On Transitional Voltages at Switching-Off Unloaded Overhead Power Transmission Lines

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***Abstract*— Results of the numerical research dedicated to the study of the impact of substation busbars' equivalent capacitance on the transitional voltages at switching off 110 kV unloaded overhead power transmission line by SF6 and vacuum circuit breakers are presented in the paper. Typical curves of change in transitional functions dependently on the total capacitance of all the connections to the busbar and ratios of transitional voltage across the overhead power transmission lines terminals and recovery voltage across the circuit breakers contacts were obtained and analyzed for the range of line length 5 – 80 km. The article also provides information about the software and modeling tools (methods, algorithms) used in the study.**

Keywords*— *Busbar Capacitance, Power Transmission Line, Transitional Functions, Stability, Arcing

I. Introduction

Switching of overhead power transmission lines is one of the most unfavorable transients in electrical networks and systems [1]. Transitional processes caused by this type of transient, especially switching-off unloaded power transmission lines are accompanied by over-voltages that can be dangerous for the insulation of the line itself and the system equipment [1,2]. Repeated re-ignitions and restrikes of arc in circuit breakers at separating circuit breaker poles (contacts) and inrush currents can also negatively impact the substation's electromagnetic environment and compatibility [3].

Magnitudes (ratios) of transitional voltages and currents and their behavior at switching-off unloaded overhead power transmission lines depend on:

- the type of circuit breaker (SF6 or vacuum);
- longitudinal parameters of line, its length;
- line's equivalent circuit;
- circuit breaker's poles separation time;
- a beginning instant of circuit breaker poles separation;
- equivalent parameters of the load connected to the same bus-bars with switched-off line and so on [4,5].

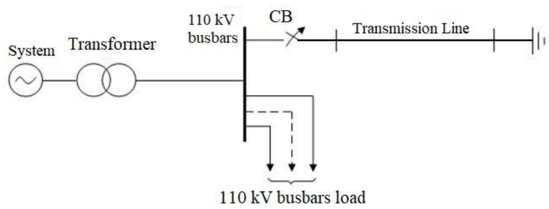
Note here that an equivalent circuit chosen for simulation can be essential for adequate modeling since electric lines belong to the class of electrical installations with distributed parameters [6].

The article presents the research results on the impact of the equivalent capacitance connected to the substation's certain standard voltage busbars, on transitional voltages conditioned by the switching-off of one of the power transmission lines connected to the same busbars system.

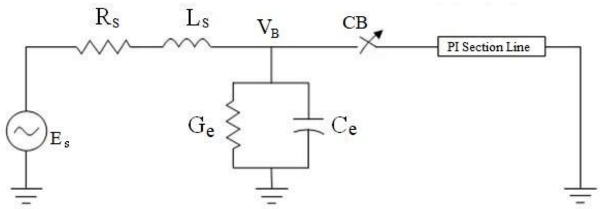
Note that one of our earlier researches studied the impact of substation equivalent capacitance on transitional voltages at switching-off another capacitive element, namely high-voltage power capacitor banks [7].

II. Research Ground

The electrical network under consideration and its corresponding equivalent circuit are presented in Fig.1.



a)



b)

Fig. 1. Single phase representation of unloaded power transmission line switching-off, (a) electric scheme, (b) equivalent network

As regards the computational tools we can note that for the computer simulation of this type of problem, the best methods, solvers, and algorithms from the point of view of getting stable solutions are:

- the robust algorithm of the ode 23tb (stiff/TR-BDF2) solver [8];
- both fast and robust algorithms of the ode 23s (stiff/NDF) solver [9];
- the ode 23s (stiff/Mod. Rosenbrock) solver [10].

The results obtained from the computer simulation of the problem under consideration, presented and discussed below, are the same for the cases of using all the above-minded methods, solvers, and algorithms. Notice that we used mostly the ode 23s solver for the presented investigation, which realizes the Rosenbrock method, and sometimes other of the minded solvers and algorithms.

The technique of finding the maximum transitional voltage (either voltage across the terminals or recovery voltage, in our case we searched for the maximum value of the line voltage) at numerical simulation consists of:

- varying the set value of an initial instant of contact separation for the finding the time instant at which an intersection of the functions of the voltage across the line terminals and electric strength restoration of the circuit breaker occurs [2];

- to find a possible higher magnitude of VB we should try simulations at a slightly less initial time instant than one determined in the previous simulation with arc restrike, as a rule with a step 0.0001 – 0.00001 seconds (which shouldn't be confused with a set initial step size of simulation).

Once the examination form's results have been fully determined, the data is processed by the system to assess the accuracy of the test questions. The examiner's answers are compared with the correct answers, and specialized algorithms are used to establish the final assessment of the examination form.

In order to ensure transparency and objectivity, all data, including the graphical representation of the examination form, exam results, and correct answers, are made available online in the examinee's personal account.

III. DISCUSSION

Results of the research carried out are generalized in Fig.2 – Fig.5 presented below.

Analyzing the research results given in Fig.2 – Fig.5 we can state the following (on the example of 110 kV line):

- an increase of the equivalent capacitance connected to the substation's busbars leads to an increase of transitional voltage across the terminals of the overhead power transmission line terminals at its switching off either by SF6 and vacuum circuit breaker, for the lines of short and medium length. This dependence for the longer lines is more complicated: the voltage decreases at the bus-bars capacitances less than 1.5 – 2.5 μF and increases at the higher ones (see Fig.2 and Fig.4);

- almost the same behavior occurs for the transitional recovery voltages across the circuit breaker poles. Notice only, that at switching-off longer lines by SF6 circuit breaker recovery voltage decreases and begins to increase at equivalent capacitance greater than 2.5 μF whereas at the use of vacuum circuit breaker recovery voltage decreases till 2.5 μF and then stays almost constant (see Fig.3 and Fig.5);

- maximum differences in calculated magnitudes of transitional voltages at varying busbars equivalent capacitance between 0.5 – 4.5 μF determining relatively to least of them equal 18 – 25 % for the case of use SF6 circuit breaker and 27 – 33 % for vacuum one. At that, lesser differences concern recovery voltages, greater ones – to the voltage across the line terminals. Note here that despite such significant differences ratios of both transitional voltages do not exceed the allowable value for the considered voltage standard;

- magnitudes of transitional voltages at the use of a vacuum circuit breaker can be 20% more than at the use of an SF6 circuit breaker.

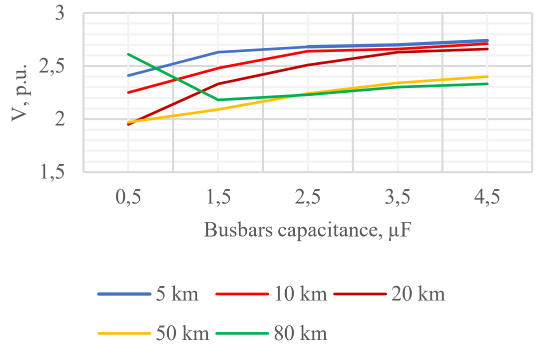


Fig. 2. Ratios of voltages across the line terminals against busbars equivalent capacitance (vacuum circuit breaker case)

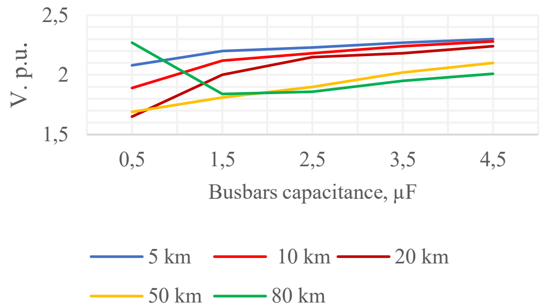


Fig. 3. Ratios of voltages across the line terminals against busbars equivalent capacitance (SF6 circuit breaker case).

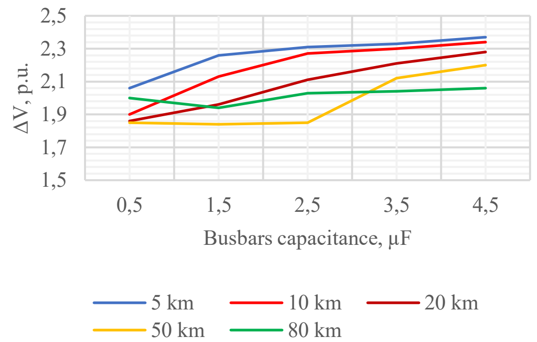


Fig. 4. Ratios of recovery voltages against busbars equivalent capacitance (vacuum circuit breaker case)

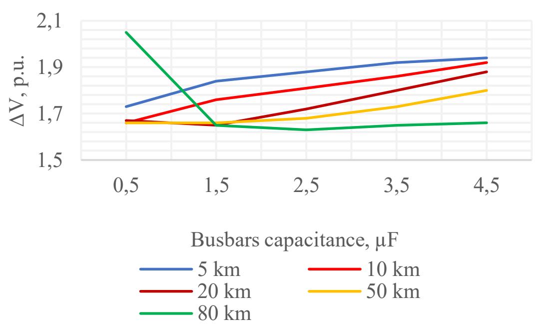


Fig. 5. Ratios of recovery voltages against busbars equivalent capacitance (SF6 circuit breaker case)

IV. ONE NOTE ON THE SIMULATION FEATURES

Our research on the transitional process of switching-off power capacitor banks in dependence on busbars' equivalent capacitance showed that change in this capacitance could impact transitional functions (solutions) behavior and stability [7].

Fortunately, the presented research did not reveal such a feature for the switching-off power transmission lines. We did not have to change the simulation parameters (initial step size and tolerances) by changing the set values of equivalent capacitance. We assume that this is conditioned by the distributed character of the long power transmission line parameters and use for this reason, the line's pi-section model in the present research [12].

V. INFLUENCE OF ARCING IN CIRCUIT BREAKER

As it is known switching processes in circuit breakers are accompanied by arcing in their intercontact spaces [1, 2]. As it was shown in [13], the resistance of arc and arcing time can have a notable impact on magnitudes of transitional voltages at switchings high-voltage electrical installations (especially, when switching at repeated arc restrikes).

As we stated earlier, when switching off 110 kV power transmission lines of 20 – 80 kilometers in length the impact of the arc is not significant for transitional voltages across the line terminals (no more than 2 – 2.5 %), and can reach almost 13 % for recovery voltages across the circuit breaker terminals. These notable differences take place if we don't consider the arc phenomenon (resistance of arc and arcing time) in circuit breakers at simulation for lines of small length. Note also, that the minded differences for the recovery voltages take place at the use of either SF6 and vacuum circuit breakers.

Our presented research confirmed the above-minded conclusions. At that, at taking into consideration the arcing phenomenon all the curves presented in Fig.2 and Fig.3 almost do not change, the blue, red, and brown graphs in Fig.4 and Fig.5 undergo some corresponding decreasing.

Note, that the modeling of arc was done in correspondence with [14, 15].

VI. CONCLUSION

1. The equivalent connected capacitance of substation buses has a notable influence on the magnitudes of transitional voltages, especially their behavior depending on the line length when a high-voltage overhead power transmission line is switched-off from the same busbars system.

2. Change in transitional voltages at switching-off overhead power transmission line of 110 kV conditioned by a change in the equivalent capacitance of the busbars the line connected to, can exceed 30% for voltages across the line terminals and 25% for recovery voltages.

REFERENCES

[1] R. Smeets, L. Van der Sluis, M. Kapetanovic, et al., "Switching in Electrical Transmission and Distribution Systems", John Wiley and Sons, Ltd., New York, USA, 2015.

[2] Razevig, D. V., High Voltage Engineering, Khanna Publishers, Delhi, 1989.

[3] https://single-market-economy.ec.europa.eu/sectors/electrical-and-electronic-engineering-industries-eei/electromagnetic-compatibility-emc-directive_en

[4] T. Lazimov, E.A. Saafan, R. Ahmadov, A. Sadigov, "Improving Adequacy of Simulation Transitional Processes in Electric Systems by More Comprehensive Consideration Phenomena in Circuit-Breakers", The 2019 Modern Electric Power Systems (MEPS), pp. 1-4, 2019.

[5] S.M.Wong, L.A.Snider, E.W.C.Lo, "Over-voltages and re-ignition behavior of vacuum circuit-breaker", Proceedings of the IPST International Conference (on Power Systems Transients). New Orleans, USA, 2003, pp.1-6

[6] https://web.mit.edu/6.013_book/www/chapter14/14.1.html

[7] T. Lazimov, R. Ahmadov, "Some Features of Capacitor Banks Automatic Switching-offs Computer Simulation", The IFAC TECIS 18 Conference, Vol. 51, No. 30, pp. 632-635, Baku, Azerbaijan, 2018.

[8] https://www.mathworks.com/help/matlab/ref/ode23tb.html

[9] https://www.mathworks.com/help/matlab/ref/ode23s.html

[10] H.H. Rosenbrock, "Some general implicit processes for the numerical solution of differential equations", Computer Journal, Vol. 5, 1962/63, pp. 329-330

[11] T. Lazimov, E.A. Saafan, "Computational Features of Numerical Simulation of Some Transitions in Electric Power Systems", The 2019 Modern Electric Power Systems (MEPS), pp. 1-4, 2019.

[12] https://www.mathworks.com/help/sps/powersys/ref/pisectionline.html

[13] Hashimov, T. Lazimov, and S. Imanov, "On counting arc resistance in circuit-breakers while simulating switching processes," Power Engineering Problems, vol. 8, no. 2, pp. 13-16, 2007.

[14] H. A. Darwish and N. I. Elkalashy, "Universal Arc Representation Using EMTP", IEEE Transactions on Power Delivery, vol. 20, no. 2, pp. 772-779, April 2005.

[15] Shengwen Shu, Jiangjun Ruan, Daochung Huang, and Gaobo Wu, "Influencing factors of breaking capacity of double-break vacuum circuit-breakers," Telkomnika, vol. 11, no. 6, pp. 2903 -2911, 2003.