Study 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 modeling of a static var compensator (SVC). For this purpose Mat lab 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 standards was introduced, which stipulates the limits for voltage quality.

A. Quality of Voltage in Power Transmission System

Wind turbine, connected to often produce active power with significant fluctuations due to the wind speed variation, wind gradient. The output power variation causes the voltage fluctuations. Because of power quality requirement from utilities, theses voltage fluctuations or voltage flickers must be mitigated. Theses voltage fluctuations and flickers have adverse effect power system stability and consumers.

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

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.

B. FACTS Controllers A C Power System

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.

The advantages of F ACTS are:

- 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, and frequency or phase angle.

The series controller can be variable impedance, such as capacitor or reactor, or 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 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 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).

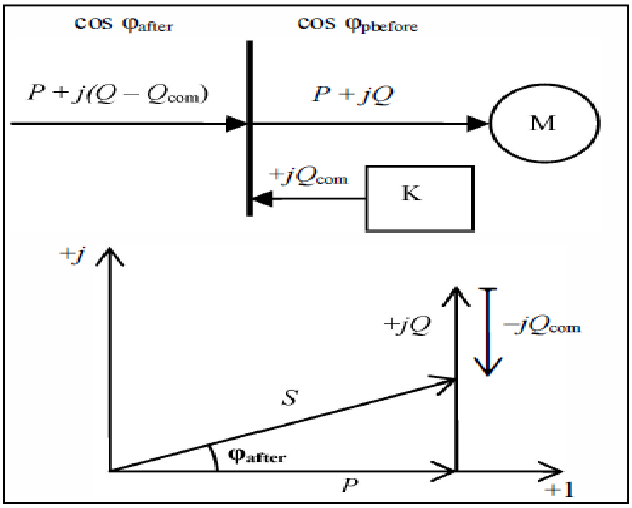
II. POWER FACTOR CORRECTION

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 <p is defined as a ratio between active power P and apparent power S as follows:

cos <p = PIS (I)

If cos <p = I 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.

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 is 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. I 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 (Qcom) 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.



III. STATIC VAR COMPENSATOR

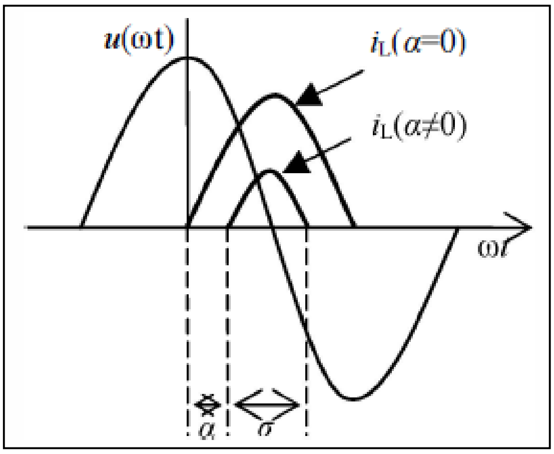
Static var compensator belongs to shunt-connected FACTS controllers. The primary function of SVC is shunt power factor correction and reactive power compensation. SVC injects reactive current into the system at the point of connection. It supplies or consumes variable reactive power in order to control 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 a (Fig. 2). It is the time delay between supply voltage peak value and firing pulse when a thyristor is triggered on.

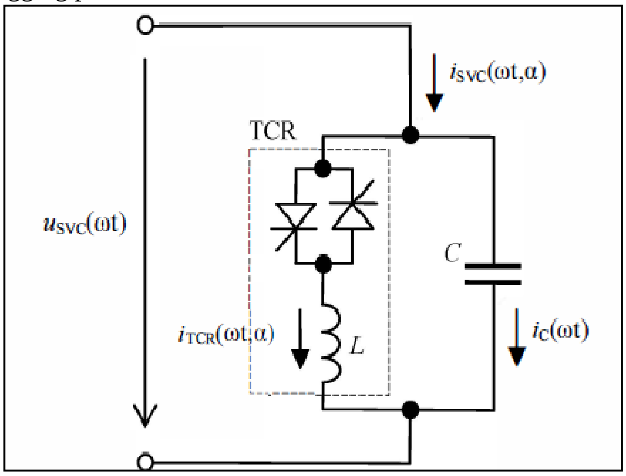
When a = 0, thyristor valve is switched on completely and the current reaches the highest value. When a = 90°, thyristor valve is switched off and no current flows.

According to this assumption, the inductive reactive current can be easily controlled by changing the value of a. G is the conduction interval [5]. It is the time period when the thyristor is in the conductive state.



B. *Single-phase SVC*

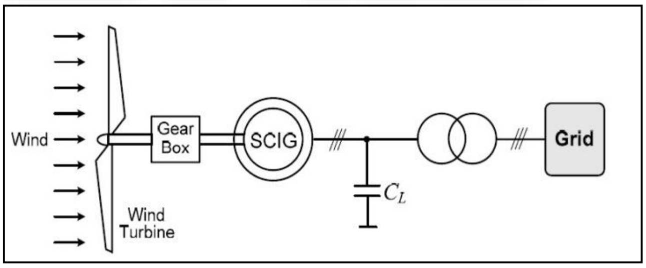
A single-phase SVC consists of shunt connected TCR branch and fixed capacitor (FC) (Fig. 3). In comparison, the reactive power of FC is a half of the maximum reactive power of TCR. Thus, the output SVC reactive power can be controlled in both directions - from maximum var power generation to maximum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



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.

1) *Wind Farm and Dynamic Modeling of Individual WTG*

Wind farm or Wind Park is a group of wind turbines in the same location used to produce the electricity. A large wind farm consists of several hundred individual wind turbines and covers an extended area of hundreds of squire mile. A wind farm can also be located offshore.



Configuration of fixed speed wind turbine generator

The typical configuration of an individual fixed speed wind turbine generator is shown in fig.. it consists of a squirrel cage induction generator driven by a wind turbine through a mechanical shaft system and operate at a certain wind speed. Gear box is used to connect the low speed wind turbine shaft to the high speed SCIG shaft. Compensating capacitors are generally added at the SCIG stator terminal to generate the magnetizing current for squirrel cage induction generator [3].

The mechanical power produced by a wind turbine is given by

$$P_w = \frac{1}{2}\rho A_r V_w^3 C_p(\lambda,\beta) \qquad (1)$$

Where ρ is the air density in kg/m^3, A_r is the blade impact area in m^3, V_w is the wind velocity in m/s and C_p is the power coefficient of the employed wind turbine [9]. The parameter C_p can be expressed by

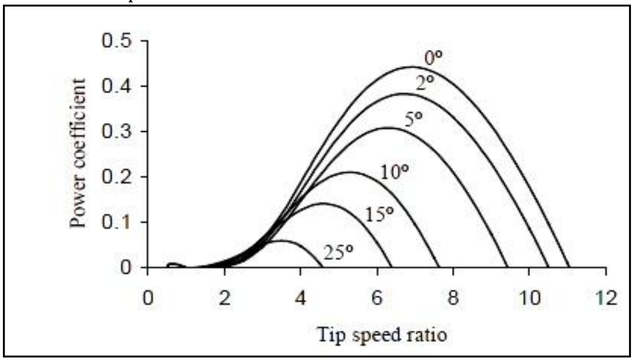
$$C_p(\psi_k,\beta) = \left[c_1\left(\frac{c_2}{\psi_k} - c_3\beta - c_4\beta^{c_5} - c_6\right)\right]\exp\left[-\frac{c_7}{\psi_k}\right] \quad (2)$$

Where

$$\frac{1}{\psi_k} = \frac{1}{\lambda + C_8\beta} - \frac{C_9}{\beta^3+1} \quad (3)$$

$$\lambda = \frac{R_b\,\omega_b}{V_w} \quad (4)$$

Where $c_1 - c_9$ are constants of power coefficient C_p, R_b is the blade radius in meter, ω_b is the blade angular velocity, λ is the tip speed ratio, β is blade pitch angle in degree. Fig shows the steady state characteristics of power coefficient C_p Vs tip speed ratio λ [2].



Steady state characteristics between C_p and λ for different pitch angle (β)

C. *Modeling of SVC*

The basic models attribute are reactive power range (capacitive and inductive) at one per unit high side bus voltage, slope, voltage set point, high side reactive power set point, and voltage dead band for reactive power control mode. The slope should be in per unit on the specified SVC base. The base model as per CIGRE report is given in Fig.

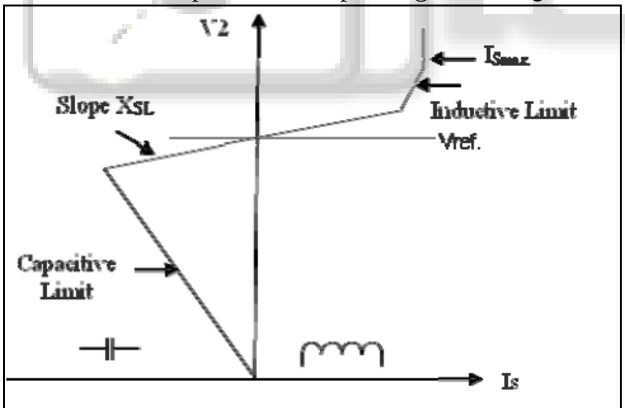
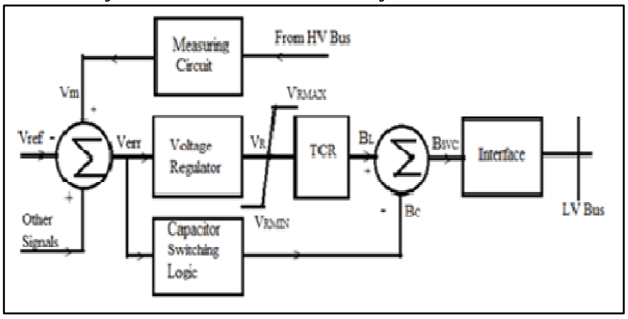


Fig.1. Steady State V-I Characteristic of SVC

General approach for modeling of SVC, by taking different blocks, first we consider measurement modules. It converts voltages and currents to DC control signal that is proportional to the amplitude of the positive sequence and the fundamental.

Thyristor block represents the variation of reactor susceptance as a function of firing angle. The thyristor controlled reactor can be modeled as shown in Fig.6, depending upon application with gain K4 and time delay signal T1. Considering rector rating double the size of fixed capacitor the variation is considered 0.0 p.u. to 2.0 p.u.

Main SVC combinations are, Thyristor Controlled Reactor (TCR) and Fixed Capacitor (FC) SVC, mechanical controlled switched reactor and capacitor SVC and Thyristor controlled reactor and Capacitor SVC. The voltage stability at the connected bus can be maintained by controlling the inductive or capacitive current output. TCR uses firing angle control to decrease/increased the inductive current. The reactive power compensation in electric power system achieved by SVC in the different ways.



D. *Case Study of Simulated Results*

The power system model which is used for investigation of system performance, when it is subjected to various disturbances, is shown in fig. 6. The system short circuit level is fixed at 1200 MVA with an X_1/R_1 ratio of 20. The mechanical input torque to the FSIG was set at 1 pu [5]. The parameters of lumped FSIG are given in table.

Rated power	60 MW
Rated voltage	11KV
Stator resistance	0.0108 pu
Rotor resistance	0.01214 pu
Stator leakage inductance	0.107 pu
Rotor leakage inductance	0.1407 pu
Mutual inductance	4.4 pu
Lumped inertia constant	3s

Table 1: Parameters of lumped FSIG model

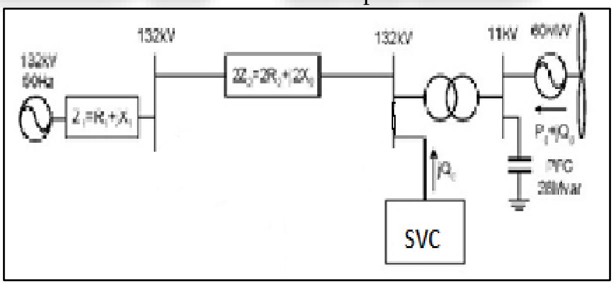
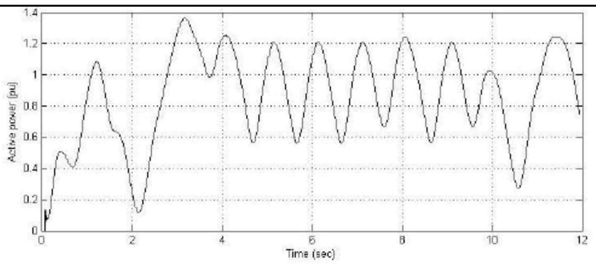


Fig. 6: schematic diagram of simulated system

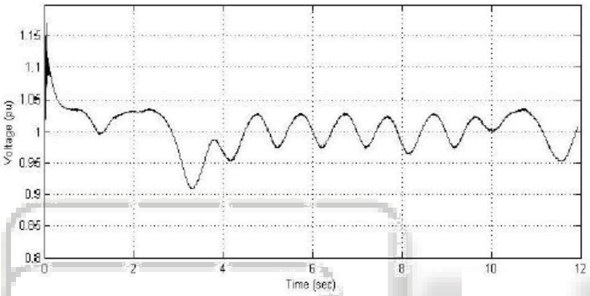
E. *Application to a Real Power System*

The application of an SVC based damping controller for a real power system is demonstrated in this section. For this study, a portion of a large power system was modeled by representing external power systems using static equivalent Models. The reduced power system has 59 buses, six Types 3 wind farms and 5 series compensated transmission lines.

The frequency of the SSI mode is 40.4Hz and its damping is 0.5%. Investigation of the observability and controllability of this mode revealed that the SSI mode is observable in the PCC transformer current and it is controllable through the SVC voltage reference. Therefore, an SSI damping controller was added to the SVC. With the SVC damping controller, the damping of the SSI mode improved to 3%. Figures show the response of the wind farm active power output with and without the SVC when an N-1 contingency occurs in the power system network. Figure shows the response of the same variables when a high impedance fault occurs during the N-1 contingency. Also, the SVC reactive power output, for the two disturbances are shown in the two figures. As shown in the figures the damping of the sub synchronous oscillation improves with the addition of the SVC.



ACTIVE POWER FLUCTUATION DUE TO WIND SPEED VARIATION



VOLTAGE FLUCTUATIONS DUE TO POWER FLUCTUATIONS (WITHOUT SVC)

System results with Static VAR compensator are shown in fig. . It is clear from characteristics the ac voltage after the fault clearance, recovers to higher value compared to system with PFC only, that results high post fault electric torque.

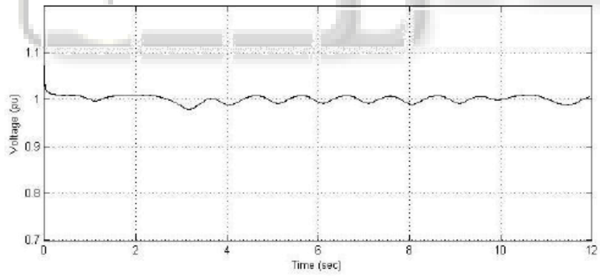


Fig. 8: Simulated results with PFC and SVC

IV. CONCLUSIONS

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 modeling 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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