FREEDM Systems Center

NSF

NYPA FACTS CSC System

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North Carolina State University

FACTS and HVDC User Meeting

NC STATE UNIVERSITY

ASU Arizona State University

Florida State University

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RWTH Aachen University

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

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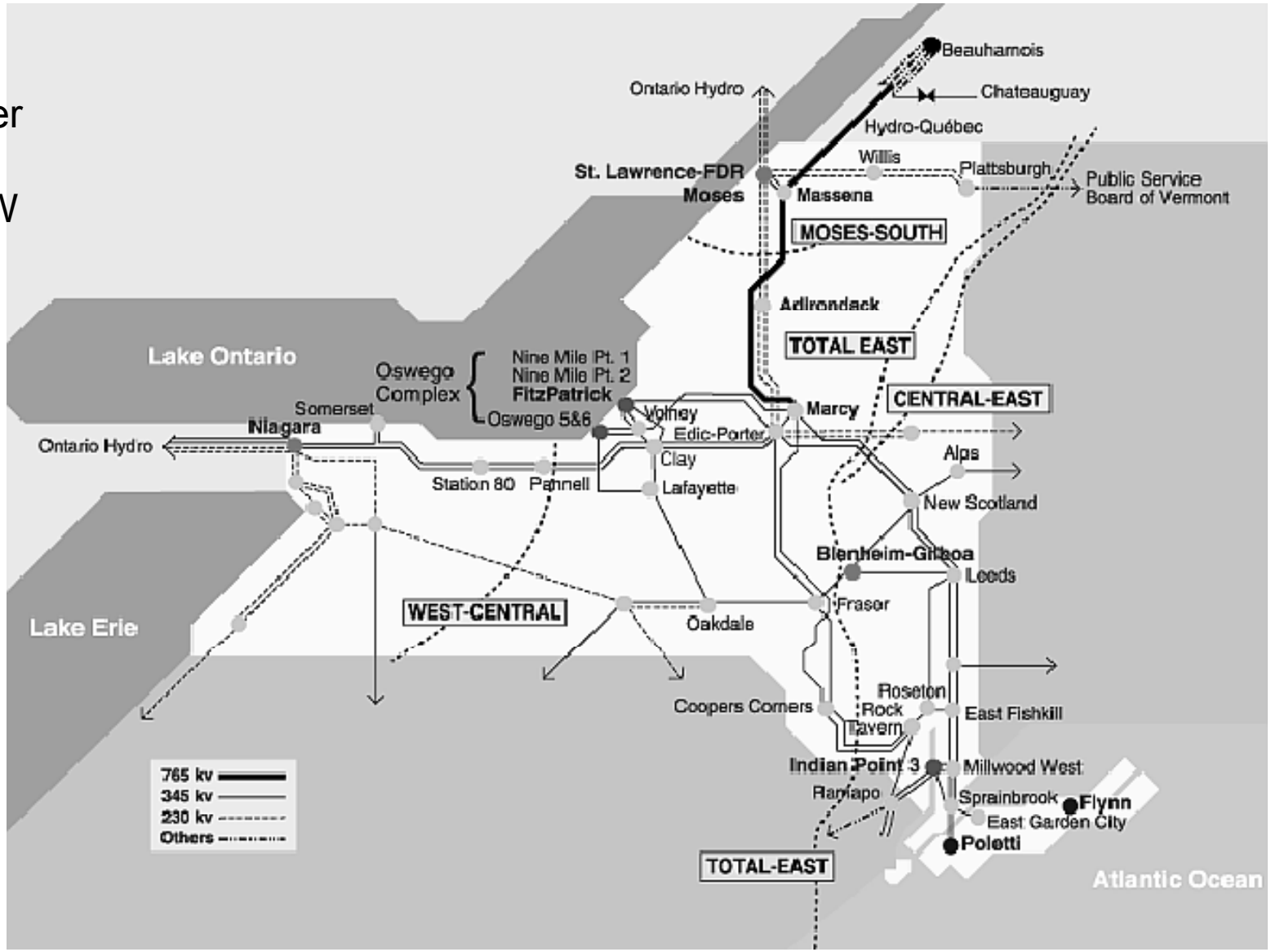
Outline

- VSC based FACTS Control System Structure and Convertible Static Compensator (CSC) Control System Overview
  - CSC Configurations and Control Modes
  - Control boards
- FACTS Simulator (TNA) testing and Control HIL (Hardware-in-the-loop) control testing
- Control system upgrade plan
- Other potential FACTS sites – AEP, TVA, KEPCO, PG&E, SMI/CMC steel

FACTS

Convertible Static Compensator (CSC) - Marcy Substation

Increase power transfer by total of 240MW by CSC



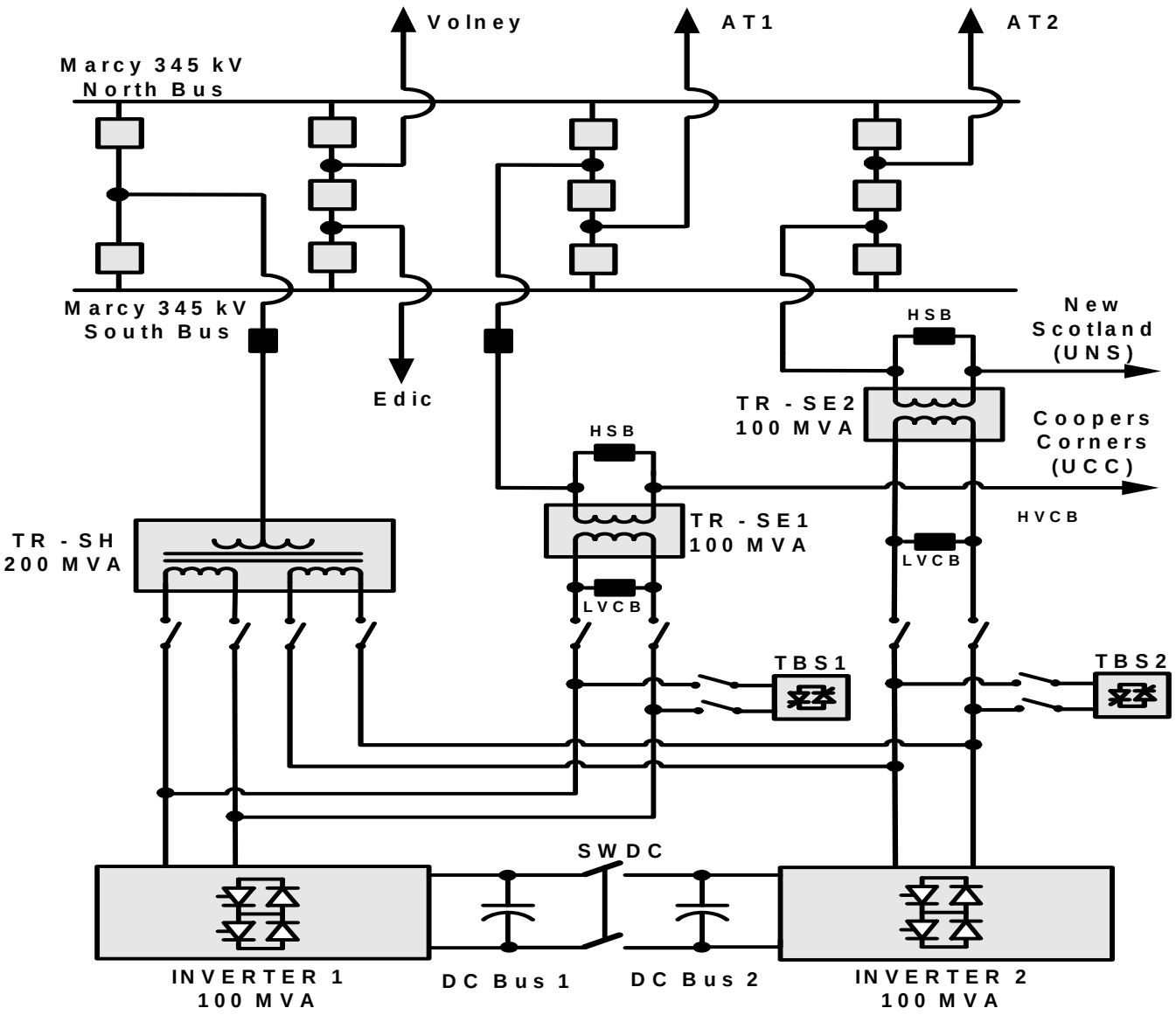
FACTS

Convertible Static Compensator (CSC) - Marcy Substation

Marcy 345kV SC is 18,000 MVA

There are 11 possible configurations

- STATCOM
- SSSC
- UPFC
- IPFC



FACTS

Convertible Static Compensator (CSC) - Marcy Substation

The inverters can operate independently or together with the DC bus switch closed

CSC has 11 configurations

- STATCOM
- SSSC
- UPFC
- IPFC

On the fly transitions

Operator Screen

Circuit Configuration Selection

Menu

Circuit Configuration = [#0] OFF

Config.	Type	Inverter Connection			Allowable Transitions
		Inv #1 to:	Inv #2 to:	SWDC1	
0	OFF	not used	not used	Open	ALL
1	STATCOM100-1	TR-SH(LV1)	not used	Open	0, 3, 7
2	STATCOM100-2	not used	TR-SH(LV2)	Open	0, 3, 8
3	STATCOM200	TR-SH(LV1)	TR-SH(LV2)	Open	0, 1, 2
4	SSSC100-UCC	TR-SE1	not used	Open	0, 6, 8
5	SSSC100-UNS	not used	TR-SE2	Open	0, 6, 7
6	SSSC100-UCC SSSC100-UNS	TR-SE1	TR-SE2	Open	0, 4, 5
7	STATCOM100-1 SSSC100-UNS	TR-SH(LV1)	TR-SE2	Open	0, 1, 5
8	SSSC100-UCC STATCOM100-2	TR-SE1	TR-SH(LV2)	Open	0, 2, 4
9	UPFC100/100-UNS	TR-SH(LV1)	TR-SE2	Closed	0
10	UPFC100/100-UCC	TR-SE1	TR-SH(LV2)	Closed	0
11	IPFC100-UCC/100-UNS	TR-SE1	TR-SE2	Closed	0

Inverter #1 Sequence
OFF
Step # 1

Inverter #2 Sequence
OFF
Step # 1

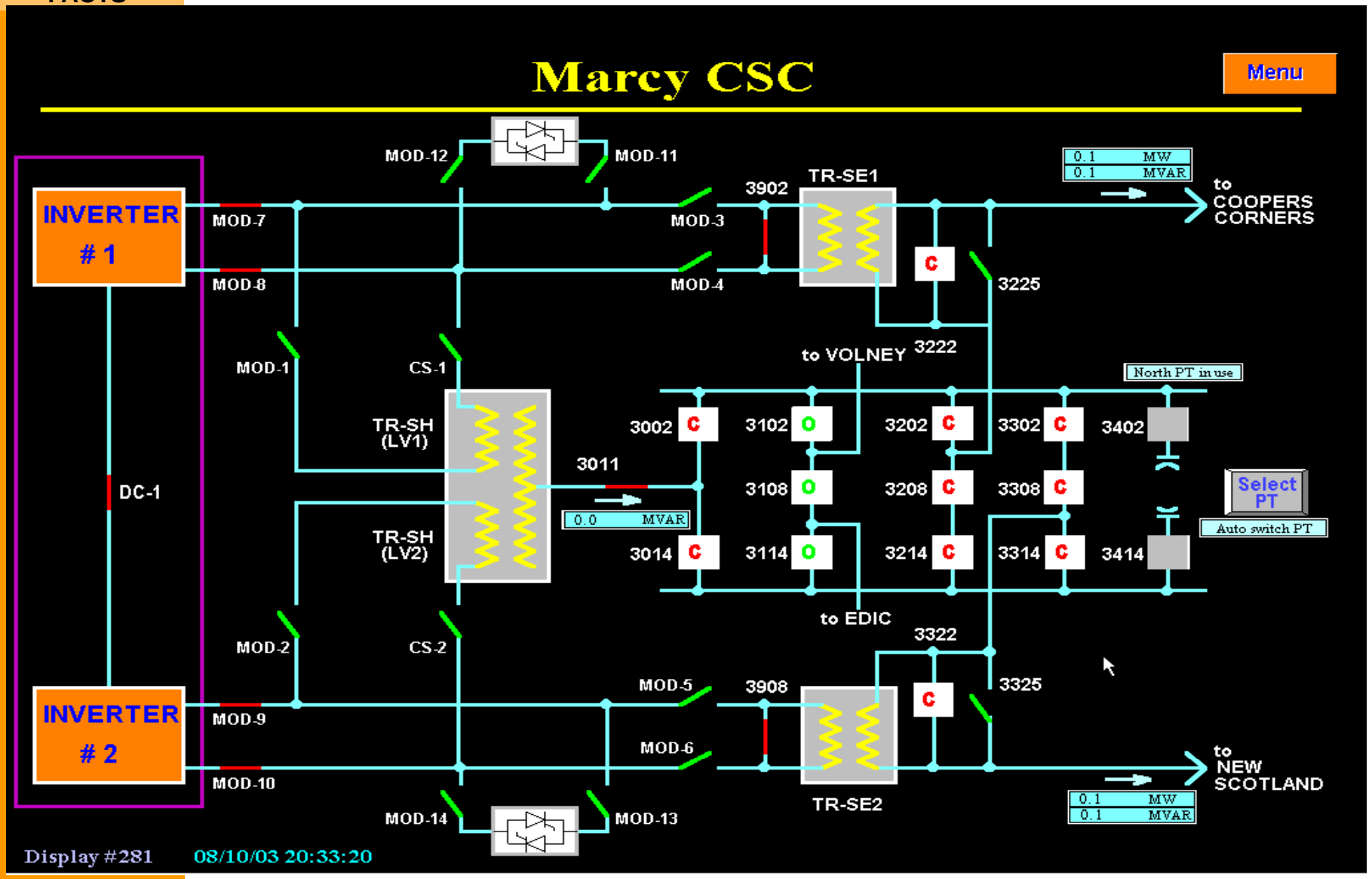
TRIP RESET

CSC First Trip Indicator:(No Trip)

Display #110 04/30/03 18:23:27

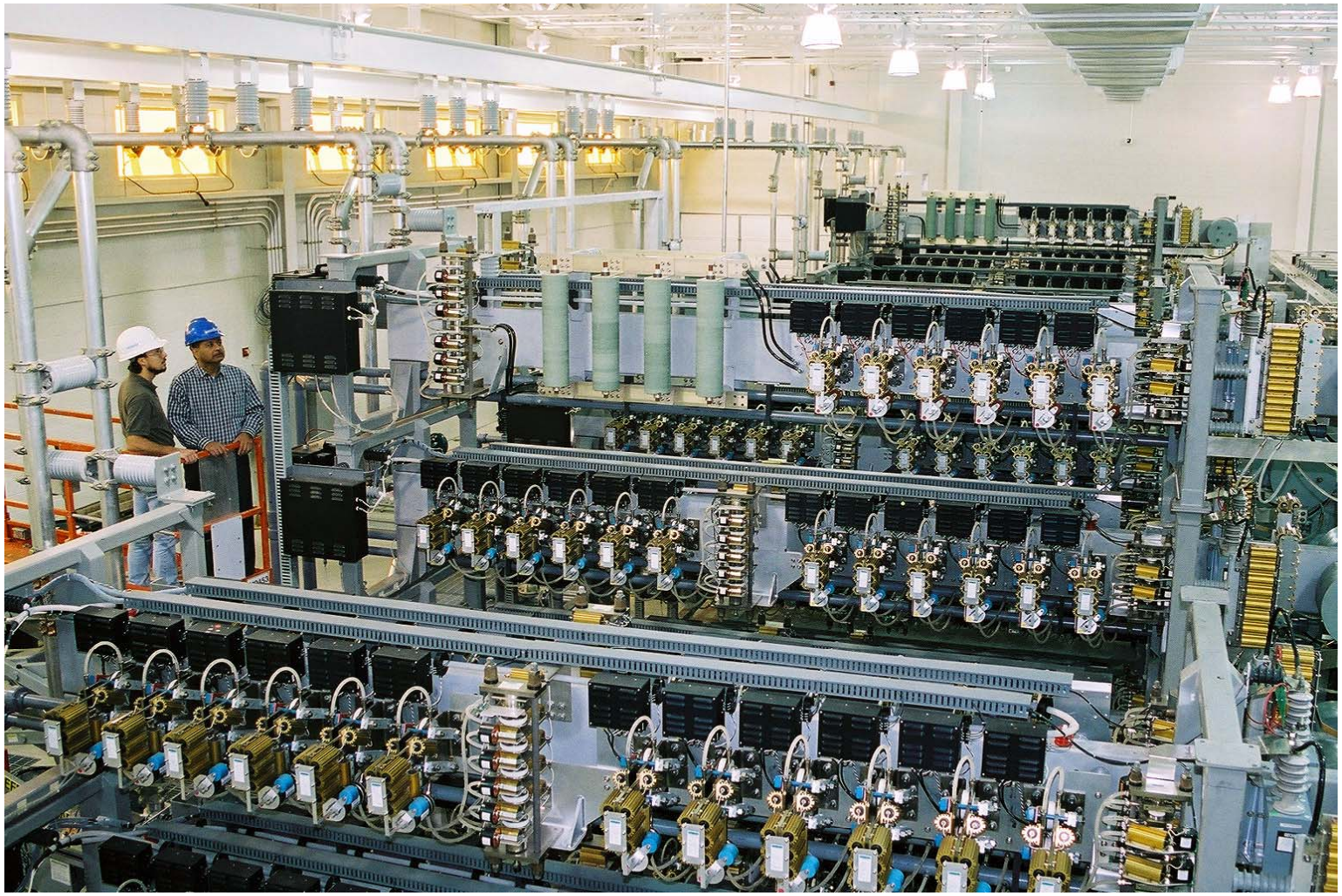
FACTS

Convertible Static Compensator (CSC) - Marcy Substation



FACTS

Convertible Static Compensator (CSC) Inverter Hall

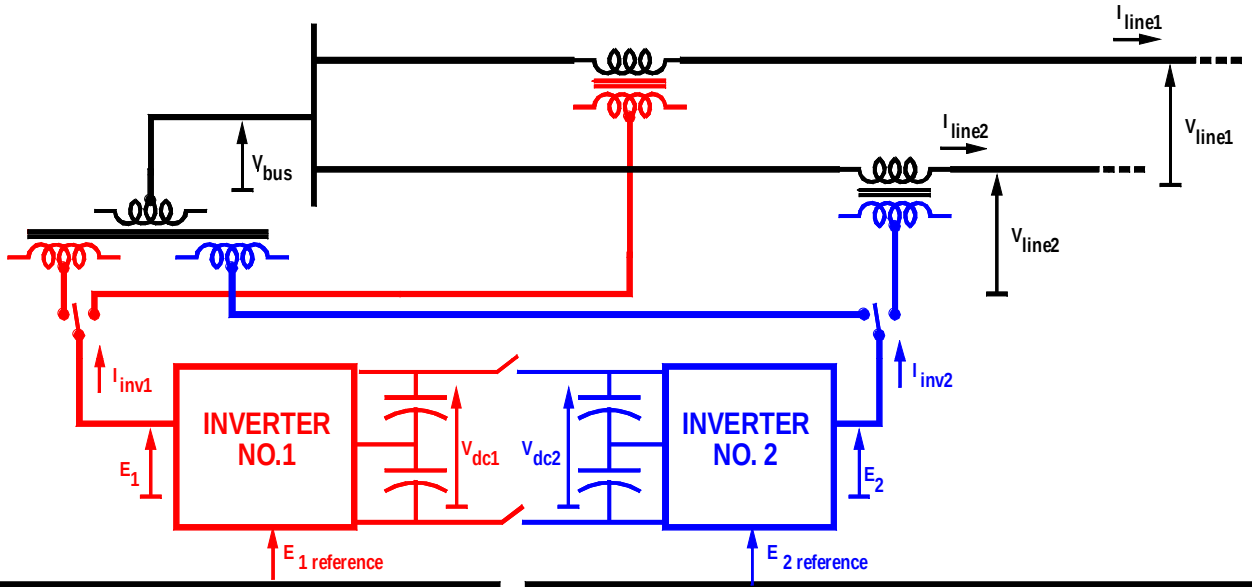


Objectives

- FACTS Control System – upgrade
  - 8 VSC FACTS sites – 1 NYPA, 1 TVA, 3 AEP, 1 PG&E, 1 KEPCO, 1 SMI/CMC steel
  - Control system upgrade to a commercial controls platform - Life extension of these FACTS projects
- Migration and validation of existing controls on a standard simulator (RTDS) platform
- Development of RTDS Simulator (TNA) for any FACTS controls and Control HIL (Hardware-in-the-loop) testing
  - Provide platform for evaluation of FACTS controllers for system study and planning tool
  - Development, upgrade and testing of HMI tool

FACTS

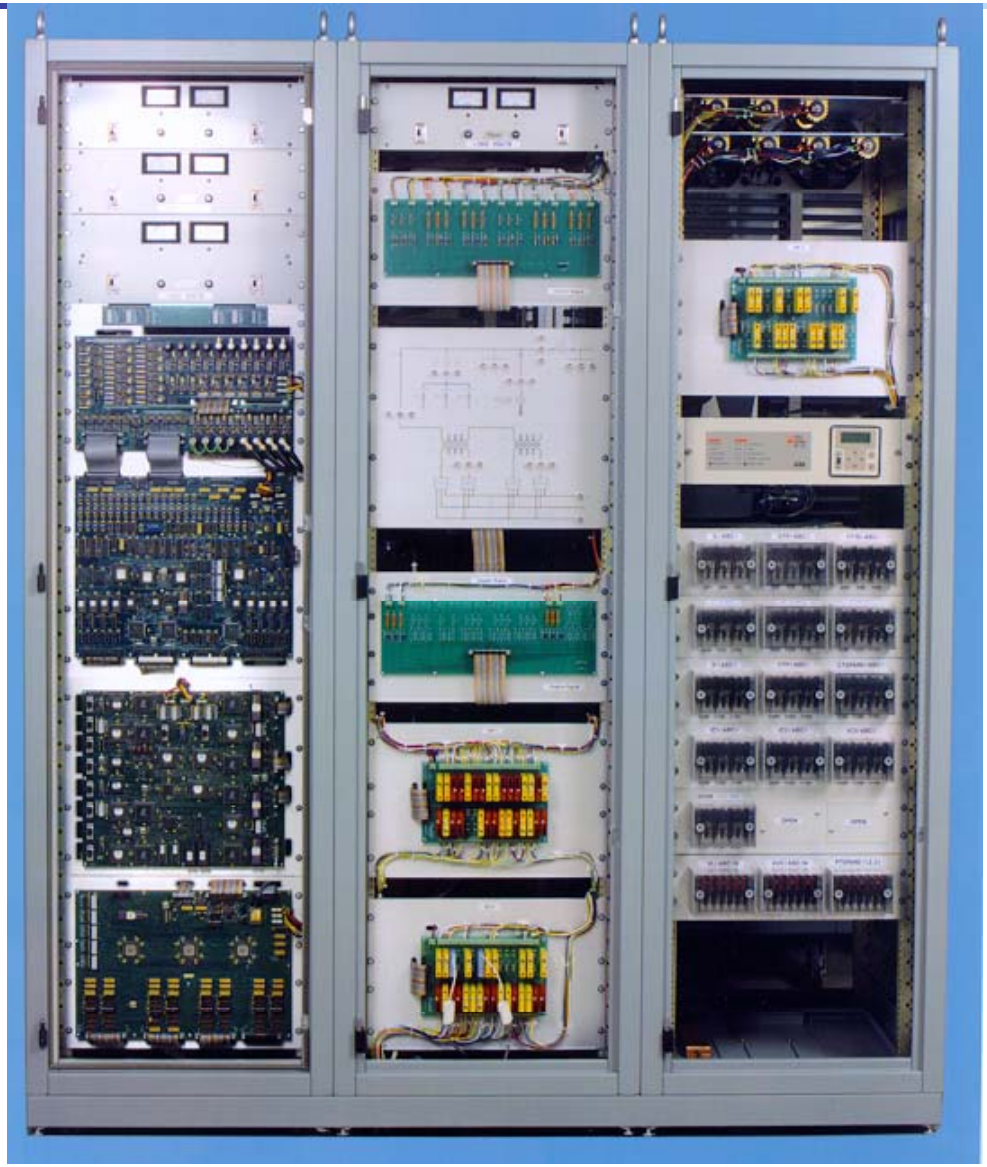
NYPA CSC Controls Provide Different Modes For Each Power Circuit Configuration



CONFIGURATION/MODE SELECTOR			
STATCOM CONTROL	**SSSC CONTROL**	**UPFC SERIES INV. CONTROL**	**IPFC CONTROL**
VOLTAGE CONTROL MODE	REACTIVE VOLTAGE INJECTION MODE	VOLTAGE INJECTION MODE	PRIMARY CONTROL MODE
VAR CONTROL MODE	AUTOMATIC POWER FLOW CONTROL MODE	AUTOMATIC POWER FLOW CONTROL MODE	REACTIVE VOLTAGE INJECTION MODE
V_{bus} reference Var reference Slope factor VAR reserve level V_{bus} I_{inv1} V_{dc1}	V_{inject} reference P_{line1} reference V_{dc1} I_{line1} V_{line1}	V_{inject} reference P,Q line1 reference V_{dc1} I_{line1} V_{line1} V_{bus}	V_{inject} reference P,Q line1 reference V_{dc1} I_{line1} V_{line1} V_{bus}

CONFIGURATION/MODE SELECTOR			
STATCOM CONTROL	**SSSC CONTROL**	**UPFC SERIES INV. CONTROL**	**IPFC CONTROL**
VOLTAGE CONTROL MODE	REACTIVE VOLTAGE INJECTION MODE	VOLTAGE INJECTION MODE	PRIMARY CONTROL MODE
VAR CONTROL MODE	AUTOMATIC POWER FLOW CONTROL MODE	AUTOMATIC POWER FLOW CONTROL MODE	REACTIVE VOLTAGE INJECTION MODE
V_{bus} reference Var reference Slope factor VAR reserve level V_{bus} I_{inv2} V_{dc2}	V_{inject} reference P_{line2} reference V_{dc2} I_{line2} V_{line2}	V_{inject} reference P,Q line2 reference V_{dc2} I_{line2} V_{line2} V_{bus}	V_{inject} reference P,Q line2 reference V_{dc2} I_{line2} V_{line2} V_{bus}

Central Controls Comm. with VSC Poles



Optical Fibers

FACTS Controls Upgrade Plan

- **Phase I**: Develop a RTDS based digital TNA simulator for a variety of VSC-based FACTS controller platforms. The NYPA CSC system will be used to test the simulator.
  - Develop PSCAD based detailed simulation of the ac system, VSC converter topology, controls (exacting as implemented in the field)
  - Include VSC and system level protection, switchyard devices with open/close timing
  - Verify developed model with commissioning test results and TNA test results

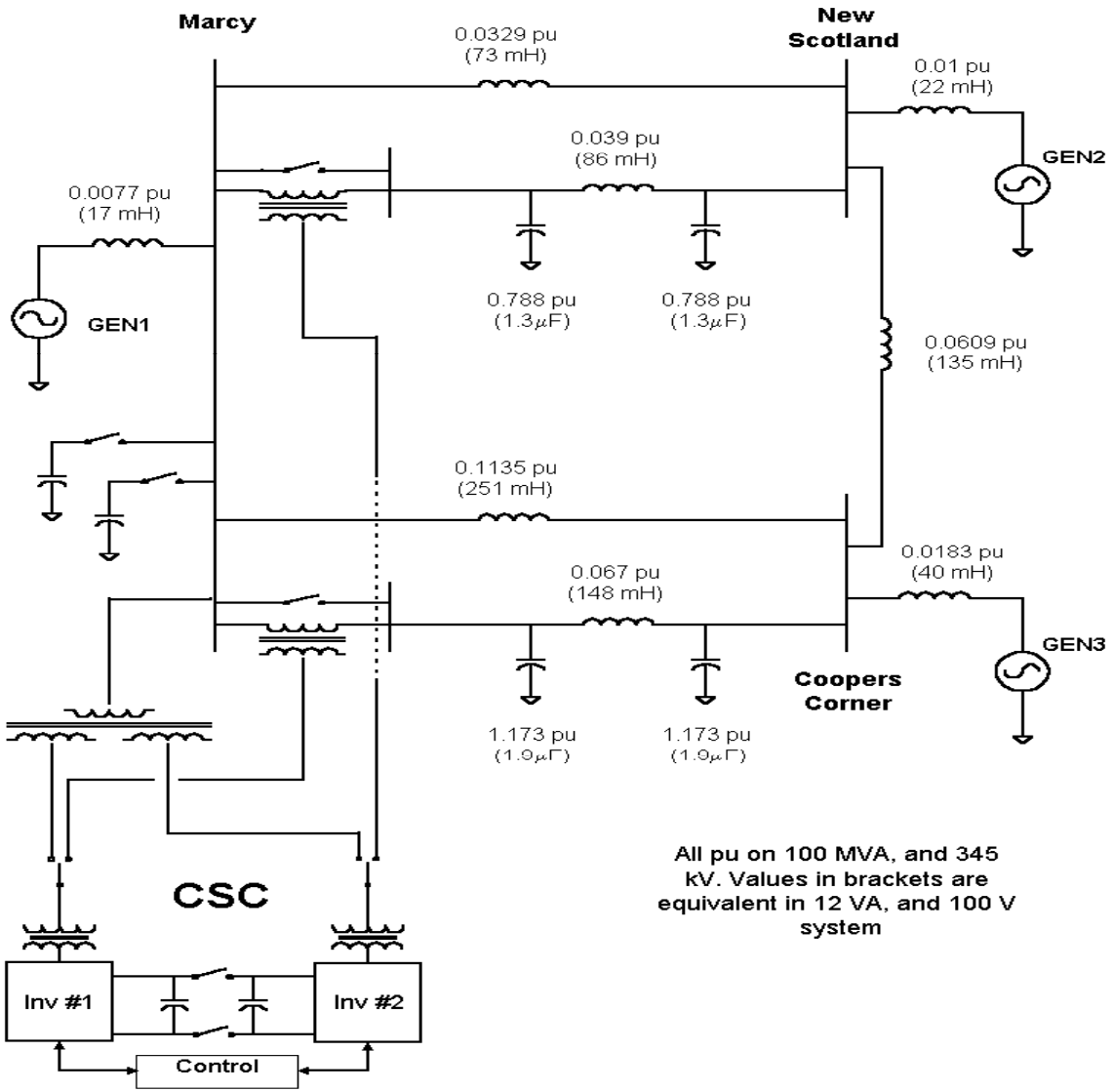
FACTS Controls Upgrade Plan

- **Phase II**: RTDS hardware and CSC system and controller setup on the RTDS simulator system
  - Verification of the FACTS controller models on the RTDS system results with TNA results and CSC commissioning test results
  - Evaluation of the possible interface of the HMI "Genesis" with the CSC system on RTDS

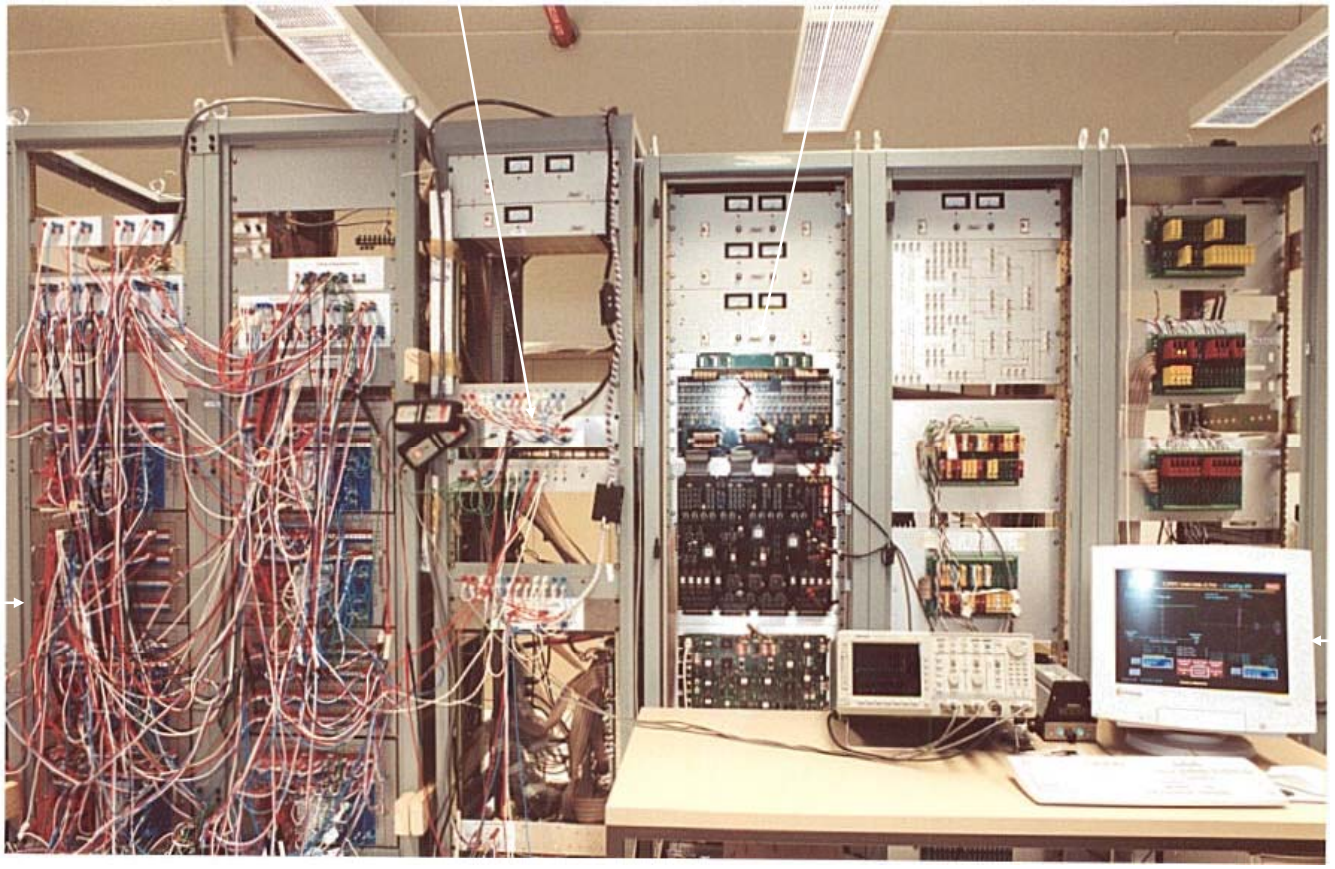
- **Phase III**: Control system upgrade to a commercial controls platform
  - To provide a testbed for hardware-in-the-loop (HIL) testing and verification of a commercial vendor control system for CSC/FACTS system

Control TNA Studies

- Thoroughly test and validate control system
  - Steady state characteristics
  - Response to control set point changes
  - Behavior during system transients
  - Protective functions
- 11 possible equipment configurations
- Various inverter control modes in each configuration
- Different fault types/locations
- ‘Peak’ and ‘light’ system load conditions

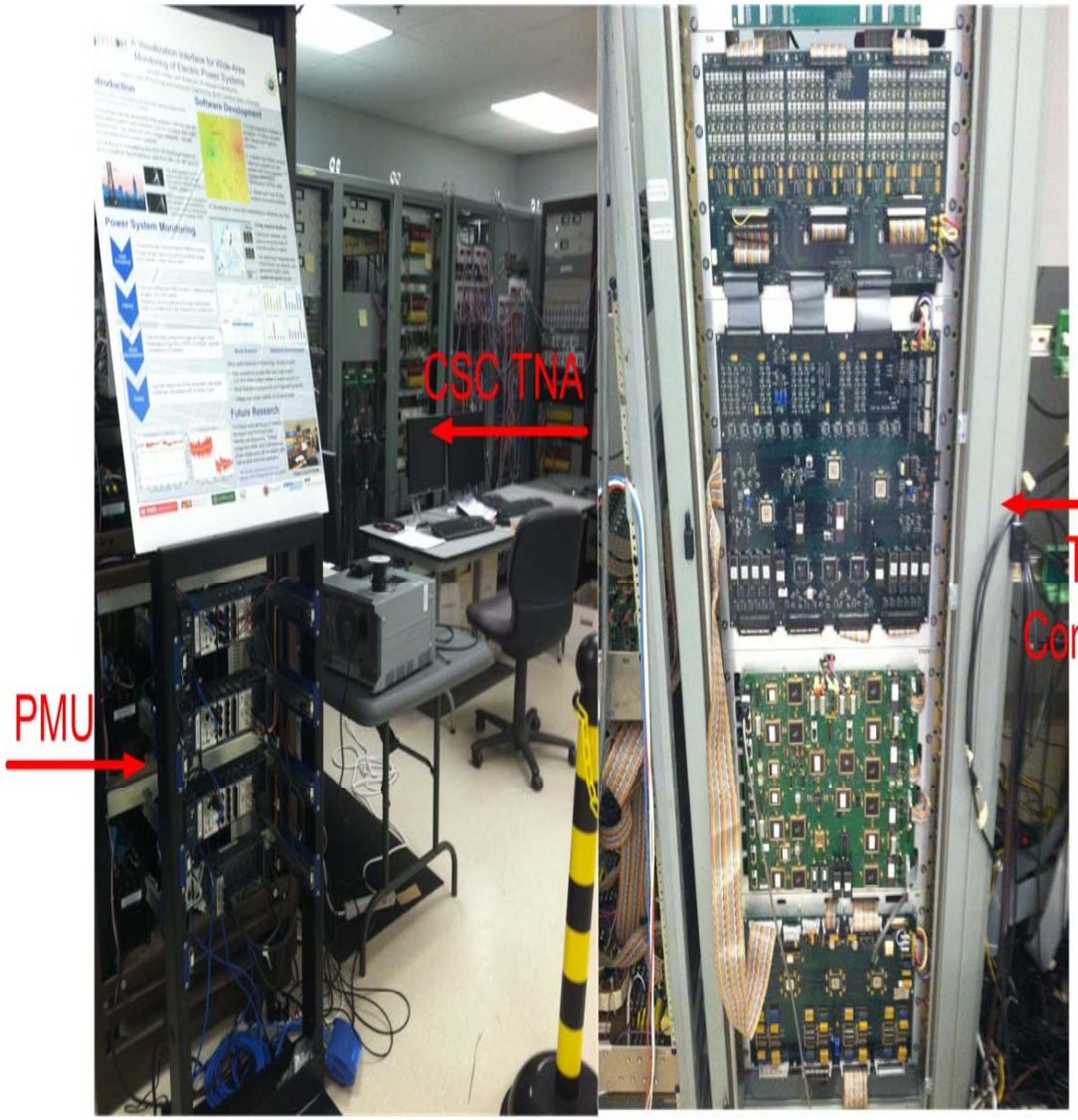


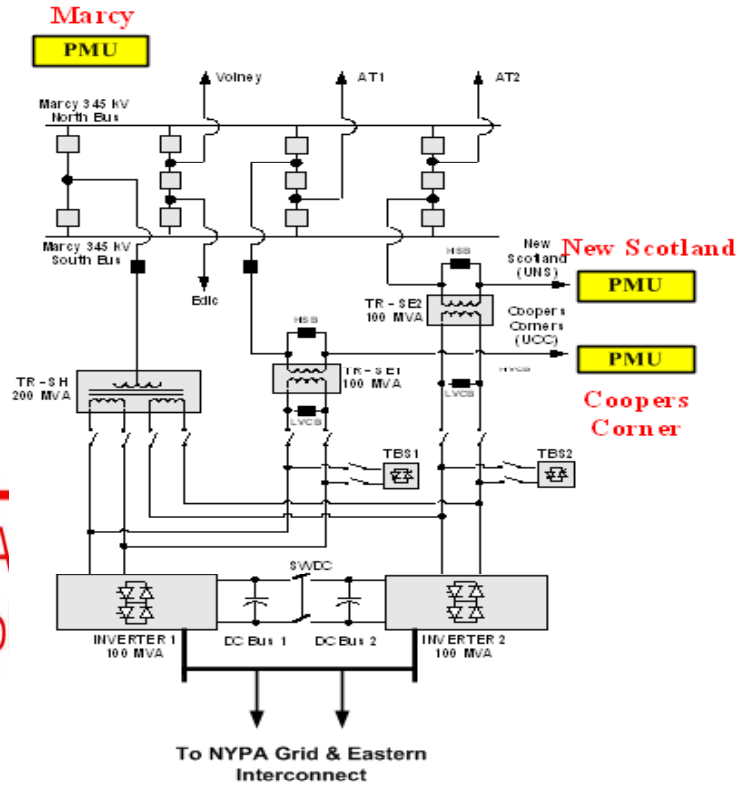
TNA NYPA CSC TNA Model



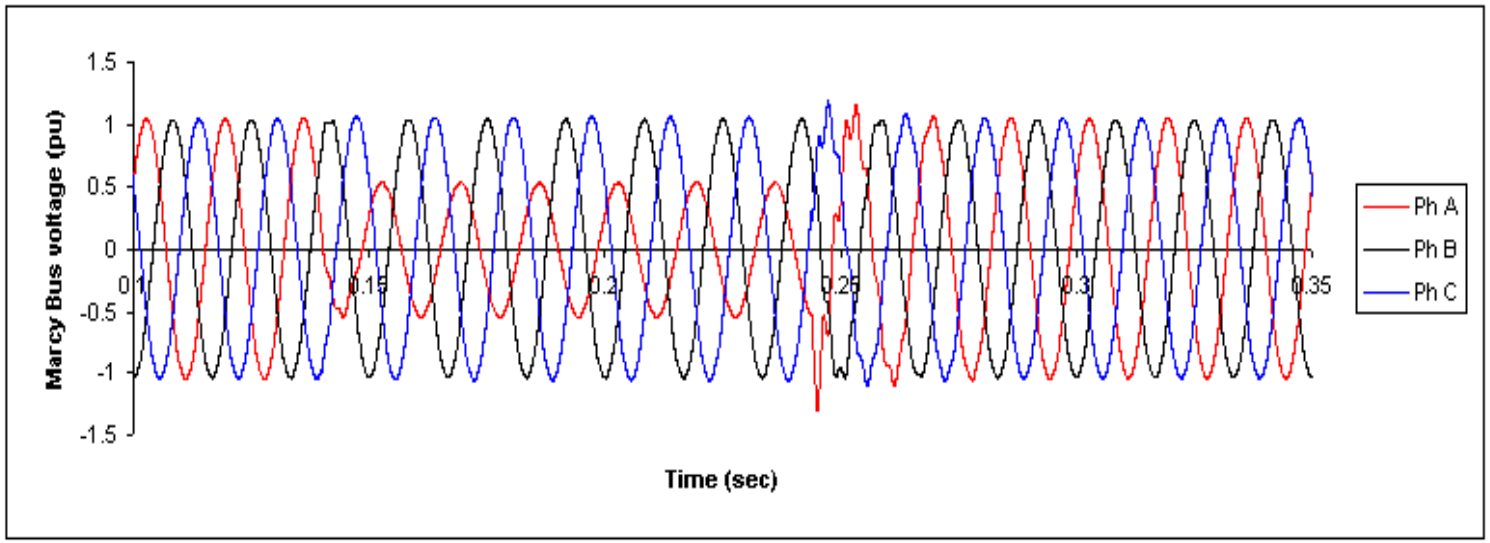
(AC network simulator not shown)

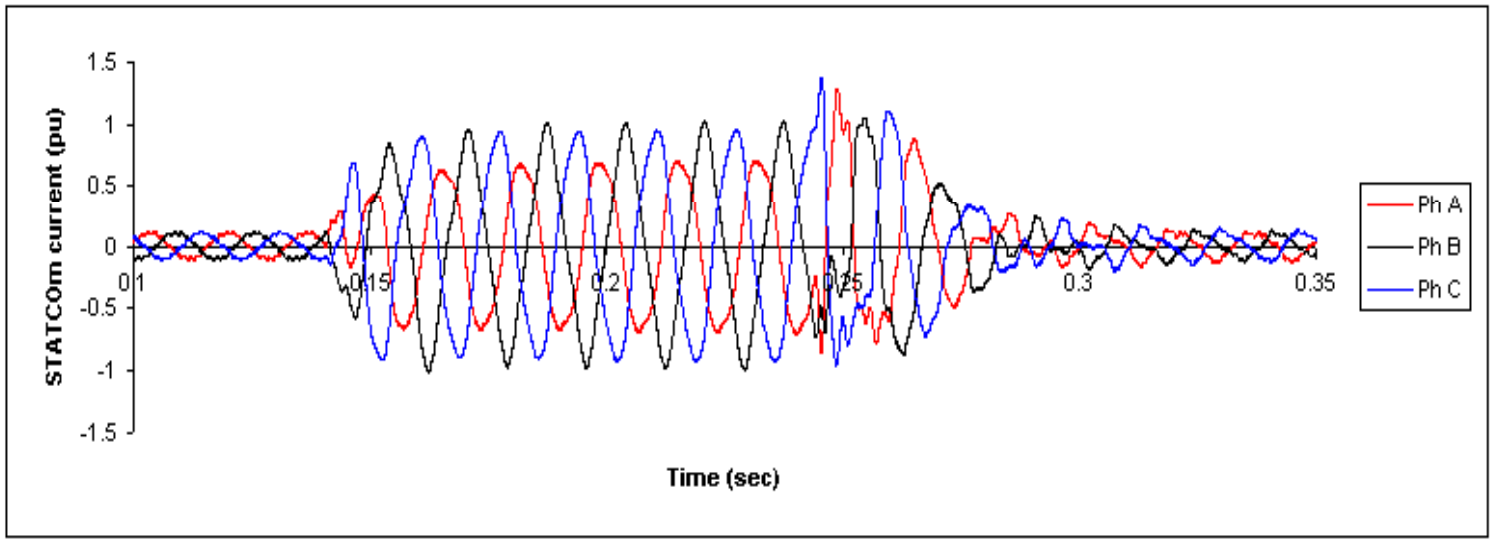
TNA NYPA CSC TNA Model





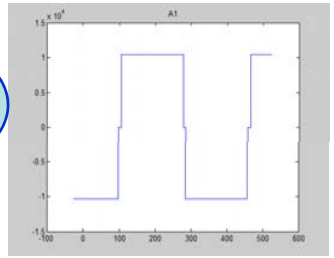
TNA NYPA CSC STATCOM response to line-GND fault



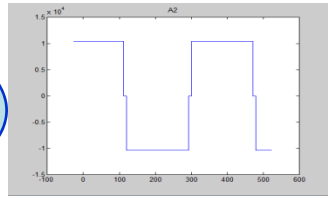


NYPA CSC Converter Waveform Analysis with MATLAB

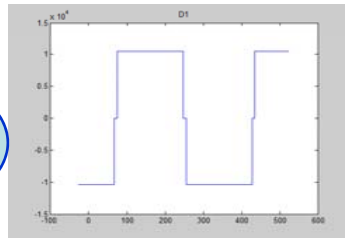
Phase A Conv 1



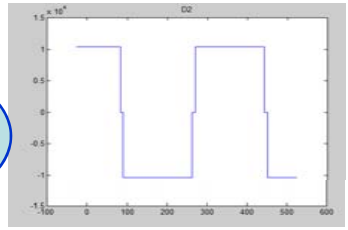
Phase A Conv 2



Phase A Conv 3

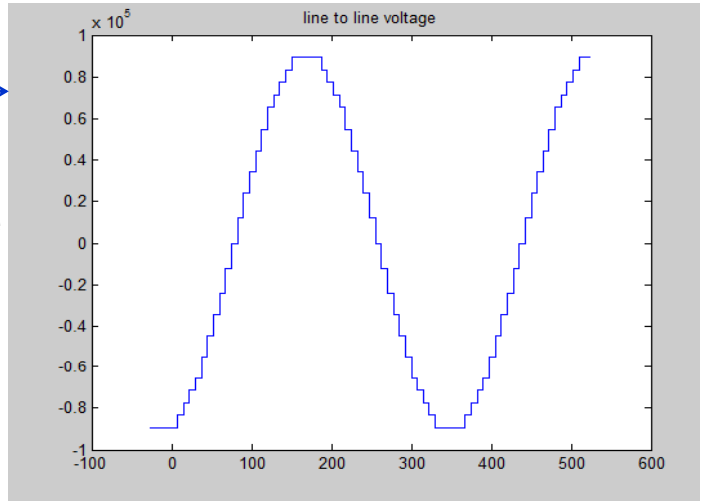


Phase A Conv 4

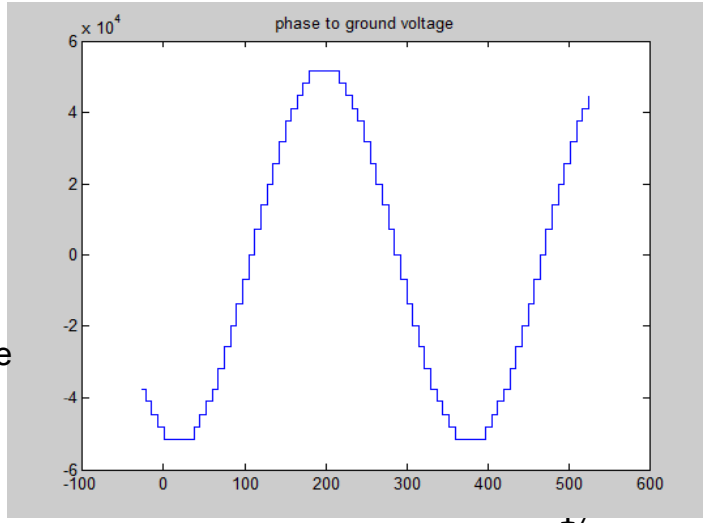


Construction of 48 pulse voltage based on NYPA converters concept in MATLAB. (the voltage amplitude is not the same as NYPA and only wave construction has been considered.)

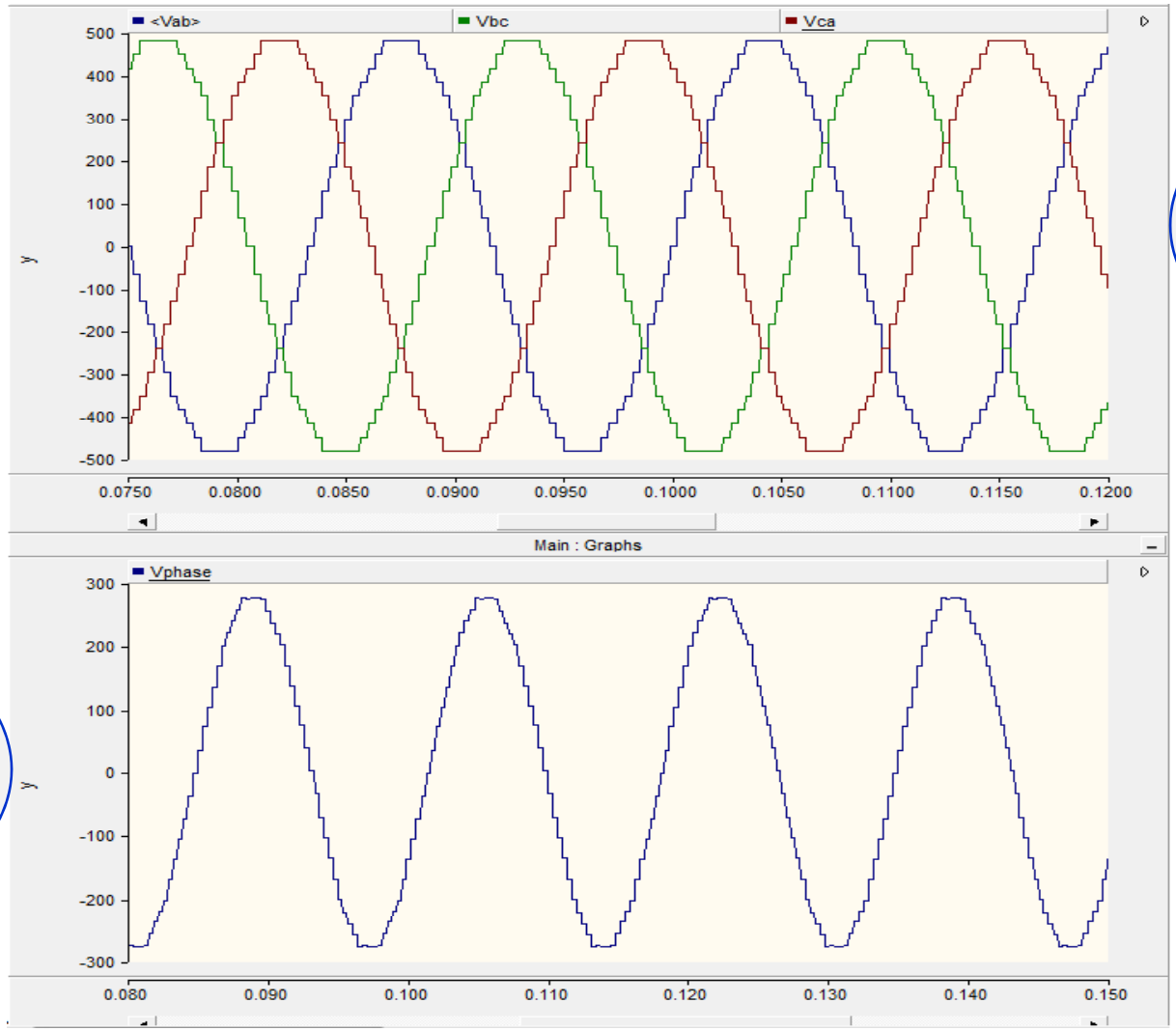
Line to line voltage



Phase voltage



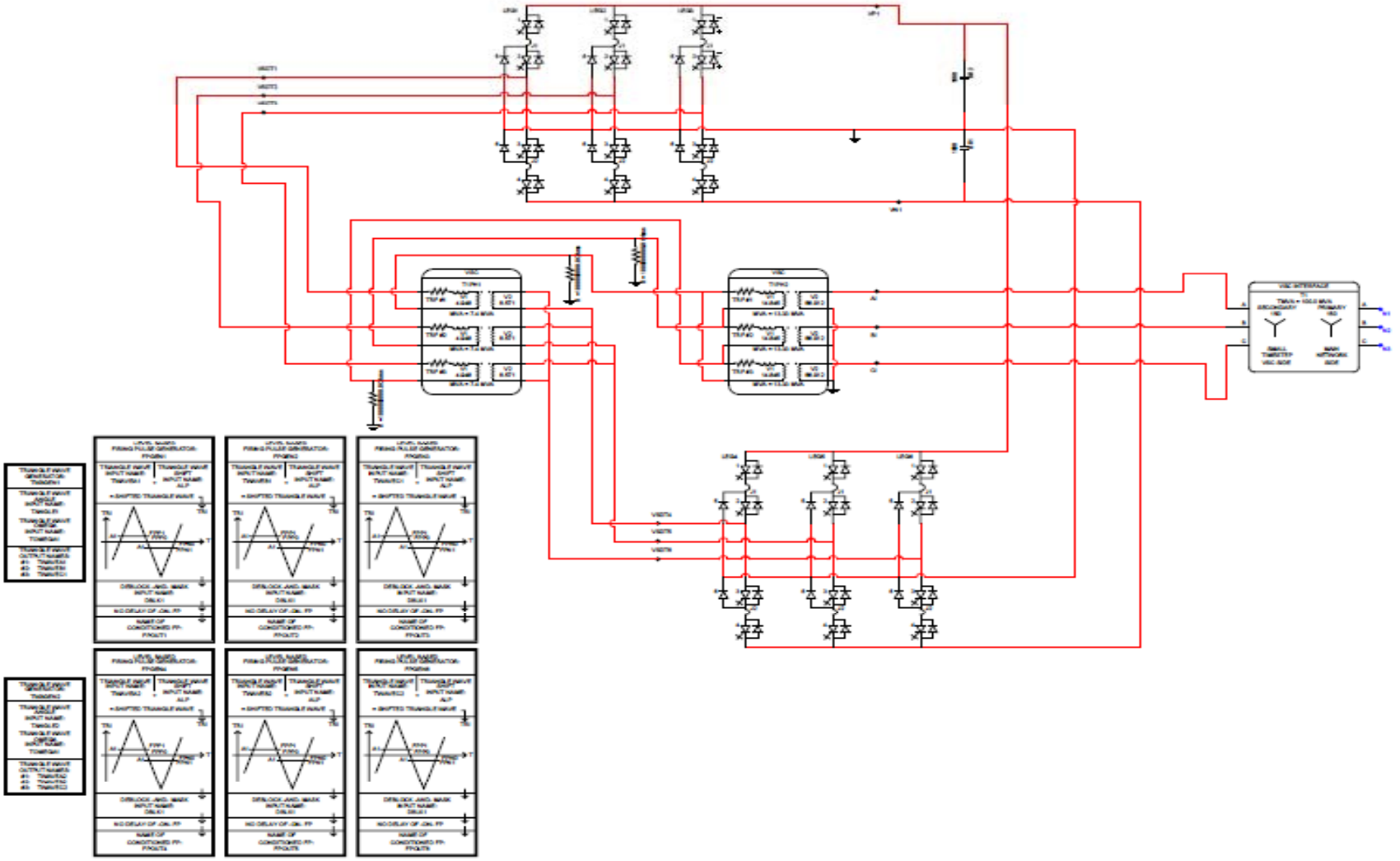
CSC Converter System performance in PSCAD



48 pulse Line to line Voltage

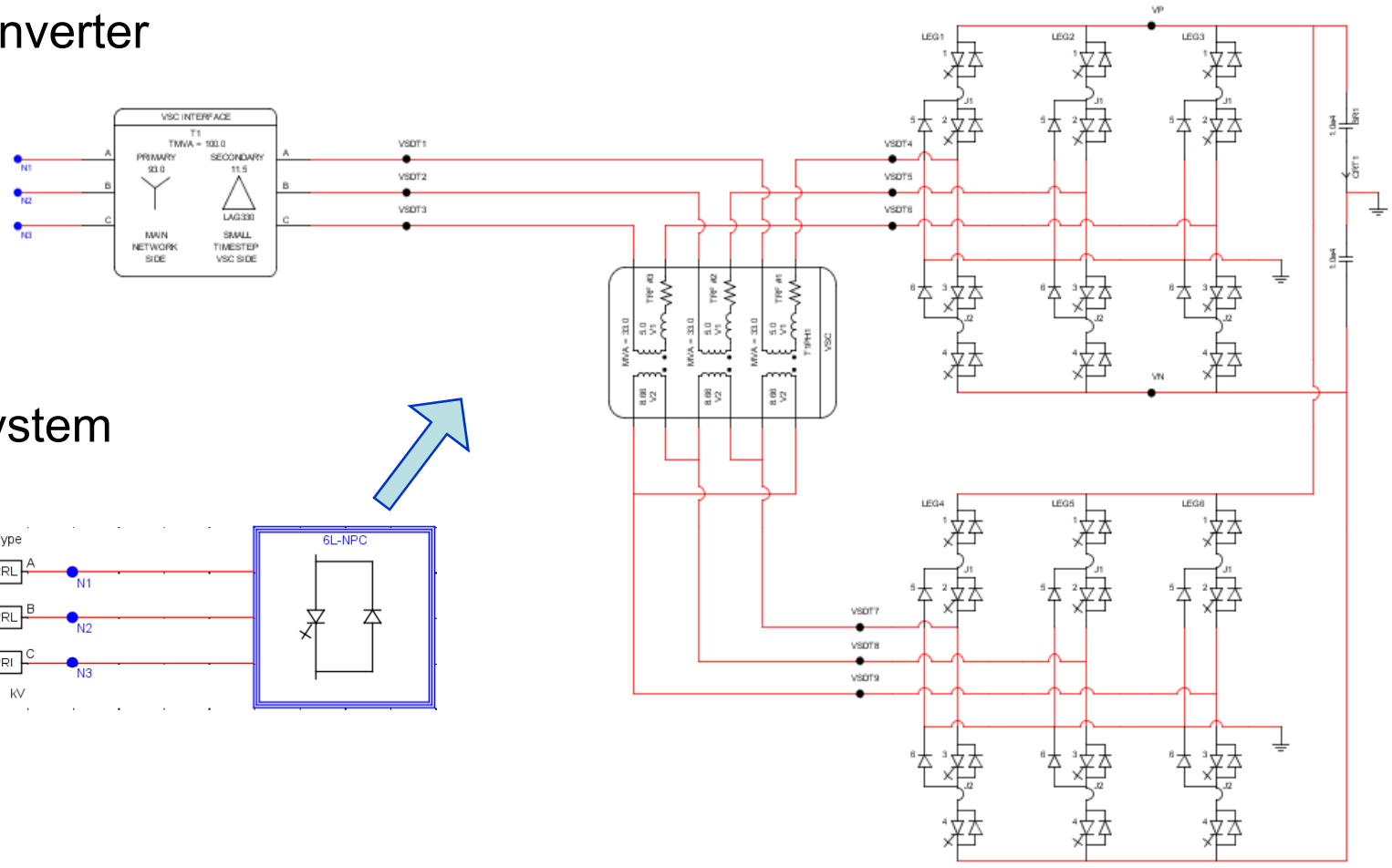
48 pulse Phase to neutral Voltage

CSC Converter System in RSCAD / RTDS



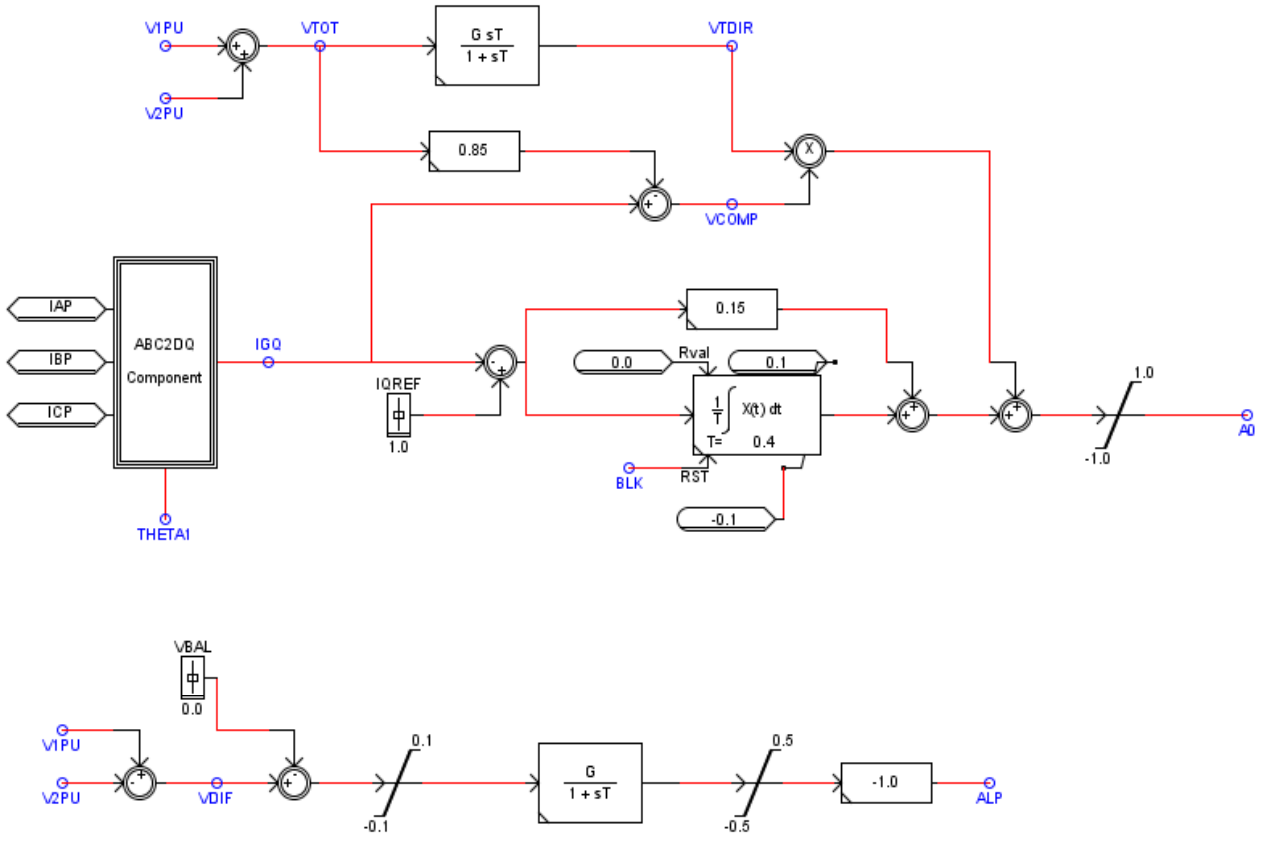
24-pulse STATCOM in RSCAD / RTDS

Converter



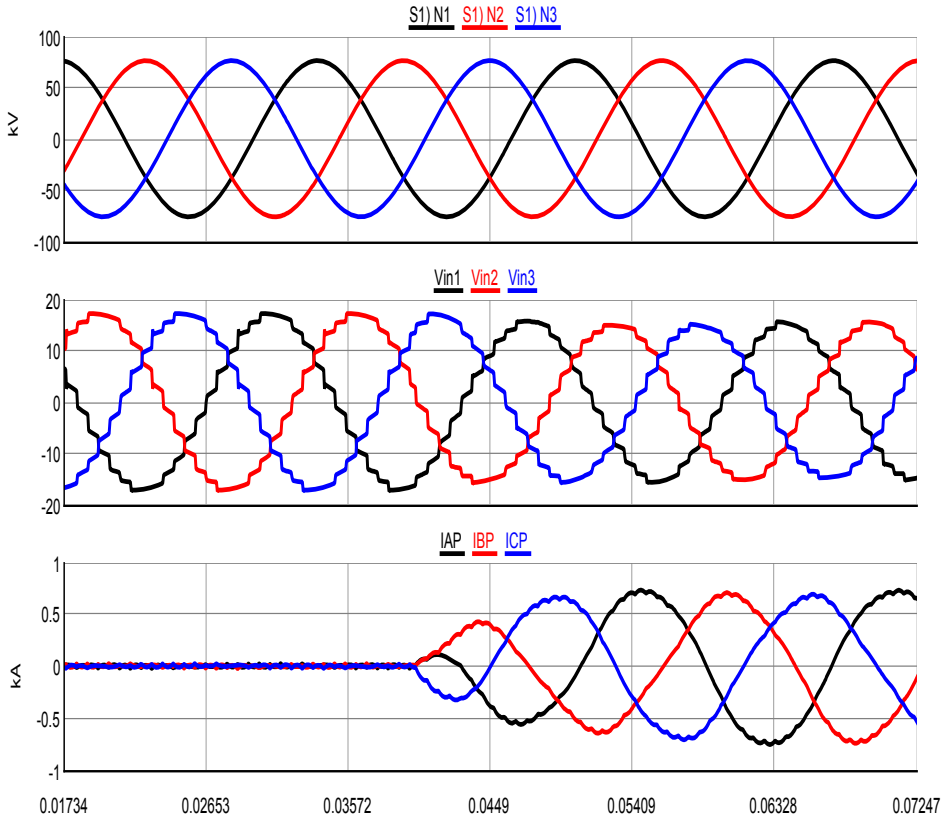
System

Angle control (Iq control) STATCOM in RSCAD / RTDS

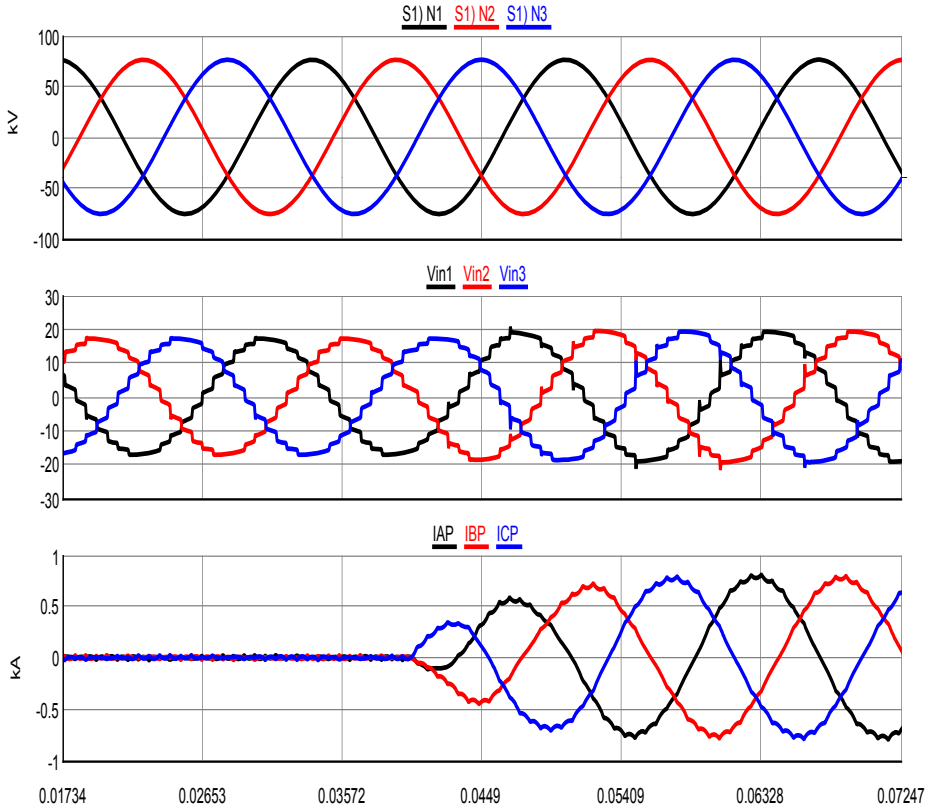


STATCOM with Angle Control Results in RTDS

Iq: 0 pu → 0.8 pu

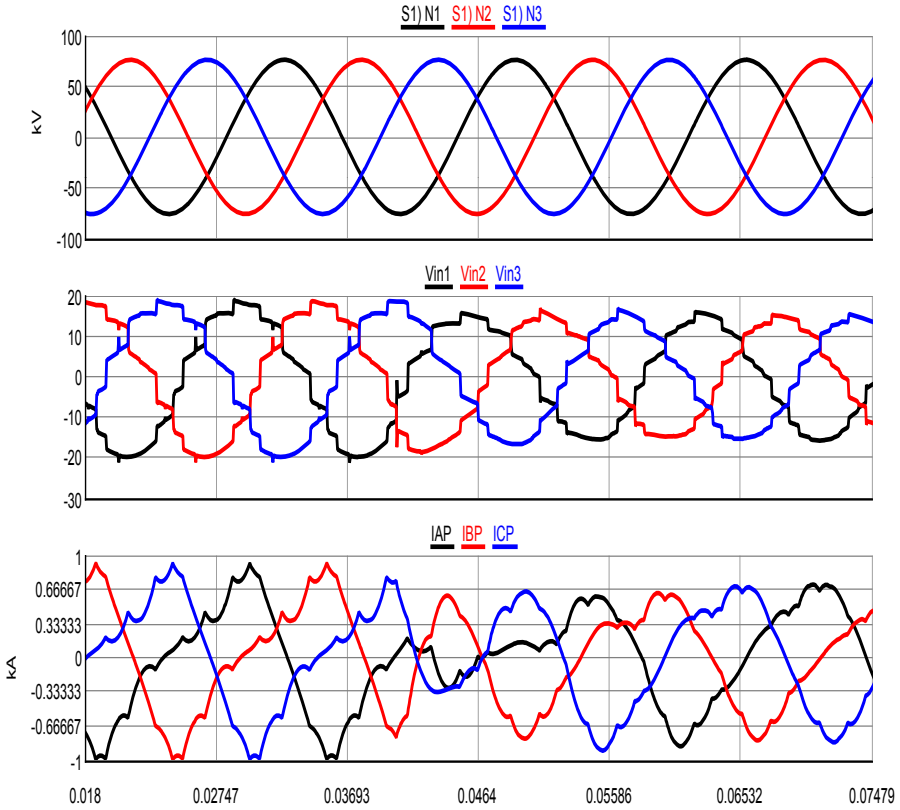


Iq: 0 pu → -0.8 pu

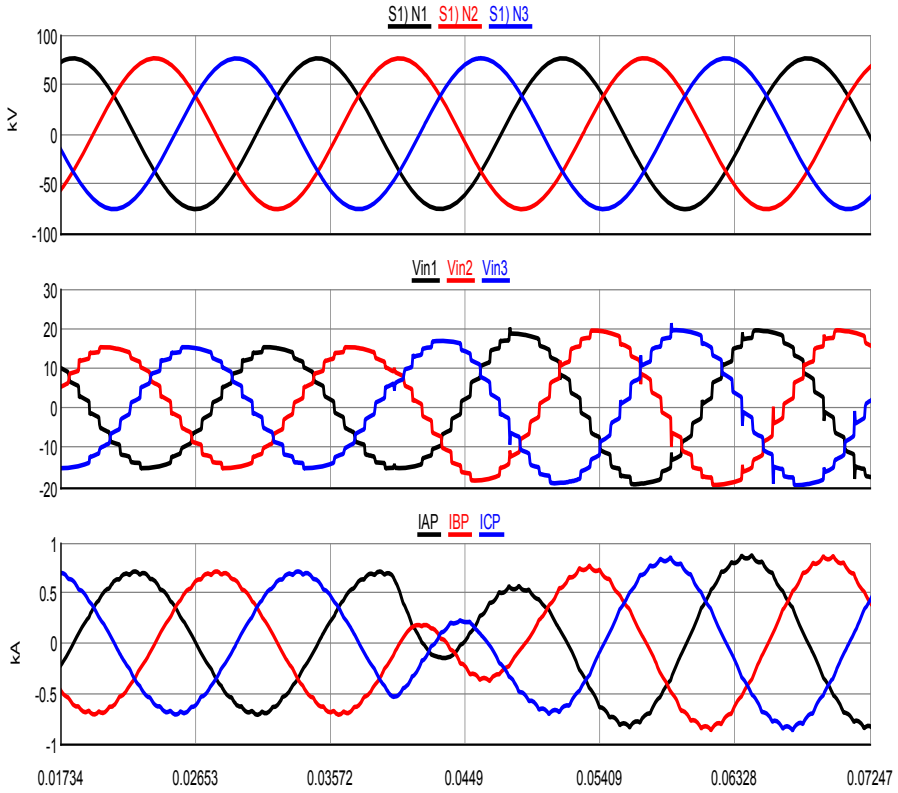


STATCOM with Angle Control Results in RTDS

Iq: -0.8 pu → 0.8 pu

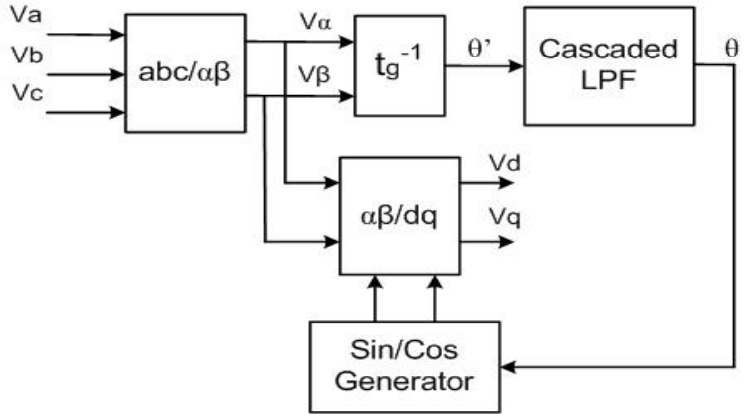


Iq: 0.8 pu → -0.8 pu

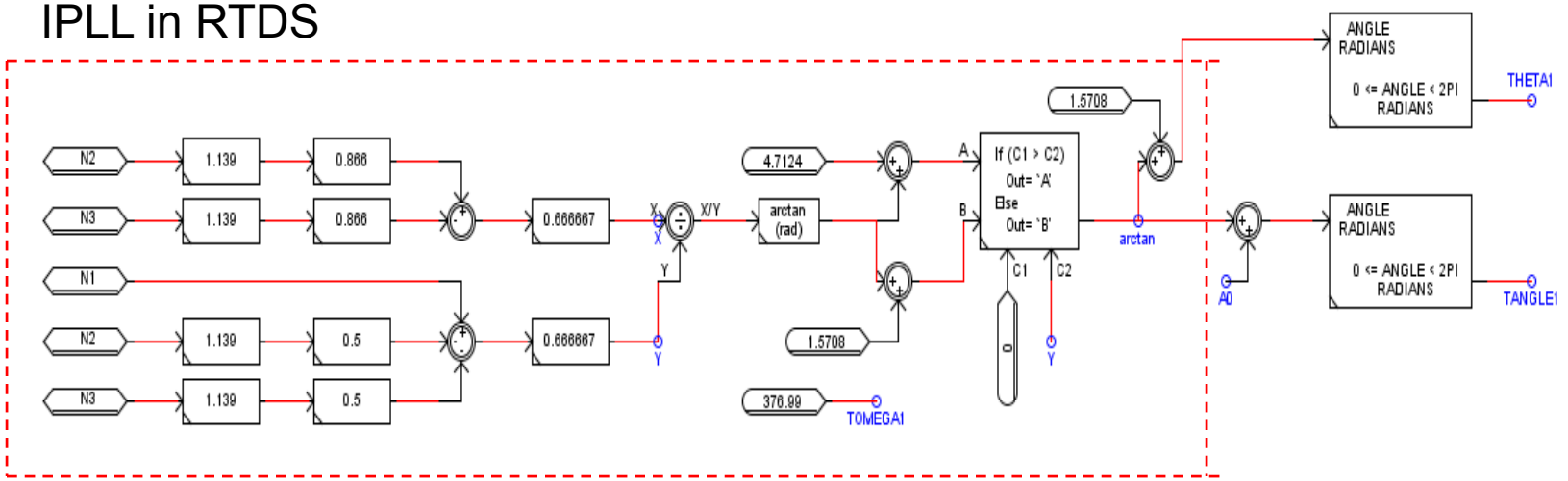


Instantaneous PLL (IPLL) in RTDS

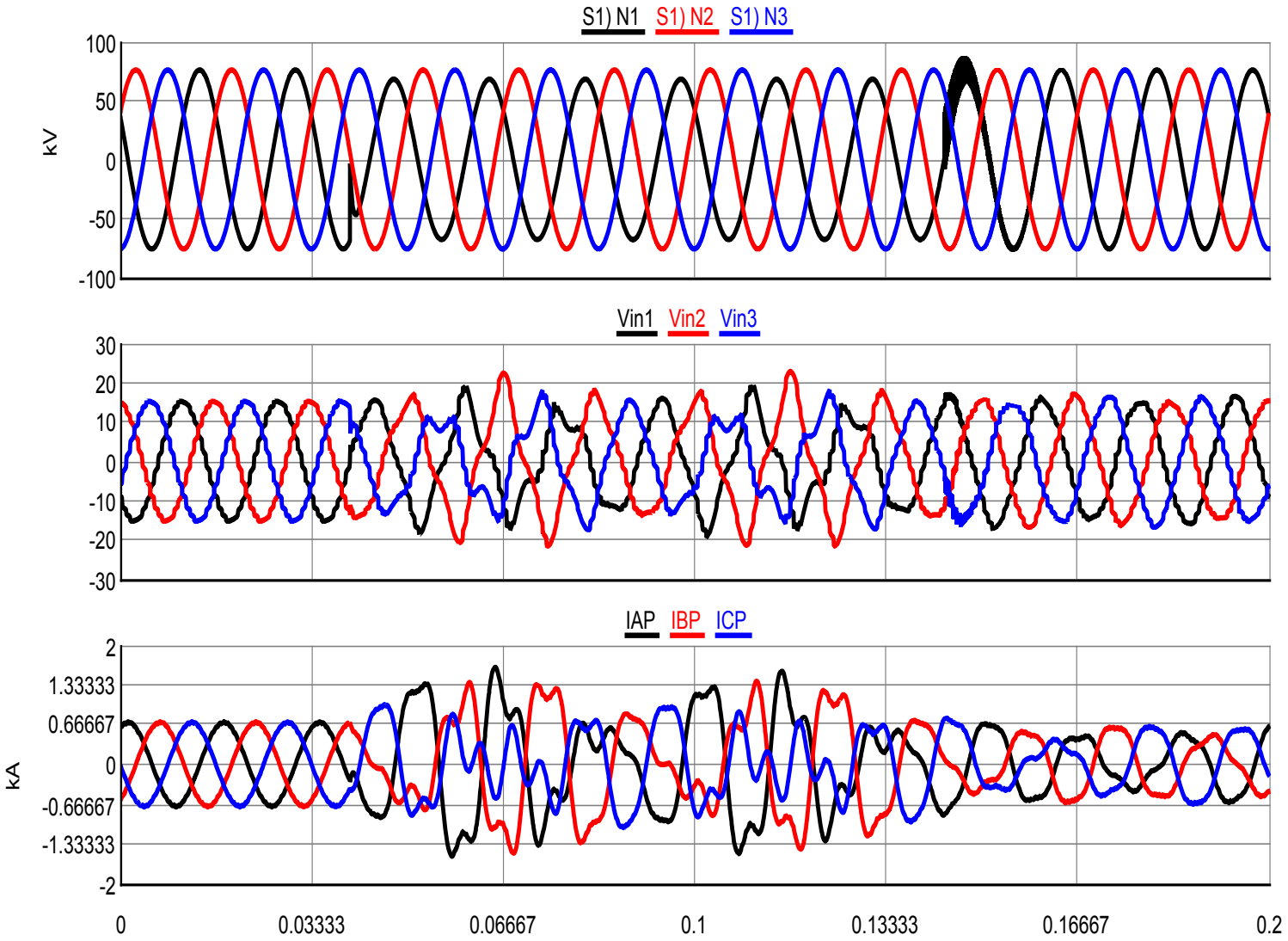
IPLL based on instantaneous voltage



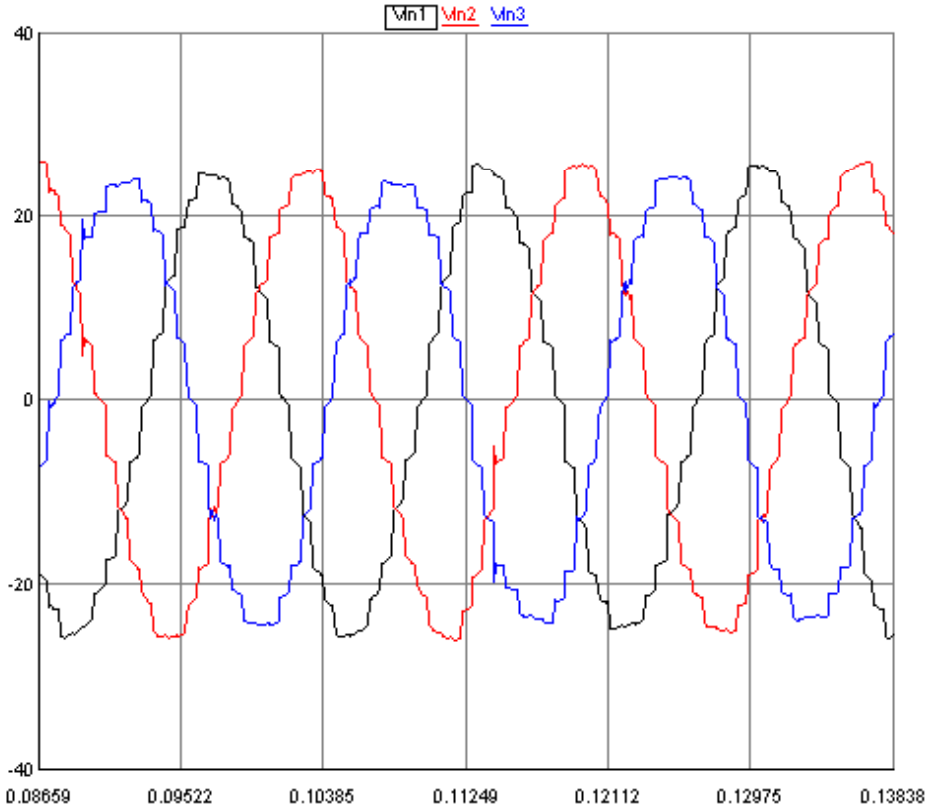
IPLL in RTDS



STATCOM w/ SLG fault in RTDS

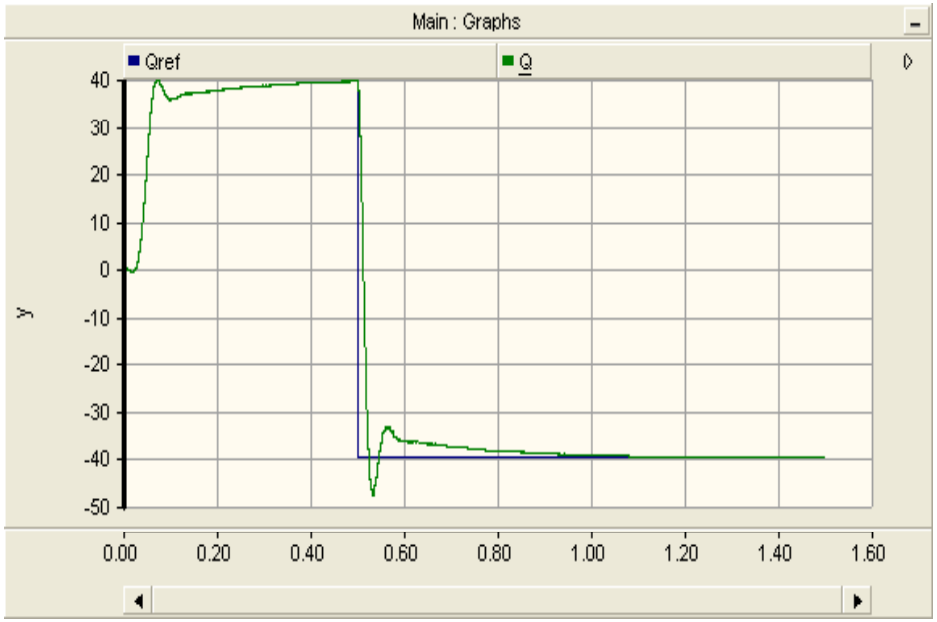


CSC Converter System RSCAD and PSCAD results

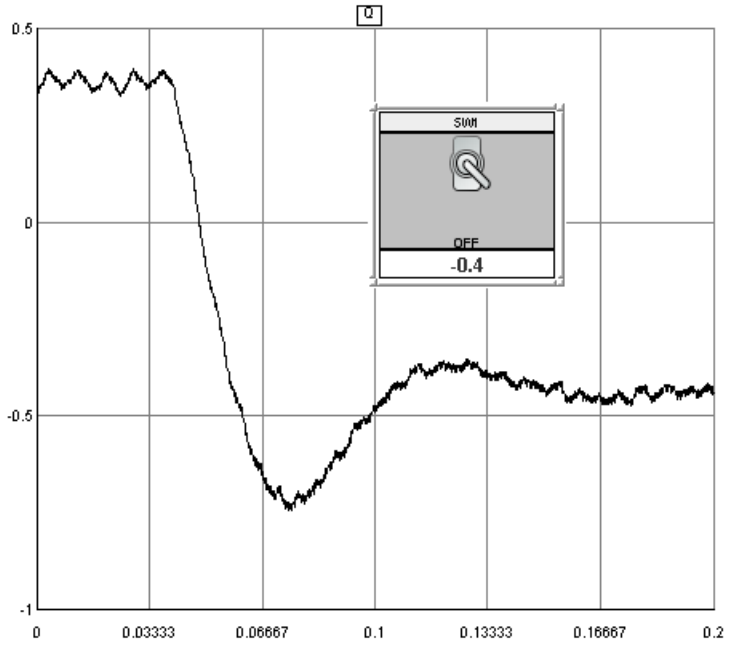


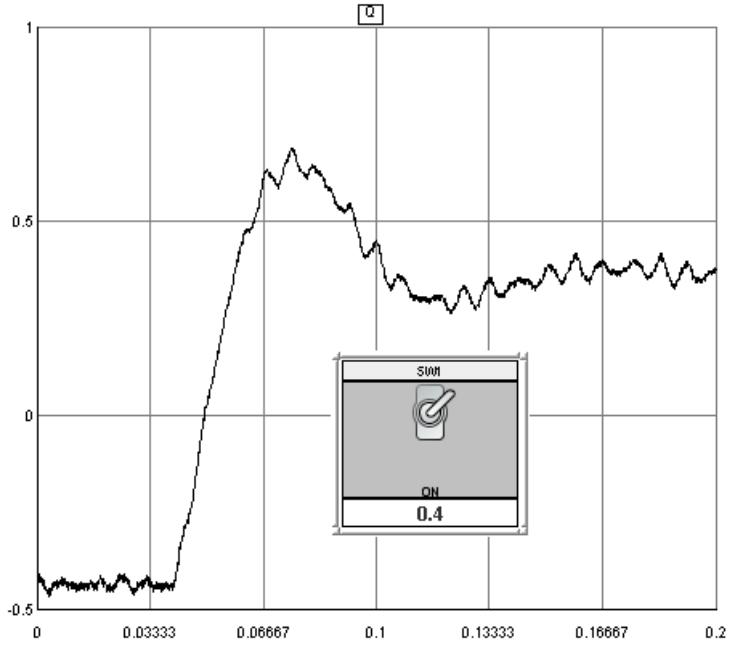
STATCOM performance when 40 MVAr reactive power is injected to the bus

Injected reactive power to the bus and reference reactive power simulated by PSCAD

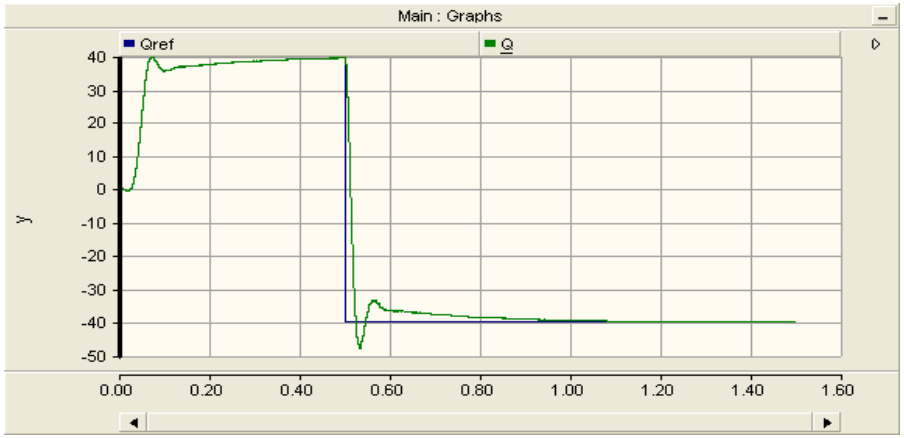


Controller performance in PSCAD and RSCAD



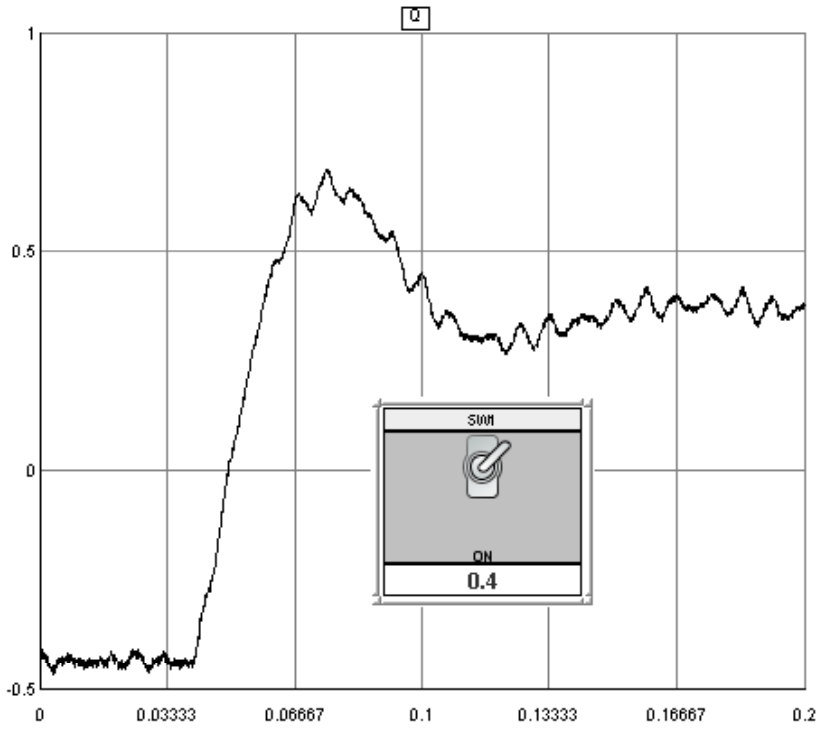


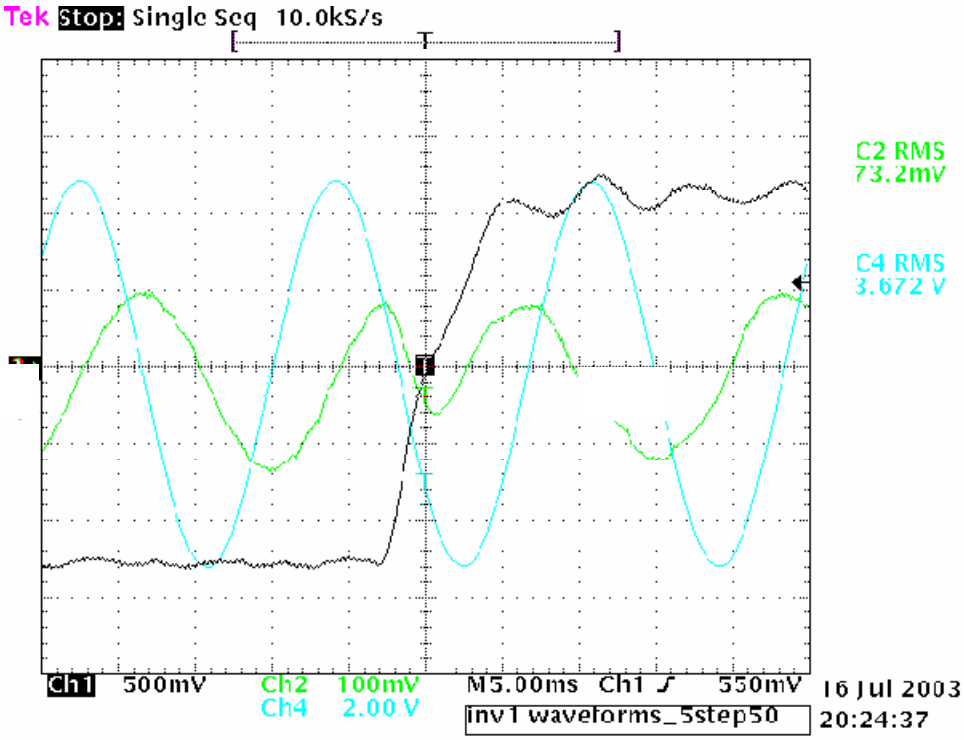
Injected reactive power to the bus after flipping the switch from 0.4pu to -0.4pu.



Injected reactive power to the bus after flipping the switch from -0.4 pu to 0.4pu.

Comparison between Field and RSCAD results

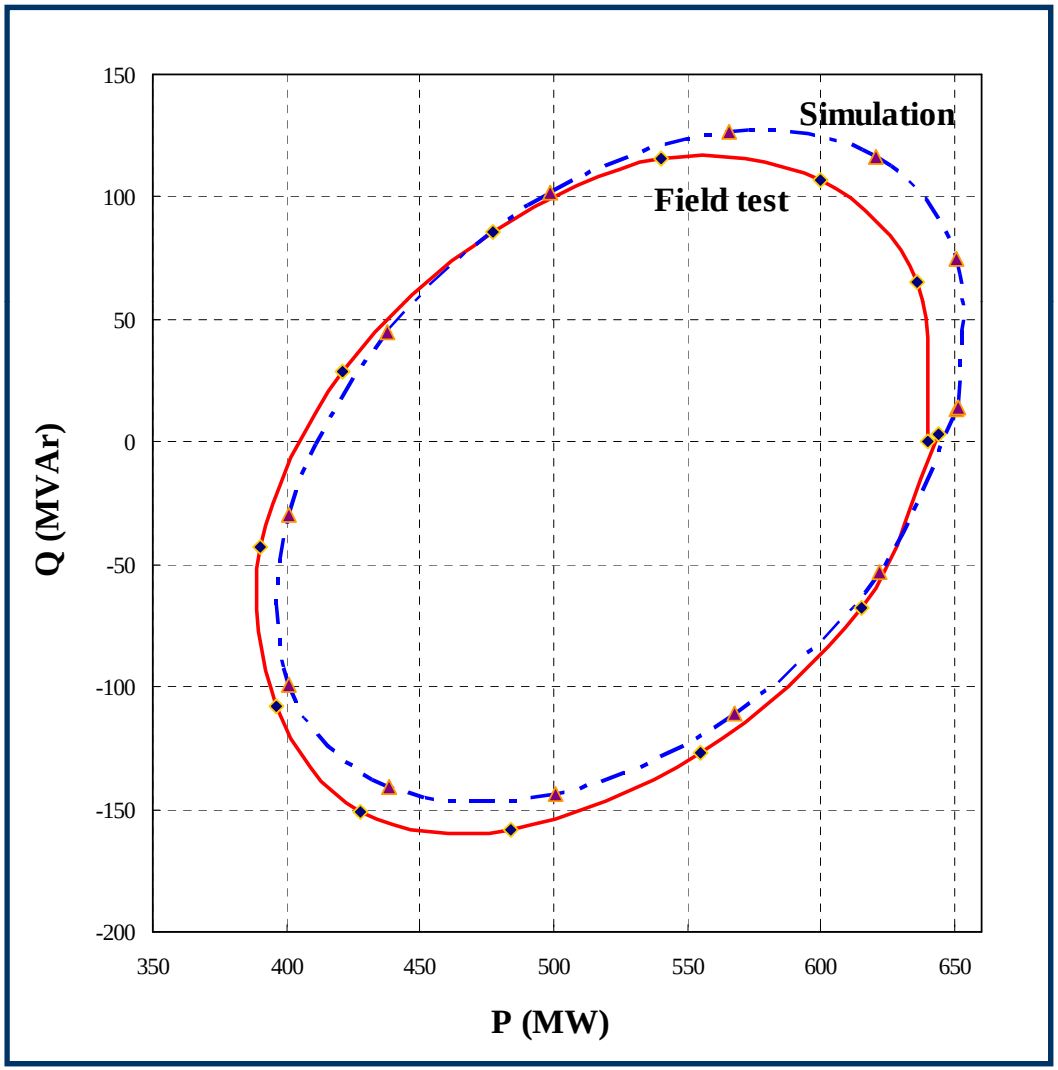




UPFC on UNS
Comparison of field test & simulation

UPFC with shunt inverter at 100% capacitive output of 100 MVAR

- Controllable real power range 255 MW
- Controllable reactive power range 275 MVAR
- Line real power increased by 25%



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Thanks!

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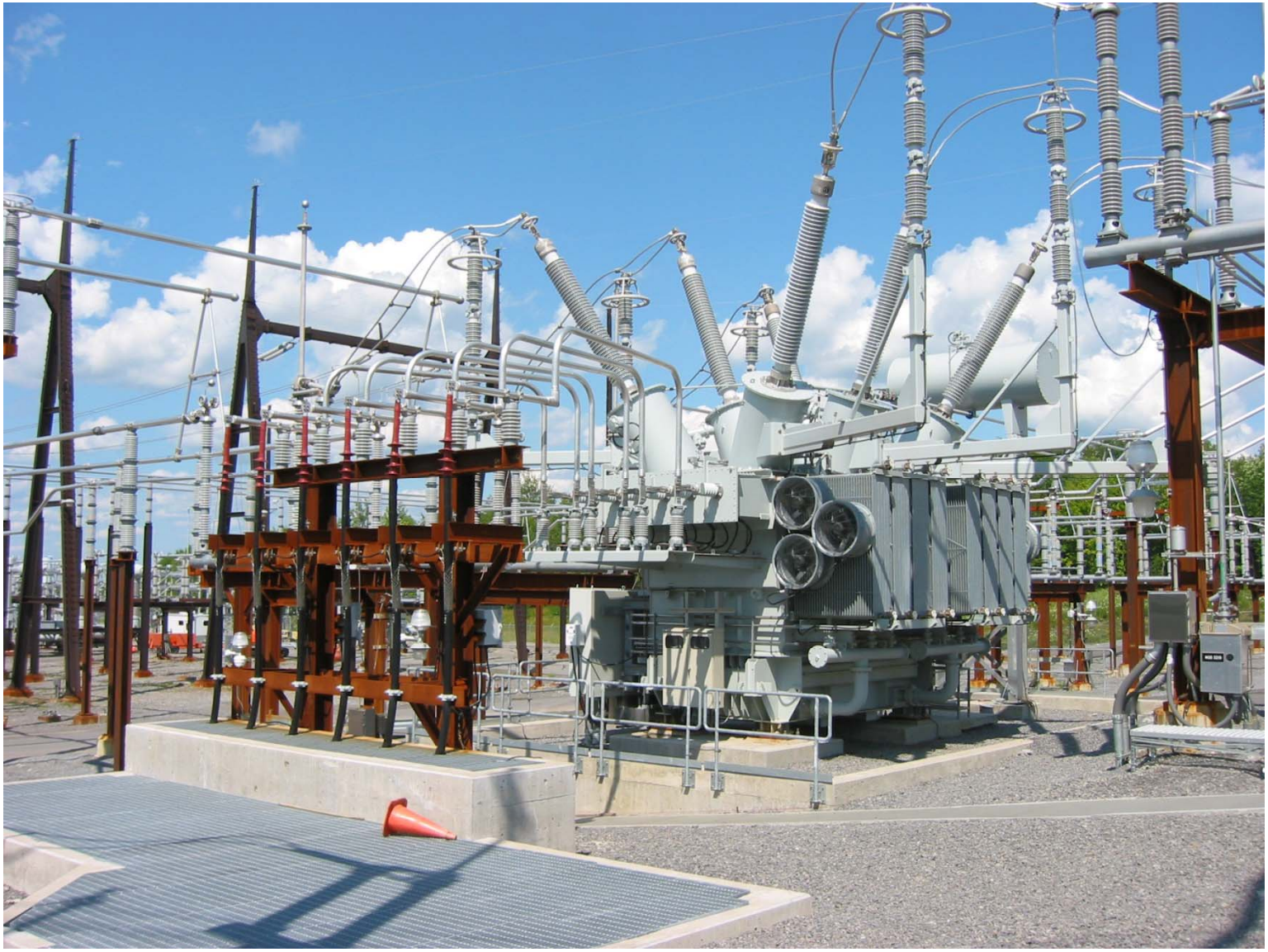
CSC 345 kV, 100 MVA Series Transformer



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CSC 345 kV, 200 MVA Shunt Transformer

Future Renewable Electric Energy Delivery and Management Systems Center