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SWITCHING OF MSC IN FLEXIBLE AC TRANSMISSION SYSTEMS

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Abstract- Switching-on and switching-off of mechanically switched capacitors in flexible AC transmission system dependently on value of firing angle of thyristor-controlled reactors connected to the same bus-bars system with capacitor banks and harmonic filters were considered in the paper for the cases of delta-connected and star-connected three-phase reactors. There was revealed certain qualitative correspondence between behaviors of forced voltage components and transitional voltages at switching-on capacitor banks (by phases) for the case of star-connected reactors, which is violated for the case of delta-connected reactors. This different behavior depending on the reactor neutral mode was explained as the behavior due to the voltage displacement of the isolated neutral in the case of delta-connected reactors. There were also estimated and explained differences between magnitudes of transitional voltages ratios at use vacuum circuit breakers in comparison with SF_6 ones at switching-off capacitor banks in flexible AC transmission system with delta-connected reactors and autonomous ones. There also considered some other features of processes under study and their computer simulation in the paper.

Keywords: Flexible AC Transmission Systems, Power Harmonic Filters, Power System Simulation, Reactive Power Control, Static VAR Compensators, Switched Capacitor Circuit.

1. INTRODUCTION

As it is widely-known, switching of power capacitor banks can be accompanied by significant increasing of transitional voltages (voltages across the capacitor banks terminals and across the circuit-breaker poles) [1-3]. At that case, the most unfavorable magnitudes of transitional voltages take place at capacitor banks switching-off whereas the maximum extra currents appear at their switching-on and arc repeating re-strikes in switching-off mode [1, 4].

The modern FACTS (Flexible AC Transmission Systems) devices are equipped by Mechanically Switched Capacitor (MSC) banks whose function is to provide transmission system by capacitive power [5, 6]. FACTS can provide smooth control of reactive power sent to the bus-bars [7, 8]. This takes place due to possibility of purposeful varying the thyristor firing angle [9-11].

Note here that IEEE defines FACTS as a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability [12].

Control of value and type of reactive power (inductive or capacitive) produced by FACTS is implemented by the reactor connected to the bus-bar through bidirectional thyristor valve (thyristor-controlled reactor, TCR). Typical schemes of FACTS have a common topology TCR/MSC/FC (where via FC are denoted harmonic filters) were used for Static VAr Compensators (SVC) [13].

Numerous researches of transitional processes at switching of MSC installations have been carried-out, were implemented out of the FACTS context. It means that these researches were conducted for the case of absence of thyristor-controllable reactor and filters (for separate capacitor banks, MSC). At the same time, firing angle control mode of TCR should have impact on magnitudes of transitional voltages, first of all via influence on steady-state transient voltage component.

The present paper is dedicated to study transitional voltages at switching (switching-on and switching-off) MSC included in FACTS installation. We studied dependence of transitional voltages across the capacitor banks terminals and across the circuit-breaker poles (recovery voltage) on firing angle of TCR thyristors. Results of this research and discussion are presented below.

2. FACTS EQUIVALENT CIRCUITS

The FACTS 3-phase schemes considered in the research are presented below in the Figures 1 and 2.

It was studied in this research the switching of MSC (110 kV, 25 MVAr) by SF_6 circuit-breaker at varying firing angle of TCR thyristors. In the case corresponding to Figure 1, TCR reactors are delta connected, which eliminates the need for the 3rd harmonic filter in the FACTS circuit, so there are used just the 5th and 7th harmonic filters. In the case corresponding to Figure 2, TCR reactors are star connected, so this scheme should contain the 3rd harmonic filter.

Parameters of the transformer (to the 110 kV buses of which FACTS is connected), TCR, and harmonic filters elements (inductances and capacitances) are shown in the Figures 1 and 2. There also are given parameters of load connected to the 110 kV bus-bars of the substation.

Parameters and electric strength restoration law of 110 kV SF_6 circuit-breaker were set in accordance with [14].

Note here that all phases of the circuit-breaker have a common drive that determines simultaneous movement of all the phases' movable contacts.

Conditions of MSC switching-off (arc quenching) and arc repeated re-ignitions were set in accordance with [15, 16].

PSCAD/EMTDC V4.2 software was used for computer simulations of the problem under consideration.

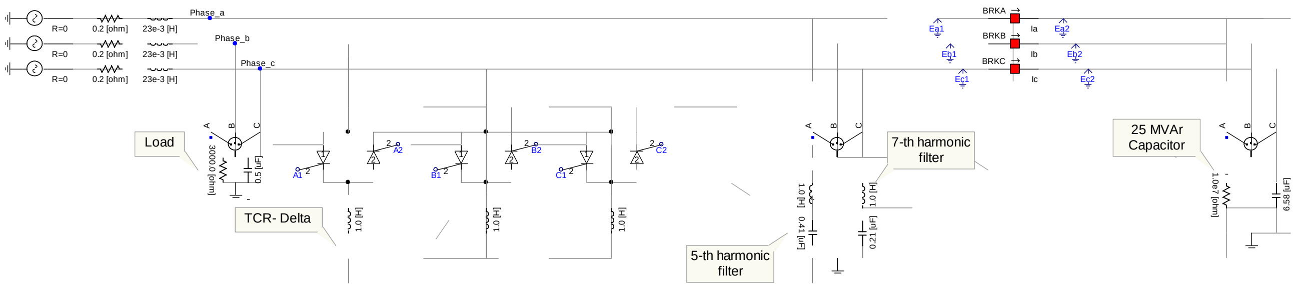

Figure 1. FACTS with delta connected TCR

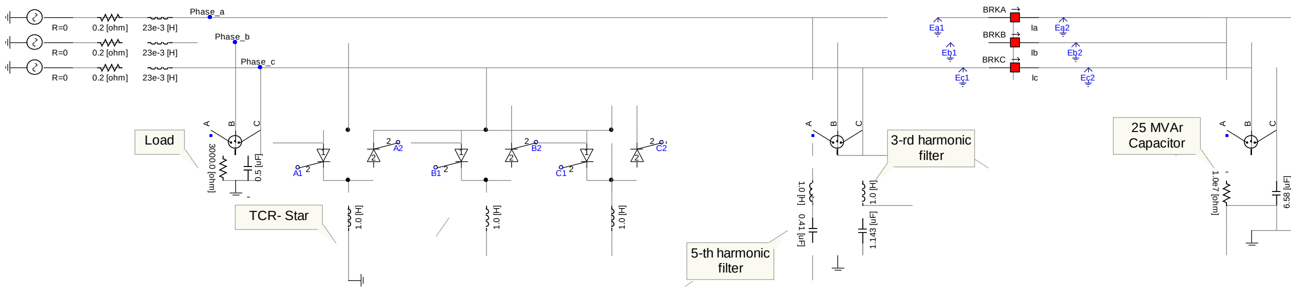

Figure 2. FACTS with star connected TCR

Note that computer simulation of that kind of problems has usually faced with the necessity of control the behavior and stability of solutions conditioned by the differential equations' stiffness concept. The stiffness concept was considered in general in [17, 18] and in relation to the network parameters and stability problem at numerical simulation the transitional processes in electric power systems in [19] and some other research.

In the presented study, we strictly followed the known methods of controlling the stability of numerical solutions. Fortunately, as our research showed the problem of getting the stable solutions at simulation MSC switching transitions in the FACTS network is not stronger than the case of switching separate capacitor banks, as it could be expected due to periodic (two times per period) switching of thyristor valves in FACTS schemes.

3. RESULTS OF SIMULATION AND DISCUSSION

3.1. Switching-on Process

Typical curves of transitional voltages across the MSC terminals at its switching-on by SF_6 circuit-breaker, got due to computer simulation, are given in the Figure 3 for the case of delta-connected TCR and in Figure 4 for the case of star-connected TCR (for arbitrarily value of thyristor valves equaled to 30°).

It is expedient to analyze dependences of transitional voltages and their components on thyristors firing angle to study ways of impact on transitional process to control switching over-voltages in FACTS circuits.

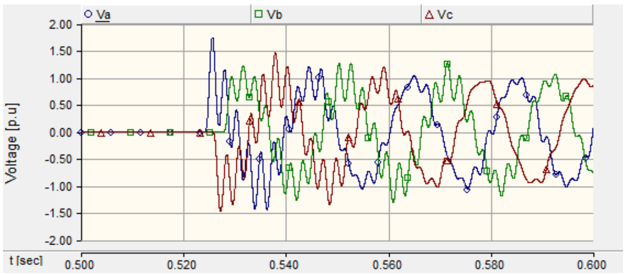

Figure 3. Voltages across the MSC 110 kV, 25 MVAr terminals at its switching on by SF_6 circuit-breaker (TCR are delta connected, firing angle of thyristors equals 30°)

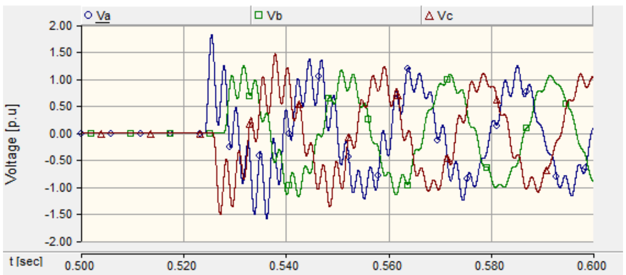

Figure 4. Voltages across the MSC 110 kV, 25 MVAr terminals at its switching-on by SF_6 circuit-breaker (TCR are star connected, firing angle of thyristors equals 30°)

Let us consider dependences of transitional voltages and their forced components on thyristors firing angle for the cases of delta-connected TCR (Figure 5) and star-connected TCR (Figure 6).

Joint considerations of the curves given in Figures 5 and 6 show the following:

- there is an obvious behavior correspondence between dependences of transitional voltages and their forced components on thyristors firing angle for the case of TCR star-connection, for each phase (Figure 6);
- such correspondence does not take place for the case of TCR delta-connection (Figure 5) that is conditioned by isolated neutral's voltage displacement, which equals to zero for star connection. Thus, there is taken place an interphase influence via neutral's voltage displacement leading to distinguished behavior of phases' transitional voltages;
- there is more notable change of forced voltages dependently on TCR firing angle for delta-connection in comparison with the case of star-connection, namely about 16% against 7% for the FACTS under consideration.

This means that transitional voltages at switching-on MSC are more sensitive to change of thyristors firing angle in the delta-connected TCR. Note here that control of forced voltage by change of TCR firing angle may have great importance for the high-voltage side of UHV (Ultra-High Voltage) substations, to the medium or low voltage of which the FACTS installation is connected. It is conditioned by the fact that forced voltage (unlike free voltage) is not undergone attenuation at transmission from transformer lower or medial winding to the higher one. In addition, UHV installations have a reduced level of permissible voltages.

These results were confirmed at the checking simulations carried-out at parameters variations.

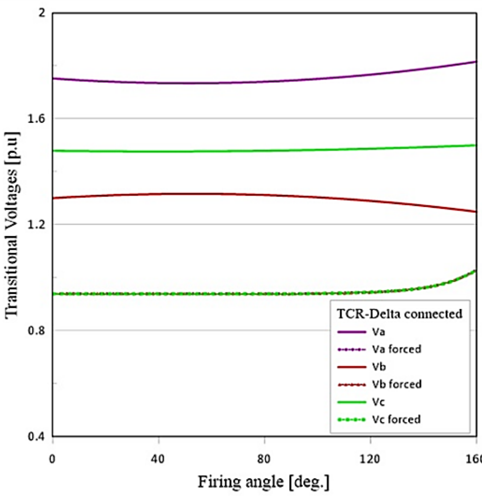

Figure 5. Dependences of transitional voltages and their forced components on thyristors firing angle for the case of delta-connected TCR

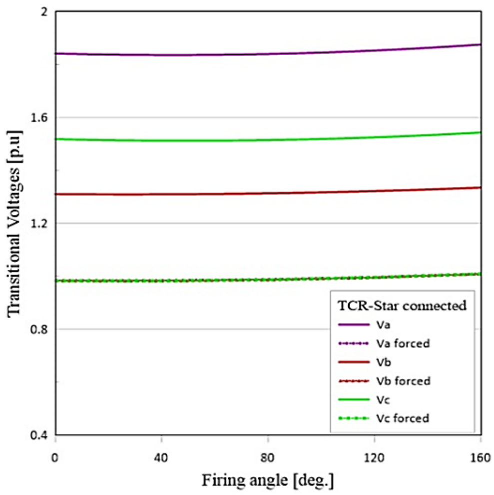

Figure 6. Dependences of transitional voltages and their forced components on thyristors firing angle for the case of star-connected TCR

3.2. Switching-off Process

Simulated curves of transitional voltages across the MSC terminals and across the circuit breaker poles (recovery voltages) at MSC switching-off by SF_6 circuit breaker are presented in the Figures 7 and 8 respectively. These curves were got for the FACTS with delta-connected TCR.

As it is seen from Figures 7 and 8, voltages across the MSC terminals and recovery voltages have distinguished behavior by phases. Thus, voltage across the MSC terminals has its maximum value on the phase-A, less for the phase-B and the least one for the phase-C (Figure 7). It means that the repeated restrike on the phase-A occurred at higher instantaneous voltage than on the phase-B whereas separation of contacts on the phase-C was not accompanied by repeated restrikes. In the same time the phase-A has the least stayed voltage among all the phases of MSC. Figure 8 presents temporal change of recovery voltage and instants of current interruption (arc quenching) and re-ignitions.

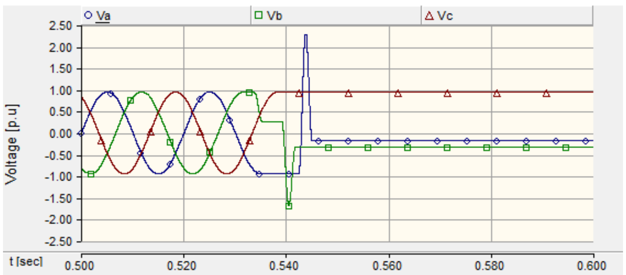

Figure 7. Voltages across the MSC 110 kV, 25 MVAr terminals at its switching-off by SF_6 circuit-breaker (TCR are delta connected, firing angle of thyristors equals 120 degrees)

Unfortunately, we could not reveal any correspondence between transitional voltages and their forced components at switching-off MCS neither with star-connected nor delta-connected TCR. This is conditioned by that MSC switching-off process may be accompanied by repeated re-ignitions of arc in circuit breakers which fact leads to significantly different behavior of transitional voltages by phases and also, relatively to their forced components.

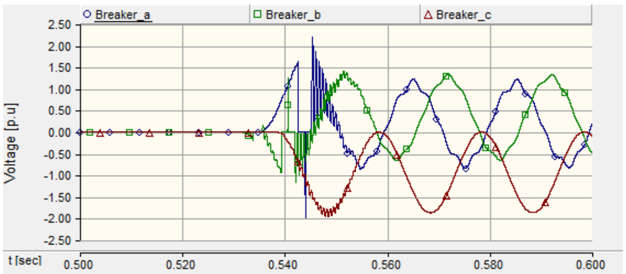

Figure 8. Recovery voltages at MSC 110 kV, 25 MVAr switching-off by SF_6 circuit-breaker (TCR are delta- connected, firing angle of thyristors equals 120 degrees)

Let us note one more feature revealed due to computer simulation. As we stated before, there have taken place higher magnitudes of transitional voltages at switching-off power capacitor banks by vacuum circuit-breakers in comparison with SF_6 ones, see [14]. The present research showed that differences between transitional voltages at switching-off MSC included in FACTS with delta-connected TCR are sufficiently greater than for pure power capacitor banks. The minded differences for the switching-off separate MSC were about 10-20 percent [19], whereas for MSC included in FACTS these differences turned about to be equal 65-90 percent. Such a great difference for the FACTS case may be explained by simultaneous impact of two factors - displacement of neutral voltage in delta-connected TCR and additional restrike of vacuum gaps in the final stage of contacts closing may have taken place for vacuum circuit-breakers [14] that is caused by significantly non-linear law of vacuum circuit-breaker dielectric strength restoration [21-24].

We also study possible influence of arc in circuit-breakers to the transitional process of switching-off MSC in the FACTS network. The arc influence for the same problem for separate capacitor bank was considered in [25, 26]. Simulations carried out at use the arc model presented in [27] showed absence of features of taking into consideration arc in circuit-breakers conditioned by switching of MSC, as a FACTS element (in the terms of magnitudes of transitional voltages).

To determine necessity of use three or single-phase model, we carried-out comparative simulations for a single-phase model. These researches show necessity of use three-phase models especially for FACTS with delta-connected TCR. It is possible to get the same or almost the same results for a single-phase model of FACTS with star-connected TCR just in hypothetical case of autonomous drive for each phase.

Note finally, that FACTS installations being one of the most important and state of the art Smart technologies for the modern electric power systems have lots of functions and provide ample opportunities to control steady-state and transitional modes of high-voltage electric networks and systems. The main functions of FACTS in accordance with [9, 28, 29] are increasing power transfer capability, improving stability of system operation in different modes, oscillations damping, control of power flows and voltages, improving electromagnetic compatibility and so on.

As it was shown in the presented research, there is one more opportunity to impact positively on system transitional modes due to FACTS features, namely the purposeful varying of TCR's firing angles for decreasing transitional voltages at switching MSC. This can be done by preliminary short-term change of the thyristors firing angle before the MSC switching.

4. CONCLUSIONS

Change of transitional voltages at switching-on MSC in the FACTS schemes with star-connected TCR corresponds to change of these voltages' forced components, for each phase.

Varying the TCR firing angle can allow controlling the level of transitional voltages at MSC switching-on.

Transitional voltages at switching-on MSC in the FACTS schemes are more sensitive to variations of thyristors firing angle in the delta-connected TCR.

Transitional voltages at switching-off MSC in the FACTS schemes with delta-connected TCR have significantly different ratios and behavior by phases.

Switching-off MSC in the FACTS schemes by vacuum circuit-breakers can be accompanied with significantly high ratios of transitional voltages in comparison with the same switching of separate MSC installation.

NOMENCLATURES

1. Acronyms

FACTS: Flexible AC Transmission Systems
SVC: Static VAr Compensator
TCR: Thyristor-Controlled Reactor
MSC: Mechanically Switched Capacitor
FC: Harmonic Filter

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BIOGRAPHIES

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