The question of specific features of overvoltages when switching parallel-connected vacuum breakers

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Abstract. The paper presents the results of analyzing switching overvoltages occurring with simultaneous shedding of active inductive load by vacuum breakers jointly connected to one bus. It is established that with the available spread in current choppings of vacuum breakers, the maximum overvoltage occurs on the contacts of a vacuum breaker out of the number of parallel connected ones, in which the gap is de-ionized last. It is recommended to damp any occurring overvoltages by arresters located in parallel to separate groups of breakers connected to one bus.

1. Introduction
Distribution substations are one of the basic elements of electric networks 6 (10) - 35 kW of power supply systems. Recently they are upgraded primarily by replacing outdated types of breakers with vacuum ones as having better operation properties [1–4]. Specific features of vacuum breakers are their higher arc-suppressing ability and an option to switch off high-frequency currents. Due to this, vacuum switching devices have more restrikes compared to other types of breakers, which is accompanied by high-frequency overvoltages [5–7], which are the greatest danger for turn insulation of electric equipment and cables of cross-linked polyethylene.

High-frequency overvoltages occurring in electrical switching usually damage insulation of equipment. It should be noted, however, that small-frequency overvoltages also have negative impacts on insulation by multiple influence on it. This significantly reduces electrical strength of insulation and increases likelihood of its damage during subsequent impacts of overvoltages.

2. Setting objectives
This paper discusses an occurrence of switching overvoltages with simultaneous opening of breakers jointly connected to one bus. Such situation is possible, for instance, during operation of a breaker opening backup device (BOBD) (Figure 1). Upon a short circuit (SC) on one of the outgoing lines (1), the relay protection of this connection (RP2) sends a signal to open a respective breaker Q2. BOBD controls operability of the breaker and its opening, if an opening signal is sent to it. If, for any reasons, a breaker does not open, then after a certain time a repeated signal is sent to open this breaker and to open all nearest breakers which might power up the uneliminated SC, namely to the breakers of Input and outgoing lines 2 and 3 (since their load may be motive and, consequently, they have to be disconnected from the damaged section of the network).

Also a simultaneous opening of several breakers can happen if differential bus protection (DFP) is used as basic RP for a distraction device (DD) (Figure 2).
Figure 1. Case No.1 in question. Breaker Q2 failure at SC and simultaneous opening of Q1, Q3 and Q4 breakers.

Figure 2. Case No.2 in question. At SC in the DFP coverage area Q1, Q2, Q3 and Q4 breakers open simultaneously.

DFP is performed without time delay and has absolute selectivity (coverage area is within the protected element). DFP controls the sum of currents flowing through connections extending away from the bus, in case of an external SC (for instance, on outgoing lines) or in normal operation, the sum of currents is close to zero, in case of an internal SC (on buses and upstream from the current transformers) the sum of currents rapidly increases. In this case DFP sends signals to open in parallel to all the electromagnets for opening power breakers of connections connected to this busbar system, in order to eliminate power-up of the damaged site (the SC point).

The same occurs during an arc barrier of DD bus bars, the protection being triggered in this case by optic arc sensors installed in the compartment of DD bus cars and the compartments of power circuit breakers of each cell.

To study the overvoltages occurring upon simultaneous switching of several vacuum breakers, and analyze efficiency of the means of protection from these overvoltages, which is the goal of this paper, it is necessary:

1. To review processes unfavorable and dangerous for electric equipment in middle class voltage networks during switching of vacuum breakers.
2. To create a simulation model of transient processes in the Simulink environment of the Matlab package when switching vacuum breakers.
3. To analyze the obtained data and make a conclusion as to the efficiency of using the means of protection from overvoltages of vacuum breakers.

3. Methods of studies

A distribution substation (DS) is an electric installation serving to receive and distribute electric power in municipal electric networks, large industrial and oil extracting enterprises. In some cases a distribution substation can be combined with one or several transformer substations (DTS). There are two varieties of DS and DTS: standalone or embedded. As an item to study for simulation take an embedded distribution substation (DS) 10 kW (Figure 3), in which there are installed: switchgear of unilateral maintenance cells, BB/TEL vacuum breakers, power transformers, bus tie switches, bus and line isolating switches, current and voltage transformers, low voltage boards, earthing knives, nonlinear overvoltage suppressors.
Further on, to study overvoltages with simultaneous opening of several vacuum breakers, a model was built depicted in Figure 4.

**Figure 3.** One line diagram of a distribution substation.

**Figure 4.** Model with several vacuum breakers in MATLAB Simulink.
To study transient processes with simultaneous switching of vacuum breakers 6 (10) kW in distribution networks, first it is necessary to build a model of one vacuum breaker in order to assess overvoltage upon its opening. This model of a vacuum breaker takes into account current chopping and transient recovery voltage [8–11].

Overvoltages occurring upon opening of vacuum breakers are the most widespread type of overvoltage in distribution electric networks. Possible overvoltages will be assessed by computer simulation, since it can rarely be conducted experimentally.

Simulation of the operation of a vacuum breaker is characterized by a complexity of physical processes occurring in it and their mathematical description. Most models of vacuum breakers are designed in EMTP/ATP environment [2, 8, 12–13], and part in Simulink MATLAB environment [14–17]. This paper is devoted to the development of a model of a vacuum breaker in Simulink MATLAB environment, allowing simulation of a restrike process at the insufficient rate of dielectric strength recovery.

The results of simulation are given in Figure 5-8.

**Figure 5.** Voltage between vacuum breaker contacts. First breaker.

**Figure 6.** Voltage and current of outgoing feeder. First breaker.

**Figure 7.** Voltage between vacuum breaker contacts. Second breaker.

**Figure 8.** Consumer’s voltage and current. Second breaker.
4. Conclusion
By the results of the experiment the following was obtained:

Processes unfavorable and dangerous for electric equipment in medium-voltage distribution networks during switching of vacuum breakers have been reviewed and overvoltages occurring when switching vacuum breakers studied.

A simulation model of a vacuum breaker has been created in Simulink environment of Matlab package, allowing assessment of transient processes occurring when switching vacuum breakers.

In chapter three the obtained results have been analyzed, according to which the following can be said:

1) A situation when simultaneous switching of breakers is possible can pose, though unlikely, a serious threat for transformer substation equipment.
2) Measures taken to protect from switching overvoltages at the moment do not cover all possible emergency conditions. Nonlinear suppressors with parallel switching of vacuum breakers not always reduce the overvoltage down the acceptable level.
3) As an additional protective measure, it is recommended to install an additional protective device on transformer substation buses. And to use a nonlinear overvoltage suppressor with a higher power capacity class.

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