Secondary Voltage-Var Controls Applied to Static Compensators (STATCOMs) for Fast Voltage Control and Long Term Var Management

John J. Paserba
(Senior Member)
Mitsubishi Electric Power Products, Inc.
Warrendale, Pennsylvania, USA

Abstract: This paper presents the concept and applications of secondary voltage-var controls applied to Static Compensators (STATCOMs) for fast voltage control and long term var management. The main purpose of the secondary controls is to ensure that an adequate range of the STATCOM dynamic capability is available for major system disturbances. The output of the secondary controls presented here call for the switching of capacitor banks to "reset" the reactive power output of the STATCOM to a pre-specified level after a system event or during the course of a daily load cycle, or for fast voltage control. Two recent applications of STATCOMs coordinated with local and remote capacitor banks for the purpose of fast voltage control and long term var management are presented.

Keywords: Static Compensator (STATCOM), power electronic equipment, secondary voltage control, Flexible AC Transmission Systems (FACTS), var management

1. INTRODUCTION

Static Compensators (STATCOMs) apply advanced power electronic devices such as GTOs (Gate Turn Off Thyristors) or GCTs (Gate Commutated Thyristors) and are able to exchange reactive current (inject or absorb) with the power system at a range of voltage levels, similar to a synchronous condenser. Thus, STATCOMs are able to provide voltage support to the power system in the vicinity of the bus to which it is connected. The reactive current injection capability of STATCOMs is illustrated in Figure 1.

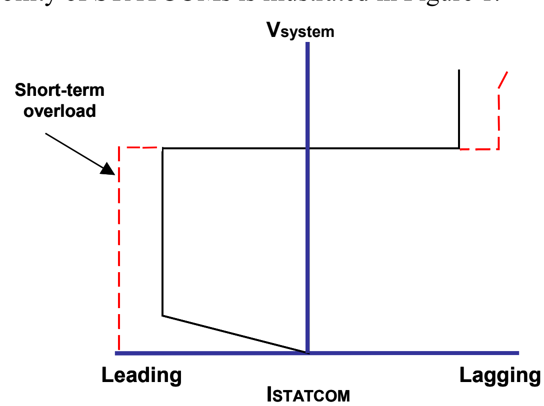

Figure 1. Reactive current capability of a STATCOM.

STATCOMs has been successfully applied in a number of projects over the past decade [1, 2, 3, 4]. In addition to these referenced and other applications, there are several other recently completed STATCOMs in the U.S., in the states of Vermont [5, 6] and Texas, and an on-going project in California.

Feedback controls in a STATCOM can mitigate voltage instability and improve system transient stability. Auxiliary controls, such as for power swing damping, can also be implemented in a STATCOM to help system oscillatory stability. Furthermore, secondary controls are often implemented in STATCOM installations to coordinate local and remote capacitor banks for fast voltage control and long term var management. The secondary control functions are the main focus of this paper.

2. PRIMARY CONTROLS FOR STATCOMS

The primary control objective of a STATCOM is to support the bus voltage to which it is connected by injecting or absorbing reactive current. This is accomplished by a regulator using bus-measurement feedback, typically bus voltage. The typical step-response time of the STATCOM for this primary function of voltage control is on the order of 50 msec.

Figure 2 is an example of the primary control of STATCOMs applied by Mitsubishi Electric at two recent projects, namely by Vermont Electric (VELCO) at the Essex 115 kV substation [5, 6] and by San Diego Gas & Electric (SDG&E) at the Talega 138 kV substation. The figure illustrates that the Mitsubishi Electric primary control has two main portions, namely, an automatic voltage regulator (AVR) with bus-voltage feedback, and an automatic reactive power regulator (AQR) with a STATCOM-reactive-power-output feedback, along with associated limiters.

Figure 2 shows that the AVR also has an available input for an auxiliary voltage signal, such as for a power swing damping control. Also shown in this figure is an auxiliary input for the AQR, which can be used for a coordination function for local and remote capacitor banks for fast voltage control and long term var management, as discussed in the next section.

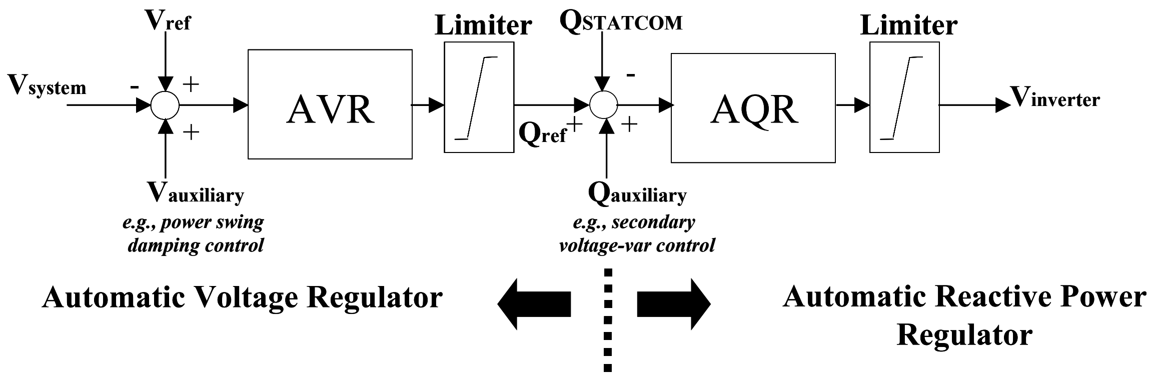

Figure 2. Functional block diagram of the primary control the Mitsubishi Electric STATCOMs.

3. SECONDARY CONTROLS FOR STATCOMS

The main purpose of secondary controls applied to a STATCOM is to ensure that it maintains an adequate range of dynamic capability for major system disturbances. The output of the secondary controls calls for the switching of capacitor banks to "reset" the reactive power output of the STATCOM to a pre-specified level after a system event (long term), or during the course of a daily load cycle (long term), or during an event for voltage control (fast). The concept of the primary and secondary control is illustrated in Figure 3.

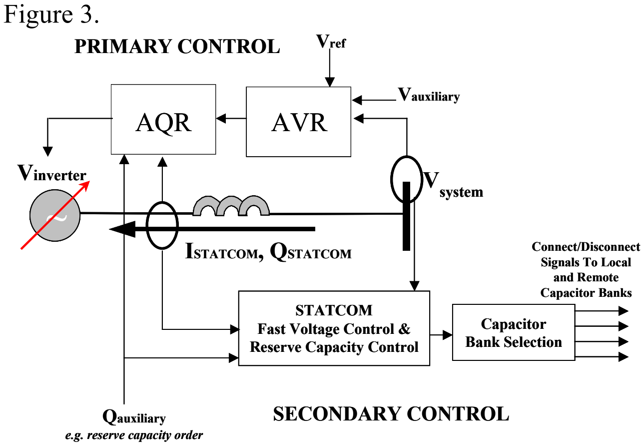

Figure 3. Functional diagram of the primary and secondary control of a STATCOM.

Reference [7], also by this author, discusses the concept of coordinating a STATCOM with local voltage-var control devices such as load-tap changers (LTCs) and capacitor banks, for long term voltage-var management. Reference [7] introduced the concepts of long term voltage-var management for any one of the following three objectives:

- Resetting a STATCOM by a simple reactive power runback function so that it would be available for the "next" dynamic event on the system.
- Improving the overall system voltage profile by coordinating the STATCOM with local LTCs and/or capacitor banks.
- Reducing LTC tap movements by coordinating the STATCOM with local LTCs and/or capacitor banks.

Reference [7] discusses the advantages and disadvantages of applying secondary controls to STATCOMS for each of the above-listed objectives.

The remainder of this paper discusses two recent applications of STATCOMs by Mitsubishi Electric, namely by Vermont Electric (VELCO) at the Essex 115 kV substation and by San Diego Gas & Electric (SDG&E) at the Talega 138 kV substation, and the related application of secondary controls for fast voltage control and long term var management.

4. THE VELCO ESSEX STATCOM

Description of the STATCOM System

The STATCOM in the VELCO power system at the Essex 115 kV substation was installed to provide compensation for heavy increases in summertime electric usage, which have rendered the existing system increasingly vulnerable to events on the VELCO system. The requirements (i.e., the purpose of the STATCOM) can be categorized as dynamic reactive compensation needed for fast voltage support during critical contingencies.

As shown in Figure 4, the STATCOM system consists of two groups of voltage-sourced converters (37.5 MVA each) and two sets of shunt capacitors (24.75 Mvar each). Each 37.5 MVA converter group consists of three sets of 12.5 MVA modules plus a 5 Mvar harmonic filter, with a nominal phase-to-phase ac voltage of 3.2 kV and a DC link voltage of 6,000 V. The two STATCOM groups are connected to the 115 kV system via two three-phase inverter transformers rated at 43 MVA, 3.2 kV/115 kV. This STATCOM was put into service in May 2001.

In addition to the primary control requirements described above, there were secondary power system control issues associated with this STATCOM application. The secondary control issues concerned both reserve capacity control and fast voltage control. Therefore, the STATCOM control is coordinated with several local and remote capacitor banks to perform these secondary control functions. The STATCOM control monitors and switches (in or out) seven other capacitor banks: four local 24.75 Mvar banks at Essex, and three remote 24.75 Mvar banks at the Sandbar, Williston, and Georgia substations. There are also provisions built into the controller for two future banks at Essex. A one-line diagram of the VELCO 115 kV system in the vicinity of the Essex STATCOM is shown in Figure 5.

The secondary control functions are illustrated in Figure 6 and described in the following subsections.

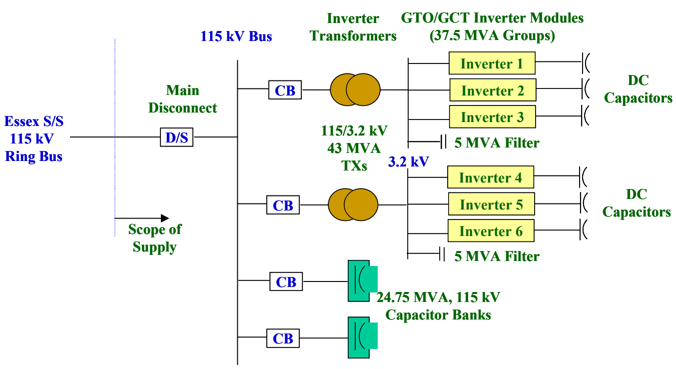

Figure 4. VELCO Essex STATCOM system one-line diagram (CB=circuit breaker, D/S=disconnect switch).

Fast Voltage Control

As illustrated in Figure 6, the secondary control function for fast voltage control monitors the voltage error of the STATCOM from the primary control (AVR), and if the error exceeds a threshold for a specified time, then a connect (for low voltage conditions) or disconnect (for high voltage conditions) signal is given. The panel of the STATCOM controller for the fast voltage control is shown in Figure 7. This figure shows that the available settings are for the voltage error (typically +/- 2%), a time for how long the voltage error must be exceeded (typically seconds), and a time interval before a subsequent switch signals can be given (typically tens of seconds or a few minutes). There are separate timer settings for connect and disconnect control actions.

Since the monitored voltage error is based on the Essex substation, to which the STATCOM is connected, this fast voltage control is primarily for severe system conditions when the STATCOM is pushed into its limits. Thus an action of capacitor bank switching can move the STATCOM back into its controllable range.

Reserve Capacity Control

The reserve capacity control is designed to enable the operating point of the STATCOM inverters to be offset into the inductive region so that a desired “net capacitive range” or “reserve capacity” can be achieved. Reserve capacity is defined as the available net change in STATCOM inverter output towards the capacitive region from a given operating point. For example, if the STATCOM inverters are operating with zero net output, the reserve capacity will be equal to the maximum output rating of the inverters (75 Mvar). If the operating point is biased into the inductive region, for example to 24 Mvar or 48 Mvar inductive, then the reserve capacity will be 99 Mvar or 123 Mvar, respectively. The reserve capacity of the VELCO STATCOM can be selected by the operator to one of three positions; high, medium, and low, which add inductive offsets of 48, 24 and 0 Mvar respectively to the operating setpoint of the STATCOM. This is illustrated in Figure 6.

The desired reserve capacity is a function of the system loading conditions with generally higher reserve capacity (i.e., more biasing into the inductive region) being required under heavy load conditions. Under light load conditions the system requirements for reserve capacity are lower and it is advantageous to operate the STATCOM at the low or medium reserve capacity settings to reduce the losses. The reserve capacity requirement is achieved by automatically connecting or disconnecting shunt capacitors at the Essex, Sandbar, Williston, and Georgia substations.

The panel for the STATCOM controller for the reserve capacity control is shown in Figure 7. The capacitor banks selection logic is discussed in the next subsection.

Capacitor Bank Selection

The STATCOM secondary controls (fast voltage control or the reserve capacity control) sends a signal when a capacitor bank switching event (connect or disconnect) is being requested. The algorithm adopted for the VELCO STATCOM first switches all capacitor banks at Essex with the “first-on/last-off” logic. For the remote capacitor banks at Williston, Sandbar, and Georgia, they are switched on or off based on their bus voltage (e.g., lowest voltage on first, highest voltage off first). If a selected capacitor bank is already on-line at the specified substation or is disabled, the selection controller searches for the next one in the hierarchy. The capacitor banks status panel of the STATCOM control is shown in Figure 8.

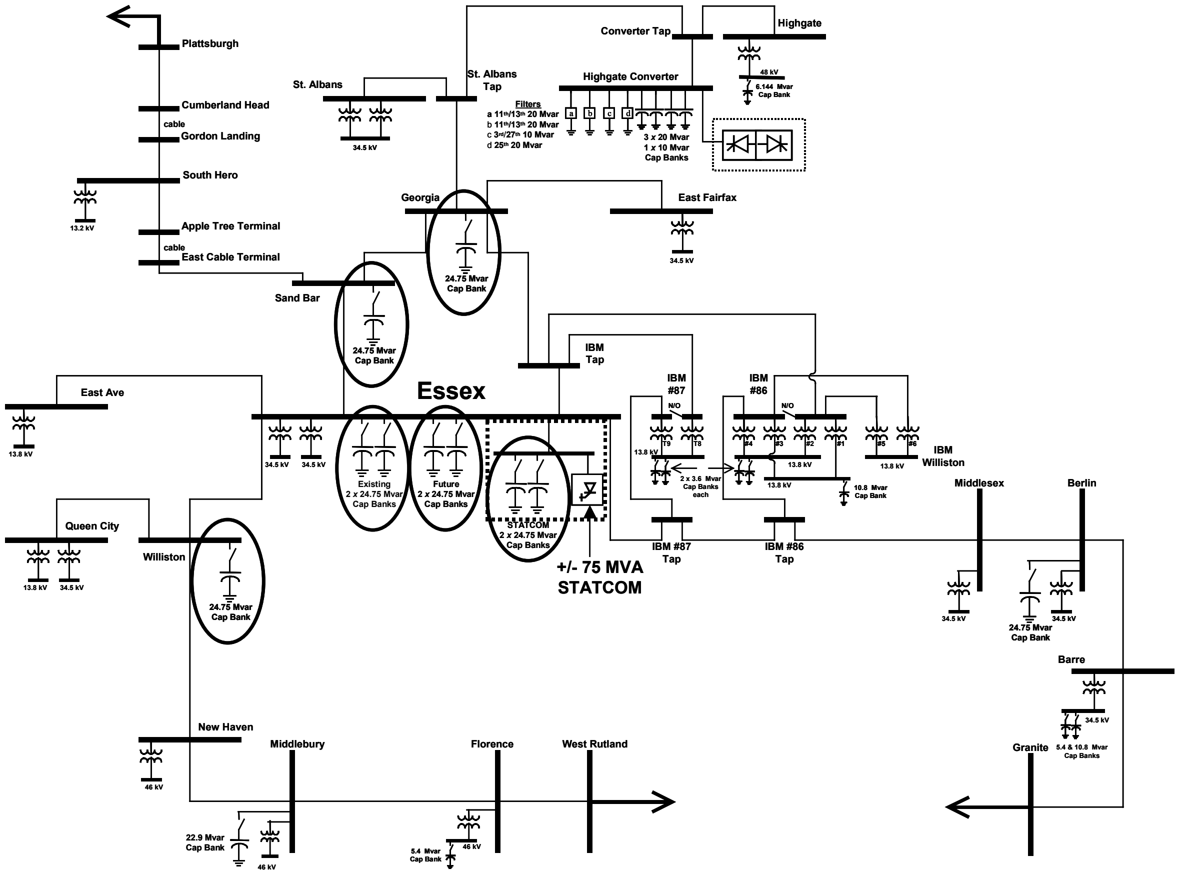

Figure 5. One-line diagram of the VELCO 115 kV system in the vicinity of the Essex STATCOM. The highlighted capacitor banks are coordinated with the STATCOM for fast voltage control and reserve capacity control.

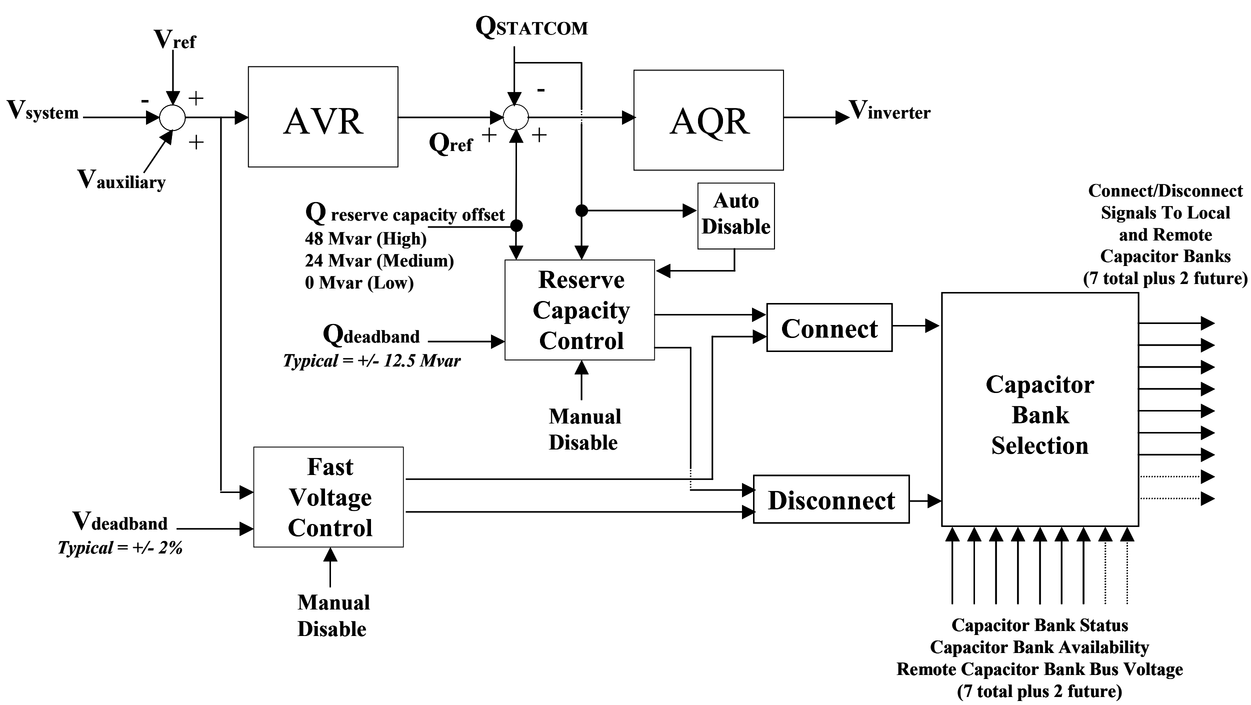

Figure 6. Functional block diagram of the overall voltage-var control for the VELCO Essex STATCOM.

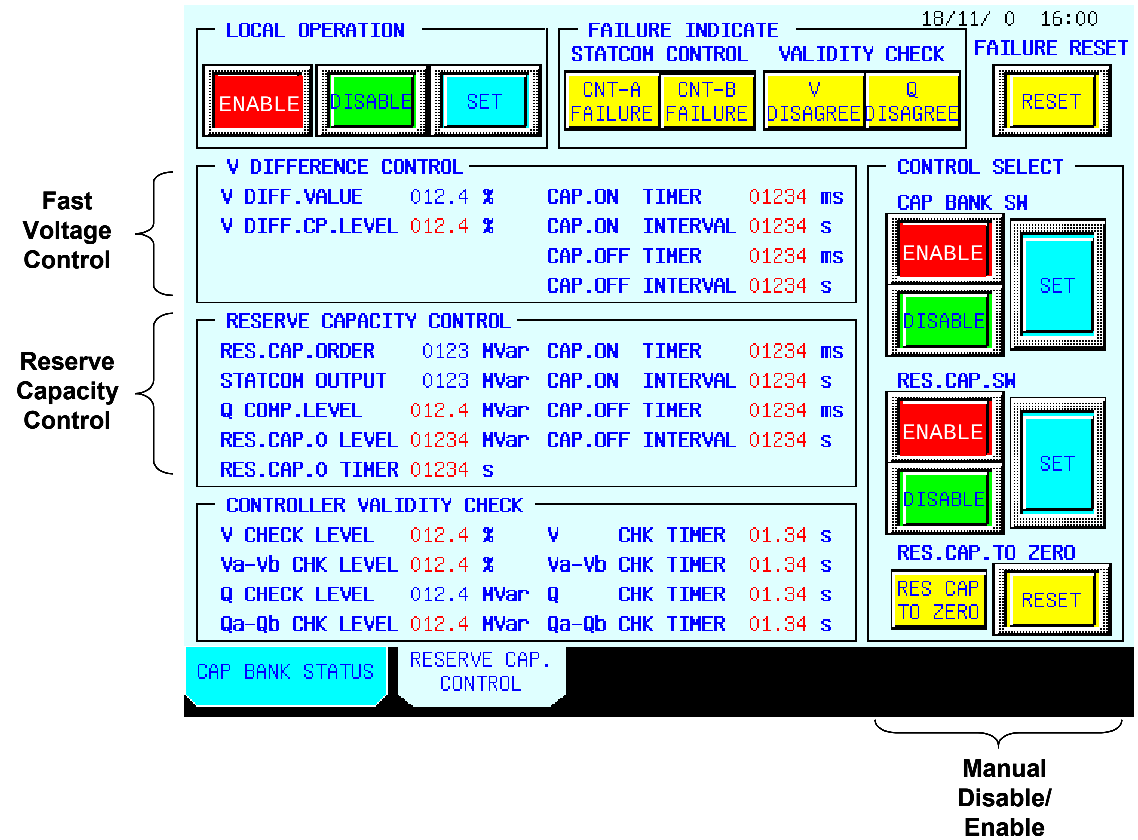

Figure 7. Secondary control panel (fast voltage control and reserve capacity control) of the VELCO Essex STATCOM controller (Note all input values are shown here as "01234….." before factory settings were in-place. Values shown in this panel for the STATCOM secondary control are settable by VELCO).

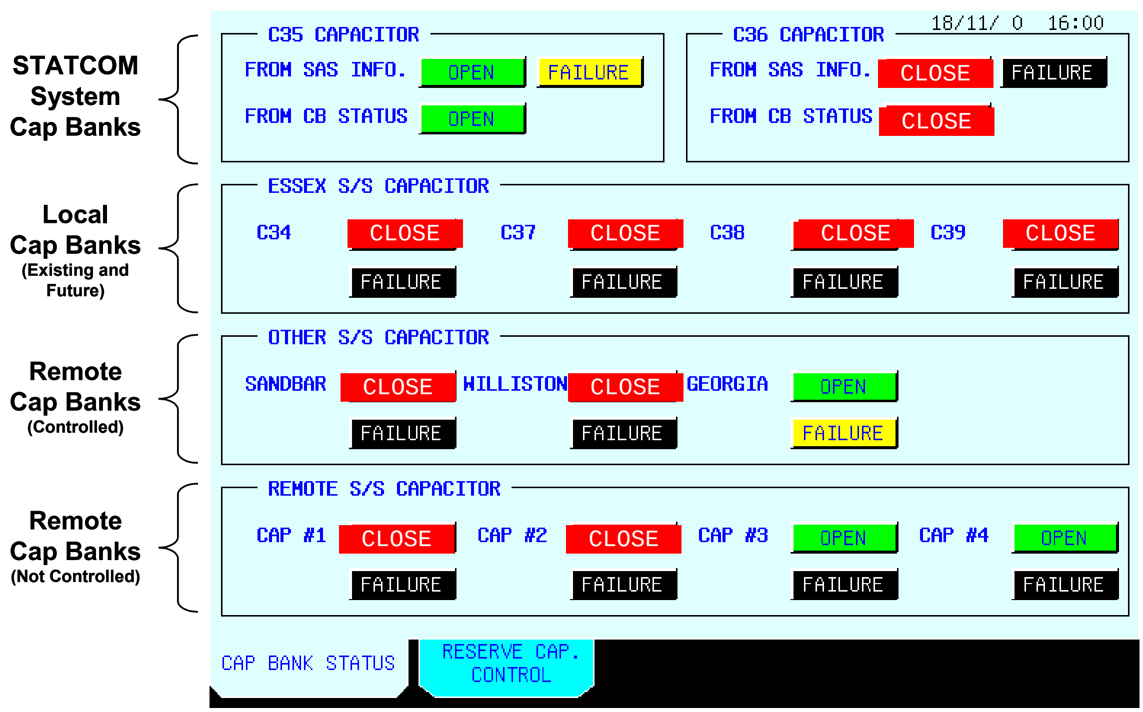

Figure 8. Capacitor bank status panel of the VELCO Essex STATCOM controller.

There are provisions for control of four capacitor banks currently at Essex (two of which are associated with the STATCOM installation) plus two future banks at Essex, plus for the three remote banks. The information transmitted from the local and remote capacitor bank substations into the selection logic of the STATCOM secondary control, illustrated in Figure 6, is as follows:

- Capacitor bank status
- Capacitor bank availability
- Remote capacitor bank bus voltage

To avoid frequent switching of the capacitor banks for the fast voltage control, the capacitor bank selection logic has voltage deadbands, settable by VELCO on the STATCOM control panels, as illustrated in Figure 7.

5. THE SDG&E TALEGA STATCOM

Description of the STATCOM System

The STATCOM currently being installed in the SDG&E system at the Talega 138 kV substation is being applied for dynamic var control during peak load conditions, which have rendered the existing system increasingly vulnerable to system events on the transmission system.

As shown in Figure 9, the STATCOM system has a rated capacity of +/- 100 MVA. The STATCOM system consists of two groups of voltage-sourced converters (50 MVA each). Each 50 MVA converter group consists of four sets of 12.5 MVA modules plus a 5 Mvar harmonic filter (plus one spare filter switchable to either group), with a nominal phase-to-phase ac voltage of 3.2 kV and a DC link voltage of 6,000 V. The two 50 MVA STATCOM groups are connected to the 138 kV system via three three-phase inverter transformers each rated at 55 MVA, 3.2 kV/138 kV (includes one “hot” spare). Either 50 MVA STATCOM group or both can be connected to each of the 138 kV buses via the various automatically controlled motor operated disconnects. This STATCOM is scheduled by SDG&E to be in-service in September 2002.

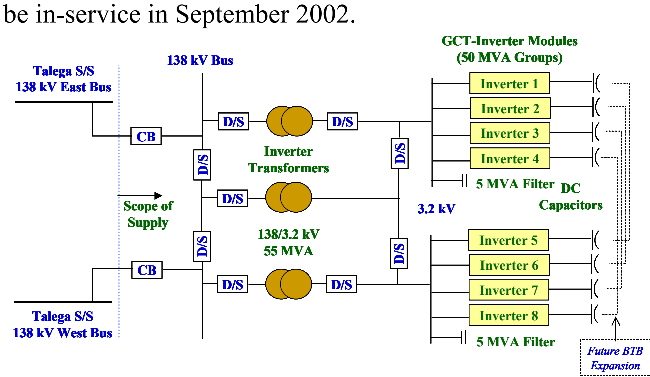

Figure 9. SDG&E Talega STATCOM one-line diagram (CB=circuit breaker, D/S=disconnect switch).

As part of the overall reactive compensation scheme at the Talega substation, there are also three 69 Mvar shunt capacitors that are connected to the Talega 230 kV system. Figure 10 shows a one-line diagram of the SDG&E 230/138 kV system in the vicinity of the Talega STATCOM installation.

The secondary control functions are illustrated in Figure 11 and described in the following subsections.

Fast Voltage Control

The fast voltage control of the Talega STATCOM is similar to that of the VELCO STATCOM. As illustrated in Figure 11, the secondary control function for fast voltage control monitors the Talega 138 kV bus voltage and if the voltage is outside a settable deadband for a specified time, then a connect (for low voltage conditions) or disconnect (for high voltage conditions) signal is given.

As noted for the VELCO STATCOM, since the monitored voltage is at the Talega substation, to which the STATCOM is connected, this fast voltage control is primarily for severe system conditions when the STATCOM is pushed to its limits. Thus an action of capacitor bank switching can move the STATCOM back into its controllable range. There is an added function to the SDG&E fast voltage control that will call for the connection of all available capacitor banks at the Talega 230 kV bus simultaneously for a rapid severe voltage drop.

Figure 12 is a time-chart illustrating the SDG&E Talega STATCOM fast voltage control logic.

Reserve Capacity Control

The reserve capacity control of the SDG&E Talega STATCOM has the function of keeping the output of the STATCOM to a minimum value, so as to minimize losses. If the reactive power output of the STATCOM is outside a settable deadband for a specified time, then a connect (for large capacitive Mvar output) or disconnect (for large inductive Mvar output) signal is given by the control. The deadband is rather large due to the fact that the capacitor banks being switched are rated at 69 Mvar.

Figure 13 is a time-chart illustrating the SDG&E Talega STATCOM reserve capacity control logic.

Capacitor Bank Selection

The capacitor banks selection logic will select one of the three capacitors at the Talega 230 kV substation (69 Mvar each) according to the status and availability/failure information. The selection logic includes cycling of the three banks.

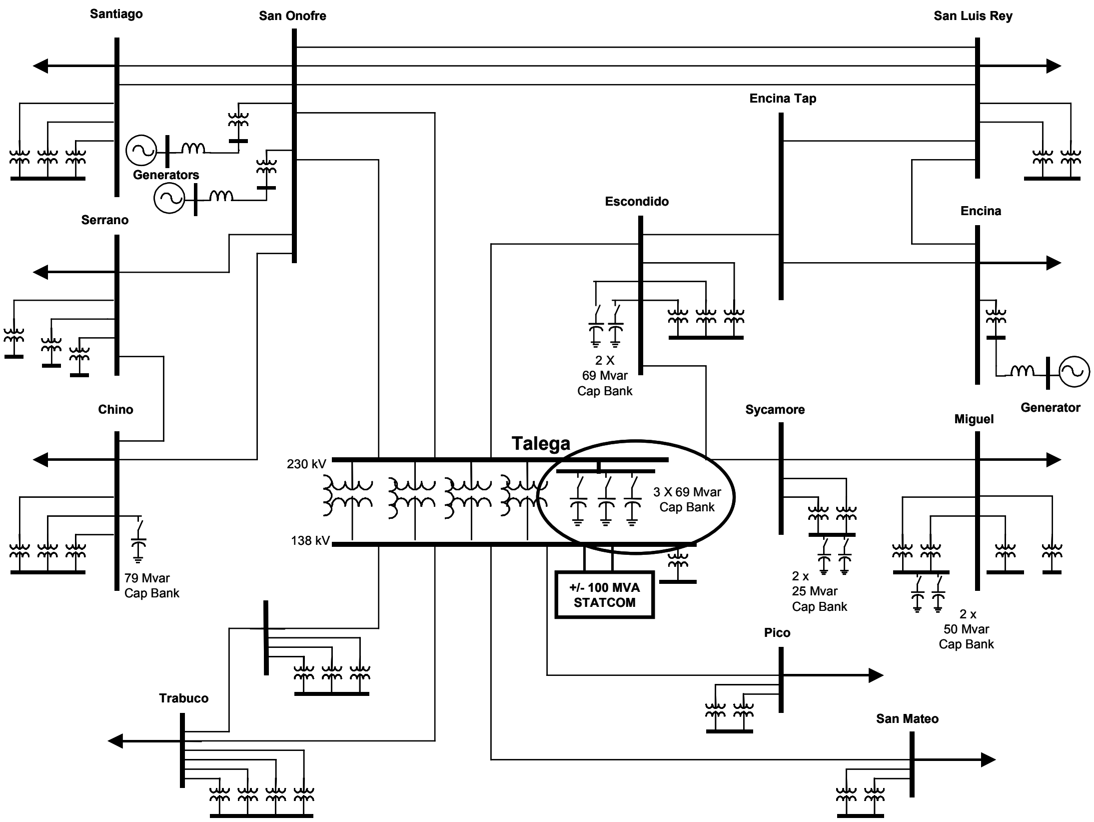

Figure 10. One-line diagram of the SDG&E 138 and 230 kV system in the vicinity of the Talega STATCOM. The highlighted capacitor banks are coordinated with the STATCOM for fast voltage control and reserve capacity control.

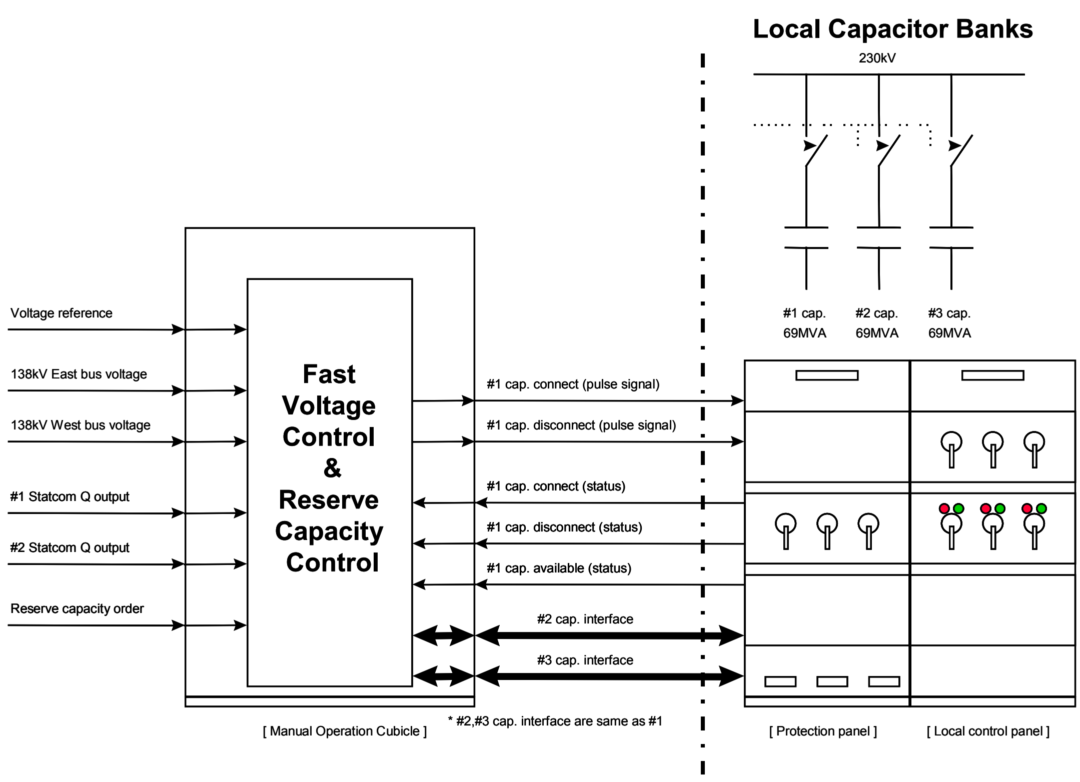

Figure 11. Functional block diagram of the secondary control for the SDG&E Talega STATCOM.

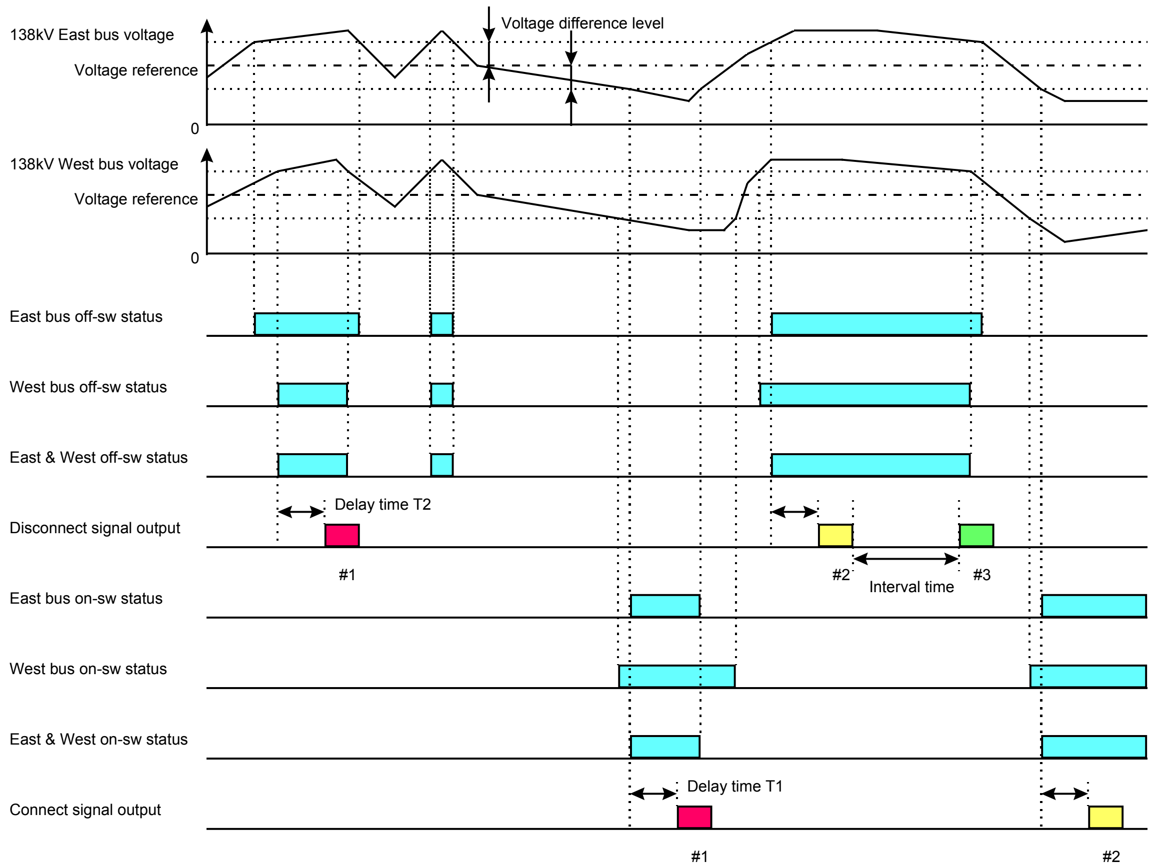

Figure 12. Illustration of the logic for the SDG&E Talega STATCOM fast voltage control (Note: Timers, delays, and thresholds are settable by SDG&E on the STATCOM controller panels).

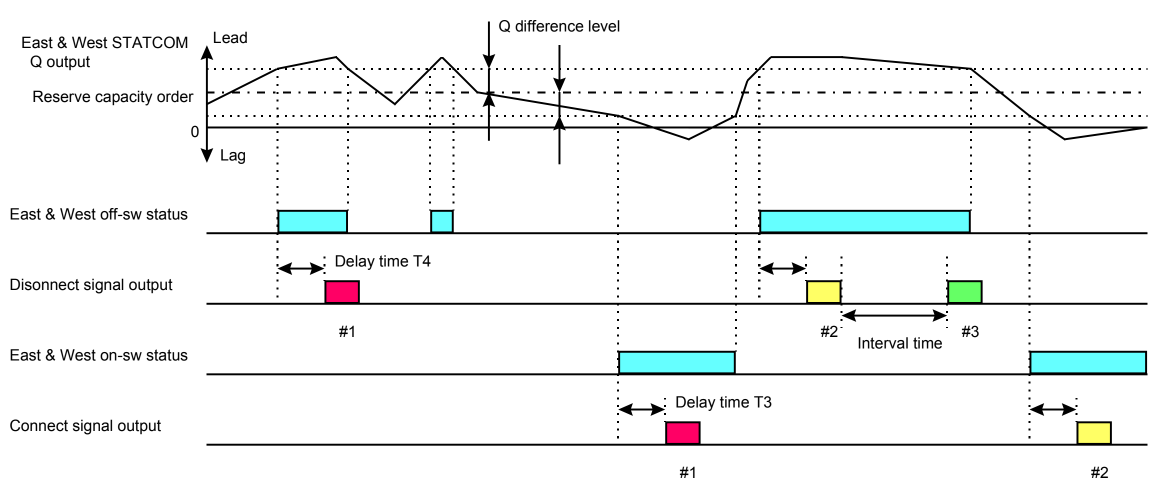

Figure 13. Illustration of the logic for the SDG&E Talega STATCOM reserve capacity control (Note: Timers, delays, and thresholds are settable by SDG&E on the STATCOM controller panels).

6. SUMMARY

This paper presented the concept and applications of secondary voltage-var controls applied to Static Compensators (STATCOMs) for fast voltage control and long term var management. The primary purpose of the secondary controls is to ensure that an adequate range of the STATCOM dynamic capability is available for major system disturbances. The output of the secondary controls presented here call for the switching of capacitor banks to "reset" the reactive power output of the STATCOM to a pre-specified level after a system event (long term), or during the course of a daily load cycle (long term), or for voltage control (fast). Two recent applications of STATCOMs coordinated with local and remote capacitor banks for the purpose of fast voltage control and long term var management were presented, namely the Vermont Electric +/- 75 MVA STATCOM at the Essex 115 kV substation, and the San Diego Gas & Electric +/- 100 MVA STATCOM at the Talega 138 kV substation.

ACKNOWLEDGEMENTS

There were numerous people involved in the various technical aspects of the topics presented in this paper. The following individuals are gratefully acknowledged, in alphabetical order by company. At Mitsubishi Electric Power Products (MEPPI): T. Anthony, T. Croasdaile, G. Reed, D. Shoup, and R. Westover. At Mitsubishi Electric Corporation (MELCO): T. Aritsuka, M. Funahashi, Y. Hamasaki, K. Higashi, I. Iyoda, S. Jochi, H. Kuwabara, Y. Kono, H. Matsuba, K. Matsuno, N. Morishima, M. Nambu, N. Toki, M. Takeda, S. Sugiyama, S. Yasuda, T. Yoneda, and others. At the Vermont Electric Power Company (VELCO): W. Allard, T. Earle, F. Ettori, J. Fiske, D. Haas, R. Johnson, D. LaForest, G. Parker, C. Smith, and L. Thomas. At San Diego Gas and Electric (SDG&E): A. Abed and T. Snow. At Teshmont: M. Bennett and B. Bisewski. At Commonwealth Associates (CAI): D. DeCosta. At Power Engineers: J. Keeling.

This author regrets if any omissions were made in this list of acknowledgements.

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BIOGRAPHIES

John Paserba earned his BEE ('87) from Gannon University, Erie, PA., and his ME ('88) from Rensselaer Polytechnic Institute, Troy, NY. Mr. Paserba worked in GE's Power Systems Energy Consulting Department for over 10 years before joining Mitsubishi Electric Power Products Inc. (MEPPI) in 1998. He was the Chairman of the IEEE PES Power System Stability Subcommittee and for CIGRE Task Force 38.01.07 on Control of Power System Oscillations, and sat on the Editorial Board for the IEEE PES Transactions on Power Systems. He also served as the Technical Program Chair for the IEEE PES Winter 2002 Meeting in New York. He is currently the Secretary for the Power System Dynamic Performance Committee. In addition to the activities in the Power Engineering Society, Mr. Paserba is also active in promoting IEEE student professional awareness and is a member of the IEEE-USA Student Professional Awareness Committee (S-PAC), the IEEE Regional Activities Board Student Activities Committee (SAC), and is the IEEE Pittsburgh Section Student Activities Chair. (j.paserba@ieee.org)