Scientific Papers of the
Institute of Electrical Power Engineering of the
Wrocław University of Technology

PRESENT PROBLEMS OF POWER SYSTEM CONTROL

No 1

Wrocław 2011

Keywords:
SF6 and vacuum circuit-breakers, small inductive currents,
dielectric strength restoration, overvoltage, recovery voltage

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ON INTERACTION BETWEEN CIRCUIT-BREAKER AND NETWORK AT SMALL INDUCTIVE CURRENTS' SWITCHING-OFFS

Results of an investigation of interaction between circuit-breaker against its dielectric strength restoration law and parameters such as chop current and operation time (all conditioned by the circuit-breaker type and arc quenching medium) at small inductive currents' switch-offs are presented in this article. The results include curves of transitional voltages at switching under consideration and also conclusions on dependence of overvoltages and recovery voltages ratios on re-ignitions in inter-contact space. The results concerning investigation of stability are also presented. The analyzed methods were investigated from the point of view of stability in wide range of simulation parameters.

1. INTRODUCTION

Interaction between circuit-breaker and network means, in general, influence of circuit-breaker characteristics on transitional processes which may occur at circuit-breakers' switching. The minded problem has been investigated since 1970's of the last century (e.g. see [1, 2]). Note that the first researchers were mainly interested in the circuit-breakers design and construction in the view of transitional processes rather than in the influence of circuit-breakers themselves on the transient processes may take place in electric networks.

Switching-offs the small inductive currents in power systems were investigated for no-load transformers of rated voltage 110 kV. The equivalent networks used for the problem under consideration (e.g. see [3, 4]) have no great differences. The one presented in [4] and shown in Fig. 1 has been used in the analysis.

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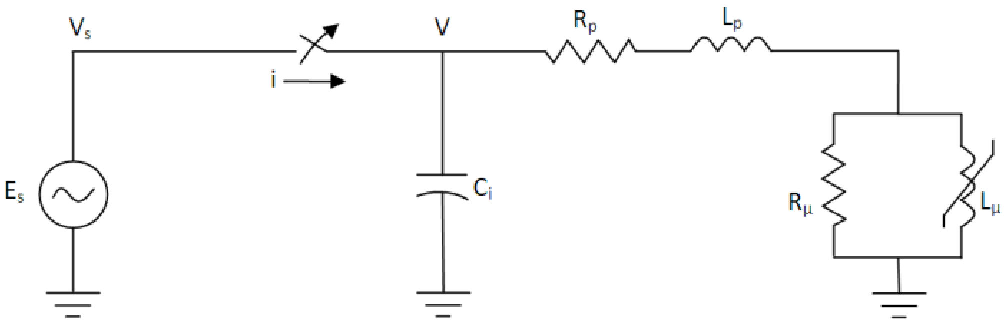

Fig. 1. Equivalent network

In Fig. 1 R_p is the transformer's primary resistance; L_p is the transformer's primary inductance; R_μ is the transformer's core resistance; L_μ is the transformer's core inductance; C_i is the transformer's input capacitance.

The maximum values of the chop current for SF6 circuit-breakers were determined depending on switched currents values in accordance with [5]. For vacuum circuit-breakers the maximum chop current given in [6] was used. This is due to that unlike auto-compression circuit-breakers vacuum ones have the chop current which does not depend on switched currents

For the modeling of dielectric properties of the inter-contact spaces the following laws have been used:

- the co-sinusoidal law of dielectric strength restoration in auto-compression (SF6) circuit-breakers presented in [7],
- the logarithmic law of dielectric strength restoration in vacuum circuit-breakers, as in [8].

For computer simulation of transitional processes conditioned by 110 kV no-load transformers switching-offs the MATLAB ode 23tb method and also 23t and 15s methods (see also [9]) have been mostly used. As it was stated earlier the ode 23tb method has given the best solutions from the point of view of stability for the problem considered in the article [9].

The parameters of the computer simulation such as initial step size, absolute and relative tolerances were chosen under the necessity to provide stability of the solution got. As it was shown in [9, 10] this is conditioned by stiffness of differential equations formalized currents and voltages and their first temporal derivatives for the transitional regimes of electric networks. The investigation of stability of computations is presented further.

Note that alike capacitive currents switching-offs the same commutation of small inductive currents is one of the most dangerous regimes from the point of view of influence on insulation of electric systems and circuit-breakers themselves.

2. RESULTS OBTAINED AND DISCUSSION

Numerous runs of computer simulations of no-load transformer (autotransformer) switching-off process realized the known models described in [3, 4] for the cases of switched current less or equal to chopping current of circuit-breaker have been carried out. Description of the gotten results follows.

The greatest ratios of overvoltages and recovery voltages take place at absence of repeated re-ignitions in inter-contact space during the contacts separation time. It means that maximum values of overvoltages and recovery voltages at switching-off small inductive current may depend just on the circuit-breaker chop current and transformer input capacitance and no-load regime inductance. Note that for capacitive currents switching-off there is more complicated dependence of overvoltages and recovery voltages on appearance and number of repeated re-ignitions which causes overvoltages [3, 11]. In the same time too great number of repeated re-ignitions may even limit the overvoltage ratios at switching-off capacitive currents of capacitor banks [12].

In Fig. 2 and Fig. 3 the calculated curves of transitional voltages at switching-off the transformer (ТД type, rated apparent power 31.5 MVA, rated voltage of switched winding 110 kV) by the SF6 circuit-breaker with chop current 6.11 A and vacuum circuit-breaker with chop current 5 A (for chrome-copper contacts) are presented, respectively. As it seems from the obtained results there takes place greater values of overvoltage and recovery voltage for the SF6 circuit-breaker. It is conditioned by the greater value of the chop current for the SF6 circuit-breaker in the network under consideration in comparison with vacuum ones equipped with chrome-copper contacts [5]. If accept the same values of chop current for either kind of circuit-breaker we would get the strongly same ratios at absence repeated re-ignitions. Also for the vacuum circuit-breakers with copper-bismuth contacts one will get greater overvoltages and recovery voltages than for SF6 circuit-breakers [5]. It is conditioned by the minded fact on correspondence of maximum overvoltages and recovery voltages to the condition of absence of repeated re-ignitions. As a result, a transitional process at maximum V and ΔV does not depend on dielectric strength restoration law which is the most important factor determining interaction between a circuit-breaker and a network. In Fig. 4 the calculated curves of transitional voltages for the switching-off process accompanied with repeated re-ignitions (at SF6 circuit-breaker use) are presented. Note that for all the cases accompanied with repeated re-ignitions ratios of overvoltages and recovery voltages are less than the ones presented in Fig. 2 and Fig. 3. One may also conclude that use of vacuum circuit-breakers with copper-bismuth contacts for switching of transformers and autotransformers is not expedient.

Value of the chop current has generally a significant influence on ratios of overvoltages and inter-contact recovery voltages at switching-offs small inductive currents of no-load transformers and autotransformers. In Fig. 5 the calculated curves of transitional voltages at switching-off the 110 kV winding of the ТД type transformer of apparent rated power 31.5 MVA by the SF6 circuit-breaker with chop current 4 A for the case of absence of repeated re-ignitions (i.e. for the worst case) are given. Comparing curves of *V* and Δ*V* presented in Fig. 2 and Fig. 5 one can state that less value of chop current causes less magnitudes of overvoltage and inter-contact recovery voltage. The differences are equal to 24% for *V* and 38% for Δ*V*. Remind that values of chop current depend on circuit-breaker camera's construction and contacts' material [13] (see also the previous conclusion). For auto-compression SF6 circuit-breakers it also depends on amplitude of switched-off current [5].

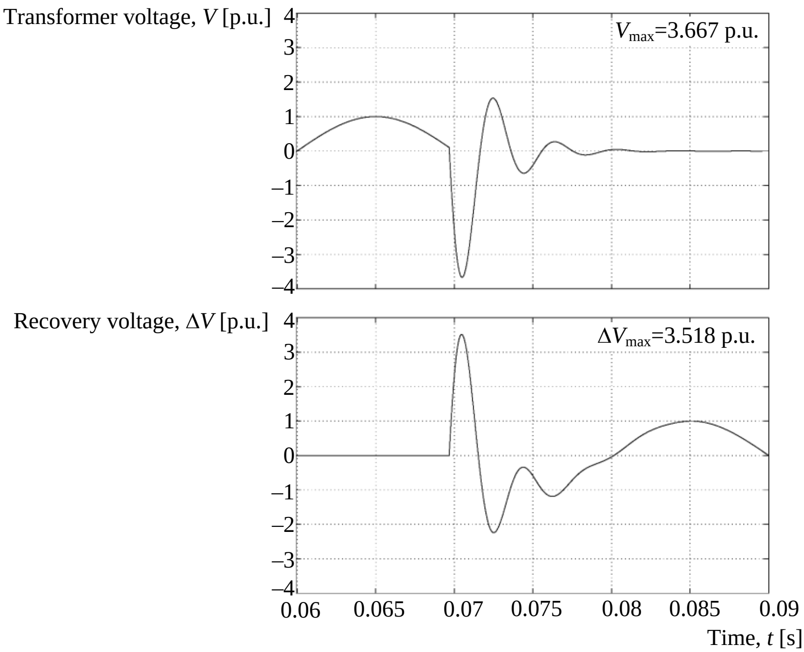

Fig. 2. Transient voltages at switching-off transformer of 31.5 MVA, 110 kV by SF6 circuit-breaker (with no repeated re-ignitions)

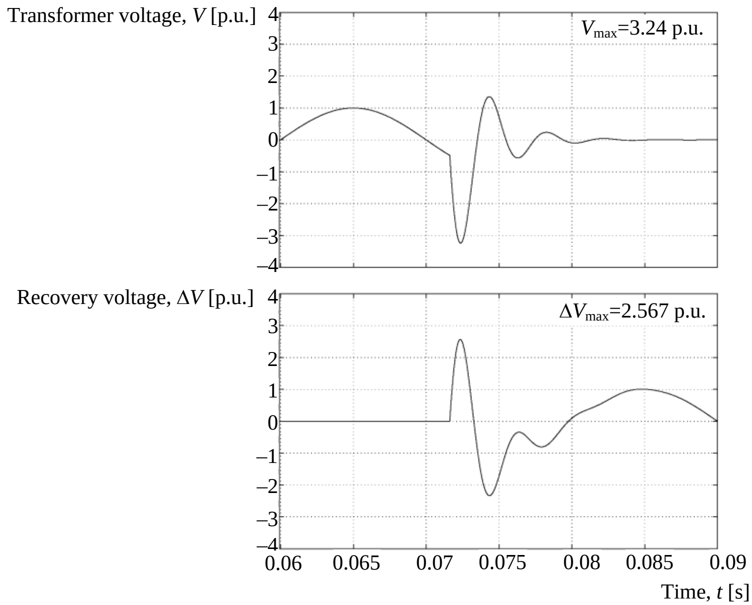

Fig. 3. Transient voltages at switching-off transformer of 31.5 MVA, 110 kV by vacuum circuit-breaker (with no repeated re-ignitions)

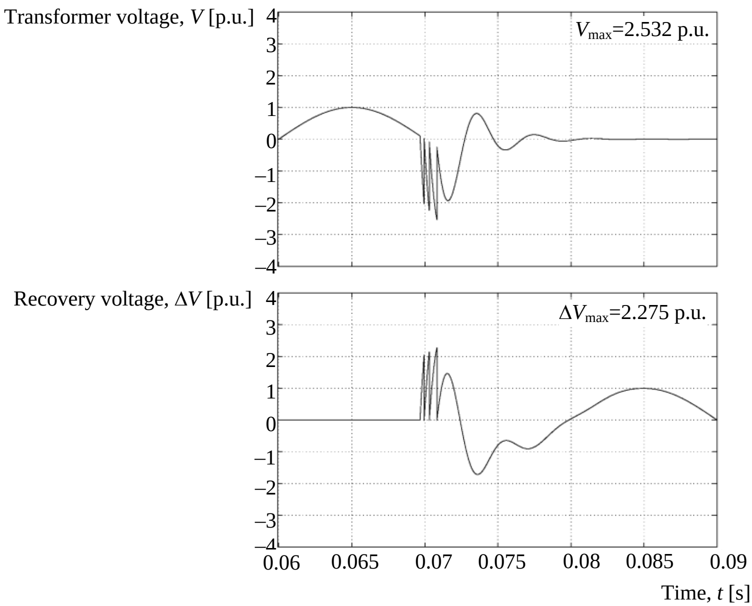

Fig. 4. Transient voltages at switching-off transformer of 31.5 MVA, 110 kV by SF6 circuit-breaker (with repeated re-ignitions)

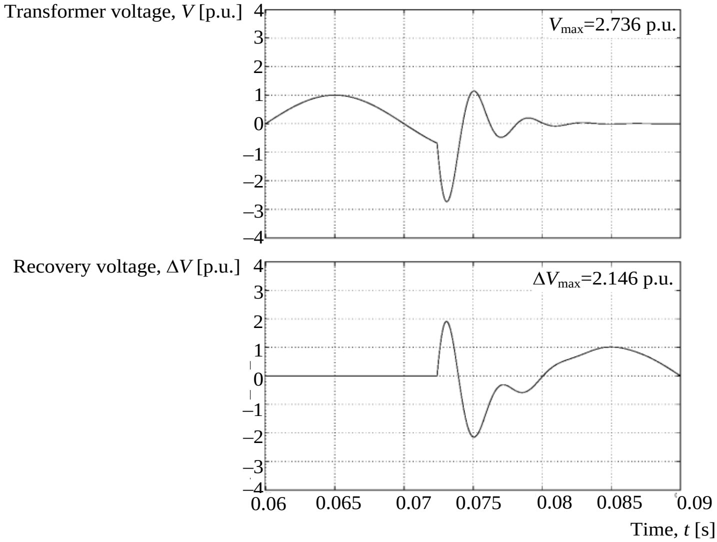

Fig. 5. Transient voltages at switching-off transformer of 31.5 MVA, 110 kV by SF6 circuit-breaker with less chop current (with no repeated re-ignitions)

As it was stated earlier the ratios of overvoltages while switching-off small inductive currents of no-load transformers and autotransformers of rated voltages 110-220 kV do not exceed triple value [4]. However, our last research led for transformers and autotransformers of wide range apparent powers has let us to find out that in only case for the ТД type (Ukraine produced) transformer of 31.5 MVA, 110 kV the overvoltage ratio has prevailed triple value of rated voltage. These cases are presented in Fig. 2 and Fig. 3. Note that both overvoltage ratio and inter-contact recovery voltage of the considered transformer may exceed the allowable voltage of high voltage networks. It is conditioned by relatively little value of no-load inductance of this type of transformer and correspondingly by relatively great free frequency and free oscillations of transitional voltages. For the considered cases of relatively small chopping currents (less or equal to chopping current of circuit-breaker) an interruption takes place at equality of chopping current and amplitude of switched current.

3. INVESTIGATION OF STABILITY

Computer simulation of transitional processes in electrical systems is based on solution of differential equations systems. Switching conditions is usually given due to logical conventions. Both differential equations and logical conventions form mathematical model of problem under consideration [4].

As it is known differential equations formalized mathematically transitional processes in electrical systems concern to the class of so called “stiff” differential equations [10]. Obtaining solutions of “stiff” differential equations and their systems may face with stability problems because that, just for this kind of equations the minded problem is serious enough [13, 14].

The calculated ratios of overvoltages and recovery voltages for the case of absence repeated re-ignitions corresponded to Fig. 2 for wide ranges of tolerance and initial step size are given in Tables 1, 2 and 3. In the tables results obtained at use of the ode23tb, ode23t and ode15s methods are presented, respectively.

Analyzing computer simulation results from the computational point of the following remarks have been stated.

All the methods used give the same stable values of V and ΔV at the initial step size equal to 0.1 μs. The maximum deviations (by modules) from stable solution for all the ranges of tolerance and initial step size are less than 2% by overvoltages and less than 3% by recovery voltages. The least deviation from the stable solutions took place at use the ode23tb method (less than 0.5% by V and less than 1.8% by ΔV). The greatest deviations took place for the initial step size 0.1 ms.

Behavior of recovery voltage is less stable in comparison with overvoltage function and calculated values of ΔV have greater deviation in comparison with V. It means that at computer simulation of transitional processes under consideration stability of whole problem must be evaluated by stability of recovery voltage function.

Change of calculated values V and ΔV is more uniform at fixed initial step size and tolerance varied than at fixed tolerance. This may be taken into account at computer simulation. Note that the same conclusion were presented in [9] for the problem of capacitive currents switching-off.

The carried out investigations have shown that realization of simulation at appearance of arc repeated re-ignitions becomes more difficult from the point of view of stability. E.g. realization of the ode15s method for initial step size 10^{-4} s becomes impossible, deviations of V and ΔV from their stable values become greater for all the considered methods.

Table 1. Calculated ratios of overvoltages (V) and recovery voltages (ΔV) for wide ranges of tolerance and initial step size at use ode23tb, $V/\Delta V$

Step size	Tolerance			
	10^{-6}	10^{-5}	10^{-4}	10^{-3}
10^{-7}	3.667/3.518	3.667/3.518	3.667/3.518	3.667/3.518
10^{-6}	3.667/3.518	3.668/3.518	3.668/3.517	3.668/3.517
10^{-5}	3.675/3.504	3.671/3.512	3.677/3.498	3.677/3.498
10^{-4}	3.669/3.514	3.680/3.489	3.679/3.485	3.677/3.455

Table 2. Calculated ratios of overvoltages (V) and recovery voltages (ΔV) for wide ranges of tolerance and initial step size at use ode23t, $V/\Delta V$

Step size	Tolerance			
	10^{-6}	10^{-5}	10^{-4}	10^{-3}
10^{-7}	3.667/3.518	3.667/3.518	3.667/3.518	3.667/3.518
10^{-6}	3.668/3.518	3.668/3.517	3.668/3.517	3.667/3.518
10^{-5}	3.669/3.515	3.669/3.514	3.675/3.501	3.667/3.504
10^{-4}	3.607/3.449	3.672/3.506	3.667/3.513	3.675/3.467

Table 3. Calculated ratios of overvoltages (V) and recovery voltages (ΔV) for wide ranges of tolerance and initial step size at use ode15s, $V/\Delta V$

Step size	Tolerance			
	10^{-6}	10^{-5}	10^{-4}	10^{-3}
10^{-7}	3.667/3.518	3.667/3.518	3.667/3.518	3.667/3.518
10^{-6}	3.668/3.517	3.668/3.517	3.668/3.518	3.668/3.519
10^{-5}	3.673/3.504	3.674/3.499	3.677/3.496	3.668/3.513
10^{-4}	3.661/3.427	3.681/3.419	3.672/3.486	3.675/3.440

4. CONCLUSIONS

This paper presents results of computer simulation of transitional processes at small inductive currents switching-offs.

It was stated that at switching-off of no-load inductive currents (less than circuit-breaker chopping current) the greatest overvoltages and recovery voltages take place at absence of arc repeated re-ignitions. There was shown that for only kind of transformer (ТД type of 31.5 MVA, 110 kV) ratios of overvoltages and recovery voltages at switching under consideration can exceed the triple value i.e. permissible level although for all the other types the minded level is not exceeded.

Concerning to stability it was stated that all the methods of computer simulation provide stable results at initial step size 0.1 μs and worst results at 0.1 ms. It was also found that recovery voltage is more sensitive to variations of simulation parameters and recommended to evaluate solutions' stability by the stability of recovery voltage.

REFERENCES

[1] KLAUS RAGALLER, *Current interruption in high voltage networks*, Plenum Press, New-York, 1978.
[2] EL-AKKARI F. R., TUMA D. T., *Simulation of transient and zero current behavior of arcs stabilized by forced convection*, IEEE Transaction on PAS, 1977, vol. 96, No. 6, 1784–1788.
[3] VAN DER SLUIS L., *Transients in power systems*, New-York: John Wiley & Sons, 2001.

[4] LAZIMOV T. M., AKHUNDOV S. A., *Research on influence of high voltage circuit-breakers' characteristics on switching overvoltages and overcurrents*, Proceedings of the Third International Conference on Electrical and Electronics Engineering ELECO'2003, Bursa, Turkey, 2003, 1–4.
[5] RUBEN D. GARZON, *High voltage circuit breakers design and applications*, New-York: Marcel Dekker, 2002.
[6] YEVDOKUNIN G. A., TILER G., *Modern vacuum switching apparatus for medial voltages*, M.P. Sizov publisher, Sankt-Petersburg, 2002 (in Russian).
[7] LAZIMOV T. M., AKHUNDOV S. A., *Modeling of electrical strength of high voltage circuit-breakers*, Proceedings of the International Symposium SIEMA'2001, Kharkov, Ukraine, 2001, 112–-114 (in Russian).
[8] MAMMADOV H., LAZIMOV T., IMANOV S., *Improved model of vacuum circuit-breaker's dielectric strength restoration*, Proceedings of the ELECO'09 International Conference on Electrical and Electronic Engineering, Bursa, Turkey, 2009.
[9] LAZIMOV T.M., IMANOV S.V., *On stability while simulating the switching-offs the capacitive and small inductive currents*, Proceeding of the MEPS'06 International Symposium. Wroclaw, Poland, 2006, 407–410.
[10] LAZIMOV T., AKHUNDOV S., *Peculiarities of transients' simulation in electrical circuits*, Proceedings of the Republican Conference on IT, Baku, Azerbaijan, 2003.
[11] BICKFORD J. P., MULLINEUX N., REED S. R., *Computation of power system transients*, Peter Peregrinus Ltd. England, 1976.
[12] MIRONOV G. A., JAFAROV E. M., LAZIMOV T. M., et al. *Overvoltages conditioned by switching-offs of capacitor banks equipped by protecting devices*, Electricity, 1979, No. 11(in Russian).
[13] SHAMPINE L. F., *Numerical solutions of ordinary differential equations*, Chapman and Hall, New-York, 1994.
[14] HAIRER E., NORSETT S. P., WANNER G., *Solving ordinary differential equations*, Part 1, Springer-Verlag, Berlin, Heidelberg, New-York, London, Paris, Tokyo, 1987.

O WZAJEMNYM ODDZIAŁYWANIU WYŁĄCZNIKA I SIECI PODCZAS WYŁĄCZEŃ MAŁYCH PRĄDÓW INDUKCYJNYCH

W artykule przedstawiono rezultaty badania wzajemnego powiązania rodzaju wyłącznika oraz prawa odbudowy wytrzymałości dielektrycznej i jego parametrów (determinowanych rodzajem wyłącznika oraz zastosowanym medium gaszenia łuku), takich jak prąd ucięcia oraz czas wyłączenia podczas wyłączania małych prądów indukcyjnych. Badania dotyczyły określania napięć przejściowych podczas rozważnych operacji łączeniowych oraz zależności przepięć i napięć powrotu na ponowne zapłony w przestrzeni między biegunami wyłącznika. Przedstawiono również rezultaty badań stabilności obliczeń, przeprowadzonych w szerokim zakresie parametrów symulacji.