DESIGN AND APPLICATION OF POLYPHASE RESONANT CONVERTER-MODULATORS

by

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May 2006

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Outline

- Review of SNS Polyphase Resonant Power Conditioning Technology
- Design Possibilities of Large “MW” Class Converter-Modulators
- Smaller, Higher Frequency MOSFET Converter-Modulators
- Conclusion

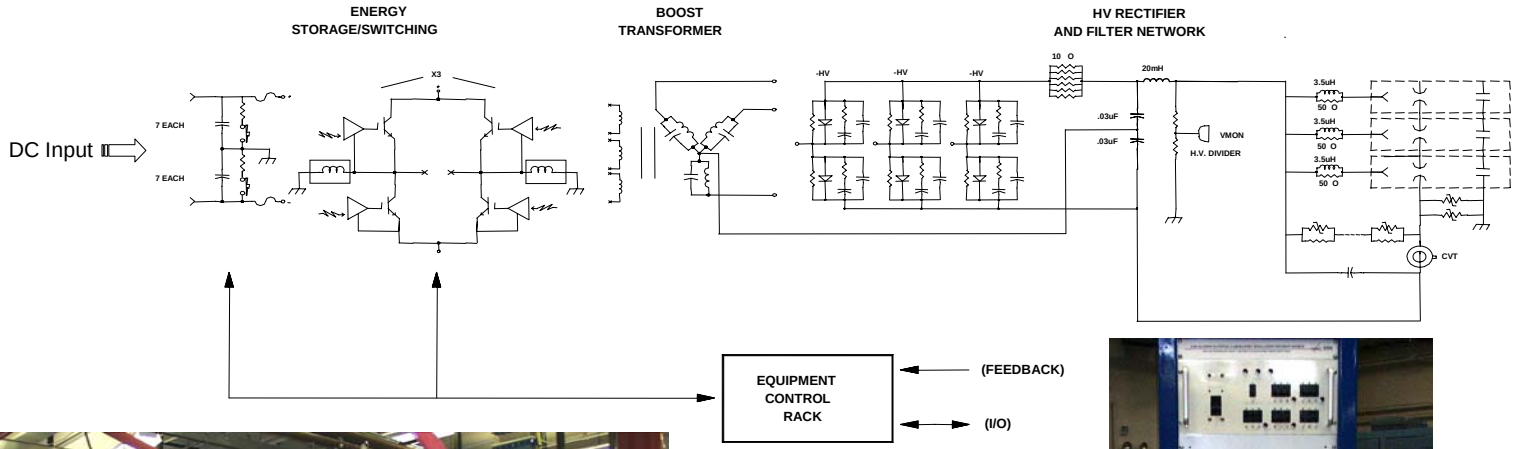
What is Polyphase Resonant Power Conditioning?

- New method to generate high voltages with high power
- Essentially a large (polyphase and resonant) DC-DC Converter
  - At least 1/10 size, weight, and volume of any previous method
- Uses recently proven technologies
  - Traction Motor Metallized Hazy Polypropylene Self-Clearing Capacitors for energy storage
  - Multi-megawatt capable Insulated Gate Bipolar Transistors
- Transformer cores of Amorphous Nanocrystalline Alloy
  - 1,000 times more efficient than steel
  - 1/300 core volume and weight for same power as 60Hz steel
- Polyphase resonant voltage multiplication to further minimize transformer volume and weight
- Easily scaleable to 10's of MW and 100's of kV
  - Easily optimized for various use (and lower power/voltage)
- Design is fault tolerant and inherently self-protective
  - Protect systems not necessary
  - Permits long cable lengths and remote location

Polyphase Resonant Power Conditioning Uses New LANL/LANL Funded Technology Developments

- Low Inductance Self-Clearing Capacitors
  - Thomson Passive Components (AVX), France
- Low Inductance High Power Capacitors
  - General Atomics Energy Products, San Diego, Ca.
- Amorphous Nanocrystalline Core Material
  - MK Magnetics (Stangenes), Adelanto, Ca.
- New Engineering Techniques
  - Polyphase Resonant Voltage Multiplication
  - Resonant Rectification
  - Self DeQing (No crowbars and self protective)
  - Snubberless IGBT Switching

Simplified Block Diagram of Polyphase Resonant Converter Modulator (10 MW Long Pulse)



HIGH VOLTAGE CONVERTER MODULATOR

EQUIPMENT CONTROL RACK

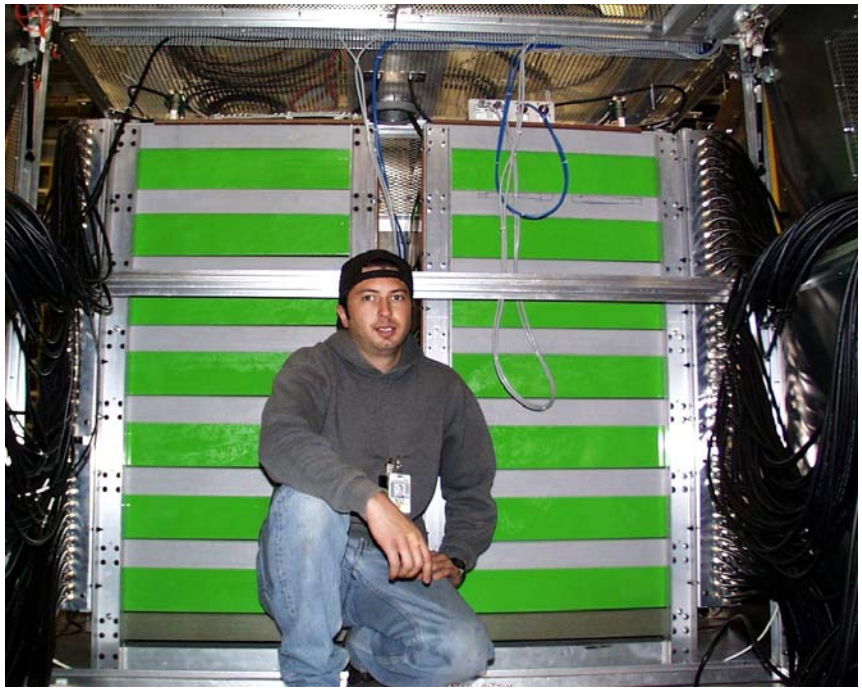
Los Alamos High Frequency "Polyphase Resonant Power Conditioning" Compared To Conventional 60Hz Technology Is Significantly Smaller

10 Megawatt Pulse, 20 KHz, 140 kV
Polyphase Resonant Converter-Modulator

- Developed for Oak Ridge SNS Accelerator
- All components operate at 10 MW level
- Can be optimized for 10 MW CW
- Can be optimized for 30 MW Long Pulse
- Resonant conversion is fault tolerant
- Small and compact
- Reliable components
- Can operate with kilometer cable lengths
- No crowbars needed

Los Alamos Low Voltage Energy Storage Compared To Conventional High Voltage Method Is Very Compact And Reliable

Self-Clearing Metallized Hazy Polypropylene



- 300,000 hour lifetime
- Graceful degradation
- High frequency design, variable rep-rate capabilities
- Extremely high volumetric efficiency
- High safety factor

Conventional
High Voltage Paper and Foil Capacitors

- Limited lifetime
- Explosive failure modes
- Highly frequency dependant and lossy
- Large footprint
- Poor safety factors and dangerous
- Crow Bar required

Nanocrystalline High Frequency Transformers Are Over 150 Times Lighter And Significantly Smaller

Typical H.V. Transformer

- 100 kV, 60 Hz
- 20 Amp RMS
- 2 MW Average
- 35 Tons
- ~30 KW Loss

HVCM Transformer

- 140 kV, 20 KHz
- 20 Amp RMS
- 1 MW Average (3) present use
- 450 LBS for 3
- 3 KW Loss At 2 MW

Load Protection Networks Not Needed For Los Alamos Technology

Typical H.V. Crowbar Protect Network

- Large
- Reliability concerns
- Maintenance concerns

Resonant Converter Protect Network

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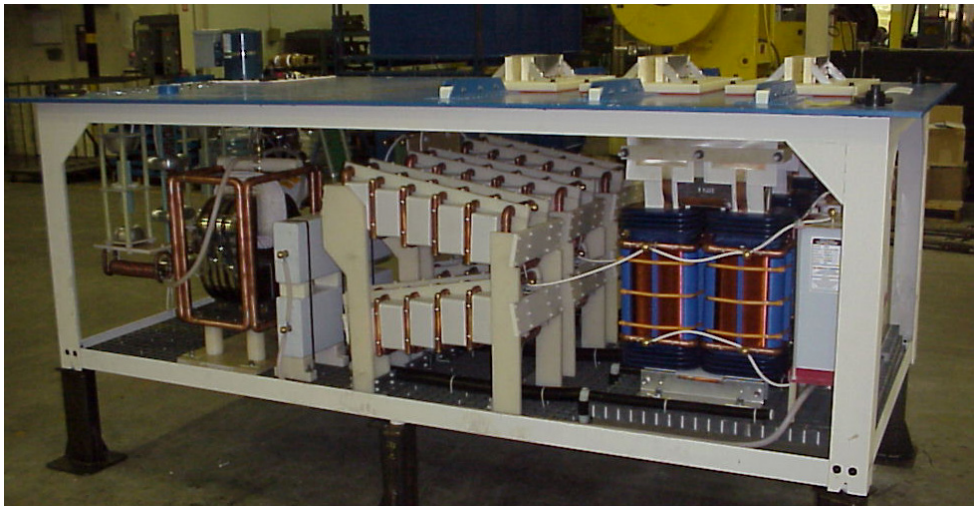
(none required)

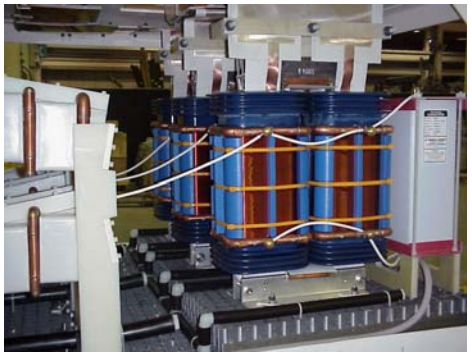
- Converter-Modulator inherently self protective
- Automatic fault “ride-through”
- Safe for all components

Tank Basket Assembly; 1 MW Average, 10 MW Long Pulse

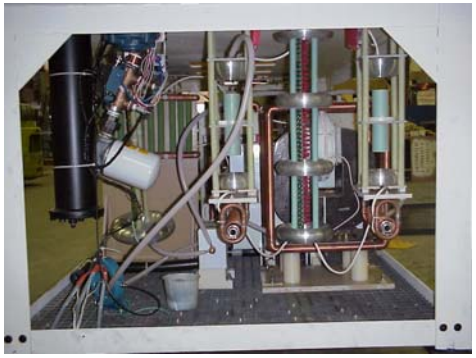
Filter Network



Tank Basket Assembly

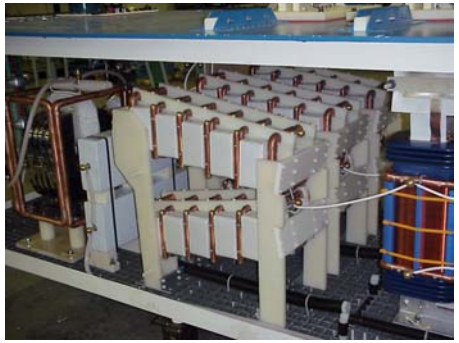


Transformers

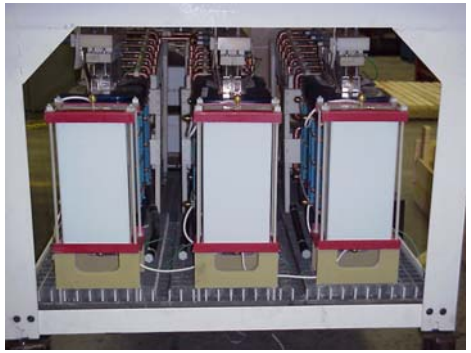


Output Sockets
&
Varistor Assembly

Oil Pump & Voltage Divider



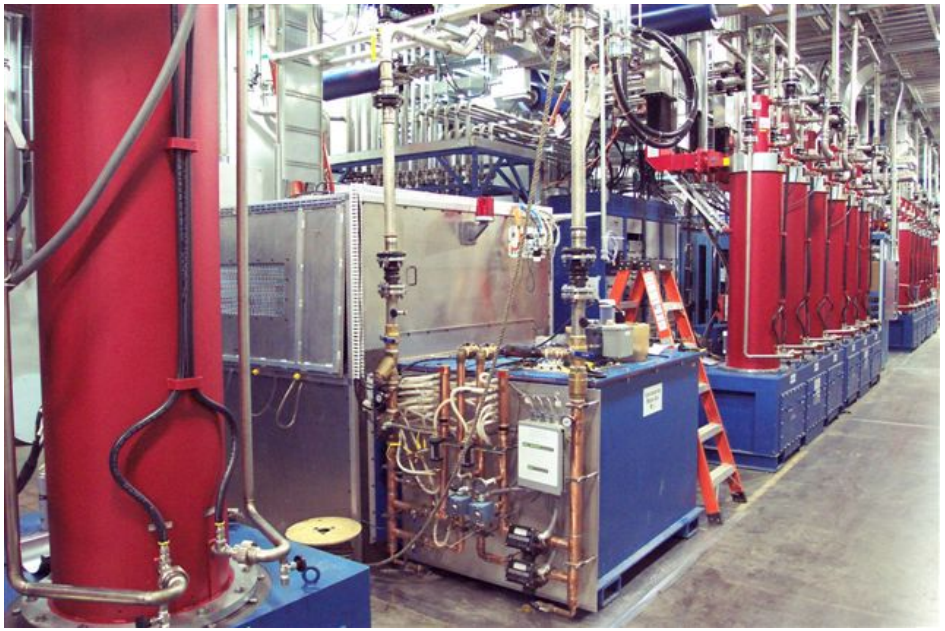
Diode Rectifiers



Transformer Resonating Capacitors

All Oak Ridge HVCM's Installed

DTL-ME3 with Klystrons
"The Workhorse"



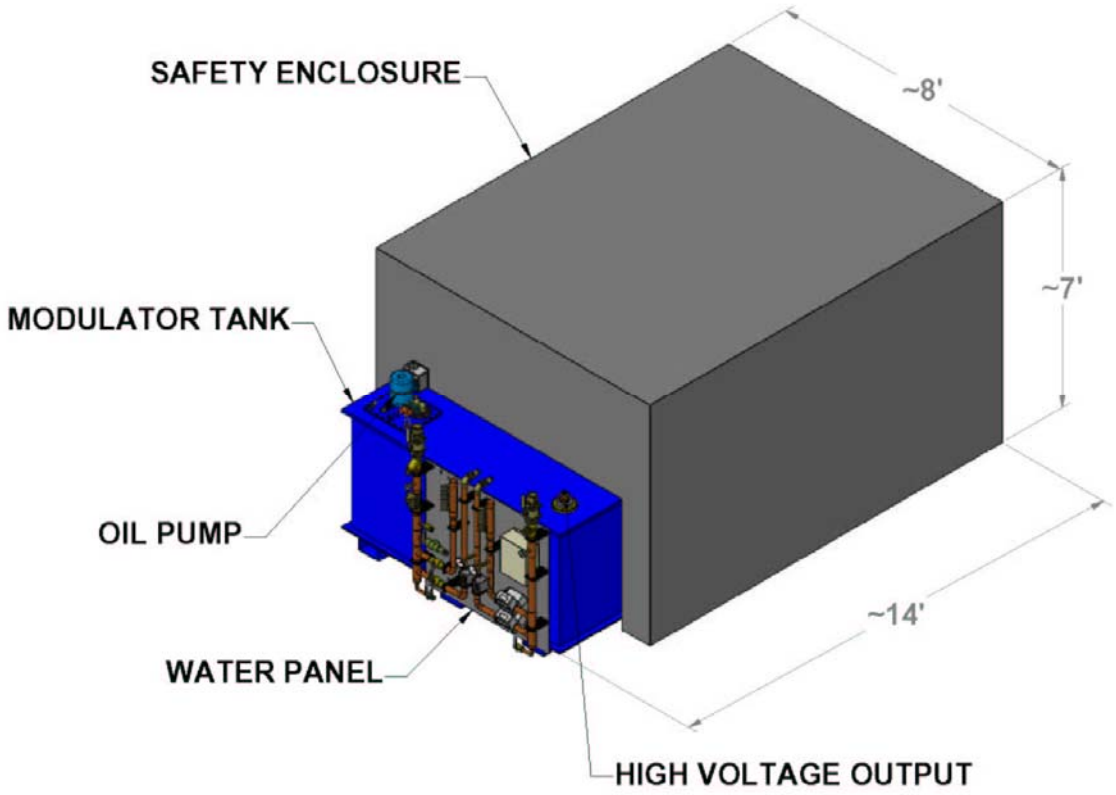
SCL-ME1 with 12 pack

Capabilities of Polyphase Resonant Conditioning

- IGBT Long pulse systems demonstrated
  - 140 kV, 1 MW Average (10 MW Long-Pulse)
  - Efficiency ~94%
- IGBT CW systems to 10 MW realizable
  - Efficiency ~97% possible
  - Similar footprint to SNS system
  - Does not require increase in component current or voltage ratings
- Medium pulse MOSFET (10 – 100uS) to 2.5 MW, 250 KW Average
  - 50 kV, 50 Amp, 250 KW Average
  - Small and compact
  - Agile in voltage, pulse width, and rep-rate

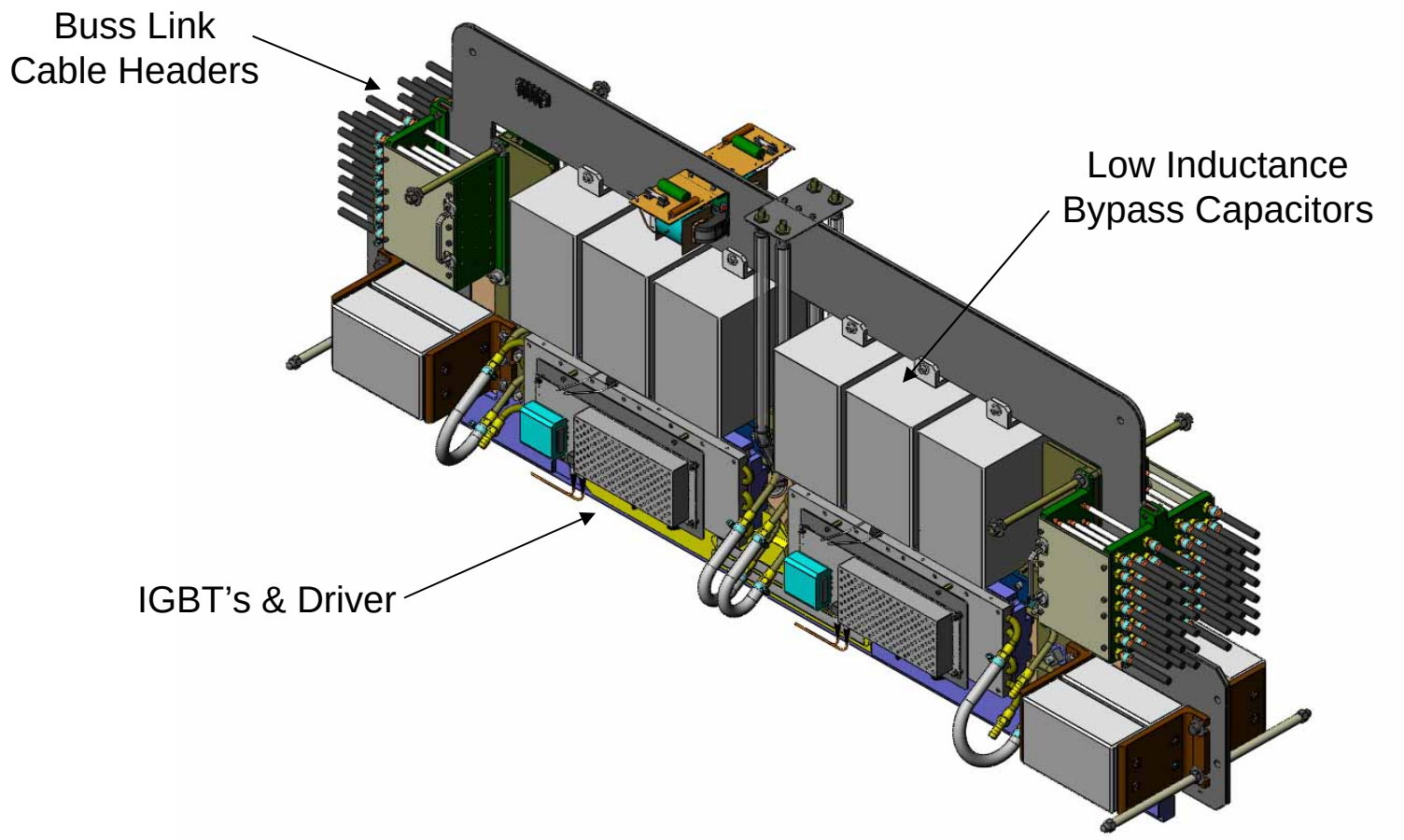
View Of Proposed 30 MW ILC Pentaphase Converter-Modulator System Or 10MW “CW” Converter

Size: 7’ X 8’ X 14’

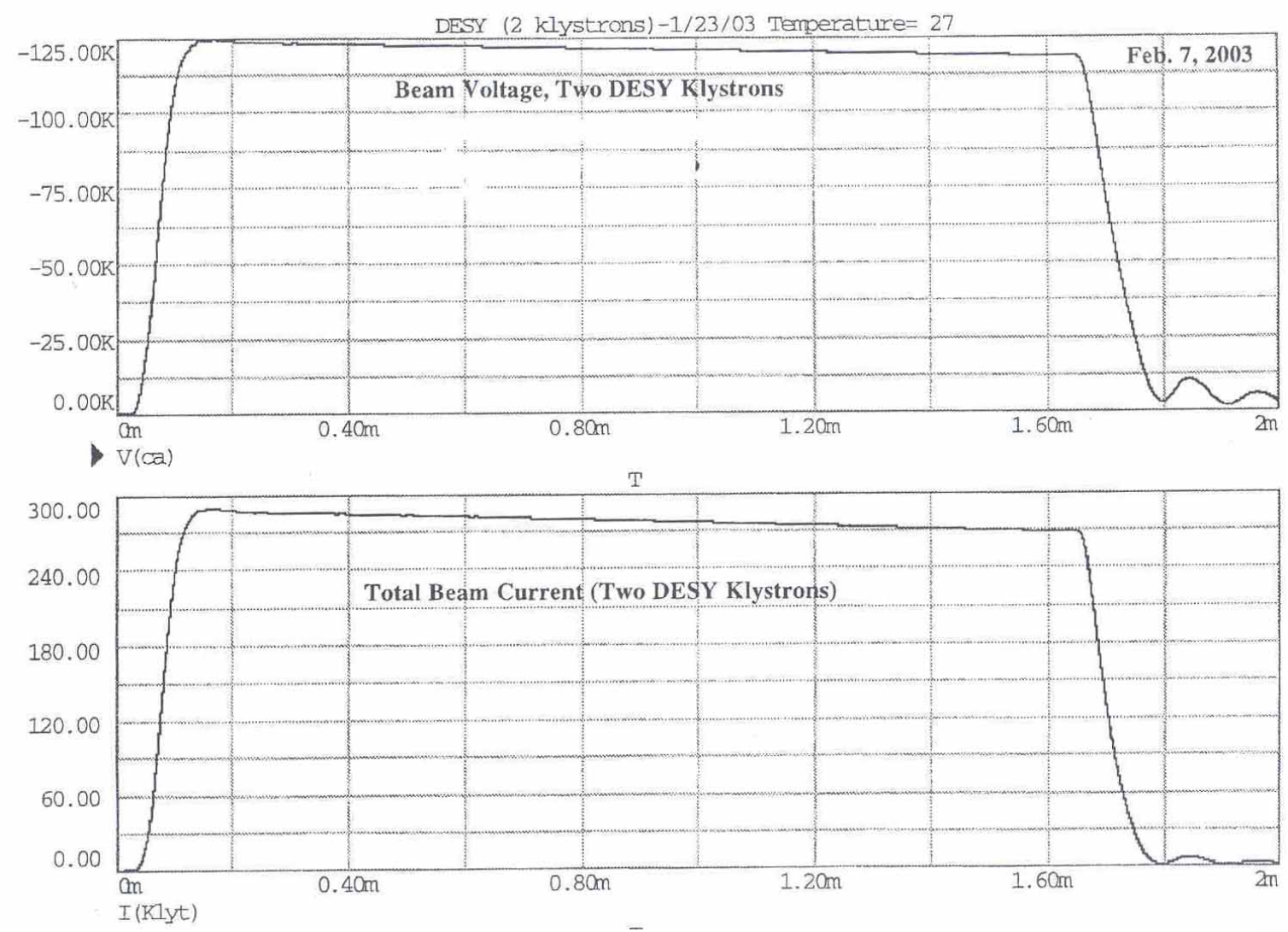


- Operates 2 MBK’s
- Fault tolerant, automatic fault “ride-through”
- Can operate with long output cables (over 1 kilometer)
- Cannot harm klystron
- Multiple units operate from common DC bus
- Lower IGBT Loading than SNS Application
  - 900KW / IGBT (SNS)
  - 750KW / IGBT (ILC)
- Different Optimization for CW

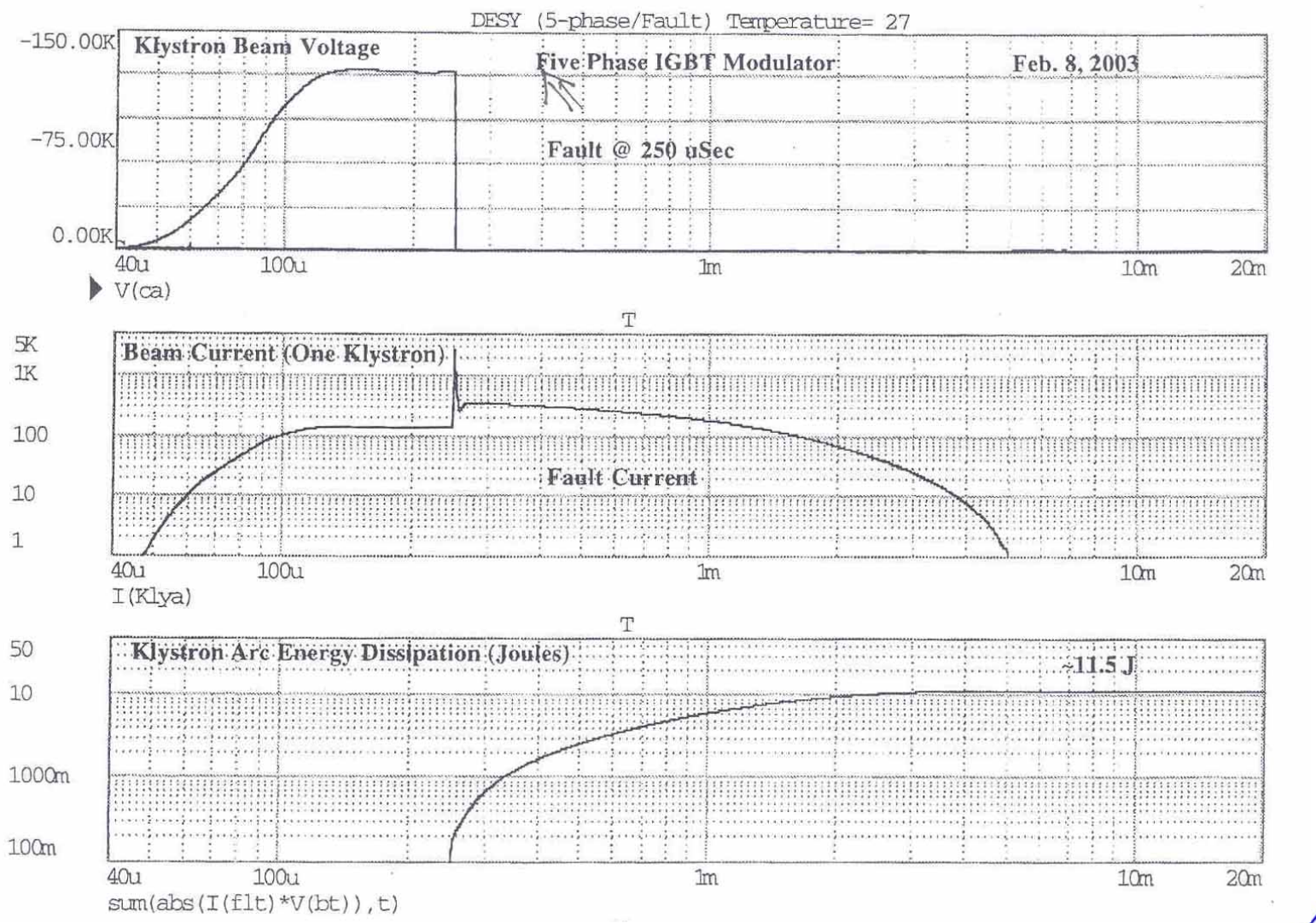
Parallel H-Bridge IGBT Switch Plate Assembly



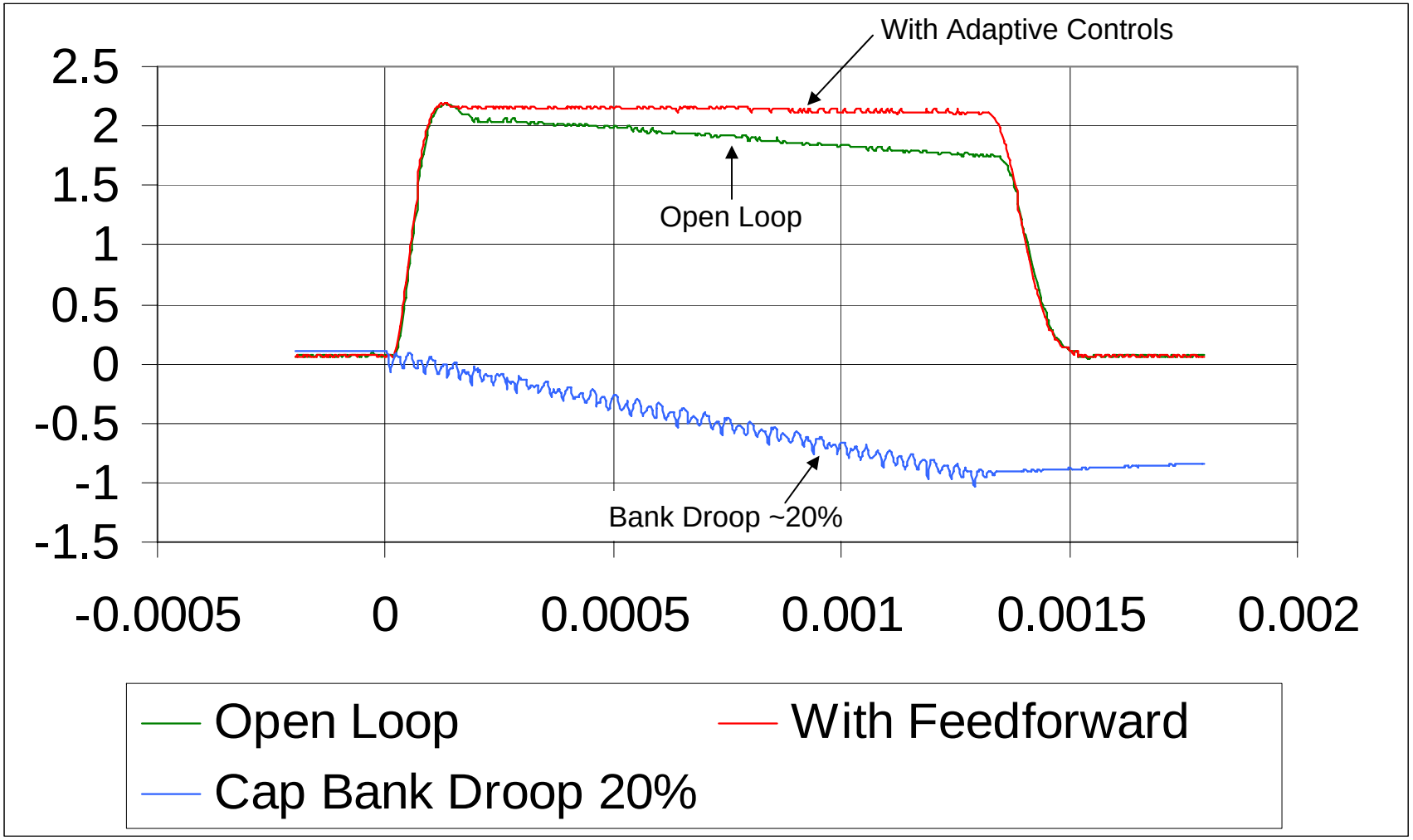
Beam Voltage And Current After 1KM Of Cable



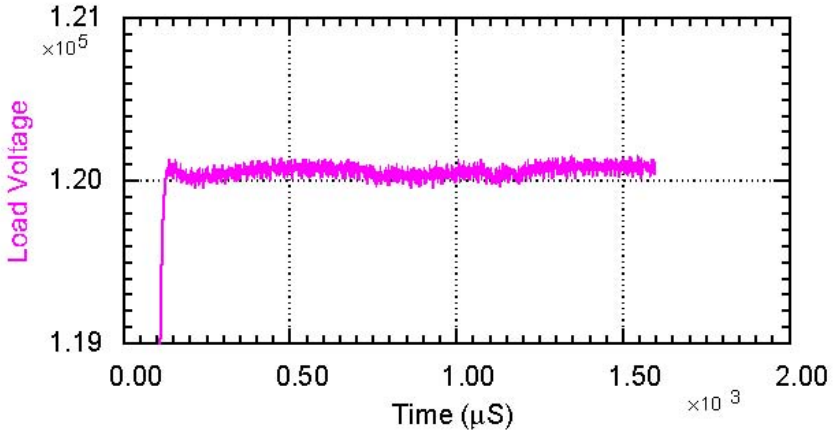
Klystron Fault Energy – 1KM Of Cable

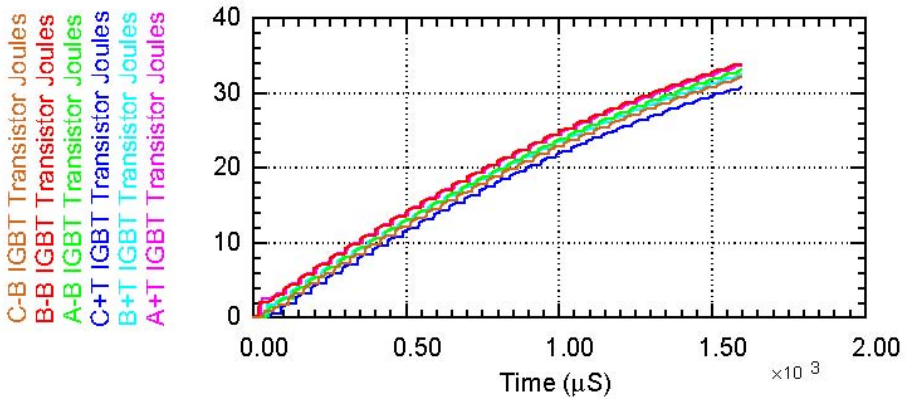


Novel Adaptive Feedforward/Feedback For Modulator Control



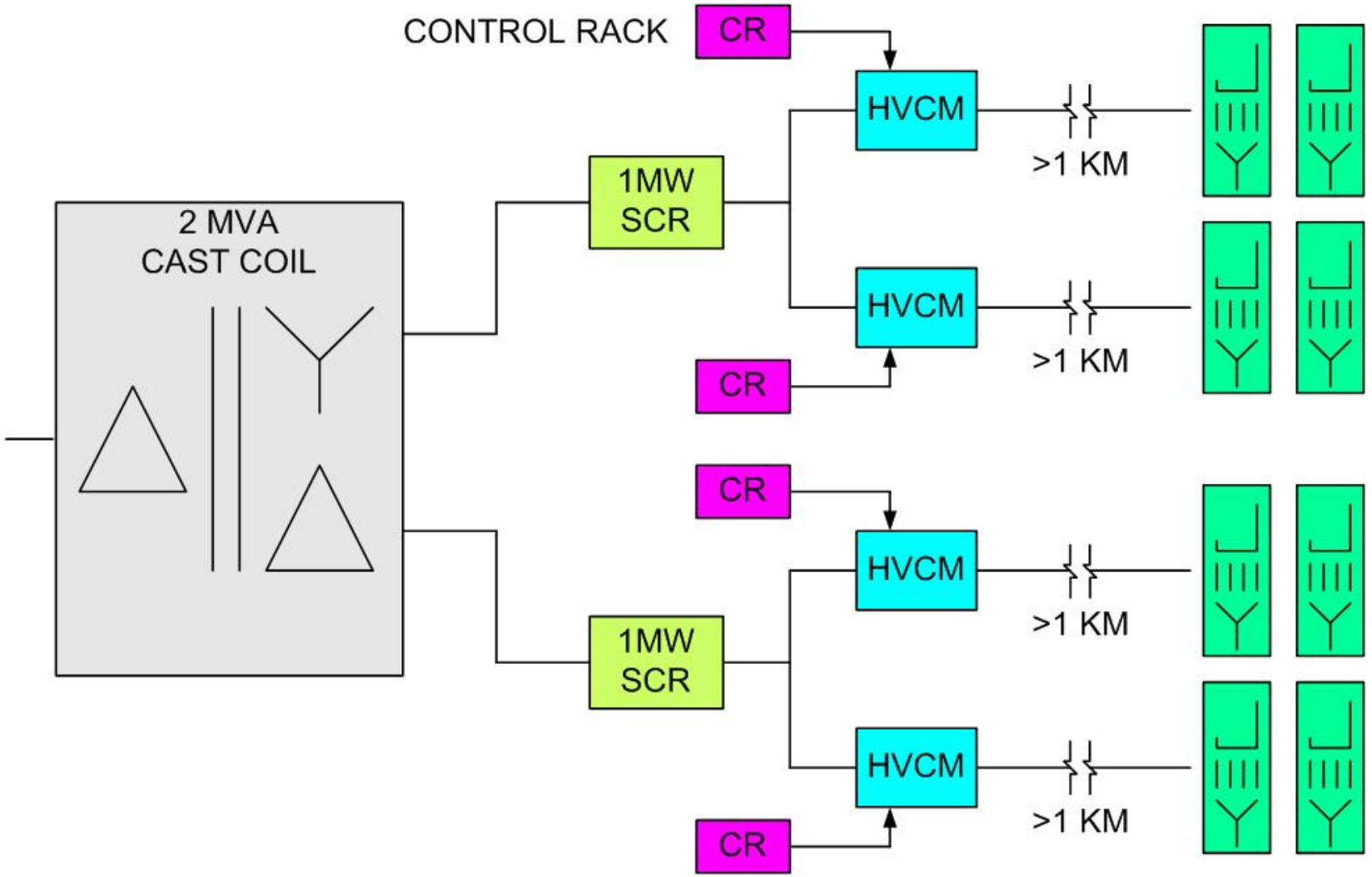
High Efficiency Adaptive Control Methods Now Viable





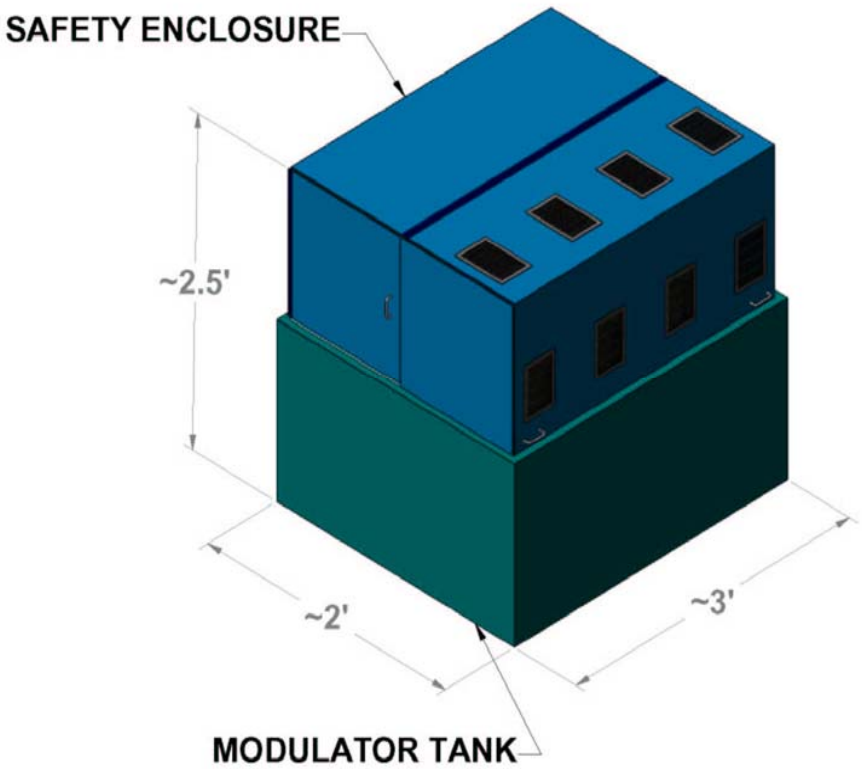
- High Efficiency
- Reliable for Solid State Components
- Better Than 0.25% Regulation
- About 2KW Total IGBT Loss

Proposed ILC Configuration 1.5mS Pulses at 10Hz



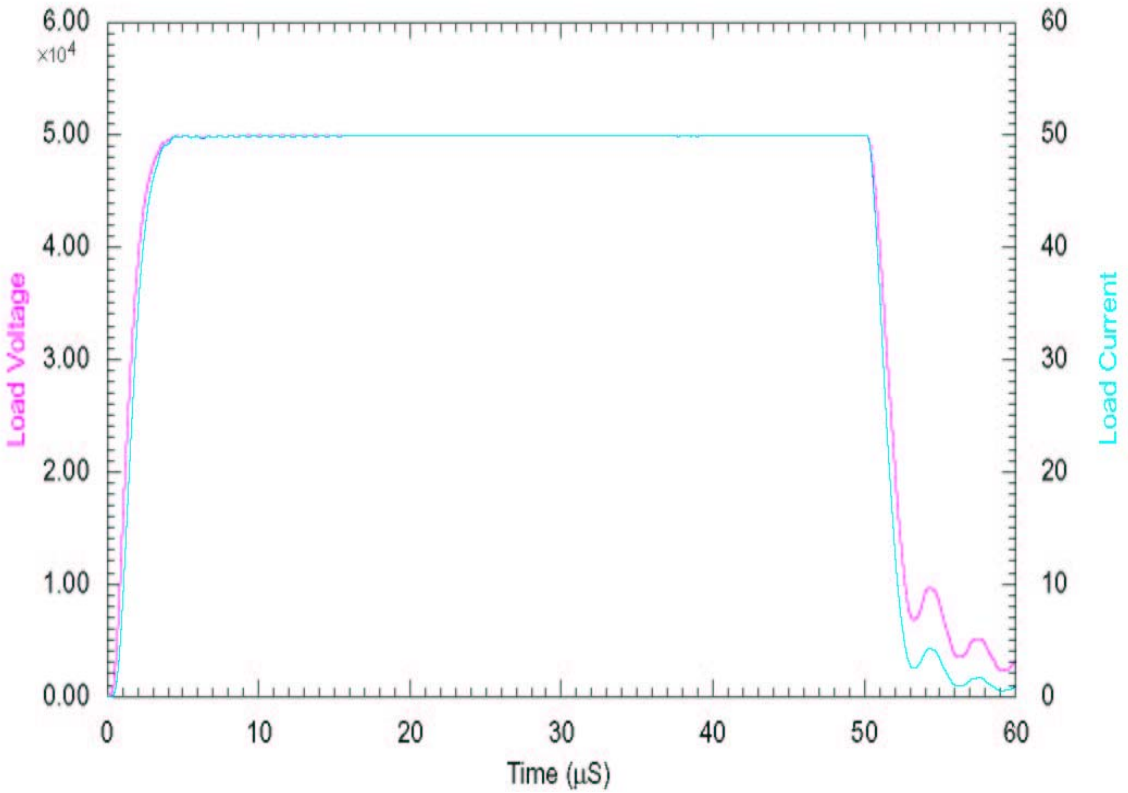
View of 2.5 MW Pulse, 250 KW Average, MOSFET Converter-Modulator

Size: 2.5’ X 2’ X 3’



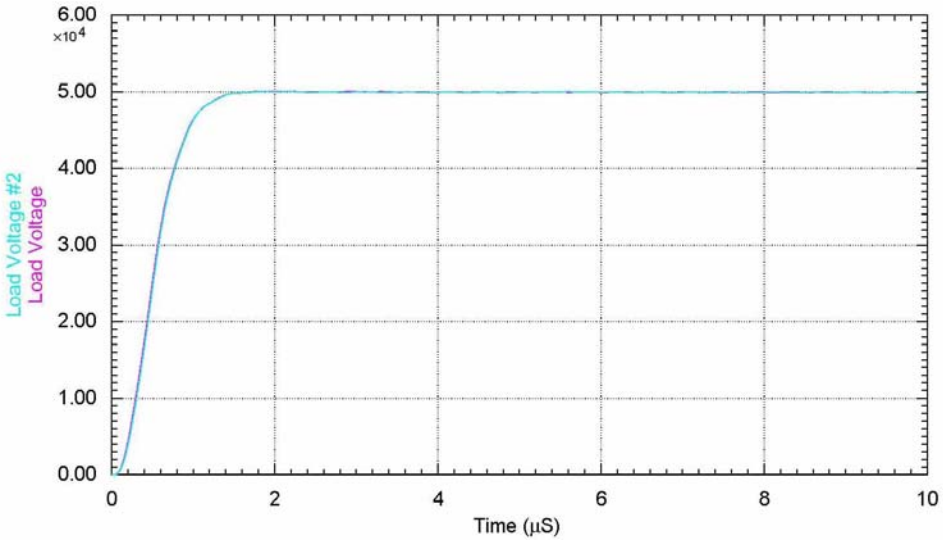
- Design Based On Available Components And MOSFET Switches
- Higher Frequency And Smaller
- Can Be Optimized For Mobile/Airborne Applications
- Typical Uses May Be Search Radar, DE, And Medical Applications
- Pulse Width/Rep-rate/Voltage Agile
- “CW” Designs Also Possible

Model Output Of Medium Pulse Converter

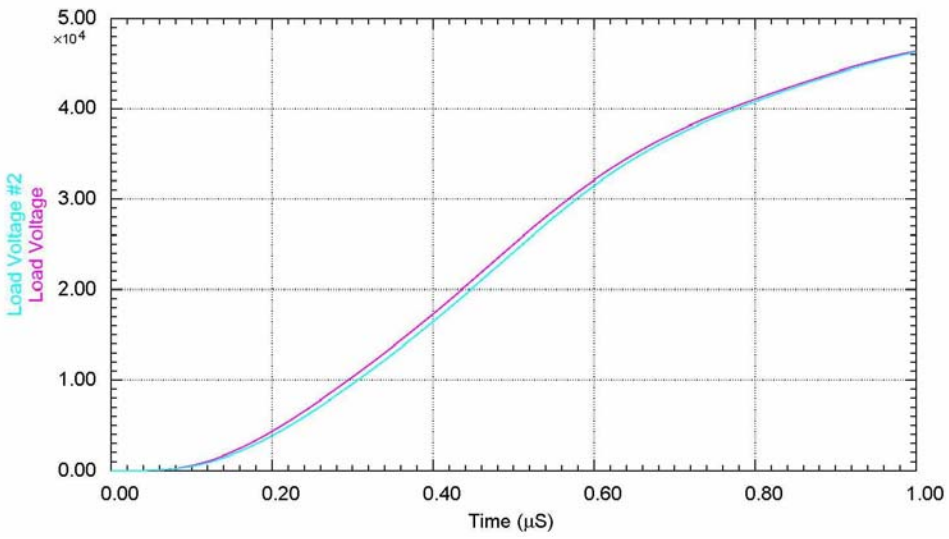


- Rectified 480V 3Ø Input
- 50 kV Output
- 50 Amp Output
- Tr, Tf ~ 800nS
- ~ 94% Efficiency
- Other Optimizations Possible
- Pulse Width And Voltage Agile
- Multi KHz Rep-Rate

Soft Failure Mechanism 12 Pulse / 10 Pulse



10 & 12 Pulse Output Voltages "Overlay"



Slight Change In Rise Time For
10 Pulse vs. 12 Pulse Operation

Other Applications Of Fault Tolerant Polyphase Resonant Converters

- Motor Drives
  - At Remote Locations
- Radar Modulators
- Power Distribution Networks
- Directed Energy, Area Denial Systems
- High Power Transducers/Drivers
- Electronic Pulse Generators
- Power Converters/Chargers For Pulse Power Application

Conclusion

- Los Alamos Developed Polyphase Resonant Power Conditioning Design Topology Techniques Now Proven
- Designs Can Be Optimized For Any Load Or Pulse Requirement
- Efficient Adaptive Control Methods Now Possible
- Inherently Self And Load Protective
- Significant Change In High Power, Power Conditioning Topology
- Ideal For Many Military, Medical, Broadcast, And Scientific Applications
- Systems Installed At LANL, ORNL, And SLAC

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