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MULTI-CONTROL MODULE STATIC VAR COMPENSATION TECHNIQUES FOR ENHANCEMENT OF POWER SYSTEM QUALITY

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Abstract: Power quality is often defined as the electrical network's or the grid's capability to deliver a clean and stable power supply. Flexible AC transmission systems (FACTS) devices consist of power electronics circuits that's depend on the thyristor for controlling active and reactive power flows and to maintain the voltage within the allowable limits in normal and abnormal operating conditions. Static Var Compensation (SVC) is one of the most important FACTS devices, that's combined between shunt capacitor and shunt reactor, that's connect with the system by control setting. The control of reactive power by SVC module is depending on firing angle of thyristors. The shunt capacitor module can be called thyristor switched capacitors (TSC) and thyristor-controlled reactors (TCR), that's provide harmonic filters and/or dynamic shunt compensation. TSC operates with series bi-directional thyristor and a damping reactor to prevent the shunt resonance, the thyristors are used to control the capacitor to operate at the required value. TCR operates with series thyristor switch for control. SVC is easy and more accurate to operate with the medium voltage. SVC can be connected with the extra high voltage system via step-down transformer. This paper discusses the SVC to be uses to improve the power system quality, by adding the reactive power to the system. Also, this paper discusses the SVC control by using the MATLAB/Simulink software to discuss the step operation for the SVC with the power system.
Keywords: FACTS, SVC, Voltage Sag, MATLAB and Power Quality

1. INTRODUCTION

Power quality ideally creates a perfect power supply that is constantly available, has a pure noise-free sinusoidal wave shape, and is always within voltage and frequency tolerances. Power quality is extremely significant because of the impact it can have on the electric power industry. Whether it is for generation, transmission, distribution, or consumers, the quality of power plays an important role and can cost millions and millions if it is not transferred properly. In the past, if power was on, the customer was in business. Today, rather than merely a question of power being on, the proper question lies in whether the power delivered meets the right requirements. There are several openings for customers' complaints on the quality of power. The competitive electricity markets are generally more customer-oriented. High voltage substations have considered the most important task in the design of energy and a safe system of work. Which contain of the generator, transformers, circuit breakers, busbar and isolator switches. That can be transmit the power for high long distance depend on Over Head Transmission Line (OHTL). OHTL is a very important part in electrical system, which linked between the generation and the distribution for loads. So, it is possible to simulate faults along the OHTL which ranges from conduction that failure to loss of insulation [1] [2]. The stability of the power system is the accurate operation of the electric grid by recovering a state of operating balance after being subjected to an abnormal condition such as faults, line switching, load rejection, and loss of excitation [3]. Power system accuracy is saved when the entire system remains intact with no tripping of loads or generators, except for those isolated from the faulted elements, or by the intentional tripping of some elements to maintain the continuity of operation of the remaining part of the power system [4-5].

A Static Var Compensator (SVC) is a device which compensates for the reactive power of the load connected to a power system. Because of its fast response it can stabilize the busbar voltage even during fast changes of the load. An SVC is usually directly connected to a medium voltage power system. In the past, many SVCs were based on the effect of self-saturation of the iron core of a so-called saturated reactor. Since the end of the seventies, thyristor-controlled SVCs have been available on the market and for a few years one has been able to observe the development of new SVC technologies based on GTO or IGBT semiconductors [6]. The aim of this development is to improve dynamic performance, flicker control and speed of reactive power regulation as well as the reduction of losses which form a major part of the operating costs of such an installation. Figure (1) shows the SVC design and figure (2) shows the sample single line diagram for SVC module to be used with the power system.

SVC modules can be used to: Increase power transfer in long lines, improve stability (both steady-state and transient) with fast acting voltage regulation, damp power oscillations, control dynamic over-voltages and under-voltages and improve the power factor.

This paper explains the underlying principles of static var compensation to enhance the power system quality and gives an overview example simulation by using the MATLAB/Simulink software.

Figure 1. Static Var Compensation design (ABB-Ref.)

2. SVC OPERATION WITH THE POWER SYSTEM

— Reactive power compensation

Firstly, it's important to discuss the active and reactive power. Figure (3) shows Phasor diagram of active, reactive and apparent power. Where, the resistor *R* connected to a three-phase a.c. voltage source will see a current which is in phase with the voltage across this resistor. If an inductance *L* or a capacitance *C* is connected to the same source, the current will be 90° lagging or leading with respect to the voltage. Real power systems represent a combination of *R*, *L* and *C*, which means that voltage and current are usually not in phase [6-7]. The angle between voltage and current is called the phase angle ϕ.

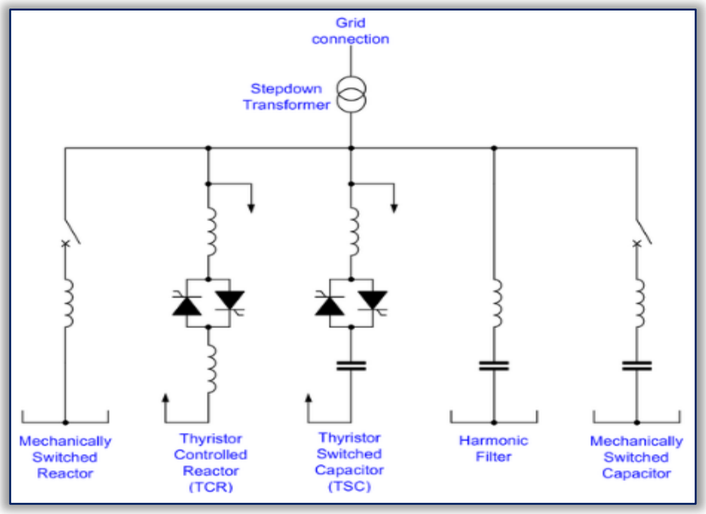

Figure 2. SVC design coupled with the power system

Apparent power *S* is the product of voltage (*U*) and current (*I*) and has the unit volt-ampere [VA].

$$S = \sqrt{3}\; UI \quad \text{[VA]} \tag{1}$$

Like voltage and current, apparent power can also be represented in a phasor diagram as a complex quantity. The real component of this phasor is called active power and the imaginary component is the reactive power. The cosine of the angle between active and apparent power is the power factor cosϕ.

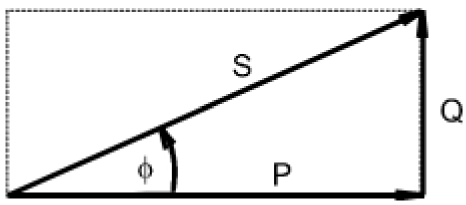

Figure 3. Phasor diagram of active, reactive and apparent power

Active power *P* is the product of the voltage and the in-phase (active) component of the current. The active power is measured in watts [W].

$$P = \sqrt{3}\, UI \cos\phi = S \cos\phi \quad \text{[W]} \tag{2}$$

Reactive power Q is the product of the voltage and the watt-less (reactive) component of the current. The unit of the reactive power is volt-ampere reactive [var]. According to IEC Publ. 27-1 the unit abbreviation 'var' should be written in lower-case letters, while all other power unit abbreviations are to be in capital letters [7].

$$Q = \sqrt{3}\, UI \sin\phi = S \sin\phi \quad \text{[var]} \tag{3}$$

Reactive power can be either positive or negative, depending on the sign of the phase angle ϕ. By definition, positive reactive power means power consumption and is characteristic for inductive loads such as power converters, reactances and motors. Negative reactive power indicates reactive power generation typical for generators or capacitor banks.

Reactive power compensation, SVCs usually generate the reactive power which is consumed by the load, meaning that positive reactive power of the load is compensated for by negative reactive power of the SVC. It is desired to reduce the remaining reactive power as far as possible in order to reduce the equipment ratings and energy transmission losses.

— Voltage control

Reactive power compensation is often the most effective approach to improve both voltage stability and power transfer capability. Basic means of voltage control are offered through generating units due to the fact that the automatic voltage regulators control field excitation to maintain voltage levels at the terminals of generators. This, however, does not completely control the voltage throughout the system; hence, additional devices have to be used to compensate reactive power [7]. One approach for compensating voltage drops in transmission networks is to add substations containing shunt capacitors along the line. The installation of shunt capacitor substations acts in such a way that it breaks the transmission line into shorter segments, with each substation responsible for providing a constant voltage along that segment. Switching the shunt capacitors in and out compensates the voltage along the transmission line [8]. These shunt capacitors have to mechanically be switched on and off; hence, there is usually difficulty when it comes to coordination. Due to this, other, more sophisticated methods of voltage regulation are necessary [6-9]. A load current passing through the series impedances *R+jX* of transmission lines, cables or transformers creates a voltage drop *ΔU* across this impedance, causing a voltage difference between the sending end and the receiving end of the transmission system. Without additional measures, the voltage at the receiving end is usually smaller than the voltage at the sending end. This voltage drop can be calculated approximately by applying the following equation:

$$\Delta U = U_s - U_r \approx RI\cos\Phi + XI\sin\Phi \tag{4}$$

From Eq. (4) it can be seen that any change in load current *I* will cause a change in busbar voltage. Very large cyclically varying loads, such as the SPS having a large reactive and active power swing and very short rise times of the pulse, will cause heavy disturbances of the 18 kV and 400 kV busbar voltages, making the operation of the accelerator impossible and disturbing other electrical loads connected to the power network [7].

Equation (4) also shows that the reactive power is an excellent means to control the voltage drop and therefore the busbar voltage. Modern SVCs are able to change their reactive power output within 100 ms, making them highly suitable for the voltage control of busbars feeding fast changing or pulsing loads such as electric arc furnaces, rolling mills or particle accelerators.

The system voltage Vk and the susceptance B_{SVC} is determined as shown in the following equation:

$$I_{SVC} = j\,B_{SVC}\,V_K \tag{5}$$

In the function for the step-down transformer the susceptance can to determine by the following equation [8-9]:

$$B_{SVC} = \frac{B_\sigma(B_{C1}+B_{C2}+\cdots\ldots\ldots+B_{Cn}+B_{TCR})}{(B_\sigma+B_C+B_{TCR})} \tag{6}$$

where B_σ corresponds to the susceptance of the transformer, B_{TCR} varies from 0 to B_L with firing angles changes and control from 180◦ to 90◦, B_L consider the susceptance of the reactor and B_C is the susceptance of capacitor bank [9-10]. Thus, expressions for the maximum and minimum susceptance are determined as shown below:

$$B_{SVC}^{Max} = \frac{B_\sigma(B_{C1}+B_{C2}+\cdots+B_{Cn})}{B_\sigma+B_{C1}+B_{c2}+\cdots+B_{Cn}} \tag{7}$$

$$B_{SVC}^{Min} = \frac{B_\sigma(B_{C1}+B_{C2}+\cdots+B_{Cn}+B_L)}{B_\sigma+B_{C1}+B_{c2}+\cdots+B_{Cn}+B_L} \tag{8}$$

The thresholds of reactive power that can be exchanged to the system are defined as shown below:

$$Q_{SVC}^{Max} = -V_{Max}^2 B_{SVC}^{Min} \tag{9}$$

$$Q_{SVC}^{Min} = -V_{Min}^2 B_{SVC}^{Max} \tag{10}$$

3. SIMULATION SVC FOR VOLTAGE REGULATOR

By using MATLAB/Simulink software, we can to simulate the SVC module with the power system. Figure (4) shows the SVC system, the SVC is set to Voltage regulation mode with a reference voltage Vref = 1.0 pu. The voltage droop reactance is 0.03 pu/200 MVA, so that the voltage varies from 0.97 pu to 1.015 pu when the SVC current goes from fully capacitive to fully inductive. Double-click the blue block to display the SVC V-I characteristic [11-13].

The Three-Phase Programmable Voltage Source is used to vary the system voltage and observe the SVC performance. Initially the source is generating its nominal voltage (500 kV). Then, voltage is successively decreased (0.97 pu at t = 0.1 s), increased (1.03 pu at t = 0.4 s) and finally returned to nominal voltage (1 pu at t = 0.7 s). Start the simulation and observe the SVC dynamic response to voltage steps on the Scope. Waveforms are reproduced on the figure (5). Where, Trace 1 shows the actual positive-sequence susceptance B1 and control signal output B of the voltage regulator. Trace 2 shows the actual system positive-sequence voltage V1 and output Vm of the SVC measurement system.

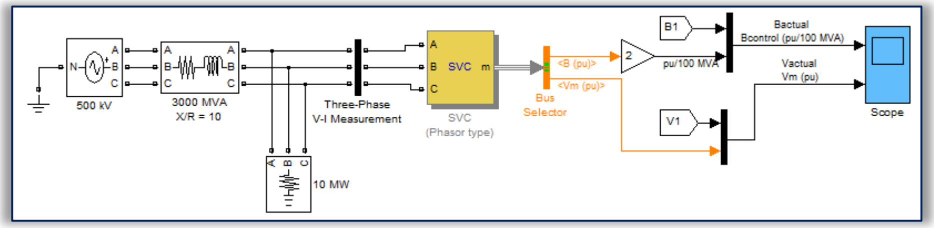

Figure 4. SVC module with the power system

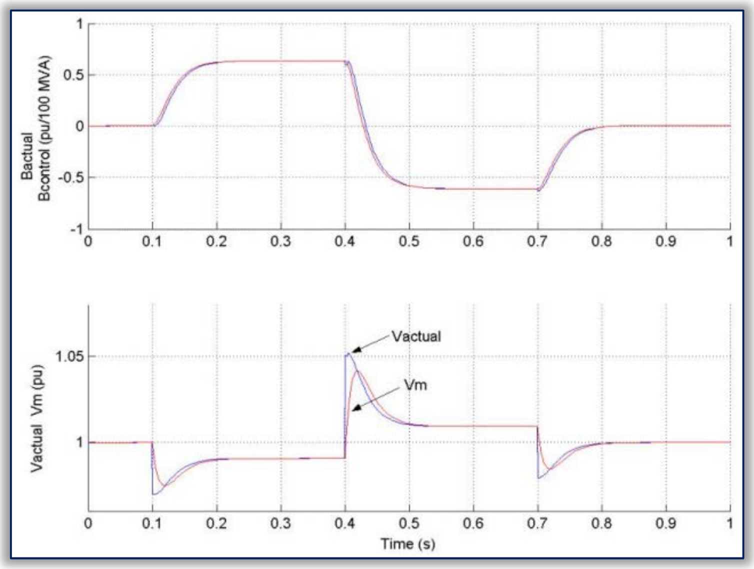

Figure 5. Results of the voltage after initiation the SVC system

The SVC response speed depends on the voltage regulator integral gain Ki (proportional gain Kp is set to zero), system strength (reactance Xn), and droop (reactance Xs) [12-13]. As mentioned above, neglecting the voltage measurement time constant Tm and the average time delay Td due to valve firing, the system can be approximated by a first-order system having a closed-loop time constant:

$$T_c = \frac{1}{X_c * (X_s + X_n)} \quad (12)$$

With given system parameters (Ki = 300; Xn = 0.0667 pu/200 MVA; Xs = 0.03 pu/200 MVA), the closed-loop time constant is Tc = 0.0345 s. If you increase the regulator gain or decrease the system strength, Tm and Td are no longer negligible, and you instead observe an oscillatory response and eventually instability. Figure (6) shows compares the SVC susceptance (B output of the voltage regulator) for two different short-circuit levels: 3000 VA and 600 MVA.

4. CONCLUSION

Modern power transmission networks are becoming increasingly stressed due to increasing demand and limitations on building new lines. Losing stability is a major threat of such a stressed system following a disturbance. This paper aims to improve the power quality and the issues facing the world today due to power quality and reliability problems by using the FACTS devices. This paper focuses on using a static VAR compensator to improve power quality issues. The SVC is part of the FACTS family and is capable of adequately controlling network conditions and improving the quality of power. The SVC consists of a group of shunt-connected capacitor and reactor banks with fast control action by means of thyristor switching. A SVC can be considered as a variable shunt reactance, which is adjusted in response to power system operative conditions in order to control specific parameters of the network. Overall, the effective performance of a SVC was demonstrated in this paper on the MATLAB/Simulink. Although the SVC is one of many FACTS devices that can be used to improve power system quality.

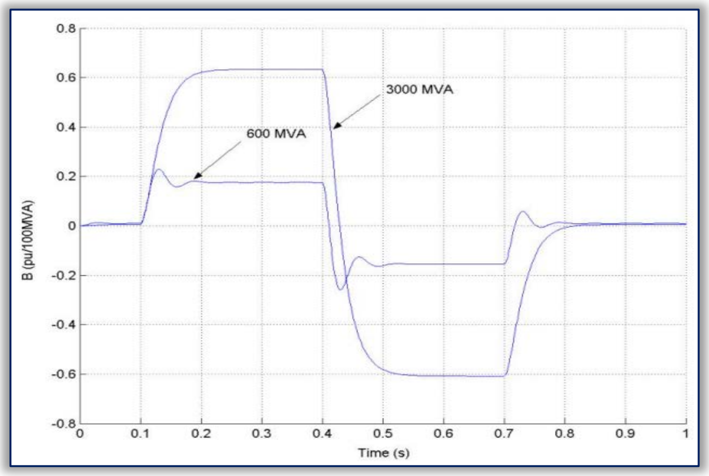

Figure 6. Compares the SVC susceptance (B output of the voltage regulator) for two different short-circuit levels: 3000 VA and 600 MVA

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