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Device, Converter and Controller Development for 10 MVA ETO Based STATCOM

Principal Investigator: Prof Alex Q. Huang
FREEDOM Systems Center
North Carolina State University, Raleigh

SNL Project Manager: Dr. Stan Atcitty
DOE Manager: Dr. Imre Gyuk

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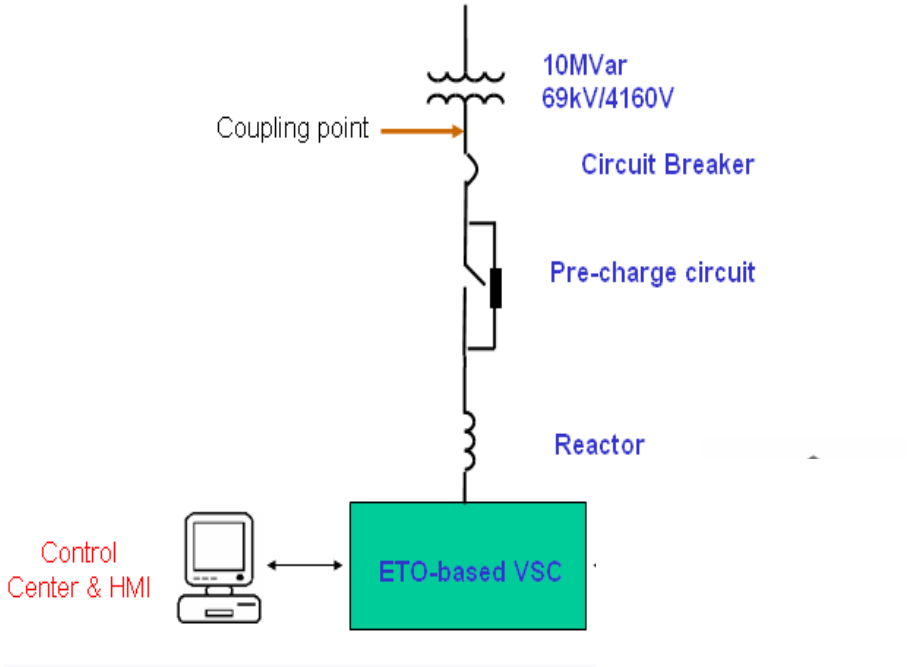
Presentation Outline

- 10 MVA ETO based STATCOM overview
- STATCOM converter topology
- Status of the devices and converter
- Controller architecture and test
- Summary
- Future work

Project Objective: Windfarm Integration

Power rating	**10 MVA**
Transmission Line voltage	**69 kV**
STATCOM voltage	**4.16 kV**
Phase current	**1.39 kA**
Transformer	**69kV/4.16kV**
Converter	**Cascade multilevel converter**
Device	**Gen-4 ETO (4.5kV/4kA)**

Maximize power output by controlling voltage



10 MVA ETO-based STATCOM one line diagram

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Other Project Objectives

To demonstrate the following major benefits of ETO technology

Low Cost

- Low-cost mega-watt rated power semiconductor device (ETO)
- Modular converter design (H-Bridge Building Block)
- Highly efficient air-cooled system

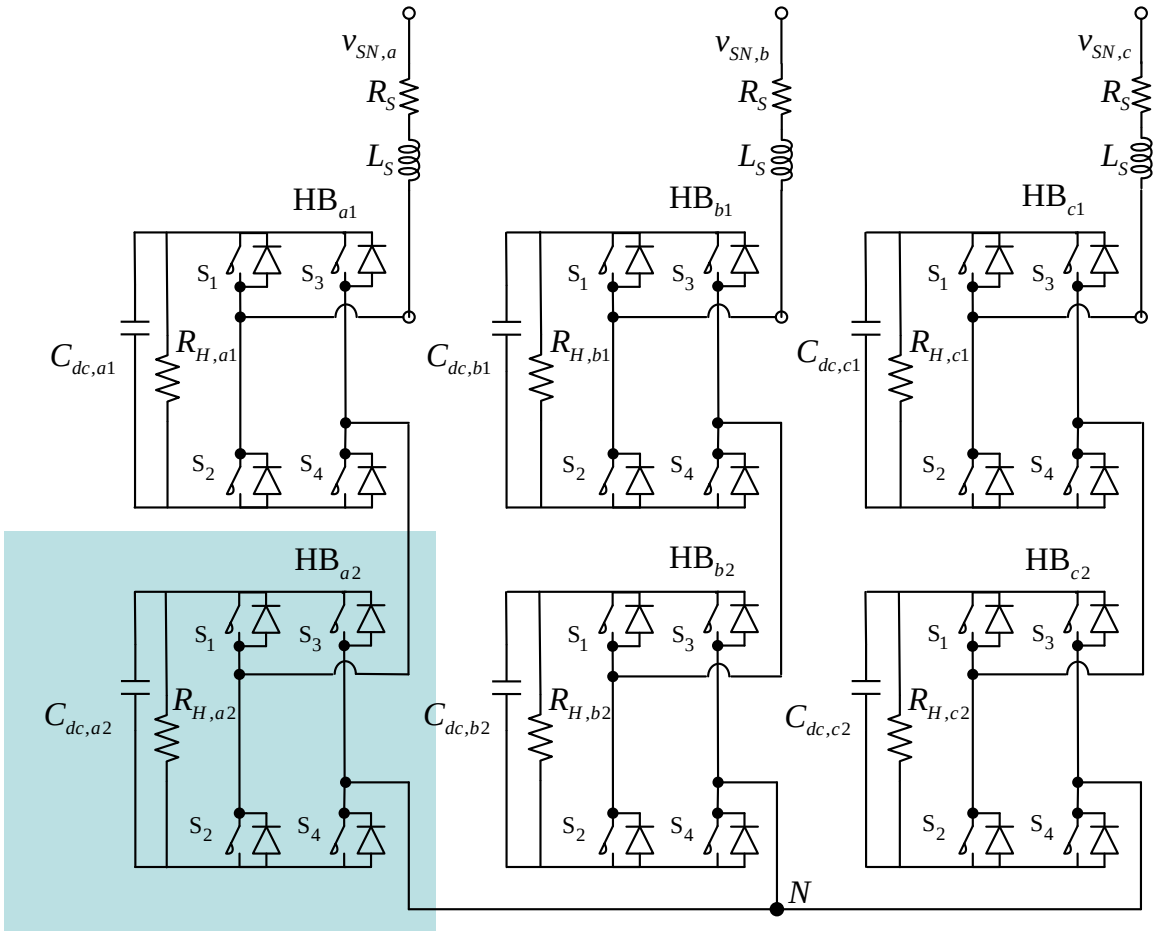
High Reliability

- Large turn-off safe-operation area (SOA) of power device
- High performance cooling system
- Multi-layer protection

Scalability and Extensionality

- Modular H-Bridge Building Block (HBBB)
- Scalable control system

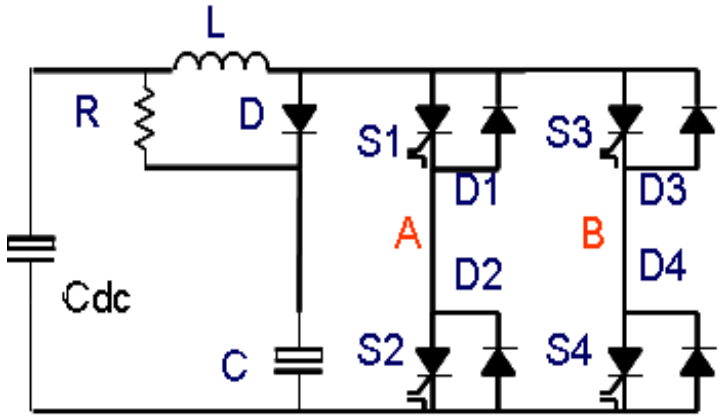
Converter Topology for 10 MVA ETO Based STATCOM



Five-level cascade multilevel converter based on six modular H-Bridge Building Block (HBBB)

Modular H-Bridge Building Block (HBBB)

DC capacitor	2170 kV
DC capacitors value	12 mF
Device forward voltage	3.3 V
Diode forward voltage	3.1 V
Clamp L	5 µH
Clamp R	1 Ω
Clamp C	12 µF



Topology of the modular HBBB

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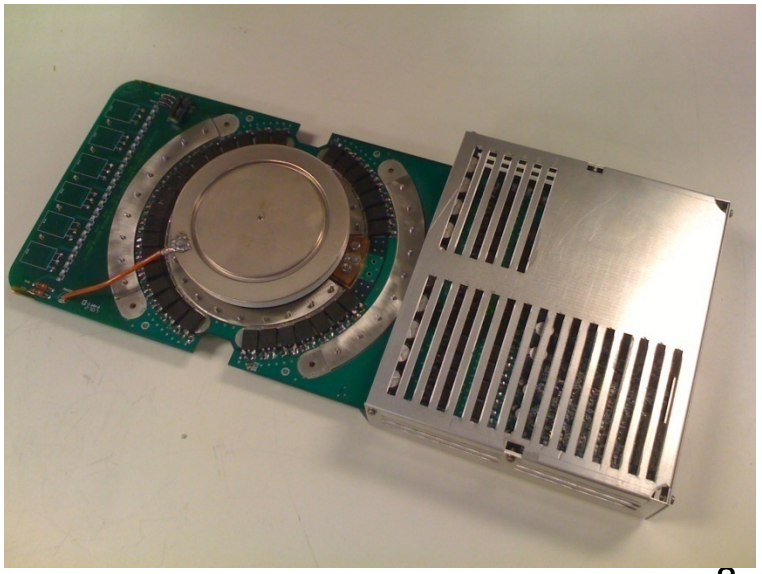
Gen-4 ETO Power Switch

- ✓ Switching Device Used in the HBBB is the Emitter Turn-Off Thyristor
- ✓ Hockey Puck Shaped, Press-pack device
- ✓ Self Powered Gate Drive
- ✓ Built-in Current, Voltage & Temperature Sensors
- ✓ Self-Protection capability
- ✓ Full Optical Control and Intelligent Feedback
- ✓ Clamping force required for correct operation



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HBBB Losses@10 MVA

	$P_{switching}$ (kW)	$P_{conduction}$ (kW)	TOTAL (kW)
S1	1099.5	1076	2175.5
S2	1099.5	1076	2175.5
S3	1099.5	1076	2175.5
S4	1099.5	1076	2175.5
D1	82.95	1049	1131.95
D2	82.95	1049	1131.95
D3	82.95	1049	1131.95
D4	82.95	1049	1131.95

CAPACITIVE

	$P_{switching}$ (kW)	$P_{conduction}$ (kW)	TOTAL (kW)
S1	740.31	1062	1802.31
S2	740.31	1062	1802.31
S3	740.31	1062	1802.31
S4	740.31	1062	1802.31
D1	116.07	1024	1140.07
D2	116.07	1024	1140.07
D3	116.07	1024	1140.07
D4	116.07	1024	1140.07

INDUCTIVE

Total = 13 kW /per HBBB

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LOSS SUMMARY of CLAMP CIRCUIT

<table>
<tr><td rowspan="4">Clamp Circuit Loss</td><td rowspan="4">5.32 kW
(resistor loss
+ diode loss)</td><td>Resistor Loss</td><td colspan="2">4.85 kW</td></tr>
<tr><td rowspan="3">Diode Total Loss : 472W</td><td>Forward recovery</td><td>196 W</td></tr>
<tr><td>Conduction</td><td>61W</td></tr>
<tr><td>Recovery</td><td>216 W</td></tr>
<tr><td>DC Capacitor (ESR Loss)</td><td colspan="4">382W</td></tr>
<tr><td>Di/dt Inductor</td><td colspan="2">Copper Loss
(Resistance = 1.7 mΩ)</td><td colspan="2">663.63 W (CAP)
486.58 W (IND)</td></tr>
<tr><td>Maximum Clamp Capacitor Voltage @4000A</td><td colspan="4">3900 + 200 (ripple) = 4100V</td></tr>
<tr><td>Reset time @ 2000A</td><td colspan="4">16μs</td></tr>
</table>

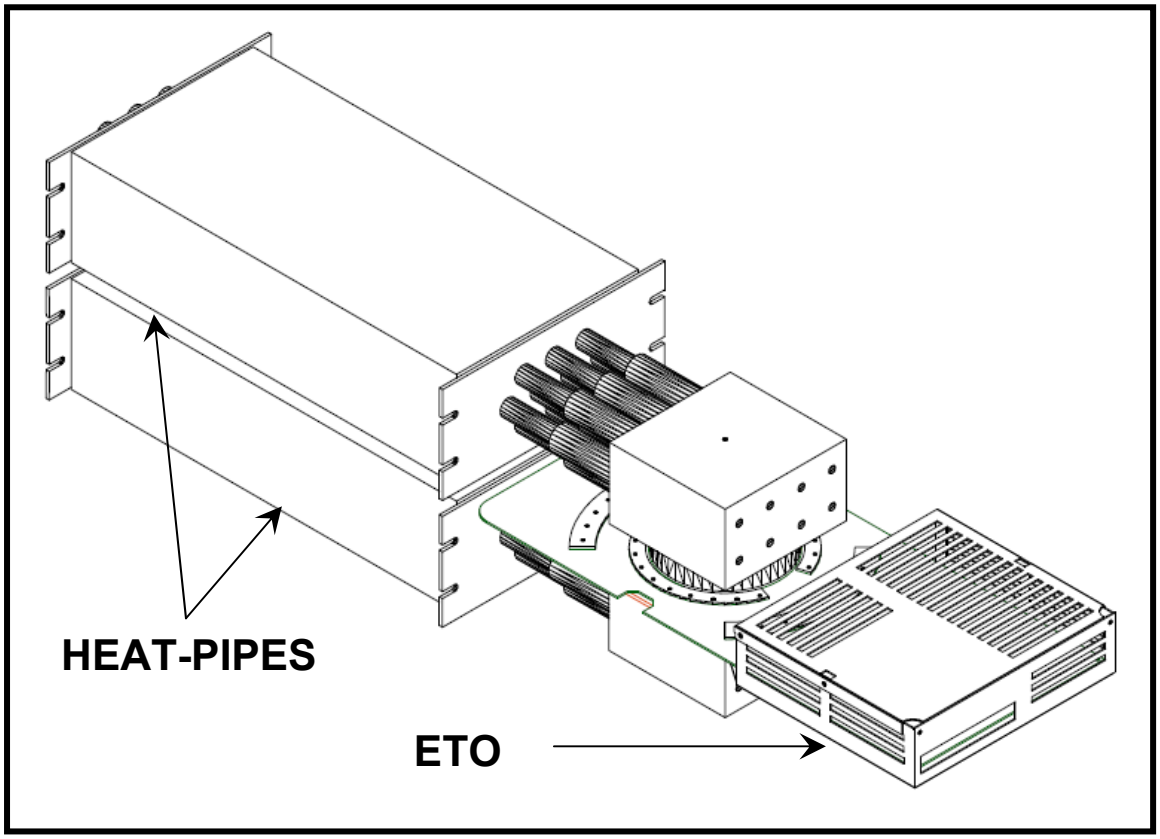
THERMAL MANAGEMENT OPTIONS

- ***DESIGN CONSIDERATIONS:***
  - ✓ ***Heat-Load is large and total HBBB loss = 20 kW***
  - ✓ ***Largely Press-pack Devices are used in HBBB***
  - ✓ ***Dog-House Resistors are used for the Clamp Resistor***
  - ✓ ***Snubber Inductor has NO EXTERNAL FINS***
  - ✓ ***SYSTEM HAS TO BE AIR-COOLED***

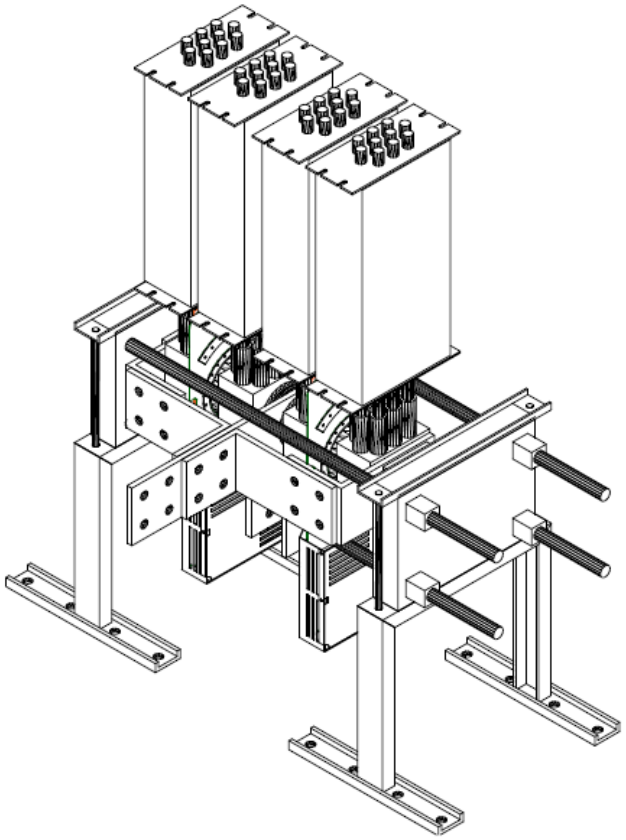
THERMAL MANAGEMENT OPTIONS

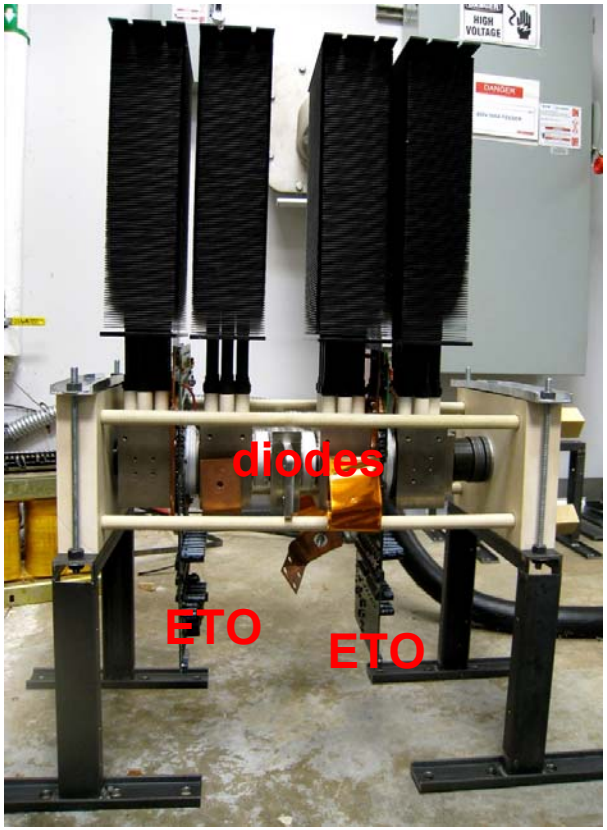
- ***Press-Pack Devices:***

  - ✓ ***Heat-Pipes are a good option for the ETO and Diode.***

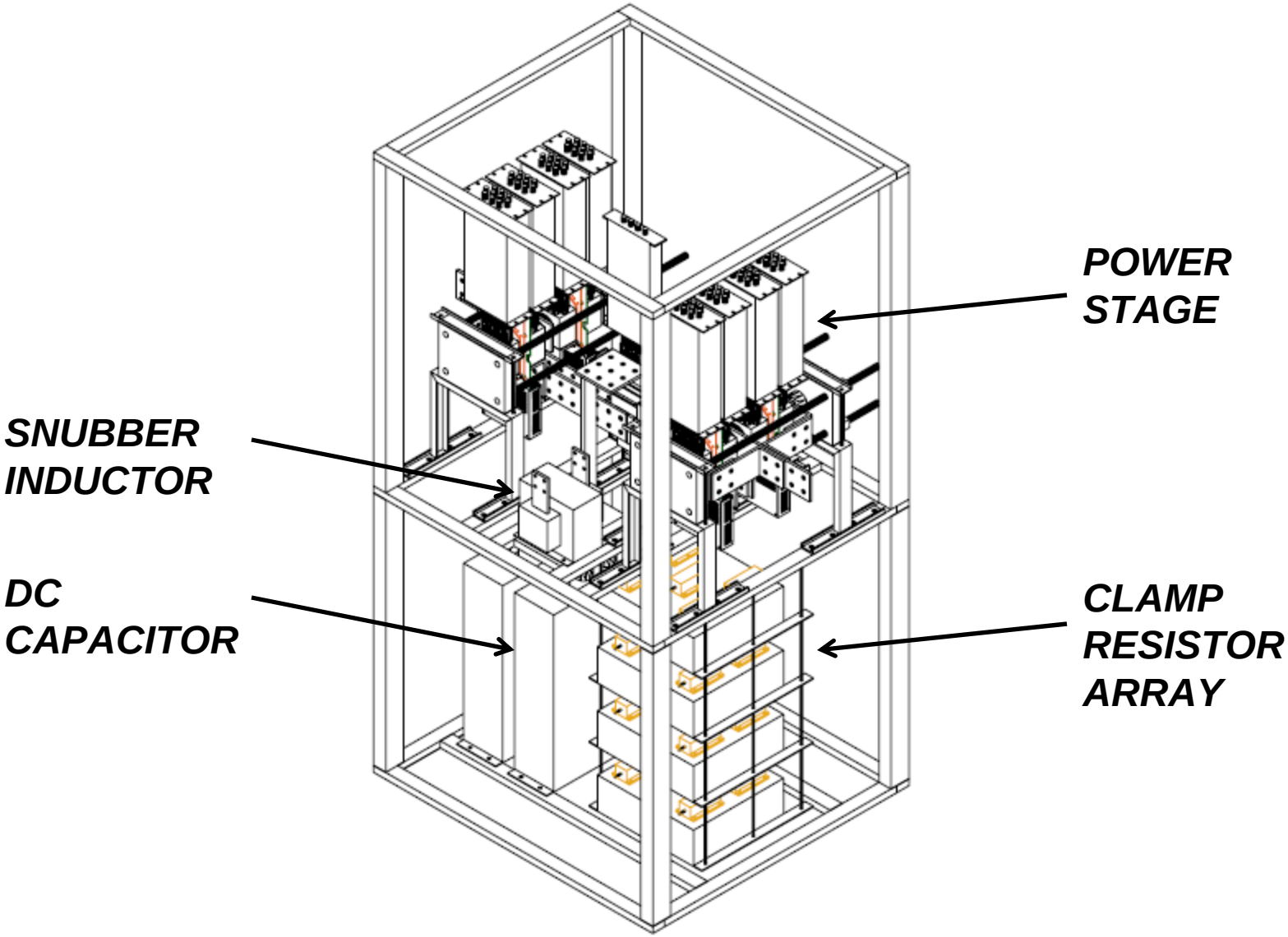


ETO based Half-Bridge





MECHANICAL DESIGN: HBBB Housing



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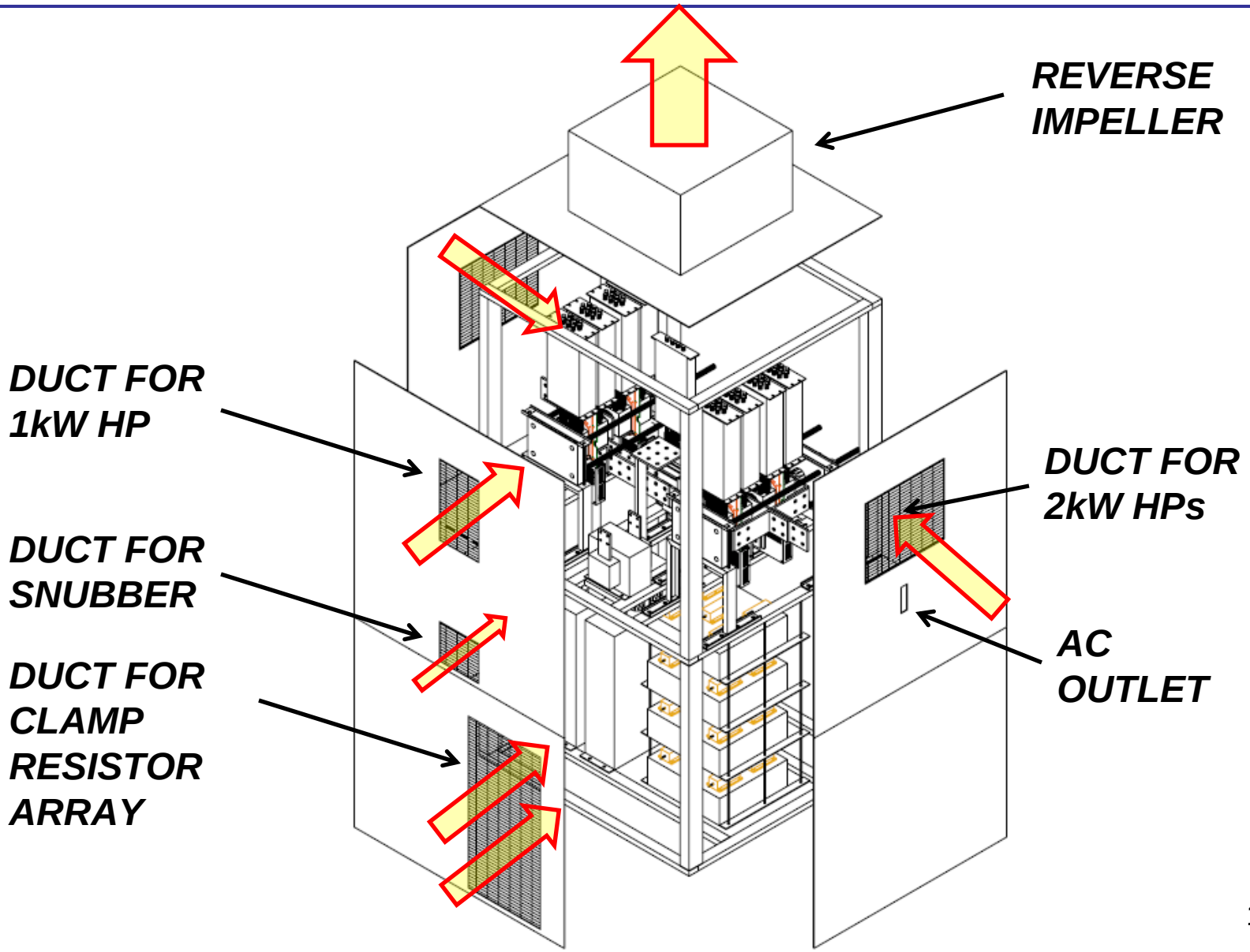
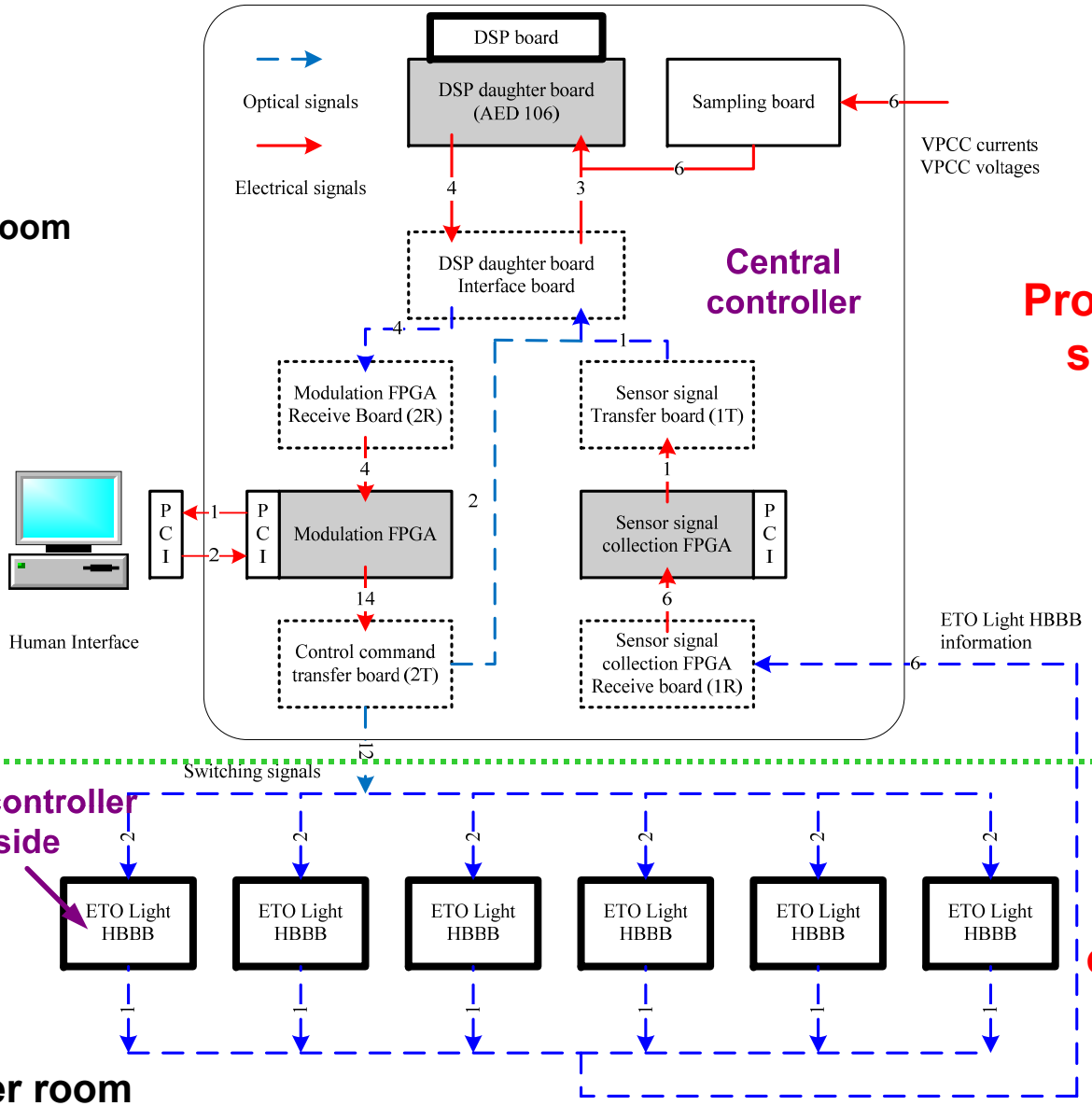
AIR-FLOW DESIGN



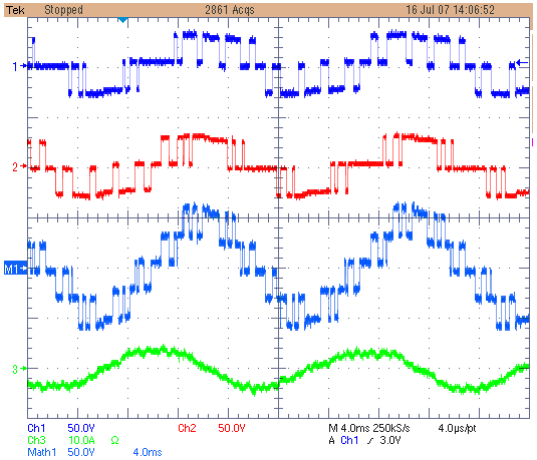
STATCOM Controller Architecture



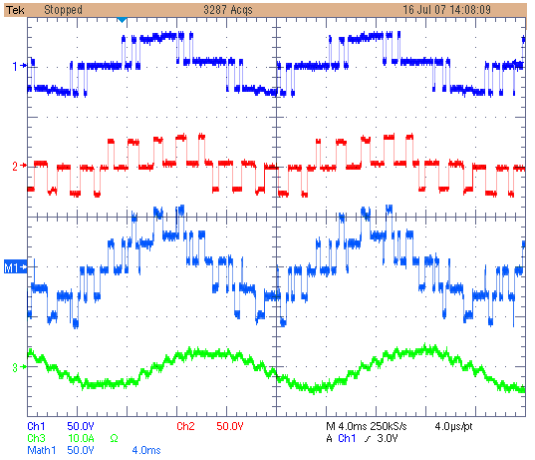
Central controller: Proprietary OPWM control scheme developed for the STATCOM

Local controller: Implement intelligent over I, V, T protections

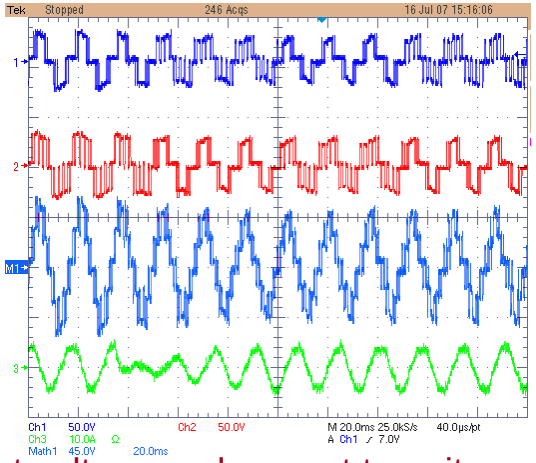
Controller Experimental Waveforms



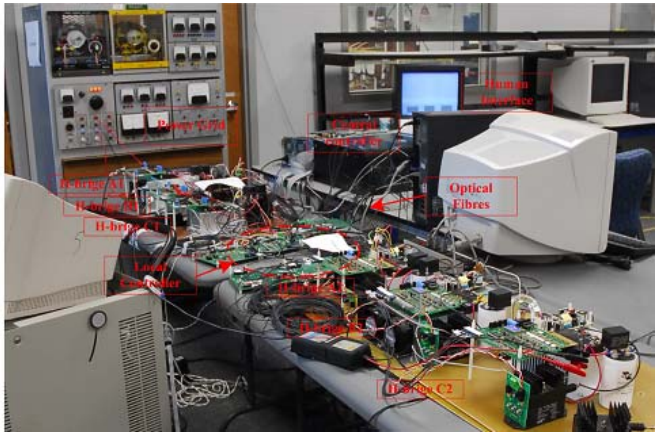
Output voltages of HBBBs and current in capacitive mode in the C phase



Output voltages of HBBBs and current in inductive mode in the C phase



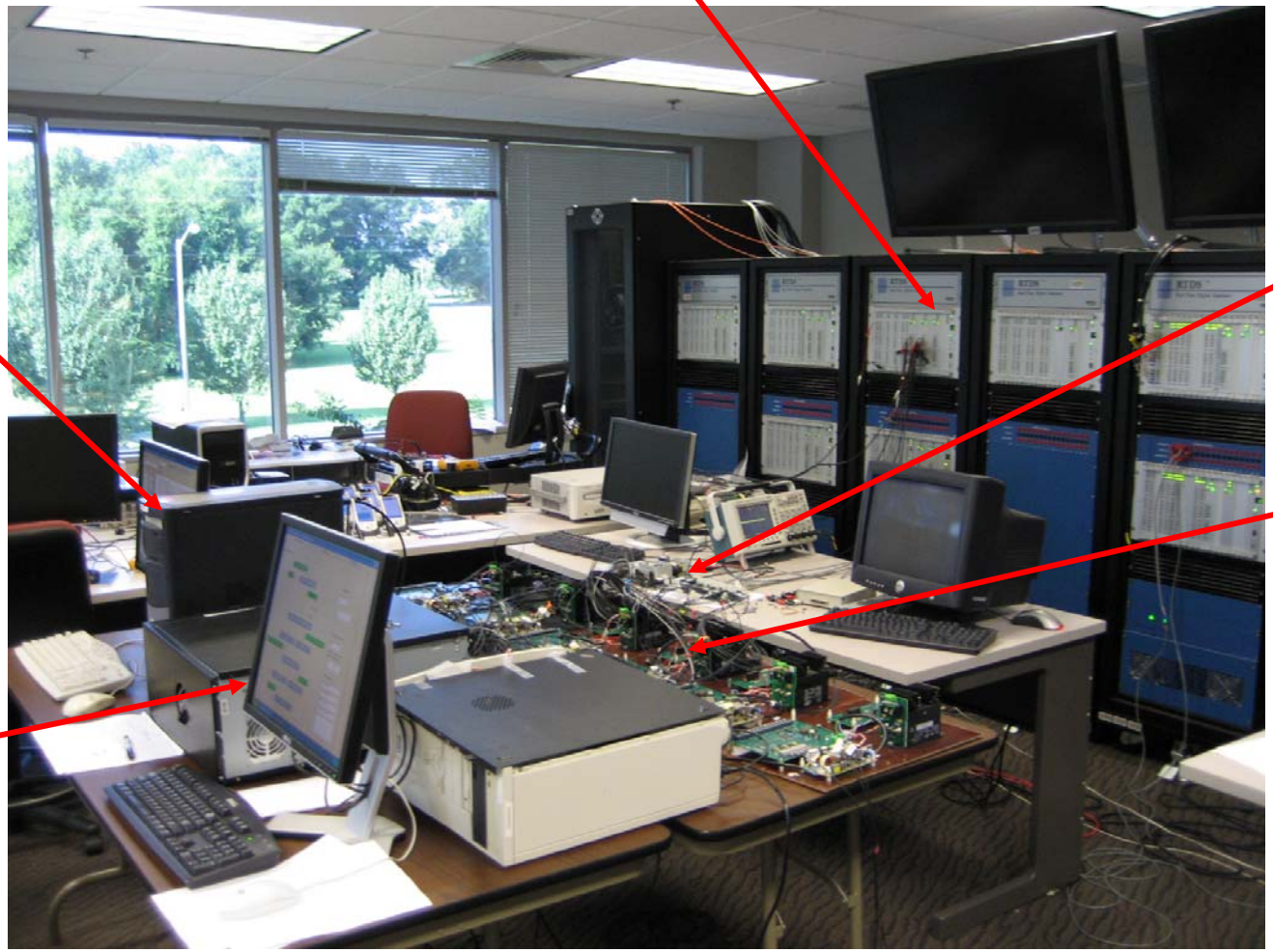
Output voltage and current transit response during the transition from capacitive mode to inductive mode in the C phase



Controller setup in the laboratory (Six IGBT modules are built as six HBBBS)

Controller Hardware in the Loop Test With RTDS

RTDS (Real Time Digital Simulation) in FSU



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Project Summary

- **10 MVA STATCOM system power stage hardware are developed and ready**
  1) ETOs/diodes, Heatpipes, DC capacitors, clamp circuit for six HBBBs are ready
  2) Bus bar and mechanical design are finished.
  3) Bus bar manufacturing and assembly are needed to finish the 10 MVA system

- **STATCOM controller system is developed and is being tested in RTDS system supported**
- **Successful demonstration of ETO STATCOM will allow us to move to the next phase demonstration, an ETO Energy Storage System**

THANK YOU