Aspects concerning the Static Var Compensator

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Abstract: - The paper presents some considerations regarding the structure and behaviour of the static var compensator (SVC). Thus, starting from a structure of the compensator it determinates the fundamental impedance of the SVC and it analyses the dependence of the impedance v.s. the components elements (*C, R,* L_c). Also, it has been realised and the analyses regarding the overvoltages which can appears on the SVC capacitor in function of the charging voltage and the moment of the capacitor switching.

Key-Words: - FACTS devices, TCR, TSC, SVC, power systems

1 Introduction

The appearance and evolution of the power semiconductor components (thyristors, GTO thyristors, IGBT transistors) have been allowed to realises some shunt compensator schemes which eliminates from the disadvantages of the classic compensators (high responding time, expensive maintenance, step by step adjustments etc.), [1], [2].

Already exist a big number of types of shunt compensators; from these it can remember, [1-3]:

- *thyristor controlled reactor* (TCR) is an 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 ignition delay angle (α) of the thyristors, Fig.1;
- *thyristor switched reactor* (TSR) is an reactor switched with thyristors at which its effective reactance is stepwise adjusted, through the operating in total conduction or blocking of the thyristors;

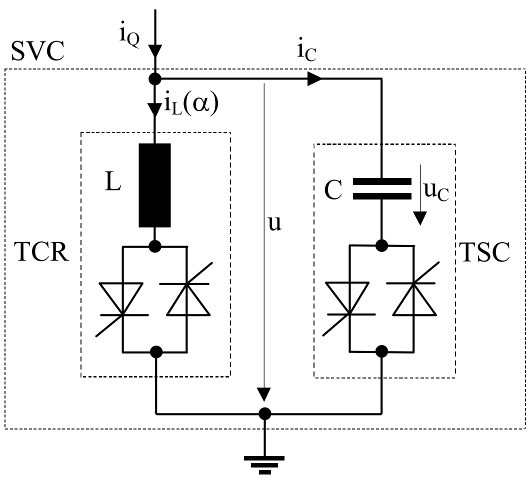

Fig. 1 Shunt compensator scheme – SVC

- *thyristor switched capacitor* (TSC) is an 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 can not be adjusted;
- *static var compensator* (SVC) is a static compensator shunt connected with the output controlled to inject or absorb a reactive current with the purpose 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, in comparison with SVC, is that it can generates a constant capacitive current until small values (approximate 0,15...0,2 p.u.) of the network voltage (zero theoretically).

2 Impedance of the Compensator

Considering the SVC structure from Fig.1 at which is added a resistor *R*, in series with the inductance *L*, respective 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:

$$\underline{Z}_{SVC} = \frac{\underline{Z}_{TCR} \cdot \underline{Z}_{TSC}}{\underline{Z}_{TCR} + \underline{Z}_{TSC}}. \qquad (1)$$

The TCR complex impedance is given by the relation, [4-6]:

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

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

$$\underline{Z}_{TSC} = j\left(\omega L_c - \frac{1}{\omega C}\right), \quad \omega = 2\pi \cdot f, \qquad (3)$$

f being the voltage frequency.

The SVC fundamental impedance modulus will be:

$$\left|Z_{SVC}^{(1)}\right| = \frac{\sqrt{K_1^2 + K_2^2}}{R^2 + K_3^2}, \qquad (4)$$

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

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

$$K_2 = R^2\left(\omega L_c - \frac{1}{\omega C}\right) - \frac{L}{\beta}\left(\frac{1}{C} - \omega^2 L_c\right) \cdot K_3. \qquad (5)$$

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

It considers a SVC, designed to be mounted into a 220 kV network, which can generates, respective absorbs a maximum reactive power of 90, respective 150 MVAr.

In Fig.2 and Fig.3 are shown the fundamental impedance evolutions, respective of the SVC reactive power in function of the ignition angle of the TCR thyristors, for various values of the C capacitor. It can observe the followings: - both possible regions (inductive, capacitive) of SVC operation; - the resonance appearance for a certain value, α_r, of the ignition angle of the TCR thyristors;

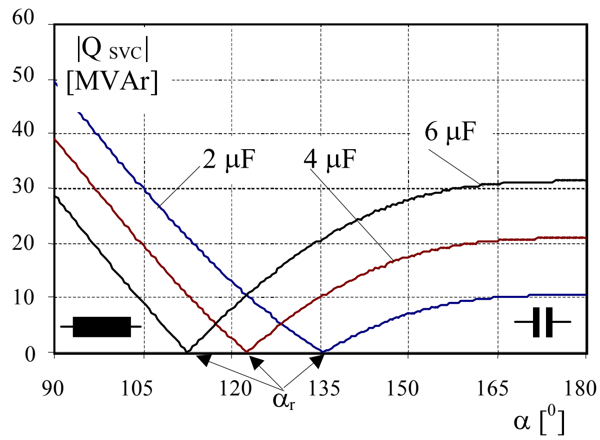

Fig. 3 SVC reactive power for different values of the C capacitor

- the movement of the α ignition angle value, for which appears the resonance, at the increasing of the C capacity; - the adjustment range extend, in capacitive zone, at the increasing of the C capacity; - the necessity of a restricted adjustment interval of the ignition angle, interval which contains the resonance value.

The influence of the resistance R and inductance L_c values to the SVC impedance is shown in Fig.4 and Fig.5. It consists that in the zone of the resonance angle α_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 interval of the resistance R to the ignition angle α is small, [α_r-1,5^0, α_r+1,5^0], it being practically included in the restricted zone of the ignition angle α. Thus, the resistance R will have a limited contribution to the SVC impedance. The decreasing of the inductance L_c values determinates an increasing of the ignition 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 C capacity values

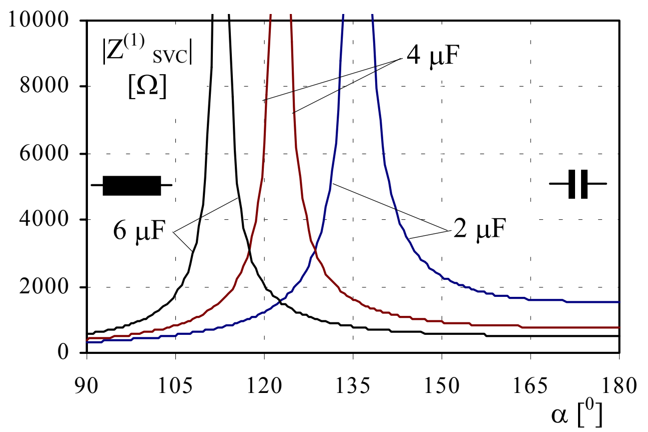

Fig. 2 SVC fundamental impedance for various values of the C

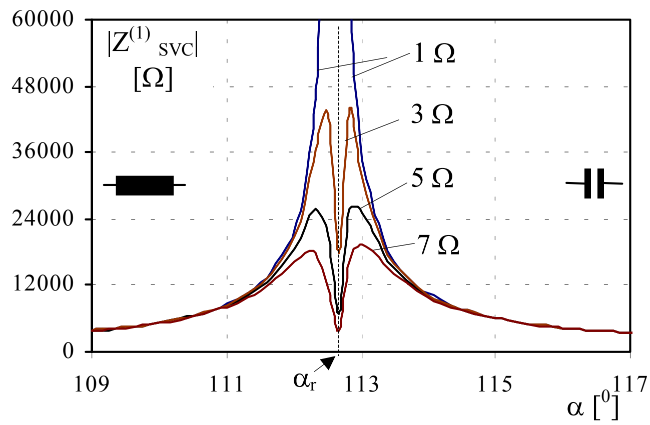

Fig. 4 SVC fundamental impedance for various values of the R

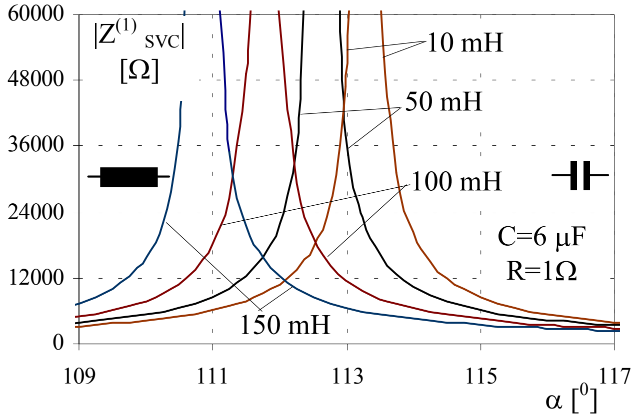

Fig. 5 SVC fundamental impedance for different values of inductance L_c

modifications, Fig.5, Fig.2.

3 Capacitor Switching of the SCV

If the disconnecting of the C capacitor of TSC don't involves high problems, its connection must be realised very careful because can appear dangerous transient states (overvoltages, overcurrents). The C capacitor disconnection is realised through the suppress of the ignition impulses on the TSC thyristors gate, at zero crossing of the current i_C, Fig.1. The C capacitor will remain charged with the voltage U_{Cm} given by the relation:

$$|U_{Cm}| = \frac{U_m}{1 - \omega\sqrt{C \cdot L_c}}, \qquad (6)$$

where U_m is the amplitude of the source voltage u, sinusoidal considered.

At the capacitor connection is necessary to have in view the charging voltage of the capacitor and also the connection's moment.

Fig.6, Fig.7 and Fig.8 show the voltage u_c and current i_c evolution at the capacitor connection, for different initial values u_{C0} of the voltage on capacitor ($0, +0.5U_{Cm}$ and $+U_{Cm}$).

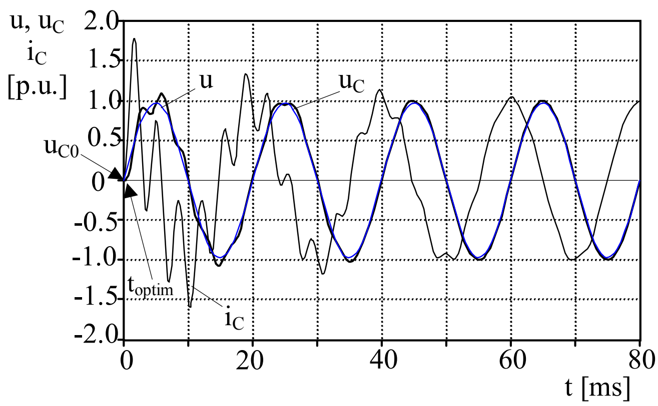

Fig. 6 The voltage u_C and current i_C evolution at the capacitor connection, for $u_{C0}=0$

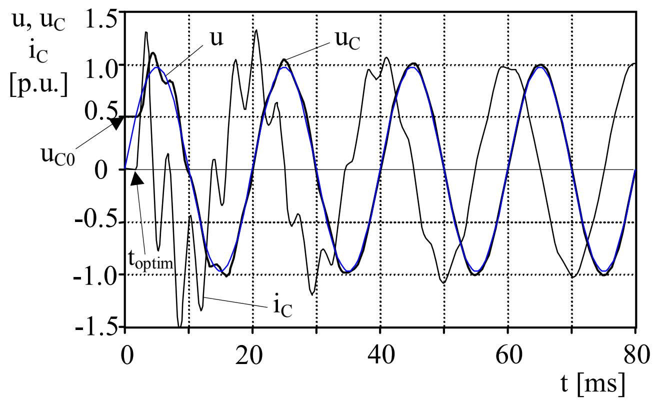

Fig. 7 The voltage u_C and current i_C evolution at the capacitor connection, for $u_{C0}=0.5U_{Cm}$

In these cases the connection is realised in the optimum moments, more precisely when $|u_{C0} - u|$ is minimum. In the first two cases, although the overvoltages are small, its appear overcurrents which could be limited through the modification of the inductance L_c value. The best situation is that shown in Fig.8 ($u_{C0}=+U_{Cm}$ and $t_{optim}=5$ ms, at 50 Hz) when disappear the overvoltages and overcurrents. The Fig.9 presents the voltage evolution on capacitor, for $u_{C0}=+U_{Cm}$, considering two different moments for connection, t_1 and t_2, one before and another after t_{optim}.

The maximum overvoltages, U_{Cmax}, in function of the connection moments, considering three values for the charging voltage on capacitor, u_{C0}, are presented in Fig.10. It consists the followings:

- for $u_{C0}=0$ exist two optimum moments for connection at 0 and 10 ms when the overvoltages are minimum. The overvoltages evolution in both half-periods is identical, the peek values of the maximum overvoltages are under 2 p.u. and can be reached if the connection is realised at approximate 4, respective 14 ms;
- in the case $u_{C0}=+0.5U_{Cm}$ exist also two optimum moments for connection which corresponds to the moments when the source voltage becomes equal

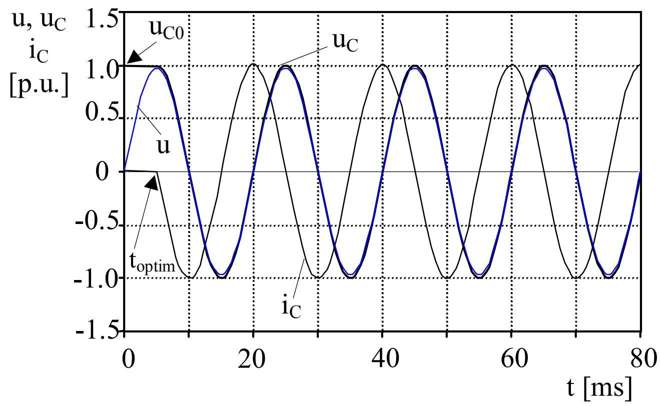

Fig. 8 The voltage u_C and current i_C evolution at the capacitor connection, for $u_{C0}=U_{Cm}$

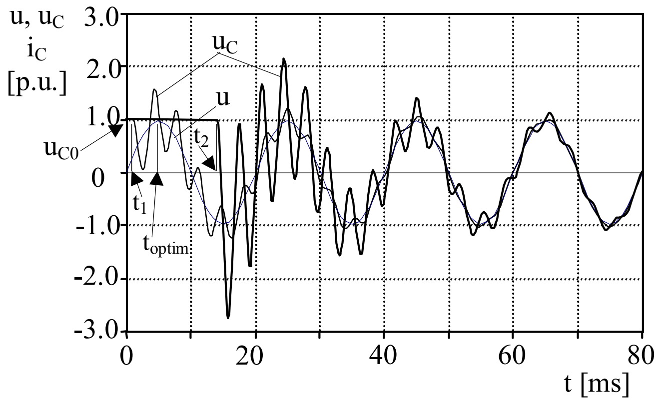

Fig. 9 The u_C voltage evolution on the capacitor at $u_{C0}=U_{Cm}$ and two different connection moments

with the charging voltage. In this situation, both moments are in the first half-period, on o side and other of the moment $t=5$ ms, because the charging voltage of the capacitor is positive. The overvoltages evolution in both half-periods is not identical in this case, the peek value of the maximum overvoltages is under 2.5 p.u. and it is obtained if the connection is realised at approximate 14 ms;

- in the situation $u_{C0}=+U_{Cm}$ exist a single optimum moment for connection, moment in which the difference between the charging voltage and the source voltage becomes minimum and corresponds to $t=5$ ms when the overvoltages are nulls . If the charging voltage of the capacitor would be $u_{C0}=-U_{Cm}$ then the optimum moment for connection of the capacitor would become $t=15$ ms. The peek value of the maximum overvoltages is between 2.5 and 3 p.u. and is obtained at approximate 14 ms.

From this analysis it can appreciates that for the overvoltages reduction is necessary to know the charging voltage of the capacitor required to establish the optimum moment for its connection.

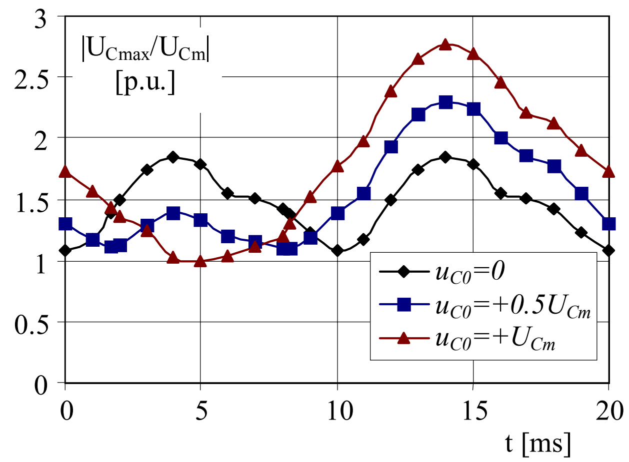

Fig. 10 Maximum overvoltages on capacitor in function of the charging voltage and the connection moment

4 Conclusions

The power semiconductor components (thyristors, GTO thyristors, IGBT transistors) have allowed to realise some shunt compensation schemes which eliminates some disadvantages of the classic compensators (high responding time, expensive maintenance, degree adjustment etc.). In practice are many types of shunt compensators controlled with thyristors like as: TCR, TSR, TSC, SVC, STATCOM.

SVC impedance depends on its structure elements (L, C, R, L_c), respective the ignition delay angle α of TCR thyristors. Thus, the increasing of the C capacity determinates the impedance's modification and also, the decreasing of the ignition angle at which appears the resonance and the increasing of the adjustment range in the behaviour capacitive zone of the SVC. The impedance can has inductive or capacitive nature in function of the ignition angle.

The connection operation of the capacitor must be realised very careful because can appear dangerous transient states (overvoltages, overcurrents). The connection overvoltages depends on the charging voltage of the capacitor and of the connection moment. For each charging voltage exist one or two optimum moments to realise the connection, situations in which the overvoltages are minimum. The biggest overvoltages can appears when the charging voltage is $\pm U_{Cm}$.

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