

Some Physical and Computational Features of Unloaded Power Transmission Lines' Switching-off Process

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ABSTRACT

The paper presents results of research some physical and computational features of unloaded power transmission lines' switching-offs. It was stated that there are not monotonous dependence between magnitudes of transitional voltages at switching-off high voltage aerial lines and their lengths. There was studied influence of the circuit-breaker type (SF₆ or vacuum ones) on transitional voltages. Features of use the ordinary differential equations' solvers at computer simulation from the point of view stability of solutions and simulation time consuming were investigated in the presented research.

Keywords: Transitional Voltages, Ode Solvers, Simulation, Stability of Solutions.

1. INTRODUCTION

Switching-off power transmission lines has always been a very important issue for power electric systems [1][2]. It is conditioned by the influence of transitional switching voltages on co-ordination of electrical installations high voltage insulation, design and setup of relay protection and automatic emergency control, power systems electromagnetic compatibility etc.

It must be noted here that the classical theory of transitions at switching-off capacitive currents were developed for the old types of high voltage circuit-breakers (oil and air blast ones) which characterized with relatively slow restoration of electrical strength in inter-contact space. This theory explains increase of transitional voltages at switching-off capacitive currents by successive repeated breakdowns in circuit-breakers' inter-contact spaces leading to a corresponding increase in the voltage across the terminals of switched-off capacitor banks or unloaded power transmission line [2][3].

In the same time characteristics of circuit-breakers have notable influence on flowing of switching processes and magnitudes of transitional voltages and currents [4][5]. As it was shown in [6] switching-offs unloaded power transmission lines by vacuum circuit-breakers are accompanied with greater magnitudes of transitional voltages in comparison with SF₆ ones. Note here, that in the research presented in [6] was used the linear restoration law of electrical strength [7] for the case of 110 kV vacuum circuit-breaker. The improved law for 110 kV vacuum circuit-breakers was worked up and published further in [8].

Moreover, the research presented in [6] was covered power transmission lines with lengths no less than 50 kilometers. In the present research are studied some

Tahir Lazimov, Esam Ali Saafan, Asif Sadigov
Some Physical and Computational Features of
Unloaded Power Transmission Lines' Switching-off Process

physical and computational features of 110 kV unloaded power transmission lines' (20 – 95 km lengths) switching-off process.

2. RESEARCH GROUND. NETWORKS, SWITCHES AND SIMULATION METHODS

The electric scheme and equivalent network considered are presented in the Figure 1 (all the denotations are given in the caption). The 110kV overhead power transmission line is replaced by one π -section, see [9].

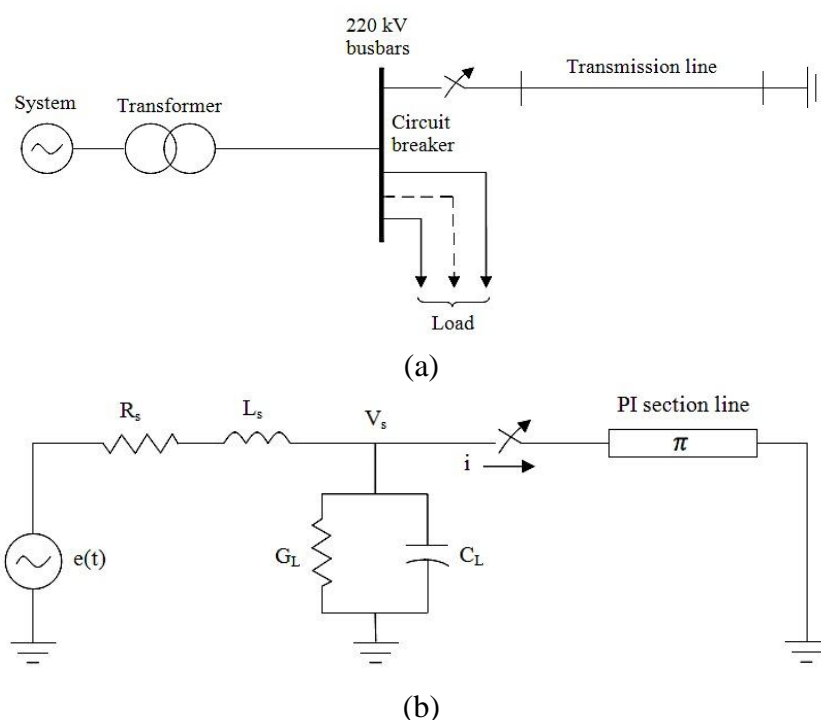


FIGURE 1. Switching-off power transmission line: (a) electric scheme; (b) equivalent network (R , L , C and G are resistance, inductance, capacitance and conductance respectively. Index “s” concerns to the source parameters, “l”- to the load parameters, E_s is e.m.f. of the voltage source)

Current interruption in circuit-breakers (i.e. arc quenching) is set at condition, where i is decreasing current passing through the switched-off arc, I_{ch} is so called chop current depending on the circuit-breaker type, which is one of important parameters of circuit-breakers from the point of view possible magnitudes of transitional voltages at switching-offs [10] [11].

$$|i| \leq I_{ch} \quad (1)$$

Repeated ignitions and strikes of arc in circuit-breakers' inter-contact spaces is set at condition,

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

where ΔV is a recovery voltage between poles of the circuit-breaker, $V_{ds}(t)$ is a function of restored electric strength between the contacts of circuit-breaker. The laws of electric strength restoration given in [7] [12] for SF₆ circuit-breaker and in [8] for 110 kV vacuum circuit-breaker were used for computer simulation. 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.

3. DISCUSSION

3.1 DEPENDENCE OF TRANSITIONAL VOLTAGES ON LINES' LENGTH

We stated earlier in [6] that switching (switching-off) over voltages across the power transmission line's terminals and recovery voltage across the circuit breakers poles have lesser ratios for the shorter lengths of lines both at use auto compression (SF₆) and vacuum circuit-breakers. We explained this by the decreasing a phase angle between voltage and switched-off current of the unloaded line (having capacitive character), since this current is proportional directly to line's length, as a result a time instant corresponded to the real switching-off (i.e. arc quenching) time will be move off away from the instant corresponded to the voltage maximum (at the same chop current). On the contrary, at higher switched-off currents a time instant corresponded to the real switching-off time will be move to the instant corresponded to the voltage maximum. Note here that the results given in [6] were got for the 110 kV lines of more than 50 kilometers length.

Our last research revealed more complicated dependence of transitional voltages at switching-off power transmission lines on their length in wider (than in [6]) range of lengths. The lengths 50 – 95 kilometers correspond to the results presented in [6] i.e. switching-off power transmission lines of this range of length is accompanied with higher magnitudes of transitional voltages for greater length. This is corresponded with the explanation given above.

On the contrary as it is seen from Figure 2 for the range of length less than 50 kilometers, we observe higher magnitudes of transitional voltages for lesser length. These results obtained for shorter lines may be explained by the influence of transitional voltages' free oscillations having high values of frequency for the lesser lengths. E.g. for the considered overhead 110 kV line frequencies of free oscillations is changed between 1200 Hz and 12 kHz for the lengths 10 – 100 kilometers wherein the higher frequencies correspond to the lesser length.

Tahir Lazimov, Esam Ali Saafan, Asif Sadigov
Some Physical and Computational Features of
Unloaded Power Transmission Lines' Switching-off Process

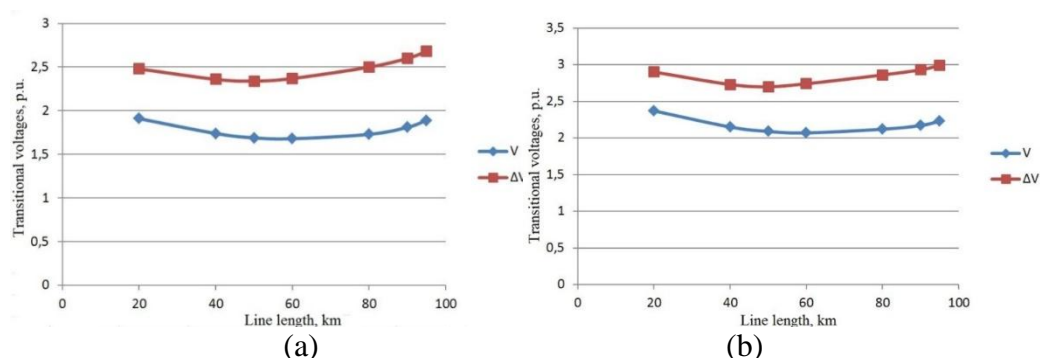


FIGURE 2. Calculated dependences of transitional voltages at 110 kV power transmission lines switching-off against their lengths at use: (a) SF₆ circuit-breaker; (b) vacuum circuit-breaker

Whereas switching-off process for longer lines flows smoother due to lower free frequencies (in other words with less steepness of transitional voltages) at switching-off shorter lines we face with possibility of interruption of high-frequency current in the instant corresponding to the higher magnitudes of transitional voltages (due to superimposing of steep high-frequency free transitional voltages). This leads to worsening of transitional process and increasing of probability of arc repeated restrikes in circuit-breakers inter-contact spaces.

3.2 DEPENDENCE OF TRANSITIONAL VOLTAGES ON TYPE OF CIRCUIT-BREAKER

We studied dependence of transitional voltages at switching-off unloaded power transmission line on type of circuit-breaker earlier [6] and stated then that switching-offs at use vacuum circuit-breakers is accompanied by (4 – 5) % higher magnitudes of voltages across line terminals and recovery voltages in comparison with SF₆ ones. In the research minded was used the simplest (linear) law of vacuum circuit-breaker electrical strength restoration presented in [13]. Our last research showed that it leads to serious underestimation of differences in transitional voltages conditioned by type of circuit-breaker because of inadequacy of the linear restoration law. In computer simulations led at use much more adequate logarithmic restoration law presented in [8] were got significantly greater differences. E.g. the differences of magnitudes of transitional voltages at switching-off 110 kV power transmission line of 60 km length obtained at use the model and software given in the section 2 are about 19 % for the line voltage and about 13 % for the recovery voltage.

3.3 COMPUTATIONAL STABILITY

Numerous numerical experiments implemented with use the stiff ordinary differential equations (ode) solvers of the R2013a MATLAB-Simulink set let us to reveal the following computational features of the problem under consideration:

- Use the ode solver 23t (both fast and robust algorithms) and the ode solver 23s (Rosenbrock method) provides obtaining stable solutions in the range of initial step

sizes no more than 1 nanosecond and relative tolerances no more than 10^{-6} . Decreasing line's length does not worsen stability of solutions.

- Use the robust algorithm of the ode solver 15s provides obtaining stable solutions in the range of initial step sizes no more than 1 nanosecond and relative tolerances no more than 10^{-7} whereas the fast algorithm of the same method provides stability at lesser values of relative tolerance. Moreover, decreasing line's length worsens stability of solutions at use the fast algorithm.

- Use the robust algorithm of the ode solver 23tb provides obtaining stable solutions in the range of initial step sizes no more than 1 nanosecond and relative tolerances no more than 10^{-6} , decreasing line's length does not worsen stability of solutions.

- Use the fast algorithm of the ode solver 23tb does not provide obtaining stable solutions in all the considered ranges of initial step sizes and relative tolerance.

There is one more important feature of the problem studied. Our researches show's that computer simulation of switching-off power transmission lines requires notably greater time needed for obtaining stable solutions in comparison with switching-off capacitor banks and unloaded transformers and auto-transformers. In our opinion it is conditioned by higher free frequencies of overhead power transmission lines reaching even 6 kHz for the lines of 20 kilometers length. As a results simulation must be implemented with very little initial step size (1 nanosecond in our case). This leads to an unnecessarily greater amount of computation with a corresponding increasing in the simulation time. Examples of stable solutions for voltages are presented in the Figure 3.

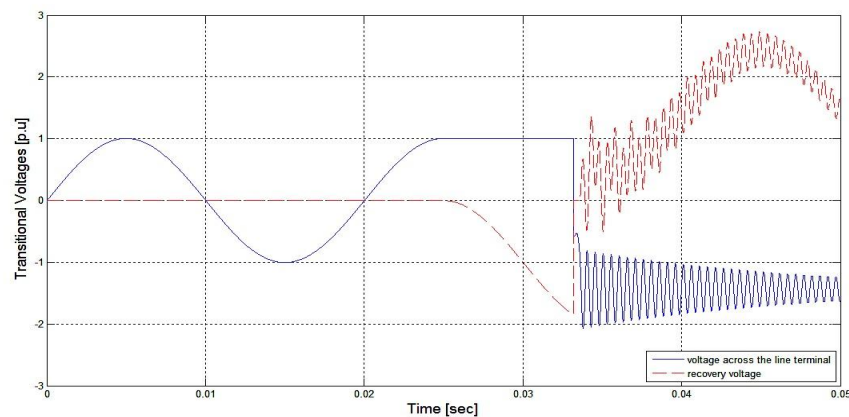


FIGURE 3. Transitional voltages at switching-off 110 kV power transmission line of 60 km length by vacuum circuit-breaker

4. CONCLUSIONS

Magnitudes of transitional voltages at switching-off unloaded power transmission lines have their least values for the lines of medial length (about 50 kilometers for 110 kV lines) and higher values for longer and shorter lines. The best methods (ode solvers included in MATLAB set) for computer simulation switching-offs unloaded power transmission lines from the point of view obtaining stable solutions are the

Tahir Lazimov, Esam Ali Saafan, Asif Sadigov
Some Physical and Computational Features of
Unloaded Power Transmission Lines' Switching-off Process

ode 23t (both fast and robust algorithms), ode 23s and ode 23tb (just robust algorithm). Computer simulation of transitions at switching-off unloaded transmission lines have a notable greater time-consuming in comparison with the same problem for power capacitor banks and unloaded transformers because of necessity of use very little initial step sizes (especially for short lines) due to high free frequencies.

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