Emitter Turn-off (ETO) Thyristor Development

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Acknowledgment

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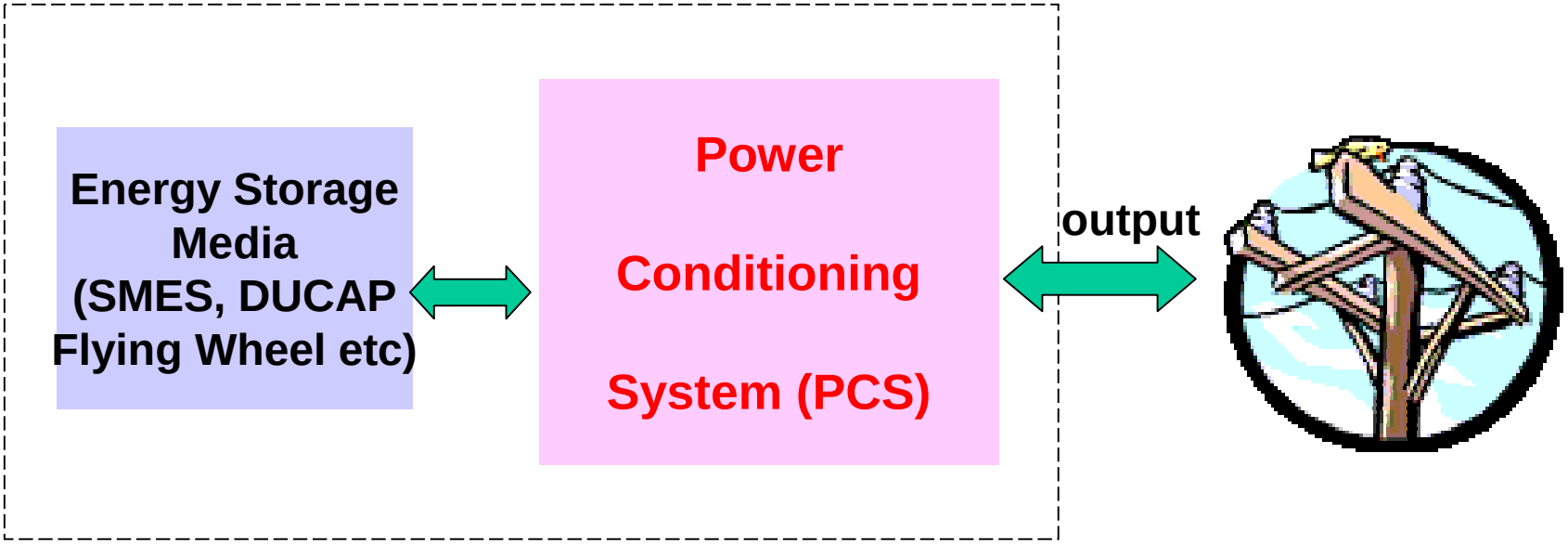
Presentation Outlines

- **Project Objectives**
- **ETO Milestones and History**
- **FY2001 Activities and Accomplishments**
- **Applications and Insertions of ETOs**
- **Planned Future Works**

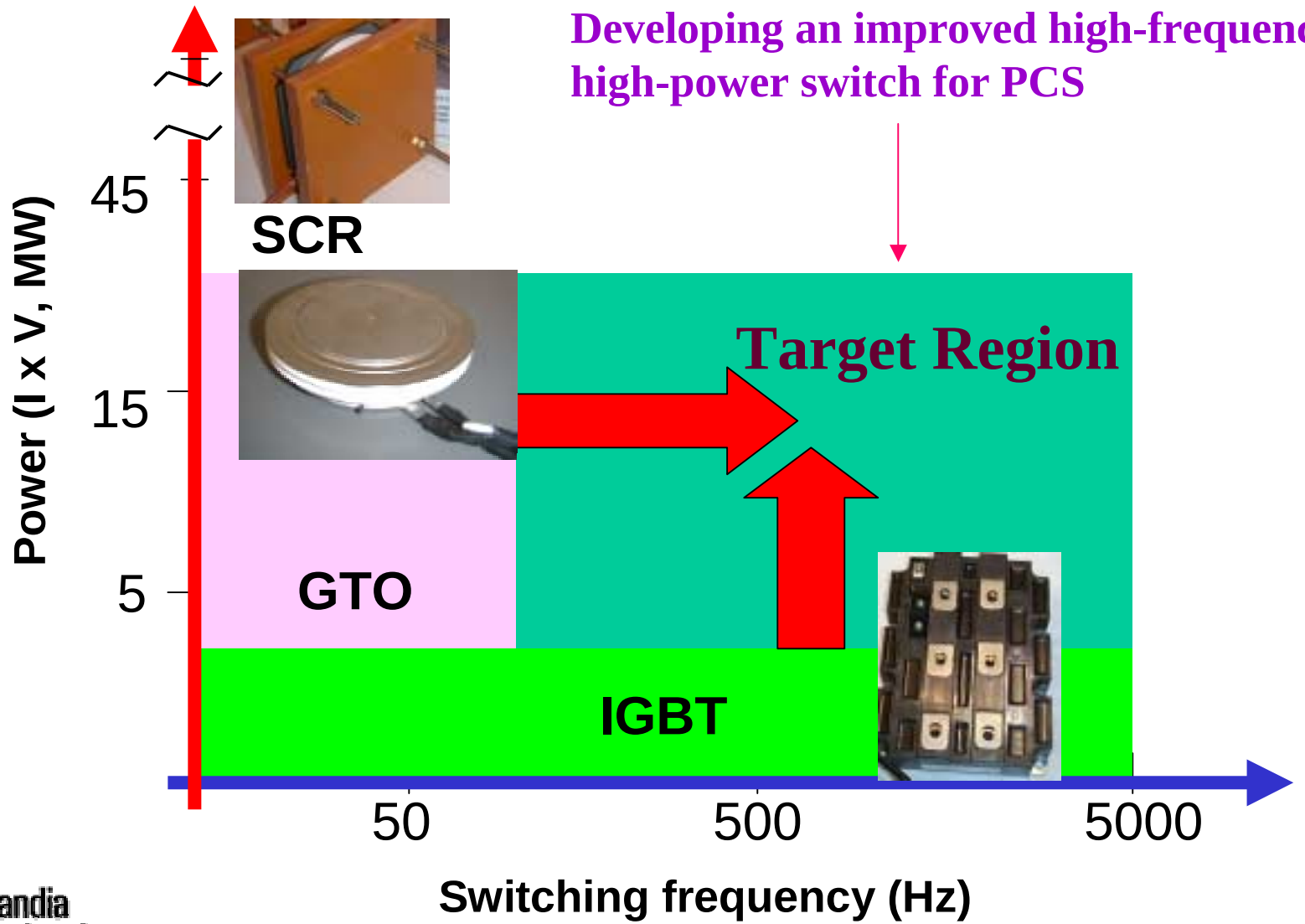
Project Objectives: Motivation

A typical energy storage system (ESS)



- ESS provides reactive and real power to the grid
- PCS is one of the most important part of ESS
- Improved high-power high-frequency power semiconductor devices are needed for the high-performance PCS

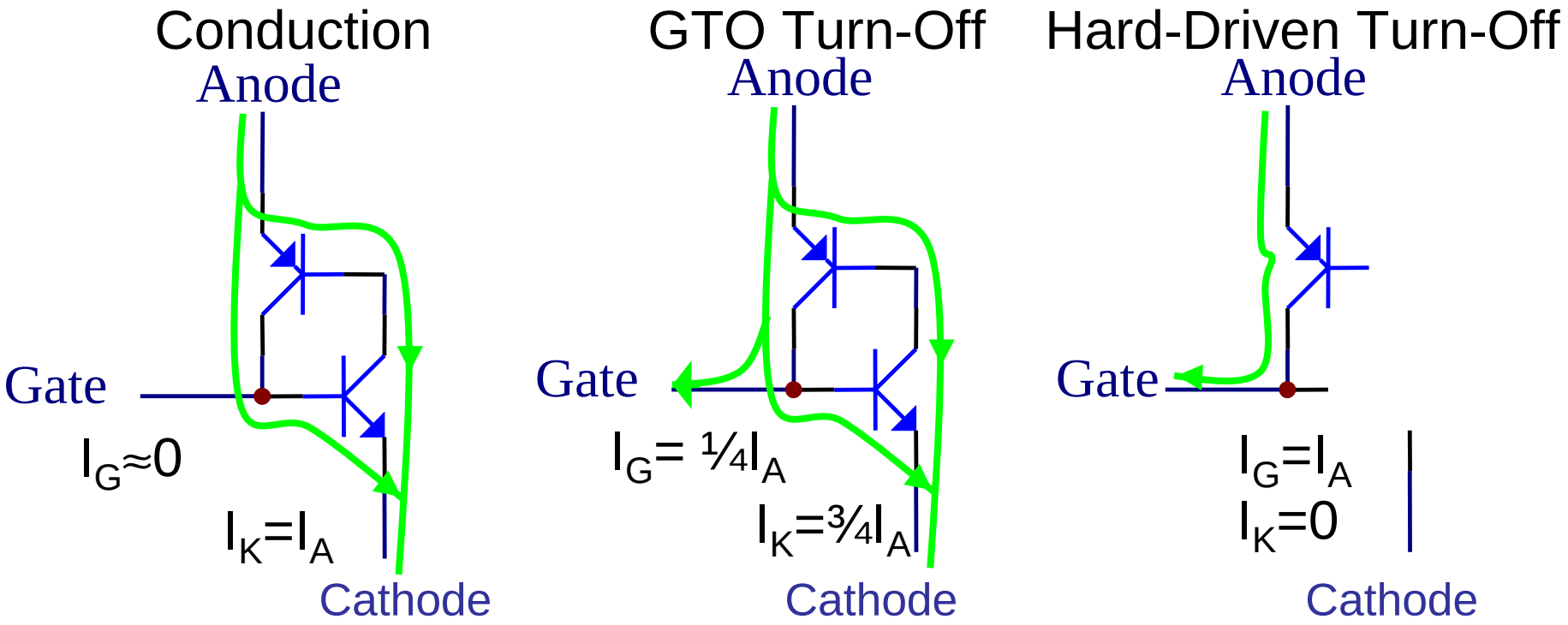
Project Objectives: Advanced High-Power Switch



Improving GTO: Unity-gain turn-off

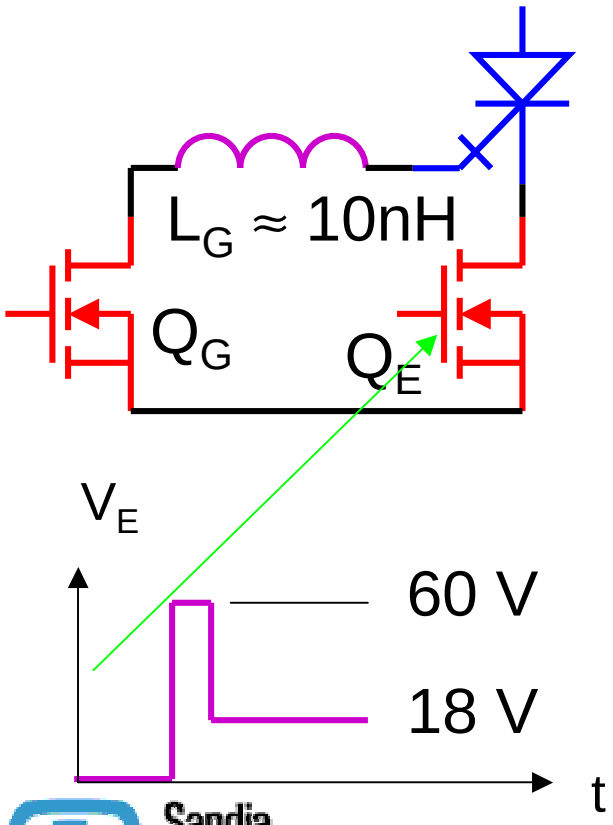
Drive the gate current equal to the anode current (unity gain)

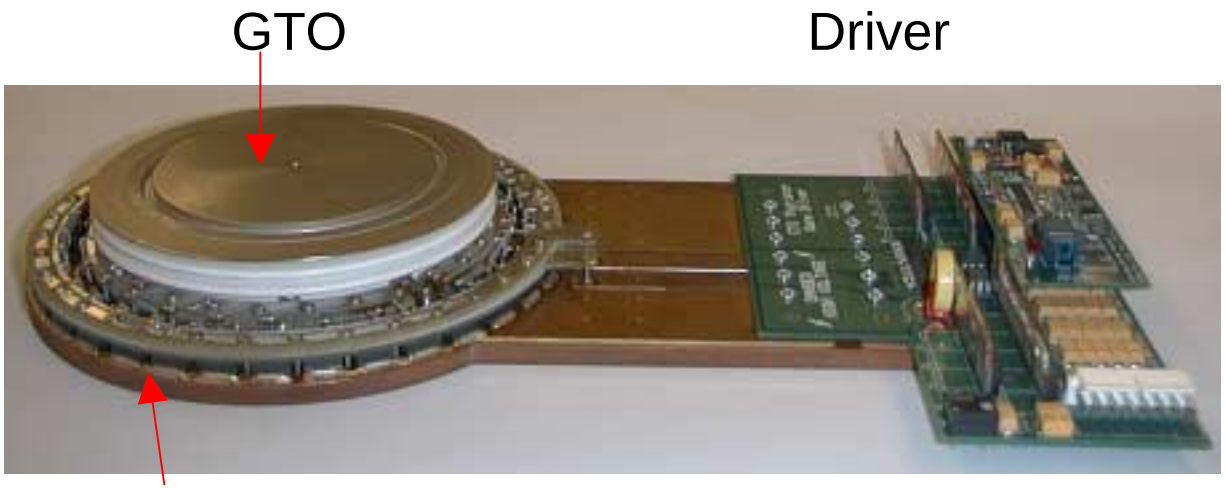
- Positive feedback loop broken
- NPN transistor turns off first
- Main turn off in open-base PNP transistor mode
- Snubberless turn-off capability



Emitter Turn-Off (ETO) Thyristor

- Low voltage MOSFETs in series with GTO
- Uses the anode current to provide the turn-off energy
- Transient voltage is equal to breakdown of Q_E





CPES Gen-1 ETO (ETO4060)

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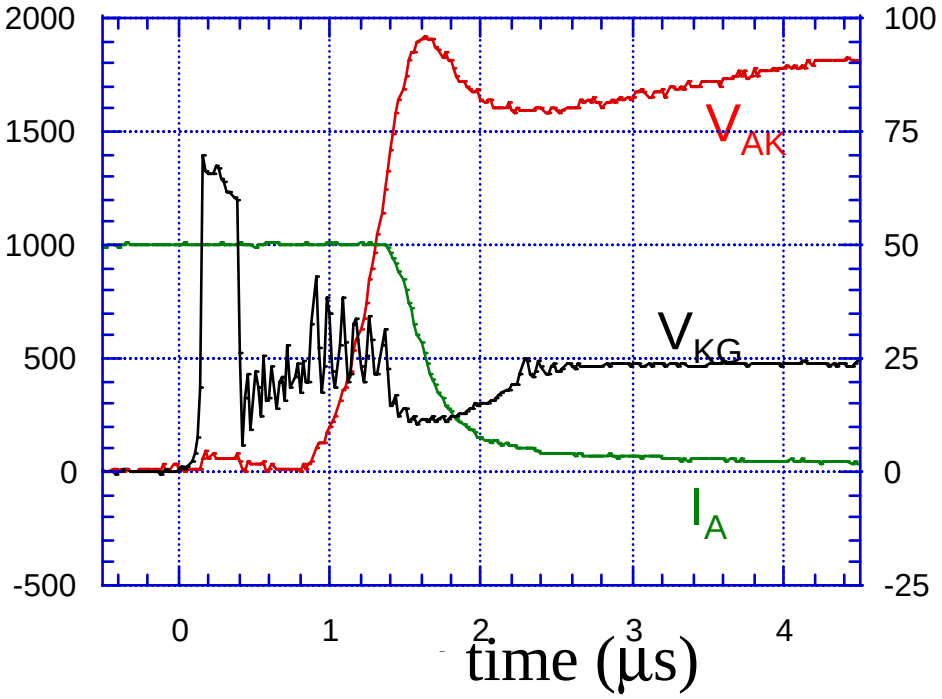
ETO Key Characteristics

+ Lower drive and control power (MOS control)
+ Lower cost solution based on conventional components
+ Lower dependence on driver performance
+ Built-in current sensing



1kA/ 4.5 kV ETO

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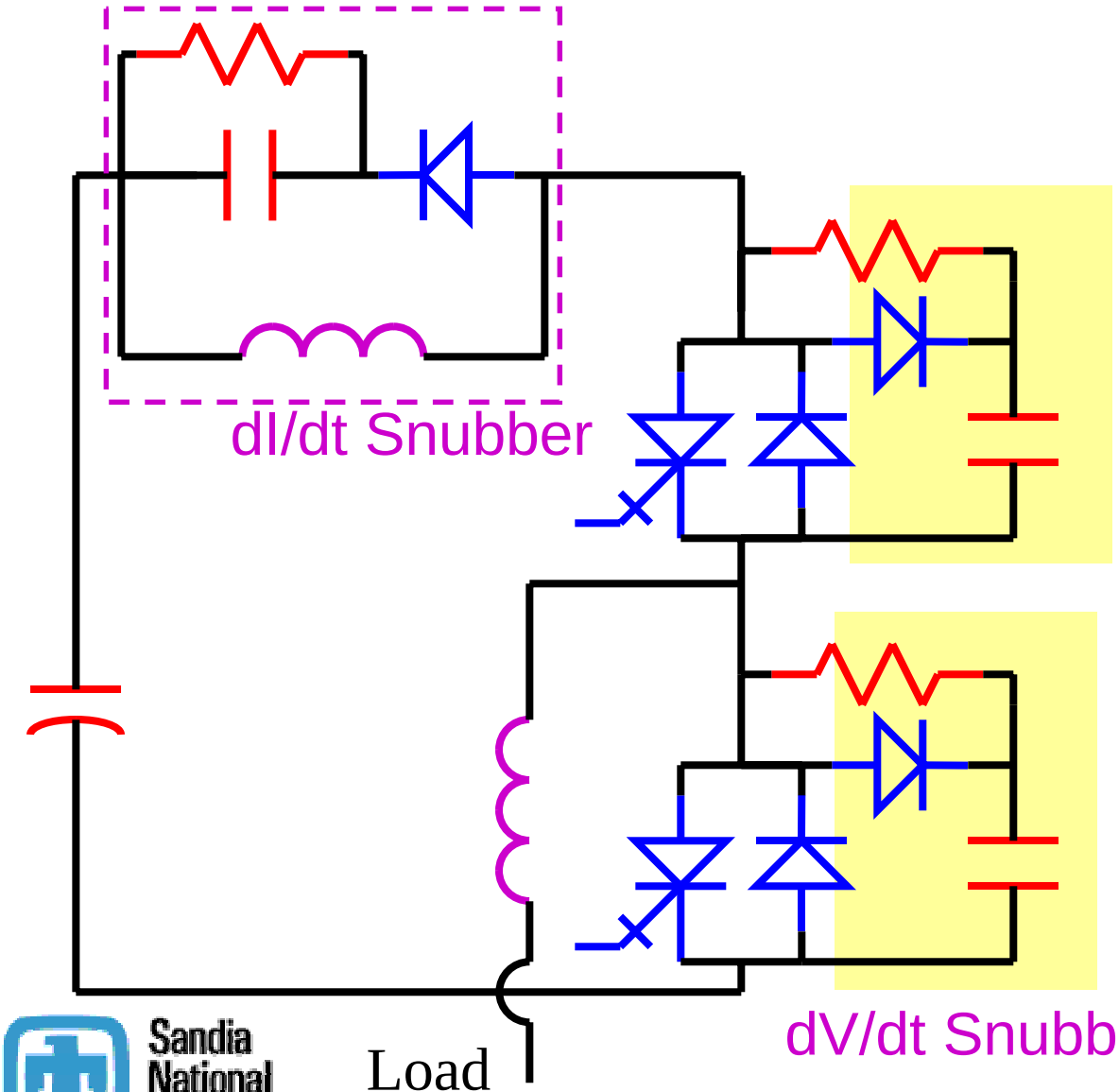
Impact on PCS: Traditional GTO Phase Leg



dI/dt snubber for turn-on

dV/dt snubber for turn-off

$P = 1/2\ C*V_{dc}^2*f_s$

For 4-kA/6-kV GTO:

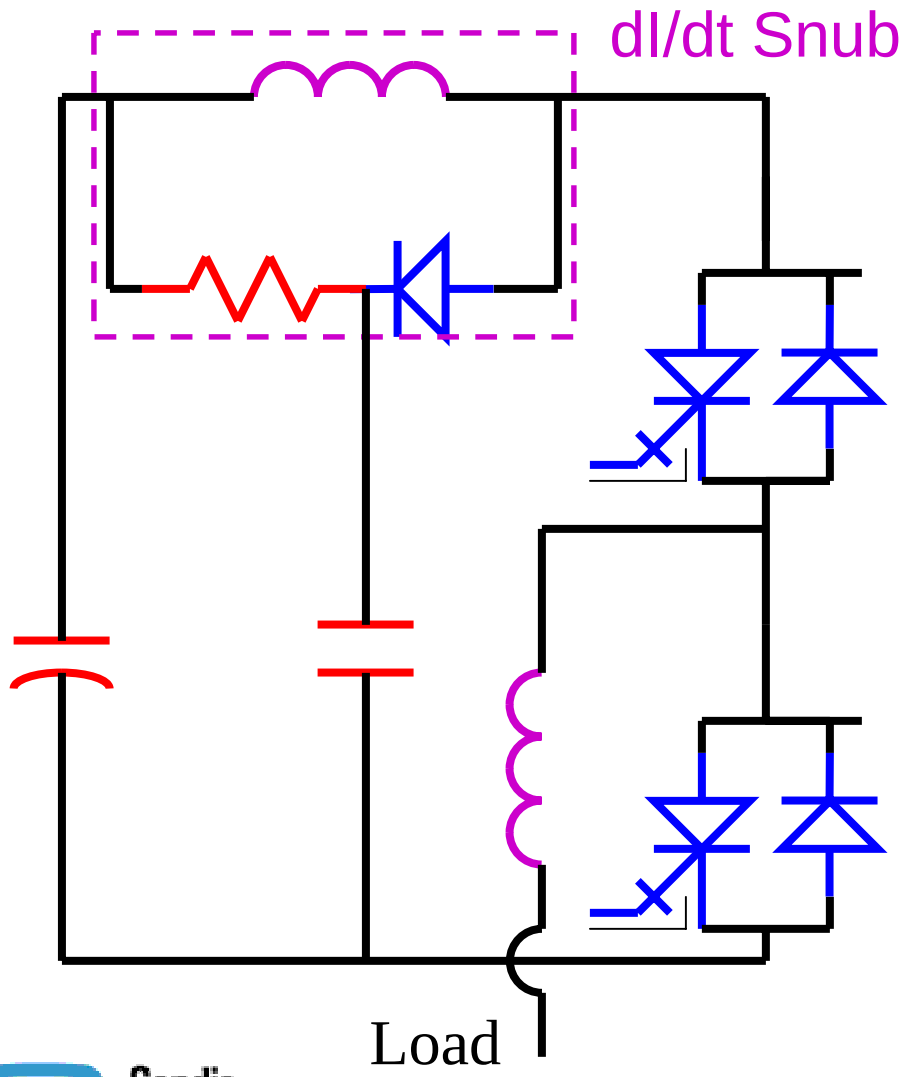
V_{dc} = 3000 V, C = 6 µF

P_{1kHz} = 27 kW per switch

Auxiliary Parts Count:

- Capacitors: 3
- Resistors: 3
- Diodes: 3
- Inductors: 1
- Total: 10

Impact on PCS: ETO Phase Leg



dI/dt snubber w/ clamp

Eliminated dV/dt snubber

Auxiliary Parts Count:

Capacitors:	1	(3)
Resistors:	1	(3)
Diodes:	1	(3)
Inductors:	1	(1)
Total:	4	(10)

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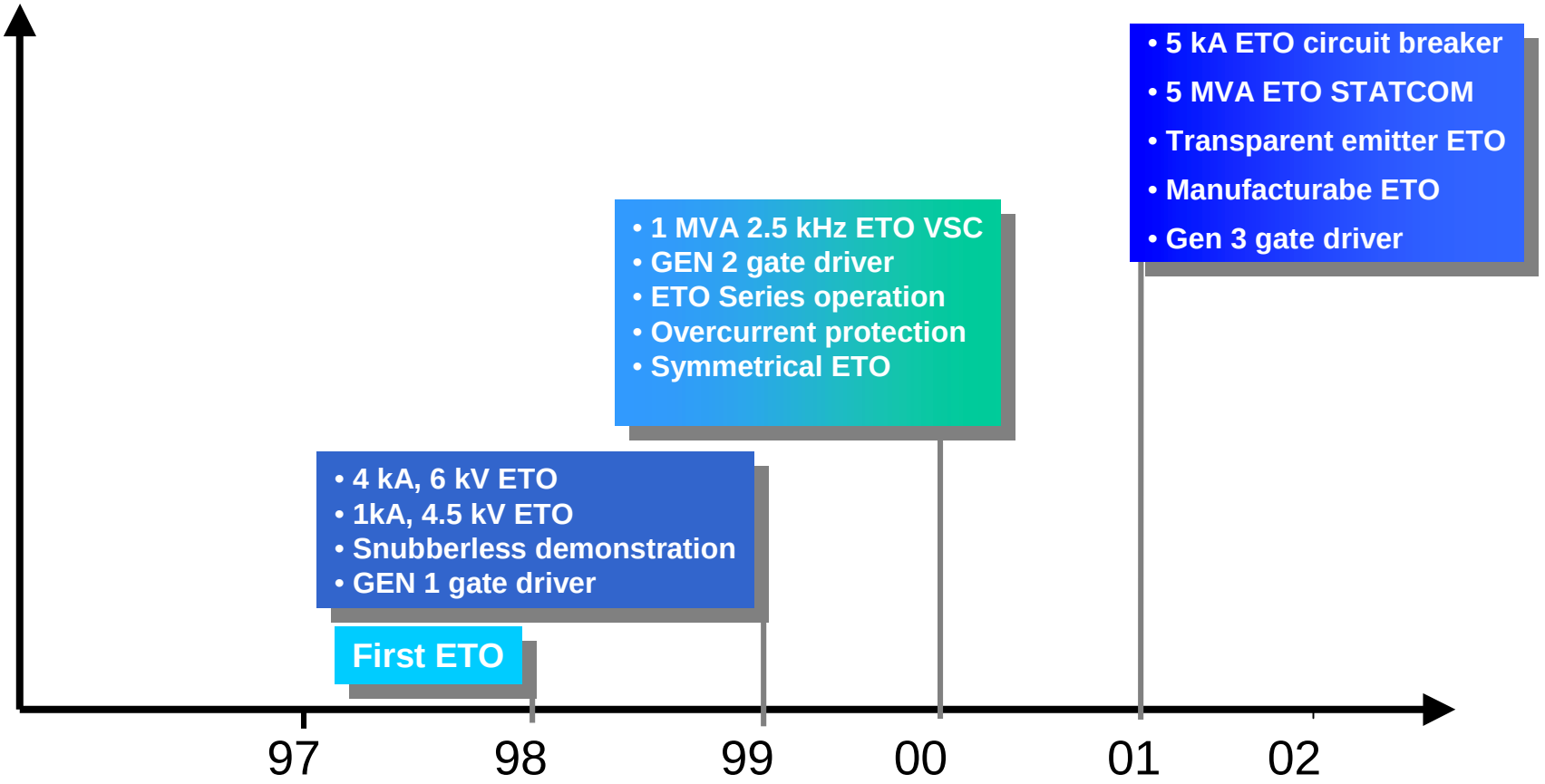
ESS ETO Project History

- Develop a better, high-power, high-frequency, reliable switch (FY1998)
- Demonstrate the ETO in a high-power system (FY1999)
- High-power ETO based PCS development (FY2000)
- Working with ACI to develop manufacturable Gen-3 ETO (FY2001)

Major ETO Milestones

Three generations of development (supported primarily by the ESS program)
ETO ratings cover all available GTO ratings
- symmetric ETOs
- asymmetric ETOs



Major ETO Milestones

Gen-0 ETOs (1998)

1.0 kA to 4 kA

4.0 kV to 6 kV

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Major ETO Milestones

Gen-1 4-kA/6-kV ETO (1999)

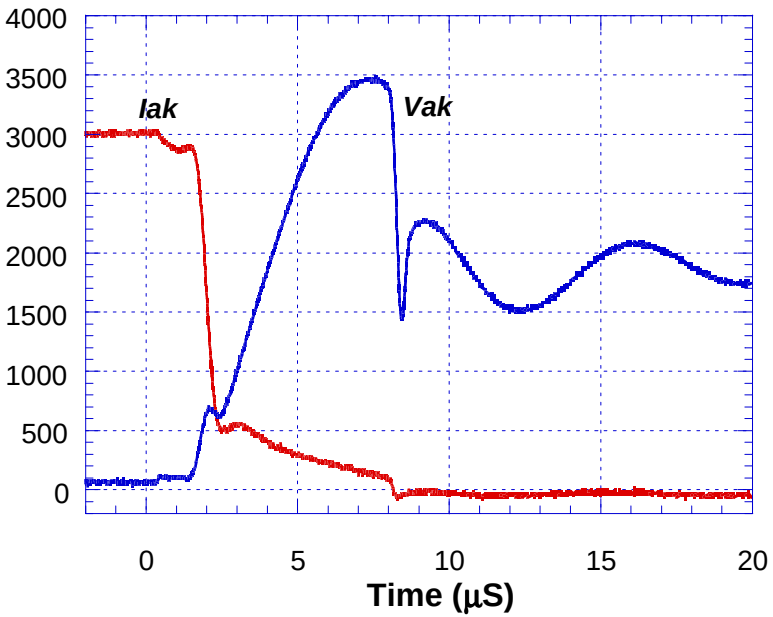
Picture

4-kA/6-kV GTO

GEN 1 gate driver

Turn-off waveforms

(3.0-kA/2.0-kV, 25 °C)

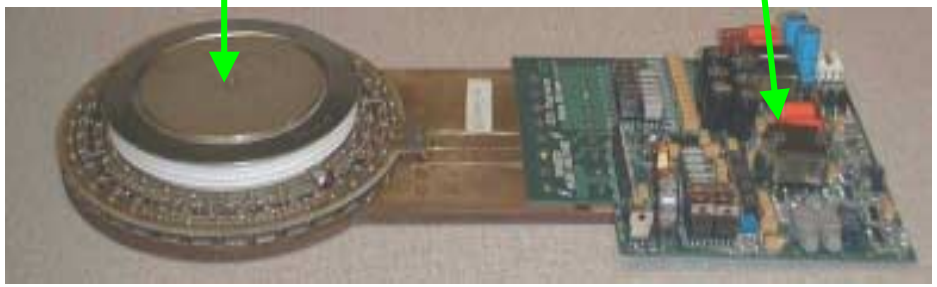


Major ETO Milestones

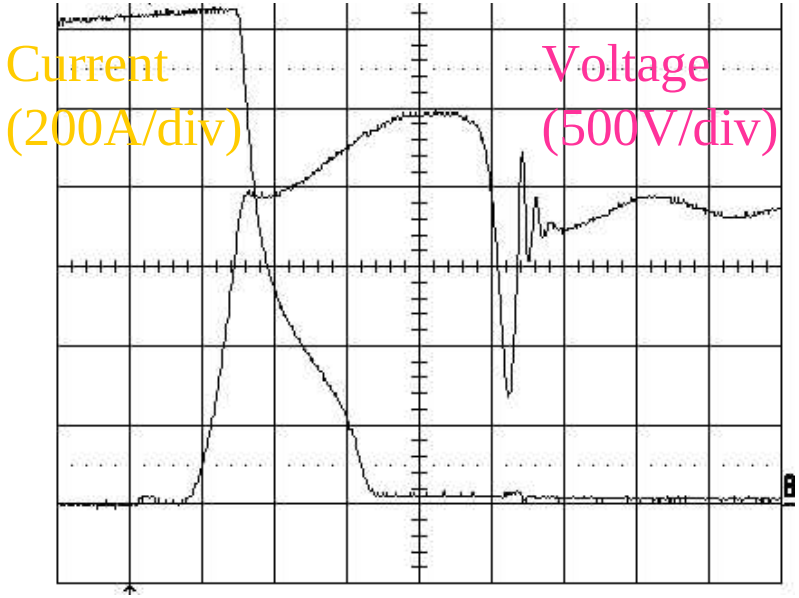
4-kA/4.5-kV transparent emitter Gen-2 ETO (2001)

4-kA/4.5-kV transparent emitter GTO

GEN-2 gate driver



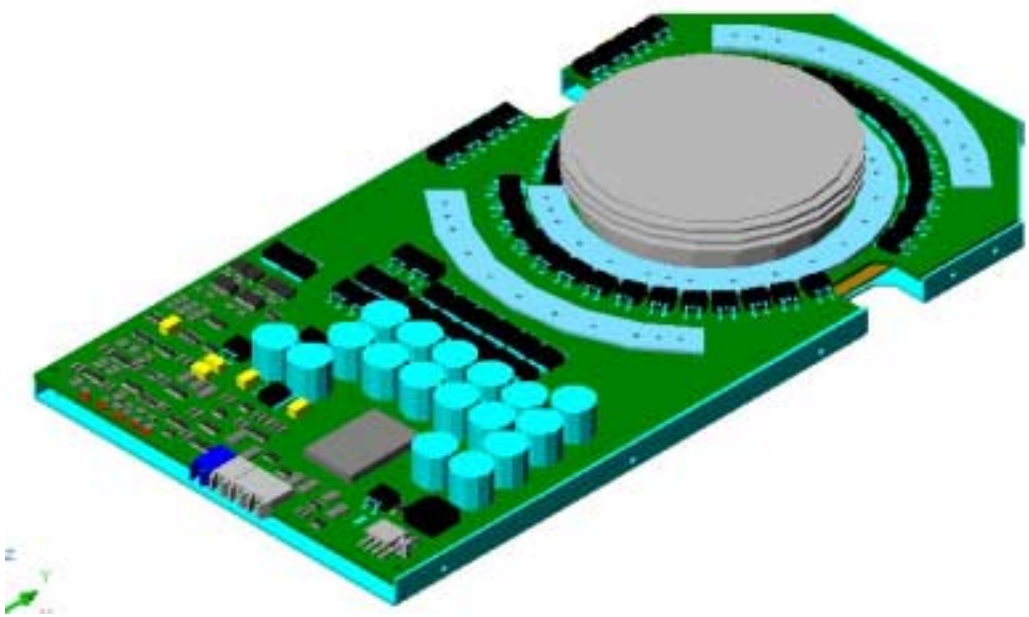
Snubberless turn-off waveforms



Time (2 μs/div)

FY2001 Activities and Major Accomplishments

Objective :Improving manufacturability and reliability of the ETO

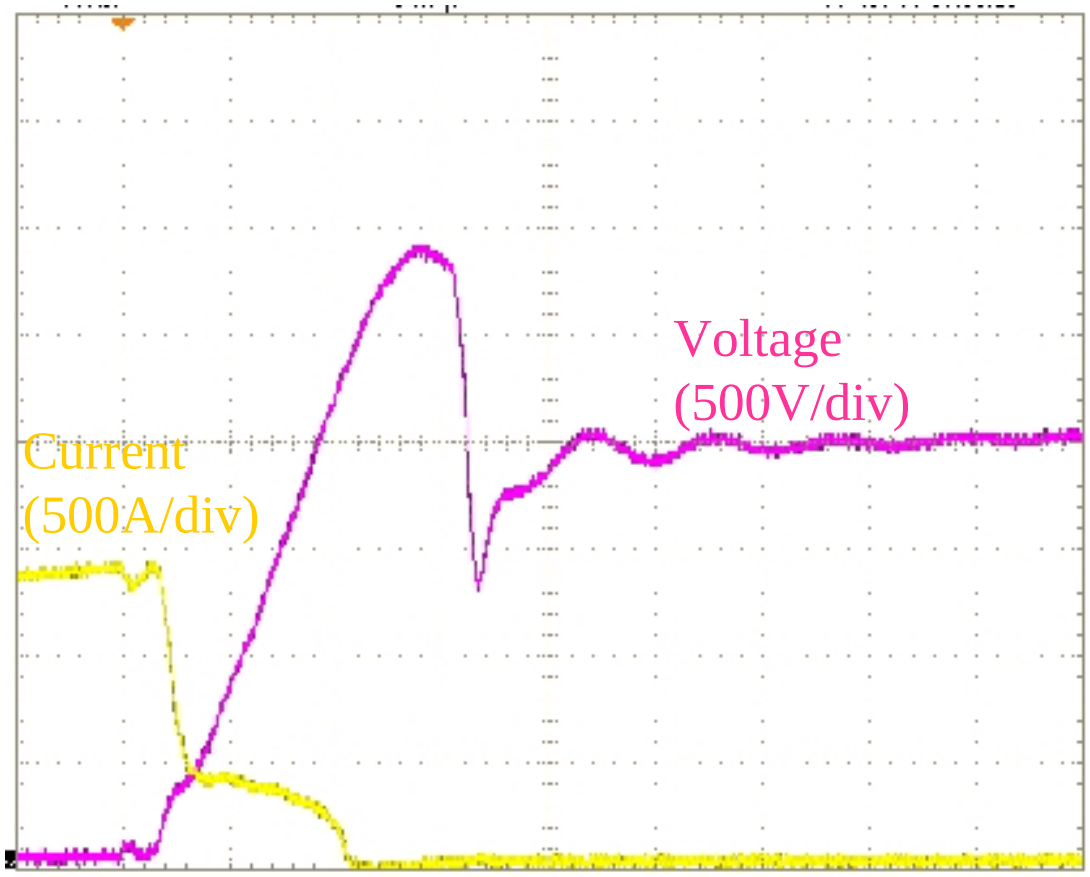


Manufacturable Gen-3 ETO (2001)

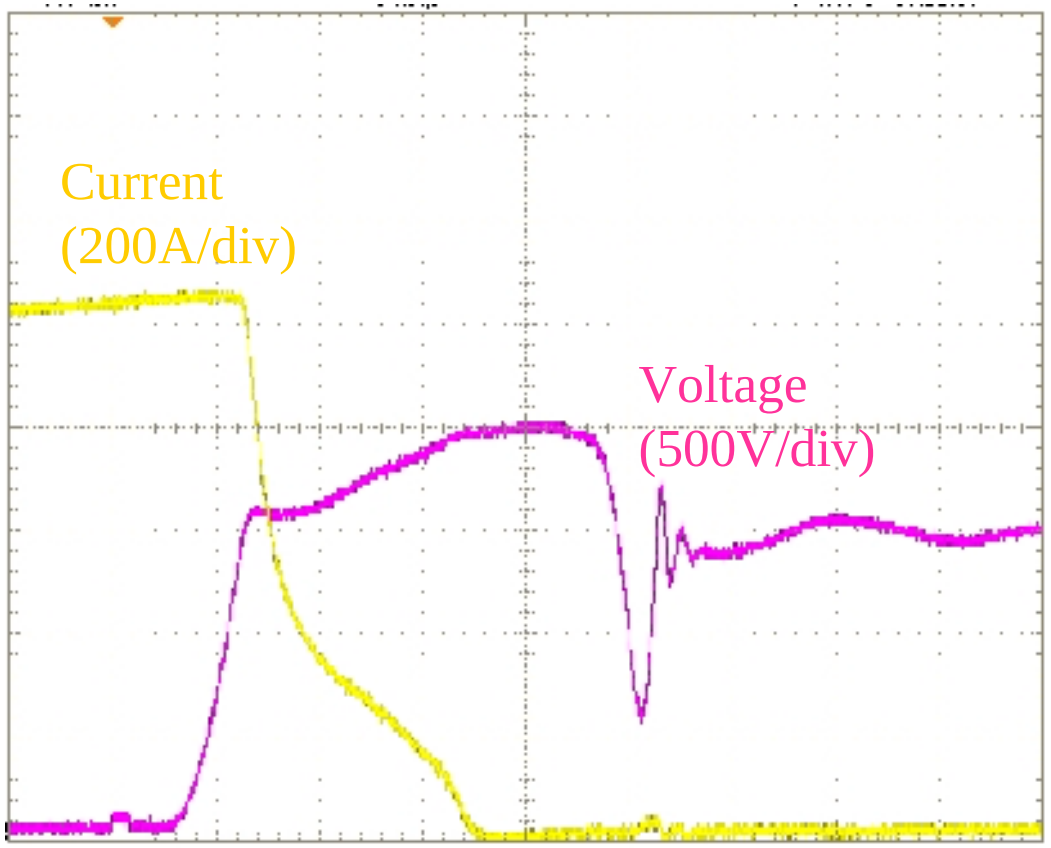
Major Accomplishments

Gen-3 ETO Prototype (OCT. 2001)

Major Accomplishments: Gen-3 ETO Test Results
Turn-off Waveforms with 3-μF Snubber



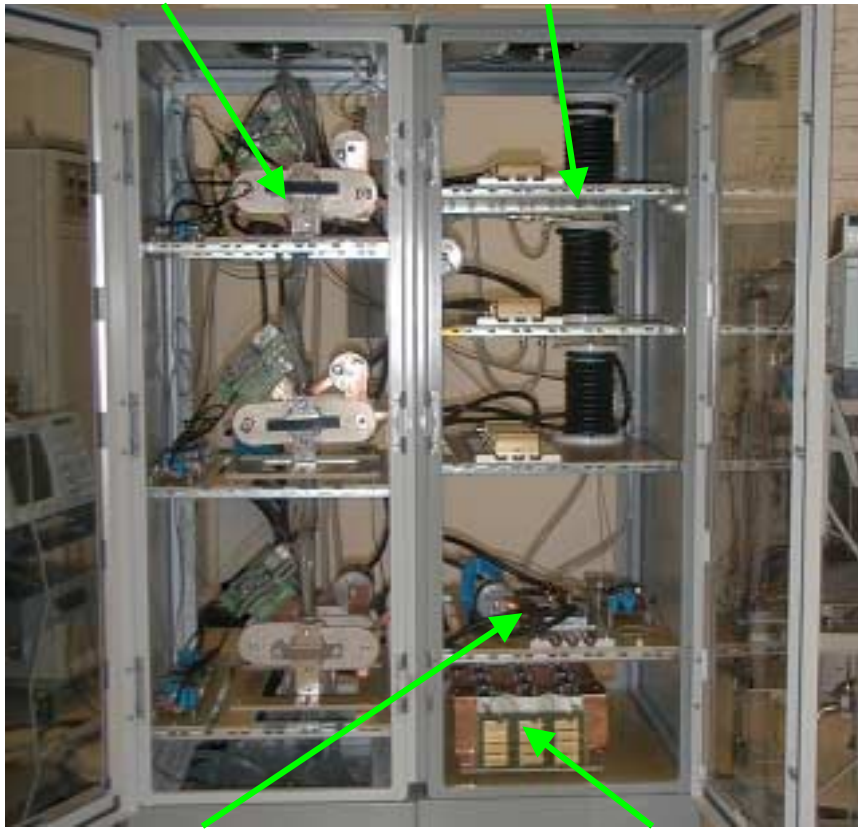
Major Accomplishments: Gen-3 ETO Test Results- Snubberless Turn-off Waveforms



Major Accomplishments

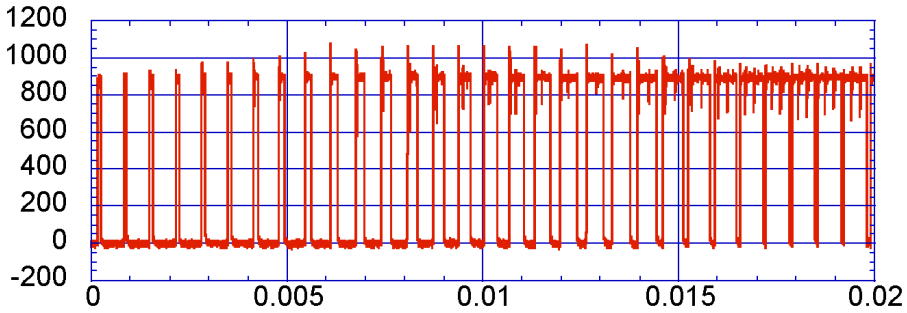
ETO-based 1-MVA 2.5-kHz VSC PCS (2000)

3 phase legs 3 di/dt snubbers

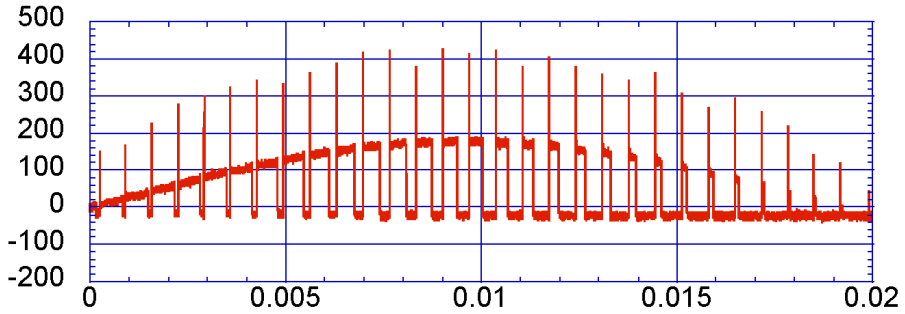


Active circuit breaker DC capacitors

Device voltage waveforms



Device current waveforms



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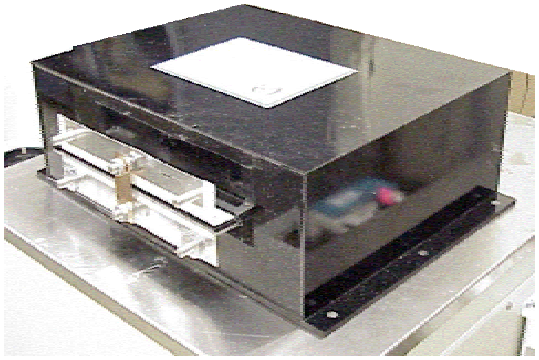
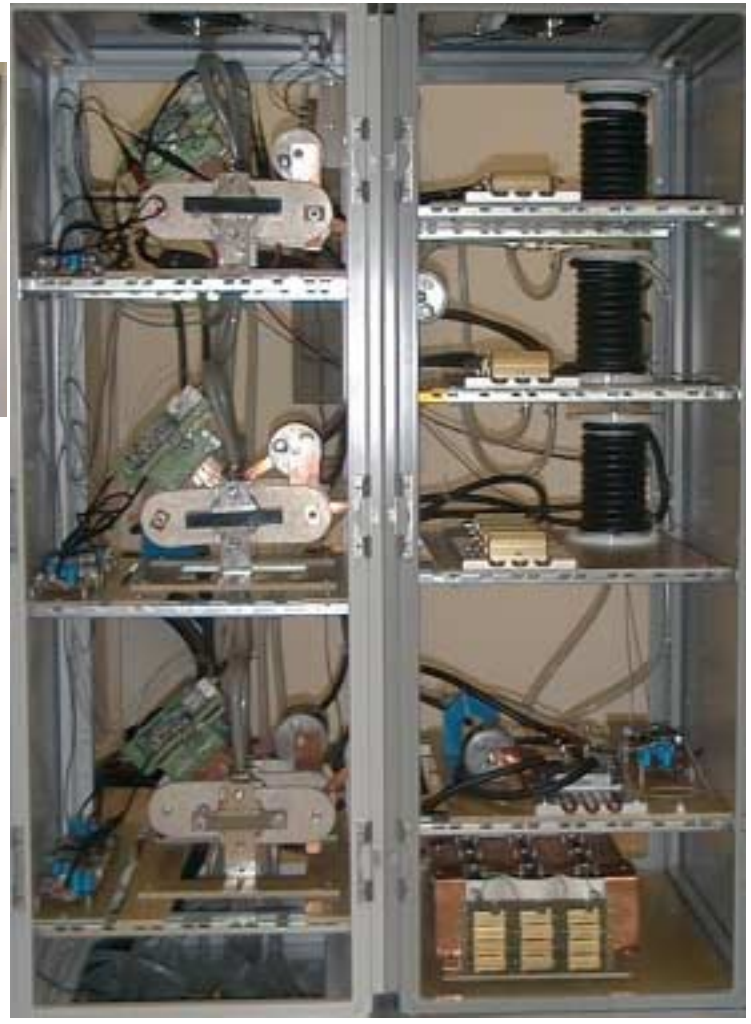
Major Accomplishments

VSC PCS Hardware Upgrade & Test (2001)

HVDC Source



HVDC Capacitor

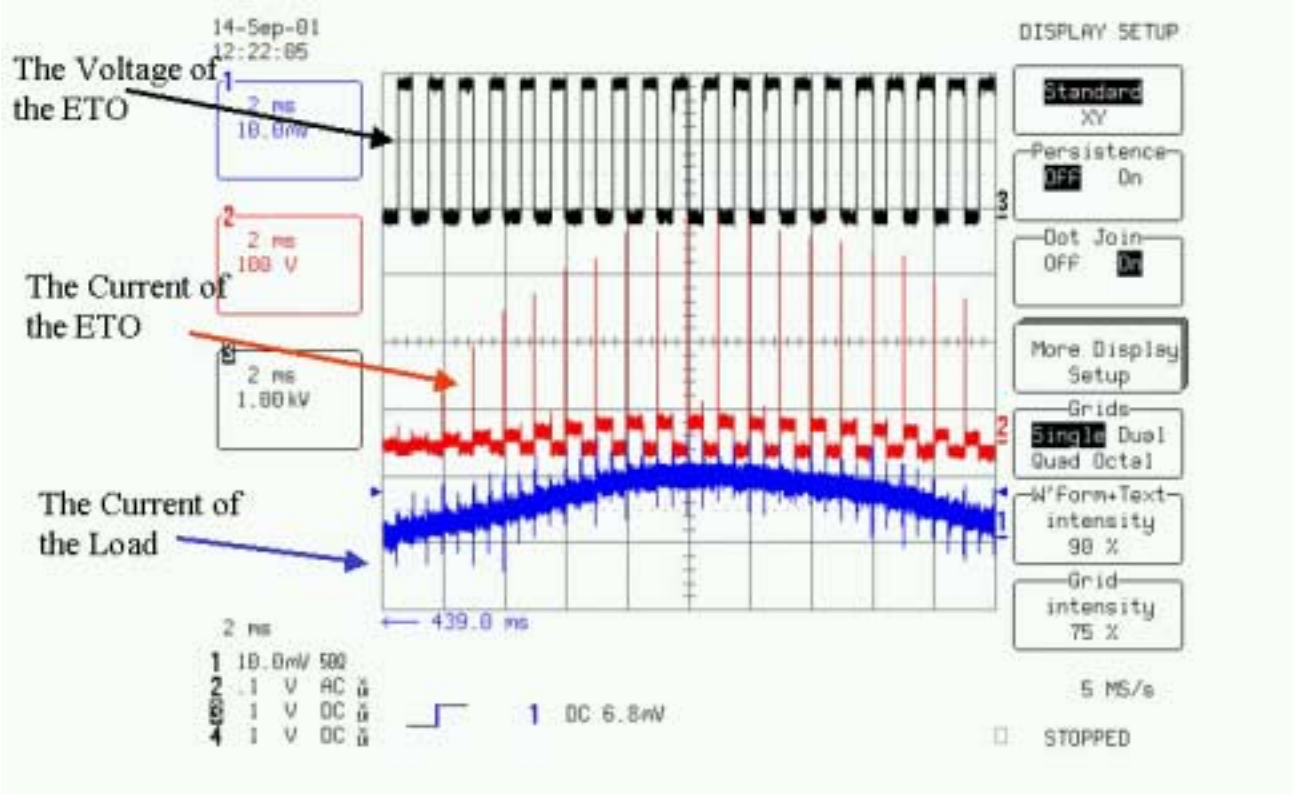


1 MVA ETO VSC PCS

Inductive load

Major Accomplishments

FY2001 Test Result @ 2000 V Bus

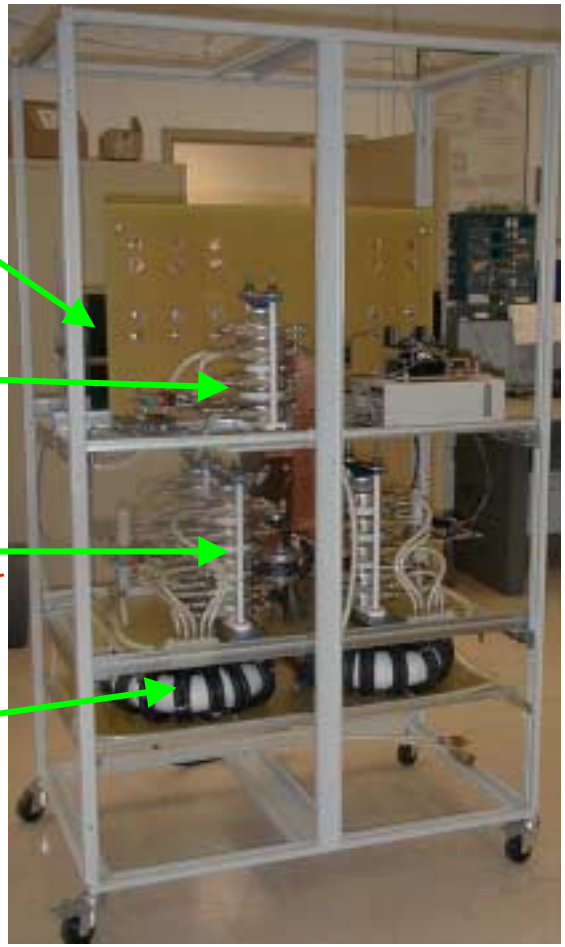


- DC bus voltage: 2000V
- Peak current of the ETO: 390A

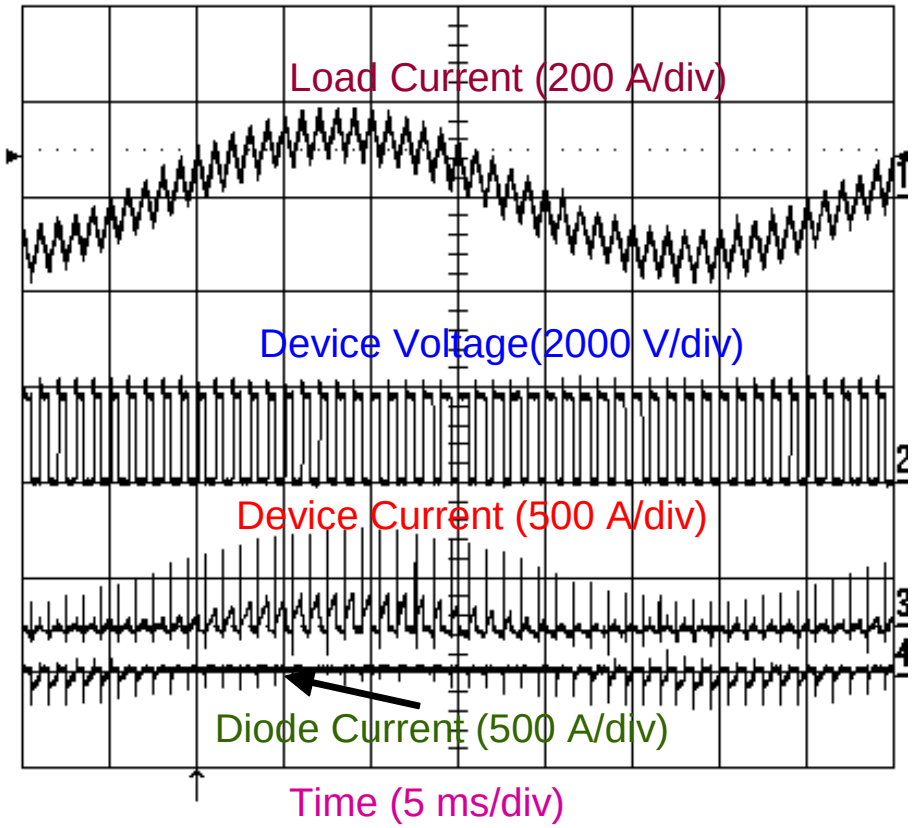
Other Major Accomplishments

5-MVA ETO-based STATCOM system (2001)

Picture of one phase leg



Experimental waveforms



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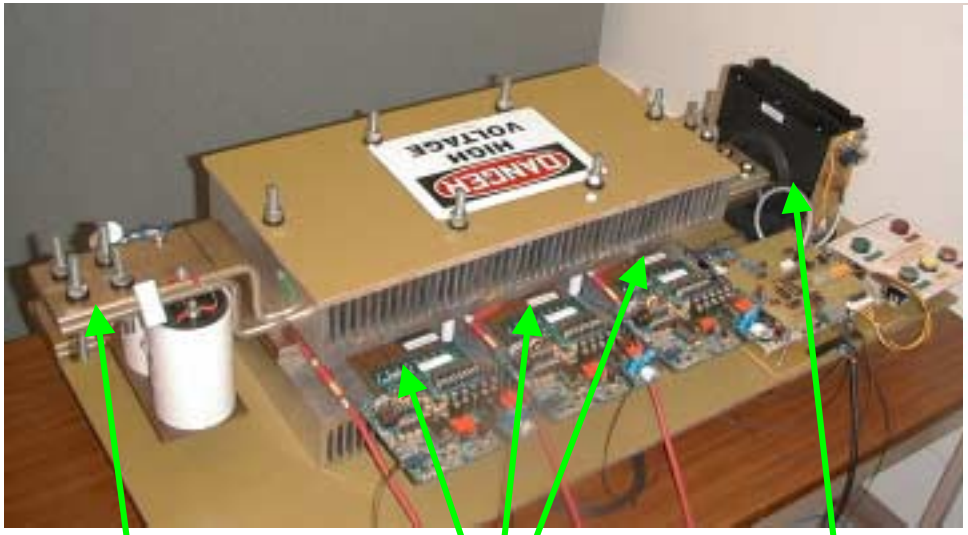
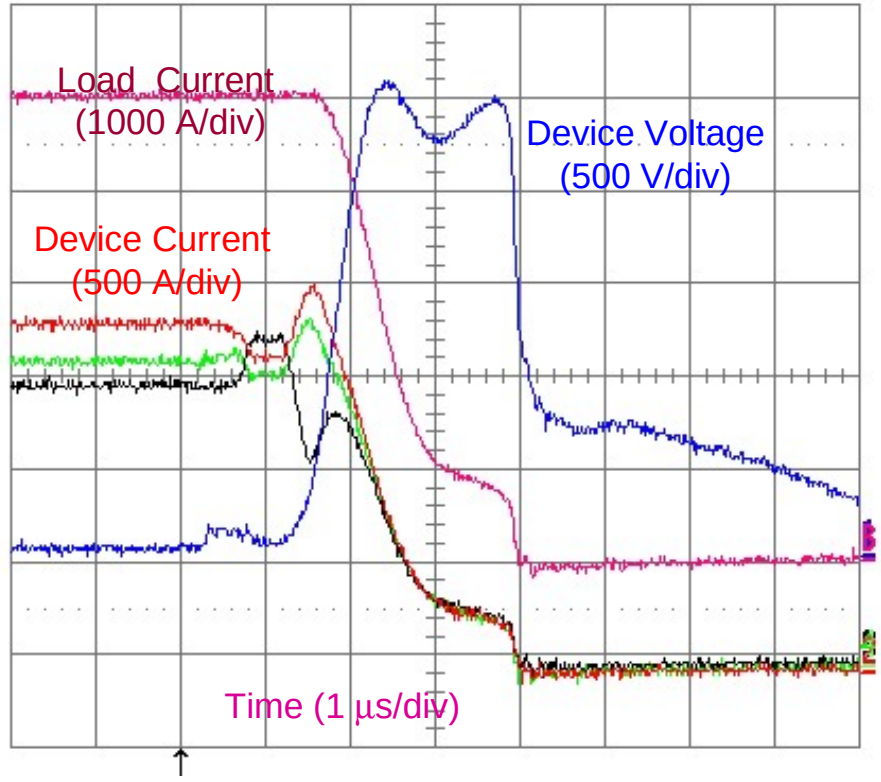
Other Major Accomplishments

5-KA/2000-V ETO-based DC circuit breaker (2001)

Picture



Experimental waveforms

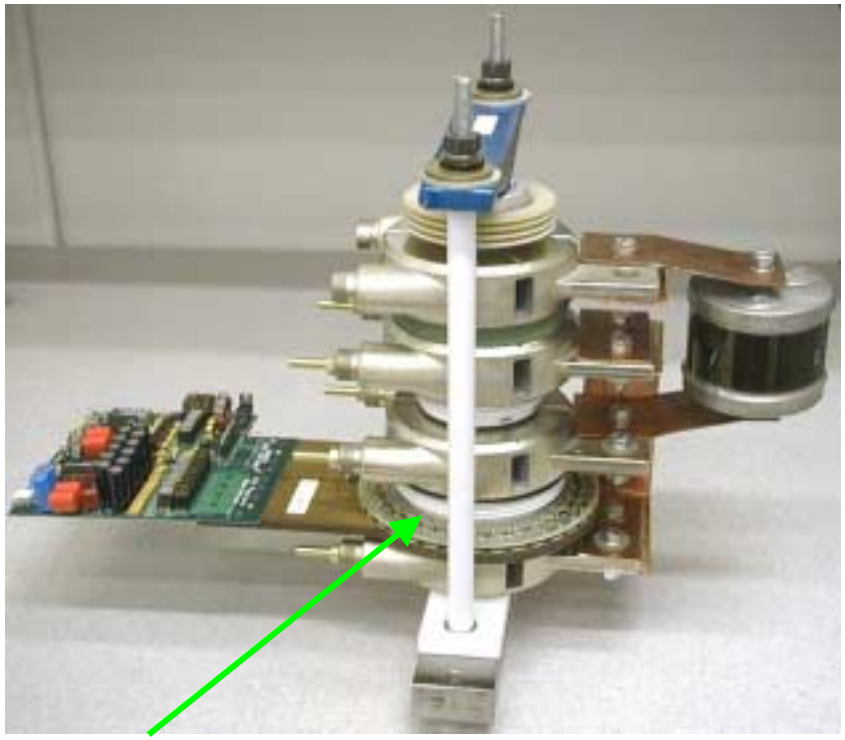


Excellent current sharing is achieved in paralleled ETOs

Other Major Accomplishments

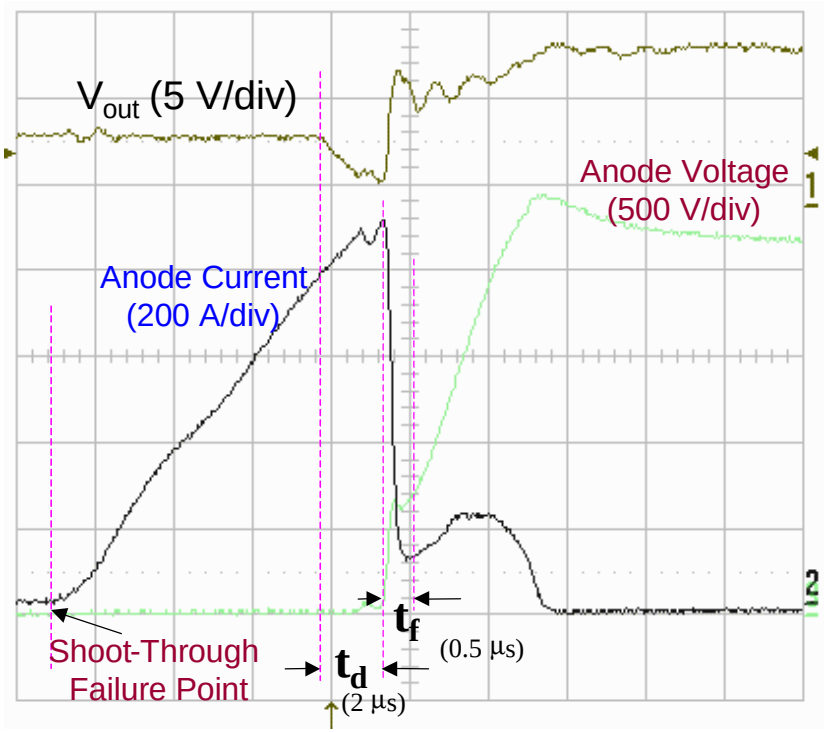
ETO-based DC circuit breaker for VSC PCS (2001)

Picture of 1.5-kA/2.5-kV DC circuit breaker



4-kA/4.5-kV ETO
(ETO4045TA)

Over-current protection waveforms under shoot-through failure



Utilize built-in current sensing in the ETO!

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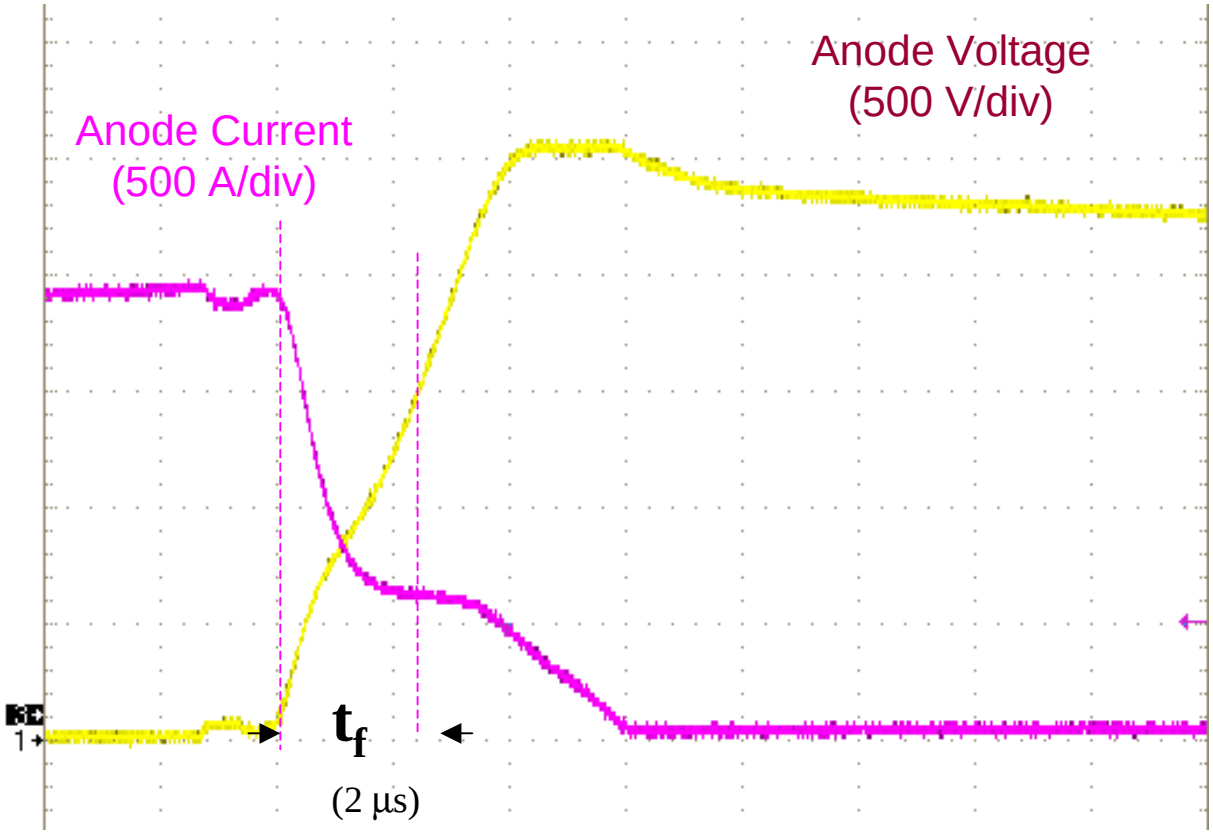
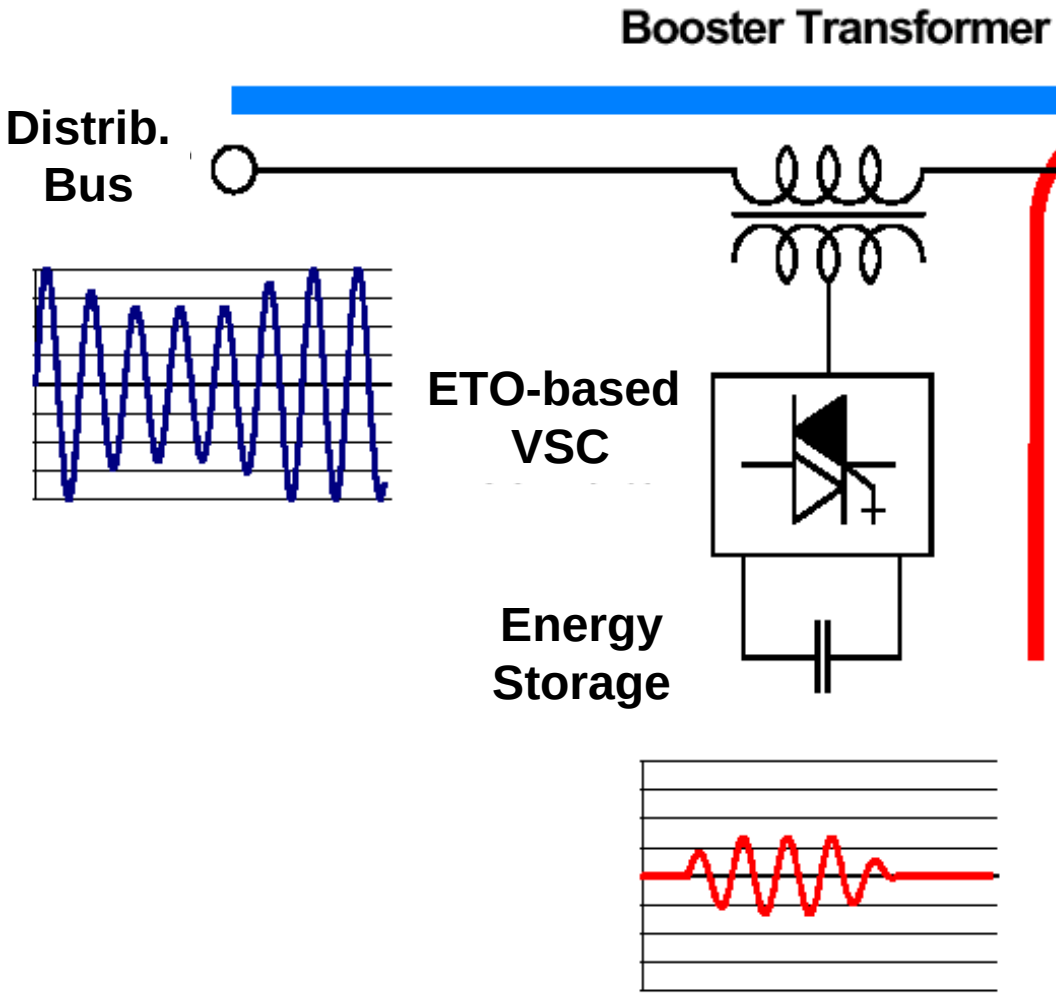
Other Major Accomplishment

Over-current protection waveforms under load short-circuit failure



- Built-in current sensing
- V_{ref} = 200 mV, trigger current is about 1900 A
- Anode current increasing rate is about 13 A/ µs

Future Plan: An ETO Based DVR/DSTATCOM



- Active filtering
- Dynamic reactive power compensation
- Active load balancing
- Flicker compensation
- Active power exchange
- Sag compensation

Conclusions

Gen-3 manufacturable ETO successfully developed in FY2001

•Improvement in manufacturability, reliability and functionality

ETOs have the following key characteristics:

- High-power rating (up to 4 kA and 6 kV)
- Low conduction loss
- Fast switching speed (up to 5 kHz)
- Snubberless turn-off capability
- Built-in Current sensing
- Capable of parallel and series operation

Suitable for the applications in

- Distributed Energy Resources, Energy Storage, FACTs, Motor drive, Power system protection