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NYPA Marcy FACTS Project - Phase II

Convertible Static Compensator (CSC)

Marcy Inter-line Power Flow Controller (IPFC)

Stability Study

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Introduction

The New York Power Authority has installed a Convertible Static Compensator (CSC) at its Marcy 345 kV transmission station. The Marcy station is located in the central region of New York State and is considered critical to the reliability of the New York Bulk Power System.

The CSC project was developed in two phases. Phase I consisted of commissioning the Marcy CSC shunt Static Compensator (STATCOM) mode and the installation of a 135 MVAr shunt capacitor bank at the Oakdale 345 kV station. In the STATCOM mode, the CSC provides post-contingency steady state and dynamic shunt MVAr support to the New York bulk power grid similar to the way the Fraser and Leeds Static Var Compensators (SVCs) are operated. The Marcy STATCOM is nominally rated +/-200 MVAr at 345 kV with two power inverters in service. The STATCOM also can be operated with a single power inverter in service at a nominal rating of +/-100 MVAr although it is not expected that this configuration would be used regularly and most likely would be reserved for maintenance conditions. The Marcy STATCOM was placed in service and authorized for commercial operation on April 11, 2001.

Phase II of the project consists of operating the CSC in various other combinations of shunt and series modes as well as the addition of a 200 MVAr capacitor bank at Edic 345 kV station. The Phase II CSC combinations include: STATCOM-Static Series Synchronous Compensator (SSSC) mode, Unified Power Flow Controller (UPFC) mode and Inter-line Power Flow Controller (IPFC) mode. The different modes are achieved by connecting various combinations of the two 100MVA power inverters to the 345kV system via the 200MVA shunt transformer, two 100MVA series transformers and the dc link between the inverters. Additionally, the 100MVA series transformers are equipped with thyristor and circuit breaker bypass devices on the low-voltage side and circuit breaker bypass devices on the high-voltage side to protect the power inverter equipment from potentially damaging overcurrents. (Refer to the one-line diagram attached.) In the IPFC mode, the dc link is in service and power transfer is permitted between the two series-connected inverters.

A dynamics study report dated September 28, 2001 that covered the STATCOM-SSSC mode was approved by the NYISO Operating Committee on November 14, 2001. In addition a dynamics study report dated March 15, 2002 that covered the UPFC mode was approved by the NYISO Operating Committee on May 23, 2002. This report will cover the IPFC mode. Commercial operation of the STATCOM-SSSC and UPFC modes of Phase II associated with the UNS-18 line is planned for the winter of 2002. Commercial operation of the IPFC mode as well as the STATCON-SSSC and UPFC modes associated with the UCC2-41 line is planned for the spring of 2003.

This report documents the results of transient stability studies that were conducted to determine the impact on bulk power system dynamics for the IPFC modes of the CSC project. The studies covered two IPFC modes:

1) 100 MVA IPFC master series inverter on the Marcy-New Scotland 345kV transmission line (UNS-18) and 100 MVA IPFC slave series inverter on the Marcy-Coopers Corners 345 kV transmission line (UCC2-41);
2) 100 MVA IPFC master series inverter on the Marcy-Coopers Corners 345 kV transmission line (UCC2-41) and 100 MVA IPFC slave series inverter on the Marcy-New Scotland 345kV transmission line (UNS-18).

The report is not seeking to increase or determine new transient stability limits for NYISO interfaces. Rather, the study demonstrates that the existing NYISO dynamics limits are secure for these CSC IPFC configurations. This stability assessment has been done in accordance with all applicable NYISO, NYSRC and NPCC rules and procedures.

Recommendation

Based on the results provided in this report, it is recommended that the Marcy CSC IPFC modes examined in this study be approved for use on the New York Bulk Power System. Under the IPFC modes examined, all contingency cases tested showed positive stability swing damping at margined transfer levels based on existing NYISO stability limits. There was a variation in the amount of damping depending on the series voltage injection setting and the type and location of the tested contingency. The stability testing demonstrates that existing NYISO dynamics limits for all lines in service are secure with these IPFC modes in service.

Study Method and Results

IPFC Models for Load Flow and Dynamics

IPFC Load Flow Model

The Marcy CSC IPFC mode is represented in the load flow with PTI's PSS/E FACTS control device model using the appropriate setpoints and limits. This model first became available in PSS/E rev. 28. PSS/E rev. 29 is required to model constant series voltage injection which is the control mode that is expected to be used. Two separate IPFC models were added to the load flow base case to provide flexibility in setting up transfer cases with the IPFC master controller in either the UNS-18 or UCC2-41 lines. A small reactance (0.0003pu) was added in series with the line to account for the series transformer.

IPFC Dynamics Model

The IPFC dynamics model was developed by Siemens as part of the CSC contract and is coded as a PTI user model. The IPFC dynamics model, like the load flow model, can be set for voltage or power control modes, however the voltage control is expected to be used. In the voltage control mode, a constant magnitude voltage will be injected on the inverter side of the series transformer. The angle of the inserted voltage also is held constant with respect to the Marcy bus voltage. The model consists of two series elements; one is designated as the master and the other as the slave. Different control limits are applied depending on whether the series element is in the master or slave mode. Algebraic calculations are used to develop the voltage phasors that are added to the system voltage phasor at the sending end of each line. In the IPFC voltage injection mode, the mode that is the focus of this study, both the master and slave injected voltage settings can be of variable magnitude and angle. However, the master inverter has priority over the slave inverter in achieving its set-point requirements. The model calculates the maximum power that can be transferred by the slave inverter and may limit the master inverter in-phase component of injected voltage to remain within that constraint. In addition, the slave inverter gives priority to the power requested by the master inverter and may reduce its quadrature component of injected voltage to accommodate that constraint.

The protection functions for the IPFC dynamics model (voltage error, phase error and instantaneous overcurrent) are modeled the same way as was done for the Marcy STATCOM-SSSC stability study for series elements and are fully described in that report (refer to report entitled "NYPA Marcy FACTS Project –Phase II Convertible Static Compensator - Marcy STATCOM-SSSC Stability Study" dated September 28, 2001). As with the STATCOM-SSSC study, appropriate commands were placed in the PSAS files to force these protection functions as needed. These are labeled "branchf" or "branchf2" in the contingency PSAS files. The IPFC model includes the same overload functions for the series elements as were used for the STATCOM-SSSC models. The model also includes a zero voltage injection function (electronic bypass) that operates when the sending end bus voltage is greater than 1.15pu or less than 0.3pu. Dynamic modulation of the injected voltage for additional system oscillation damping has not been implemented at the present time.

Dynamics modeling also must consider cases where one of the series inverters (master or slave) is bypassed due to an overload or disconnected due to a line trip. For these cases the series inverter remaining in service (master or slave) reverts to the Half-IPFC mode. In this mode, the dc power transfer is forced to zero. The remaining inverter modifies its voltage reference to ensure that the inverter only injects voltage that is in quadrature to the line current.

Base Case Load Flow Development

The study used the NERC SDDWG/NPCC/NYISO dynamics representation that was used in the Marcy FACTS Project -- Phase II UPFC stability analysis (which included the Oakdale 135MVAr and Edic 200MVAr capacitor banks). This case has a NY control area summer peak load of approximately 28,360 MW. The IPFC load flow models were added to this case. Four pre-contingency cases were set up for the bulk of the stability testing which was done with the master and slave inverters set for maximum capacitive voltage injection: two with 10% margin on Central East interface (approximately 3445MW test level) and two with 10% margin on Moses South (approximately 2200MW test level). Six additional Central East margin cases were set up to for sensitivity testing with various combinations of inductive and capacitive voltage injection for the master and slave inverters.

The margined transfer cases are based on the existing, NYISO transient stability limits-3100MW for Central East and 2000MW for Moses South. The limits are based on four Oswego Complex units (Nine Mile 2, J.A. FitzPatrick, Oswego 5 and Oswego 6), and five Sithe/Independence units and 1170 MW (all AC) Beauharnois, two Chateauguay transformer configuration. These configurations were selected based on previous system studies that have shown to be the most dynamically limiting for the New York contingencies. Cases included only five Sithe units since this configuration is considered to be more severe than the six Sithe unit dispatch. The Leeds and Fraser SVCs were dispatched to approximately 0 MVAr to permit full dynamic support. Based on the results of previous screening studies, it was shown that, when in service, best performance could be obtained with the IPFC master and slave inverters operated in the constant-inverter-voltage injection control mode with maximum rated capacitive voltage injection (0.056pu @ +90° with respect to the line current). Thus, the IPFC load flow model was set to simulate this condition for most testing. As mentioned above, since the IPFC master series injected voltage can be applied at any angle, sensitivity cases were tested which examined various combinations of operation with the master and slave inverters setting at approximately -90°(inductive), and +90° (capacitive) with respect to the line current. See Tables 5 and 6 for a comparison of the pre-fault load flow settings for the series inserted voltage and the effect on line flows in the Central East margined case. Several of the most severe normal criteria contingencies were tested on these cases.

Depending on the series insertion voltage magnitude and angle, the IPFC either increases or decreases the real and/or reactive power flow on the circuit in which it is located. Thus small generation shifts were required to maintain the margin on Central East approximately constant for the cases tested. This results in somewhat different levels of Total East for about the same level of Central East in the transfer cases as shown below:

Table 1 – IPFC Master and Slave Inverters at Maximum Capacitive Setting

Pre -Contingency Flow	Central East Margin As Found (Two STATCOM)	Central East Margin IPFC master in UNS-18	Central East Margin IPFC master in UCC2-41
Central East (MW)	3451	3445	3447
Total East (MW)	6070	6018	6025
UNS-18 (MW/MVAr east) @Marcy	1331/260	1390/312	1390/313
UCC2-41 (MW/MVAr south) @Marcy	864/190	909/214	908/214
IPFC Pdc (MW)	N/A	0	0

Table 2 – IPFC Master Maximum Capacitive, Slave Maximum Inductive Setting

Pre -Contingency Flow	Central East Margin As Found (Two STATCOM)	Central East Margin IPFC master in UNS-18	Central East Margin IPFC master in UCC2-41
Central East (MW)	3451	3453	3445
Total East (MW)	6070	5933	6180
UNS-18 (MW/MVAr east) @Marcy	1331/260	1399/316	1240/191
UCC2-41 (MW/MVAr south) @Marcy	864/190	781/108	949/265
IPFC Pdc (MW)	N/A	0	0

Table 3 – IPFC Master Maximum Inductive, Slave Maximum Capacitive Setting

Pre -Contingency Flow	Central East Margin As Found (Two STATCOM)	Central East Margin IPFC master in UNS-18	Central East Margin IPFC master in UCC2-41
Central East (MW)	3451	3446	3454
Total East (MW)	6070	6180	5934
UNS-18 (MW/MVAr east) @Marcy	1331/260	1242/194	1400/316
UCC2-41 (MW/MVAr south) @Marcy	864/190	948/269	781/109
IPFC Pdc (MW) (positive flow is from Marcy bus to line)	N/A	0	0

Table 4 – IPFC Master Maximum Inductive, Slave Maximum Inductive Setting

Pre -Contingency Flow	Central East Margin As Found (Two STATCOM)	Central East Margin IPFC master in UNS-18	Central East Margin IPFC master in UCC2-41
Central East (MW)	3451	3445	3451
Total East (MW)	6070	6085	6088
UNS-18 (MW/MVAr east) @Marcy	1331/260	1245/193	1251/191
UCC2-41 (MW/MVAr south) @Marcy	864/190	821/148	823/148
IPFC Pdc (MW) (negative flow is from line to Marcy bus)	N/A	0	0

Table 5 – IPFC Master on UNS-14 and Slave on UCC2-41: Inserted voltage - Capacitive, Inductive (Central East Margined Case)

	IPFC Master Capacitive, Slave Capacitive	IPFC Master Capacitive, Slave Inductive	IPFC Master Inductive, Slave Capacitive	IPFC Master Inductive, Slave Inductive
Master Inserted Voltage: Magnitude and Angle with respect to line current	.056pu, 90.0deg	.056pu, 90.0deg	.056pu, -90.0deg	.056pu, -90.0deg
Slave Inserted Voltage: Magnitude and Angle with respect to line current	.056pu, 90.0deg	.056pu, -90.0deg	.056pu, 90.0deg	.056pu, -90.0deg
UNS-14 line flow: MW, MVAr	1390 MW, 312 MVAr	1399 MW, 316 MVAr	1242 MW, 194 MVAr	1245 MW, 193 MVAr
UCC2-41 line flow: MW, MVAr	909 MW, 214 MVAr	781 MW, 108 MVAr	948 MW, 269 MVAr	821 MW, 148 MVAr

Table 6 – IPFC Master on UCC2-41 and Slave on UNS-18: Inserted voltage – Capacitive, Inductive (Central East Margined Case)

	IPFC Master Capacitive, Slave Capacitive	IPFC Master Capacitive, Slave Inductive	IPFC Master Inductive, Slave Capacitive	IPFC Master Inductive, Slave Inductive
Master Inserted Voltage: Magnitude and Angle with respect to line current	.056pu, 90.0deg	.056pu, 90.0deg	.056pu, -90.0deg	.056pu, -90.0deg
Slave Inserted Voltage: Magnitude and Angle with respect to line current	.056pu, 90.0deg	.056pu, -90.0deg	.056pu, 90.0deg	.056pu, -90.0deg
UNS-14 line flow: MW,MVAr	1390 MW, 313 MVAr	1240 MW, 191 MVAr	1400 MW, 316 MVAr	1251 MW, 191 MVAr
UCC2-41 line flow: MW,MVAr	908 MW, 214 MVAr	949 MW, 265 MVAr	781 MW, 109 MVAr	823 MW, 148 MVAr

Contingencies

All contingencies required by the NYISO were tested with all lines in service cases. A list of contingencies tested for this study is contained in Appendix D. In general, all contingencies (Central East, Total East and Moses South contingencies) were tested on the Central East margin case and Moses South faults were tested on the Moses South margin case. Also tested was a single line-ground fault on Scriba-Volney 21 with a stuck R935 breaker at Scriba 345 kV on the Moses South margin case.

Load Model for Dynamics

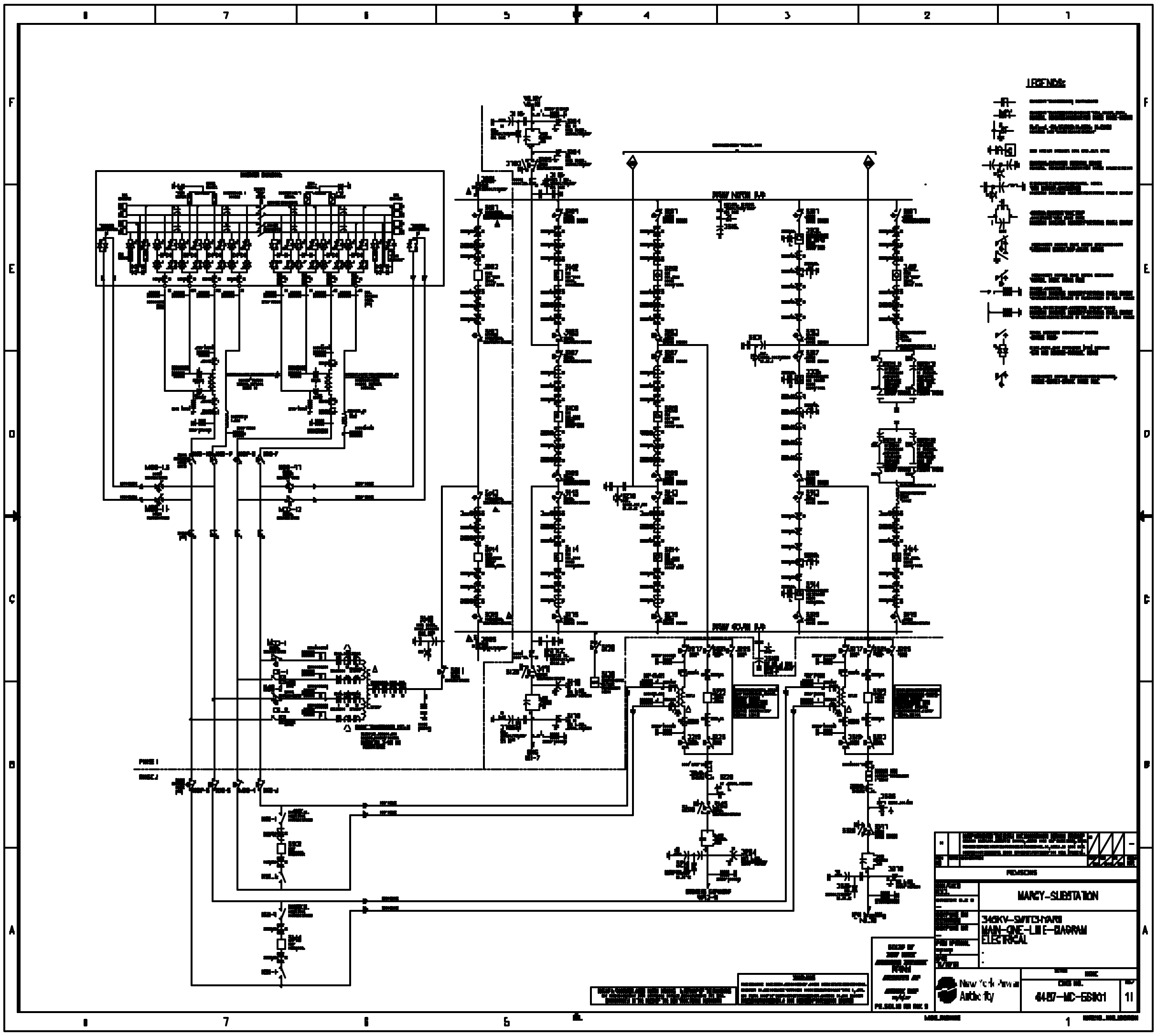
The following table provides the static load model conversion for dynamics in accordance with standard MEN/VEM dynamics study convention.

Region	Real	Reactive
NPCC		
ISO-NE	100% KZ	100% KZ
NYISO	100% KZ	100% KZ
OH	50% KI, 50% KZ	100% KZ
HQ	100% KI	13% KI, 87% KZ
NB	100% KI	100% KZ
NS	50% KI, 50% KZ	100% KZ
MAAC	100% KI	100% KZ
MAPP	100% KI	100% KZ
ECAR	100% KI	100% KZ
MAIN	100% KI	100% KZ
SPP	100% KI	100% KZ
ERCOT/WSCC	100% KI	100% KZ
SERC	100% KI	100% KZ
FLORIDA	90% KI, 10% KP	100% KZ

Results

Load flow summaries and transcription diagrams are contained in Appendix A; simulation plots of all contingencies tested in the maximum capacitive mode are contained in Appendix B. Channel file names that include the term "branchf" or "branchf2" as part of the file name indicates that the protection functions mentioned above are included in the PSAS file. The difference between "branchf" and "branchf2" is "branchf2" forces an immediate permanent bypass of both IPFC series elements as soon as the fault is applied in addition to the protection functions included in "branchf". Appendix C contains plots of selected severe contingencies for the inductive/capacitive, capacitive/inductive and inductive/inductive operating modes of the IPFC; a list of all contingencies tested can be found in Appendix D.

All simulation results with the Marcy IPFC in service indicated stable, damped responses.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APPENDICES
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