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COMPUTER SIMULATION OF SWITCHING POWER CAPACITOR BANKS BY CIRCUIT BREAKERS WITH PRE-INSERTION RESISTORS

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Abstract- The article presents results of numerical research of switching (energization and de-energization) power capacitor banks equipped by special switchers which include the sets of pre-insertion resistors with different resistances, in the terms of possible magnitudes of switching transitional voltages (over voltages) and inrush currents, and also the features of the circuit breakers operations with pre-insertion resistors at energization high-voltage (namely 110 kV in the presented article) power capacitor banks. Due to numerous simulations, there were estimated possible ratios of switching overvoltage at switching capacitor banks by SF_6 circuit breakers with pre-insertion resistors for all the range of resistances they are equipped, explained the nature of inrush currents spikes at presence of capacitive load (capacitances of connected cable and aerial power transmission lines) on busbar the capacitor banks are connected to. There were stated that, the use of circuit breakers with pre-insertion resistors for switching capacitor banks provide effective mitigation of switching overvoltage (at appropriated pre-insertion times) whereas the ratios of inrush currents at switching-on power capacitor banks by circuit breakers with pre-insertion resistors can reach high values (more than 4.5 amplitude of rated phase current). Right option of resistance and pre-insertion duration can help to reduce the inrush current. Magnitudes of currents at arc repeated restrikes in the capacitor banks switching-off mode can prevail their energization inrush current.

Keywords: Pre-Insertion Resistor, Inrush Current, Pre-Insertion Time, Capacitor Switchers, Back-to-back Arrangement, Wave Impedance.

1. INTRODUCTION

Pre-insertion resistors (PIRs) are mostly used to mitigate transitional voltages at switching high-voltage electrical installations [1, 2]. Initially they were used for the switching-on power transmission lines, so there were produced circuit breakers with resistance of PIR equaled to the aerial power transmission lines' wave impedance i.e., 300-400 Ohms [3].

These resistances of PIR were not appropriated for reliable switching of power capacitor banks since the typical wave impedances of the loops consisting of capacitor banks' capacitance and transformers' inductance can be significantly less than aerial power transmission lines' wave impedance. But presently there are produces so called CapSwitchers, the special type of circuit breakers to switch capacitor banks with no high overvoltage and inrush currents due to the wide range of PIR's resistances (37.5-300 ohms) for standard voltages 123-170 kV [4]. Pre-insertion times (PITs) of these CapSwitchers are 5-10 msec.

The use of these switchers for power capacitor banks, evaluation of switching over voltages and inrush currents, study of the features of the operation circuit breakers with PIRs at switching-on capacitor banks are studied in the presented research. Note here that effectiveness of use the circuit breakers with PIRs have been actively studied in last years, thus some important results concerned to switching-on (energization) of power capacitor banks are presented in [5-9], to energization of aerial power transmission lines. In [10] were considered some peculiarities of switching-off (de-energization) high-voltage power capacitor banks by CapSwitchers.

2. RESEARCH GROUND

A connection circuit and equivalent network of the problem under study are presented below in figure 1. The corresponding numerical values of the parameters used for computer simulation are given in [10]. For implementation the present research there was applied a numerical model described in [11, 12]. In the present research we used both the MATLAB and PSCAD/EMTDC program sets to provide and be confident in obtaining stable solutions for transitional functions. This is conditioned by the nature of such type of the problems belonging to the class of so called "stiff" problems [11-12]. Features of computer simulation "stiff" problems in relation to transient processes in electrical networks are considered in [13-15].

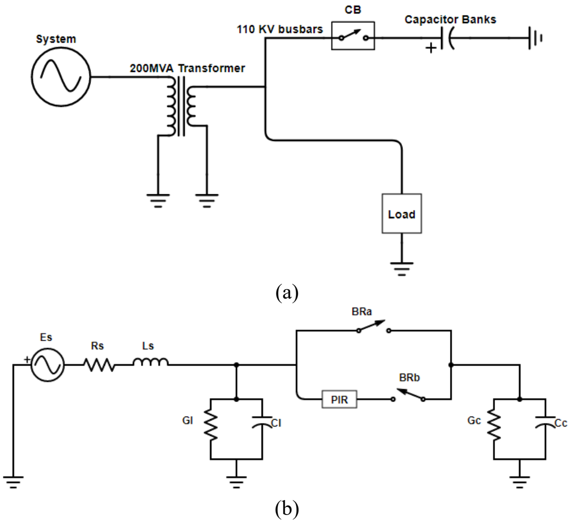


Figure 1. (a) Connection scheme, (b) equivalent network, Case under study for switching-on capacitor bank by circuit-breaker with pre-insertion resistor (PIR)

3. RESULTS AND DISCUSSION

The numerous simulations implemented within this research let us to reveal some features of the process studied. They are presented and considered below.

3.1. Switching-on (Energization) Process

3.1.1. Ratios of Over Voltages and Inrush Currents

In accordance with our results the ratio of overvoltage at switching-on power capacitor banks of 110 kV with no pre-insertion resistors can exceed 1.8-1.9 p.u. This should be taken into consideration at designing substations with power capacitor banks connected to the medial or lower voltage bars of ultra-high voltage (UHV) transformer or autotransformer since the allowable UHV insulation levels are less than 2.0 p.u. [16] and relatively little natural frequencies (about 260 Hz in the case under study) cannot provide effective attenuation at transition to the UHV side.

All the resistances of PIR provide effective mitigation of switching overvoltage in the range of pre-insertion time 5-10 msec. For example, the results of computer simulation at pre-insertion time 6 msec for switching-on the power capacitor bank of 110 kV, 56 MVAr is presented in the table 1. It is seen from this table that, the maximum overvoltage occurred can reach 1.33 p.u (at R_{pir} = 25 ohm, T_{pir} = 6 msec). Moreover, minimum overvoltage occurs at PIR closed to the wave impedance of the circuit consisting of capacitor banks' capacitance and transformers' inductance.

Not all the resistances of PIR provide effective decreasing of inrush currents, e.g., ratios of inrush currents at switching-on capacitor banks of 110 kV, 56 MVAr by CapSwitcher with R_{pir} = 37.5-300 ohms equal to 2.1-4.7 p.u. At that the minimum inrush currents take place at the resistances of PIR approximately equaled to the doubled wave impedance of the switched circuit. In Table 1 standard PIR resistances (37.5, 75, 150, 300 ohms) are used, and the rest (25, 50, 100, 200 ohms) are intermediate resistances for the analysis of the computer simulation results.

The samples of graphs showing temporal dependences of transitional voltages and currents are presented in Figure 2. These graphs are concerned to the case of use pre-insertion resistor of 75 ohm at pre-insertion time 6 msec.

3.1.2. Inrush Current Spikes

As it is seen in the Figure 2 the inrush current has a spike in the very initial period after the switching instant. At that, the magnitudes of these spikes decrease at increasing the PIR's resistance as shown in Table 1.

Table 1. Simulation results for 110 KV, 56 MVAr capacitor bank switching-on at different values of PIRs (T_{pir} = 6 msec)

PIR resistance [ohm]	Voltage on 110 kV bars [pu]	Inrush current [pu]	Energy dissipated [kJ]
25	1.33	6.78	1317
37.5	1.18	4.65	930
50	1.16	3.54	718
75	1.20	2.40	493
100	1.23	2.13	375
150	1.26	2.28	253
200	1.26	2.28	196
300	1.24	2.16	126

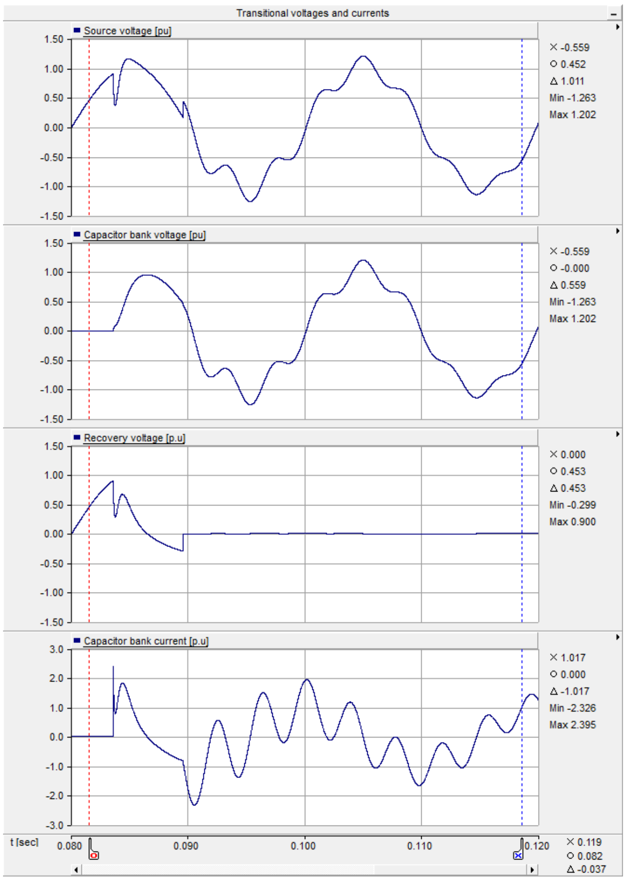
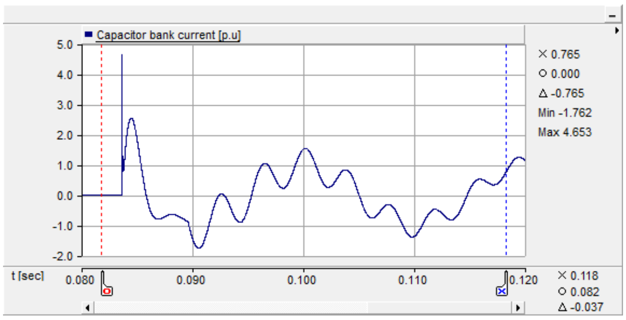
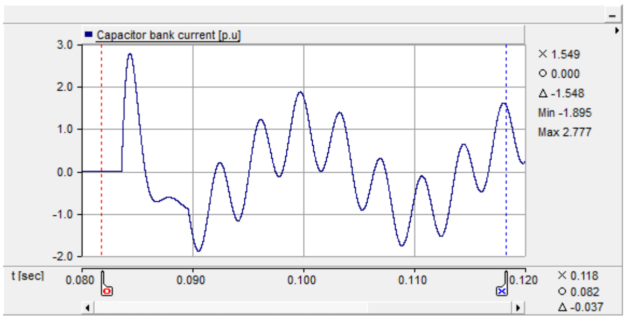


Figure 2. Curves of transitional functions at switching-on 110 kV, 56 MVAr capacitor banks at R_{pir} = 75 ohm and T_{pir} = 6 msec

To clarify the nature of these spikes we implemented some simulations at the case of absence of connections (load) to the 110 kV busbars the switched capacitor banks are connected to. It has turned out that for these cases there are not any inrush currents' spikes at switching-on, as shown in Figure 3. This phenomenon can be explained due to the known fact of sudden jump of inrush current at switching-on the capacitor banks connected by the back-to-back arrangement at already switched-on another one [4]. These two cases i.e., switching-on capacitor banks connected to the busbars having other connections (e.g., aerial and/or cable power transmission lines, instrument transformers and so on) and switching-on the second capacitor bank in the back-to-back arrangement are physically similar.



(a)



(b)

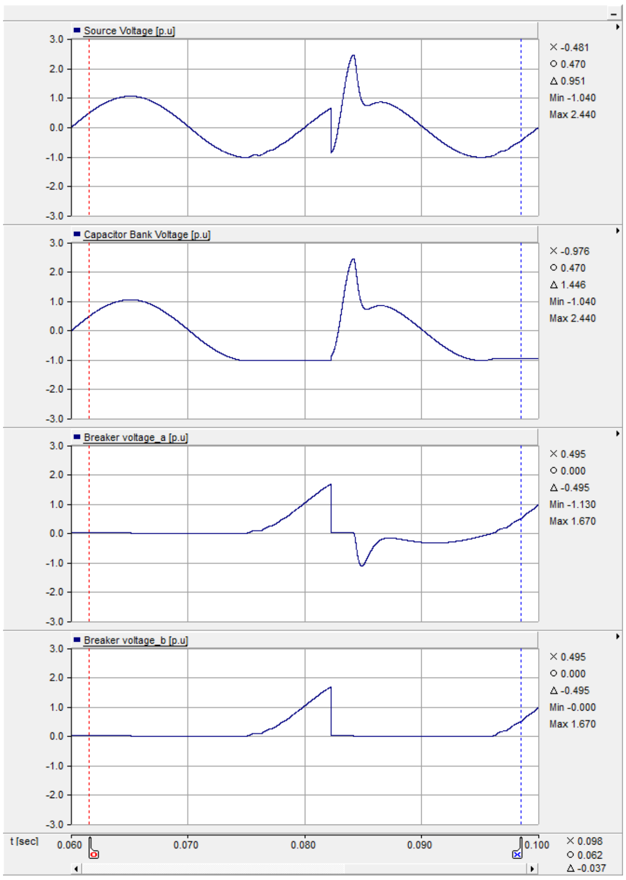
Figure 3. (a) at presence of capacitances connected to busbars, (b) at absence of capacitances connected to busbars, Curves of inrush currents at switching-on capacitor bank of 110 kV, 56 MVAr at R_{pir} = 37.5 ohm and T_{pir} = 6 msec

3.2. Comparison of Switching-on and Switching-off Processes in the Terms of Inrush Currents' Ratios

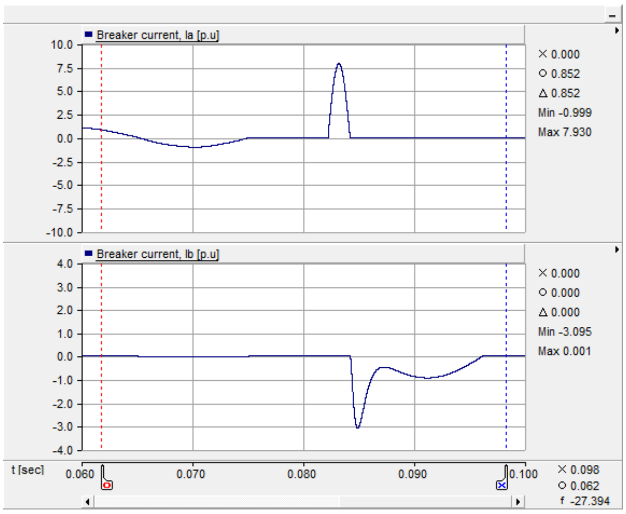
3.2.1. Influence of Pre-Insertion Time on Switching Processes

Comparing results got in the presented research with ones obtained in the research work [10] devoted to the study of power capacitor banks switching-off (de-energization) we can state the following:

- The ratios of transitional currents conditioned by arcs repeated restrikes at switching-off capacitor banks can notably prevail the ratios of inrush currents at their energization. In our opinion this takes place because of significantly higher magnitudes of intercontact voltages at the arcing instant at switching-off process (recovery voltage can exceed 3.0 p.u), E.g., the calculated current ratios are equalled 2.4 p.u and 3.0 p.u (see [10]) for the cases of switching-on and switching-off capacitor banks of 110 kV, 56 MVAr at PIR resistance 75 Ohm and pre-insertion time 6 msec, respectively.
- Magnitudes of power capacitor banks' inrush currents may have a significant impact on substation's electromagnetic environment and electromagnetic compatibility. In our opinion, use of circuit breakers with pre-insertion resistors can effectively improve electromagnetic environment of substations due to mitigation of inrush currents.

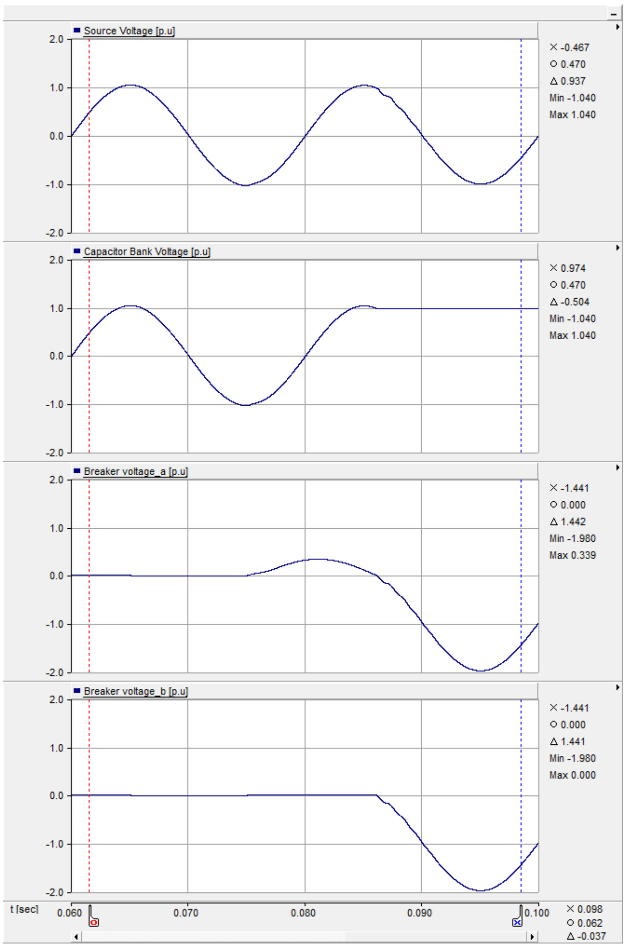


(a)

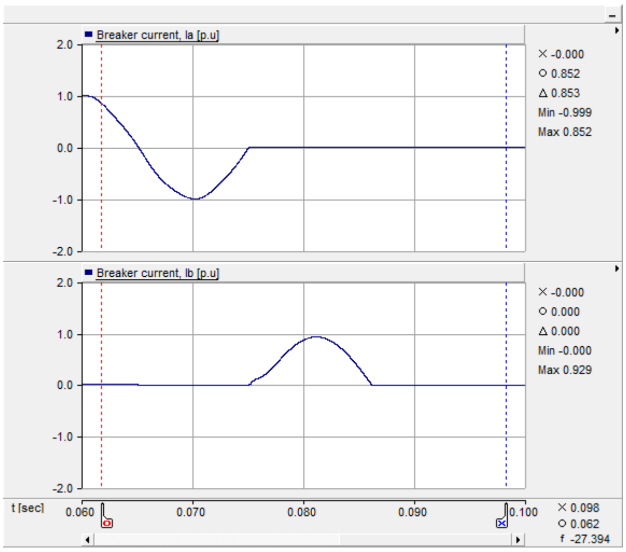


(b)

Figure 4. Simulated curves of transitional voltages (a) and currents (b) at switching-off 110 kV capacitor banks by SF_6 circuit-breaker with pre-insertion resistor (T_{pir} = 6 msec, R_{pir} = 75 ohms)



(a)



(b)

Figure 5. Simulated curves of transitional voltages (a) and currents (b) at switching-off 110 kV capacitor banks by SF_6 circuit-breaker with pre-insertion resistor (T_{pir} = 7 msec, R_{pir} = 75 ohms)

• Pre-insertion times can significantly affect on switching transitional process. As it was stated in our research this influence is mostly evident for the switching-off power capacitor banks. Influence of pre-insertion times on the switching-off processes is illustrated by above presented Figures 4 and 5.

3.3. Energy Dissipated in PIR

Graphs of dependence of the energy dissipated in PIR in all the range of PIR resistances at pre-insertion times 5 msec and 10 msec are presented in Figure 6. All the possible values of the dissipated energy for pre-insertion times between 5 msec and 10 msec lie in the region between the curves given in Figure 6. Note that, the PIR's under consideration were designed for such values of dissipated energy [4]. Fortunately, the energy dissipated in the pre-insertion resistors at switching-off process is quantitatively alike one at switching-on process [10].

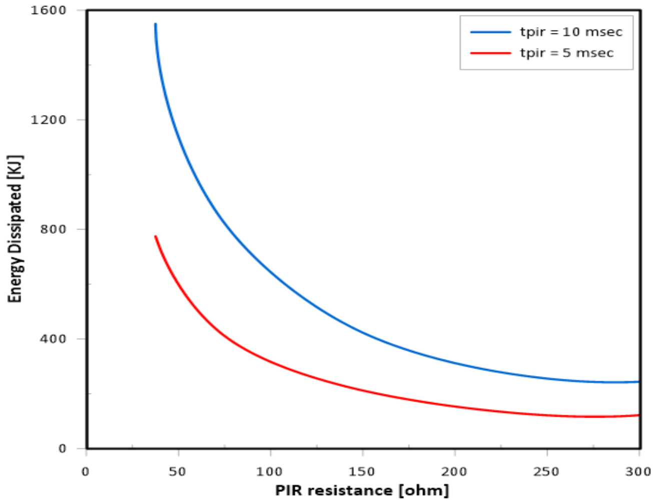


Figure 6. Energy dissipated at switching-on capacitor bank of for 110 KV, 56 MVAr at different values of PIRs resistance and pre-insertion time

Note that taking into consideration arc in circuit breakers with pre-insertion resistors seem not so important as for conventional ones [17].

4. CONCLUSIONS

The use of circuit breakers with PIR for power capacitor banks leads to effective mitigation of switching overvoltage (at appropriated pre-insertion times), wherein the maximum possible overvoltage that can appear on transformer's higher voltage windings is less than its permissible value for EHV and UHV isolation.

Ratios of inrush currents at switching-on power capacitor banks by circuit breakers with PIR can reach high values (e.g., more than 4.5 amplitude of rated phase current for capacitor banks of 110 kV, 56 MVAr). Right option of PIR resistance and pre-insertion time can ensure effective mitigation of inrush current. Splashes of current at arc repeated restrikes in the capacitor banks switching-off mode can prevail switching-on inrush current of the same capacitor banks. Use of circuit breakers with PIR can improve electromagnetic environment on substation.

NOMENCLATURES

1. Acronyms

UHV	Ultra-High Voltage
EHV	Extra-High Voltage
PIR	Pre-Insertion Resistor
PIT	Pre-Insertion Time

2. Symbols / Parameters

R_s: Source resistance L_s: Source inductance
G_l: Load conductivity C_l: Load capacitance
G_c: Capacitor bank conductivity
C_c: Capacitor bank capacitance
E_s: e.m.f. of voltage source (rms value)

REFERENCES

[1] R. Smeets, L. Van Der Sluis, M. Kapetanovic, et al., "Switching in Electrical Transmission and Distribution Systems", Wiley, New York, USA, 2014.
[2] D.V. Razevig, "High Voltage Engineering", Khanna Publishers, New Deli, India, 1989.
[3] Gujarat Energy Transmission, "Technical Specifications of 400 kV SF_6 Circuit-Breakers with PIR and Spring-Spring Mechanism", April 2013.
[4] S.S. Southern States, "110-170 KV RMS CapSwitcher Sales Brochure", Hampton, Georgia, 2012.
[5] P.A.A. Pramana, A.A. Kusuma, B.S. Munir, "Inrush Current Investigation of Capacitor Bank Switching for 150 kV Electrical System in Indonesia", High Voltage Engineering and Power Systems (ICHVEPS) International Conference, pp. 259-263, 2017.
[6] L.V. Teli, H.T. Jadhav, "A Review on Protection of Capacitor in Power Quality Industry", Current Trends Towards Converging Technologies (ICCTCT) International Conference, pp. 1-5, 2018.
[7] A.H. Fajariawan, A.I. Fadlika, et al., "A New Switching Control Approach to Reduce Capacitor Bank Inrush Current", Annual International Conference on Renewable Energy (ICORE), University Negeri Malang, Malang, Indonesia, August 9-10, 2019.
[8] V. Kuchanskyy, P. Satyam, O. Rubanenko, et al., "Measures and Technical Means for Increasing Efficiency and Reliability of Extra High Voltage Transmission Lines", Electrotechnical Review, Vol. 96, No. 11, pp. 135-141, 2020.
[9] S.M. Sangeeta, M.S. Sureban, "Effect of Pre-Insertion Resistor on Energization of Long Lines", International Journal of Scientific an Engineering Research, Vol. 10, No. 5, May 2019.
[10] T. Lazimov, E. Saafan, "Transitional Processes at Switching-Off Capacitor Banks with Pre-Insertion Resistors", The MEPS'15 Symposium, pp. 1-4, Wroclaw, Poland, July 2015.
[11] J.C. Butcher, "Numerical Methods for Ordinary Differential Equations", John Wiley and Sons, Ltd., p. 538, New York, USA, 2016.
[12] L.F. Shampine, "Numerical Solutions of Ordinary Differential Equations", Routledge, p. 632, Oxford shire, England, 2020.
[13] T. Lazimov, E. Saafan, "Influence of Arc Resistance on Transitional Functions, Stability at Computer Simulation of Switching-Off Processes", IEEE PES Asia Pacific Power and Energy Engineering Conference (APPEEC), pp. 1-4, Hong Kong, 2014.
[14] 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.
[15] T. Lazimov, S. Akhundov, "Peculiarities of Transients' Simulation in Electrical Circuits", The Republican Conference on IT, Vol. II, pp. 104-107, Baku, Azerbaijan, 2003.
[16] E. Shim, E. Zaima, "Introduction of Insulation Coordination for UHV AC Systems", Journal of Electrical Engineering and Technology, Vol. 10, No. 3, pp. 1293-1297, May 2015.
[17] T. Lazimov, S. Imanov, "Some results of unloaded line switching-offs' computer simulation", Proceedings of the 5-th International Conference ELECO, 2007, pp. 147-150, Bursa, Turkey, 2009.

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