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**Refurbishment and Life Extension of Existing Facilities in Vermont**

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**SUMMARY**

The power system in Vermont consists of a mini Grid embedded in North America's transmission network. This system has been developed and implemented with innovative and customized ideas and features over the years based upon the technologies available at that time. The system has operated reliably within its 115kV and 345kV transmission network, as well as the controllable power intertie facilities such as the Highgate Back-to-Back converter station, Essex STATCOM, Sandbar Phase Shifting Transformers (PST) and the Granite synchronous condensers.

Over the past 10 years, the nuclear power plant at Vermont Yankee, the largest power generation in Vermont, has been phased out and replaced with more renewable generation such as wind and solar farms. These are being installed and interconnected to the Vermont's electrical system which requires more stringent control and operation.

To strengthen the existing system to facilitate the increasing load demand and green power energy transfer, VELCO has taken the economical approach to refurbish existing facilities for the larger power transfer capacity and improved voltage support.

This paper describes the two major refurbishment projects in Vermont, upgrade of Highgate back-to-back converter station and Essex STATCOM.

**KEYWORDS**

Refurbishment and Life Extension, HVDC System, FACTS device, Control and protection, Valve cooling replacement

## 1. Introduction

Vermont Electric Power Company (VELCO) is one of the utilities that had the earliest installation of the HVDC systems and FACTS devices when the technologies became available.

Highgate back-to-back converter station was commissioned in 1985. It is located in the northwest portion of Vermont interconnecting 120 kV electrical system of Hydro-Quebec in Canada and 115kV system of Vermont in USA. This facility was originally rated at  $\pm 56$ kV, 200MW with a continuous overload capacity 225MW at 30°C ambient temperature.

In 2001, VELCO installed a Static Synchronous Compensator (STATCOM) at its Essex Substation in Chittenden County, which is in close proximity to an IBM Production Facility. The primary purpose of the STATCOM was to provide dynamic system voltage support during heavy load conditions coincident with outage(s) of transmission lines or other transmission equipment. As a secondary benefit, the device provides continuous steady state voltage regulation and power quality improvement in the Chittenden County area.

Highgate converter and Essex STATCOM have been playing an important role to the reliable performance and operation of Vermont's electrical system since they were commissioned. After years of reliable operation, both of these facilities at times have seen some issues which have comprised the availability and reliability of the overall system. In 2012 the Highgate converter station was refurbished and upgraded with new technology. Currently, the Essex STATCOM is in the beginning stages of a refurbishment. This paper provides an overview of VELCO's experience with these two refurbishment projects.

## 2. Highgate Back-to-back Converter Station Refurbishment Project

Prior to the refurbishment, the Highgate converter station as shown in Figure 1 had been operated and maintained by Vermont Electric Power Company (VELCO) since 1985. Due to issues as the equipment aged, lack of knowledge and support of existing control system, increased control failures and the desire to increase the nominal rating to 225MW at 40°C ambient temperature; a technical life assessment was performed in 2009 to investigate the condition of the converter station facility and explore all possible options to extend its useful lifetime.

The assessment indicated that a cost effective solution to extend the life and increase the rating of the Highgate converter station was to replace the major components that were approaching the end of their respective useful lifetimes and upgrade the equipment that limited the maximum power transfer at 40°C.

The following sections cover the main upgrades implemented for Highgate converter Stations as well as the execution of project.



Figure 1 Highgate Back-to-back Converter Station

### 1.1 Upgrade of the HVDC Controls and Protections

The original control system was one of the first HVDC digital control systems based upon circa 1984 ASEA PLM language digital controls. The overall performance of the control system had been excellent for the first 20 years of operations. Shortly after that timeframe, the controls began to stall on a regularly basis and even misoperate leading to increased forced outages. In addition, the remote alarming system failed every few months.

The obsolete control and protection system was replaced with ABB's MACH2 system. The MACH2 system allows for visual real-time monitoring of controls, protections, cooling systems; which provide the user information on the operation, troubleshooting, and maintenance of the facility. During system

events, the TFR that is embedded into the control system significantly improves the analysis capabilities. Figure 2 (a) and (b) shows the control room before and after the upgrade.



(a) Old Control Desk



(b) New Control Desk

Figure 2 Control Room before and after replacement

### 1.2 Upgrade of the thyristor valves to maintain the facility reliability

The original oil-filled snubber capacitors of the thyristor valves were replaced with oil free capacitors eliminating exposure to oil leaks and reducing the risk of fire in the valve hall. The thyristor control units were replaced with modern thyristor control units that will protect the valves more efficiently and provide additional data to the control system. In addition, 79 additional thyristors were purchased as spares to ensure enough spares to cover the guaranteed failure rate over the next 30 years.

### 1.3 Upgrade of the valve cooling system to support transfer capability up to 225 MW

The valve cooling system was approaching its twenty-five years of designed service life when the assessment was made. In the years leading up to the assessment, high conductivity in the fine water system became an increasing concern. Investigations during the assessment lead to the discovery of rust particles in the fine water loop.

Another significant issue was increased pump motor bearing failures. The skids connection points began to wear and become elongated; the motors were no longer sufficiently attached leading to increased bearing failures. Figure 3(a) shows the old water pump and processing skids. Lastly, the original system did not have any redundant cooling towers which lead to reductions of the converter power order for maintenance.

The old valve cooling system was replaced with a new cooling system to ensure that the continuous overload capability of the plant can be maintained at 225 MW at an increased maximum ambient temperature of 40°C. The new valve cooling system includes a new Pump Cooling System (Figure 3(b)), Outdoor Cooling Towers and new Cooling Controls Interface. The piping into the valves was retained.



(a) Fine Water Pump and Processing Skid



(b) New Pump Cooling System

Figure 3 Water Pump Cooling System

### 1.4 Replacement of Smoothing Reactor

The original smoothing reactor has a 40 year designed life and was evaluated to be in good condition. It was rated for 3600 A for the continuous operation at 200MW. As part of the refurbishment, the converter would be uprated to a nominal continuous operation of 225 MW at 40°C, a new air core smoothing reactor was thus ordered and installed with a rating of 4200 A. The existing smoothing reactor was retained and used as a spare.

### 1.5 Project Planning and Execution

The project was planned and scheduled for the shortest outage time to minimize the disturbance to the system. Figure 4 shows timeline of the Highgate Converter Station Refurbishment Project. The project team consists of facility owner/operator, HVDC technical consultants, HVDC suppliers and its subcontracts.

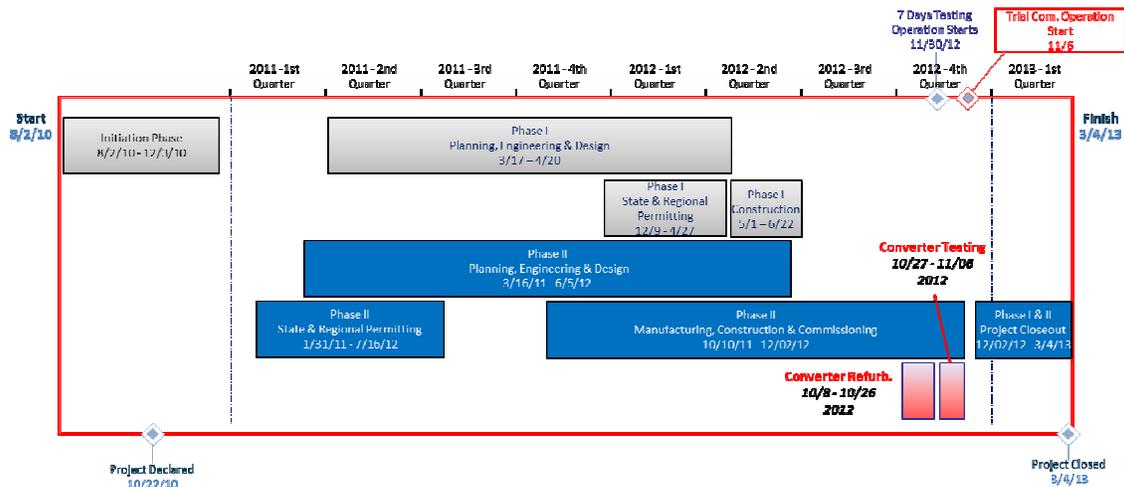


Figure 4 Overall Project Timeline

A total of four outages were planned throughout the project for the removal of existing parts and equipment and installation of new equipment as shown in Figure 5.

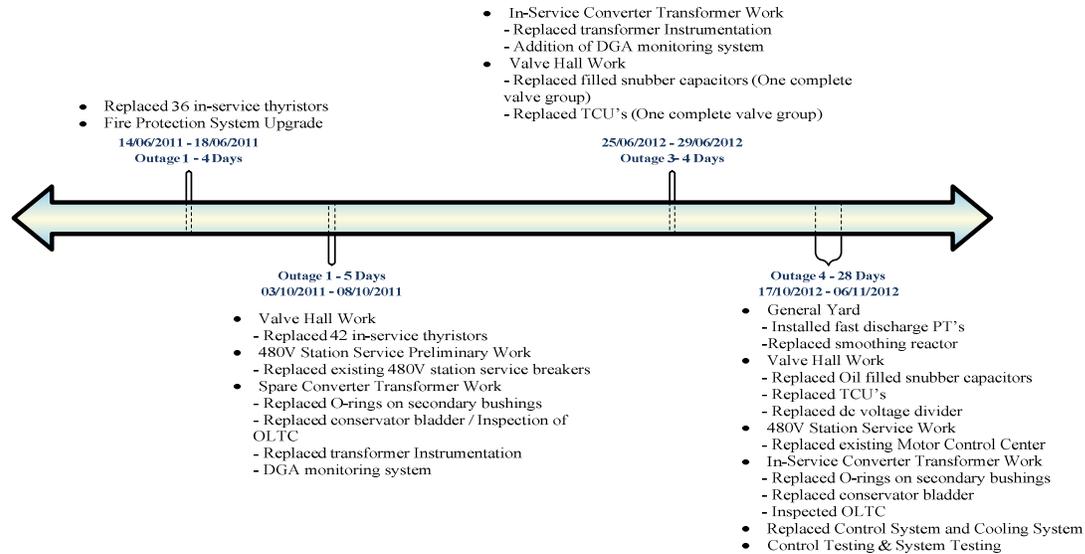


Figure 5 Project Construction Sequence (Planned Outages)

After the successful upgrade, the Highgate converter station is expected to operate for another twenty-five to thirty years with the improved system stability and increased capacity for power transfer to Vermont electrical system. The converter station has been operating at its updated dc power of 225MW most of time since commissioning.

## 2. Essex STATCOM Refurbishment

The Essex STATCOM was designed and implemented with the unique features specified by VELCO.

It is rated for -41 MVAR (Inductive) and +133 MVAR (Capacitive). The system consists of two separate STATCOM units, each containing three inverter units. The inverters interface to 115 kV bus through two 115 kV/3.2 kV transformers. Each of the six inverters is capable of producing 12.5 MVAR capacitive or inductive reactive power, yielding a +/- 37.5 MVAR dynamic reactive power rating at each STATCOM terminal. Each STATCOM unit also has a non-switchable 5 MVAR filter bank at the 3.2kV bus as shown in Figure 2.

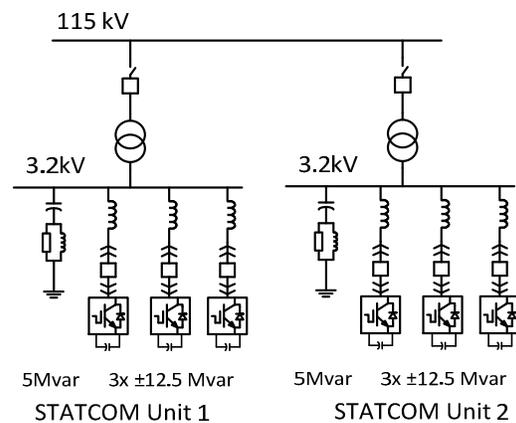


FIGURE 6 - CONFIGURATION OF ESSEX FACTS DEVICE

It provides an automatic reserve capacity control with multiple levels: High, Medium and Low to ensure dynamic capacity and minimize losses using the shunt capacitors at Essex Substation. This control along with the modular design of the STATCOM's allows for a dynamic range suitable for Vermont's power system even with one inverter out of service. Hence, redundancy for this facility is built into the design rather than in-series spares.

The existing STATCOMs have provided reliable performance since commissioned in 2001. Table A summarizes the forced and scheduled outage data recorded since the operation of Essex STATCOM in 2001. The information is used to calculate the availability based on methodology similar to that outlined in CIGRE B4-590 for the STATCOM as a whole. The STATCOM is considered available as

long as 5 out of the 6 inverters are in service. The data shows that after the replacement of the GTO stacks with GCT stacks in 2002; the availability improved significantly.

Recent changes in the Vermont power system, most notably the development of renewable generation resources, predominantly wind, have increased the importance to maintain the reliability of the facility at a very high level. The facility also remains critical to maintain compliance with transmission reliability standards.

Due to the perceived risk of an extended outage of the facility, a detailed technical investigation was initiated by VELCO to assess the existing condition of the Essex STATCOM and identify options to address the above concerns and extend its useful life.

The assessment of Essex STATCOM included a review of equipment condition, known performance issues and deficiencies over the last thirteen years, and availability of critical spares. The results of technical assessment of Essex STATCOM are summarized in Table 1.

**Table 1 – Summary of Assessment of Essex STATCOM Equipment**

Equipment/ System	Assessment Results	Minimum Requirement to Extend Reliable operation of Essex STATCOM
<b>AC Switchyard Equipment</b>	<b>Good Condition</b> Expected remaining life greater than 25 years.	No ac equipment upgrades are needed. Asset optimization to utilize the spare in a rotation with the in service transformer units.
<b>STATCOM</b>		
Inverters	<b>Inverter performance limitations</b> Due to overcurrent gate blocks that lead to DC capacitor overcharging during certain faults.	Install active DC Capacitors discharge circuits to shorten gate block time.
Valve Cooling & Control	<b>Main cause for facility outages</b> Inadequate design Obsolete control PLCs Piping Leaks Water cooled resistor leaks Ethylene Glycol Coolant Offline redundancy in outdoor coolers	Replace the control PLCs with a more modern design. Requires manually recoding and testing the control programs. Ensure adequate spares of deteriorating components such as water cooled resistors. Investigate options to permanently seal leaks and protect staff from ethylene glycol exposure. Investigate possibility to place redundant cooler into service rather than leaving it off line.
Valve Control & Protection	<b>Obsolete control hardware</b> Obsolete electronic firing control cards Control system reliability is adequate at present but could deteriorate with increasing age. Onsite refurbishment of printed circuit boards is required as spare firing control cards can no longer be obtained.	Ensure spares of all cards are available and functional Develop plan for firing control printed circuit board capacitor replacement one inverter at a time. Upgrade interfaces so the communications will be more visual friendly
<b>SAS</b>	<b>Obsolete and unreliable</b> Obsolete control hardware Obsolete operating system software Failures of DAC boards and spares no longer available Limited documentation and test equipment of the circuit boards Increased failures and wrong readings associated with RIO	Replace the entire SAS system with most up-to-date computer hardware and supported operating system, and new HMI components and software. Develop emergency action to deal with multiple failures associated with RIO.
<b>Ancillary (HVAC)</b>	<b>Compromised performance at high output</b> Output of STATCOM is dependent on the availability of the valve hall HVAC without any redundancy	Completely re-design the HVAC system and add redundancy.

The AC switchyard equipment and components are generally in good conditions and no specific equipment upgrades are required to extend its useful life. However, much of the remainder of the equipment has surpassed or is approaching the end of its useful life expectancy, and VELCO has been experiencing an increasing number of failures.

The risk of declining reliability performance of this facility is compounded by increasing equipment age, declining availability of replacement parts, obsolescence of software and digital hardware and

increasing maintenance requirements all at a time when the demands for high reliability of the equipment are increasing. The condition assessment matrix below supported the decision making process for the best course of action.

Based on the overall assessment, available technical alternatives for this project as well as the project execution risk in the event of a new project, it was determined that the most economical approach to extend the life of the Essex STATCOM is to reuse the AC yard equipment, which is in good to fair condition, and to refurbish the equipment and systems that are either obsolete, have had evidence of failure issues in the past, or which have significant performance limitations. The requirement for refurbishment or replacement as listed in Table 1 was considered as a minimum so that the facility will continue to have the same or better steady state and dynamic range output capability, response performance and reliability.

The overall assessment indicated significant work was needed to ensure continued reliable operation of the facility. The magnitude and complexity of the work especially on the cooling systems, HVAC system and control and protection systems is beyond what could reasonably be handled within VELCO engineering or carried out under routine maintenance. It was concluded that the only reasonable way to manage the work and complete it in a short time without the risk of a prolonged outage would be to engage a qualified contractor to perform the work.

### 3. SUMMARY

This paper presents VELCO's latest experience with Highgate BTB converter station refurbishment project and ongoing Essex STATCOM refurbishment project. There were many challenges and lessons learned during the entire project execution of Highgate converter station, which has become valuable project input for the planning and execution of Essex STATCOM refurbishment project.

Essex STATCOM refurbishment project has moved into the execution phase with the kick-off meeting held in July 2015. The upgraded Essex STATCOM is scheduled to be in operation in May 2017.

#### Appendix A - Reliability and Availability of Essex STATCOM

**Table A - Scheduled and Forced Outage Summary Based on Historical Record**

Year	Scheduled Unavailability	Forced Unavailability	Total Availability
2001	0.03%	0.04%	99.90%
2002	9.36%	6.44%	84.21%
2003	0.54%	0.00%	99.41%
2004	0.52%	4.12%	95.36%
2005	0.24%	4.50%	95.26%
2006	0.65%	0.04%	99.31%
2007	0.26%	0.16%	99.58%
2008	0.42%	0.10%	99.48%
2009	0.96%	0.24%	98.80%
2010	0.36%	0.04%	99.60%
2011	0.45%	0.02%	99.53%
2012	0.27%	0.06%	99.93%
2013	0.71%	0.00%	99.29%