Control of a SVC for power factor correction

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***Abstract*—The question of voltage quality is rapidly increasing. New technologies are introduced and we are facing many new power quality requirements. Flexible alternating current transmission systems (FACTS) are modern devices in power transmission and grid stability. The paper deals with the modelling of a static var compensator (SVC). For this purpose Matlab/Simulink was used. SVC is designed for the implementation in a three-phase 22 kV power line model. Several simulations and tests have been performed in order to examine the function of the proposed control algorithm and SVC system as a whole.**

***Keywords*— FACTS, SVC, power factor, voltage quality.**

I. INTRODUCTION

At the present, with the increasing demand for the electrical energy and rapidly growing number of new production technologies, the voltage quality requirements are becoming stricter. In order to evaluate the level of the power quality, STN EN 50160 standard was introduced, which stipulates the limits for voltage quality [1].

A. *Voltage quality in power system*

The most severe power quality problems are voltage sags and interruption, harmonics and flickers and low power factor [2]. Failures due to such disturbances cause a huge impact on production cost. Especially, modern industrial equipment is more susceptible to power quality problems.

Reference [2] defines power quality problems as follows: computers or other electronics damage, lights dim and flickers, loss of synchronization of processing equipment, motors or other process equipment malfunctions, transformers and cables overheating, problems with power factor correction equipment, noise interference to telecommunication lines and many more.

Companies are often forced to save its facilities on their own. One of the options for power quality and system stability improvement is to introduce FACTS devices [3].

B. *FACTS controllers*

FACTS (*Flexible Alternating Current Transmission systems*) are alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability [4].

The major advantages of FACTS are [5]:

- power lines transmission capabilities improvement,
- power flow control,
- static and dynamic stability enhancement,
- secure interconnections between neighboring utilities.

The main disadvantage of using FACTS is a very high startup cost of these devices and economic requirements. FACTS controllers are able to control one or several key parameters in power transmission, such as current, voltage, active and reactive power, frequency or phase angle. Reference [5] divides FACTS into four basic types – series connected, shunt connected, combined series-series and combined series-shunt controllers.

The series controller can be a variable impedance, such as capacitor or reactor, or a power electronics based variable voltage source. In general, all series controllers inject *voltage* in series with line. They are able to compensate voltage sags or swells and eliminate harmonic distortion as well. These are static synchronous series controller (SSSC), thyristor-controlled series capacitor (TCSC) or dynamic voltage restorer (DVR).

As in the case of series controllers, the shunt controllers may be a variable impedance, variable source, or a combination of these. In principle, all shunt controllers inject *current* into the system at the point of connection. These are thyristor controlled reactor (TCR), static synchronous controller (STATCOM) or static var compensator (SVC).

Combined series-shunt controllers are the most flexible FACTS devices. They are able to regulate and affect many different parameters at the same time. One of these devices is unified power flow controller (UPFC).

II. POWER FACTOR CORRECTION

Electrical devices, such as transformers, motors or converters, need magnetizing power or current to work properly. This power is not transformed to heat but oscillates between the load and the source and it is called reactive power. The power factor (PF) cos φ is defined as a ratio between active power P and apparent power S as follows:

$$\cos \varphi = P/S \tag{1}$$

If cos φ = 1 it is named unity PF and no reactive power flows in the line. If reactive power is positive the PF is leading and, on the other hand, if reactive power is negative the PF is lagging. In general, it is required that the loads connected to the public networks should operate at PF close to unity. The value of 0.95 and leading PF is a minimum. Any deviations from this value mean additional fees for the customer. In order to remain the PF within permissible limits, some countermeasures must be adopted. This means power factor correction.

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Basically, there are two major types of PF correction - series and shunt compensation.

Series compensation is used due to voltage drops at the end of long power transmission lines. Simply, there are capacitor banks connected in series with the line. It raises the voltage at the end of the line and also short-circuit power is increased additionally [6].

Shunt compensation is done by a shunt-connected compensating device. The required reactive power is generated by a shunt-connected capacitor or inductor. Thus, no or just little reactive power is drawn from the main source. Fig. 1 shows the basic principle of PF correction using a shunt-connected compensating device K. It is brought to the main bus, from which the load M (motor) is fed. Both the main source and the compensating device K (Q_{com}) cover the load reactive power demand (Q) altogether. Generally, the reactive power drawn from the main source has been decreased and the low PF of the load is corrected.

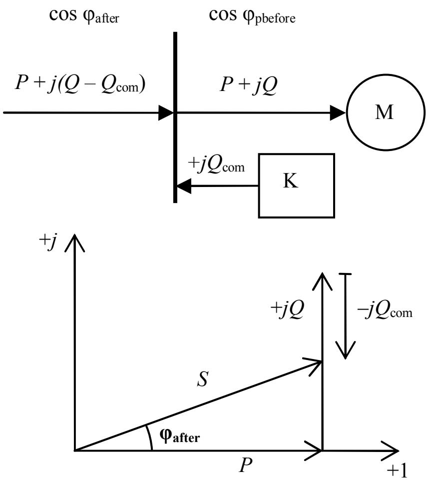

Fig. 1. Shunt power factor correction

III. STATIC VAR COMPENSATOR

Static var compensator belongs to shunt-connected FACTS controllers. The primary function of SVC is shunt power factor correction and reactive power compensation. SVC injects reactive current into the system at the point of connection. It supplies or consumes variable reactive power in order to control bus voltage and to maintain the desired power factor value [5].

A. *Thyristor controlled reactor*

The fundamental component of a SVC is a thyristor controlled reactor (TCR). TCR is thyristor controlled inductor, whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve [4]. It contains a thyristor valve and an inductor connected in series. The current within the coil can be continuously controlled by the thyristor firing angle α (Fig. 2). It is the time delay between supply voltage peak value and firing pulse when a thyristor is triggered on. When $\alpha = 0$, thyristor valve is switched on completely and the current reaches the highest value. When $\alpha = 90°$, thyristor valve is switched off and no current flows. According to this assumption, the inductive reactive current can be easily controlled by changing the value of α. σ is the conduction interval [5]. It is the time period when the thyristor is in the conductive state.

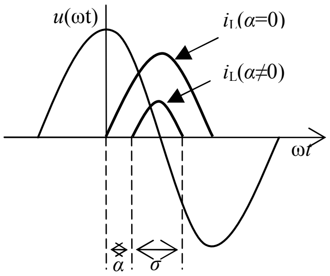

Fig. 2. Voltage and current time courses depending on firing angle α

B. *Single-phase SVC*

A single-phase SVC consists of shunt connected TCR branch and fixed capacitor (FC) (Fig. 3). In comparison, the reactive power of FC is a half of the maximum reactive power of TCR. Thus, the output SVC reactive power can be controlled in both directions – from maximum var power generation to maximum var power absorption. It means, both leading and lagging power factor can be corrected.

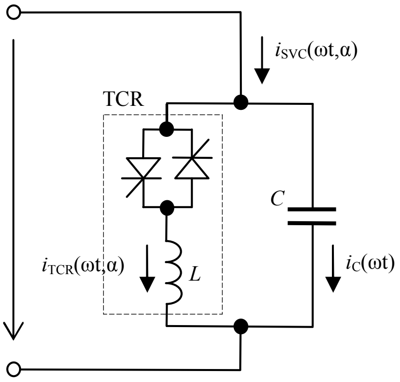

Fig. 3. Single-phase FC-TCR SVC

The proposed SVC model is based on three-phase FC-TCR delta-connected arrangement [7], [8]. SVC is designed to operate in such a way that reactive power can be controlled in each phase independently and automatically adaptable to the load conditions.

C. *Proposed control algorithm*

SVC model consists of three main parts: measuring unit, control unit and power unit (Fig. 4).

The measuring block provides measurements of actual instantaneous voltages and currents (u,i). These signals are inputs for control section and the measuring unit is considered as a major source of information about the system. The control executes several calculations described below in more detail. The deviations of measured and reference values of reactive power are computed dynamically and the manipulated variable is firing angle α. Thus, low power factor can be corrected in a real-time manner with just a little time delay. Power unit consists of three power circuits in delta-connection. Each single-phase branch contains a thyristor valve, capacitors and inductors (as it is in Fig. 3). The power unit is controlled by firing pulses generator (FPG) which generates firing pulses for the thyristors depending on the value of σ.

Fig. 4 shows principal block diagram of the proposed automatic control algorithm. There is a load connected at the end of the line and it consumes active power P and reactive power Q_L. The compensating power of SVC is Q_{SVC}. Variables P and Q are actual values of active and reactive power respectively, that are drawn from the grid.

In general, the control unit regulates the compensating reactive power of SVC (Q_{SVC}) automatically by three PID regulators and it contains five basic stages:

1. Firstly, the actual active P and reactive power Q in phases are calculated by means of instantaneous voltage u and current i values.
2. Secondly, a reference reactive power Q_{ref} is computed from a desired power factor cos φ_{ref} and actual active power P.
3. Q is compared with Q_{ref} and the error ΔQ continues to PID controller.
4. PID regulates the deviation between the actual reactive power and the desired value in order to reduce the difference to zero. It is done by alternating the firing angles α of the thyristors.
5. At last, a firing-pulses generator (FPG) is needed. This unit generates the switching pulses (SP) to trigger the thyristors on.

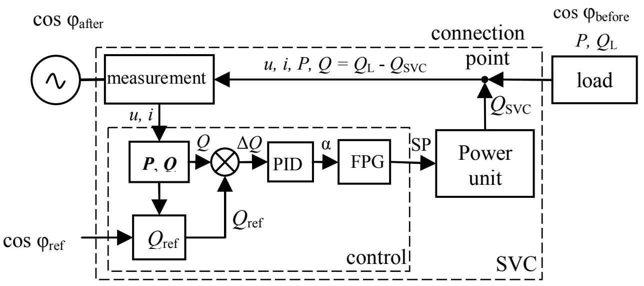

Fig. 4. Proposed control algorithm of SVC in Simulink

IV. SIMULATION MODEL IN SIMULINK

In order to check the correct function of the proposed control algorithm it was necessary to create a simulation model. For this purpose Matlab/Simulink was used.

A. SVC model

Fig. 5 depicts the proposed SVC simulation model in Simulink. There is a measuring block, control unit and power section. The function of control unit is presented above and it is constructed according to Fig. 4.

The power unit is represented by three identical single-phase FC-TCR branches in delta connection (Fig. 6). SVC is designed for a three-phase 22 kV power line model with nominal phase-to-phase voltage $U_n = 220$ V. The maximum three-phase reactive power of SVC ranges from – 150 var to + 150 var, single-phase reactive power is $Q_{1fSVC} = \pm 50$ var, coil inductance L = 1.54 H and capacitance C = 3.29 µF. Firing pulses are synchronized with the supply voltage.

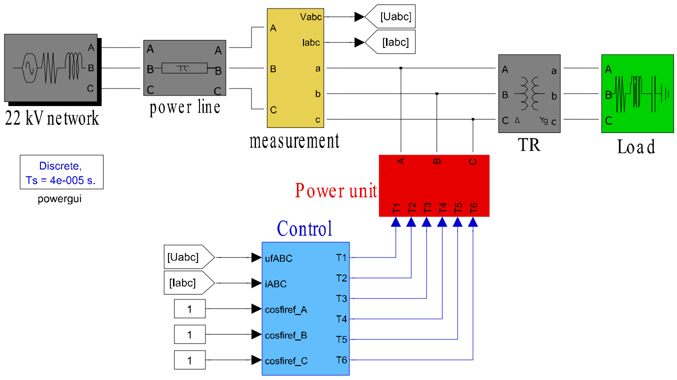

Fig. 5. SVC simulation model in Simulink

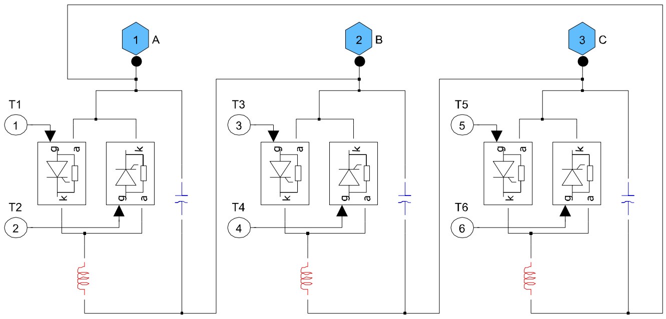

Fig. 6. Power unit in Simulink: three-phase delta connection of FC-TCRs

B. Results

The primary function of a SVC is to control reactive power of a load with a low power factor. Fig. 7 illustrates time course of three-phase active (P_L) and reactive (Q_L) power of a load and reactive power (Q_S) that is drawn from the source. SVC is set to compensate all the reactive power in every single phase (cos φ_{ref} = 1). It means, there should be only active power flowing from the source side.

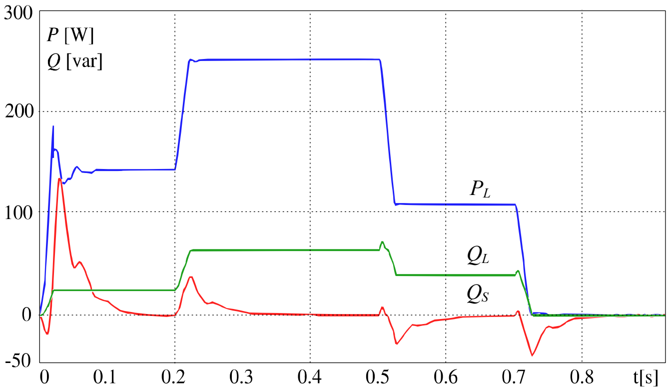

Fig. 7. Time course of SVC compensation

The simulation starts at the time of 0 s. A load (P_L = 145 W, Q_L = 25 var) is connected to the grid and SVC automatically starts to compensate reactive vars so that after a short instant (140 ms) the reactive power flowing from the source is none. The load is fed by SVC solely (only reactive power). At the time 0.2 s, the load parametres changed (P_L = 255 W, Q_L = 65 var) and the compensator regulated its compensating power in such a way that no reactive power is drawn from the grid. Again, the load changed at 0.5 s (P_L = 110 W, Q_L = 40 var) and SVC reacted correspondingly. At 0.7 s, the load was disconnected from the grid and the controller adjusted the compensating power Q_{SVC} to zero.

Fig. 8 illustrates another test. There is a compensation of power factor in each phase independently. In this case, the load is constant, but asymmetric: P_A = 90 W, Q_A = 40 var, P_B = 70 W, Q_B = 40 var, P_C = 65 W, Q_C = 45 var. At the start, reference power factors values were set to 0.95; 0.9 and 0.8. SVC managed to adjust its compensating power in such way, that power factors at the load side became desired. At 0.5 s reference PF were changed to be 0.9 and SVC reacted as well. Lastly, at 1 s reference PF changed again and PF were set to different new values (0.8; 0.85; 0.9).

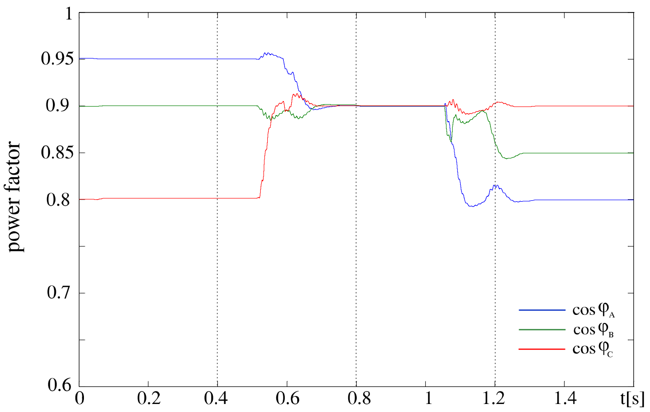

Fig. 8 Independent power factor correction in each phase at load side

As the simulation results showed, it is clear that the proposed SVC model and its control algorithm are designed correctly and the controller provides reliable and proper power factor correction in each phase automatically and independently.

From fig. 2 it is clear that the injected current, especially at higher firing angles, is strongly distorted. The analysis presented in reference [5] indicates that the strongest harmonic distortion of injected current of SVC is at the firing angle α = 25°. At this point, the corresponding compensating reactive power is generated. From the simulation tests it is given that the worst value of total harmonic distortion of SVC's current is THD_i = 130 % at α = 21°. However, the power circuit of SVC is in delta-connection arrangement and it means that the third harmonic and its multiples are eliminated and do not enter the grid. Therefore, total harmonic distortion of the currents in the power line is reduced rapidly THD_i < 5 % and thus the line voltages remain fairy intact.

V. CONCLUSION

To sum up, SVC belongs to shunt connected FACTS controllers. Its primary purpose is to compensate low power factor of loads, to control the reactive power and to improve voltage quality at the point of connection.

In this paper, the description of designing and modelling of a static var compensator is presented. The SVC model is designed for implementation in a three-phase 22 kV power line model. The proper function of the proposed control technique was verified by simulation calculation and tests in Simulink. The results proved the theoretical assumptions and the SVC system operates correctly. It is able to compensate a low power factor (both lagging and leading) in each phase independently and automatically within a very short time period (depending on the type of load and system conditions). In the future, the created model can be extended by various improvements and utilities and it can be used for demonstration of the basic operation principle of FACTS controllers, power factor correction or for science and educational purposes.

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