SOME RESULTS OF UNLOADED LINE SWITCHING-OFFS' COMPUTER SIMULATION

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ABSTRACT

The article presents results of research concerned to unloaded power transmission line switching-offs' computer simulation. Dependence of transient voltages on circuit breaker's dielectrical strength restoration law and on switched line's length, influence of arc resistance on overvoltages are considered.

Key words: dielectrical strength restoration law, intercontact voltage, arc resistance

I. INTRODUCTION

It is widely known that switching-offs of great capacitances in electrical systems are a kind of dangerous transitional process from the points of view of overvoltages ratios and currents (due to repeating re-ignitions of arc) [1, 2]. Although this fact is known for a long time the problem has been stayed. Even application of modern circuit-breakers cannot close this matter. For example, it is known that autocompression and especially vacuum circuit-breakers switch-off the capacitor banks with less probability of repeating re-ignitions of arc but ratios of overvoltages may reach the magnitude 3.0 U_{ph} (U_{ph} is value of amplitude of phase voltage), i.e. are great enough [3].

Saying on switching of capacitances we mean of course capacitor banks used for the voltage control in electrical systems and power transmission lines.

We researched before a lot of problems concerned to switching-offs capacitor banks. We have stated in particular that:

– accepted law of circuit-breaker's dielectrical strength restoration may have a noticeable influence on calculated values of overvoltages, intercontact voltages and probabilities of re-ignitions [4];

– taking arc resistance (it is meant resistance of arcs appearing between contacts of circuit-breaker while disconnecting) into account may have a certain influence on calculated overvoltages and intercontact voltages. In the same time this influence is more for overvoltages ratios and less for intercontact voltages ratios [5].

The present article shows results obtained due to research the same problems for power transmission lines switched-off in unloaded regime, at which the line may be considered as a capacitive element of electrical system.

The third matter researched and presented in article is dependence of overvoltages while switching-off unloaded power transmission line on their length.

The simulation methods applied are researched and described in the paper [6], where recommendations to choose an initial step size and tolerances are given. The

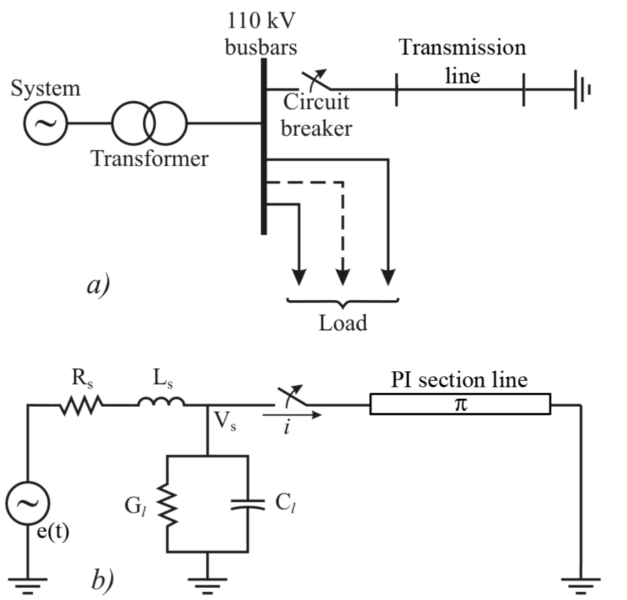


Fig 1. Switching-off a transmission line:
a) connection scheme;
b) equivalent network (index "s" concerns to the source parameters, "l"-to the load parameters. R, L, G, C are resistance, inductance, conductance and capacitance respectively).

corresponding description of the method used is shortly presented in the third chapter of the present paper (see below). The connection scheme and equivalent electrical network are presented in the figure 1.

II. RESULTS OBTAINED & DISCUSSION

The calculated ratios of transitional voltages while switching-offs unloaded 110 kV, 100 km power transmission line at the certain switch-off time are presented in the table 1 (see below). These results demonstrate dependence of transitional voltages on law of circuit breaker dielectric strength restoration

Table 1. The calculated rates of overvoltages for the different laws of dielectric strength restoration

Accepted law of the dielectric strength restoration / Voltage	Linear	Co-sinusoidal
V	2.06	1.98
ΔV	2.40	2.33

If denote transitional voltage on the terminals of power transmission line and intercontact voltage correspondingly through V_{lin} and ΔV_{lin} for the accepted linear law and V_{cos} and ΔV_{cos} for the accepted co-sinusoidal law we may write that

$$V_{lin} > V_{cos}, \quad \Delta V_{lin} > \Delta V_{cos}.$$

Note that the same qualitative correlations had been obtained in [3, 4] for capacitor banks switching-offs. Note also that acceptance of linear law of dielectric strength restoration is more expedient for vacuum circuit-breakers [3, 7, 8]. In the same time for autocompression circuit-breakers it is more expedient to use co-sinusoidal law of restoration [3, 9].

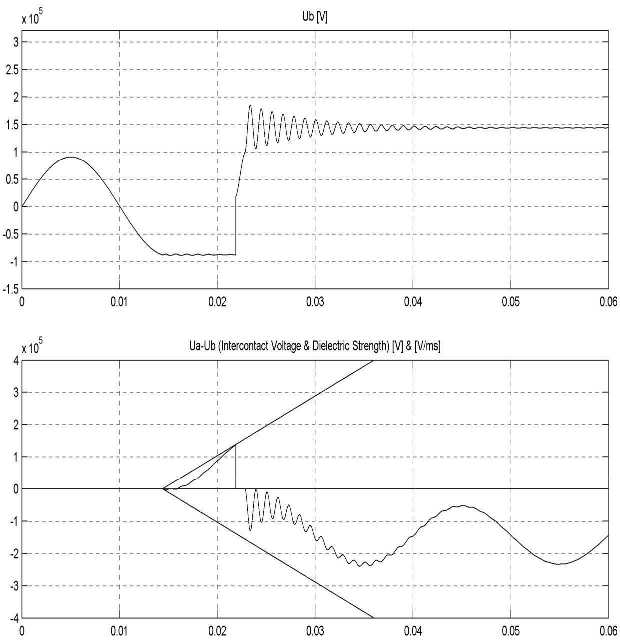
The calculated curves of V and ΔV for the both considered cases of accepted restoration laws corresponded to the table 1 are presented below in the figure 2.

We also researched dependence of overvoltages and intercontact voltages on counting (or not counting) arc appearing in intercontact space of high-voltage circuit breaker while it contacts are separating.

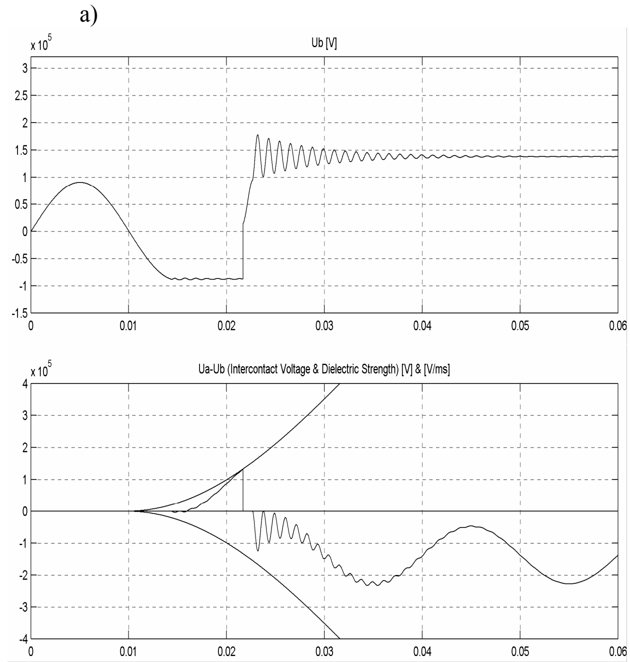
The calculated ratios of transitional voltages while switching-offs unloaded 110 kV line for the different arc characteristics are given in the tables 2 and 3. The results are presented for two values of line's length (for the further analyze of dependence of transitional voltages on line's length)

Note that in the tables 2 and 3 through R_{arc} and V_{arc} are correspondingly denoted resistance of arc and potential difference between contacts (voltage drop on arc).

As it is evidently seemed from the table 2 and 3, counting of arc while modeling numerically switching



a)

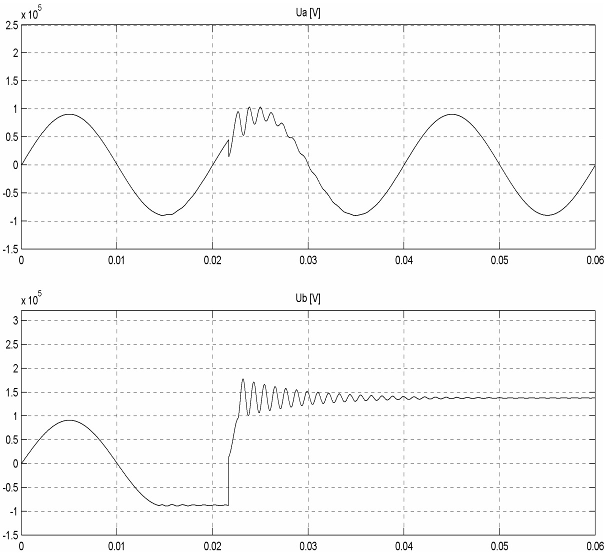


b)

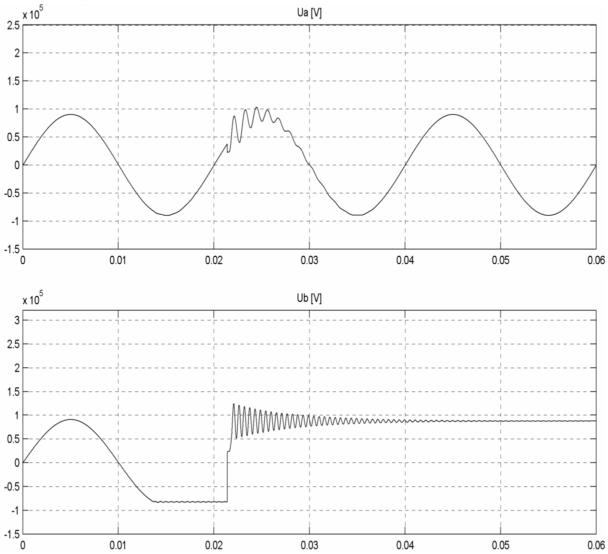
Fig. 2. The calculated curves of V and ΔV while switching-off the unloaded power transmission line (l = 100 km) for the cases of:

a) linear restoration law;
b) co-sinusoidal restoration law

transients of power transmission lines has just a little influence on the values of calculated voltages (unlike capacitor banks switching [5]). Varying the line parameters has shown that counting of arc resistance has given just a 1.5 % difference (in maximum)



a)



b)

Fig. 3. The calculated curves of V and ΔV while switching-off the unloaded power transmission lines with lengths: a) 100 km; b) 50 km.

Let us now consider a dependence of transitional voltages on line length. We can see from the tables 2 and 3 that minded dependence is quite evident.

Corresponding calculated curves are shown in fig. 2 and fig.3, some of them concerns to the voltage on a 110 kV substation busbars, another - to the line voltage.

The presented curves are shown for a comparison of transitional voltages just for two values of length. Numerous calculations have been carried out show that diminishing of line’s length leads to the decreasing of

Table 2. The calculated rates of overvoltages for the different characteristics of arc in circuit-breaker, l = 100 km

Arc characteristics / Voltage	$R_{arc} = 0$ ($V_{arc} = 0$)	$R_{arc} \neq 0$ (V_{arc} = 1500 V)	$R_{arc} \neq 0$ (V_{arc} = 2000 V)
V	2.10	2.08	2.12
ΔV	1.98	1.98	2.00

Table 3. The calculated rates of overvoltages for the different characteristics of arc in circuit-breaker, l = 50 km

Arc characteristics / Voltage	$R_{arc} = 0$ ($V_{arc} = 0$)	$R_{arc} \neq 0$ (V_{arc} = 1500 V)	$R_{arc} \neq 0$ (V_{arc} = 2000 V)
V	1.39	1.37	1.37
ΔV	1.82	1.81	1.81

overvoltages while switching-off power transmission lines. The explanation of this will have been given below.

We have also carried out a comparative research of switching-offs capacitor banks and power transmission lines (either with rated voltage 110 kV), which full capacity corresponds to the capacity of capacitor banks. For all compared cases we got some exceeding of transitional voltages while switching-offs capacitor banks upon power transmission lines. This is in quite accordance with statement given in [10] about greater danger while switching electrical installations with lumped parameters (e.g. capacitor banks) rather than switching of installations with distributed parameters.

III. ON THE METHOD USED

The theoretical bases of the research under consideration were some known fundamental works, especially [11, 12]. Note that we had earlier stated that the best method for the numerical research the switching-offs of capacitor banks is ode 23tb (stiff /TR – BDF2) [6]. As it is known this method is included into the MATLAB ODE Solvers. We have stated that the ode 23tb (stiff /TR – BDF2) method is also the best one while researching numerically switching-offs of power transmission lines. So, just this method was used.

Note that decreasing a line’s length leads to worsening of stability. Searching of values of initial step size and tolerance provides stability of solutions becomes difficult enough. We reckon that it is conditioned by increasing of free frequencies with diminishing of line’s length. As a result local errors become more. In one’s turn it leads to increasing the global error and worsening of stability.

IV. CONCLUSIONS

1. A law of dielectric strength restoration in circuit-breakers accepted while simulating switching-offs unloaded power transmission lines may have a noticeable influence on overvoltages' ratios. According to our evaluations differences between transitional voltages calculated with different (linear or co-sinusoidal) accepted laws may reach 4÷5% for overvoltages on line busbars and 3÷4% for intercontact voltage of circuit breaker.
2. Neglecting of arc resistance in circuit-breakers while simulating switching-offs unloaded power transmission lines does not exert a noticeable influence on overvoltages ratios (while capacitor banks switching-offs). Our calculations have shown that differences between voltages calculated with and without counting arc resistance do not exceed 1÷2% for overvoltage on busbars and intercontact voltage. These voltages have tendency to decrease with diminishing line length.
3. Diminishing of lines' length leads to noticeable decreasing of switching-off overvoltages. For example, consistent diminishing of 110 kV's line's length from 100 km to 50 km leads to decreasing the overvoltages calculated ratio by circa 34% (a third). It is explained by the decreasing a phase angle between voltage and switched-off current of unloaded line (having capacitive character), since this current is proportional directly to line's length as a result instant corresponded to real switching-off (arc quenching) time will be move off away from the instant corresponded to the voltage maximum.

APPENDIX

On the circuit-breakers dielectric strength restoration laws used

While simulating switching-offs power transmission lines we have used linear and co-sinusoidal laws of circuit-breakers dielectric strength restoration. The linear law is usually used for vacuum circuit-breakers. Sometimes while modeling some special cases it may be also used for auto compression circuit-breakers. The linear law is expressed as following:

$$U(t) = U_{\max} t_{so}^{-1} (t - t_b), \text{ if } t_b < t \le t_b + t_{so}.$$

There t is actual time, t_b is the beginning instant of contacts separation, U_{max} is full breakdown voltage of the circuit-breaker corresponded to the maximum distance between contacts, t_{so} is the full time of contacts separation.

Co-sinusoidal restoration law is used mainly for auto-compression circuit-breakers. In the paper presented the law obtained on the base of [13] and given in [4] is used. The corresponding formula is the following:

$$U(t) = (U_{\max} / 2)[1 - \cos(\pi t / t_{so})], \text{ if } t_b < t \le t_b + t_{so}$$

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