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Additional functions of the upgraded TCSR with split windings

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SUMMARY

The design of a 500 kV thyristor controlled shunt reactor (TCSR) with split windings developed in Russia is considered. The article discovers some up-to-date research results of TCSR operation in 500 kV grids conducted by R&D center of the Federal Grid Company of Unified Energy System. It is shown that the discussed type of TCSR is effective for extinguishing the secondary arc current caused by the phase line to ground fault. It is shown that the discussed type of TCSR can speed up line auto reclosing. HV transmission line equipped with TCSR is considered during single-phase auto reclosing and it is shown that the rate of controlled shunt reactor allows to avoid resonant overvoltage during single-phase auto reclosing of transmission line. Causes of SF6 circuit breaker failure on fully compensated overhead lines (OHL) are being researched. Using a thyristor controlled shunt reactor eliminates the roots of this problem without any other specific means.

KEYWORDS

TCSR, transmission line, SPAR, transient recovery voltage, no load.

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1. Introduction

1.1 TCSR design

Variable shunt reactors (VSR) are a class of directly connected to HV grid FACTS devices that are used for controlling reactive power and voltage in a step-less manner. At present there are two types of VSR used in Russian HV electric grids: magnetically controlled shunt reactors (MCSR) and thyristor controlled shunt reactor (TCSR) . Equivalent inductance of the MCSR reactor is regulated by the degree of saturation of its magnetic circuit by constant current obtained by means of a special converter. Equivalent inductance of the TCSR is regulated by phase controlled thyristos connected to valve windings. Both of MCSR and TCSR emit current harmonics if special filters are not used.

In 2012 JSC «R&D center @ FGC of UES» developed a novel type of TCSR with low harmonic emission level. This type of TCSR can operate without harmonic filters due to low harmonic emission level provided by split valve windings [1]. Electromagnetic part of TSCR (rated voltage 500 kV) is shown at figure 1. Magnetic circuit of a phase is shown at figure 2. The magnetic core consists of two limbs and two yokes. Each limb is coupled with HV-half-winding and valve-side half-winding. Valve-side half-windings WV1a, WV1b and WV1c are Delta-connected. Other Valve-side half-windings WV2a, WV2b and WV2c are Y-connected. All HV windings are Y- connected with grounded neutral point. Thyristor valves of both valve groups of TCSR are Delta-connected.

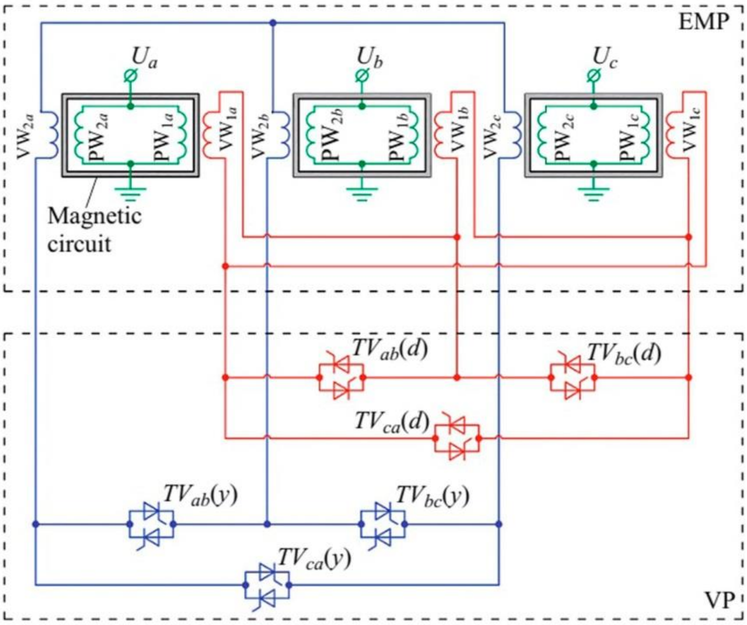

Fig.1

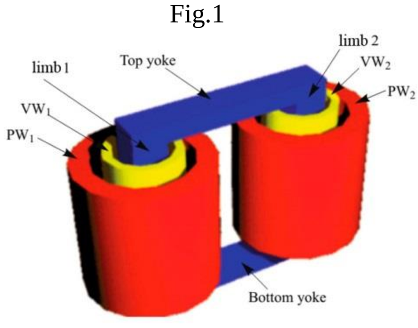

Fig.2

1.2TCSR functions

Variable shunt reactors are mainly used for:

1. voltage stabilization;
2. preventing mode of deep reactive power consumption by synchronous generator;
3. improving power system stability;
4. reducing the number of on-load tap-changer commutations.

TCSR functionality depends on the way it is connected to the grid. TCSR can be connected to the bus bar (fig.3a) or to the line (fig.3b). In the last case TCSR has the following additional functions:

1. limiting transient overvoltage caused by transmission line energization;
2. preventing circuit breaker (CB) current zero-crossing missing at compensated transmission line;
3. shortening the single-phase auto reclosing (SPAR) cycle time in 500 kV Lines;
4. preventing resonant overvoltage during SPAR of transmission line.

In 2016 JSC «R&D center @ FGC of UES» upgraded control system of TCSR to implement the described additional functions.

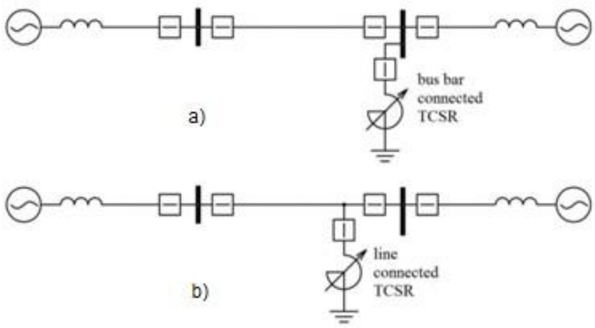

Fig.3

2. TCSR operation during SPAR of transmission line

2.1 Secondary arcing current compensation during SPAR of transmission line

OHL to ground faults are due to insulation flashover caused by lightning overvoltages. Arc faults are unstable - they can be self-cleared if the faulty phase of the transmission line is de-energized for the time enough for the air gap dielectric strength recovery . This is why auto-reclosing is widely used on overhead transmission lines.

A typical sequence of events during successful SPAR of HV transmission line is presented below. After a fault occurs the relay protection of the line forces circuit breakers of the faulty phase to open. After the phase is disconnected from the grid the arc continues to burn due to the capacitive coupling of transmission line phases (figure 4). Hot arc lifts so its length and resistance increase until it breaks. Air gap dielectric strength starts to recover after the fault is cleared. In 150-200 ms after the arc extinction the disconnected phase of the transmission line can be reconnected to the power system and the operating regime of the grid is restored to a state close to the pre-fault one. TCSR operation cycle during SPAR is illustrated by figure 5.

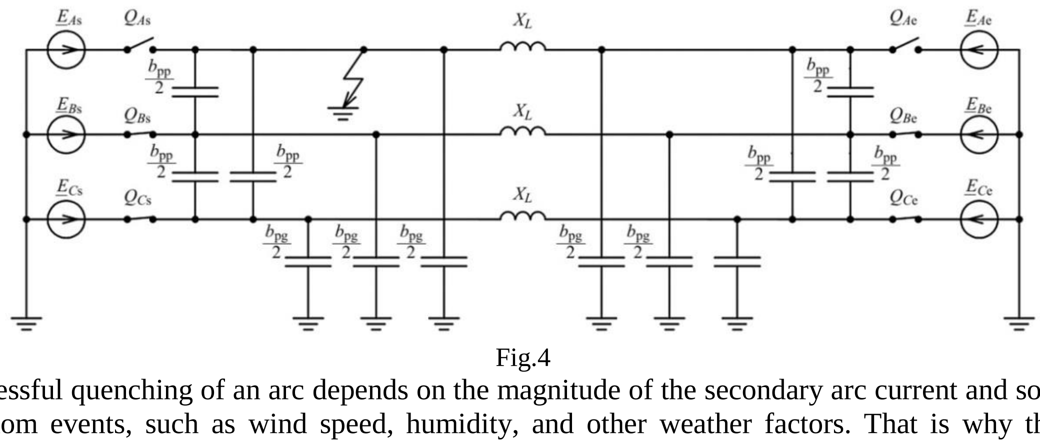

Fig.4

Successful quenching of an arc depends on the magnitude of the secondary arc current and some of the random events, such as wind speed, humidity, and other weather factors. That is why the arc burning time is the time during which the arc extincts with a defined probability. In the USSR the statistical dependences of the quenching time of a single-phase SC arc in OHL versus the arc current were obtained [3] on the basis of the experimental data:

$t_{0,95} = 0{,}2 + 2{,}86 \cdot 10^{-4} \cdot I_d^2,$

where $t_{0.95}$ is the time in which the arc is quenched with the probability of 95%; Id is the amplitude of the arc current. By shortening the arc burn time it is possible to decrease the zero-current pause and increase the probability of preserving the dynamic stability of the power system.

Secondary arc current is a sum of electrostatic and electromagnetic components. The electrostatic component is due to the interphase capacitance and is weakly dependent on the fault location and the power transmitted in the line, since the inductive reactance of a transmission line is much lower than the capacitive reactance. The electromagnetic component is due to the mutual inductance of the phases of transmission line and depends on the fault location and the power transmitted in the line. For most 500 kV transmission lines secondary arc current is mainly influenced by electrostatic component $\underline{I}_{d(es)}$:

$$\underline{I}_{d(es)} = (\underline{E}_B + \underline{E}_C) \cdot j \cdot b_{pp}$$

where $\underline{E}_B$ and $\underline{E}_C$ are voltage in phase B and C respectively; b_{pp} is interphase conductance. It is shown [1] that TCSR current is in counter-phase with electrostatic component of the secondary arc current, while the magnitude of TCSR current is defined by:

$$\underline{I}_A = \left(\underline{E}_B + \underline{E}_C\right)/(3j\omega L_\sigma).$$

Equivalent circuit of transmission line and TCSR during line to ground fault is shown at figure 6. For more details read [2].

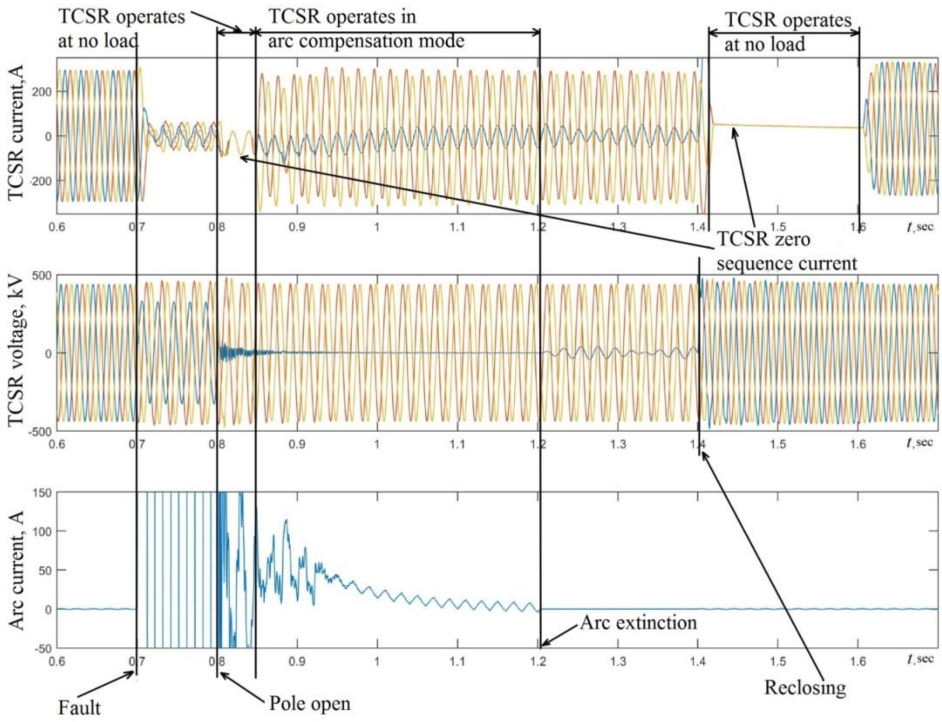

Fig.5

2.2. Resonant overvoltages prevention

Line connected shunt reactors (figure 3) may lead to resonant overvoltages during unbalanced voltage of transmission line in case of fully compensated transmission lines. In particular such modes occurs during SPAR of a transmission line. It is important to limit overvoltages to prevent equipment failure. This problem is solved by de-turning the resonant circuit (figure 6). Fast types of VSR such as TCSR may be used for it. Some experts state that transients should be simulated because peak overvoltages significantly increase steady state ones.

Steady state simulation has led to a conclusion that in case of installing one line connected TCSR 500 kV during SPAR leads to:

1. Overvoltages if the line length is in between 175 and 190 km and valve windings are short-circuited (figure 7).
2. Overvoltages if the line length is less then 90 km and thyristor valves are blocked (figure 7).
3. In other cases recovery process does not lead to overvoltages.

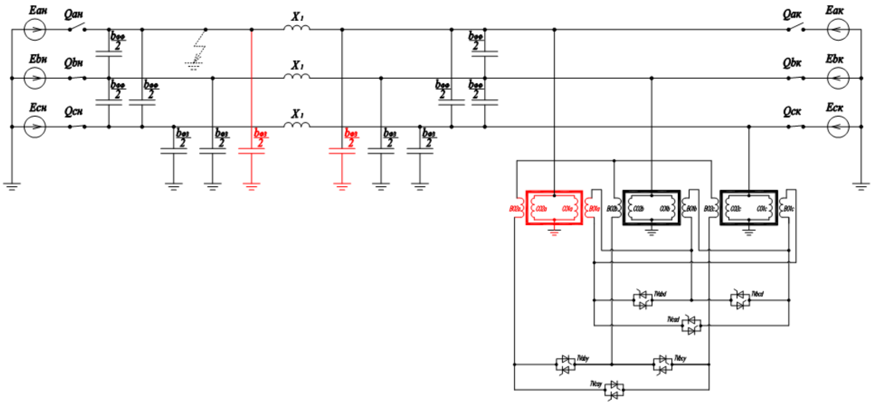

Fig.6

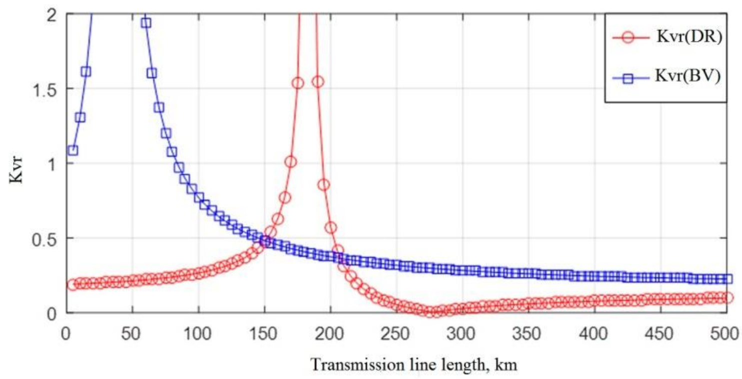

Fig.7

At figure 7 the following notation is used: voltage recovery coefficient

- Кvr(DR) voltage recovery coefficient in short-circuited under thyristor valve windings mode of operation;
- Кvr(BR) voltage recovery coefficient in short-circuited under blocked thyristor valve mode of operation.

Voltage recovery coefficient is the ratio of the voltage amplitude at the disconnected phase to the phase voltage amplitude at rated voltage of the network. Transient simulation has led to understanding that thyristor valves blocking is effective for preventing overvoltages in case of installing one line connected TCSR 500 kV to the transmission line of resonant length 190 km (figure 8). TCSR should not be connected to the bus bar if the transmission line is shorter than 90 km. For more details read [4].

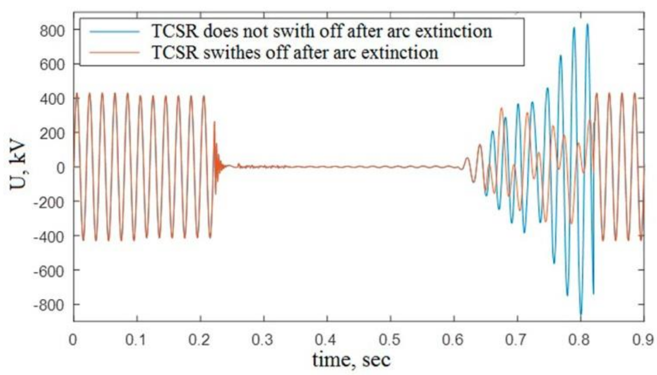

Fig.8

3 Features of TCSR for transmission line operation at no load

3.1 Strategies of TCSR start-up

TCSR is used for limiting overvoltages of transmission line at no load mode of operation. When the transmission line is energized the TCSR starts up automatically. Two strategies of TCSR start-up can be used. If a «common» strategy is used phase control of thyristor valves provides current without aperiodic component (figure 9). In this case TCSR begins to consume reactive power in 100-150 ms after line energization. Transmission line energization excites transient process. The delay is needed for PLL synchronization to grid voltage distorted by harmonics. The main advantage of this strategy is absence of an aperiodic component in line current which can lead to CB current zero missing and CB failure [5] if the CB is opened immediately after line energization.

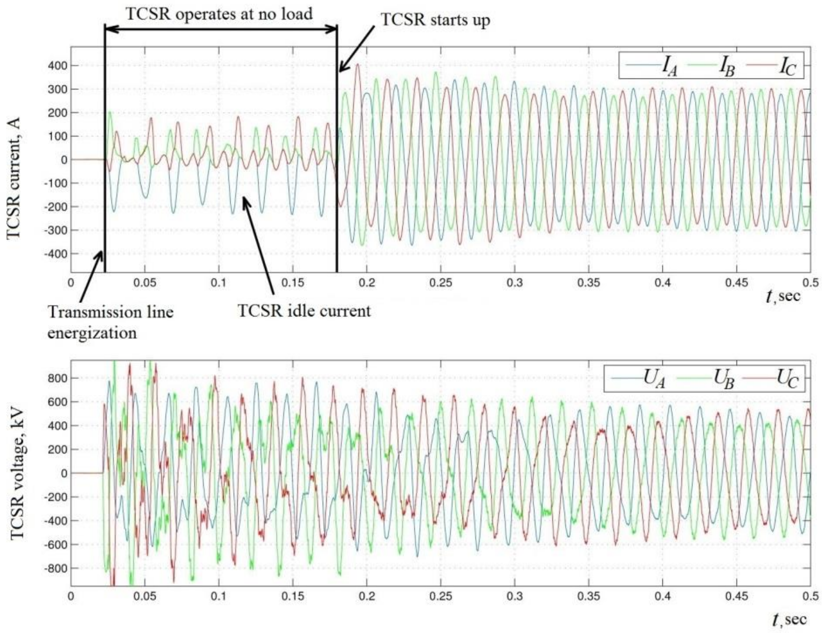

Fig.9

During the delay TCSR emits inrush current which includes even harmonics. Inrush current can exite ferro-resonance if one of the line natural frequencies close to the 2-nd harmonic. This is likely for the HV line length 475-525 km. In such a case «accelerated start-up» strategy is used (figure 10). Accelerated start-up strategy differs from a common one only during synchronization when thyristor valves are operational in diode mode. Hence the disadvantage of this strategy is aperiodic component in CB current during synchronization.

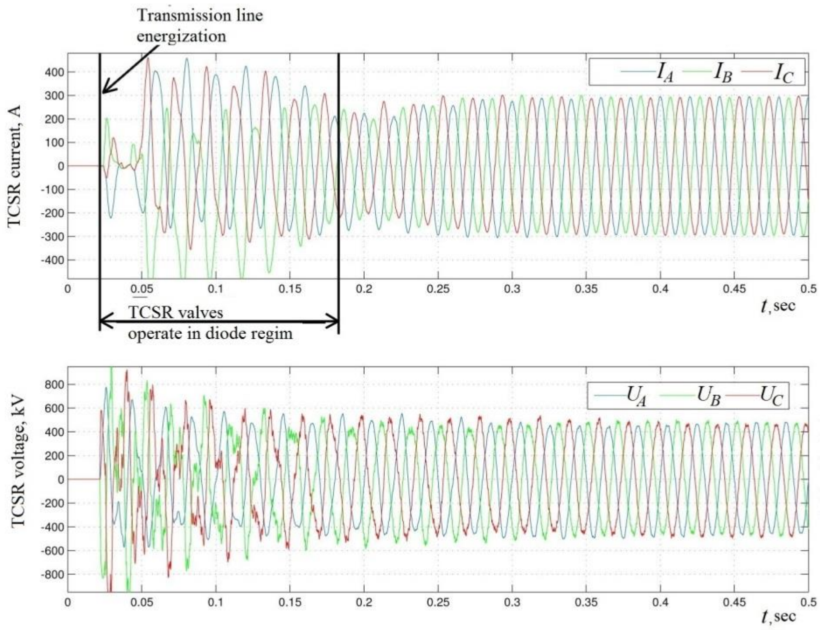

Fig.10

3.2 TCSR features providing safe energizing of compensated overhead 500 kV line

When single phase to ground fault occurs immediately after the transmission line energization unfaulty phases may content aperiodic component of the current high enough for zero missing. As far as SF-6 CB have very low current chopping the arc between its contacts may burn for the time longer than SF-6 blows from the chamber. All described above may lead to CB damage caused by overheating. SF-6 CB may fail to cut the current in case of presence of the DC component sufficient for zero missing. Such a problem arises when almost fully compensated transmission line is de-energized immediately after it was energized. To guarantee a safe operation of the CB current must cross zero in 20 ms after contacts are disconnected.

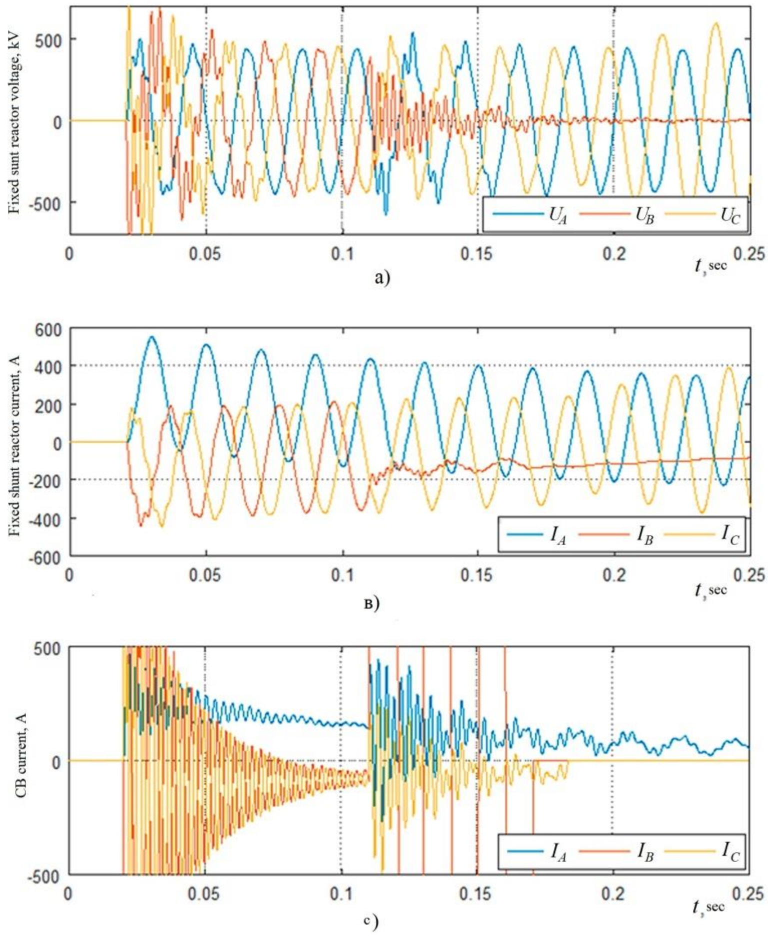

Fig.11

Transient process caused by transmission line with fixed shunt reactor energization is shown in figure 11. It was assumed that simultaneous CB contacts in all phases connect simultaneously in the moment of 20 ms when the phase A voltage crosses zero. It is known that an aperiodic component of the current is maximum in such a case. At the time instant of 110 ms a phase B to ground fault occurs. All CB contacts disconnect at 170 ms. Aperiodic components in reactor and CB behave as presented in figures 11 b and 11 c respectively. It can be concluded that SF-6 CB in phase A can be damaged because zero missing is far longer than 20 ms. Transient process caused by transmission line with TCSR reactor energization is shown in figure 12. All timings are the same as described above. «Common» start-up strategy is used. Application of TCSR eliminates the causes of this problem without using any other specific means such as controlled switching of CB or CB with special resistors. For more details read [6,7].

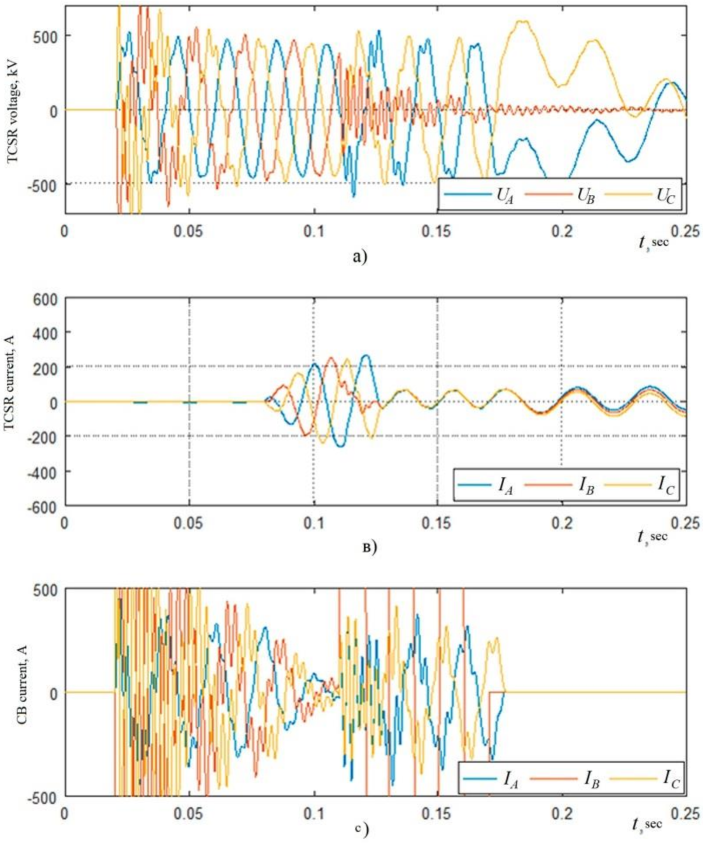

Fig.12

Conclusions

When the TCSR with split valve windings is connected to the transmission line directly it may be used for shortening the SPAR Cycle Time in 500 kV Lines and preventing resonant overvoltages during single-phase auto reclosing of transmission line. The use of TCSR of the type examined in this work increases the effectiveness of SPAR and the stability of power systems.

Application of TCSR eliminates aperiodic component in CB current which may damage SF-6 circuit breaker if zero missing occurs. Application of TCSR solves this problem without using any other specific means due to absence of an aperiodic component. The use of TCSR of the type examined in this work increases the reliability of the power system.

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