

NYPA Convertible Static Compensator (CSC) Application Phase I: STATCOM

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Abstract: The paper provides a description of planning, testing, and performance validation of a flexible ac transmission system (FACTS) device called the Convertible Static Compensator (CSC), on the New York State (NYS) transmission system to provide increased power transfer capability and greater operational flexibility. The CSC can function as shunt and/or series compensating devices providing various control modes. At present, the CSC is operated only in shunt mode for voltage support at a major 345kV substation increasing power transfer limits across a key transmission corridor in NYS. A general methodology for FACTS controller planning for power systems is also presented.

I. INTRODUCTION

Concentration of generation in the north and west of the New York State (NYS), coupled with the concentration of load in the southeast results in an East/Southeast power flow pattern across the State [1]. The major transmission links between the supply and demand centers, therefore, might be subject to thermal, voltage or stability constraints.

For example, transfers across the State in the early 1990 were restricted because of stability limits. The system of today has an improved dynamic response but is still limited by voltage considerations.

Even without normal transfer restrictions with all facilities in service, improvement in dynamic system performance is necessary to increase the resiliency of the transmission grid especially for extreme contingencies and various maintenance scenarios. Further, it is possible that the dynamic performance can once again restrict normal transfers.

Reduced coordination between plant and transmission operators in a deregulated market as well as a lessening of long term planning of the generation/transmission combination contributes to a less predictable power system-operating environment. Therefore, future physical structure of the networks of supply and transmission is less certain. Consequently, there is a need for transmission owners and operators to have an increased capability of control for maximum utilization of transmission assets, improving the security of the network and even operating the network in ways not planned for.

FACTS technology can be used to add operational flexibility and provide transmission operators with the

capability of maximizing the usage of the existing assets, controlling power flow over contract paths and mitigating the adverse effects of loop flow. These "steady-state" enhancements can be complemented improving the power system dynamic performance through intelligent use of FACTS controllability.

II. FACTS CONTROLLER PLANNING METHODOLOGY

Voltage-Sourced Converters (VSC) can be connected together [2-4] to provide convertible, flexible, modular and multi-functional FACTS controllers. Such a controller can operate in the shunt mode, convert to a series mode, or have both shunt and series controllers on the system simultaneously in either independent or coupled modes [5-11]. A FACTS controller of this nature is called a Convertible Static Compensator (CSC).

Recognizing the flexibility offered by the VSC-based FACTS technology, it is necessary to determine the optimum methods in which this technology could be utilized in operation of transmission systems. Obviously, the existing and new capacitive and reactive compensating devices should be included as part of a compensation package that is optimal in terms of both cost and performance.

Assuming total control over power flow in a system, maximum steady-state power transfer levels would be reached when all circuits are at thermal limit. This transfer level needs to be established at the onset of system studies. Then, starting from the pre-compensation levels, power transfers should be increased in steps up to the maximum. At each loading point, optimal power flow techniques can be utilized to identify series and shunt compensation requirements needed for normal and contingency conditions in order to maintain the system within operational and planning criteria. It is clear that incremental increases in transfers will generally require an increase in voltage support and eventually might need the introduction of flow control devices in series with critical line sections.

A relationship between equipment requirements and power transfer levels needs to be established. Cost versus performance improvement breakpoints need to be identified

and relative merits of individual system reinforcement solutions need to be considered.

The specific steps that can be taken in FACTS application planning studies are:

- Identify the near-term system reinforcement needs to address current operational problems.
- Identify the evolution of system reinforcement needs over the longer-term and the required flexibility from the FACTS controller.
- Identify the manner in which a multifunctional, flexible, and modular approach to FACTS application would satisfy both near-term and longer-term system requirements.
- Determine the optimum size and location of the FACTS controller.
- Compare various newer VSC-based solutions to the more established FACTS solutions such as SVC and TCSC.

III. NYS SYSTEM

Figure 1 shows a simplified one-line diagram of the New York State transmission system showing a major transmission corridor or interface of concern. The transfers along this interface, called "Central-East", are currently voltage limited. This interface is a subset of the "Total-East" interface extending from the northeastern interconnection with Vermont down to the Coopers Corners substation to the feeds into New York City.

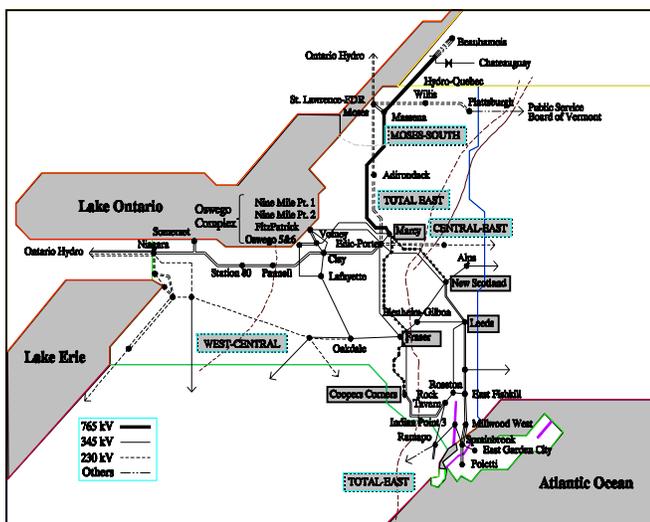


Fig. 1 Major transmission lines in New York State

These limits are presently imposed by voltage collapse conditions encountered during some of the more critical

contingencies considered for operations and planning in the State. Additional operational restrictions are imposed during outage of voltage support equipment such as SVCs at Fraser and Leeds and large shunt capacitor banks at other 345 kV substations. These transfer limits are also dependent on the availability of generation in the Oswego area.

The initial phase of the CSC project, currently in operation, consists of the ± 200 MVA STATCOM and a 135 MVar capacitor bank at Oakdale substation. This phase provides an increase of 60 MW in Central-East transfer limit. The corresponding Total-East limit is increased by 114 MW. The second phase of the CSC consists of the series voltage injection equipment and 270 MVar of additional fixed shunt capacitors. This phase will enhance the transfer limits by an amount similar to the first phase.

IV. CSC DESCRIPTION

The 200 MVA 345 kV CSC consists of two voltage-sourced converters connected to the Marcy bus through the 200 MVA shunt transformer or two 100 MVA series coupling transformers as shown in Figure 2.

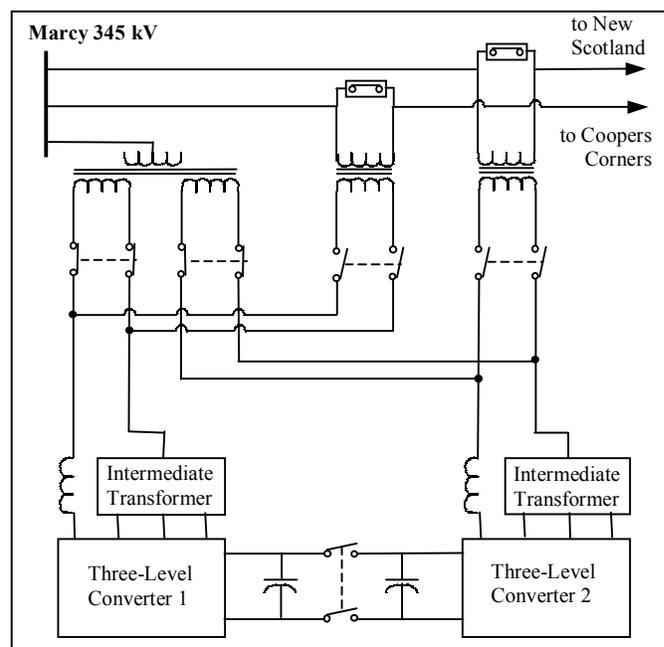


Fig. 2 Simplified schematic of the Convertible Static Compensator

The CSC, through appropriate arrangement of disconnect switches and circuit-switchers, can have 11 configurations. The CSC can function as a STATCOM, SSSC, UPFC or IPFC, as listed in Table 1 [3]. The changes between different configurations are achieved through appropriate switching of circuit breakers, disconnect switches and the DC switch connecting the DC buses of the two converters. The SSSC can

be placed either on Marcy – New Scotland or Marcy – Coopers Corners line.

If the DC switch is closed the corresponding UPFC and IPFC configurations allow real power transfers from Converter 1 to Converter 2 and vice versa. It should be noted that the DC switch does not have current interruption capability and is operated only when equipment is de-energized. In general, any configurations can be obtained at any time, which gives the CSC great operational flexibility.

Table 1. CSC Configurations and MVA Ratings

	Configuration	MVA Rating
1	STATCOM	100 or 200
2	SSSC	100 or 200
3	STATCOM & SSSC	100 & 100
4	UPFC	200
5	IPFC	200

The 345/21.4 kV shunt transformer is rated at 200 MVA, while the 11/21.4 kV series transformers, which inject voltages in series with the transmission lines, are rated 100 MVA each. There are also two 11.87/11.87 kV, 55 MVA intermediate transformers associated with each converter. Each of the voltage-sourced converters consists of 4 sets of three-phase three-level poles as shown in Figure 3. The building block for the pole valves are GTO modules which consist of 4.5 kV, 4 kA Gate Turn-Off Thyristors and the anti-parallel diodes of the same rating.

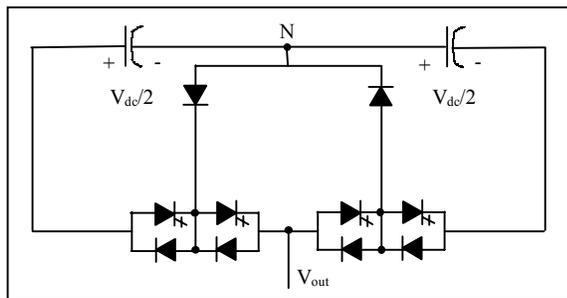


Fig. 3 Simplified schematic for a three-level valve

The advantage of three-level converters is that there is a reduction of some characteristic harmonics; the valves switch at fundamental frequency, i.e. in six-pulse operation, but at a specific conduction time, the converter output voltage lacks fifth and seventh harmonics and the converter almost behaves like a twelve-pulse converter. The STATCOM generates a voltage that is practically harmonic-free with the lowest harmonics being of 47th and 49th order, which basically implies that there is no need for filter installation.

The CSC equipment is located both outdoors and indoors in a building specifically built for this purpose. The building is approximately 29 m wide and 36 m long and consists of

several rooms where the converter poles, control circuit boards, cooling skids, power supplies and protection equipment are housed. The shunt, series and intermediate transformers together with disconnect switches are placed outdoors.

V. TNA AND COMMISSIONING TESTS

In order to analyze the CSC steady-state and transient performances and its effect on the NYPA system during various disturbances, the EMTP and TNA simulation tools were utilized. The EMTP was mainly used during the planning stage of the project when the CSC rating and functionality were being determined. The TNA studies were conducted later in the project development to provide an insight into the CSC steady-state and transient operations, the range of its performance and to ensure compliance with NYPA requirements.

The specific objectives of the TNA testing were:

- To determine the steady-state characteristics of all CSC configurations;
- To validate and optimize the CSC control system;
- To analyze CSC responses during and following various system disturbances;
- To confirm the EMTP study results.

It is important to emphasize that the TNA model consisted of the actual CSC control circuit boards that were connected with fiber optic links with low-loss FET switches that represented the Gate Turn-Off thyristor valves. The transformer models were designed to accurately represent the saturation and leakage reactances of the actual transformers and were sufficiently flexible to allow adjustments of turn ratios, saturation and leakage reactances.

The power system was modeled up to three buses away from the Marcy bus and was terminated with equivalent voltage sources. These voltage sources were represented by the corresponding Thevenin equivalents. The model consisted of 36 transmission lines, 5 transformers, 20 equivalent voltage sources and 10 capacitor banks.

All CSC configurations were tested. Comprehensive testing lasted 14 weeks and included over 1000 tests for a total of several thousand switching operations. The TNA testing which resulted in several control circuit modifications has proven to be a great tool for assessing and validating control design and performance and for optimizing the control gains and other parameters.

The STATCOM commissioning tests were completed on February 27, 2001. They were limited to the operation and performance of the three STATCOM configurations (± 100 MVar Converter 1, ± 100 MVar Converter 2, ± 200 MVar Converters 1&2). The off-line tests assured correct

STATCOM circuit connections and correct phasing of all relays and monitors. The on-line tests confirmed the STATCOM steady-state characteristics. They also included tests such as the DC bus charging, starting of Converter 2 when Converter 1 is already in service, etc. Dynamic tests such as step changes in the bus voltage or the injected reactive current reference were also performed.

VI. FIELD PERFORMANCE and EMTP RESULTS

Figure 4 shows the STATCOM response to a phase-to-phase fault north of Marcy substation. The STATCOM output waveforms were captured with a Digital Fault Recorder (DFR) placed in the Marcy 345 kV substation and dedicated to recording of the STATCOM dynamic response. Before the fault, the STATCOM was in the VAR-Reserve control mode. This control mode is a modified version of automatic voltage control, where the STATCOM reactive power output is maintained within -40 to $+40$ MVar range, provided that the Marcy voltage disturbance is not larger than a certain preset value. If the Marcy bus voltage disturbance is larger than this preset value, the VAR-Reserve control mode is disabled and the STATCOM reverts to automatic voltage control mode to support the bus voltage.

The first three plots in Figure 4 represent phases a, b, and c voltages at the Marcy bus. A remote a-phase-to-c-phase fault produced voltage sags on these phases at the Marcy bus. This voltage sag coupled with a voltage unbalance resulted in the disabling of VAR-Reserve function. During the fault, the STATCOM was supplying capacitive current and supporting the Marcy bus voltage, as it can be seen from the plots (Fig. 4) for the Marcy bus rms voltages and STATCOM rms output currents. The voltage sag with the STATCOM support is about 8%.

It should be noted that the CSC in STATCOM configuration is primarily used for dynamic regulation of the Marcy bus voltage, which in steady-state operation is supported by two 345 kV 200 MVar capacitor banks and one 765 kV 200 MVar shunt reactor bank on the high side of the two 345kV/765kV auto-transformer banks at Marcy.

The EMTP was used in earlier stages of the CSC application studies to identify the limiting conditions, and to assess the extent to which the CSC controller may enhance dynamic performance of the NYS system. Typical EMTP studies included the CSC responses to system faults and assessment of control strategies.

The EMTP simulation studies were performed for the remote phase-to-phase fault mentioned above to confirm the STATCOM response captured by the DFR. As it can be seen from Figure 5, the STATCOM model developed in the EMTP produces a similar response to that of the real STATCOM. During the fault the STATCOM reached an output level of about 200 A rms which is equivalent to 120 MVar or 60 MVar per converter. The STATCOM overload capability of

1.23 p.u. for 1 s was not utilized in this case. In general, the EMTP proved to be a reliable tool in assessing the CSC responses to a variety of contingencies under different power system conditions.

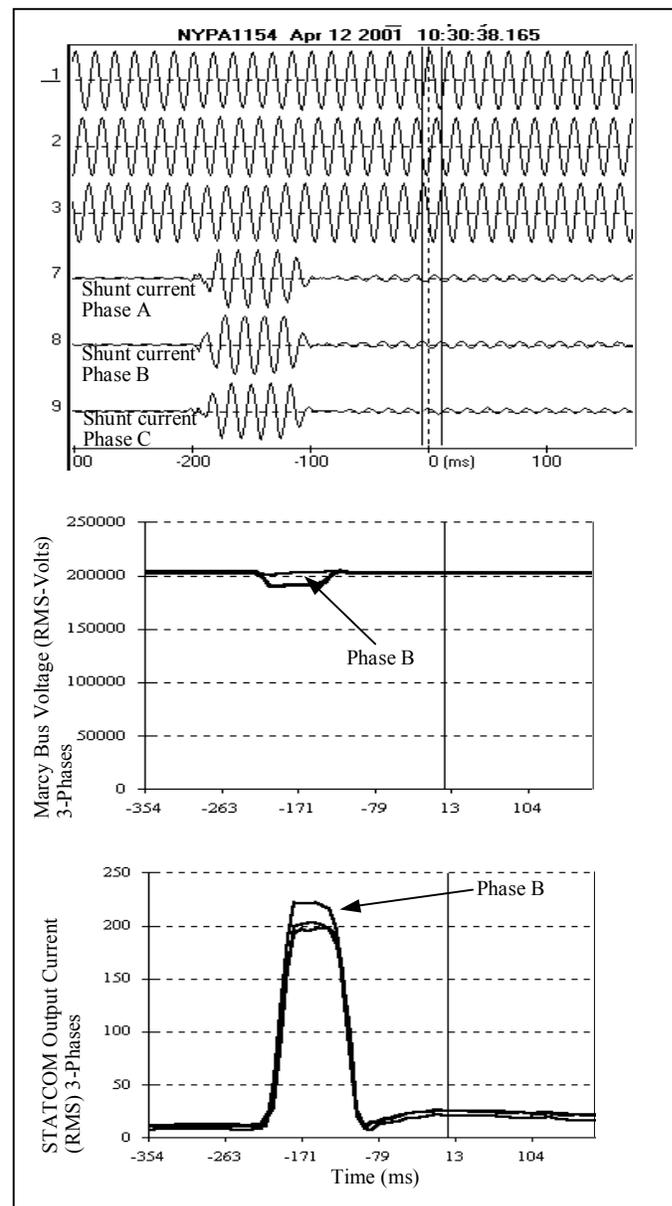


Fig. 4 DFR records for system fault on April 12, 2001

VII. CONCLUSIONS

This paper describes the first phase of the CSC application on the New York State transmission system. Phase I of the CSC project, namely, ± 200 MVA STATCOM is already in service and is used for dynamic regulation of the Marcy bus voltage. The series portion of the CSC controller should be operational in 2002. The paper stresses the importance of system studies in different stages of project development. The DFR recordings and corresponding EMTP results for a remote system fault are also presented and discussed.

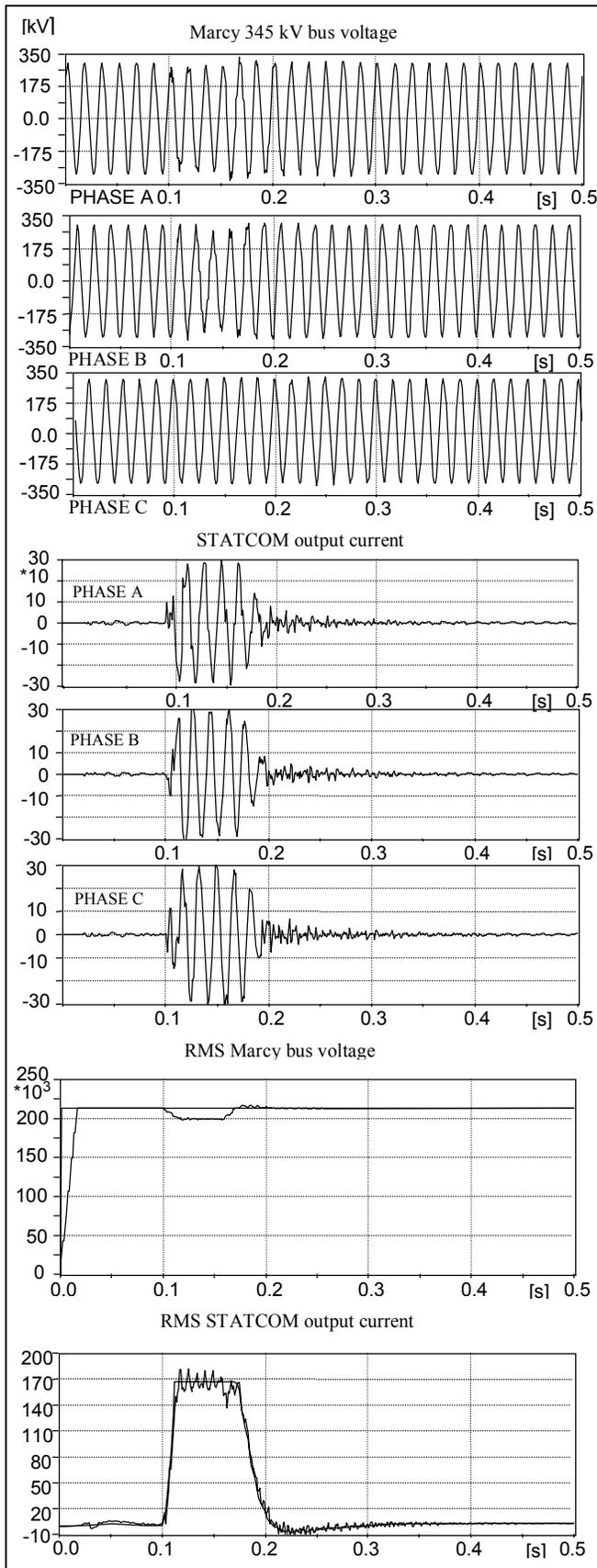


Fig. 5 EMTF results for system fault north of Marcy

VIII. REFERENCES

- [1] B. Fardanesh, M. Henderson, B. Shperling, S. Zelingher, L. Gyugyi, B. Lam, R. Adapa, C. Schauder, J. Mountford, and A. Edris "Convertible Static Compensator: Application to the New York Transmission System", CIGRE 14-103, France, September 1998.
- [2] L. Gyugyi, "Dynamic Compensation of AC Transmission Lines by Solid-State Synchronous Voltage Sources", IEEE Trans. Power Delivery, Vol. 9, No. 2, April 1994, pp. 904-911.
- [3] N. G. Hingorani, and L. Gyugyi "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems", The Institute of Electrical and Electronics Engineers, Inc., New York, 2000.
- [4] B. Fardanesh, B. Shperling, E. Uzunovic, and S. Zelingher "Multi-Converter FACTS Devices: The Generalized Unified Power Flow Controller (GUPFC)", Proceedings of IEEE Summer Power Meeting, Seattle, July 2000.
- [5] 1 MVAR Advanced Static VAR Generator Development Program, ESEERCO Report, EP 84-30, April 1987.
- [6] C. Schauder, M. Gernhardt, E. Stacey, T. Lemak, L. Gyugyi, T. W. Cease, and A. Edris "Development of a ± 100 MVAR Static Condenser for Voltage Control of Transmission Systems", IEEE Trans. Power Delivery, Vol. 10, No. 3, July 1995, pp. 1486-1493.
- [7] E. Larsen, N. Miller, S. Nilsson, and S. Lindgren "Benefits of GTO-based Compensation Systems for Electric Utility Applications", IEEE Trans. Power Delivery, Vol. 7, No. 4, October 1992, pp. 2056-2062.
- [8] L. Gyugyi, C. D. Schauder, and K. K. Sen "Static Synchronously Series Compensator: A Solid-State Approach to the Series Compensation of Transmission Line", IEEE Trans. Power Delivery, Vol. 12, No. 1, January 1997, pp.406-417.
- [9] M. Rahman, M. Ahmed, R. Gutman, R. J. O'Keefe, R. J. Nelson, and J. Bian "UPFC Application on the AEP System: Planning Consideration", IEEE Winter Meeting, PE-582-PWRS-0-01-1997, February 1997.
- [10] L. Gyugyi, K. K. Sen, and C. D. Schauder "The Interline Power Flow Controller Concept: A New Approach to Power Flow Management in Transmission Systems", PES Summer Meeting, 1998.
- [11] C. D. Schauder and H. Mehta "Vector Analysis and Control of Advanced Static Var Compensator", IEE Proceedings - C, Vol. 140, No. 4, July 1993, pp. 299-306.