Some Features of Computer Simulation Transitional Processes at Switching-off Unloaded Transformers

T. Lazimov, A. Sadigov, and Sh. Mammadly

***Abstract*— Stability of computer simulation transitional processes at switching-off unloaded power transformers is considered in the article. Solvability and stability of solutions of this problem had been tested by the four stiff ordinary differential equations' solvers in the wide ranges of initial step sizes and relative tolerances. On the base of analyze the calculated values of voltages across the terminals of switched-off transformer and recovery voltage across the poles of circuit-breaker there were made some conclusions and stated the features of the simulation process. Results at use both fast and robust algorithms of the ode solvers were analyzed and compared in the article.**

Index Terms— **fast and robust algorithms, initial step size, ordinary differential equations' solvers, relative tolerance, stability of solutions.**

I. Introduction

As it is known the most dangerous switching transients from the point of view the transitional voltages' magnitudes take place at switching-offs small inductive currents of unloaded transformers and autotransformers and capacitive currents of power capacitor banks and unloaded no-load power transmission lines [1], [2].

Numerical modeling and computer simulation being the main way to study transitional processes in power electric systems have usually faced with the necessity to provide stability of solutions because that these problems relate to the so called "stiff" ones [3]. Successful computer simulation (in other words, getting the stable solutions) of this class of problems requires determination of appropriated ordinary differential equations' solvers (ode solvers) and optimal simulation parameters i.e. initial step sizes an relative tolerance [4].

We had previously got some results in the area under consideration. Recall them briefly.

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Manuscript received August 23, 2016; accepted October 17, 2016.
DOI: 10.17694/bajece.292577

There was stated in [5,6] that there is a notable dependence of stability on the simulated network parameters, especially free frequencies and damping factor. The worst stability takes place as a rule for the higher free frequencies. Note in this view that there are at least 2 important features complicating computer simulation the problem under consideration, namely:
- relatively high free frequency at unloaded transformers switching-off conditioned by the very little values of their input capacitance equaled to units and tens of nanofarad;
- a steep rise of electrical strength's restoration law in the initial period of contacts separation taken place for vacuum circuit-breakers.

Both features lead to increasing of a global error of simulation via increasing the local errors with evident possible impact on stability.

As it may be assumed increasing of damping will lead to improving of stability. It may be done on the base of general suppositions concerned to physical and computational nature of the problem considered. But as we stated in [3] assumption on positive influence of damping on the stability of solutions is not so evident.

In the present article stability of solutions at computer simulations of unloaded transformers switching-off is studied in details.

II. Computational Ground and Conditions

Multi-phase induction motors are used in wind power systems, electrical and hybrid vehicles [5], electric ship propulsion [6], in 'more electric aircraft' actuators and in safety-critical applications, such as aerospace or military naval drives, where fault tolerance is a desirable feature [7].

Theoretical and computational ground of the problem considered is presented on some our previous works, e.g. [3], [7-9]. The equivalent schemes and switching-off conditions are given in [3,5-7]. The laws of restoration electrical strength of circuit-breaker (in other words the function of breakdown voltage of inter-contact space of circuit-breaker) are offered and analyzed in [9-11].

The stiffness of differential equations in relation to network parameters and stability problem at computer simulation transitional switching-offs in electric power systems were considered in [3,5,8] and some other works.

The present research was dedicated to study of stability at computer simulation switching-offs unloaded power transformer of rated voltage 110 kV and rated apparent power

32 MVAr. The transformer is switched by the vacuum circuit-breaker with electrical strength restoration law given in [9].
The numerical methods ode 23s, ode 23tb, ode 23t and ode 15s included to the Simulink ode Solvers were used for computer simulation. The MATLAB r2013a version was used for simulation.

III. Discussion

Let us now consider the results of computer simulation at use so called stiff solvers ode 23s, ode 23t, ode 23s and ode 15s included to the Simulink-MATLAB set.
Fig.1 presents graphs of transitional voltages across the switched-off transformer's high-voltage terminals got at use all the above-minded ode solvers for initial step sizes varied between 10 nanoseconds and 100 microseconds and tolerances between 10^{-6} and 10^{-4}. Fig.2 presents graphs of transitional recovery voltages at use the same methods and simulation parameters. The robust algorithms were used. As it is seen from the Fig.1 and Fig.2 the solver 23s and all the robust algorithms of the ode 23t, ode 23tb and ode 15s provide good solvability and stability of solutions both for the functions of voltage across the switched-off transformer's high-voltage terminals and recovery voltage (i.e. voltage across the circuit-breaker's poles). The most deviations from the transitional voltages' stable values in the given ranges of simulation parameters do not exceed 4 percent for the voltage across the terminals (V) and 1 percent for the recovery voltage (ΔV). For both functions' graphs of the transitional functions against the initial step size are successfully converge to their stable values.

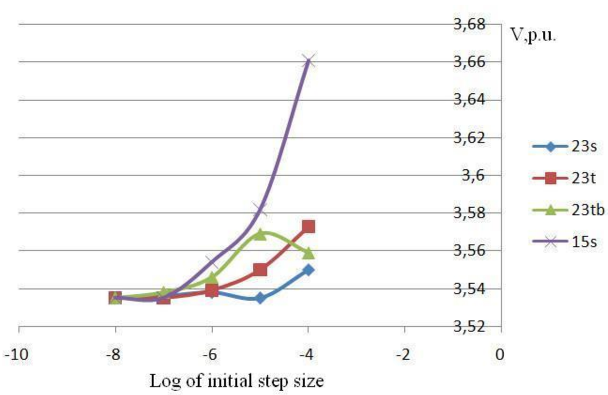

Fig.1. Calculated voltage ratios against initial step size at use robust algorithms (relative tolerance 0.000001)

Fig.3 and Fig.4 present graphs of transitional voltages across the switched-off transformer's high-voltage terminals and transitional recovery voltages respectively got at use the fast algorithms of above-minded ode solvers for initial step sizes varied between 10 nanoseconds and 100 microseconds and tolerances 10^{-6} and 10^{-4}.

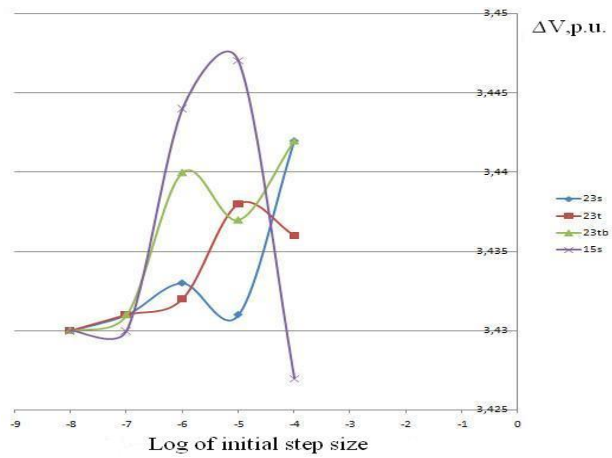

Fig.2. Calculated recovery voltage ratios against initial step size at use robust algorithms (relative tolerance 0.000001)

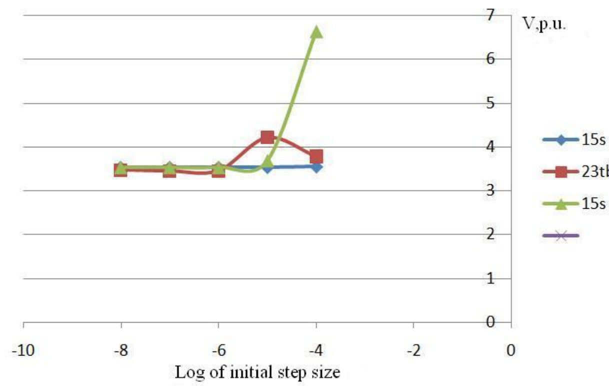

Fig.3. Calculated voltage ratios against initial step size at use fast algorithms (relative tolerance 0.000001)

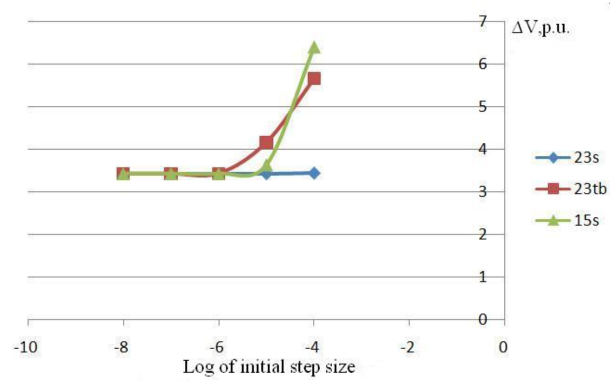

Fig.4. Calculated recovery voltage ratios against initial step size at use fast algorithms (relative tolerance 0.000001)

As we can see from these figures the fast algorithms have notable worse solvability and stability comparatively with corresponding robust ones. Thus, the fast algorithm of the ode 23t solver does not provide stability of solutions and is characterized

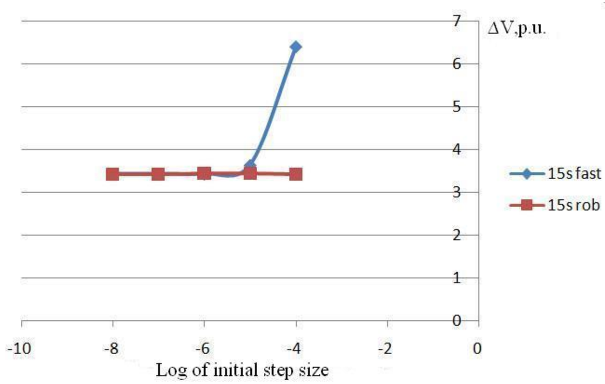

Fig.5. Comparison of calculated recovery voltage ratios at use robust and fast algorithms (relative tolerance 0.000001)

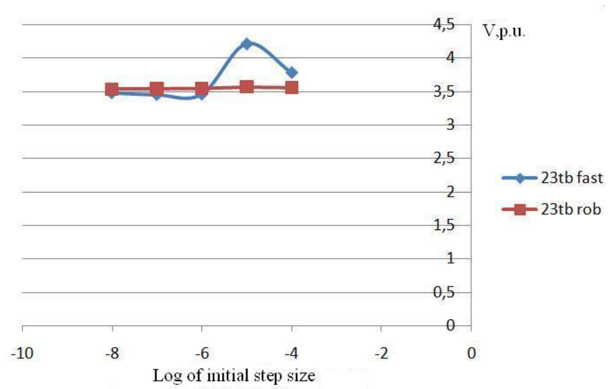

Fig.6. Comparison of calculated voltage ratios at use robust and fast algorithms (relative tolerance 0.000001)

with very big deviations from the stable solutions. The fast algorithm of the 23tb method has much better solvability but does not provide reaching of stability even at the least simulation parameters (initial step size 10 nsec and relative tolerance 10^{-6}).

For the more explicit demonstration of behavior of solutions at use the fast and robust algorithms is used comparative presentation of graphs of the transitional functions against the initial step size given in Fig.5 for the recovery voltage (ode 15s solver) and in Fig.6 for the voltages across the switched-off transformer's high-voltage terminals. As it is seen from the Fig.5 there is great difference (deviation from the stable solution) between the values of transitional voltages calculated with use the different algorithms (the fast and robust ones) of the same solver, i.e. ode 15s in the considered case. In the same time there has taken place rapid convergence of the calculated transitional functions against initial step size which stabilize beginning from the relative tolerance 10^{-4}. But in some cases transitional function calculated at use fast algorithm cannot reach its stable value got at use the appropriate robust algorithm even for very little given values of the relative tolerance (see Fig.6). As a rule further decreasing of the relative tolerance leads to significant increasing of simulation time.

IV. Conclusions

The ode 23tb and 23t solvers have no solvability for the fast algorithm. Both solvers have good solvability and convergence for the robust algorithm especially at the initial step size no more than 10^{-5} sec and relative tolerance no more than 10^{-5}.

The ode 23s solver (having no robust algorithm) demonstrates good solvability and convergence at simulation the problem under consideration in given ranges of initial step size (between 10 nsec and 100 μsec) and relative tolerance (between 10^{-6} and 10^{-4}).

The ode 15s solver demonstrates good solvability and convergence for the robust algorithm especially at the initial step size no more than 10^{-6} sec and relative tolerance no more than 10^{-4}. Worse (but satisfactory) solvability and convergence have taken place for the fast algorithm at the initial step size no more than 10^{-6} sec and relative tolerance no more than 10^{-4}. Note that the value of tolerance 10^{-4} is satisfactory just at the least values of the initial step size i.e. 10 nsec.

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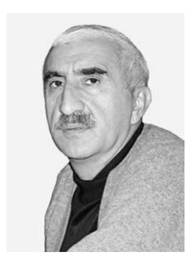
Biographies



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