FACTS FOR VOLTAGE CONTROL AND POWER QUALITY IMPROVEMENT IN DISTRIBUTION GRIDS

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ABSTRACT

FACTS (Flexible AC Transmission Systems) and in particular SVC (Static Var Compensator) and STATCOM are devices suitable for voltage stability and power quality improvement in grids. They offer remedies to voltage drops and fluctuations, harmonic distortion, and unbalance between phases, caused for instance by wind generation, heavy industrial processes or high speed rail traffic.

The paper gives some salient design features of SVC and STATCOM and highlights three current cases of application in distribution systems.

INTRODUCTION

Modern society relies heavily upon electricity. Simultaneously, constraints on building new power lines are appearing as a consequence of increasing focus on environmental aspects as well as of growing scarcity of land available for the purpose. These tendencies constitute strong driving forces for more efficient use of existing facilities rather than building new as the need for transmission capacity in power systems increases, as well as for making power transmission more cost effective in a deregulated market.

Another tendency is increasing highlight on power quality. Flickering lamps are no longer accepted, nor are de-ratings in production processes due to insufficient power quality.

FACTS (Flexible AC Transmission Systems) and in particular SVC (Static Var Compensator) and STATCOM (Static Compensator) are devices highly suitable for voltage stability and power quality improvement in grids, without the need for building new transmission lines.

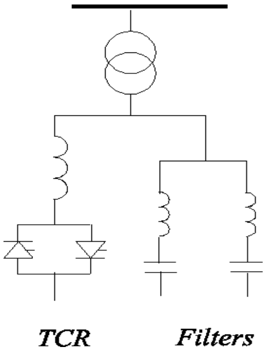

Fig. 1: SVC of TCR/FC configuration.

SVC: SOME BASICS

A common SVC design is based on Thyristor Controlled Reactors (TCR) and Harmonic Filters, as shown in Figure 1. The function of one phase of a TCR is shown in Fig. 2. A TCR consists of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fibre insulated, epoxy resin impregnated.

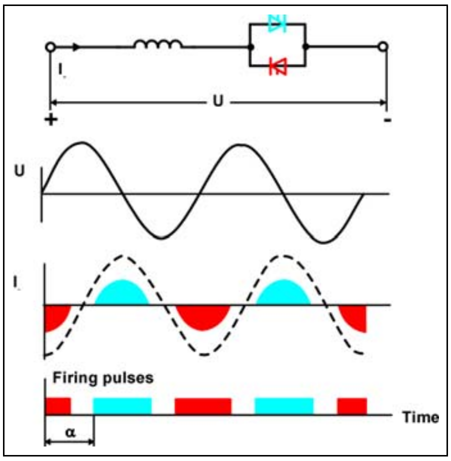

Fig. 2: Operating principle of TCR.

Thyristor valves

The thyristor valve consists of single-phase assemblies

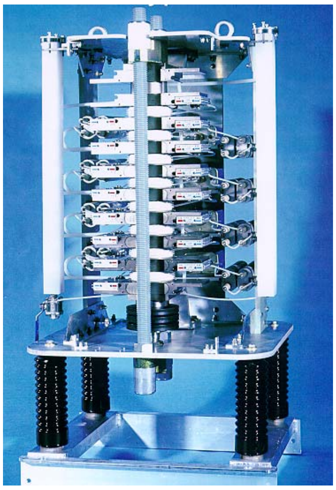

Fig. 3: Thyristor valve of BCT design.

(Figure 3). The thyristors are electrically fired. The energy for firing is taken from snubber circuits, also being part of the valve assembly. The order for firing the thyristors is communicated via optical light guides from the valve control unit located at ground potential.

In the most recent SVCs supplied, the thyristor valves are equipped with so-called Bi-Directional Control Thyristors (BCT). In such devices, two thyristors are actually integrated into one wafer with separate gate contacts.

The valves comprise only one thyristor stack in each phase instead of two, which of course enables considerable compacting of the valve design.

SVC FOR STABILITY IMPROVEMENT IN GRID WITH STRONG WIND POWER PENETRATION

The McCamey Area is a sparsely populated part of west Texas where the penetration of wind power has grown to 750 MW and is expected to grow to well over 1 GW in the next few years. This corresponds to some 80% wind power penetration. To improve and maintain system stability, four SVCs have been installed, each rated at -40/+50 Mvar and directly connected to grid nodes at 69 kV or 35 kV. The primary function of the devices is to provide reliable reactive power support to the wind farms under steady state conditions as well as transient disturbances in the network.

In the planning stage, two possible approaches to fulfill the dynamic var demand were investigated: either a number of distributed, small SVCs, or few, larger SVCs at selected key points in the grid. The latter option was chosen, for several reasons:

Few, larger SVCs cost less than many small SVCs.

Less total area demand.

Less total need for service and maintenance.

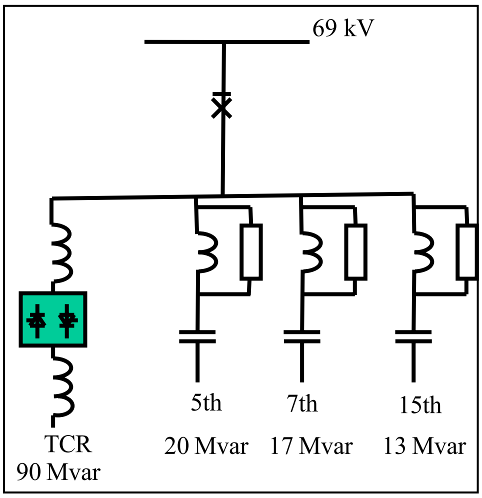

Fig. 4: Single-line diagram, 69 kV, -40/+50 Mvar SVC.

A key benefit in the project was that all four SVCs could be connected to the grid without any need for step-down transformers. This was true not only for 35 kV, but also for 69 kV (Figure 4).

In Figure 5, a site photo of one of the SVCs is displayed, the Crane 69 kV SVC.

Fig. 5: Crane 69 kV, -40/+50 Mvar SVC, Texas.

STATCOM

STATCOM, or SVC Light, makes use of a power electronic voltage source (VSC). The converter utilises semiconductors having turn-off capability. The converter can inject or consume reactive power to/from the bus where it is connected. This alternative has the benefits of a smaller footprint as the big air-cored inductors are not used. Another advantage stems from the fact that a smaller parallel capacitor bank can be used as the converter itself may contribute reactive power.

The function of a VSC is a fully controllable voltage source matching the system voltage in phase and frequency, and with an amplitude which can be continuously and rapidly controlled, so as to be used as the tool for reactive power control (Figure 6).

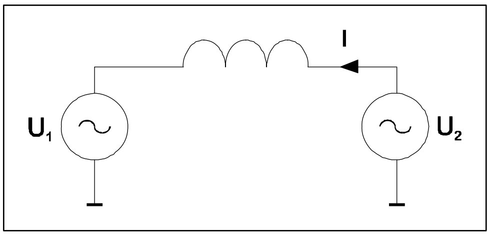

Fig. 6: VSC: a controllable voltage source.

In the system, the VSC is connected to the system bus via a small reactor. With the VSC voltage and the bus voltage denoted U_2 and U_1 respectively, it can be shown that the output of the VSC can be expressed as follows:

$$P = \frac{U_1 U_2}{X} \sin\delta \tag{1}$$

$$Q = \frac{U_1 U_2}{X} \cos\delta - \frac{U_1^2}{X} \tag{2}$$

P: Active power of the VSC
Q: Reactive power of the VSC
U_1: Bus voltage
U_2: VSC voltage
δ: Phase difference between the voltages
X: Reactance of the coupling reactor.

From equations (1) and (2) it can be seen that by choosing zero phase-shift between the bus voltage and the VSC voltage ($\delta = 0$), the VSC will act as a purely reactive element. (In reality, a small phase shift is allowed, in order to make up for the VSC losses.) It is further seen that if U_2 › U_1, the VSC will act as a generator of reactive power, i.e. it will have a capacitive character. If U_2 ‹ U_1, the VSC will act as an absorber of reactive power, i.e. it will have an inductive character.

Converter valve

A VSC of three-level configuration is built as in Figure 7.

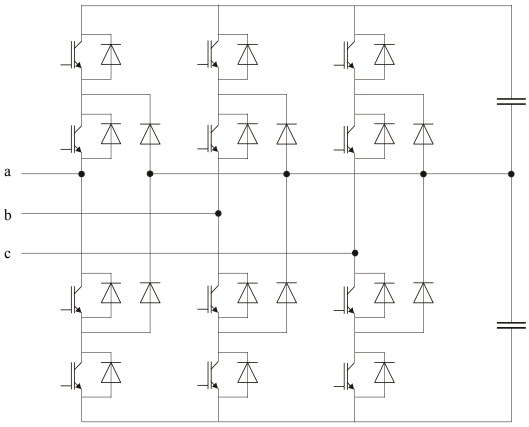

Fig. 7: 3-level VSC configuration.

One side of the VSC is connected to a capacitor bank, which acts as a DC voltage source. The converter produces a variable AC voltage at its output by connecting the positive pole, the neutral, or the negative pole of the capacitor bank directly to any of the converter outputs.

By use of Pulse Width Modulation (PWM), an AC voltage of nearly sinusoidal shape can be produced without any need for harmonic filtering. This contributes to the compactness of the design, as well as robustness from a harmonic interaction point of view.

In the converter, there are four IGBT (Insulated Gate Bipolar Transistor) valves and two diode valves in each phase leg. The valves are built up by stacked devices with interposing coolers and an external pressure applied to each stack (Figure 8).

STATCOM FOR GRID VOLTAGE CONTROL

A utility plans to decommission an old oil- and gas-fired power plant near downtown Austin, Texas. The power plant was constructed in the 1960s. In addition to providing the generation capacity, an important reason the plant has been kept in operation is to stabilize the voltage on the transmission system. Retirement of the power plant without a reliable dynamic reactive source would have a negative impact on the transmission system voltage stability.

Fig. 8: SVC Light® valve assembly.

An initial study showed that the needs could be met using a compact STATCOM [1]. A STATCOM is particularly suited for supplying full compensating current at very low AC network voltages and has the ability to compensate for unbalances. The STATCOM design features also include minimum footprint and effective electro-magnetic screening, both of which were required in this application.

The STATCOM consists of a VSC inherently symmetrically rated at +/- 95 MVA as well as 15 Mvar of harmonic filters as seen from the 138 kV bus. In total this gives an operating range from 80 Mvar inductive reactive power to 110 Mvar capacitive reactive power. There are also three 138 kV mechanically switched capacitor banks (MSC) each rated at 31 Mvar for providing steady-state reactive power

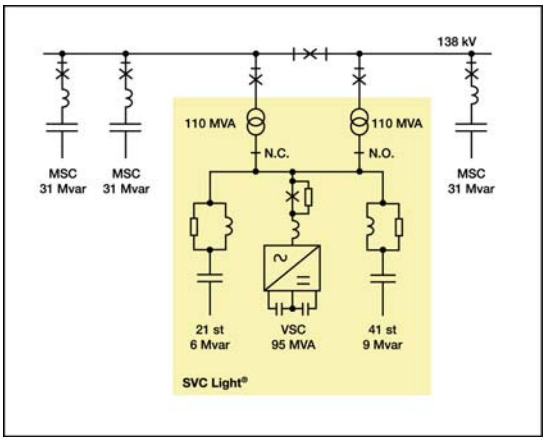

Fig. 9: Single-line diagram, STATCOM plus MSC.

support to the grid. Including the three 138 kV MSC, the reactive power range is 80 Mvar inductive to just above 200 Mvar capacitive. The dynamic portion of this is two times the VSC rating of 95 Mvar, or 190 Mvar.
Figure 9 shows a simplified single line diagram of the STATCOM (including the dual redundant step-down transformers and the three 138 kV MSC).
The entire installation can be seen in the site photo of Figure 10.

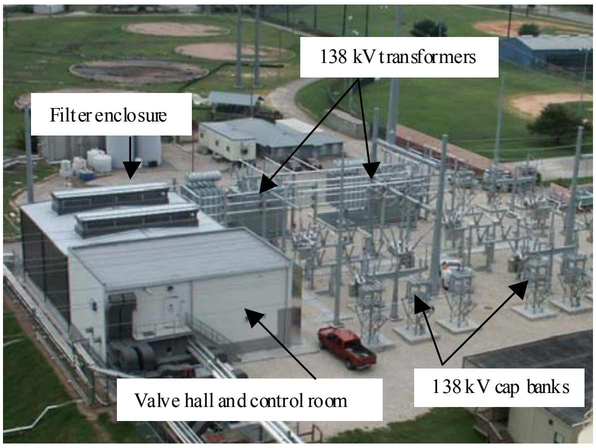

Fig. 10: Site view, STATCOM and MSC.

STATCOM FOR RAIL LOAD BALANCING

Evron is a substation in the French high-speed rail system fed from the national power grid. An SVC Light is utilized for dynamic balancing of asymmetry between phases caused by the mode of traction feeding, single-phase takeoff of power from a three-phase grid. The SVC Light also performs the task of active filtering of harmonics generated by thyristor and diode locomotives. Active filtering is enabled due to the high dynamic response inherent in the SVC Light concept.
The reason for installing the SVC Light was to enable the fulfilling of the National Grid Code concerning voltage fluctuations, phase unbalance and harmonic distortion at the point of connection to the grid of the traction feeder. The option to the SVC Light was building a new transmission line, to increase the fault level of the power grid. In feasibility studies performed before the project, it was demonstrated that the SVC Light approach was less costly as well as less time consuming than building new transmission lines. Not having to build new lines was also very attractive from an environmental as well as concessional point of view [2].
The load balancer is rated at 90 kV, 16 MVA. Its configuration is shown in Figure 11. It is rated to accommodate a single-phase active load size of ≤ 17 MW. Its task is to confine the grid unbalance at 90 kV as follows:
≤ 1% for $S_{SC} \geq$ 600 MVA (normal network conditions);
≤ 1.5% for 300 MVA ≤ $S_{SC} \leq$ 600 MVA (abnormal (N-1) network conditions).

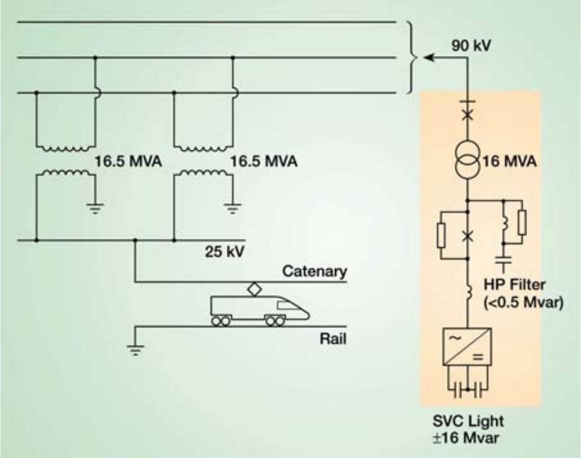

Fig. 11: Single-line diagram of the Evron 90 kV Load Balancer.

Unbalance improvement

Measurements performed since the installation of the SVC Light have shown a distinct improvement of voltage unbalance, Figure 12 [3]. With the SVC Light in operation, the voltage unbalance does not exceed 1%.

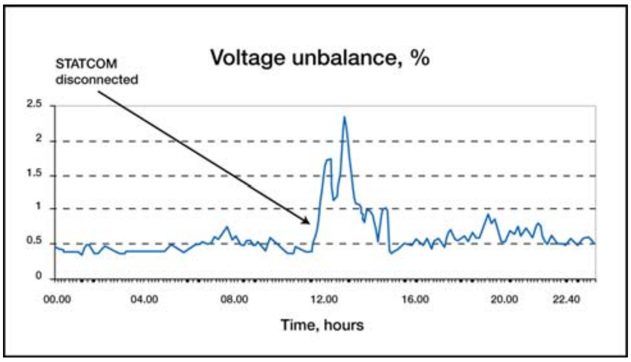

Fig. 12: Measurement of voltage unbalance.

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