

JPE 1-2-1

STATCOM Helps to Guarantee a Stable System

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ABSTRACT

Transmission System Operators are governed by operational security standards that are applied in real time. During system disturbances, the System Operators must rely on the installed protection and control equipment, prior to human intervention. New power electronic solutions bring rapid and repeatable responses to disturbances, which will help System Operators to guarantee a stable system. Last year, ALSTOM completed the world's first competitively bid STATCOM to support the voltage on National Grid's 400kV network that supplies London and the Southeast from the north of the UK. It is rated $\pm 75\text{MVAR}$ and forms part of a Static Var System (SVS) with a total rating of 0 to 225MVAR. This paper will describe the reasons for its size, location, its chain-link configuration and give examples of its operating performance. The paper will also describe the features that allow this STATCOM to deliver much more than reactive compensation in support of a wider transmission service objective, as system conditions require.

Key Words : AC System, Chain Circuit Convertor, FACTS, GTO, STATCOM, SVC, Voltage-Sourced Convertors

1. Introduction

Static VAR compensators (SVC) are used extensively to control the AC voltage in transmission networks. Modern power electronic based equipment, such as thyristor controlled reactors (TCR) and thyristor switched capacitors (TSC) have gained a significant market, primarily because of their fast speed of response, low maintenance requirements and low cost. With the advent of high power gate turn-off (GTO) thyristors^[1], a new generation of power electronic equipment is born, and is poised to take a share of this markets.

2. History of STATCOM

2.1 History of Static VAR Compensators

Early power systems depended on generators to set and control voltage. As systems grew, remote points had the voltage boosted by local generators or, removing the prime mover, by synchronous compensators. In the early 1960s the first static (i.e. non-rotating) solution appeared in the saturated reactor, which used the saturation of an iron core to absorb reactive power in a proportionate response to voltage. In the late 1970s the thyristor introduced the phase control of reactive current, still widely used today.

The uptake of these devices at first was to compensate for the flicker produced by arc furnaces and rolling mills. Later the value to a transmission system of regulated voltage provided by a static device was widely applied and there are over 1,000 SVCs in use today.

2.2 Benefits of Static VAR Compensators

Static VAR Compensators (SVC) provide a variable and dynamic source of reactive power, which has a number of generic benefits to Transmission System Operators:

Paper JPE 01-27 presented at the 2001 International Conference on Power Electronics, Seoul, October 15~19, 2001.

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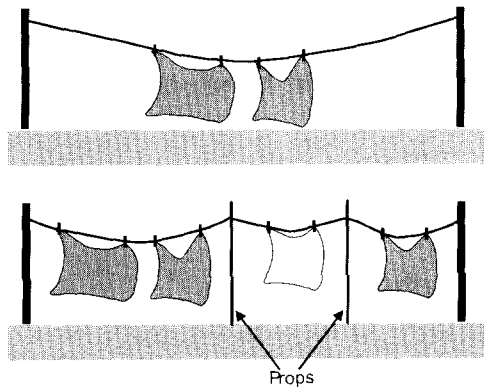


Fig. 1. Voltage Props of Transmission Line are Analogous to a Washing Line

1. Regulates the voltage profile in weak transmission systems almost instantaneously.
2. Reduces the incidence of blackouts and brownouts, and allows greater flexibility in network operation, allowing higher power flows.
3. Improves the steady-state and dynamic performance of transmission networks, regulates power factor, reduces losses and maximizes the capability of existing transmission facilities.
4. Assists in the post-fault recovery of a transmission system.

In summary a SVC or STATCOM, whilst operating within its controlled range, provides a prop of regulated voltage along a transmission line (Fig. 1). Stability limit calculations are given a new starting point at each point of regulated voltage and therefore stable capacity can be greatly increased. This is at the core of the justification for such a device.

In addition, the SVC (or STATCOM) control system can be designed to provide the following functionality:

5. Power Oscillation Damping - modulation of the SVC output based on the AC system characteristics.
6. Maintaining three equal phase voltages in spite of differences in load currents or impedances between phases.

2.3 Characteristics of SVC and STATCOM

The SVC performance is defined by a linear voltage/current characteristic. The characteristic passes through a given voltage (reference or target voltage) at

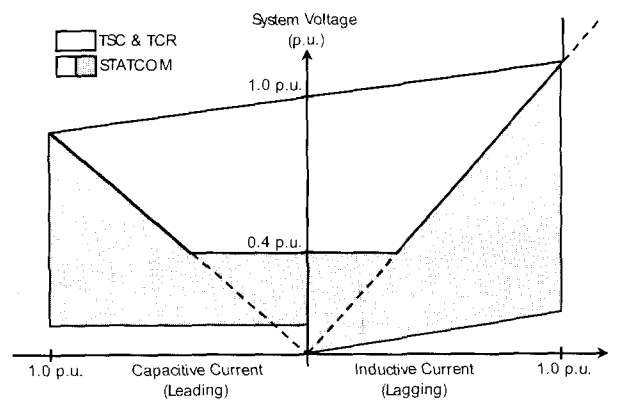


Fig. 2. Comparison of SVC Characteristics

zero output and the line has a slope which is defined as the percentage voltage change between two defined currents, normally zero and the design output current. Both the reference voltage and the slope can be varied over a given range.

A comparison between the steady state characteristics of a conventional SVC (using a TCR and TSC) and a STATCOM is shown in Fig. 2. A conventional SVC varies its MVar output by the appropriate switching of fixed impedances. At the limits of its range, the maximum leading or lagging current varies in proportion to the system voltage. A minimum voltage threshold affects the TSC valve characteristic and surge arrester design criteria, and a typical value of approximately 0.4 p.u. is shown.

In contrast, owing to its principle of operation, a STATCOM can still maintain its rated leading (or lagging) current, even if the voltage becomes very low, acting essentially as a constant current device. A STATCOM is thus able to generate more MVar at reduced levels of busbar voltages than would the equivalent fixed susceptance device, which is a significant improvement in performance.

3. Basic Design and Implementation of the STATCOM GTO Convertors

In its simplest form a STATCOM consists of a DC capacitor and a GTO convertor connected to the AC system via an inductive impedance. The dual control feature of the GTO, by which current can be turned on and turned off, allows an AC waveform to be developed from

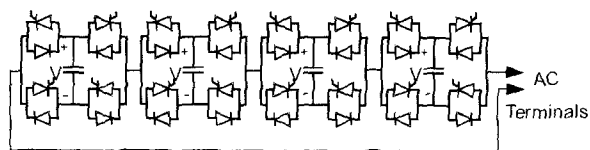


Fig. 3. Single-Phase Four-Link Chain Circuit

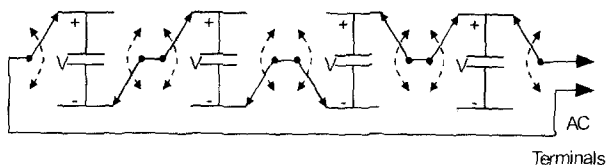


Fig. 4. Switch Analogy of a 4 Link Chain Converter

the DC capacitor voltage. When the converter voltage is greater than the AC system voltage a capacitive current is drawn from the system. Conversely when the converter voltage is lower than the AC system voltage an inductive current is drawn.

In reality a single converter and capacitor would never be used since the AC waveform produced would be far from sinusoidal and totally unacceptable for connection to the AC transmission network. Instead, a multi-level converter circuit with distributed capacitance is used by ALSTOM to produce a high quality pseudo-sine wave output. This multi-level topology is known as the "Chain Link Circuit" where a number of identical converter-capacitor modules are referred to as links. Fig. 3 shows the arrangement of a single phase, four link chain converter.

The STATCOM uses three chain link converters connected in delta to form a three phase converter.

Each link in a converter chain can independently switch its capacitor voltage into the ac circuit in the positive or negative direction or alternatively the capacitor can be bypassed. The output voltage of the converter will therefore be the sum of the tri-state (+/-/0) voltages for all links in the chain circuit. This is demonstrated by a simple switch analogy in Fig. 4.

Converter control action alternates the switching status of each link in real time to construct the desired output waveform. A typical output from a four link circuit is shown in Fig. 5.

The design of each link in the STATCOM convertor consists of a single-phase, voltage-source convertor bridge using four GTOs, freewheel diodes and a DC capacitor. Fig. 6. shows the power circuit of a single link.

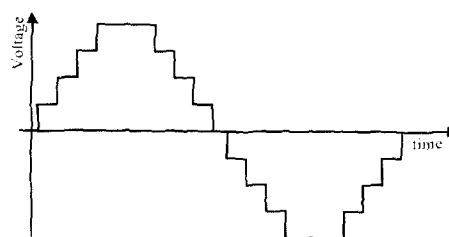


Fig. 5. Stepped Voltage Waveform for 4 Link Chain

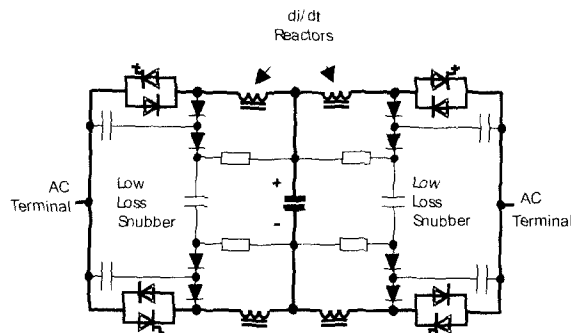


Fig. 6. Single Link Power Circuit

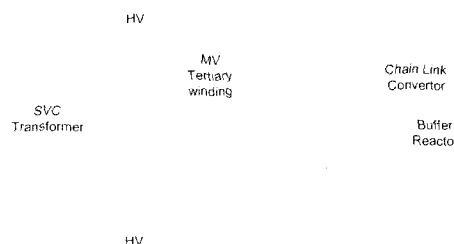


Fig. 7. STATCOM Circuit

The total number of series links in a STATCOM chain is determined by the nominal AC voltage and the acceptable level of harmonics in the output waveform. Typically two more links than necessary are included in the chain circuit to provide an element of redundancy in case of component failure.

The STATCOM circuit is completed by including a small buffer reactance in series with each converter chain to give the circuit shown in Fig. 7.

4. Chain Link Converter Construction

The physical arrangement of the power electronic equipment for each link has been carefully engineered to deliver a compact modular unit that is still adequately

accessible for maintenance. The core assembly of the STATCOM convertor is a module shown in Fig. 8 which constitutes half of one chain link without the DC capacitor.

Complete link units are assembled from the basic module with the DC capacitors separately mounted on top. Figs. 9 and 10 show one link assembly and a complete chain of 16 converter links respectively.

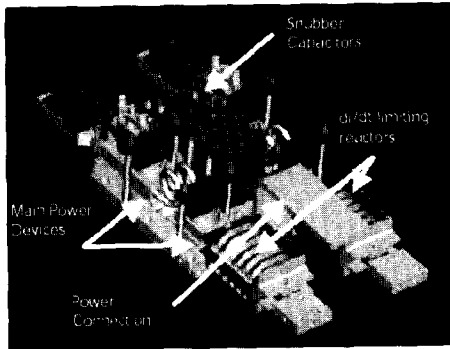


Fig. 8. Half-link converter module

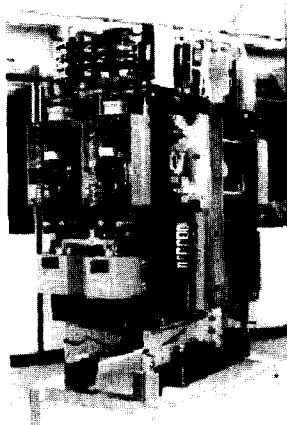


Fig. 9. One STATCOM Link



Fig. 10. A Single Phase Chain Link Converter – 16 Links

5. STATCOM for National Grid Company, UK

To give a specific example, The National Grid Company (NGC) required additional relocatable reactive compensation for its southern UK transmission system. Its first location is the East Claydon 400kV Substation located to the northwest of London.

NGC specified an SVC with a smoothly variable output range of 0-225MVar (capacitive only, no inductive range was needed). In response to system voltage changes, the SVC was required to change its output over any part of the range within 100ms. In addition, the installation was to have a 40-year lifetime and a six month relocation period [3].

The single line diagram of the TSC/STATCOM is shown in Fig. 11.

The whole 225MVar capacitive output of the SVC could have been generated using only a STATCOM. However, this would have the disadvantage that the STATCOM would have a total dynamic rating of 450MVar (i.e. $\pm 225\text{MVar}$) and the inductive range and rating would be unused.

Following detailed consideration of different designs, a STATCOM with a total dynamic range of 150MVar (i.e. $\pm 75\text{MVar}$) was chosen, combined with a small, permanently connected shunt filter bank. This would ensure that the STATCOM operates at a low current in the float region 0-30MVar which is the normal quiescent mode, and correspondingly incur a low energy loss.

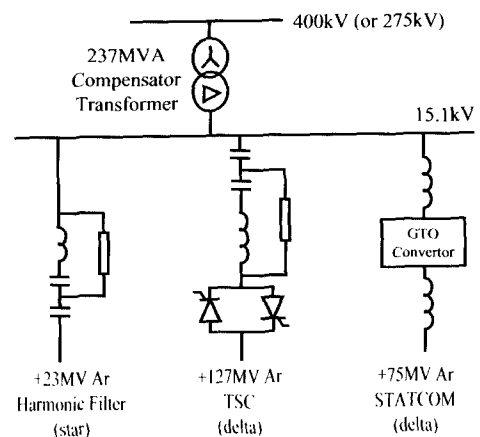


Fig. 11. East Claydon TSC/STATCOM Single Line Diagram

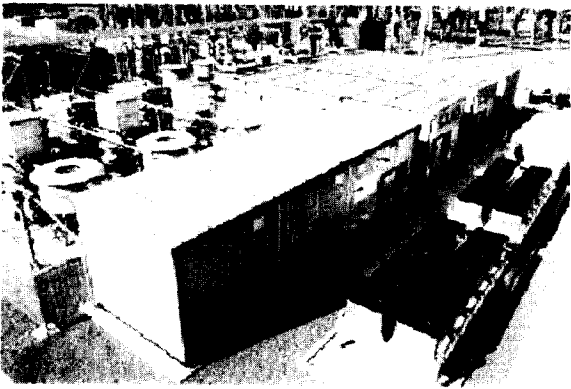


Fig. 12. East Claydon TSC/STATCOM SVC

A TSC was selected to provide the additional SVC capacitive output when more than about 100MVar is required. To avoid discontinuity in the characteristics or any tendency for the controls to hunt near to the TSC switching point, the TSC rating is less than the dynamic range of the STATCOM. When the TSC is switched off, the SVC has an available inductive range, which can be used to reduce temporary system overvoltages following system disturbances.

The total site area for the SVC equipment is 35m x 40m, that is 15,000sq.ft. Twice this area would have been required by a conventional SVC. Transportable cabins accommodate the indoor-type equipment and all other equipment is designed for straightforward mounting and connection. Metal frames group items together for ease of transport.

Fig. 12 shows a view of the STATCOM equipment on site. The far three cabins each contain a single phase chain link converter.

6. STATCOM Operating Capabilities

This section describes the features of a STATCOM, including for other examples those that deliver much more than reactive compensation in support of a total transmission service objective.

6.1 Reactive Power & Voltage Support

The STATCOM's characteristic is similar to that of a generator or synchronous compensator, generating a voltage that is in synchronism with the system voltage. When this generated voltage differs from the system

voltage, a leading or lagging reactive current flows between the system and the compensator via buffer reactors and the transformer. Inherently, a STATCOM has approximately equal capacitive and inductive rating capabilities. The voltage generated by a STATCOM can be changed by a large amount even within half a cycle and it can therefore respond extremely rapidly to changing supply system conditions.

The STATCOM is capable of maintaining its rated current output at low ac system voltages, giving more reactive power when it's really needed. This capability is not impedance related and offers a solution to the concern that a transmission system is brittle when its loading approaches the limit. The brittleness arises where the whole voltage support of a system derives from shunt capacitors (whether breaker or thyristor switched) whose output MVar is proportional to voltage squared. As voltage drops, MVar output drops accordingly, leaving the system liable to voltage collapse. Generator excitations respond positively but slowly in such conditions though they may be distant from the affected area. A STATCOM reacts not only faster but also to a greater extent without being reliant on fixed impedances. Being relocatable, it can be moved if a new critical area appears.

6.2 Single Phase Operation

Chain link convertors are essentially single phase, which offers the potential for AC system phase balancing.

In the example, the following voltage control philosophy is applied. Each phase of the STATCOM is controlled separately and is therefore capable of independent voltage control to match the prevailing system conditions.

In normal operation, when the negative phase sequence (nps) voltage of the system is below a pre-set value (which may be adjusted in the range 0-10%), each phase of the STATCOM receives the same current order. However, when the nps limit is exceeded the individual current orders diverge in order to oppose the system nps voltage.

Fig. 13 shows a simulated example of a distant system fault between phase A and earth. As the transformer secondary winding is connected in delta, phase AB of the STATCOM generates a leading current in response to the fault, while the other two phases provide a lagging current output.

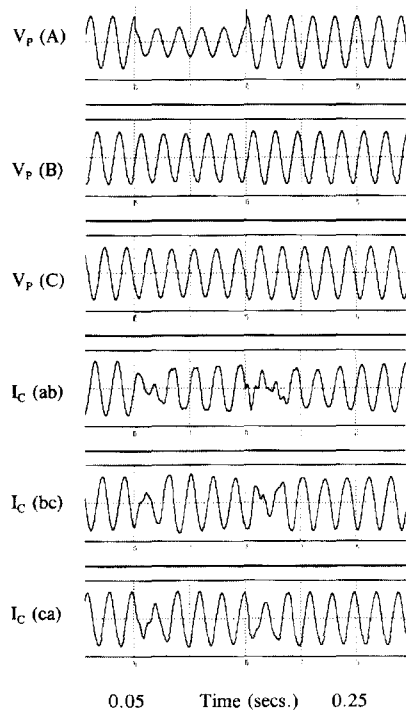


Fig. 13. STATCOM Response to a Single Phase-to-Earth System Fault

6.3 Dynamic Filtering

As explained above (Fig. 4 and 5), the chain-link STATCOM generates a sine-wave by the controlled timing of each GTO switching. The timing is adjusted to counter the self-generated harmonic voltage arising in each phase. A 16-link chain can counter harmonics below the 13th harmonic. This ability can be extended in principle to create an active filter.

6.4 System Damping

By varying the busbar voltage in a controlled manner, assistance can be provided to damp power swings during transients and disturbances in the power system. Though every situation requires specific study and application, such assistance is another example of the versatility of the SVC and the STATCOM.

7. Conclusion

The STATCOM is the latest in a line of static equipment available to a transmission or distribution power system to regulate voltage. Like each of its predecessors, the STATCOM adds some new elements to

the vital service of ensuring stability and reliability in a power system.

At its most basic function, the STATCOM brings a quicker and a greater contribution in reactive power provision than do alternative means. The STATCOM can also provide phase balancing. By assembling it in movable cabins, relocation to a critical area is straightforward as the demand on a power system changes.

The STATCOM is harmonically self-compensating, allows operation to a low AC system voltage and is considerably more compact than a conventional SVC.

Acknowledgment

The authors acknowledge the permission granted by The National Grid Company plc to publish information contained herein.

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Dr. Bjarne Andersen was educated at the Technical University of Denmark, and obtained a MSc in electrical power engineering and a PhD in High Voltage Technique before joining what is now ALSTOM T&D Power Electronic Systems Ltd (PES) as a development engineering in 1977.

Apart from two periods in other parts of ALSTOM (then GEC), where he worked on Surge Arresters and Instrument Transformers, he spent the rest of his career working at various engineering levels within ALSTOM on HVDC, SVC and FACTS systems. He is currently the Technologies Director with responsibility for Research and Technical Auditing.

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