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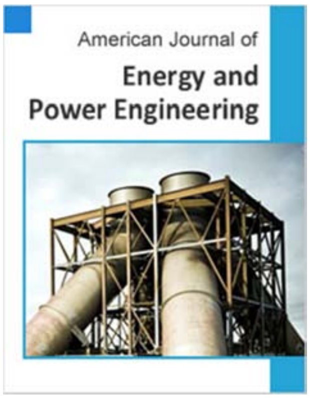

On Stability and Behavior of Solutions at Computer Simulation of Transients in Electric Power Systems

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Keywords

Transitional Functions, Local and Global Error, Repeated Re-Strike, Computer Simulation, Simulation Parameters, Stiffness of Equations

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Abstract

Stiff ordinary differential equations' solvers included in the MATLAB set are investigated in this paper from the point of view stability in the context of transitions in electric power systems. Quantitative and qualitative distinctions conditioned by the four different stiff methods (solvers) used in the wide ranges of initial step sizes and tolerances are studied on high-voltage power capacitor banks switching-off example. It is shown in the paper that in some cases even a little quantitative distinction of transitional functions' instantaneous values from ones for stable solutions due to step-to-step accumulation of local errors may cause qualitative distinctions in solutions' behavior.

1. Introduction

As it is known computer simulation is one of the main and sometimes even only facilities for studying scientific and engineering problems. It is very important for solving numerous problems in the electric power engineering area especially in studying switching transients in electric power systems.

The most important definitions of transitional processes' numerical modeling and computer simulation are "stiffness" of differential equations and stability of solutions [1, 2]. These two concepts are closely related [3]. Note that formalization of transitional voltages' equations with "stiff" differential equations is the main mathematical feature of transitional processes in electric networks [4].

It was shown in our previous research and papers how the simulation methods and parameters (initial step size and tolerance) may influence on stability of solutions (i.e. adequacy of results) at studying transitional processes in electric power systems [5, 6].

Note that distinctive behavior of solutions got at use different modeling and simulation methods (ode solvers) was examined in detail in [1, 3]. There was shown in [1] how the methods themselves used with the same simulation parameters (such as initial step size and tolerances) may influence on result of integration and behavior of solutions. We can also notice in this view that minded analyze presented in [1, 3] was implemented for non-stiff problems, so we can expect more distinctive behavior of solutions got at use different simulation methods for stiff problems that concerned to transients in power electric systems [4].

The present paper is devoted to research of influence the global error conditioned by local rounding and limitation errors have taken place at each simulation step and accumulating from step to step, on the development of the transitional process and magnitude of transitional functions.

2. Computational Ground

Research of stability and behavior of transitional voltages i.e. overvoltage on the terminals of switched-off installation and recovery voltage on the circuit-breaker was carried out for only kind of switching – switching-off power capacitor banks with rated voltage 110 kV and jet power 75 MVAr by vacuum circuit-breaker. Corresponding electrical connection scheme and equivalent network are given in [5-7].

As it is known the main characteristics of circuit-breakers completely reflecting their behavior at switching processes are chopping current (or chop current), the law of restoration the electric strength in the inter-contact space of circuit-breaker, and switching-off time [7-9].

The dielectric strength restoration law used in the present research was taken from obtained in [10] and used in our previous researches.

Current interruption in circuit-breakers (i.e. arc quenching) has taken place at the instant corresponded to the condition,

$$|i| \leq I_{ch}, \tag{1}$$

where i is decreasing current passing through the circuit-breaker, I_{ch} is chopping current depended on the circuit-breaker type.

Repeated re-strikes and re-ignitions of arc has taken place at the instant corresponded to the condition,

$$|\Delta V| \geq V_{ds}(t). \tag{2}$$

where ΔV is a recovery voltage between poles of the circuit-breaker, $V_{ds}(t)$ is a function of electric strength between the contacts of circuit-breaker [7].

In the present research we took into the consideration resistance of arc appeared between the contacts of circuit-breaker. The arc resistance was given in correspondence with [11, 12].

For the computer simulation of the problem under consideration we used 4 solvers of ordinary differential equations included to the Simulink ode solvers set. The numerical methods ode 23tb, ode 23t, ode 15s and ode 23s [13] were used for simulation. Note that all the methods used concerns to so called stiff methods.

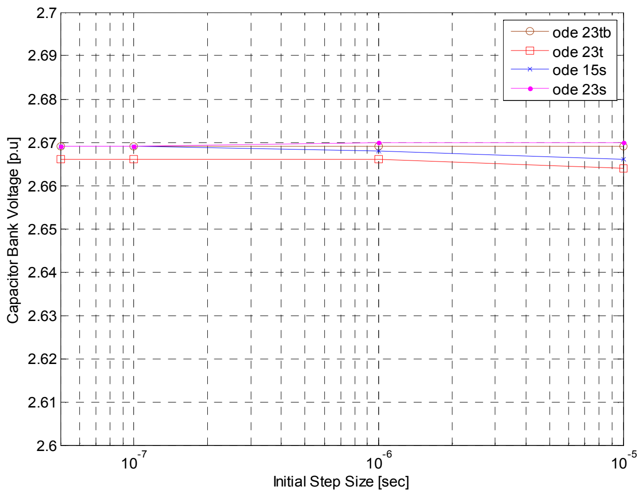
3. Discussion: Stability and Quantitative Distinctions

All the results of computer simulation switching-off capacitor banks by vacuum circuit-breaker at use different ode solvers in wide ranges of initial step size and tolerance are presented in the figures (1, 2). Figure (1) concerns to the overvoltages across the terminals of the capacitor banks whereas; figure (2) concerns to the recovery voltages across the terminals of the vacuum circuit-breaker.

Consider now how to distinguish the stable solution from the unstable ones.

The main rule lets us to recognize the unstable solution is that it has significant quantitative difference from the stable solutions whereas all the stable solutions of the same problem (got at use different modeling methods and simulation parameters) are equal to each other within a very small computational error which does not exceed tenths or even hundredths of a percent. In other words all the stable solutions are the same; the unstable solution is markedly different.

If analyze the magnitudes of overvoltage and recovery voltages at simulation switching-off capacitor banks (see chapter II) obtained due to computer simulation in the MATLAB medium (see figure 1, figure 2) we can state the following:



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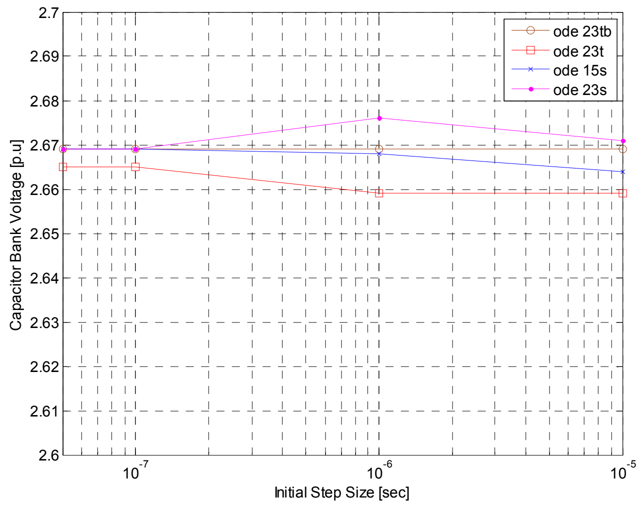

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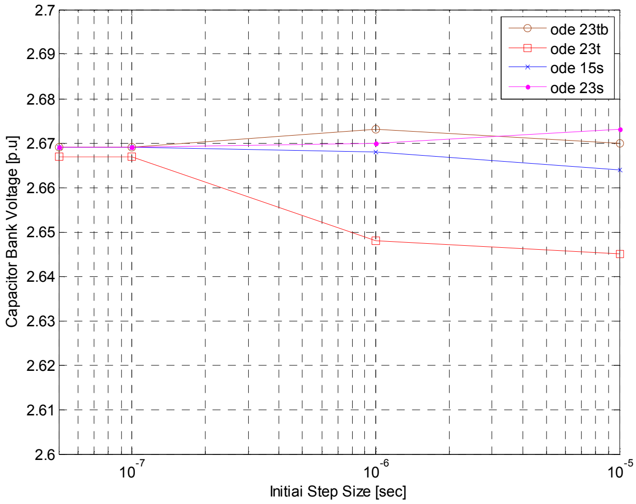

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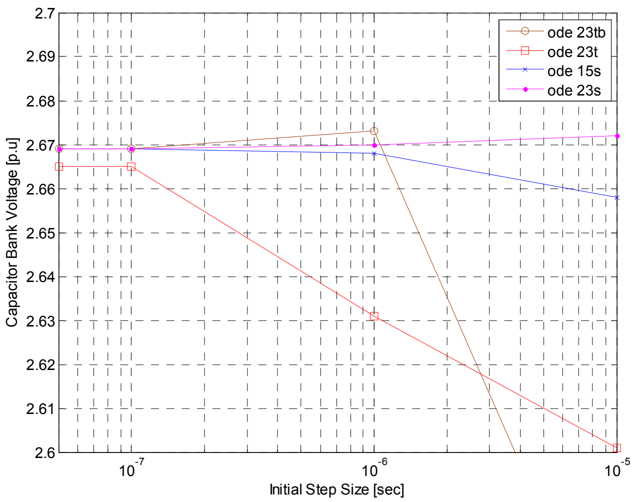
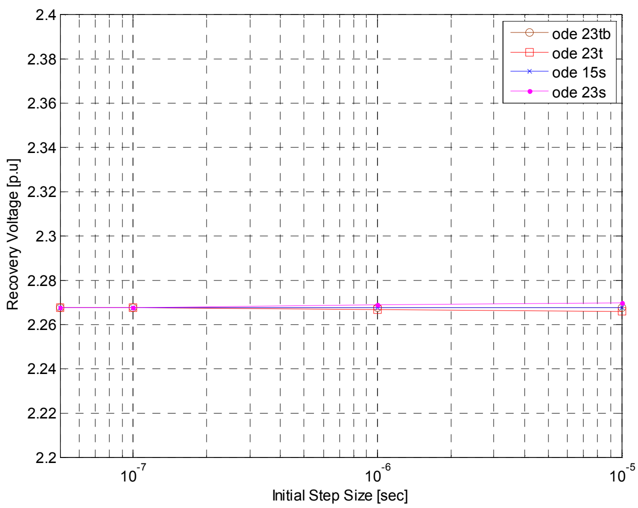


d)

Figure 1. *Voltage across the capacitor banks terminals: a) at tolerance 10^{-6}, b) at tolerance 10^{-5}, c) at tolerance 10^{-4}, d) at tolerance 10^{-3}.*



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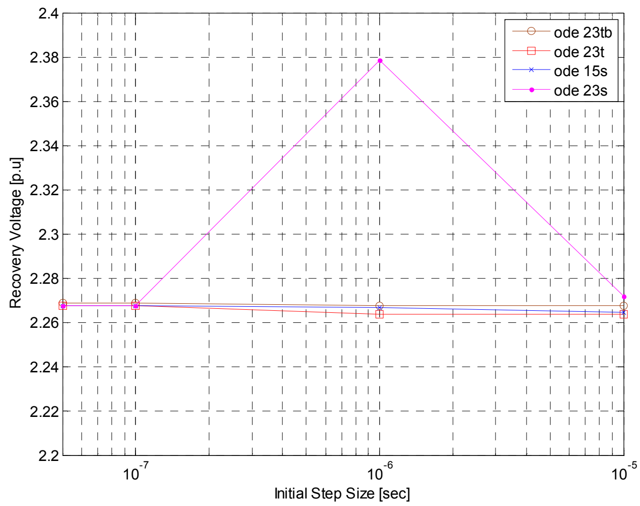

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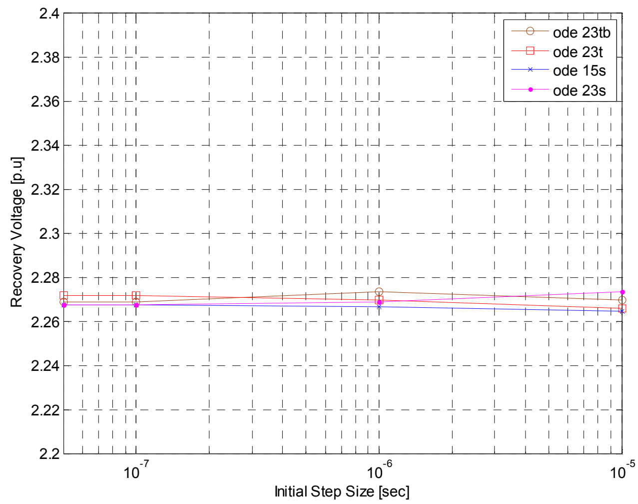

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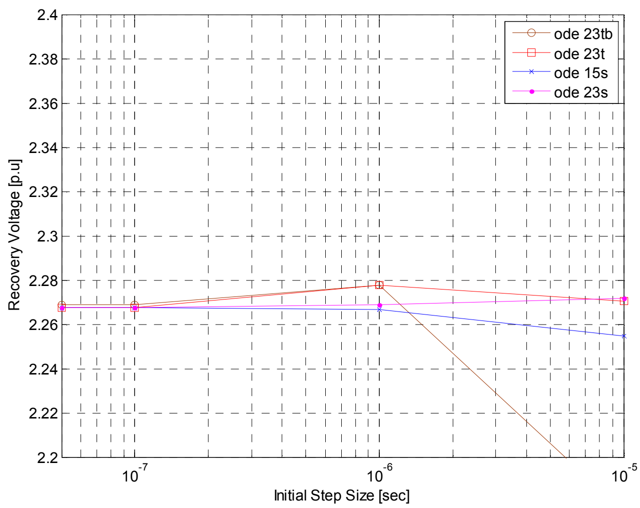


d)

Figure 2. *Recovery voltage across vacuum circuit-breaker terminals: a) at tolerance 10^{-3}, b) at tolerance 10^{-6}, c) at tolerance 10^{-4}, d) at tolerance 10^{-3}.*

- there has taken place definitive approach of the overvoltage and recovery voltage magnitudes to their stable values at decreasing initial step size for all the stiff methods included in the MATLAB set i.e. ode 23tb, ode 23t, ode 15s and ode 23s. Note that ode 23t solver gives some little deviation from the functions got by ode 23tb, ode 15s and ode 23s solvers even at the least initial step sizes used at computer simulations. Note here that the same conclusion may be done in reference of convergence of transitional functions changing by tolerance at fixed initial step sizes;

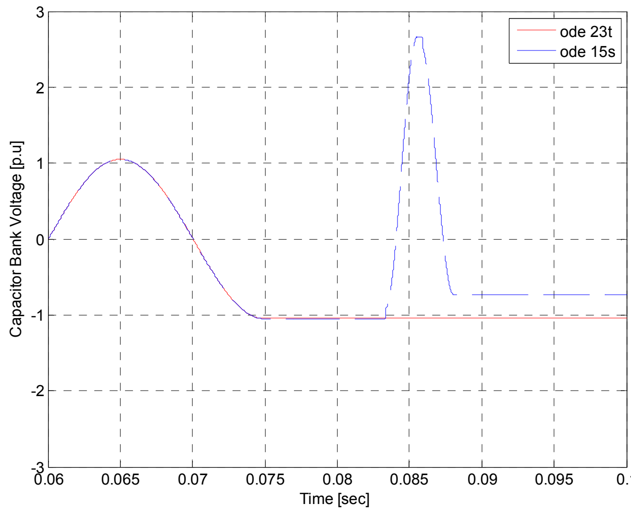
- the transitional functions having noticeably deviations from their stable values at change the initial step size and/or tolerance can successfully converge to these stable values, e.g. see behavior of transitional functions got by solver ode 23tb in the figure (1-d) and solver ode 23s in the figure (2-b). In contradistinction to this more uniform behavior of the function does not always lead to its successful convergence to the stable value, e.g. see change of transitional overvoltage function got by solver ode 23t in the figure (1);
- the greatest deviation of the transitional functions in the problem under consideration at use all the above minded simulation methods (ode solvers) and simulation parameters given in this chapter does not exceed (5 - 6)%;
- add here that how it was stated earlier in [6] behavior of transitional functions against tolerance is more uniform that one against initial step size so varying of tolerance at fixed initial step size is more preferable at search of stable solutions.
- Note that computer simulation of transients at switching-off unloaded transformers and autotransformers in electric power systems has some similarity with the problem considered [14]. The main difference between these problems is greater stiffness and subsequently worse solvability of the unloaded transformers switching-off problem.

4. Qualitative Distinctions

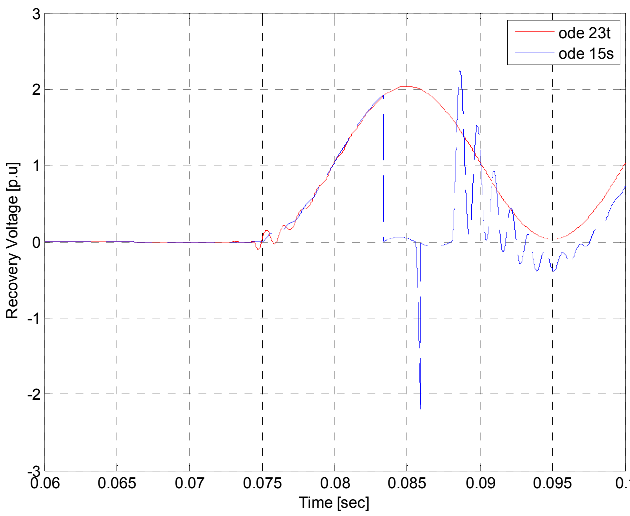
Note that in some cases unstable solutions may also have qualitatively distinctive behavior from the one for stable solution. These cases are ones for which a little calculative change of transitional functions conditioned by accumulation of local errors may cause change of some logical conditions (especially condition of occurrence of repeated re-ignitions and re-strikes in the problem under consideration) included in the mathematical model of the problem. We must notice here that overvoltages at switching-off power capacitor banks are conditioned just by repeated re-ignitions of arc in circuit-breakers [15, 16]. It means that switching-off power capacitor banks belongs just to cases sensitive to change of transitions' conditions. This is evidently seen in the figure (3).

Both simulations with results given in the figure (3) were done for the same problem and absolute identity of the physical parameters of the equivalent networks (see [5]) and initial conditions of computer simulation. Besides, the curves presented in the figure (3) were got at the same simulation parameters (initial step size 10^{-6} seconds and relative tolerance 10^{-3}). So we can state that distinctive behavior of the functions presented in the figure (3) is conditioned just by method (solver) used. In other words it will depend on stability and value of the error accumulating from step-to-step. As a result a more distinctive calculative change of recovery voltage at use the ode 23t solver (in comparison with other solvers) prevents its intersection with the curve of restored electrical strength of circuit-breaker and whereas at use the 15s ode solver we got repeated re-strikes and quite other behavior of transitional functions. Note that less tolerances (no more than 10^{-4}) lead to improving of behavior of solutions at use the ode 23t solver.

We suppose that similar conclusions may be done also for other kinds of transients in electric power systems, e.g. switching-off of no-load transformers.



a)



b)

Figure 3. *Simulated transitional functions at switching-off capacitor banks: a) voltages across the terminals; b) recovery voltages.*

5. Conclusion

Stability of the ordinary differential equations' solvers included in the MATLAB set in the context of transitional processes in electric power systems is studied in the paper. Some calculative features of high-voltage capacitor banks switching-off are investigated. It is shown in the paper that accumulation of local errors conditioned by nature of computer simulation common technique (step-by-step calculation and rounding at each step) may seriously influence on results' adequacy. In particular, in the problem under consideration accumulation of errors leads to notable calculative change of recovery voltage and may influence on condition of occurrence repeated re-strike in circuit-breaker. As a result we may get qualitatively distinguished behavior of transitional functions in comparison with ones got at use more appropriate (from the point of view stability) methods and/or more optimal simulation parameters (initial step size and tolerance).

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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 Federation, in 1989. From 1977 to 2004 he worked in the Power Engineering Research Institute, Baku, Azerbaijan. Since 2004 he has been a head of the Electric Supply and Insulation Department in the Azerbaijan Technical University, Baku. He is the author of about 170 published scientific works. Professor T. Lazimov is IEEE Senior member, the member of some academic and editorial boards in Azerbaijan and abroad.

Esam 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 Saafan research areas include transitional processes in power electric systems and their computer simulation, power systems electromagnetic compatibility.