# The VELCO STATCOM-Based Transmission System Project


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**Abstract:** The Vermont Electric Power Company, Inc., (VELCO) initiated a major transmission system project involving a reconfiguration of a key 115 kV substation and the installation of a STATCOM-based dynamic reactive compensation system. This project has an in-operation date of May 2001. The paper gives an overview of the VELCO transmission system project with emphasis on the STATCOM-based dynamic reactive compensation system. The major items with respect to the STATCOM system addressed in this paper include:

- Power system requirements
- STATCOM system description
- STATCOM system layout
- STATCOM construction and installation



**Keywords:** FACTS project, Static Synchronous Compensator (STATCOM), power electronic equipment, transmission system projects


## 1. INTRODUCTION

As the utility industry in the United States continues to move forward with deregulation, financial and market forces are demanding a more optimal and profitable operation of the power system with respect to generation, transmission, and distribution. In addition, with the recent concerns at the US government level over transmission system reliability, including comments from the Federal Energy Regulatory Commission (FERC), more efficient utilization and control of existing networks are required. Electricity is increasingly being considered as a commodity in the United States. As a result, transmission systems are being pushed closer to their stability and thermal limits, while the focus on the quality of power delivered is greater than ever.

Now, more than at any other time in the history of the electric utility industry, the application of advanced control technologies is critical for the reliable and secure operation of power systems. Power electronics based equipment, such as Flexible AC Transmission Systems (FACTS) and Custom Power technologies, which implement voltage sourced converter based technology, constitute some of the most suitable and proven technical advancements to address the new operating challenges being presented today.

The potential benefits of FACTS equipment are now widely recognized by the power system engineering community [1,2,3,4,5]. As an advancement within the FACTS arena, voltage sourced converter based technology has been successfully applied in a number of projects [6,7,8,9,10,11,12,13,14, 15]. In addition to the applications described in the these references, there are several other recently announced voltage sourced converter based FACTS installations planned for operation in 2000 and 2001 in the USA, in the states of Vermont [16], Texas and California (no technical references are yet available for citation for projects in the latter two states). All of these voltage sourced converter based applications are in addition to the established FACTS technologies of Static Var Compensation (SVC) [17] and Thyristor Controlled Series Compensation (TCSC) [18,19,20,21].

This paper summarizes an application of a STATCOM-based dynamic reactive compensation system in the United States, currently under construction, at the Vermont Electric Power Company's 115 kV Essex Substation.

## 2. POWER SYSTEM REQUIREMENTS

The STATCOM is being applied to compensate for heavy increases in summertime electric usage, which have rendered the existing system increasingly vulnerable to failure in the event of problems elsewhere on the transmission system. The system requirements (i.e., the purpose of the STATCOM) can therefore be categorized as dynamic reactive compensation needed for fast voltage support during critical contingencies. Figure 1 shows a one-line diagram of the VELCO 115 kV system in the vicinity of the Essex STATCOM location.

There are secondary power system control issues associated with this STATCOM application. The first issue is with the STATCOM "Reactive Power Reserve". For this application, the STATCOM's primary role, as noted above, is to provide dynamic reactive compensation required for fast voltage support during critical contingencies. Therefore, it is desirable to "reset" the STATCOM output after a contingency occurs. This allows for the slower devices, such as nearby capacitor banks, to control the voltage profile as it responds to the daily load cycle.


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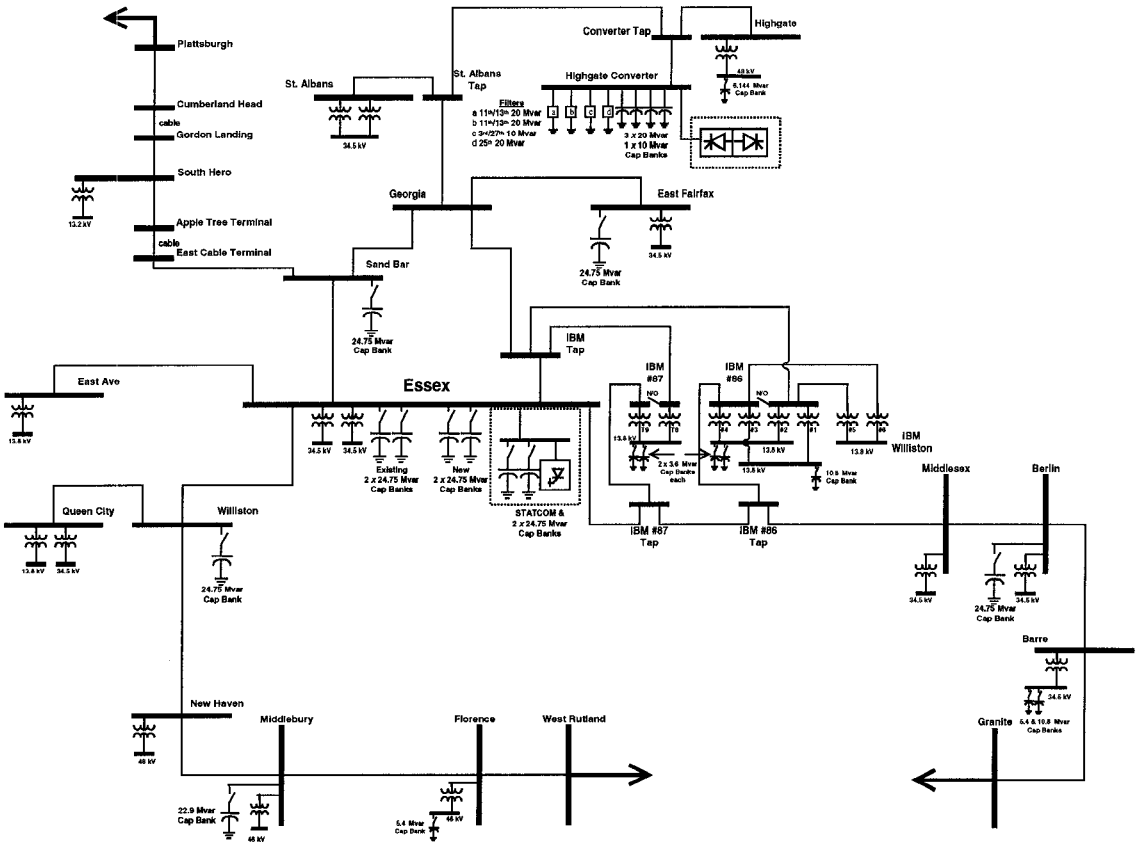


*Figure 1. One line diagram of the VELCO 115 kV system in the vicinity of the Essex STATCOM.*

Therefore, the STATCOM control is coordinated with several local and remote capacitor banks to perform this "reset" function. 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 East Fairfax substations. The control logic decision on when and where to switch a capacitor bank is based on the output of the STATCOM or the local voltage deviation, the availability of the various capacitor banks, and the voltage at each of the buses.

Another secondary power system control issue associated with this STATCOM application is the fact that the Highgate Back-to-Back HVDC tie, connecting the Vermont system to the Hydro Quebec system, is located electrically near to the STATCOM (within about 35 circuit-miles). However, it was determined through simulations that there are no significant concerns with interaction of the STATCOM control with the Highgate control for either the fast regulators or slow capacitor banks/filter switching control.

All studies for the system and equipment design aspects of the STATCOM system were performed with cycle-by-cycle type analysis programs (such as EMTP or EMTDC) and with positive sequence type programs (such as PSLF).

## 3. STATCOM SYSTEM DESCRIPTION

The STATCOM system currently being installed at the Vermont Electric Power Company's Essex 115 kV substation has an effective rated capacity of +133/-41 MVA. As shown in Figure 2, the STATCOM system consists of two groups of voltage sourced converters (43 MVA each) and two sets of shunt capacitors (24 Mvar each). Each 43 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 43 MVA STATCOM groups are connected to the 115 kV system via two three-phase inverter transformers rated at 43 MVA, 3.2 kV/115 kV. The main power semiconductor devices incorporated in the converter design are 6 inch gate turn-off thyristors, rated at 6 kV, 6 kA. These devices are arranged in each module, forming a 3-level inverter circuit, which reduces the harmonic current as compared to a 2-level design. The control of the inverter is achieved with a 5-pulse PWM (pulse width modulation), which further decreases the harmonics as compared to 3-pulse or 1-pulse PWM control. Because of these two aforementioned features, only a small high-pass harmonic filter is required on the AC side (5 Mvar at 3.2 kV for each of the STATCOM groups). A key feature of the inverter is that the snubber energy is regenerated to the DC capacitors

in the inverter circuit for a lower loss operation. The 24 Mvar shunt capacitors are connected directly at the 115 kV system. Each GTO-based STATCOM group and each shunt capacitor bank are supplied to a 115 kV bus via 115 kV SF-6 Gas Circuit Breakers (GCB's). A main disconnect switch is provided to connect the entire STATCOM system to the Essex Substation's 115 kV ring bus position.

Some of the main benefits of this STATCOM system design are as follows:

- rapidly responds to system disturbances
- provides smooth voltage control over a wide range of operating conditions
- incorporates a significant amount of built-in redundancy (i.e., any one or more of the 12.5 MVA modules, or 43 MVA groups can be out of service while all others remain in operation at their full rated capability). See Figure 2.

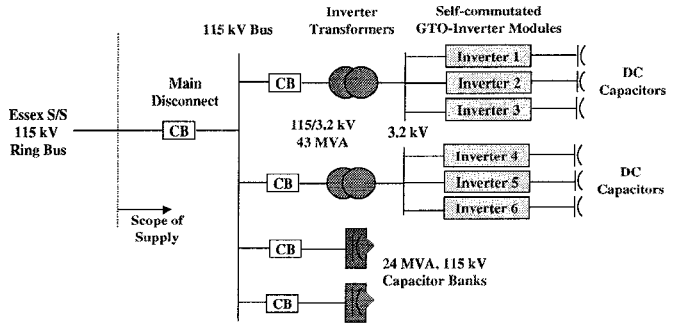


*Figure 2. Single-line diagram representation of Essex +133/-41 MVA, 115 kV STATCOM system.*

## 4: STATCOM SYSTEM LAYOUT

Figure 3 shows an overall physical layout diagram of the STATCOM system. The 115 kV ring bus position at Essex is to the far left of the diagram. The 24 Mvar capacitor banks and the 43 MVA inverter transformers are connected to the overhead buswork brought out from this position, as depicted in the middle portion of the diagram. The 5 Mvar, 3.2 kV filters are also installed outdoors on the low side of the inverter transformers. Existing 115 kV overhead transmission lines coming into the station cut across the top of the FACTS yard from the upper left of the diagram sloping towards the middle right. The upper right portion of the diagram shows the five sets of inverter cooling system heat exchanges. The large rectangular shape to the far right of the diagram is the STATCOM building.

A more detailed representation of the STATCOM building is shown in Figure 4. The building contains the converter modules; protection, automation, and control panels; cooling system controls; low voltage switchgear; and auxiliary systems. There are two separate inverter halls, as well as separate halls for the protection and control, and for the cooling systems. The connections from the building equipment to the outdoor equipment are made via underground cabling and conduit.

In addition to the STATCOM building, a second building has been erected by VELCO at the Essex substation, which contains some portions of the protection and control equipment. All interfacing between the STATCOM system and the VELCO systems are done via control wire cabling connections between the two buildings. The STATCOM control system is able to not only control the operation of the STATCOM inverters and the two 24 Mvar capacitor banks, but it is also designed to provide remote capacitor bank control in order to maintain a steady-state voltage profile during normal system operating conditions. The control is for remote capacitor banks at Essex Substation as well as three additional neighboring substations, as previously discussed. All of the control is interfaced with the VELCO SCADA system.

## 5. STATCOM CONSTRUCTION AND INSTALLATION

At the time of this article's submission, the construction phase of the STATCOM system was well underway. Some of the more difficult challenges with the installation have been from a physical space limitation. Due to a restriction on the amount of available land at the substation site, the FACTS yard footprint was extremely limited. A hillside at the site was excavated in order to provide space for the STATCOM building. Figures 5 through 8 show recent photographs of the site construction and installation work, with various views of the FACTS yard and the equipment and building installations.

The completion of this full turnkey project is expected to be on schedule, with an in-service date of May 1, 2001. Currently, various equipment manufacturing has been completed and is being delivered to the site. Simulator testing of the STATCOM inverters and control system will be completed at the time of this article's publication and they will have been shipped to the site.

## 6. SUMMARY

The installation of a +133/-41 MVA, 115 kV Static Reactive Compensator (STATCOM) system is currently underway at the Vermont Electric Power Company's (VELCO) Essex substation in Burlington, Vermont. The STATCOM is being applied to compensate for heavy increases in summertime electric usage, which have rendered the existing system increasingly vulnerable to failure in the event of problems elsewhere on the transmission system. The STATCOM is a state-of-the-art Flexible AC Transmission System (FACTS) technology that uses advanced power semiconductor switching techniques to provide dynamic voltage support, power system stabilization, and enhanced power quality for

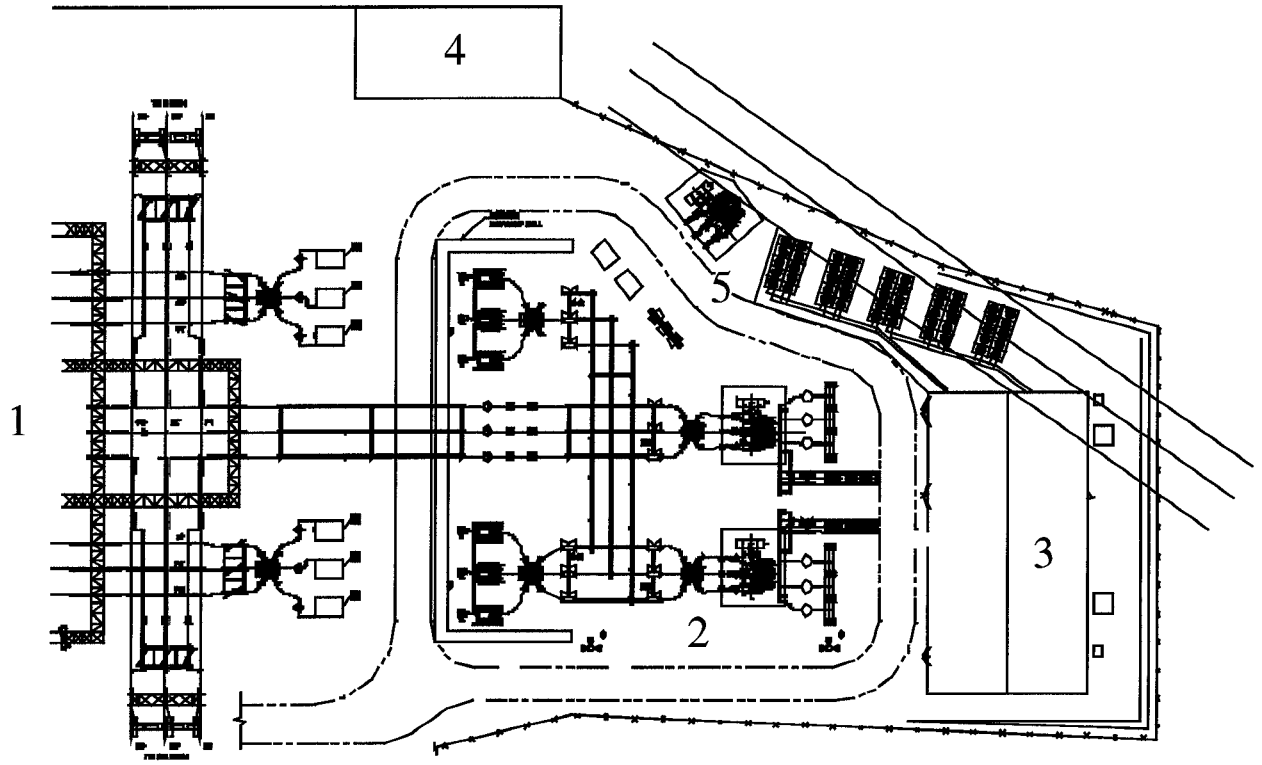


*Figure 3. Overall layout diagram of Essex +133/-41 MVA, 115 kV STATCOM system (1=VELCO 115 kV yard, 2=FACTS yard, 3=FACTS building, 4=VELCO building, 5=Heat exchangers)*

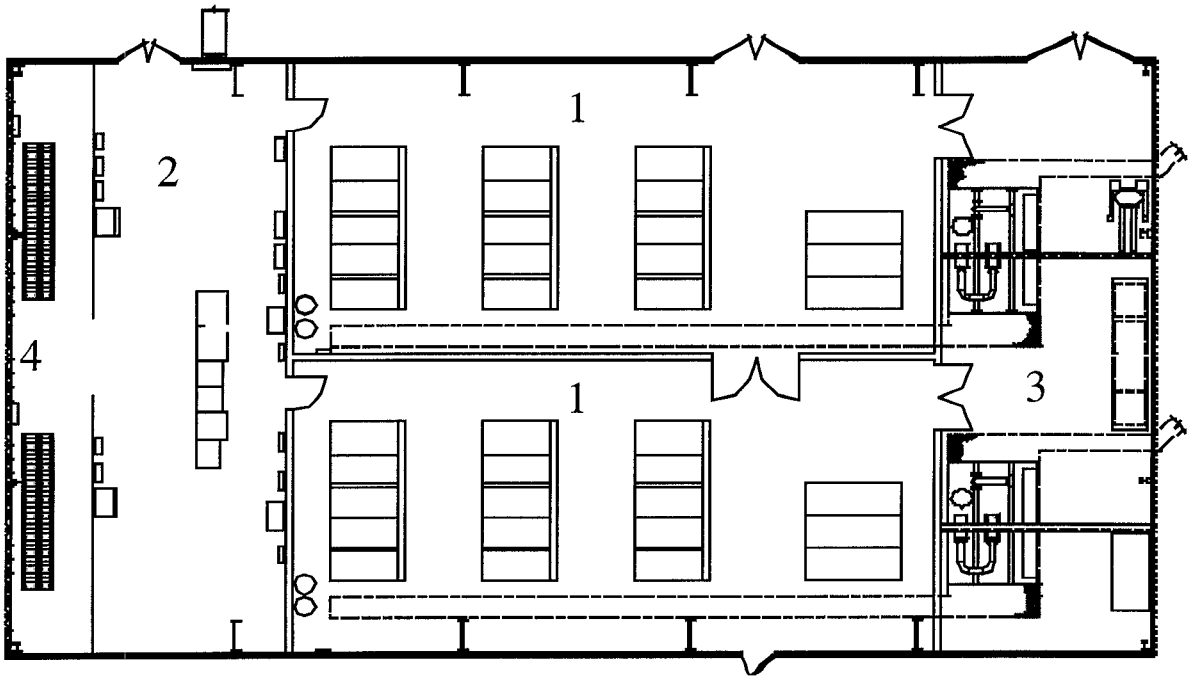


*Figure 4. Building layout diagram of Essex +133/-41 MVA, 115 kV STATCOM equipment (not to scale) (1=Inverter rooms, 2=Protection and control room, 3= Mechanical room, 4=Battery area)*

transmission and distribution system applications. This STATCOM system, rated +133/-41 MVA at 115 kV, including the associated shunt capacitor banks and filters, uses gate turn-off thyristors and offers high reliability based on a modular converter design configuration. The system also includes inverter transformers, capacitor banks, switchgear, cooling equipment, and an automated protection and control system. The scheduled in-service date for the project is May 1, 2001.

It is anticipated that an increasing number of similar applications will be required throughout the United States, North America, and other parts of the world in the very near future, to further provide solutions for the enhancement of power system operation, performance, and control.

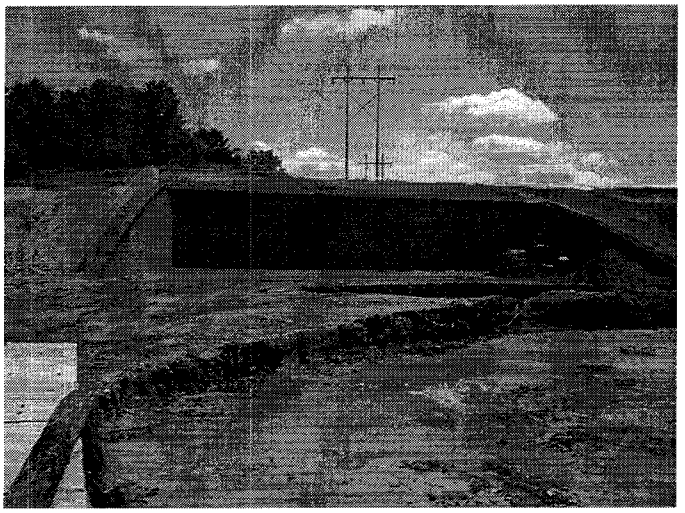

*Figure 5. View of excavation and retaining wall behind STATCOM building location (June 2000).*

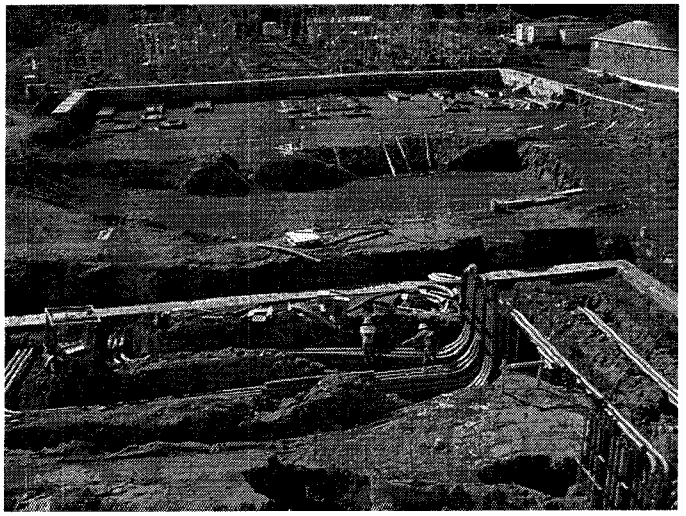

*Figure 6. View towards FACTS yard of STATCOM building foundation and conduit work, Essex 115 kV ring bus, and VELCO building (upper right) (July 2000).*

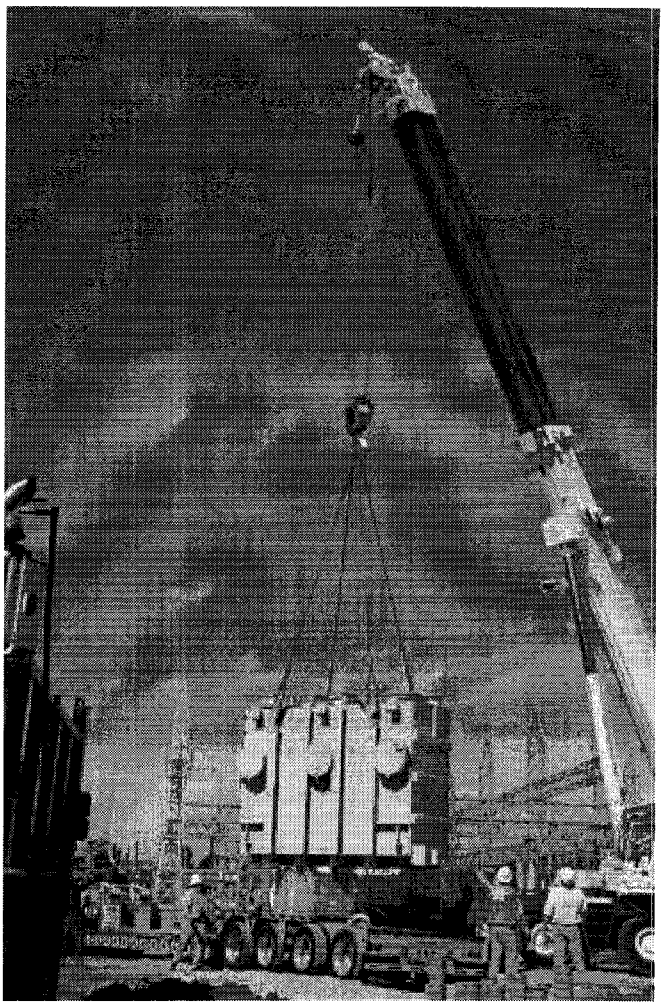

*Figure 7. Inverter transformer being unloaded on site (September 2000).*

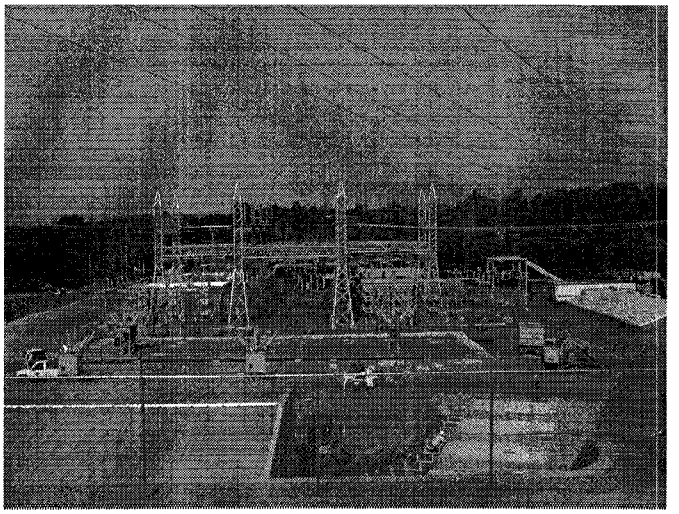

*Figure 8. View from top of STATCOM building of FACTS yard (with GCB's) and Essex 115kV station and VELCO building (middle right) (September 2000).*

## ACKNOWLEDGEMENTS

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## BIOGRAPHIES

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