

The best of both – Combining STATCOM with conventional thyristor based Static Var Compensator technology

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Abstract – For the purpose of dynamic voltage support static synchronous compensators (STATCOM) or Static Var Compensators (SVC) are available in the market. So far both technologies have been used separately depending on the respective electric requirements and project needs. In most cases the use of a STATCOM's superior undervoltage performance was limited to projects where a (almost) symmetrical operating range was required. This paper describes a new solution, where both multilevel STATCOM and conventional thyristor based SVC technology are combined into a Hybrid SVC with unsymmetrical MVar output to take advantage of both technologies' capabilities. Topics of System Design, Control and Protection and Operating Principle are covered to provide an overview of the solution's benefits and possible applications.

I. INTRODUCTION

For many years, STATCOM technology was used in special applications, often funded for R&D purposes. Most of these applications covered only small MVar ranges, with significant loss profile and represented a huge source of harmonics due to the two- or three-level switching pattern. For approximately five years now, the multilevel STATCOM technology has been available in the market and has been proven to be state-of-the-art with many installations of different sizes and applications.

With a significantly better undervoltage performance, a faster response time, significantly less equipment and consequently smaller footprint and most importantly no need for filtering harmonics, several factors seem now to favor STATCOM technology over conventional thyristor based Static Var Compensators.

But even though both, STATCOM and conventional thyristor based Static Var Compensators, serve similar or even same purposes such as voltage regulation and dynamic voltage support, STATCOM has so far not widely substituted conventional SVCs for several reasons. Operating ranges of STATCOMs are by nature symmetrical, and for large rating

applications the investment for a conventional SVC is potentially more economic – especially when it comes to operating ranges exceeding several hundred MVar.

Selection of technology for a compensation project is driven by several factors such as but not limited to design points, required undervoltage performance, existing network conditions, loss evaluation and operating scheme. Most often the electric requirements and site conditions are complex and require a specific solution.

Combining both technologies, STATCOM and conventional thyristor based SVC, was a logical and consequential natural progression.

The STATCOM with its symmetrical output is used as the main converter which can then be extended by thyristor switched capacitor branches and / or thyristor controlled reactor branches combining the electric advantages of the STATCOM with the flexibility of unsymmetrical and large scale operating ranges – creating a new kind of compensation solution: The Hybrid SVC.

II. SYSTEM DESIGN

A self-commutated Static Var Compensator also known as Static synchronous compensator (STATCOM) is a regulating device controlling the alternating current.

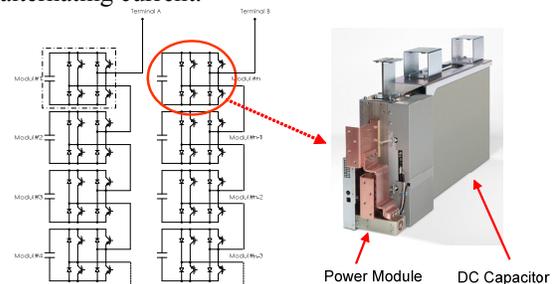


Figure 1: Siemens solution of multilevel configuration of a STATCOM (SVC PLUS®)

For years STATCOMs were based on two- and three-level switching patterns, whereas the state-of-the-art technology is nowadays the multilevel configuration.

In Figure 1 the Siemens solution for a multilevel STATCOM is shown. The heart of the converter is the H-bridge installation of a DC capacitor with four connected IGBT and anti-parallel freewheeling diodes. The power electronic with associated control electronic and auxiliary supply is assembled inside the power module which forms together with the DC-capacitor one powermodule unit. Each powermodule can be connected in series with a dedicated number of similar powermodules. The number of connected powermodules depends on the required reactive power output. The IGBT will be switched in a controlled manner to achieve $+u_{DC}$, $-u_{DC}$ or $0V$ on the powermodule terminals. The sum of all individual powermodule output voltages forms the terminal voltages u_{out} (Figure 2) and drives the reactive current output. The size of the reactive power output is controlled via the amplitude of the converter voltage u_{out} . The change of reactive current can be achieved on each time instant of the sinusoidal current waveform (self-commutated). This capability provides a significant advantage over an SVC based on thyristor technology. The switching state of the thyristor can only be changed after zero crossing of the current and produce an additional time delay in the response time of the compensation, while an immediate voltage change of the STATCOM is possible.

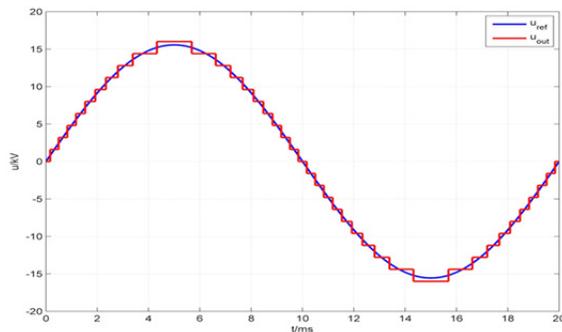


Figure 2: Output voltage of a multilevel converter and reference voltage

The STATCOM is connected via a transformer to the HV grid. On the medium voltage side of the transformer, the most simplistic configuration consists of the converter itself and a coupling reactor connected in series.

The maximum steady state current output of the converter depends on the capability of the installed power electronic switches, thereby the current (leading or lagging) is irrelevant. Therefore, the STATCOM will always have a symmetrical output range.

The current output is independent of the voltage level on the high voltage side of the transformer. This

behavior results in an identical operating range as a conventional SVC based on thyristor technology.

However, the reactive power output differences between STATCOM and conventional SVC become apparent during network contingencies, when the voltage on the connection point decreases. The task for the installed SVC is to provide capacitive current to support the network voltage. In this case the reactive power output of a thyristor based SVC will decrease with the square of the connected voltage. Contrary to the SVC, the reactive power output of the STATCOM decreases only linearly to the network voltage. Due to this difference, the network voltages in the nodes with STATCOM technology will be higher in case of a contingency compared to those nodes using conventional thyristor based SVCs. Simulations show also a faster voltage recovery for STATCOM technologies after fault clearing for the whole network. All in all the STATCOM is superior during such undervoltage events.

The usage of a nearly sinusoidal voltage source for generating the reactive current has also benefits in terms of harmonic connection criteria to the grid. Using a thyristor based SVC or a three-level STATCOM the specified criteria can only be achieved by implementation of one additional or more capacitive filter branches. In case the thyristor based SVC is used for Negative Phase Sequence control, additional 3rd harmonic filters have to be installed as well. These branches are not necessary with a multilevel converter. This will lead to:

- less possible resonances with the network,
- smaller space requirements on site,
- less complex design of the installation, and
- lower losses especially at 0 Mvar output of the STATCOM.

The specified Mvar operating range for an SVC application is very often unsymmetrical. In such scenarios, using a STATCOM with its symmetrical output would lead to unnecessary overdesign in one Mvar output direction. Obviously the solution would be more costly and could not provide the same return on investment unless the additional operating range has a positive value-add.

An obvious and commonly used solution is to combine a SVC or a STATCOM with mechanically switched devices such as shunt capacitor banks or shunt reactors. Although such external devices are relatively simple and fairly economic, they come with some disadvantages which have to be taken into consideration. These are the obvious discharge time of mechanically switched capacitor (MSC) banks of several minutes before re-energization and the overall limited number of switching cycles of a circuit-breaker reducing the overall flexibility of the

installation. By means of measuring the actual TSC DC capacitor voltage and coordinated switching in at zero crossing of each thyristor valve voltage the TSC can be switched in without any discharge time.

Mechanically switched reactors (MSR) increase the inductive operating range, and they can be switched on and off without any delay (other than the circuit-breaker), however they do create a DC offset to the system voltage imposing risk of saturation of CTs or transformers contrary to thyristor switched reactor branches.

The solution of combining the benefits of the multi-level STATCOM and providing an unsymmetrical operating range in a highly economic and flexible manner is depicted in the simplified single line diagram of Figure 3. A STATCOM branch is connected in parallel to a Thyristor Switched Capacitor (TSC) on the same MV busbar.

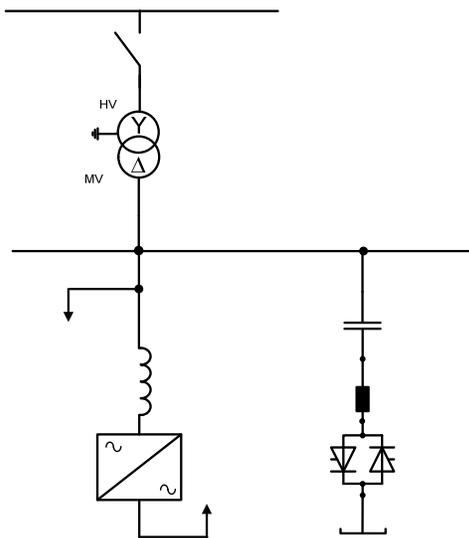


Figure 3: Simplified single line of STATCOM with parallel connected thyristor switched capacitor (TSC)

Figure 4 shows the corresponding Voltage / Current characteristic of the described Hybrid SVC solution from Figure 3 at the point of common coupling. The control will regulate the output current according to the control parameters and the corresponding voltage on the HV side. If the required capacitive output current is higher than the STATCOM rating, the TSC will be switched in and the output of the STATCOM will be set in such a way, that the reactive output is identical to the previous output before switching.

Additionally a hatched area is marked in Figure 4, which shows the increased output capability of the Hybrid solution from Figure 3 in comparison to a solution only based on thyristor technology.

Especially at voltages below 0.8pu on the HV side the combination of a STATCOM with TSC provides higher reactive power output and a significant better support for the network during contingencies.

Considering high and even further increasing costs of energy the evaluation of generated losses of a Static Var Compensator is getting more and more important and can have a decisive impact on the installed configuration. The nominal operating zone of such kind of devices will be at or nearby 0 Mvar during normal operating conditions. With this strategy the maximum Mvar output for under- and overvoltage contingencies is available. The minimum active power losses at 0 Mvar define the economically optimized design of a Static Var Compensator.

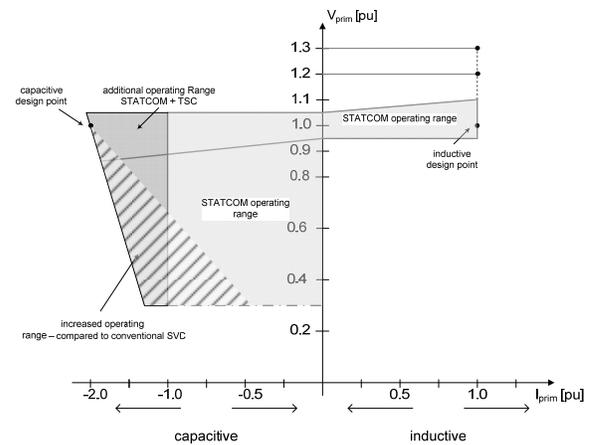


Figure 4: Voltage / Current characteristic of Hybrid SVC (STATCOM with TSC)

The STATCOM technology also with integrated thyristor switched branches will achieve this goal. Since the Hybrid SVC does not need filters, no load losses are significantly lower than those of a conventional SVC, where filters have to be actively compensated to achieve a zero MVar output.

III. CONTROL AND PROTECTION

The STATCOM / Hybrid SVC control and protection system consists of the following devices:

- Control system
- Protection system
- DFR (Digital Fault Recorder)
- Decentralized Input/Output- units
- Cooling control

The STATCOM control system design can be divided into open loop control (OLC), closed loop control (CLC) and protection functions. Siemens uses the

SIMATIC WinCC system as the HMI system which provides operation, monitoring, operator guidance, SER (Sequence of Event Recording), event analysis and trend plots to control and to analyze the STATCOM and TSC/TSR system. All three functionalities, CLC, OLC and protection, are realized in one master control system (SIMATIC TDC, Technology & Drive Control) allowing for a complete integration of both technologies within the Hybrid SVC.

The main task of the closed loop control is the fast voltage control (step response time $\leq 30\text{ms}$) of the measured high voltage busbar voltage. To achieve this, the voltage controller sends the derived current reference signal to the converter control (PLUSCONTROL) system, which is responsible for control and supervision of the powermodules of the STATCOM.

Each SVC PLUS powermodule is connected via two fiber optic cables to the converter control system. One fiber optic cable is needed for monitoring of the capacitor voltage and the status of the 4 IGBTs of each powermodule. The second fiber optic cable is needed for switching the IGBTs on and off, by electrical pulses.

Additionally the CLC also sends electrical firing pulses to the Valve Base Electronics converting it to optical pulses which are then sent to the light triggered thyristor modules. For monitoring of thyristor condition, one fiber optic for each thyristor acts as feedback fiber optic.

In case a TSC/TSR is switched in or out, the CLC controls the STATCOM in a manner that the switching will happen with a minimized voltage bump.

The open loop control regulates, interlocks and supervises all switchyard devices and handles the complete sequence of event recording which includes all installed equipment inside of the control room (e.g. auxiliary supply, HVAC), valve room (e.g. cooling system) and yard (e.g. transformer). The OLC is also responsible for the time synchronization of the whole control and protection system by use of GPS signal.

Additionally the OLC handles all sequences of the Hybrid SVC, as for example, the start and auto reclosure sequence of the STATCOM. The OLC also communicates with the cooling system and handles the SER created in the cooling system control.

The overvoltage protection of the STATCOM and TSC/TSR is also programmed inside the master control system. For converter protection the actual converter current is supervised inside the converter control system, in case of over current the SVC PLUS and TSC/TSR are tripped immediately.

As a decentralized unit for SER and DFR functionality several Input/Output-units are used. Most of the external interfaces are connected to these

units which perform the time stamping for SER and forward the incoming data stream (digital or analog) to the DFR system by means of fiber optics. This system is very compact and is taking over multiple tasks.

For the protection of the Hybrid SVC, e.g. transformer differential, busbar and feeder protection, conventional protection relays are used.

The STATCOM system is operated in a delta configuration, ungrounded in order to limit any hazardous currents in the power parts of the STATCOM system. In case of a faulty STATCOM or TSC/TSR branch, the Hybrid SVC will be switched off, the relevant branch will be isolated and the Hybrid SVC will be switched back online automatically. The system operation can be continued in a degraded mode, whether with the STATCOM only or the TSC in step control.

IV. OPERATION PRINCIPLE

If the demand of reactive capacitive power is rising (e.g. due to undervoltage), the STATCOM is operated up to its converter current limit. Breaching this limit, the TSC will be switched in, instantaneously the STATCOM is set to inductive output to compensate the TSC reactive injection to guarantee an operation with minimized voltage bumps. Afterwards the STATCOM continues with the linear operation, to achieve the required HV voltage.

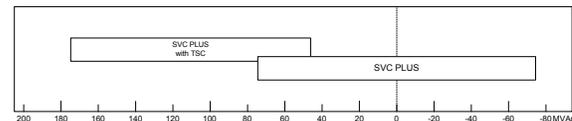


Figure 5: Exemplary operation range of hybrid system

The step response of the hybrid system is $\leq 30\text{ms}$, according to IEEE 1031-2000, with a maximum overshoot of 5%. This step response time is less than the step response of a conventional SVC.

The amount of switched branches like TSC or TSR connected to a STATCOM in a Hybrid SVC is theoretically unlimited. There are already concepts realized with up to 4 switched branches.

V. COOLING SYSTEM

Both STATCOM and TSC/TSR need a liquid cooling system (deionized water/glycol) to lower the temperatures of the semiconductors.

As both systems are installed in the same valve room, only one cooling system is necessary for the cooling

of IGBT and thyristor valve. For maintenance of TSC/TSR or STATCOM, the related cooling circuit of IGBT or thyristor valve can be by-passed, the electrical system can be operated in degraded mode.

VI. INTEGRATION OF TECHNOLOGIES

To allow flexible and efficient design of a Hybrid SVC, it is necessary to split the installation into modules that can be standardized. This leads to a unique design based on few variations that allows the use of similar components keeping the costs of the total installation low. Flexibility is not limited by such standardization.

The SVC PLUS (STATCOM) converters extendable to fully dynamic Hybrid SVCs (with TSC/TSR) are sized between ± 75 to ± 125 MVar and multiples of it.

The standardization of the symmetrical SVC PLUS converters into discrete power ranges fixes the voltage on LV-side of the transformer. To connect TSC/TSR branches, the connecting voltage of the additional branch must follow to the standard value of the SVC PLUS. The branch is therefore determined by the requested reactive power. The branch components can be designed for this maximum thyristor current to achieve a common design over all discrete SVC PLUS power ranges.

All other components needed for a TSC are the same as those of a conventional SVC branch. The valve tower arrangement, which is already modularized in classic applications, is only dependent on the transformer medium voltage, and therefore fixed also by the discrete STATCOM converter choice.

The same applies to the component insulation like insulators, current transformer and wall bushings. This leads to an efficient configurable Hybrid SVC system which comprises the advantages of VSC technology and cheap bulk-power of a TSC not losing dynamic response of voltage-sourced converters.

The footprint of a SVC PLUS solution is already very compact. The extension to a Hybrid SVC only requires some more space for the respective thyristor switched branch. All in all, the Hybrid SVC will come with space savings compared to a conventional SVC, making this solution more interesting in case available space is limited.

The common use of the converter building, auxiliary services and cooling devices of a TSC/TSR and SVC PLUS installation efficiently increases the small space requirements of a Hybrid SVC solution.

technologies and can be easily integrated into a Hybrid SVC. While a STATCOM alone is often used for very quick dynamic voltage support and superior undervoltage performance, but operating around 0 MVar for most of the time, the extension to a Hybrid SVC with TSC or TSR branches will ensure an enlarged operating range and still provide enhanced response time.

This paper has discussed the various benefits of the Hybrid SVC. Nevertheless, the applications for dynamic voltage support in high voltage networks have unique electrical and physical conditions, and consequently, the selection of optimum technology will always be on a case-to-case decision.

VII. CONCLUSION

Both multilevel STATCOM and thyristor based Static Var Compensators are today very mature