ETO Thyristor: Enabling Technology For Low Cost Power Conditioning System

Principal Investigator: Prof Alex Q. Huang
Center for Power Electronics Systems, Virginia Tech

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

• Project Objectives

• FY2002 Activities and Accomplishments
  • New generation ETO
  • The high-power pulse test of the ETO
  • Continuous high switching frequency test of the ETO

• Applications and Insertions of ETOs

• Planned Future Works
Project Objectives: Advanced High-Power Switch

Developing a low-cost high-frequency, high-power switch for energy storage and other applications

- **SCR**
- **GTO**
- **IGBT**

Power (I x V, MW)

Switching frequency (Hz)
ETO: A New High Power Switch for PCS

- Low voltage MOSFETs integrated with high-voltage GTO
- Voltage control
- Using the anode current to provide the turn-off energy
- Unity turn-off gain enables fast switching speed
- Unity turn-off gain enables snubberless turn-off capability

Emitter Turn-Off (ETO) Thyristor

<table>
<thead>
<tr>
<th>Power (I x V, MW)</th>
<th>5</th>
<th>15</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching frequency (Hz)</td>
<td>50</td>
<td>500</td>
<td>5000</td>
</tr>
</tbody>
</table>

SCR

GTO

IGBT
• ESSP supported three generations of development
• Gen-3 developed in FY2002
• Gen-4 will be developed for FY2003

1.0 kA to 4 kA
4.0 kV to 6 kV
The ETO: low cost solution for high-power

- The GTOs from different manufacturers can be used as the ETO’s main switch to achieve the highest snubberless turn-off capability.
- The ETO can be optimized according to its application.
Significant ETO Characteristics

Positive temperature coefficient allows parallel operation
Snubberless turn-off capability allows elimination of snubbers hence simpler systems.
Significant ETO Characteristics

The time intervals during turn-off at 2000A, 2000V

<table>
<thead>
<tr>
<th>ETO</th>
<th>Storage Time (us)</th>
<th>Voltage Rising Time (us)</th>
<th>Current Failing Time (us)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETO1</td>
<td>1.36</td>
<td>1.2</td>
<td>3.4</td>
</tr>
<tr>
<td>ETO2</td>
<td>1.44</td>
<td>1.2</td>
<td>3.4</td>
</tr>
<tr>
<td>ETO3</td>
<td>1.4</td>
<td>1.2</td>
<td>3.4</td>
</tr>
<tr>
<td>ETO4</td>
<td>1.4</td>
<td>1.2</td>
<td>3.4</td>
</tr>
<tr>
<td>ETO5</td>
<td>1.4</td>
<td>1.2</td>
<td>3.4</td>
</tr>
</tbody>
</table>

• Identical switching times allow series operation
Very low gate control power enables high-frequency operation.

Significant ETO Characteristics

Gate unit power consumption (W)

IGCT
Gate power @ 1kHz
ETO

Switching current (A)
Built-in Current Sensing Capability of the ETO

- Enables easy control and system protection

![Graph showing current vs. output duty cycle]
Continuous high switching frequency test of ETOs

**The 1000V/100A power supply**

**The 2000VDC, 1500A r.m.s, 1kHz ETO switch, Inductor, and diodes**

**The 20kW resistor load**

**The cap filter**

Objective: to test and evaluate the ETO’s high switching frequency operation, thermal handling capability, control power consumption, and the reliability.
The high switching frequency test results

- Operation duration: continuous
- Switching frequency: 1 kHz
- Switching loss: 3.3 kW
- ETO peak junction temperature: >100 °C
- Snubberless turn-off current: 650A
- Snubberless turn-off bus voltage: 2000V
The thermal test results

• Reliable thermal handling characteristic of the ETO at high switching frequency was demonstrated.

Switching frequency: 1kHz, bus voltage : 2 kV, Switching current: 650A
HBBB Enables Modular Multilevel Converter Design

- Modular and expandable topology for high voltage power systems,
- Considerably lower THD
- Fast dynamic (due to ETO and multilevel)
ETO-Based HBBB Prototype

**Specification:**
- Main Devices: 4kA/4.5kV ETO
- di/dt Limitation: 200 A/µs
- Bus Voltage: 2 ~ 2.5 kV
- Voltage Ripple: 10%
- Output RMS Current: 1.25 kA
- Switching Frequency: Up to 2 kHz
- Power Capacity: 1.5 MVA (3 MVA pulse)
- Cooling System: Water
System Demonstration: ETO DSTATCOM

ETO voltage
(2 kV/Div)

ETO current
(1 kA/Div)

HBBB Output Current
(500 A/Div)
Energy Storage System Demonstration Program

- Three HBBBs form a 4.5 MVA three-level VSC DSTATCOM
- Can be used for real and reactive power support

Ultra CAP (EPRI-PEAC)
Key features of the control:

- HBBB provides modular power converter design
- Ring structure provides modular control design
- Allow easy expansion of # of levels and # of FACTS nodes
- All switching and measurement signals are transferred using one single optical fiber (+backup)
- Better performance, more reliability, and cost effective
Simulation Results of Real Power Compensation

Graph6

Output voltage

(+ Real power) - Real power

Output Current

(-) : t(s)
va
vpccca

(-) : t(s)
\(V_{\text{PCC}}\)
\(i_a\)
vpccca
Three key enabling technologies are developed at Virginia Tech

- Advanced switch technology (ETO)
  - 4000A snubberless turn-off capability
  - Low cost resulting from use of conventional GTO
  - Very low control power
  - Continuous & sustained operation at 1 kHz and Tj,max >125 °C is demonstrated
  - Gen-4 will be developed in FY2003
- Advanced modular converter technology (HBBB)
- Advanced modular digital controller technology

These technologies will enable low cost, advanced ESS implementation
DSTATCOM with energy storage are being developed

ETO commercialization and insertion are underway
Acknowledgment

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