SELECTION OF TYPE, CONTROL SYSTEMS, AND RULES OF REGULATION OF SERIES COMPENSATORS

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Capacitive compensation of reactive power in alternate current electrical grids is widely used to improve efficient operation of electrical equipment and decrease losses of electric energy. Introduction of the corresponding equipment increases the throughput and dynamic stability of the overhead circuit.Power factor correction unit pays off within one year.

Keywords: series capacity devices (SCD); automatic control systems; control laws.

Series capacitive compensation devices provide capacity increase of the extended power transmission lines

INTRODUCTION

Series compensating devices (SCD), both uncontrolled (USCD) and controlled (CSCD) ones, used in AC electric grids with voltage of 500 kV and higher as standalone units or as a component of the so-called flexible AC transmission systems (FACTS) enable:

- to expand significantly the capacity of electric connections with the required margins for static and dynamic stability;
- to redistribute power flows in lines inside cross sections between energy systems, as well as between parallel lines in electric grids ensuring the acceptable and optimal load of lines and decreasing electric energy losses;
- to balance voltage levels of electrical grid, especially for long-distance transmission lines;
- to ensure effective damping of electromechanical oscillations between energy systems;

Besides, utilization of SCD allows us to refuse the construction of extra lines reducing the cost of energy transmission.

The difference between the uncontrolled and controlled SCDs is that the circuit and parameters in the uncontrolled SCD can be modified when in is de-energized, i.e. during momentary service disconnect, which limits the above SCD properties. While in the controlled SCD, the capacitive reactance of the device can be changed manually (which includes remotely) and automatically by means of controllers, with disconnecting the compensator from the grid and fully implementing the above features.

Both uncontrolled and controlled series compensating devices are widely used in foreign energy systems [1, 2]. Series compensators are of limited used in our country but according to [2] the technical solutions are devel-

CONTENT AND WIRING DIAGRAM OF ONE UNCONTROLLED SCD UNIT

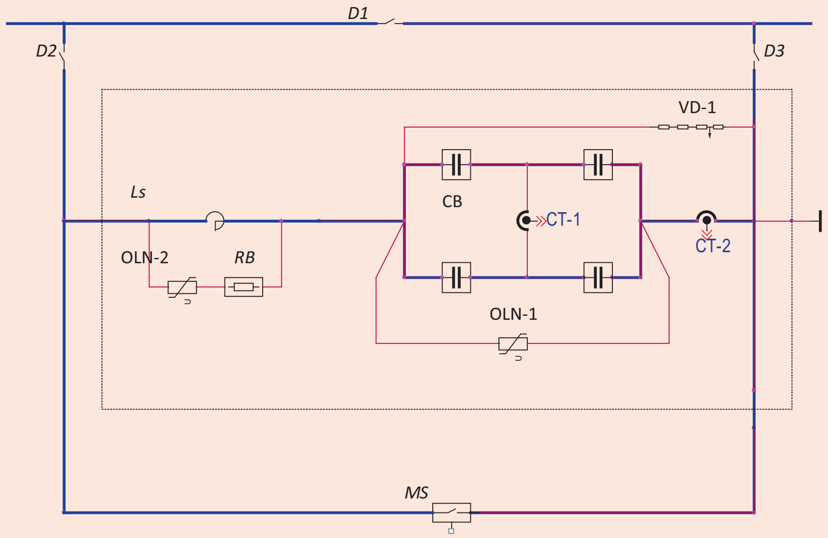

Fig. 1

INFORMATION

Capacitive compensation is the way of reactive power compensation with capacitive load. It is widely used in alternating current railroad substations in order to increase the efficiency of electrical equipment, reduce power loss, which, in particular, allows increasing the capacity of the railway transport.

Capacitive reactive power compensation is realized with the help of capacitor units. It is necessary to use adjustable condenser installations because the voltage in the electric traction network varies over time.

There are longitudinal, transversal and longitudinal-transversal capacitive compensation.

Installations of longitudinal capacitive compensation (CCP) are used to reduce the influence of the inductive component of the resistance of the transformers of traction substations and the traction network on the voltage on the current collector of the electric locomotive by including the tank in series with them.

Longitudinal capacitive compensation provides with prompt, non-inertial and continuous automatic voltage regulation.

Longitudinal capacitive compensation is one of the most effective measures to increase the long-distance transmission capacity. The use of longitudinal capacitive compensation reduces the electrical line distance and increases static and dynamic stability.

oped in order to use these devices in energy systems in the Urals, Siberia, and the Far East.

In opinion of authors of this article the application of series compensators in the Russian UES is currently deterred by the low power flows in most of long-distance transmission lines with voltage of 500 kV and more and by the lack of need in expanding capacities among the existing lines in our country due to long decline in the manufacturing output.

The main factors limiting the application of series compensators are well known: the increased levels of SC currents, danger of asynchronous self-excitation from the electrical machines near SCDs or subharmonic electromagnetic oscillation in the grid, the increased voltage levels at light loads in OHL, high price of the controlled devices.

The tasks faced by SCD monitoring and control systems are the successful implementation of the above useful features of the device and warning and timely effective prevention of the specified negative phenomena.

HOW TO CHOOSE THE TYPE OF SCD

According to the accepted classification, there are two types of series compensating devices: uncontrolled SCDs and controlled SCDs.

STRUCTURAL DIAGRAM OF MSSC, TSSC AND TCSC

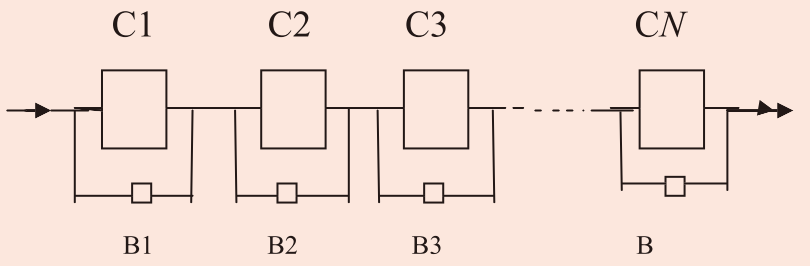

Fig. 2

SIMPLIFIED WIRING DIAGRAM OF TSSC AND TCSC MODULE

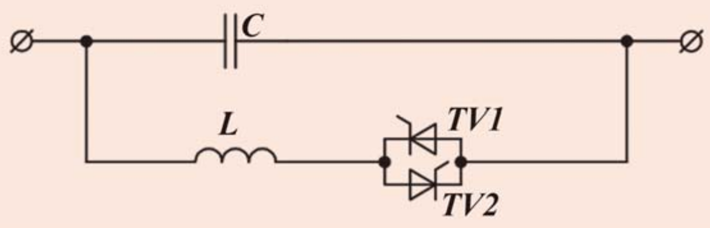

Fig. 3

USCD

Figure 1 shows the structural diagram for the phase of one USCD unit.

Here, capacitor banks are connected as per circuit with measurement of current imbalance (CT-1), the circuit breakers (P1–P3) ensure the assembly of SCD circuit, the reactor LS limits and levels currents during switching by the switch (MS); overvoltage limiters OLN-1 and OLN-2 destress capacitor tanks and reactor LS. Voltage dividers VD-1 and current transformers CT-1, CT-2 are used in the registration and control systems.

The uncontrolled SCD may consist of several units and be equipped with all necessary protections against overvoltages, overcurrents during overloads and short circuits.

USCD partially performs the above useful properties of SCD function ensuring the expanded capacity and stability margin of individual lines and cross sections between energy systems in whole, as well as pre-assigned redistribution of active power flows along the parallel connections. As a rule, these devices are installed in the middle of the line at power transmission lines under stationary steady states, when there is no necessity in frequent changes in capacitive compensation, i.e. frequent switching of units or capacitor banks within the compensating device, for example, during monthly or seasonal periods of time.

CSCD

The controlled series compensating devices are classified into three types: Mechanically Switched Series Compensators (MSSC), Thyristor-Switched Series Compensators (TSSC), and Thyristor-Controlled Series Compensators (TCSC).

MSSC

MSSC contains N modules (Fig. 2) everyone of which has a structural diagram shown on Fig. 1. The individual modules of capacitor banks (C) are switched by switches (B) with controlled switching that have a high commutation life. Apart from the uncontrolled one, such a series compensator can take a part in control of the grid operation mode or transmission mode during the daily and weekly period of time.

The simplified wiring diagram of the thyristor-controlled compensators for TSSC and TCSC is the same and is shown on Fig. 3 where C is the base capacity of capacitor bank; L is the reactor inductance; TV1 and TV2 are the thyristor valves.

The difference between TSSC and TCSC lies in principle of their operation. In the first case, a key mode of thyristor operation (TK) is used: C capacity bridging via small inductance L. In the second case, TCSC utilizes the idea of variable inductive reactance X_p = var paralleled with capacitor bank X_c:

$$X_{Срез.} = \frac{-X_P \times X_C}{X_P - X_C} \qquad (1)$$

Variation of X_{Cres} or X_{eq} depending on X_p is shown on Fig. 4.

THE FUNCTION OF THE RESULTANT REACTIVE REACTANCE OF SCD FOR PARALLELED X_C AND X_P UNDER X_{CMIN} = −11 Ω

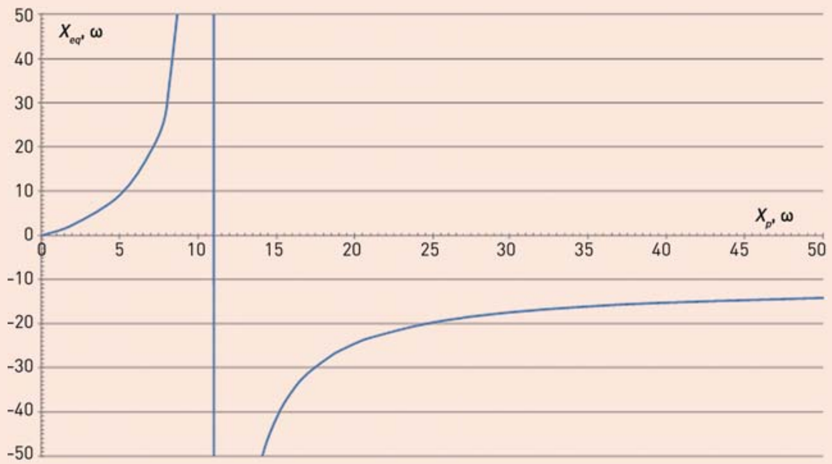

Fig. 4

It is accepted in the formula (1) and on Fig. 4 that values of X_{eq} in inductive mode have a plus sign and a minus sign in capacitive mode.

When X_p varies from 0 to ∞, two control ranges can be distinguished for X_{eq}: when reaching the resonant point from the left from $X_p = 0$ to $X_p = X_c$, the resultant reactance is of inductive character from $X_{eq} = X_{pmin} = 0$ to $X_{eq} = X_{pmax} = +\infty$; when X_p reaches the resonant point $X_p = X_c$ from the right, the resultant reactive resistance is of capacitive character with the range of reactance measurement X_{eq} from $-X_{cmin}$ to $X_{cmax} = -\infty$.

It is intrinsic that the actual range of capacitive reactance for TCSC is limited by K value and is chosen providing the following condition: $X_{cmax} / X_{cmin} \leqslant K$ where $X_{cmin} = X_c$ and X_{cmax} based on formula (1) at respective X_p. At the capacitive range of variation of X_{eq} , the maximum current value will be $X_{eq} = X_{cmax}$, that in capacitive branch (through X_c) will be $I_c = KI_{\text{вл}}$, and in the inductive branch of SCD (through X_p) — $I_p = (K - 1)\, I_{\text{вл}}$ where $I_{\text{вл}}$ is the current of a line.

The recommended values of K coefficient as per [1] shall be not more than 3. This is explained by the fact that when Xp approaches the resonant point $X_c = X_p$, the current ratios in branches X_c and X_p increase in inadmissible way from the point of equipment choice, with regard to the line current (Iвл) flowing to this parallel line. For example, with X_c = −11 ω, to get X_{Cmax} = −27 ω (K = 27/11 = 2.45), the value of shunt inductive reactance X_p will be 18.56 ω and the currents in the specified branches reach $I_c = 2.45 I_{\text{вл}}$ and $I_p = 1.45)\, I_{\text{вл}}$.

For the example in question with thyristor valves, the regulated range of capacitive compensation from X_{C1min} = −11 ω to X_{C1max} = −27 ω at phase control can be obtained in two ways:

a) by using the inductive reactor X_p = 18.56 ω (L_p = 59 mH) the controlled thyristor with angles of ignition from α_1 = 90° (TV open) to α_2 = 180° (TV closed)[1], working out the whole wide control range during TV control $\alpha_1 - \alpha_2$ = 90° — 180°, while the value X_{eq} ranges from X_{C1max} = −27 ω to X_{C1min} = −11 ω;
b) by using reactors with less rating X_p selected in the interval 0 < X_p < 11 ω (or for the inductance 0 < L_p < 35 mH), for example, X_p =

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[1] It is accepted here that angle of ignition □ of the respective thyristor is counted from the moment of voltage transition to capacitor bank through zero (see Fig. 5).

OSCILLOGRAPH PATTERNS OF VOLTAGE ON CAPACITOR BANK (A), CURRENT IN LINE (B), IN CB (C), AND IN TPГ (D), WITH MAXIMUM CAPACITIVE COMPENSATION (X_{CMAX} = −27 Ω)

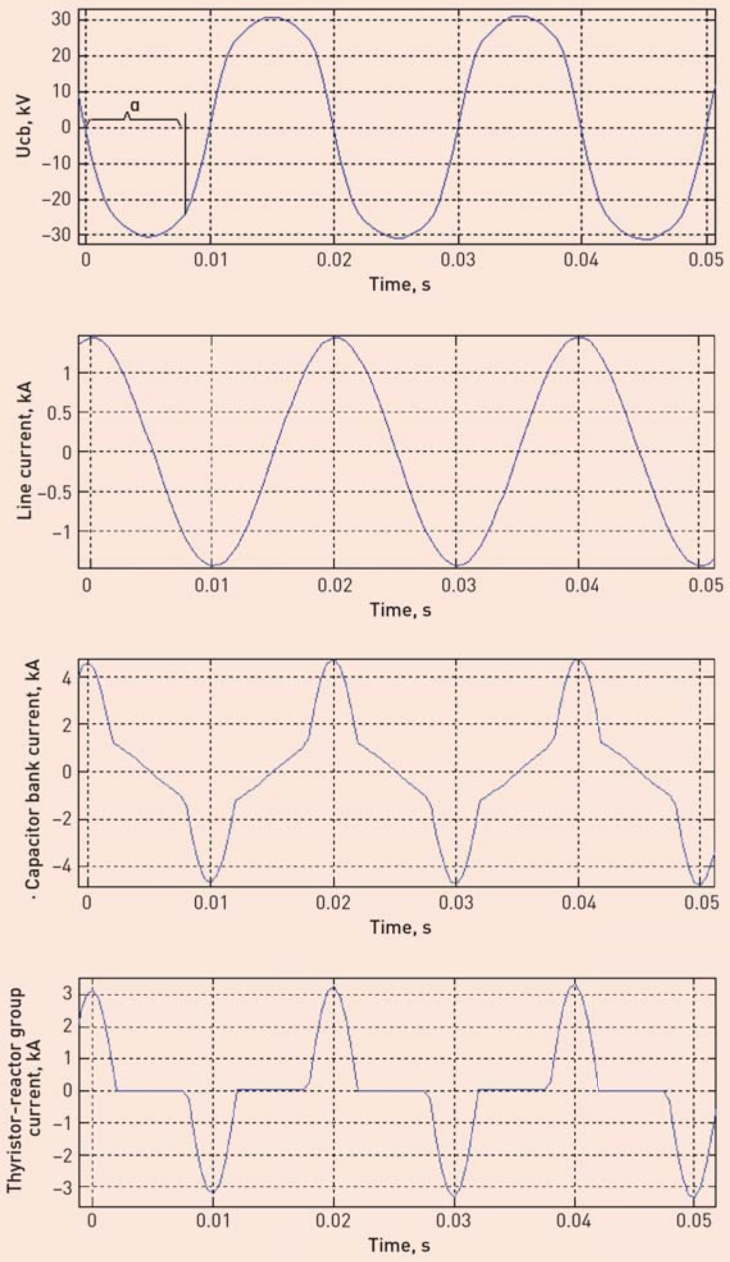


Fig. 5

3 ω (L_p = 10 mH). However, in this case, the whole control range of ignition angles of thyristor valves is used in the capacitive range of measurement X_{ceq} = [−11; −27] ω. At L_p = 10 mH, TCSC will operate with thyristor ignition angles α within the range of 135° ÷ 180°, narrowing even more at lower values of L_p.

The second method seems to be more preferable as it requires a lesser installed reactor power and the inductive mode of anticompensation can be implemented at values of inductive reactance which are more optimal for the given example, namely X_p = 2–3 ω.

In relation to the simplified diagram (see Fig. 3), Fig. 5 (a, b, c, d) shows the oscillographs of voltage on capacitor banks (U_{CB}), current in line (I_{OHL}), current in branch of capacitor bank (I_{CB}), the current on reactor-TV branch (I_{RTV}) for the case when X_{L1} = 3 ω (L1 = 10 mH) is used at the angle of ignition $α_1$ = 135° corresponding to X_{cmax} = −27 ω. It can be seen from the oscillographs that the amplitudes of instantaneous values of non-sinusoidal currents in TV and CB branches exceed the amplitude of OHL current. Effective values of currents in thyristor valves and capacitor banks at maximum capacitive reactance X_{C1max} = −27 ω exceed the currents in line by 2–3 times.

Fig. 6 shows the dependence of angle of ignition α on the value of reactor inductance (L) when the maximum value of capacitive reactance X_{cmax} = −27 ω works off at the initial value X_C = −11 ω. Fig. 7 shows the multiplicity factors of the effective values of currents in branches C and L.

It follows from Fig. 7 that the effective value of currents, in the mode of maximum equivalent TCSC capacity, in reactor and thyristor valves, capacitor bank, is 2–3 times higher as a rule than that of current in transmission line.

THYRISTOR IGNITION ANGLE DEPENDING ON REACTOR INDUCTANCE AT EQUIVALENT CAPACITIVE REACTANCE OF THE CONTROLLED SCD IS −27 Ω

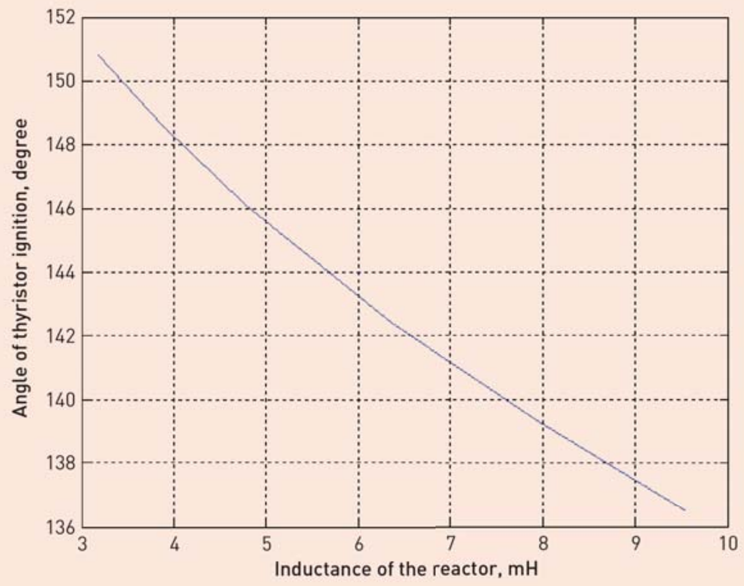


Fig. 6

Unlike in TCSC, TSSC circuit features a step control of SCD reactance. Thyristor valves shunt or de-shunt capacitor bank of SCD modules.

In TSSC in steady state operation modes, the effective value of current in capacitor bank, reactor, and thyristor valves is equal to the effective value of current in transmission line. This is why even if capacities C and inductances L are the same, the cost of power equipment of TCSC is higher than the same equipment in TSSC scheme.

The main advantage of TCSC over TSSC and uncontrolled SCD is the capability to prevent subsynchronous resonance and capacitor self-excitation [6].

The subsynchronous resonance can be observed in the energy systems in which frequencies of subharmonic (subsynchronous) vibrations in the grid are close to natural frequency of shaft torsional oscillations of multimass electric machines such as turbo machinery with heavy generator rotors, steam turbine stages, air blowers, exciters, etc. on one shaft [7].

Capacitive and as a rule asynchronous self-excitation of synchronous generators and large size electrical machines (synchronous and asynchronous motors and synchronous and asynchronous compensators) can be observed at a definite ratio between SCD capacity and parameters of these machines operating in the electrical grid containing capacity elements [8].

Fig. 8 shows the real structural diagram of a single TSSC or TCSC module. The same designations of the elements are used here as on the diagram of the uncontrolled SCD (see Fig. 1), with additional elements: thyristor valves (HVTV) with phase control or HV TK with key control, overvoltage limiters ОПН-3, inductance Lr.

Fig. 9 shows the structure of TSSC or TCSC of modular type [2] consisting of three modules.

The acceptable quality of transient process during TSSC operation is achieved if three or more modules switched by thyristor keys are available with the recommended module parameters X_c =10 ω. A test prototype of such a module for SCD on 500 kV lines has been created and tested in JSC R&D Centre of FGC UES [2].

As compared to MSSC, TSSC has a more versatile and very quick-operating compensating device that can ensure not only mode introduction in any time interval but also damping of electromechanical oscillations, and TCSC, in addition to the above functions, can ensure the control over electromagnetic processes. But thyristor devices are more complicated in design and maintenance. Unlike MSSC, TSSC includes a powerful thyristor group with a thyristor cooling system, additional inductive reactors (Lr) to limit the rate of current measurement through thyristor valves, additional battery OLN-3 (see Fig. 9). TSSC is twice as more expensive than MSSC.

With the same control range, the total power of capacitive and inductive elements, and the power of thyristor

MULTIPLICITY FACTORS OF THE EFFECTIVE VALUES OF CURRENTS IN TCSC BRANCHES DEPENDING ON REACTOR INDUCTANCE AT $X_{C\ MAX}$ = –27 Ω

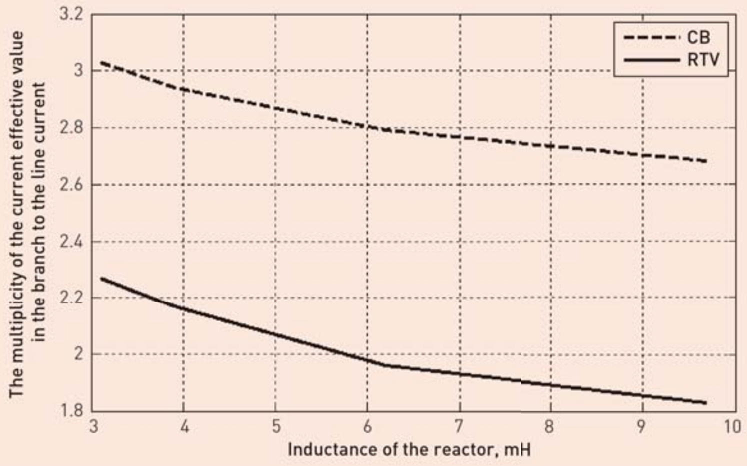


Fig. 7

STRUCTURAL DIAGRAM OF TSSC AND TCSC MODULES

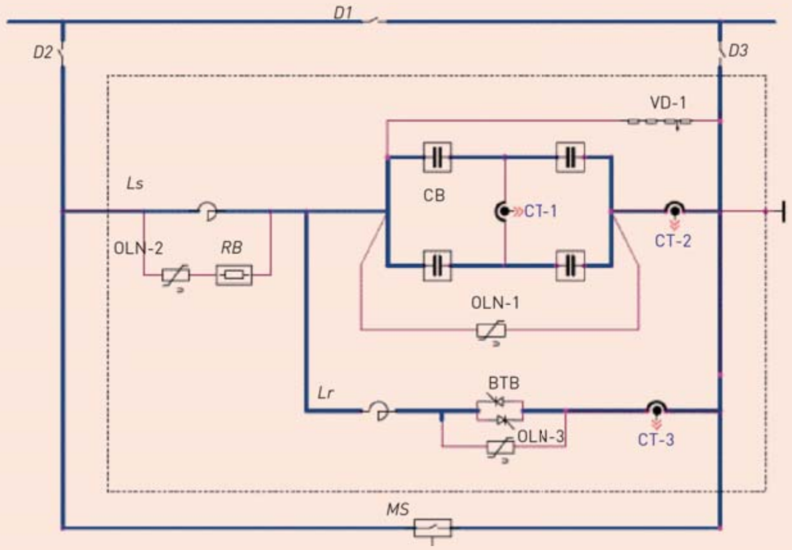


Fig. 8

units of TCSC are higher than that of TSSC. To achieve the same technical effect, the required power of TSSC equipment is approximately 2-3 times less than the installed power of the comparable TCSC equipment.

While the unit cost of TCSC according to foreign data [1, 6] is 3 times higher than the comparable cost of TSSC and 6 times higher than the cost of MSSC.

TCSC AND TSSC CONTROL RULES

If we consider mathematical single-line model of smooth controlled SCD (TCSC prototype) [3], the main regulating element in this model is the variable inductive reactance X_p at some half interval (∞ ÷ X_{pmin}].

At the regulator output, the value of inductive reactance $X_p = X_L$ can vary within the limits specified above:

$$\Delta X_L = \frac{1}{1+p\tau_{per}} \sum \mathrm{K}_i\,(\mathrm{p}) \cdot \Delta\Pi i, \quad (2)$$

where $K_i(p)$ are transfer functions of controller on change of parameters ΔΠi; τ_{per} is the equivalent time constant of control circuit taken within the range from 0.05 to 0.5 s.

As the task is to damp electromechanical oscillations of rotors of synchronous generators, oscillations of transmitted power, frequency oscillations, then the mode parameters are selected that reflect these oscillations. For example, to damp the oscillations of generator rotors, one should use control signals based on change of generator angle $\Delta\delta_r$, generator sliding Δs, and frequency Δf. To damp power fluctuations over OHL, one can use power signals $\Delta P_л$, OHL angle signals $\Delta\delta_{ВЛ}$, and line current signals $\Delta i_л$, etc.

CONTENT AND DIAGRAM OF THYRISTOR SERIES COMPENSATOR (TSSC) CONSISTING OF THREE 10 Ω MODULES, WITH STEP CONTROL BY THYRISTOR KEYS (TK)

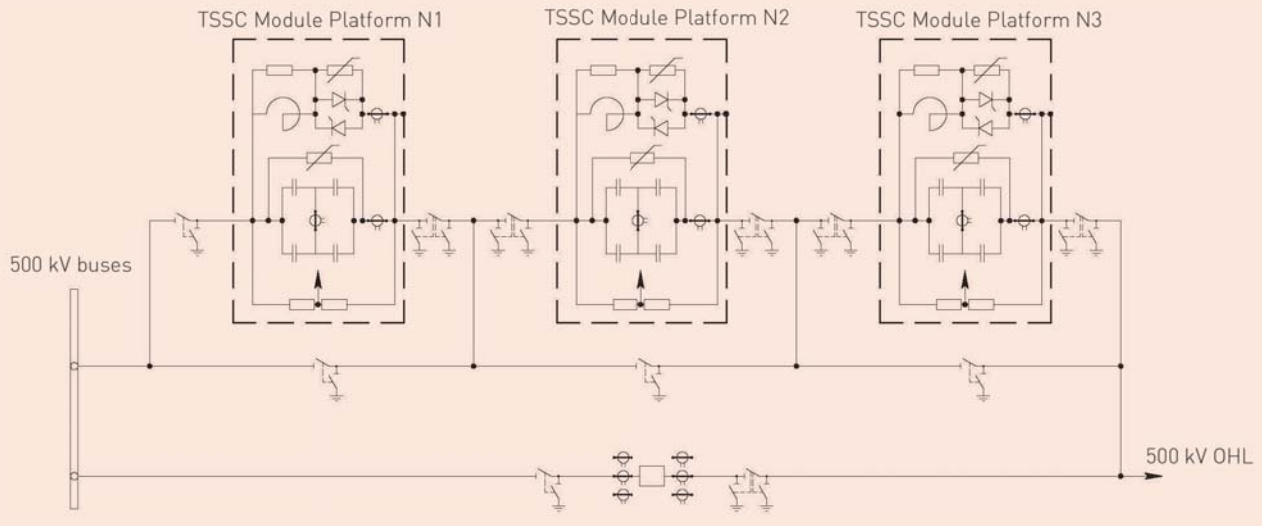


Fig. 9

STRUCTURAL DIAGRAM OF CSCD AUTOMATIC CONTROLLER OF SMOOTH CONTROL X_C

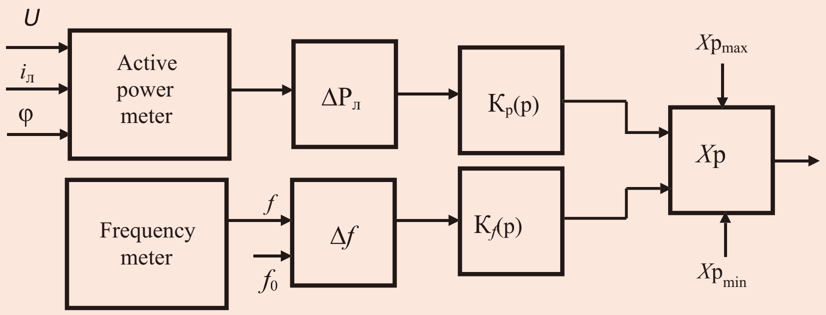


Fig. 10

SCD control should be preferred based on local parameters: variation (deviation) of active power $\Delta P_л$ transmitted over OHL (or deviation of line current $\Delta i_л$) and grid frequency Δf.

$$\sum Ki(p) \times \Delta\Pi_i = K_{op} \times \Delta P + K_{0f} \times \Delta f + pK_{1f} \times \Delta f, \quad (3)$$

where K_{op} is the control ratio based on change of transferred active power $\Delta P_л$;

K_{0f} is the control ratio based on change of grid frequency Δf;

K_{1f} is the control ratio based on derivative of grid frequency f.

Fig. 10 shows the simplified structural diagram of automatic controller of TCSC.

The initial surge of active power occurring during shedding after generator trips, loads, short circuits, etc. shall be filtered in the unit $\Delta P_л$.

The current frequency value and setpoint f_0, a synchronous frequency of grid of the previous (initial) mode, f_0 = 50 Hz, are sent to unit Δf in the place of controlled SCD connection. Units $K_P(p)$ and $K_f(p)$ generate transfer functions and set the specific values of gain ratios K_{oP}, K_{of}, K_{1f} obtained based on research on models and detailed during field trials.

At automatic controller output of single-line model of the smooth controlled SCD, the value $X_p(t)$ or its variation ($\Delta X_p(t)$) is worked out. The angle of opening of thyristor valves α(t) is worked out on three-phase model of TCSC or on real device, at automatic controller output.

Fig. 11 and 12 illustrate the operation of automatic controller of the smooth controlled SCD on single-line model of TCSC through the example of 500 kV Sayano–Shushenskaya HPP — Novokuznetskaya, Kuzbasskaya with SCD [2, 3] at double-phase short circuit on OHL 500kV Sayano–Shushenskaya HPP — Novokuznetskaya followed by its disconnection in 0.12 s at initial station load $P_{СШ\ исх}$ = 2650 MW. (Here, E, el. degr is the generator angle, U; kV is the voltage in the place of short circuit; X is the capacitive reactance, ω.).

Based on oscillographs shown on these figures, it can be concluded that electromechanical oscillations were well damped based on grid frequency derivative in the place of SCD installation.

By adjustment of settings parameters, a higher quality of transient electromechanical process can be ensured.

To damp low frequency oscillations by means of TSSC, one could use the smooth controlled SCD controller offered above (see Fig. 10) with output ΔX_L or Δα to generator of discrete signals of control [4, 5] with the set deadbands, and then through the signal issue distributor on modules TSSC [13].

A new control algorithm was developed for the real TSSC whose structure is shown on Fig. 13.

Here: link 1 is the low frequency filter of 2nd order with cutoff frequency ω_1, and damping ratio δ_1. A signal of total instantaneous active power transmitted through all three phases of SCD is sent to input of link 1. Link 2 is the element of non-linear function:

DOUBLE-LINE-TO-GROUND SHORT CIRCUIT NEAR SS 500 KV — NOVOKUZNETSKAYA WITH OHL DISCONNECTION OF 500 KV SAYANO–SHUSHENSKAYA HPP — NOVOKUZNETSKAYA WITHOUT SERIES COMPENSATOR

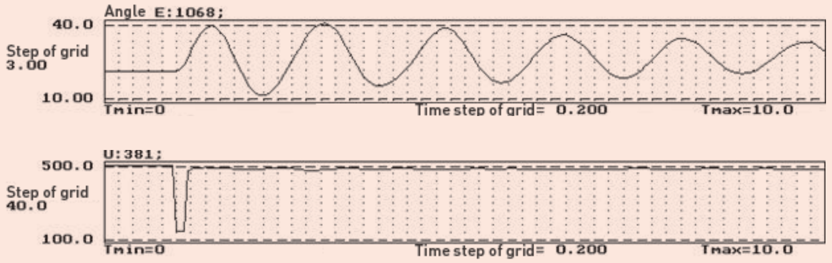


Рис. 11

DOUBLE-LINE-TO-GROUND SHORT CIRCUIT NEAR SS 500 KV — NOVOKUZNETSKAYA WITH OHL DISCONNECTION OF 500 KV SAYANO–SHUSHENSKAYA HPP — NOVOKUZNETSKAYA WITH SERIES COMPENSATOR X_C 50% (SCD 20% + USCD 30%) CSCD AUTOMATIC CONTROLLER AS PER dF / dT (K_{1F} = −3, τ_P = 0.05S)

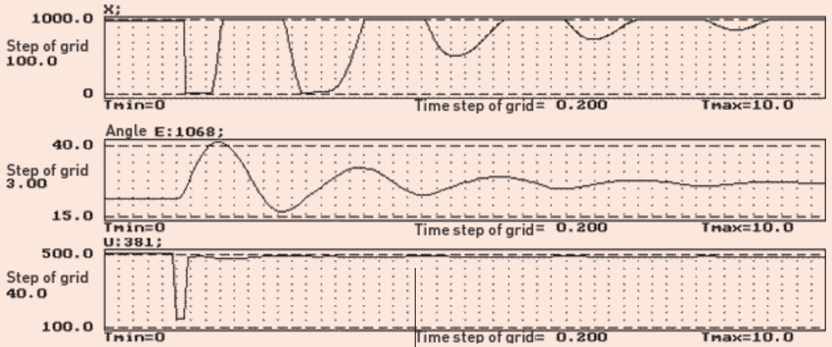


Рис. 12

STRUCTURE OF TSSC CONTROLLER

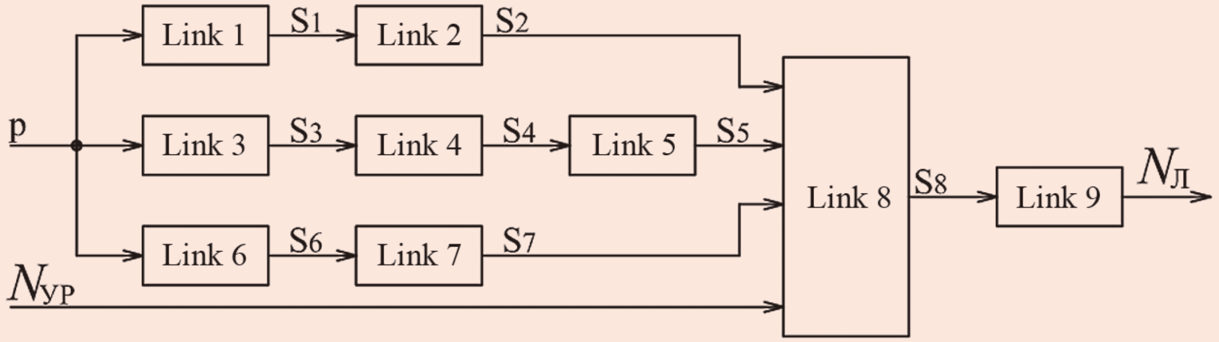


Fig. 13

$$S2 = \begin{cases} +1, \text{ for } S1 \le -P1, \\ +2, \text{ for } -P1 \le S1 < -P2, \\ +3, \text{ for } -P2 \le S1 < -P3, \\ 0, \text{ for } -P3 \le S1 < +P3, \\ -3, \text{ for } +P3 \le S1 < +P2, \\ -2, \text{ for } +P2 \le S1 < +P1, \\ -1, \text{ for } P1 \le S1, \end{cases}$$

where S1 is the unit input, S2 is the unit output; P1, P2, P3 are parameters (active power in phases of the line). Link 3 is the narrow-band filter of the 2nd order with setting frequency ω_2 and damping ratio δ_2. Link 4 is set by the equation:

$$S4 = k_1 |S3|,$$

where S3 is the unit input, S4 is the unit output; k_1 is the parameter. Link 5 is the low frequency filter of 2nd order with cutoff frequency ω_3, and damping ratio δ_3. Link 6 is the low frequency filter of 2nd order with cutoff frequency ω_4, and damping ratio δ_4. Link 7 is the relay element with switching function shown on Fig. 14 where S6 is the unit input, S7 is the unit output, and k_2 is the parameter.

Link 8 is set by the equation:

$$S8 = f(S2 \cdot S5 \cdot S7 + N_{ур}),$$

where f is the function of taking an integer; S2, S5, S7; $N_{уР}$ are the unit inputs; S8 is the output. Link 9 is set by the equation:

$$N_л = \begin{cases} 0, \text{ for } S8 \le 0, \\ S8, \text{ for } 0 < S8 \le N_{max} \\ N_{max}, \text{ for } S8 > N_{max}, \end{cases}$$

where $N_л$ is the setpoint of number of enabled modules in SCD phase. The module is considered enabled if the linear current flow through capacitor banks. N_{max} is the number of modules in SCD phase.

Operation of TSSC is illustrated through the example of double-circuit OHL with SCD in the upper circuit as shown on Fig. 15.

Disconnection of the lower branch is considered as excitation.

In case of uncontrolled series compensator (X_c=2 ω), the line break leads to destabilization: modulo build-up of power fluctuations in line are shown in green color on Fig. 16,a.

If low power TSSC is available consisting of four modules (X_c=4x1 ω) switched by thyristor keys as shown on Fig. 16 (red), the mode remains stable. Change of capacitive reactance of controlled SCD is shown on Fig. 16,b.

RELAY UNIT HYSTERESIS (OF LINK 7)

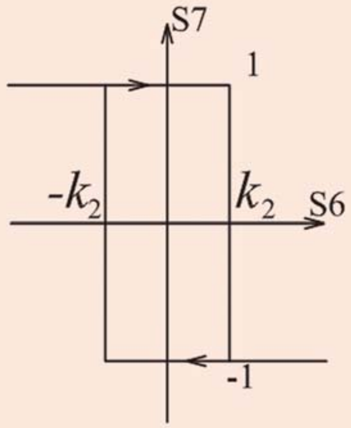


Fig. 14

Operation of TSSC and TCSC is compared for the same structural diagram but with parameters of electric connection of 500 kV Sayano–Shushenskaya HPP — Novokuznetskaya, Kuzbasskaya, on three-phase model in Matlab Simuling.

TEST CIRCUIT TO STUDY THE OPERATION OF TSSC AND TCSC

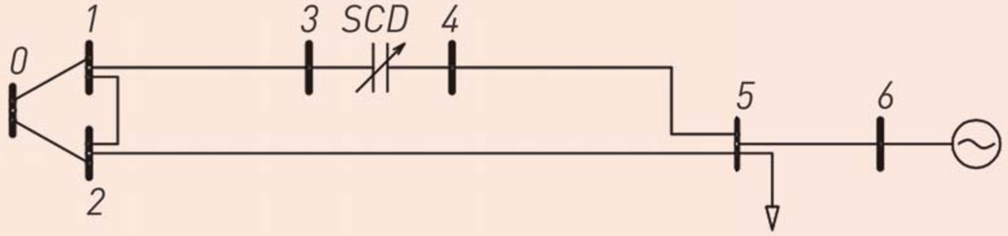
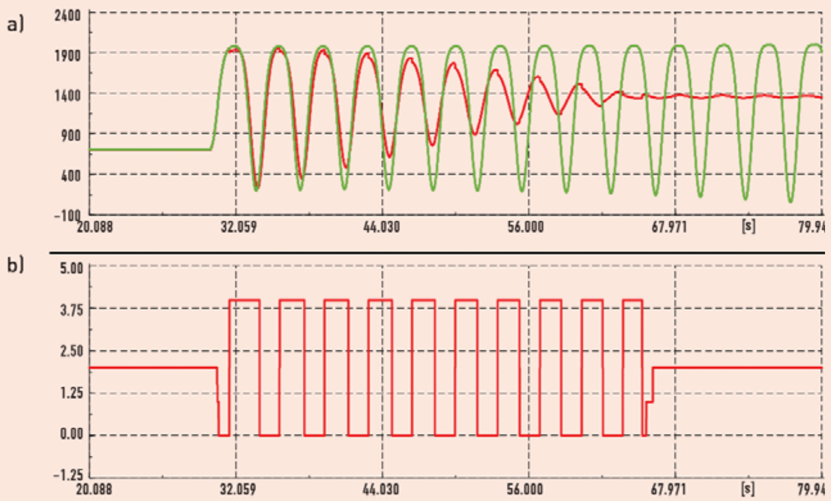


Fig. 15

16 OPERATION OF 4-STAGE TSSC DURING DISCONNECTION OF THE LOWER CIRCUIT OF THE DOUBLE-CIRCUIT TRANSMISSION LINE



a) change of active power in line;
b) change of capacitive reactance of series compensator with operating automatic controller of TSSC
Fig. 16

Branches 1–3, 4–5, 2–5 are modeled by the equivalent pi-network with the following linear electrical parameters: r = 0.029 ω/km; x_1= 0.308 ω/km; b_1 = 3.604 mcS/km.

500 kV OHL lengths of the modeled branches 1–3, 4–5, and 2–5 were 150, 300, and 450 km respectively. Branches 0–1, 0–2, 1–2, and 5–6 were simulated with inductive reactance of 30, 30, 10, and 20 ω respectively. Parameters of generators and loads are given for 500 kV. Power of equivalent generator was 9000 MW, power consumed by load was 7600 MW. The value of capacitive reactance of SCD in the branch 2–5 could vary within the range from 10 ω to 20 ω. Sharp load decrease in link 5 by 450 MW is taken as excitation.

Calculation results are given on Fig. 17 for active power in the area 1-3 of the diagram and on Fig. 18 for variation of the equivalent capacitive reactance of TCSC X_{TCSC} and TSSC X_{TSSC}.

The transient oscillographs given in the test diagrams above show that, with high excitations in the grid, TCSC and TSSC have almost the same impact on damping of the electromechanical oscillations and on dynamic stability.

CONCLUSIONS

It follows from the foreign experience of SCD operation that the most used compensators are uncontrolled series compensators (USCD) and controlled series compensators with vacuum or SF_6 switches (MSSC) in the grids with voltage 500 kV and above where the anticipated mode change is carried out and the pre-selected parameter correction is required for branches in order to increase the capacity of the electric system and optimal redistribution of power flows in the grid.

Electromechanical controlled series compensating device can take part in generation of the steady state operation modes of grid in daily and longer time intervals. In addition to the main functional units, MSSC automatic controller shall have the units designed for generation of priority of activation of stages and counters of number of switchings for each switch.

Unlike MSSC, TSSC is the quick-operating device. They can damp electromechanical oscillations between energy systems and oscillations of generator rotors of electrical stations operating on long-distance energy lines far away from consumption nodes. Two structures were offered for construction of the step controller for TSSC and control rules based on local parameters (grid frequency, line current, transmitted active power).

Thyristor devices of smooth control of TCSC are universal most quick-operating devices performing the whole range of control. Being the most expensive, these devices enable to prevent and suppress capacitive self-excitation of electric machines, prevent the development of subsynchronous fluctuations and torsional resonance. Choosing these devices requires special technical consideration and feasibility study.

OSCILLOGRAPHS OF POWER TRANSMITTED OVER OHL

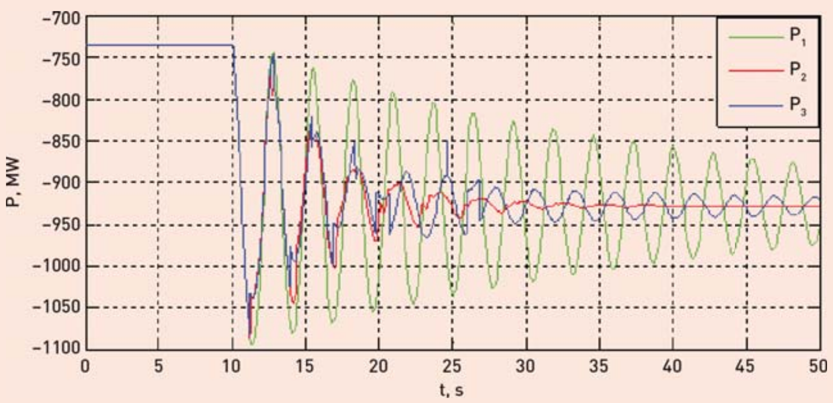


Fig. 17

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OSCILLOGRAPHS OF REACTANCE OF SCD

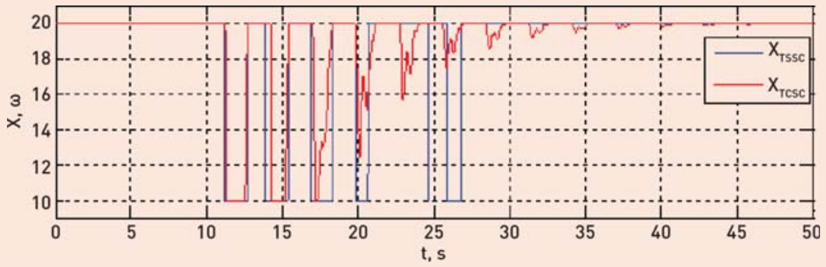

Fig. 18