About some FACTS devices from the power systems
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Abstract: - The FACTS (Flexible Alternate Current Transmission Systems) devices gives new perspectives to power systems planning and operation. The TCSC-Thyristors Controlled Series Capacitor and the SVC-Static Var Compensator are part of these devices. The paper presents some considerations regarding the Static Var Compensator and the Thyristors Controlled Series Capacitor. Thus, starting from the structures of these devices, it determinates the fundamental impedance of the TCSC and SVC and it analyses the dependence of the impedance v.s. the components elements \( (L, C, R, L_c) \) and the firing delay angle \( (\alpha) \) of the thyristors.

Key-Words: - FACTS devices, TCR, TCSC, SVC, Power systems

1 Introduction
Due to the economical, political and ecological difficulties that appears in the construction of new transmission line or/and power plants and also due to the increasing of the consumption request of the electric power, existing power transmission systems are more and more stressed.

A possible way in order to solves these problems is to use the FACTS (Flexible Alternate Current Transmission Systems) devices, [1], [2]. The concept of flexible AC transmission system consists in the realisation of a system more performed through the control of the power flow and the rise of the transmission capability until the limits tolerated by the system.

The FACTS devices are built on the development of the power electronics (thyristors, GTO thyristors, MTO thyristors, MCT thyristors) and they give the possibility to control one or more electrical parameters: voltage, current, and phase-difference angle, [1-4].

Under FACTS concept, its are included and the shunt and series compensators controlled by thyristors. Already exist a big number of types of compensators, from these it can remember, [1], [2], [5], [6]:
- **thyristor controlled reactor** (TCR) is a reactor controlled with thyristors at which its effective reactance is continue adjusted through the control of the thyristors conduction. The absorbed current \( i_L \) by the TCR is inductive and it can be adjusted through the firing delay angle \( (\alpha) \) of the thyristors, Fig.1;
- **thyristor controlled series reactor** (TCSR) is an inductive reactance compensator at which its inductive reactance is continue adjusted through the firing delay angle \( (\alpha) \) of the thyristors, Fig.2. It consists from a series reactor shunted by a thyristor controlled reactor (TCR). If the firing delay angle is 180 degrees, the TCSR operates as an uncontrolled reactor \( (L_1) \). When the angle decreases below 180 degrees, the inductive reactance of TCSR decreases and at the 90 degrees it is given by the parallel connection of the reactors \( (L/L_1) \);
- **thyristor controlled series capacitor** (TCSC) is a series compensator at which its reactance is adjusted through the firing delay angle \( (\alpha) \) of the thyristors, Fig.3. It consists from a series capacitor bank \( (C) \) shunted by a thyristor controlled reactor (TCR). If the firing delay angle is 180 degrees, the reactance of TCSC is capacitive \( (C) \) and at 90 degrees the reactance is inductive. When the angle is between 90 and 180 degrees, the reactance of TCSC can be inductive or capacitive;

![Fig. 1 SVC scheme](image-url)
thyristor switched reactor (TSR) is a reactor switched with thyristors at which its effective reactance is stepwise adjusted, through the operating in total conduction or blocking of the thyristors;

thyristor switched capacitor (TSC) is a capacitor switched with thyristors at which its effective reactance is stepwise adjusted, through the operating in total conduction or blocking of the thyristors, Fig.1. The absorbed current by the compensator is capacitive and cannot be adjusted;

static var compensator (SVC) is a static compensator shunt connected with the output controlled to inject or absorb a reactive current in order to maintain or control some specific parameters of the electrical system. SVC can be realised from a TCR and one or more TSC parallel connected, Fig.1;

static synchronous compensator (STATCOM) is an advanced VAr static compensator at which the capacitive or inductive current can be independently controlled by the alternative voltage of the electrical system. The main advantage of this converter, comparing with SVC, is that it can generate a constant capacitive current until small values (approx. 0.15... 0.2 p.u.) of the network voltage (zero theoretically).

2 TCSC impedance

The series compensation principle is to adjust the line impedance by the insertion of reactive elements in series with the line. To adjust the impedance of a transmission line (generally inductive) usually we put in series capacitive elements.

The TCSC, Fig.3, uses the property of a resonant circuit that has capacitive impedance after the resonant frequency. The TCSC fundamental impedance module of the device depends on the \( \alpha \) firing angle of thyristors, in accordance with the equation, [2], [7]:

\[
|Z_{TCSC}^{(i)}| = \frac{\omega L}{\beta - \omega^2 LC},
\]

where: \( \beta = \frac{2}{\pi} \left( \pi - \alpha + \frac{\sin 2\alpha}{2} \right) \).

The Fig.4 shows the evolution of the fundamental impedance of TCSC in function of thyristors firing angle.

The control system of the thyristors must be very precise because the value of firing angle doesn’t take the value of resonance, \( \alpha_r \). In practice, the values of the firing angle aren’t near to the resonance value because of the currents deformation and of the over-voltages that appear.

Considering the TCSC structure from Fig.3 at which is added a resistor, \( R \), in series with the inductance \( L \). The resistor \( R \) models the ohmic resistance of the TCR.

The Fig.5 and Fig.6 presents the fundamental impedance module and the impedance phase of the TCSC depending on the firing angle of the thyristors, for different values of the resistance \( R \), [7].

![Fig. 2 TCSR scheme](image)

![Fig. 3 TCSC structure](image)

![Fig. 4 The fundamental impedance of TCSC](image)
The phase of the TCSC impedance depending on the resistance $R$ for the behaviour in the capacitive zone ($|Z^{(1)}_{TCSC}|=25 \ \Omega$), respectively inductive ($|Z^{(1)}_{TCSC}|=30 \ \Omega$) is shown in Fig. 7. It observes that, the increasing of the TCSC resistance, $R$, determinate a decreasing of the impedance value in the resonance point and also a movement of this point in inductive zone, Fig. 5.

It remarks a big influence of the resistance value to the impedance phase when TCSC operates in inductive zone; in capacitive zone this effect is negligible mostly if the firing angle $\alpha$ is near 180°, Fig. 6, Fig. 7.

For example, if $R=5 \ \Omega$ the impedance phase is -71° in capacitive zone during in inductive zone is 6.9°. In this last case, the circuit behaviours as a pure resistance appearing important losses.

In order to moves much more the resonance point, in conformity with (1), it modifies inductance value $L$ of the TCSC, capacity value $C$ being kept constant because this value determinate the device minimum impedance in capacitive zone. In Fig. 8 and Fig. 9 it observes that the resonance point is much moved to inductive region if $L$ increases. The impedance value is also much influenced by the inductance’s increasing which will compensate the effect of the resitor $R$. Thus, impedance’s phase increases through the modifying of the inductance $L$ till the value of 79°. For a firing angle more than resonance angle, the increasing of the inductance $L$ influences the decreasing of the impedance’s phase till it will became equal with the value of a pure capacity. At the same time, if the resonance point is moved in inductive region, the variation of the impedance module, in report with the firing angle $\alpha$, it is decreased into the big domain of its, that allows a precise adjustment of the impedance.

### 3 SVC impedance

Considering the SVC structure from Fig. 1 in additional with a resistor $R_e$ in series with the inductance $L$, respectively an inductance $L_c$, in series
with the capacitor $C$. The resistor $R$ models the ohmic resistance of the TCR, while the inductance $L_c$ is necessary for the limitation of the variation speed of the current through the TSC thyristors.

SVC impedance depends on the TCR and TSC impedances, parallel connected:

$$Z_{SVC} = \frac{Z_{TCR} \cdot Z_{TSC}}{Z_{TCR} + Z_{TSC}}. \quad (2)$$

The TCR complex impedance is given by the relation, $[2], [8]$:

$$Z_{TCR} = R + j \frac{\omega \cdot L}{\beta}, \quad \beta = \frac{2}{\pi} \left( \pi - \alpha + \frac{\sin 2\alpha}{2} \right), \quad (3)$$

where $\alpha$ is the firing delay angle of the TCR thyristors and takes values in the range $[90^0, 180^0]$, while the TSC impedance is:

$$Z_{TSC} = j \left( \omega L_c - \frac{1}{\omega C} \right), \quad \omega = 2\pi \cdot f, \quad (4)$$

$f$ being the voltage frequency.

The SVC fundamental impedance module will be, $[5]$:

$$|Z_{SVC}^{(i)}| = \frac{\sqrt{K_1^2 + K_2^2}}{R^2 + K_3^2}, \quad (5)$$

where $K_1$, $K_2$ and $K_3$ are given by the relations:

$$K_1 = \frac{RL}{\beta} \left( 1 - \omega^2 L_c \right) + R \left( \omega L_c - \frac{1}{\omega C} \right) \cdot K_3$$

$$K_2 = R^2 \left( \omega L_c - \frac{1}{\omega C} \right) - \frac{L}{\beta} \left( \frac{1}{C} - \omega^2 L_c \right) \cdot K_3, \quad (6)$$

$$K_3 = \frac{\omega L}{\beta} + \omega L_c - \frac{1}{\omega C}$$

It considers a SVC, designed to be mounted into a 220 kV network, which can generates, respectively absorbs a maximum reactive power of 90, respectively 150 MVAR, $[5]$.

In Fig.10 and Fig.11 are shown the fundamental impedance evolutions, respectively the SVC reactive power in function of the firing angle of the TCR thyristors, for various values of the capacitor $C$. It can observe the followings: - both possible regions (inductive, capacitive) of SVC operation; - the resonance appearance for a certain value, $\alpha_r$, of the firing angle of the TCR thyristors;
- the movement of the \( \alpha \) firing angle value, for which appears the resonance, at the increasing of the capacitor \( C \); - the adjustment range extend, in capacitive zone, at the increasing of the capacitor \( C \); - the necessity of a restricted adjustment interval of the firing angle, interval which contains the resonance value, \( \alpha_r \).

The influence of the resistance \( R \) and of the inductance \( L_c \) values to the SVC impedance is shown in Fig.12 and Fig.13. It consists that in the zone of the resonance angle, \( \alpha_r \), the increasing of the TCR ohmic resistance leads to the decreasing of the SVC impedance. This thing is due to the series resonance of the \( C-L_c \) circuit of the TSC which it superposes over the parallel resonance of the SVC. The influence’s interval of the resistance \( R \) to the firing angle \( \alpha \) is small, \([\alpha_r-1.5^\circ, \alpha_r+1.5^\circ]\), it being practically included in the restricted zone of the firing angle, \( \alpha \). Thus, the resistance \( R \) will have a limited contribution to the SVC impedance. The decreasing of the inductance values, \( L_c \), determines an increasing of the firing angle values at which resonance appears. In this case the movement of the resonance angle is into a range much more limited than in the case of the capacity values modifications, Fig.13, Fig.10.

4 Conclusions

The FACTS devices are based on the development of the power electronics (thyristors, GTO thyristors, MTO thyristors, MCT thyristors) and they give the possibility to control one or more electrical parameters: voltage, current, and phase-difference angle. In practice are many types of compensators controlled with thyristors like as: TCSC and SVC.

The TCSC impedance depends on its structure elements \( (L, C, R) \), respectively the firing delay angle, \( \alpha \), of thyristors. It observes that:
- the increasing of the resistive component determinates a decreasing of the impedance value in the resonance point and also that the resonance point it moves to inductive region. It remarks a big influence of the resistance \( R \) if TCSC operates in inductive zone, during its effect is negligible if it operates in capacitive region;
- the resonance point it moves to inductive zone if the inductive component increase. The \( L \) increasing determinates an important increasing of the TCSC impedance module;
- for a firing angle more than resonance angle, the \( L \) increasing determinates a diminution of the impedance’s phase which will became equal with the pure capacity value;
- if TCSC operates in inductive zone, the harmonics degree is much more than capacitive behaviour.

SVC impedance depends on its structure elements \( (L, C, R, L_c) \), respectively the firing delay angle, \( \alpha \), of TCR thyristors. Thus:
- the increasing of the capacitor \( C \) determinates the impedance’s modification and also, the decreasing of the firing angle at which appears the resonance and the increasing of the adjustment range in the behaviour in capacitive zone of the SVC;
- the resistance \( R \) will have a limited contribution to the SVC impedance;
- the decreasing of the inductance values, \( L_c \), determinates an increasing of the firing angle values at which resonance appears;
- the impedance can has inductive or capacitive nature in function of the firing angle.
References:


