in the Power Engineering Research Institute, Baku. Since 2004 he has been a head of the Electric Power Engineering Department in the Azerbaijan Technical University, Baku. He is the author of about 180 published scientific works. Professor T. Lazimov is IEEE Senior member, the member of some academic and editorial boards.

Esam Ali Saafan was born in El-Mansoura, Egypt in 1977. He received the B. Sc. and M. Sc. degrees in Electrical Engineering from Faulty of Engineering, University of El-Mansoura, Egypt in 2001 and 2007 respectively. He obtained the Ph. D. degree in High Voltage Engineering in 2012 from Azerbaijan Technical University, Baku. From 2001 to 2012 he worked in the Electrical Engineering Department, University of El-Mansoura, Egypt as a Lecturer Assistant. Since 2012, he has been a Lecturer in the same university. Dr. Esam Ali Saafan research areas include transitional processes in power electric systems and their computer simulation, power systems electromagnetic compatibility.