CIGRÉ WINNIPEG 2017 INTERNATIONAL COLLOQUIUM & EXHIBITION

CIGRE B4-027_ADDITIONAL FUNCTIONS OF THE UPGRADED TCSR WITH SPLIT WINDINGS

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ADDITIONAL FUNCTIONS OF THE UPGRADED TCSR WITH SPLIT WINDINGS

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TCSR design

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

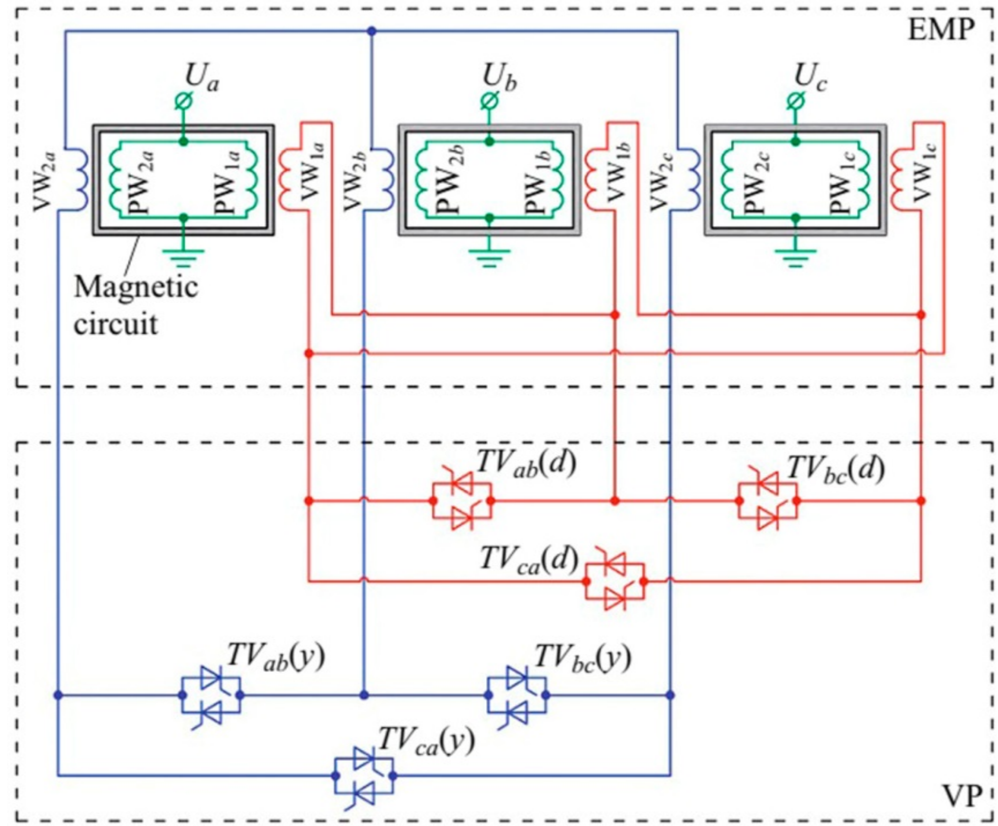

Fig 1 - Electromagnetic part of TSCR
(rated voltage 500 kV)

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 additional functions

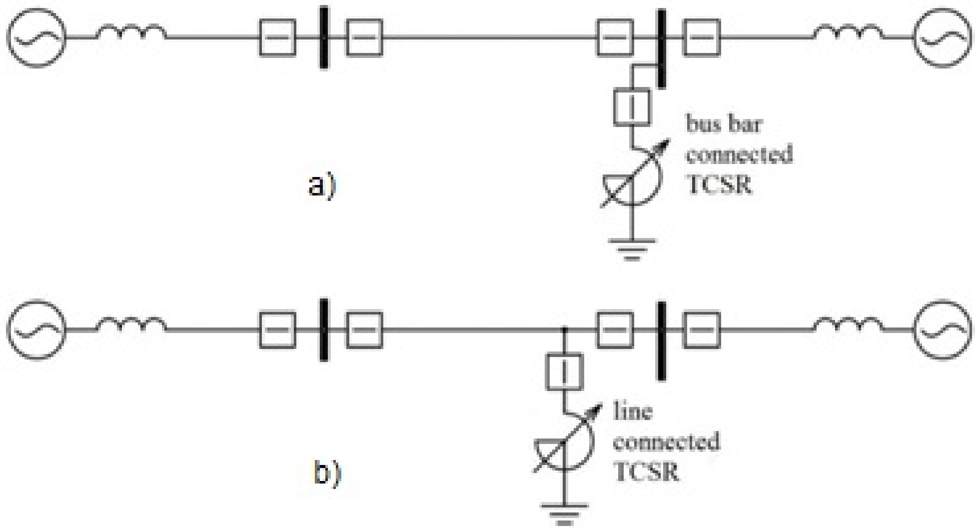

Fig 2- TCSR connection type

TCSR functionality depends on the way it is connected to the grid.

TCSR can be connected to the bus bar (fig 2a) or to the line (fig 2b).
Line connected 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.

Secondary arcing during SPAR

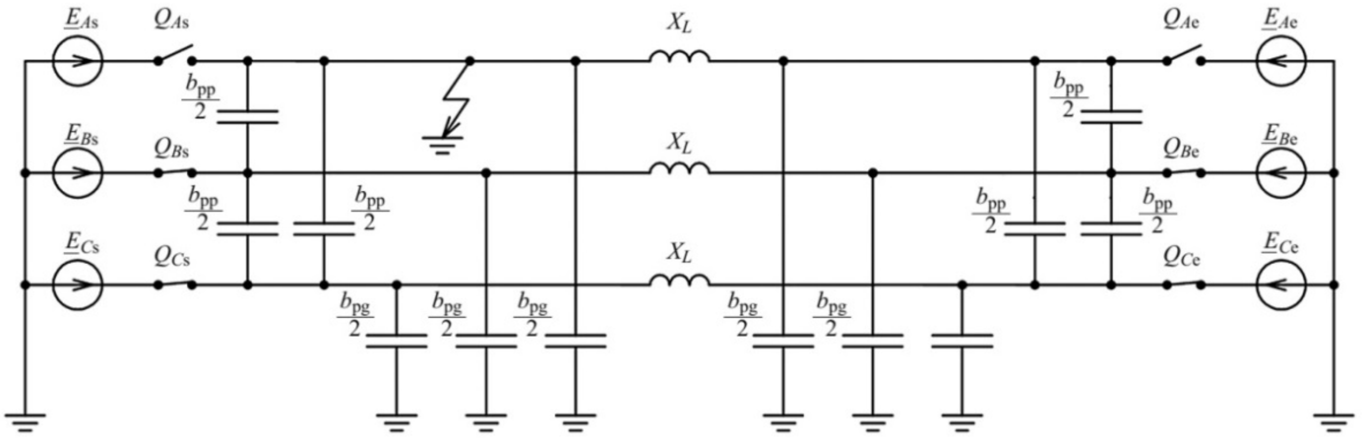

Fig 3 - Secondary arcing test scheme

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 3).

Secondary arcing compensation by means of TCSR

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 $\underline{I}_{d(es)}$:

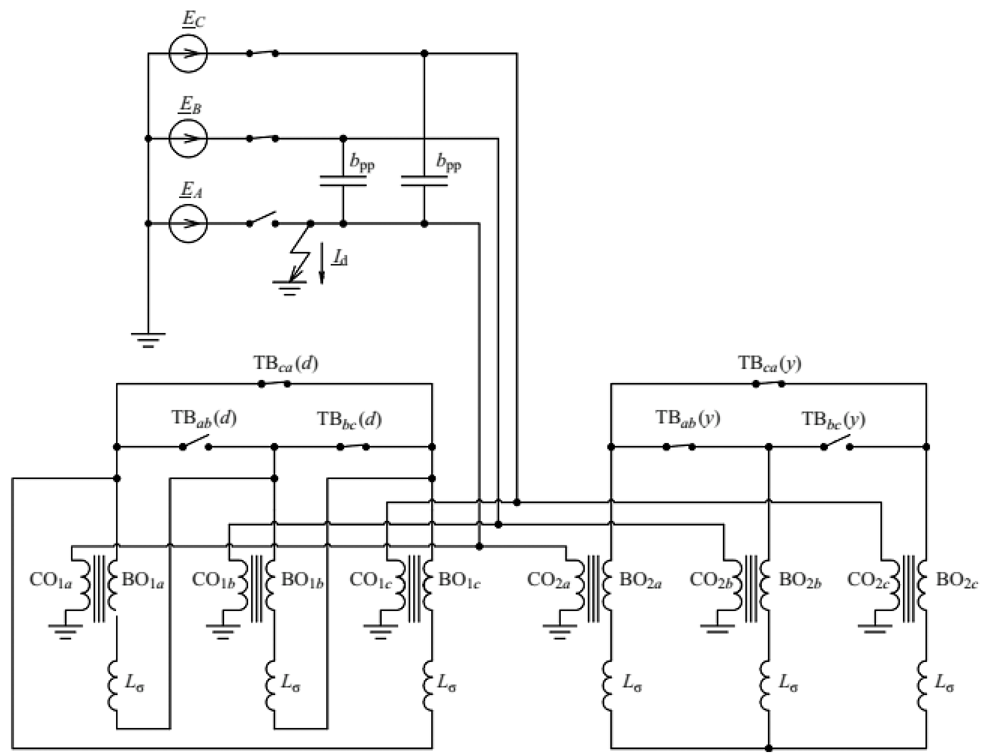

Fig 4 - Secondary arcing compensation simplified test scheme

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

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

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

Simulation of secondary arcing compensation

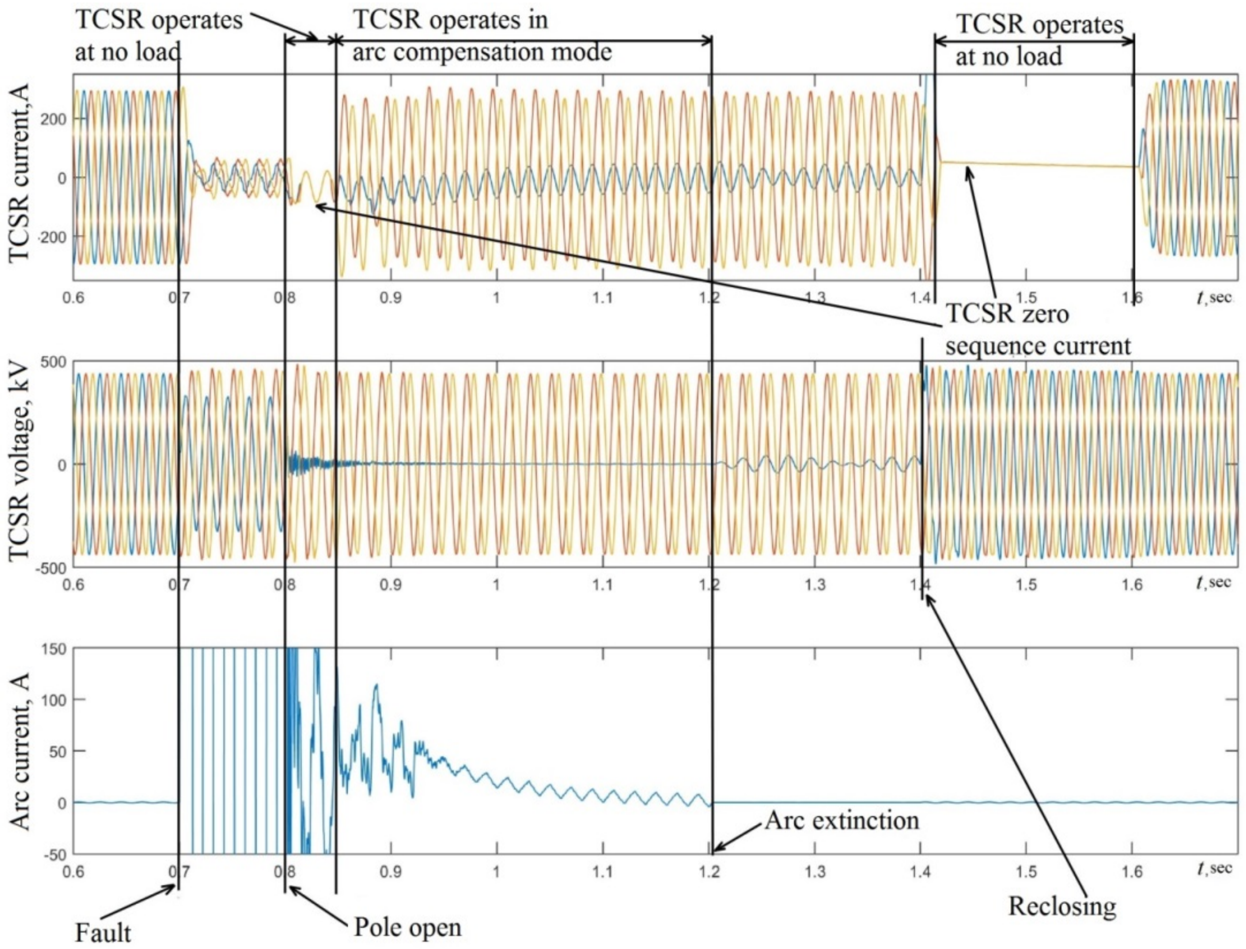

Fig 5 – Plots of secondary arcing compensation by means of TCSR

TCSR impact on SPAR duration

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 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.

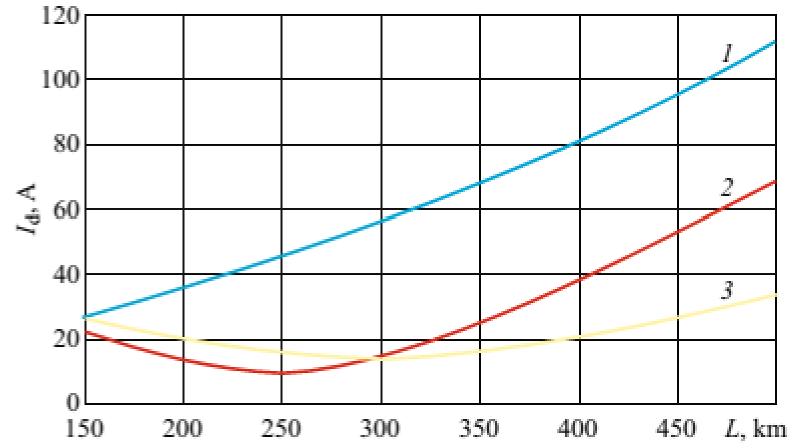

Fig 6 – Arc current vs 500 kV test line length
1 – line is uncompensated
2 – line is compensated by 180 Mvar TSCR
3 – line is compensated by 180 Mvar TSCR and by fixed snunt reactor 180 Mvar

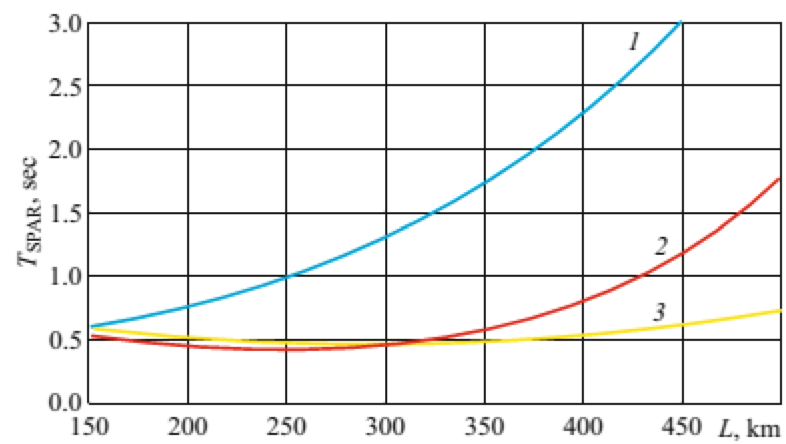

Fig 7 – SPAR duration vs 500 kV test line length

Resonant overvoltage during SPAR

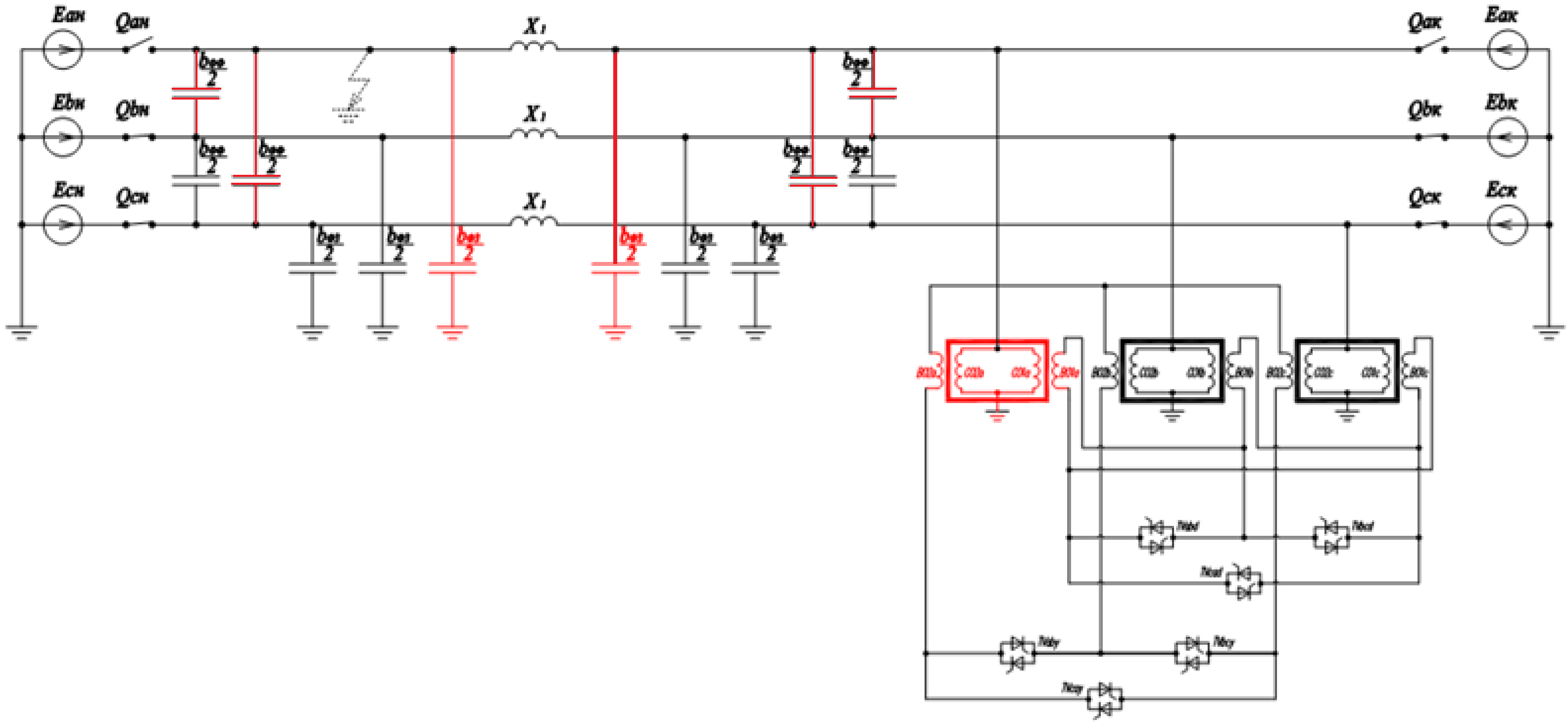

Fig 8 – Resonant circuit

Line connected shunt reactors 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 8). Fast types of VSR such as TCSR may be used for it.

Steady state resonance during SPAR

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 9).
2. Overvoltages if the line length is less then 90 km and thyristor valves are blocked (figure 9).
3. In other cases recovery process does not lead to overvoltages.

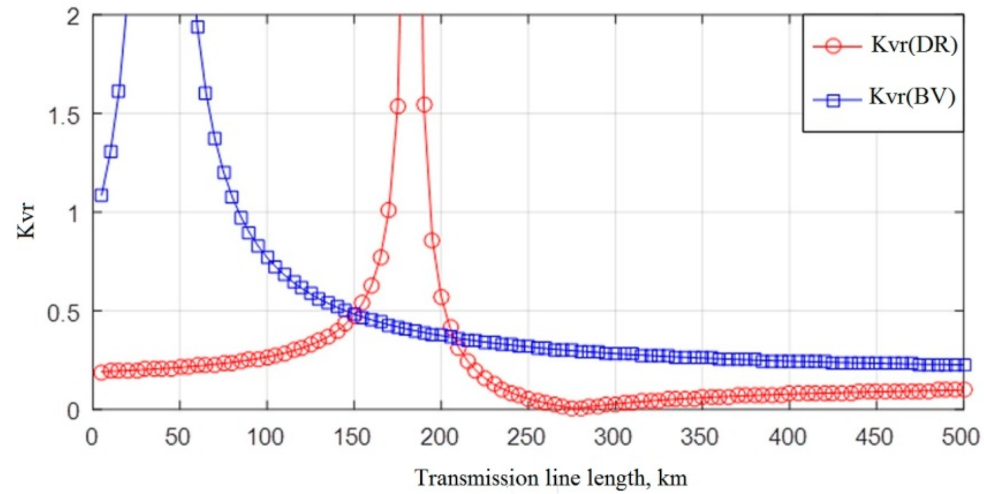

Fig 9 – Voltage recovery coefficient vs line length

Кvr(DR) voltage recovery coefficient - valve windings are short-circuited
Кvr(BV) voltage recovery coefficient - thyristor valves are blocked

Resonant overvoltage prevention during SPAR

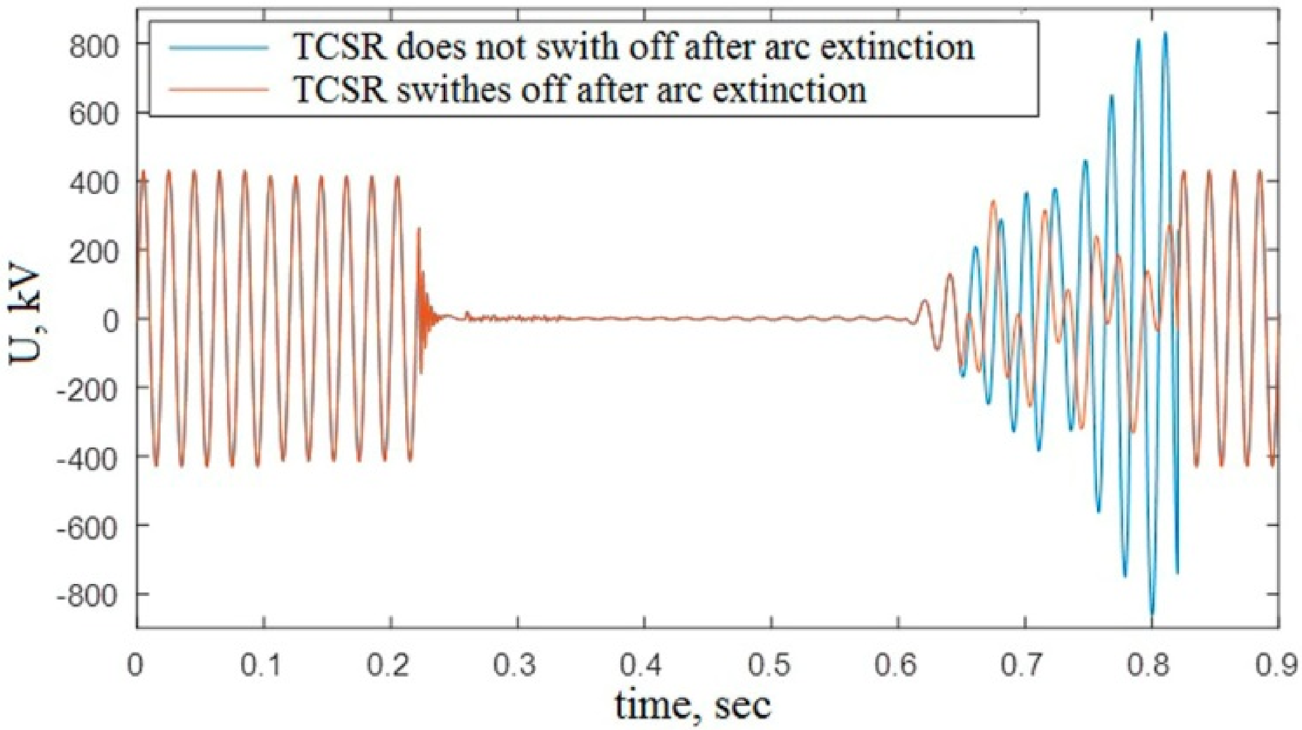

Fig 10 – Phase voltage during SPAR

Transmission line energization «Common» type start

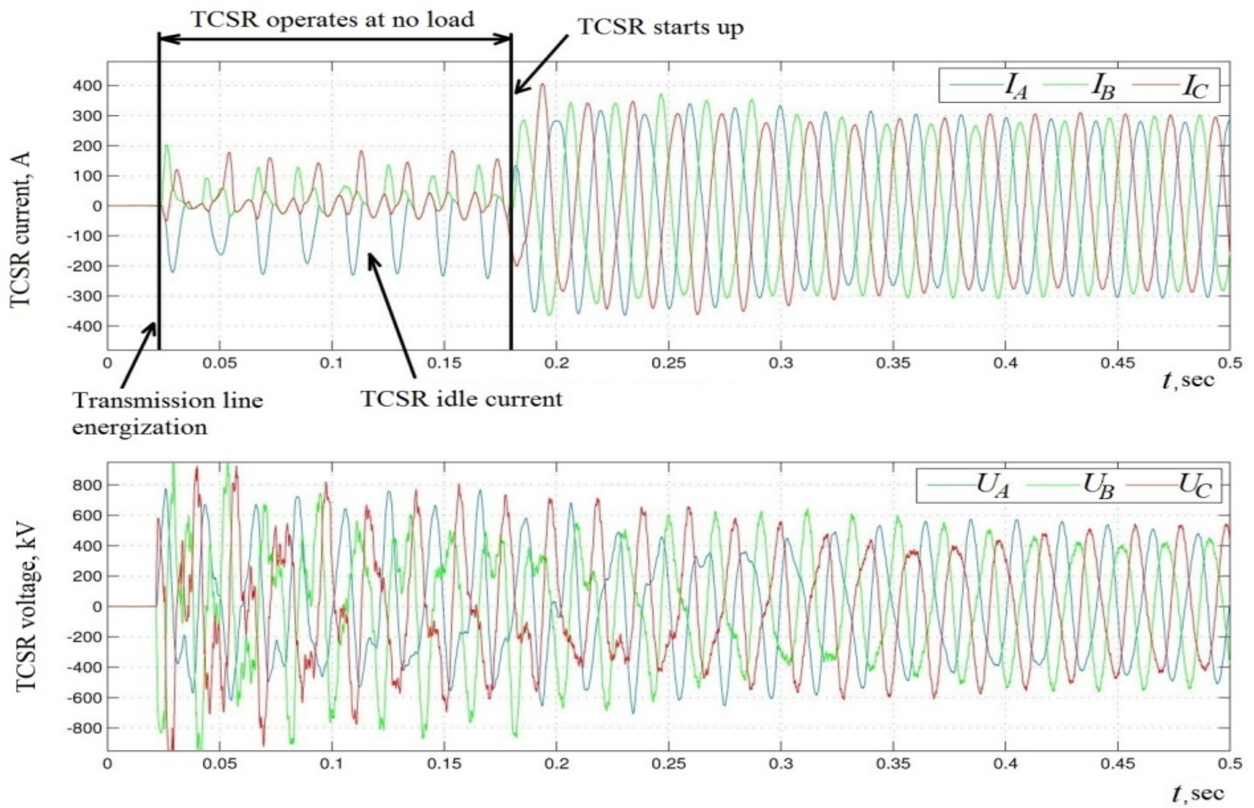

Fig. 11 – Phase to ground voltages at the open end of transmission line*

* Line length is 500 km

Transmission line energization «Fast» type start

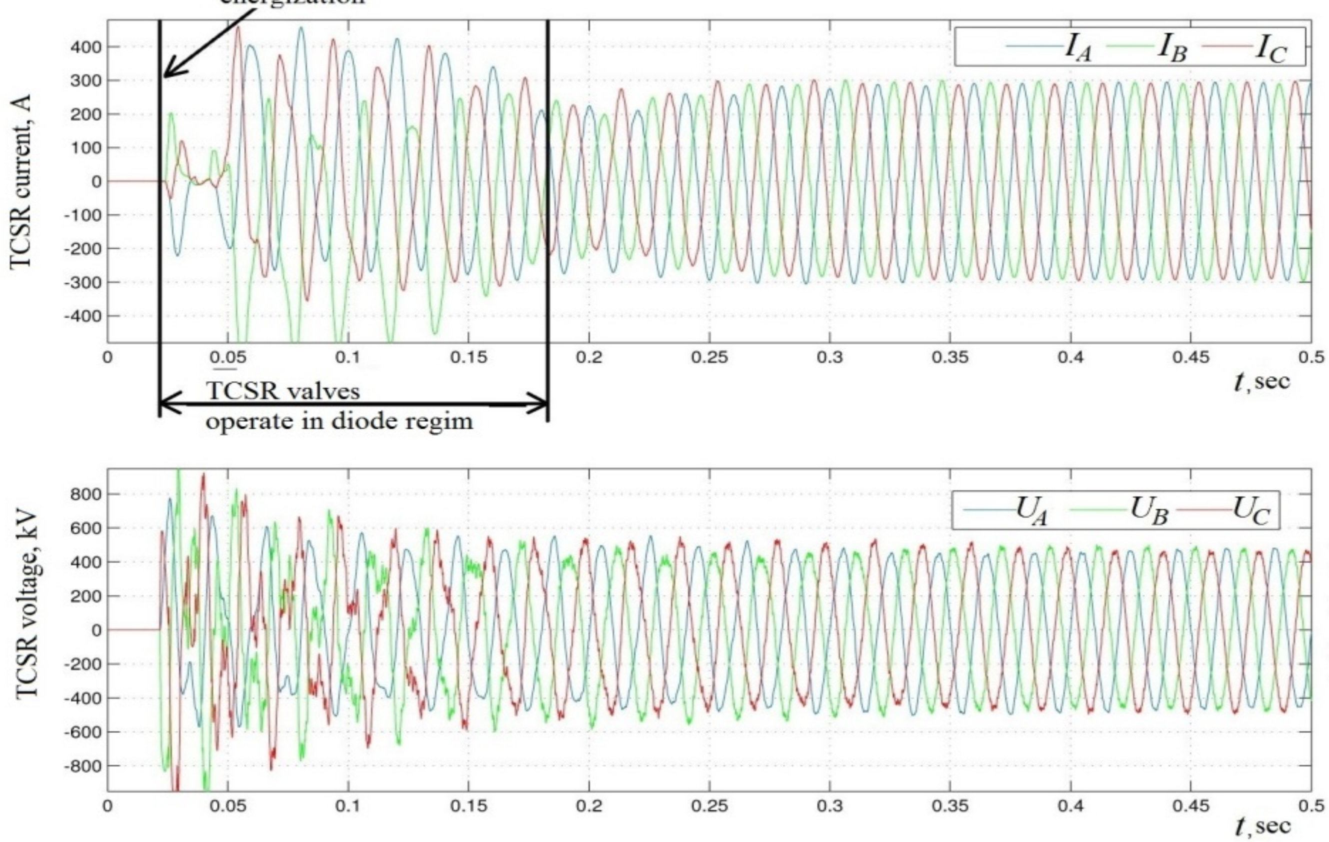

Fig. 12 – Phase to ground voltages at the open end of transmission line*

* Line length is 500 km

SF-6 CB damage in case of unsuccessful energization of transmission line with fixed shunt reactor

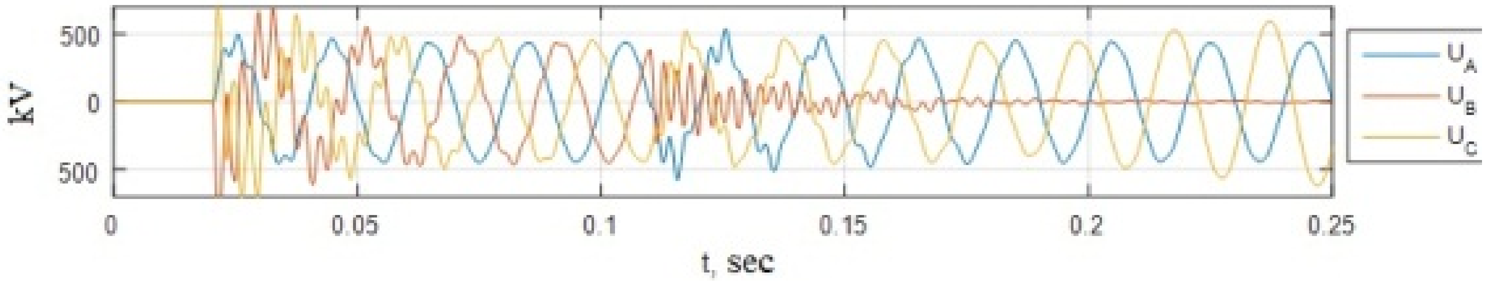

Fig. 13 – Phase to ground voltages at the open end of transmission line

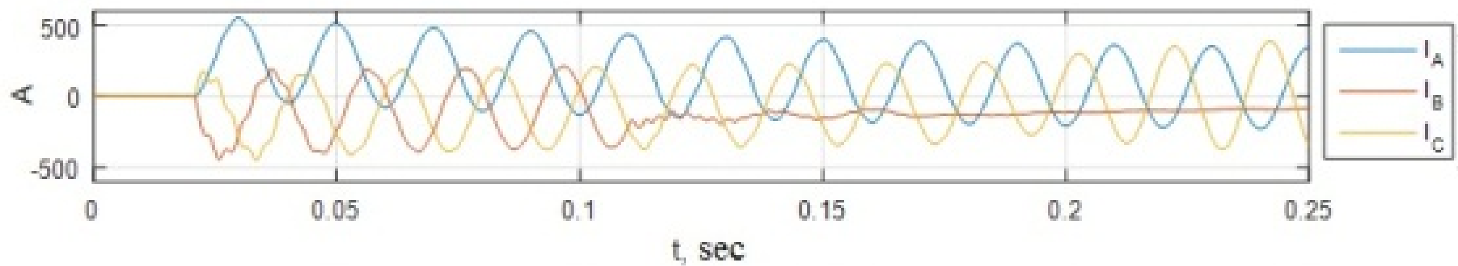

Fig. 14 – Fixed shunt reactor current

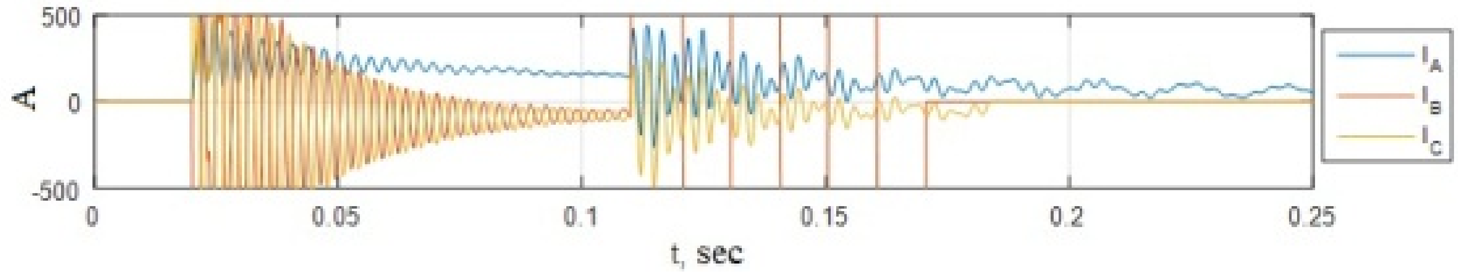

Fig. 15 – CB current

TCSR features providing safe energizing of compensated overhead 500 kV line

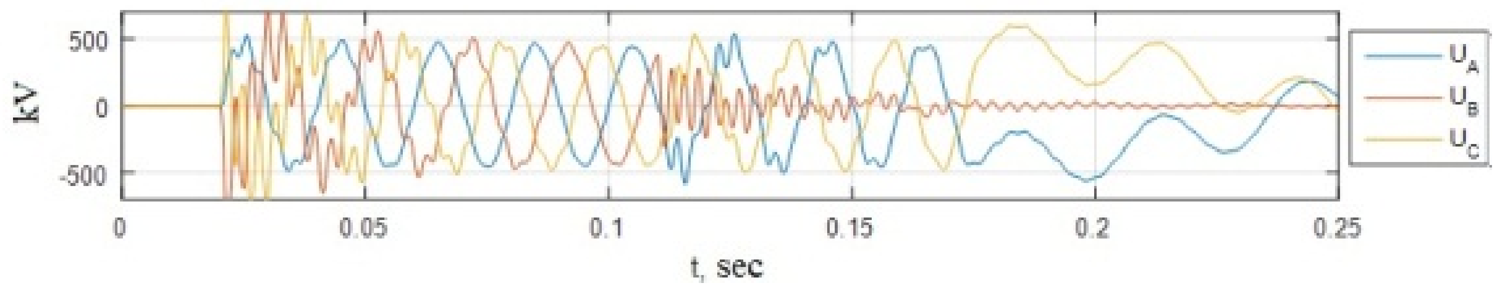

Fig. 16 – Phase to ground voltages at the open end of transmission line

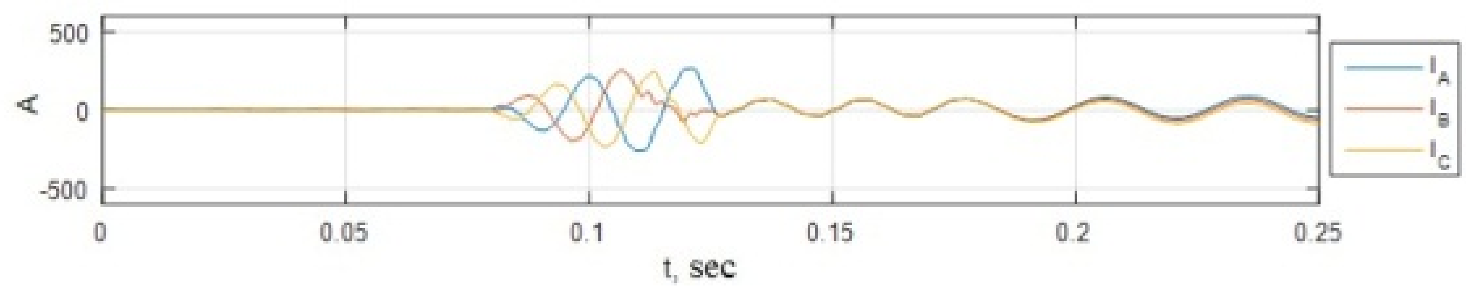

Fig. 17 – TCSR current

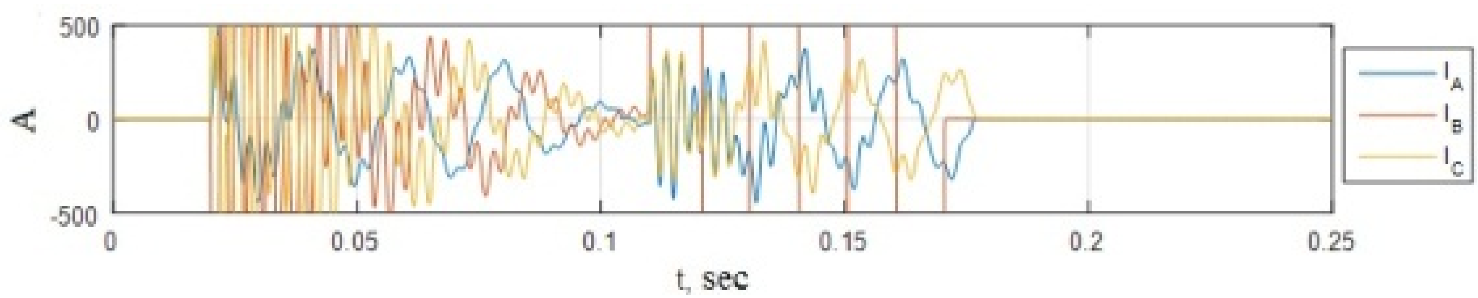

Fig. 18 – CB current

Conclusions

Developed by JSC «R&D center @ FGC of UES» a novel type of TCSR with low harmonic emission level has the following extra benefits:

1. 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 increases the effectiveness of SPAR and the stability of power systems.

2. 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 increases the reliability of the power system.

THANK YOU!