Field Demonstration of a Distribution Static Compensator Used to Mitigate Voltage Flicker

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Abstract: The DSTATCOM is a fast response, inverter based power controller that provides flexible voltage control at the point of connection for improving the power quality in distribution systems. It can also provide instantaneous power factor correction to improve line utilization and minimize energy losses. The DSTATCOM is an alternating, synchronous voltage source connected in shunt (parallel) to the distribution three-phase feeder circuit via a coupling transformer. It can exchange reactive power with the distribution system by varying the amplitude and phase angle of an internal voltage source with respect to the line terminal voltage, resulting in controlled current flow through the coupling transformer. The DSTATCOM is a solid-state, dc to ac voltage-sourced inverter, utilizing advanced power semiconductor switching devices. It can effectively replace conventional voltage and var control elements, load tap changing transformers, voltage regulators, and switched capacitors used in distribution systems. This paper presents the results of field tests conducted on the prototype model which was connected at a lumber mill for the purpose of mitigating running voltage flicker.

Key Words: power quality, distribution systems, static compensator, voltage flicker

I. Introduction

In 1995, BC Hydro was approached by a local lumber company which was planning to install a 1200 Hp whole log chipper at their mill site. Previous experience with this type of equipment indicated that considerable voltage flicker would occur on the distribution system as a result of the operation of the chipper. BC Hydro was reluctant to allow this type of load to be connected to the system because of anticipated complaints from other customers who were connected to this line.

Four options were considered for this customer, including:

1. a dedicated feeder
2. reconnection to a nearby 60kV line
3. a change in the chipper design, and
4. install equipment which would reduce the voltage fluctuations to an acceptable level.

The lumber company asked BC Hydro to investigate the availability and costs of mitigating equipment.

Investigation revealed that the Electric Power Research Institute (EPRI) was sponsoring the development of a static compensator, built by Westinghouse Electric Corporation, that could be applied to a local distribution system experiencing flicker problems. At the time of this inquiry, EPRI was searching for a host utility to test the prototype. The lumber mill was an ideal site due to the nature of its present operation (continuous variations in load current caused by the milling process in the existing plant) and their future plans to install a new log chipper. BC Hydro, EPRI, Westinghouse and the Adams Lake Lumber Co. reached agreement to test the prototype DSTATCOM (Distribution STATic COMpensator). This paper presents the results of the field tests on the prototype unit.

II. Preliminary Data

Detailed studies were conducted to determine the running voltage flicker which would occur for the addition of the new chipper. Running flicker (that is, voltage flicker caused by the normal operation of the mill and not starting flicker) was considered to be the worst case scenario for the residents in the area and was calculated at 2 times motor full load current. The studies were conducted on a number of different design scenarios with the following results:

1 x 1200 hp chipper motor...13.3% Running Voltage Flicker
2 x 600 hp chipper motors...7.1% Running Voltage Flicker
3 x 400 hp chipper motors...4.4% Running Voltage Flicker

From this study, it was evident that the running flicker could be reduced to an acceptable level by changing the design of the chipper.

III. Electro Magnetic Transients Program (EMTP) Studies

Power quality data was gathered for the mill before and after the chipper was installed (and before the installation of the DSTATCOM). The test information was entered into an Electro Magnetic Transient Program (EMTP) model of the complete system. A detailed EMTP model of Adams Lake Lumber system was used to verify the correction capability of the DSTATCOM for improving voltage fluctuations caused by a jam of the chipper.

The studies showed that the DSTATCOM would be very effective in reducing the running voltage flicker from 8% down to 4%. Based on the simulation results, it was decided to proceed with the project at this location.

IV. Site Preparation

BC Hydro was responsible for providing the interface equipment which would connect the DSTATCOM to the distribution line. The interface consisted of:

1. A single span of three phase overhead (rated 25kV)with isolating cutouts
2. Three potential transformers (metering quality) which are used by the DSTATCOM as the voltage feedback signal
3. A 25kVA single phase distribution transformer used to provide auxiliary power to the DSTATCOM
4. A three phase vacuum circuit recloser complete with infinitely adjustable protection settings to allow for an adjustment which would meet any condition
5. Surge arresters located on the source side and the load side of the circuit recloser
6. An underground dip into an in-ground junction box which was located directly under the DSTATCOM
7. A grounding grid completely around the perimeter of the DSTATCOM

V. DSTATCOM Features

The DSTATCOM is housed in a 48 foot truck trailer. The trailer was positioned over the in-ground junction box. Plywood skirting was placed around the bottom of the trailer to prevent unauthorized access to the cabling. Pre-service checks were performed on the various components.

The main components consisting of the main transformer, interphase transformer , Insulated Gate Bipolar Transistors (IGBTs), AC and DC filter capacitors and DC bus were all Doble tested prior to energization.

The auxiliary circuits (precharge circuit, gate drive circuit, blower fans, fibre optic distribution circuit, and main electronics) were all thoroughly checked for correct operation.

The control keypad allows the operator to control the unit and receive information regarding any alarm or trip conditions that have occurred. The keypad has a **MONITOR** mode which allows the operator to monitor various values within the DSTATCOM while it is operating (for example, DC bus voltage, line voltage etc.), a **PROGRAM** mode which allows the operator to change programmed values and START, STOP, and RESET pushbuttons. In the **PROGRAM** mode, there are only three settings which require changing, the voltage setpoint (Vset), the tracking limit, and the tracking rate.

The unit also has numerous safety features including:

1. Door key interlock
2. Capacitor discharge circuit
3. Trailer grounding

The DSTATCOM has a number of protection features (such as overcurrent, overvoltage, etc.) to protect the unit from damage. Each of these protection points causes the unit to trip off line. Each trip condition is time tagged so that the operator can determine what occurred and in what sequence (should multiple trip points be logged). Some trip conditions are less severe than others. For these trips, the DSTATCOM will be allowed to attempt an AUTO RESTART and come on line automatically without operator intervention.

Each trip and alarm point was tested to confirm correct operation prior to placing the DSTATCOM into operation.

VI. DSTATCOM Operation

The DSTATCOM is capable of adjusting the line voltage at this location by ±4.2% (or ±5 volts on a 120V base) between its full buck and full boost condition. It is capable of making these adjustments in one half cycle. There are only three settings to apply to the DSTATCOM, making it very easy to operate. The VOLTAGE SETPOINT adjustment allows the operator to select a percentage value of the base voltage (120V). The setpoint value is the voltage to which the DSTATCOM will try to regulate. The TRACKING LIMIT adjustment is a band limit adjustment. With the tracking limit set high (±5%), the DSTATCOM will attempt to hold the line voltage to the setpoint voltage ±5%. With the tracking limit set low (0%), the DSTATCOM will try to regulate the voltage to the voltage setpoint. Thus the DSTATCOM can be adjusted to act as an extremely fast acting voltage regulator when the track limit is set to 0%. The settings can be optimized to meet the customer's individual requirements. The TRACK RATE adjustment (adjustable from 1 to 600 seconds) is the rate at which the DSTATCOM will adjust to the running voltage level.

Various recordings were taken to evaluate the DSTATCOM's performance. After analysis of the recorded data, it was determined that the large volume of data should be presented in concise formats which were easy to interpret. Two formats were chosen:

1. The RMS voltage levels were measured continuously and voltage vs time graphs were created.
2. The rms voltage levels that were measured were analyzed and plotted on a voltage flicker graph.

Observations of the rms voltage curves, measured on a cycle by cycle basis over a five minute period, show a marked improvement in the voltage waveform. Secondary voltage excursions of 2.4 volts (DSTATCOM out of service) are reduced to 1.6 volts. In addition, the waveform's erratic behavior is reduced to a relatively smooth one.

BC Hydro uses the voltage flicker graph to determine the flicker levels on the distribution system. The data points on the graph are derived from the change in rms voltage levels divided by an average rms voltage level measured over a running 10 second period. The voltage was monitored for a 24 hour period with the DSTATCOM in service and for a 24 hour period with the DSTATCOM out of service. Overall flicker was reduced from a range of 5-8% down to 2½-4%.

Power data for the mill operation over a 24 hour period was analyzed. The DSTATCOM improves the power factor of the mill by 1% when the DSTATCOM is in the tracking mode.

The DSTATCOM utilizes gating of IGBTs to inject or absorb current, resulting in harmonics being injected into the power system. An increase in voltage THD from 1.7% to 2.4% was observed.

VII. Start Up/Prototype Problems

Startup/prototype problems were encountered with the DSTATCOM both during commissioning and after running for a period of time. Problems such as a recloser trip/close race condition and false tripouts during startup (which were caused by noise in the electronics) were encountered. All of the problems were addressed and corrected.

VIII. Conclusions

The DSTATCOM is very effective in reducing running voltage flicker caused by variable electrical loads connected to the distribution system. A voltage flicker level of 7-8% is reduced to an acceptable level of 4 %. This provides benefits to the utility by ensuring that other customers connected nearby are not subjected to high flicker levels. Benefits to the mill are also realized through improved power factor, improved voltage levels, and cleaner electrical supply.

IX. Future Considerations

During the initial commissioning, BC Hydro experienced a number of problems with the interface equipment located outside the DSTATCOM trailer (circuit recloser, potential transformers, surge arresters and distribution transformers). These problems included switching delays, wiring errors and configuration errors. These problems will be eliminated in the future by moving some of the components into the DSTATCOM trailer unit and wiring them in permanently. Also, line CTs will be installed on the distribution line so that the power quality monitor can observe load current.

X. Future Use of the DSTATCOM

The Adams Lake Lumber Mill has now completed a number of changes to ensure that undesirable voltage flicker levels are not produced on the distribution circuit. The chipper design was changed, the loads were balanced throughout the plant, capacitors were added to boost the mill voltage and improve power factor, and a large flywheel was added. All of these changes have now brought the voltage flicker to within acceptable limits without the use of the DSTATCOM.

BC Hydro intends to move the DSTATCOM to new locations where voltage flicker complaints have been encountered. Prior to installation, voltage monitoring and EMTP studies will be conducted to ensure that the DSTATCOM will mitigate the flicker. As well, consultation will occur with the customers to recommend permanent solutions, allowing the DSTATCOM unit to be freed up for use at other locations. The mobile capabilities of the DSTATCOM make it ideal for BC Hydro's intended use.

ACKNOWLEDGMENTS

The Distribution Static Compensator (DSTATCOM) was developed by the Westinghouse Electric Corporation under EPRI Project RP3389-12. The field demonstration described in this paper was conducted by Westinghouse and BC Hydro under EPRI Project WO7023-01. The Adams Lake Lumber Company was instrumental in the success of the project.

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BIOGRAPHIES

James R. Clouston, P.Eng, graduated from the British Columbia Institute of Technology in 1973 with a Diploma in Electrical Power Technology. He continued his studies at the University of British Columbia and received his BaSc degree in Electrical Engineering in 1975. Since graduation, he has been employed with BC Hydro in many facets of the organization. He spent 8 years as a Protection and Control Engineer in two of BC Hydro's major generating stations. Since 1989, he has been in his present position of Senior Engineer in the Distribution Group of the South Interior Regional Engineering department responsible for all aspects of Distribution Engineering. He has received the EPRI Innovator Award for his work on the DSTATCOM.

James H. Gurney, P.Eng. graduated in 1971 from the University of British Columbia, Canada, with a Bachelor of Applied Science in Electrical Engineering. He joined BC Hydro in 1971 where he has worked in a number of engineering and management roles. He was involved in the design of many of BC Hydro's major hydroelectric projects constructed during the 1970's and 1980's. In 1989, he was appointed Manager of BC Hydro's Protection and Control Design Department, responsible for the design of protection and control systems for all generation, substations and related facilities in the 10,000MW BC Hydro system. In 1994, he was appointed Executive Assistant to the Vice President of Engineering and Construction and in 1995 he was appointed Executive Assistant to the Senior Vice President, Transmission and Distribution. His current responsibilities include management of BC Hydro's Strategic Research and Development portfolio. He is a registered Professional Engineer in the Province of British Columbia and a Senior Member of IEEE. He has been involved in the development of a number of IEEE standards. He is a past Chair of the IEEE Hydroelectric Power Subcommittee and a recipient of the IEEE Energy Development and Power Generation Committee Distinguished Service Award. In 1998, he was appointed to the Standards Board of the IEEE Standards Association.

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