UIJRT ISSN: 2582-6832

United International Journal for Research & Technology

Volume 04, Issue 10, 2023 | Open Access | ISSN: 2582-6832

Switching of MSC in High-Voltage Systems

T. M. Lazimov[1] and A. B. Sadigov[2]

[1]Ship Electro Automatics Department, Azerbaijan State Marine Academy, Baku. Azerbaijan

[2]Energy Efficiency and Green Energy Technologies Department, Azerbaijan Technical University, Baku. Azerbaijan

***Abstract*—** The paper briefly overviews the problems associated with mechanically switched capacitor banks (MSC) used in high-voltage power systems. The article discusses the principal features of MSC switching in the view of their possible impact on the high-voltage insulation of capacitor banks and the electric system itself, as well as the electromagnetic environment and compatibility on the substation. The article deals with such issues as the influence of the type of circuit breaker (SF6 or vacuum one) on the switching transitional voltages, the use of special capacitive circuit breakers equipped with a set of pre-insertion resistors with various resistances, the switching of MSC in FACTS circuits and the ways of the transitional voltages control, the possibility of transferring overvoltage from the transformer's lower voltage windings to the higher ones having a reduced isolation level, etc.

***Keywords*—** Capacitor Switchers, Mechanically Switched Capacitors, Overvoltage, Pre-insertion Resistor, SF6 and Vacuum Circuit Breakers

I. INTRODUCTION

[The switching of high-voltage capacitor banks, now mostly referred to as mechanically switched capacitors (MSCs), has always been of great importance for the operation of electric power systems. Initially, this mode of MSC seemed to be mainly one of the most dangerous, since the occurrence of high overvoltage could damage the insulation of the electrical equipment of the system and thereby reduce the reliability of the system [1 - 4]. Historically, the focus of researchers has been precisely the MSC switching-off mode as one accompanied by the most unfavorable impact on the system and installation itself.

Later, switching of capacitor banks, namely their switching-offs accompanied by arc restrikes and re-ignitions and also switching-on high-capacitance MSC began to be considered also in the terms of electromagnetic environment of the substations in concern to electromagnetic compatibility [5].

Note that the known theory of transitional processes at disconnection of capacitive currents presented in [1,2,6] had been developed for the low-speed high voltage circuit-breakers. As we know these types of circuit breakers (oil and air blast) have a relatively slow velocity of restoration of the electrical strength in arc-quenching media. That leads to a high probability of repeated restrikes and re-ignitions at switching-off.

This traditional theory explains the increasing of switching transitional voltages by serially repeated restrikes in the between the contacts of circuit breakers, that leads to the corresponding increase in the voltage across the capacitor banks' terminals, due to the cumulation of electric charge in the MSC after each successive interruption of the current through the arc between the circuit breaker poles [1, 2, 7]. Obviously, such an interpretation could not reveal and explain the flow of the transitional processes at switching-off MSC by modern (SF6 and vacuum) circuit breakers with high electrical strength characteristics. Note that the share of low-speed circuit breakers of the old generation in their total production was negligible even at the beginning of 2000-th [8].

Presently, overvoltage at disconnection of MSC by modern vacuum and SF6 circuit-breakers having high velocities of electric strength restoration is determined by interruption of high-frequency switched-off currents (arc quenching) appeared due to the arc repeated restrikes and the instantaneous values of recovery (intercontact) voltages at the arc quenching instant [9].

II. SWITCHING-OFF. INFLUENCE OF THE CIRCUIT BREAKER TYPE

The influence of the type of circuit breaker on switching processes began to study about 20 – 30 years ago e.g., see [10-11]. As we determined in [12] capacitor banks switching-offs by vacuum circuit breakers are accompanied by less probability of repeated re-strikes of arc and higher overvoltage than auto-compression (SF6). In Fig.1 and Fig.2 are presented simulated transitional voltages for the cases of switching-off 110 kV, 56 MVAr MSC by SF6 and vacuum circuit breakers respectively.

At that, the overvoltage ratios do not exceed the triple value of the rated voltage amplitude i.e., permissible level for the 110 kV voltage class. In [12] we also offered to use vacuum circuit breakers for 110 kV MSC switching.

A high guaranteed number of switch-on / switch-off operations of vacuum circuit breakers can provide flexible use of capacitor banks i.e., their frequent switching in correspondence with the required level of voltage on the bus-bars they are connected to.

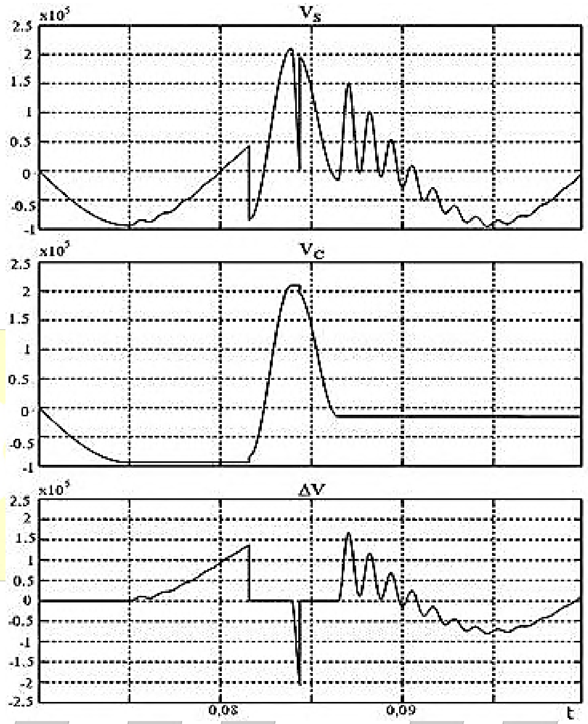

Figure 1. *Transitional voltages at switching-off MSC by SF6 circuit breaker. Vs is the voltage on the source side, Vc – voltage across the MSC terminals, ΔV – recovery voltage.*

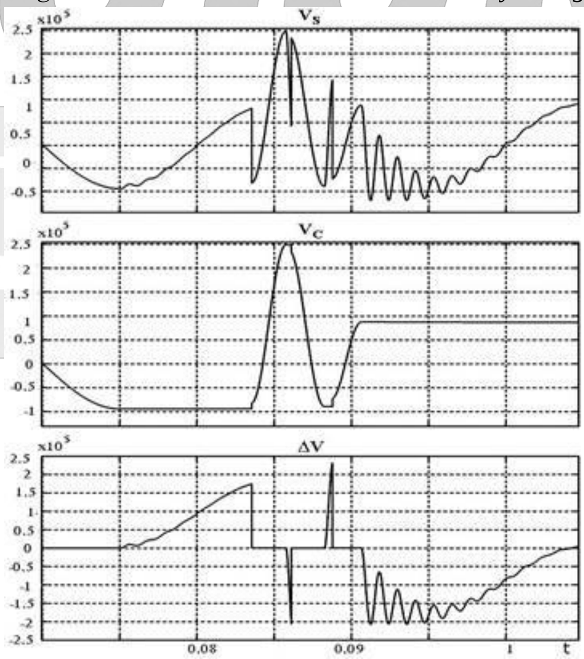

Figure 2. *Transitional voltages at switching-off MSC by the vacuum circuit breaker. Vs is the voltage on the source side, Vc – voltage across the MSC terminals, ΔV – recovery voltage.*

As we stated in [12] type of a circuit breaker (vacuum or SF6) has a notable impact on the ratios of voltages across the terminals of capacitor banks and recovery voltages across the circuit breaker poles at switching-off

MSC. The greatest overvoltage and recovery voltages at switching-off capacitor banks take place at use of vacuum circuit breakers. This conditions by decreasing of electrical strength of vacuum gaps with increasing intercontact distance, that increases the probability of breakdowns at high magnitudes of transitional recovery voltages. Remind here that just this feature of vacuum circuit breakers limits their use for higher voltage levels

The least overvoltage and transitional recovery voltages at switching-off capacitor banks take place at use SF6 (auto-compression) circuit breakers. This occurs due to the relatively little steepness of restored electrical strength function for SF6 circuit breakers in the beginning period of contact separation. As a result, breakdowns of intercontact spaces of SF6 circuit breakers occur at relatively little magnitudes of recovery voltage.

MSC can be used as a separate installation and also as a part of FACTS (Flexible Alternating Current Transmission System) [14]. As it is noticed in [15] switching-off the MSC included in FACTS, by vacuum circuit breakers can cause significantly higher transitional voltages comparatively with switching-off of the separate MSC installation.

Result. Use of SF6 circuit breakers for MSC is more preferable rather than vacuum ones from the point of view of transitional voltages (for the standard voltages where both of them are usually used).

III. SWITCHING-ON / INFLUENCE OF SWITCHING ANGLE, TRANSITIONS OF OV TO THE EHV AND UHV WINDINGS

It is known that transitional voltage at switching electrical installation depends on the circuit breaker's switching angle (switching-on phase) and maximum overvoltage cannot exceed the double value of forced voltage at the switching instant [1]. This means that overvoltage will depend on the magnitude of forced voltage corresponded to the switching instant.

Note that control of forced (source) voltage by changing the TCR firing angles can have significant importance for the highest voltage (e.g., more than 800 kV) side of the substations, to the medium or lower voltage of which the MSC installation is connected. It is conditioned by that forced voltages (unlike free, or natural voltages) are not undergone attenuation at transmission from the lower or medial winding of the transformer to the higher one. Besides, as known UHV installations and equipment have a reduced level of permissible voltages [16]. Moreover, even natural frequencies at switching-off MSC used in electric power systems do not exceed a few hundred Hertz so their transition to the highest (assumedly EHV or UHV) voltage winding faces with very small attenuation. Remind that minded free, or natural frequency is determined for the circuit consisted of the capacitance of MSC and parameters of the transformer (or autotransformer) which bus-bars the MSC is connected to.

Result. Switching-on MSC can cause undesirable overvoltage on the EHV and UHV sides of the substation.

IV. USE OF SPECIAL CAPACITOR SWITCHERS (CAPSWITCHERS)

The use of circuit breakers with previously switched resistors (pre-insertion resistors, or PIR) is one of the ways for decreasing transitional overvoltage at switching overhead transmission lines [1].

The use of that type of circuit breaker causes the effective mitigation of transitional voltages at the properly chosen resistance of the PIR. It has been also known that the optimum decreasing of switching overvoltage for overhead power lines corresponds to the PIR's resistances about the modules of their wave impedance [1 - 3].

It was worked up and produced for a certain period a new type of circuit breaker equipped by PIR, which resistances were designed for the conditions of capacitor banks switching-on. These are the SF6 circuit-breakers of voltages between 123 kV and 170 kV named Capacitor Switchers that are completed by the set of resistors in the range between 37.5 and 300 Ohms, which are chosen by necessity, close to the wave impedance of the switched installation [17].

The pre-insertion periods for these Capacitor Switchers can be set in the range between 5 and 15 milliseconds [17]. One more type of circuit-breaker has PIR' resistances equaled to the wave impedance of the aerial power lines.

For example, the 400 kV circuit breaker considered in [18] is equipped with the resistance of 400 Ohms, operating in the 6 – 10 milliseconds time period. The effectiveness of using CapSwitchers is illustrated in Fig.3 and Fig.4.

Volume 04, Issue 10, 2023 | Open Access | ISSN: 2582-6832

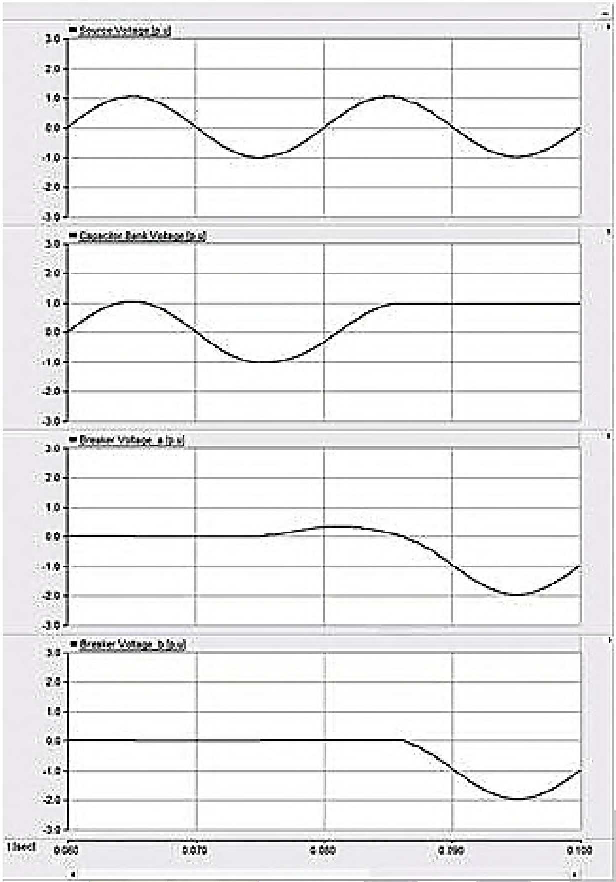

Figure 3. *Transitional voltages at disconnection MSC of rated voltage 110 kV by CapSwitcher at optimally chosen pre-insertion parameters (75 Ohms, 7 msec).*

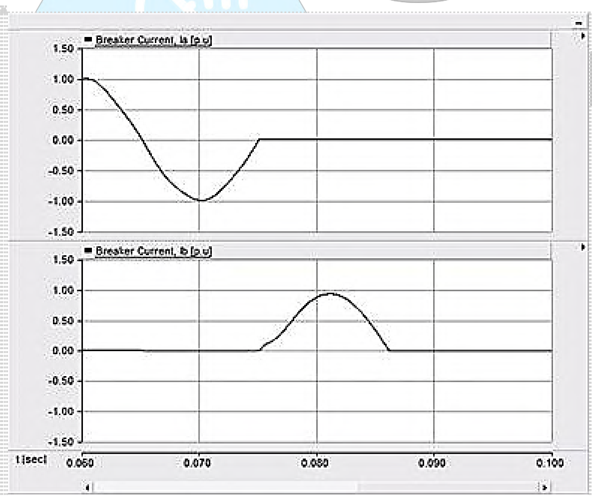

Figure 4. *Transitional currents at disconnection MSC of rated voltage 110 kV by CapSwitcher at optimally chosen pre-insertion parameters (75 Ohms, 7 msec)*

Our research showed that despite of being the MSC switching-on processes and corresponding transitional voltages in the spotlight of researchers, their switching-off can be even more dangerous than switching-on mode [19]. Remind, that transitions at switching of MSC can create electromagnetic interferences and so, have a serious impact on electromagnetic compatibility [20].

Result. Use of the special capacitive switchers lets to reduce effectively transitional currents and voltages at switching-on and switching-off MSC. This also leads to improving the electromagnetic environment and compatibility at the substation.

V. SWITCHING-ON OF MSC IN FACTS

It is known that Mechanically Switched Capacitors are a part of Flexible Alternating Current Transmission Systems (FACTS) responsible for the delivery of reactive (capacitive) power to the FACTS bus-bars [21]. The term MSC appeared precisely in connection with the application of FACTS installations since another kind of reactive power (inductive) is controlled due to the change of thyristors firing angle, that is not expedient for the capacitor banks.

As we stated in our previous works:

- behavior of the transitional voltages at switching-on MSC to the FACTS bus-bars with star-connected TCR follows to behavior of these voltages' 50 Hz components, for each phase. In other words, control of the thyristors' firing angle lets us control the magnitudes of transitional voltages. This can also help to decrease the magnitudes of the transitional voltages transmitting to the higher voltage bars of the transformer (autotransformer) from the busbars, FACTS, and consequently, MSC is connected to. The typical curve of the transitional function is presented in Fig.5 (parameters are given in the captions);
- switching-off MSC from the FACTS bars by vacuum circuit breakers can cause high ratios of transitional voltages comparatively with the switching-off of separate capacitor banks installation. Moreover, as our last researches show, the transitional functions' free oscillations in FACTS schemes have a more complicated character that can enhance the electromagnetic interferences in the substation.

Note at the end that computer simulation of switching processes of capacitor banks is not too complicated except in cases when MSC is switched-off from the bus-bars had some low connected capacitances, such as short aerial power transmission lines [22].

Volume 04, Issue 10, 2023 | Open Access | ISSN: 2582-6832

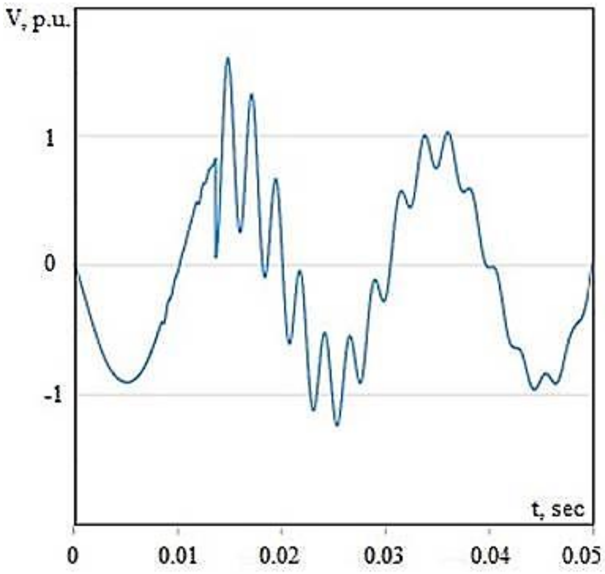

Figure 5. *Transitional voltage across the MSC 110 kV, 25 MVAr terminals at its switching-on (TCR are star connected, thyristors' firing angle equals 60 degrees)*

Result. The transitional voltages at switching MSC in the FACTS schemes can be moderately controlled by the thyristors switching mode's change.

REFERENCES

[1] D.V. Razevig, "High Voltage Engineering", Khanna Publishers, New Deli, India, 1989.

[2] Van der Sluis, Transients in Power Systems, John Wiley & Sons, New-York, 2001

[3] R. Smeets, L. Van Der Sluis, M. Kapetanovic, et al., "Switching in Electrical Transmission and Distribution Systems", Wiley, New York, USA, 2014.

[4] G.Gopakumar, , H.Yan, , B.A.Mork, , K.K. Mustaphi, "Shunt Capacitor Bank Switching Transients: A Tutorial and Case Study", Michigan Technological University, Northern States Power Company, 2009.

[5] U.S.Jelezko, "CIGRE works in the area of electromagnetic compatibility", Elektrichestvo, 10, pp. 73-78, 1995.

[6] J.C.Das, , Analysis and Control of Large-Shunt Capacitor Bank Switching Transients, IEEE Trans. Industry App., vol. 41, no. 6, pp. 1444-1451, 2005.

[7] K. Ragaller, "Current Interruption in High Voltage Network", Plenum Press, New York, USA, 1978.

[8] G.A.Yevdokunin, G.Tiler. "Modern vacuum switching apparatus for medial voltages", M.P.Sizov Publisher, Sankt- Petersburg, 2002.

[9] T. Lazimov, S. Imanov, E. Saafan, "Transitional Recovery Voltages at Capacitive Currents Switching-offs by Vacuum and SF6 Circuit-Breakers", The MEPS International Symposium, pp. 1-5, Wroclaw, Poland, 2010.

[10] 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, pp.1-6, 2003.

[11] S. Shu, J. Ruan, D. Huang, and G. Wu, "Influencing factors of breaking capacity of double-break vacuum circuit-breakers," Telkomnika, Vol. 11, No. 6, pp. 2903-2911, 2013.

[12] H. Mammadov, T. Lazimov, S. Imanov, A. Nayir, "Comparison of transients while switching-off capacitor banks by vacuum and auto-compression circuit-breakers," Proc. of Fourth ICTPE Conference, Pitesti, Romania, pp. II.9 - II.12, 2008.

[13] Y.Murai, H.Toya, T.Nitta "Statistical property of the breakdown of vacuum circuit-breakers and its influence on the surge generation in capacitive and reactive current interruption", IEEE Transactions on PAS, 1979, №11.

[14] X.P. Zhang, C. Rehtanz, B. Pal, "Flexible AC Transmission Systems", Springer Publisher, 2006.

[15] T. Lazimov, E. Saafan, S. Gahramanova "Switching of MSC in Flexible Ac Transmission Systems", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 49, Vol. 13, No. 4, pp. 201-206, December 2021.

[16] IEC TS 63042-101. Voltage regulation and insulation design, 2019.

[17] SS Southern States, "LLC. 110-170 KV RMS CapSwitcher Sales Brochure," Hampton, GE, 2012.

[18] Gujarat Energy Transmission Co LTD., "Technical specifications of 400 kV SF6 circuit-breakers (with PIR and spring-spring mechanism)," April, 2013

[19] 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.

[20] https://e-cigre.org/publication/SYMP_LAU_1993-lausanne-power-system-electromagnetic-compatibility

[21] https://new.abb.com/facts/static-var-compensation-(svc)

[22] 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.