MONASH University
Engineering

*Special Presentation **SP4.1** – 23rd March 2006*

A High Efficiency, Low Cost, Utility Interactive Inverter – Australia's Winning Entry For The 2005 Future Energy Challenge Competition

Presented by
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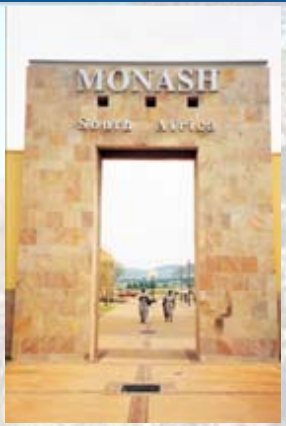
Monash University

- **Australian Campuses**
  - **Clayton Campus (Largest and Main Campus)**
  - **Caulfield**
  - **Berwick**
  - **Gippsland**
  - **Parkville**
  - **Peninsula**
- **Malaysia Campus**
- **South Africa Campus**
- **Prato Centre, Italy**
- **London Centre, England**
- **A total of 53,000+ students and 2,400+ academic staff**



Outline

- 2005 International Future Energy Challenge
- Monash University's Team
- Inverter Hardware Overview
- Inverter Control Overview
- Unit Performance

2005 International Future Energy Challenge

- Student engineering competition sponsored by the Power Electronics Society of Institute of Electrical and Electronics Engineers (IEEE)
- The challenge is to design and construct a low-cost, high efficiency, 1kW, utility interactive inverter for small-scale distributed generation systems
- First prize US$10,000, with a total of US$32,000 in prize money

2005 International Future Energy Challenge

Vision of the Future Energy Challenge

"To bring dramatic improvements to alternative energy systems for homes in the developing world"

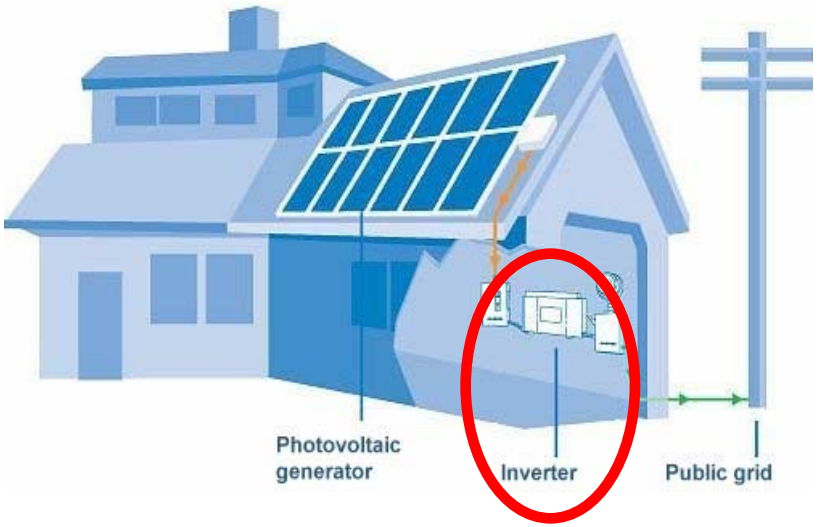
Faculty Advisor
Professor Grahame Holmes

- Faculty member of the ECSE department for over 20 years
- Director of Power Electronics Group
- Actively involved in practical applications in this area of industry.

About The Team

- 10 Undergraduate Engineering Students (no post-grads!)
  - Final and Penultimate Years
  - Electrical and Computer Systems Engineering
  - Computer Science

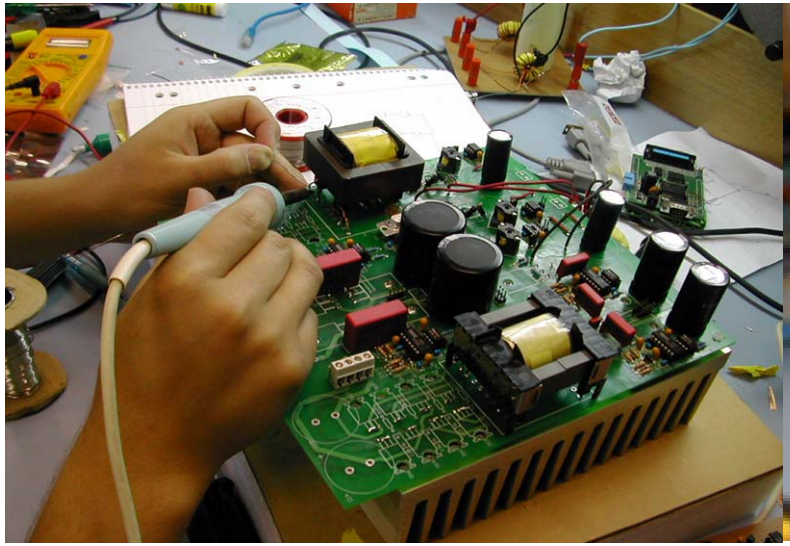
Utility Interactive Inverter



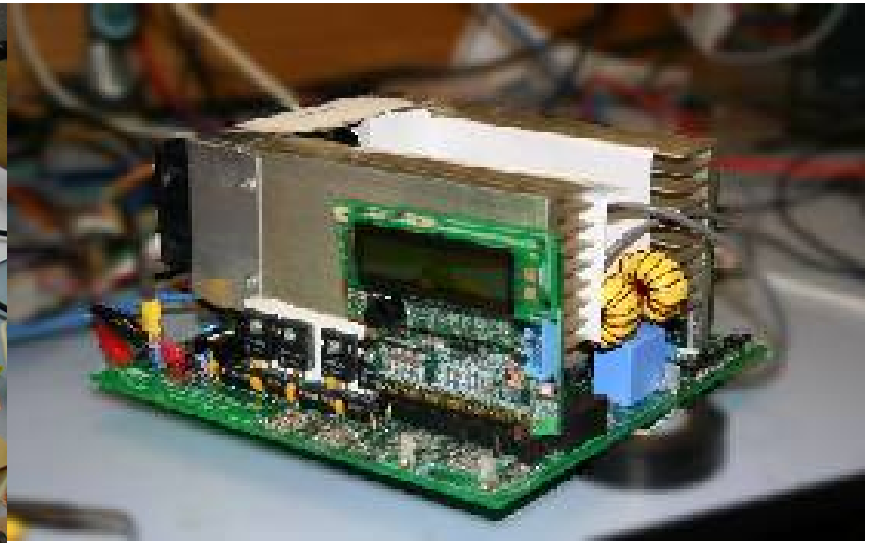
- Interface between PV source and utility grid
- Allows renewable energy to feed into utility grid
- Facilitates reduction of grid peak requirements
- Assists developing countries to meet growing energy demand

http://www.nfcrc.uci.edu/fcresources/FCexplained/Stationary_IMAGEfiles/image006.gif

Hardware Overview



Unit under construction



Unit ready for testing

Primary Design Challenges

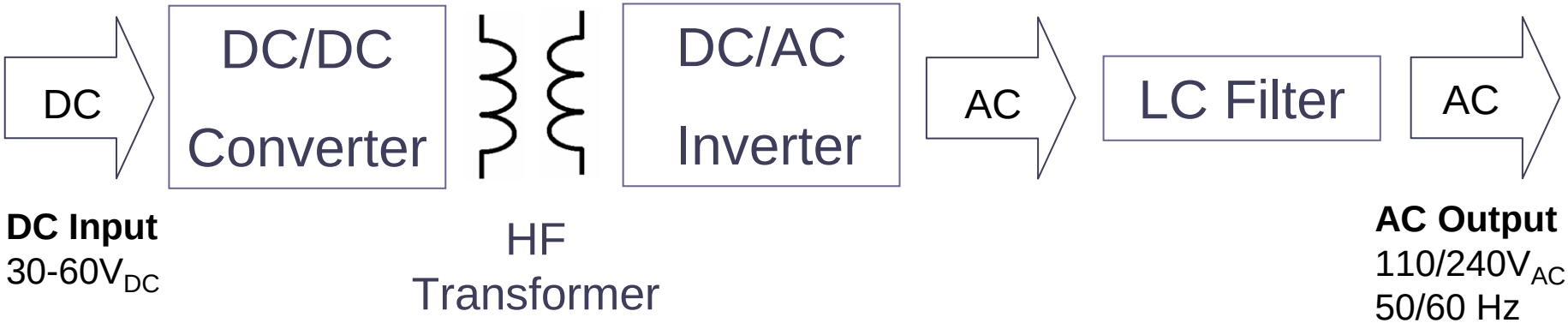
- Weight (< 3kg)
- Efficiency (> 90%)
- Volume (< 7.5 litres)

- Wide input voltage range (30-60 V_{DC})
- Standalone and grid-interactive modes of operation
- Easily selectable dual output voltage (110/240 V_{AC})

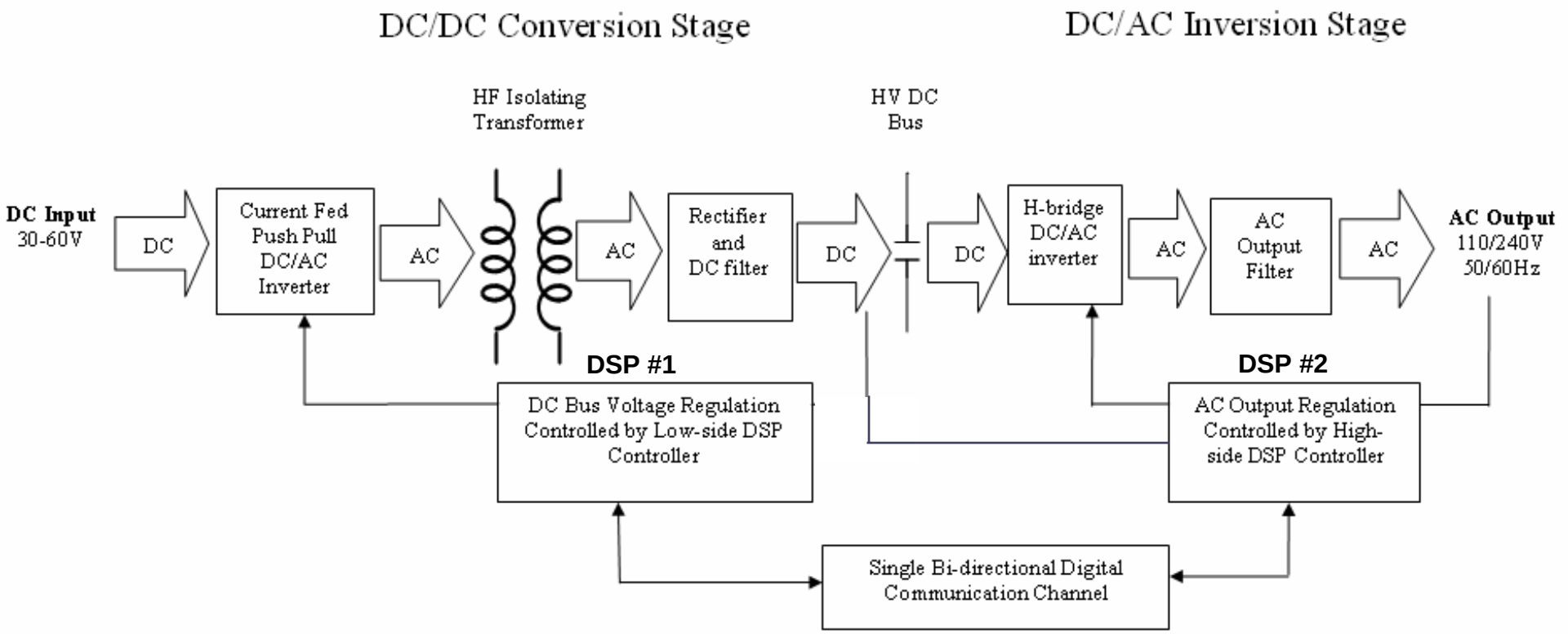
Secondary Design Considerations

- Galvanic isolation between source and load
- Meet relevant standards (NEMA 3R, IEEE 519 etc.)
- Low cost, high reliability, long lifetime
- Manufacturable with low skill base work force

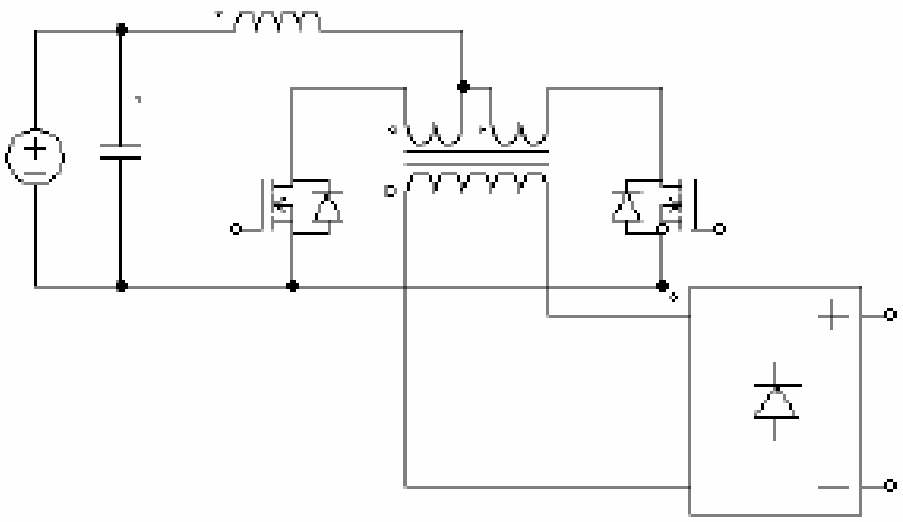
Design Concept



Design Overview



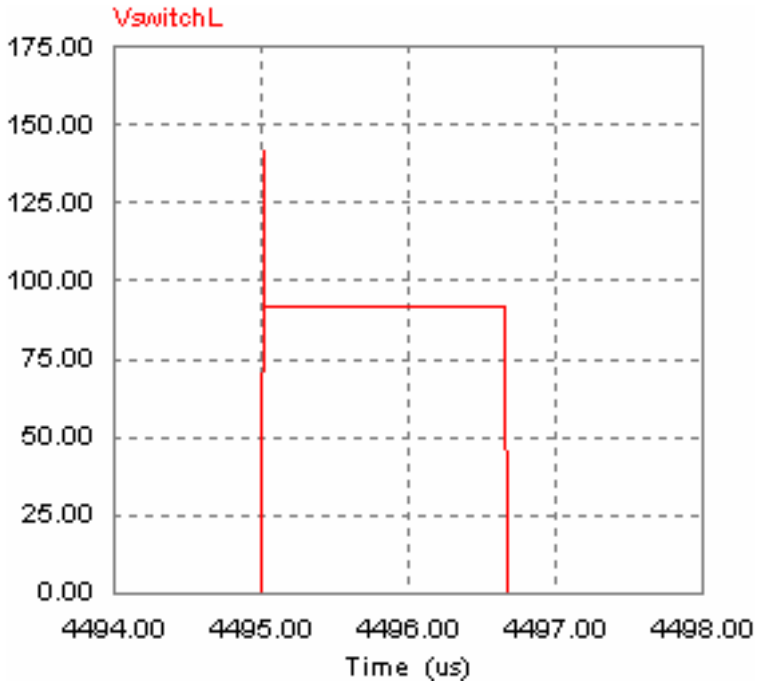
Current-Fed Push Pull DC-DC Converter

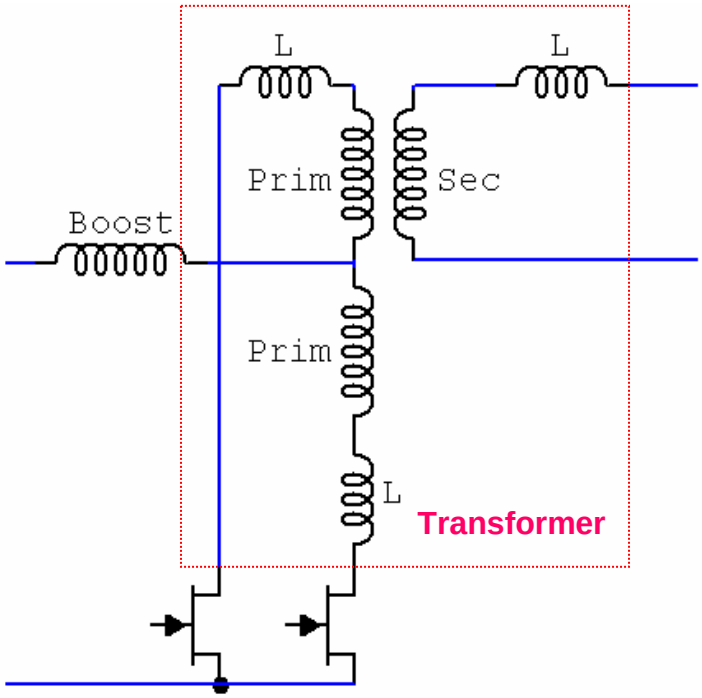


Switching frequency - 100kHz

- High efficiency – integrated boost and isolation
- Input-side current flows through single switch only
- Each switch implemented with two parallel devices
- Continuous input current to reduce conducted EMI

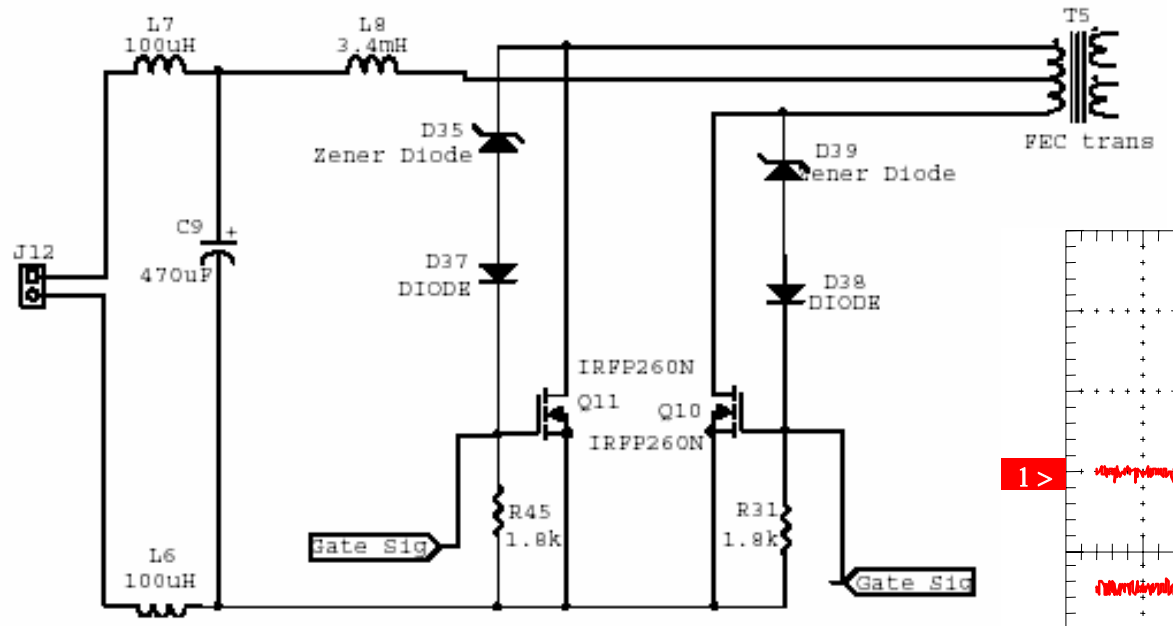
Transient Overvoltage

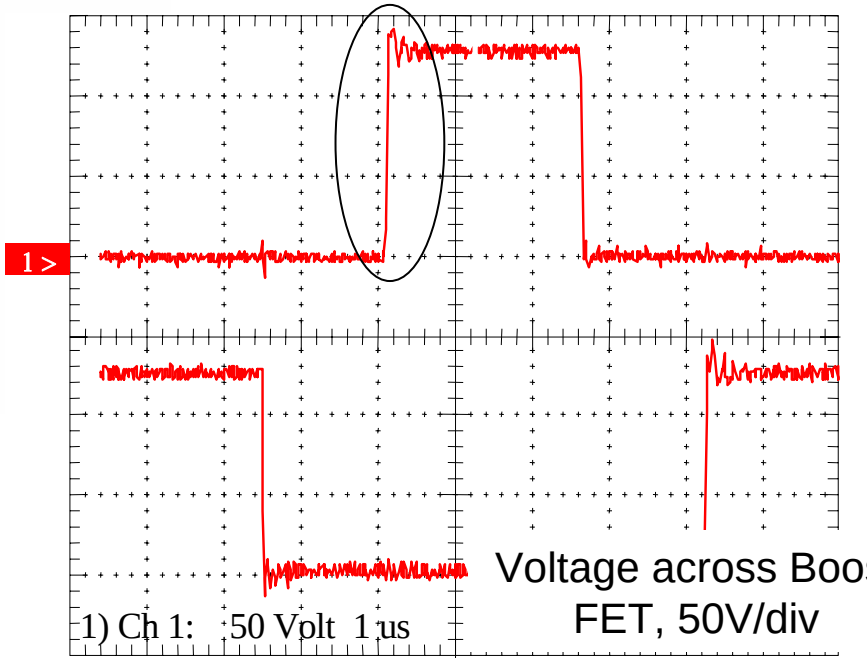




- Voltage spike caused by device switching
- Solved by careful magnetics design and active clamping

Active Clamping

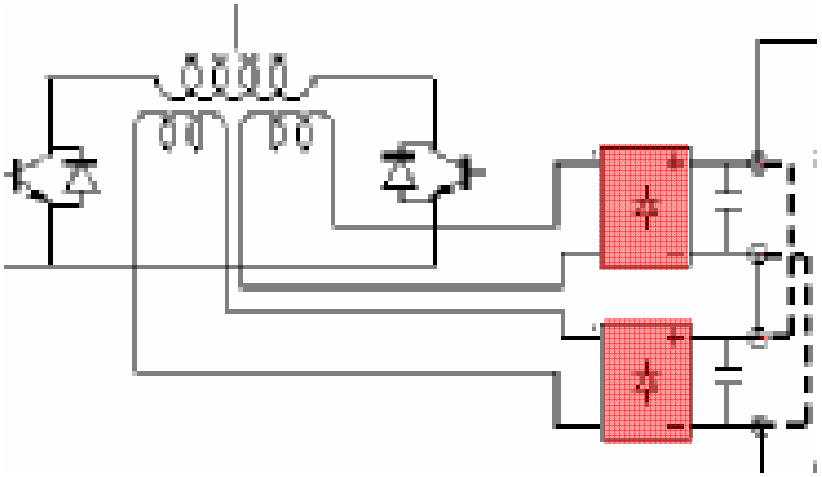




Voltage across Boost FET, 50V/div

CFPP Switching Waveform

Two Rectifiers for Dual Voltage Operation

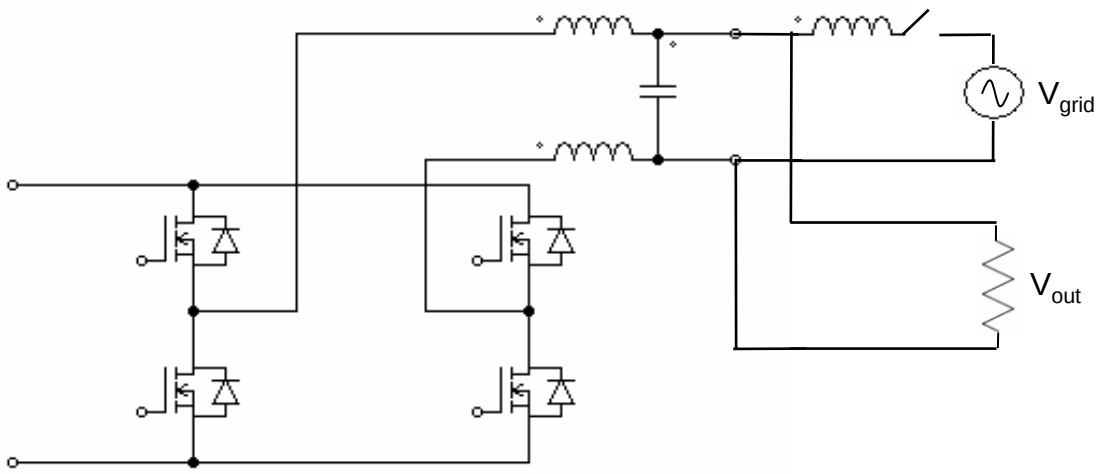


- Can configure High Voltage DC bus to 200/400 V
- Achieves efficient output stage switching

Output H-Bridge DC-AC Inverter

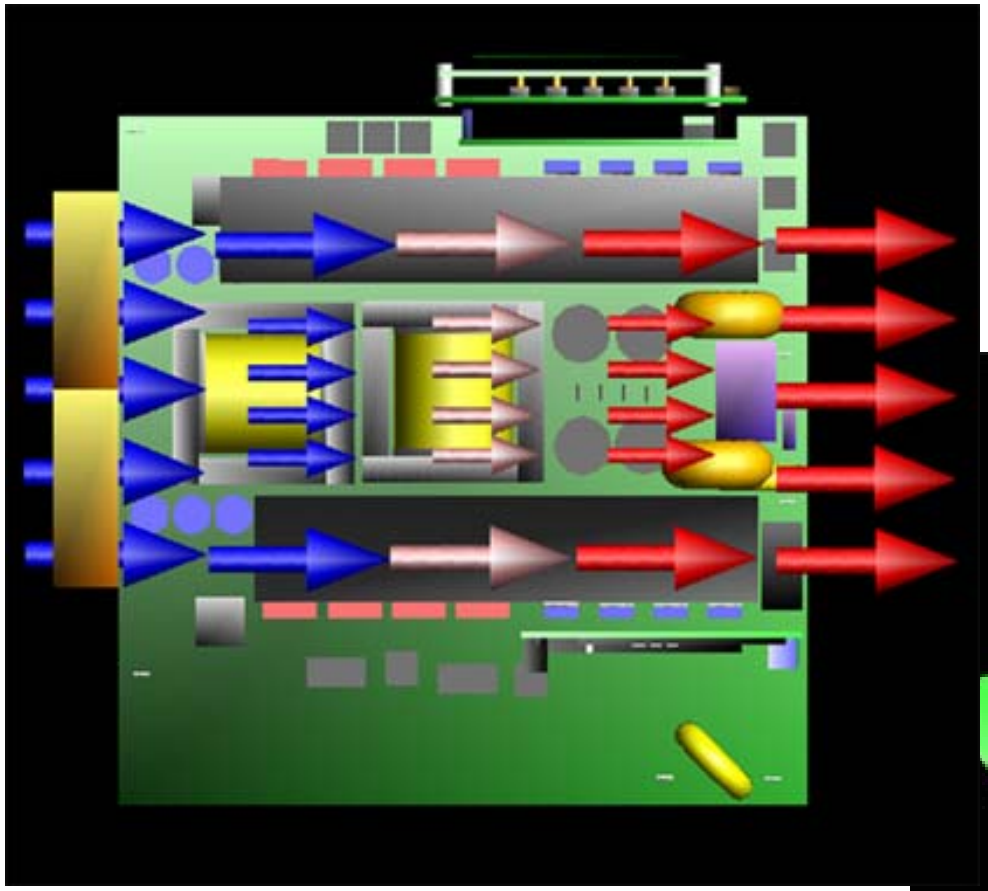
- Conventional output inverter design

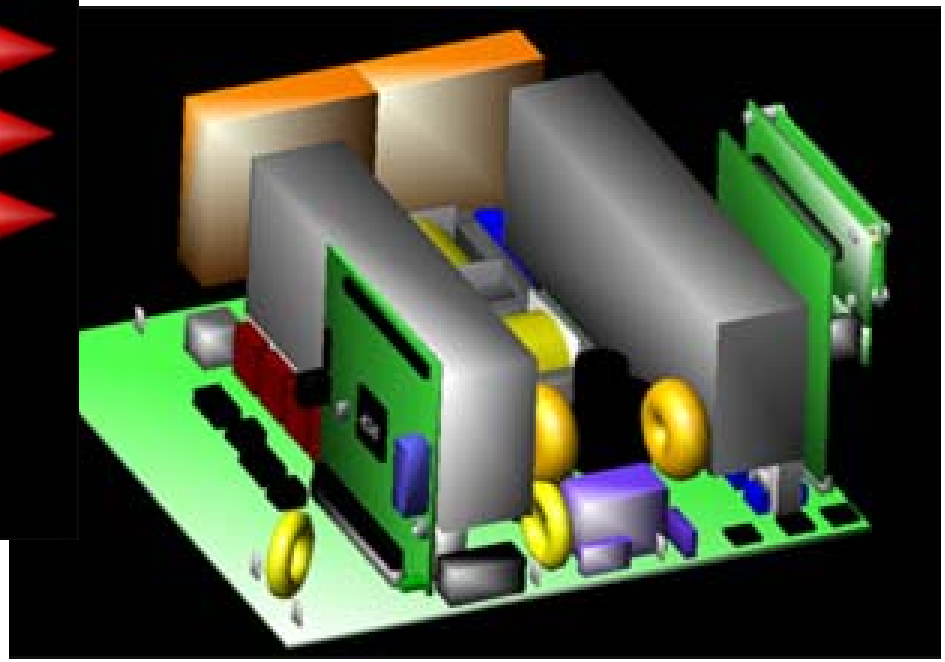
- Devices overrated to handle 110/240 V_{AC} and 3kW



Switching frequency - 20kHz

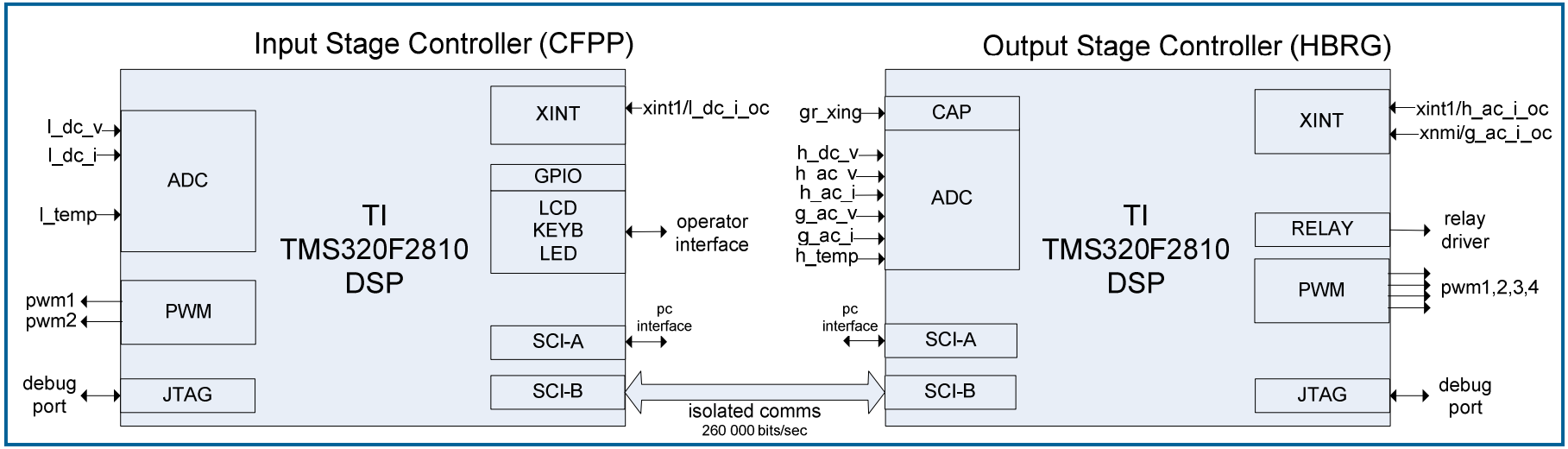
Thermal Management Design





Control Electronics

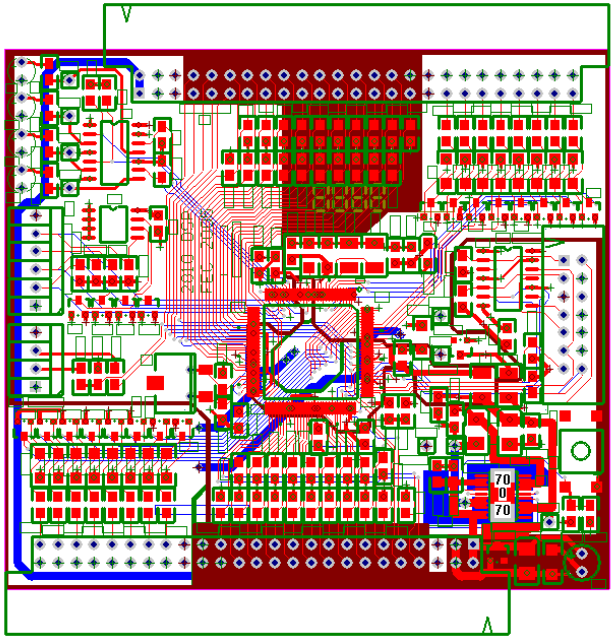
- Dual DSP approach
  - Separation of control responsibilities
- Isolated, high-speed communications channel
  - Eliminates need for analogue isolation
  - Cheaper solution



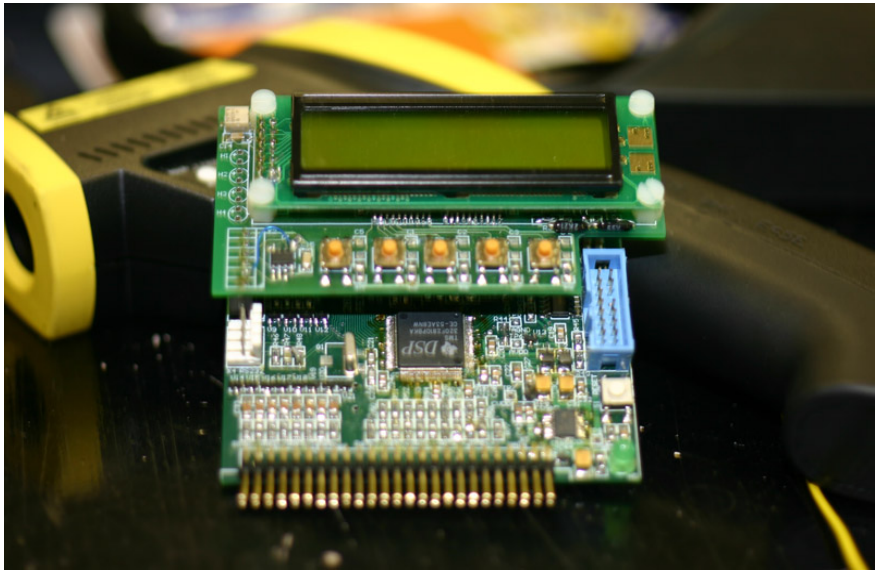
Innovative Design Features

- Single stage boost DC / DC converter
- High switching frequency (small components)
- LCL AC output filter
- Fully digital, dual-DSP controller
- Light weight and compact volume

Control Overview



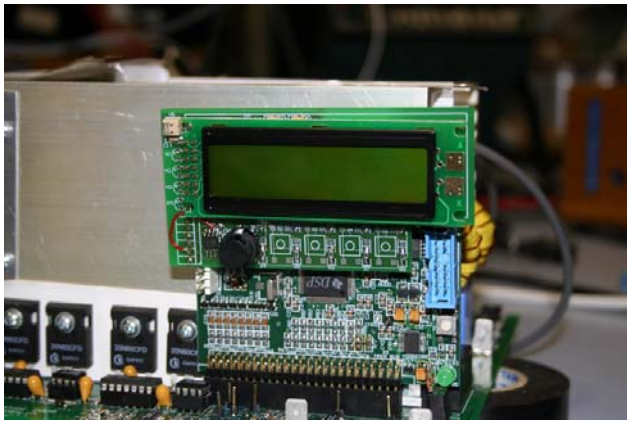
DSP Controller Card PCB



DSP Controller and LCD Display

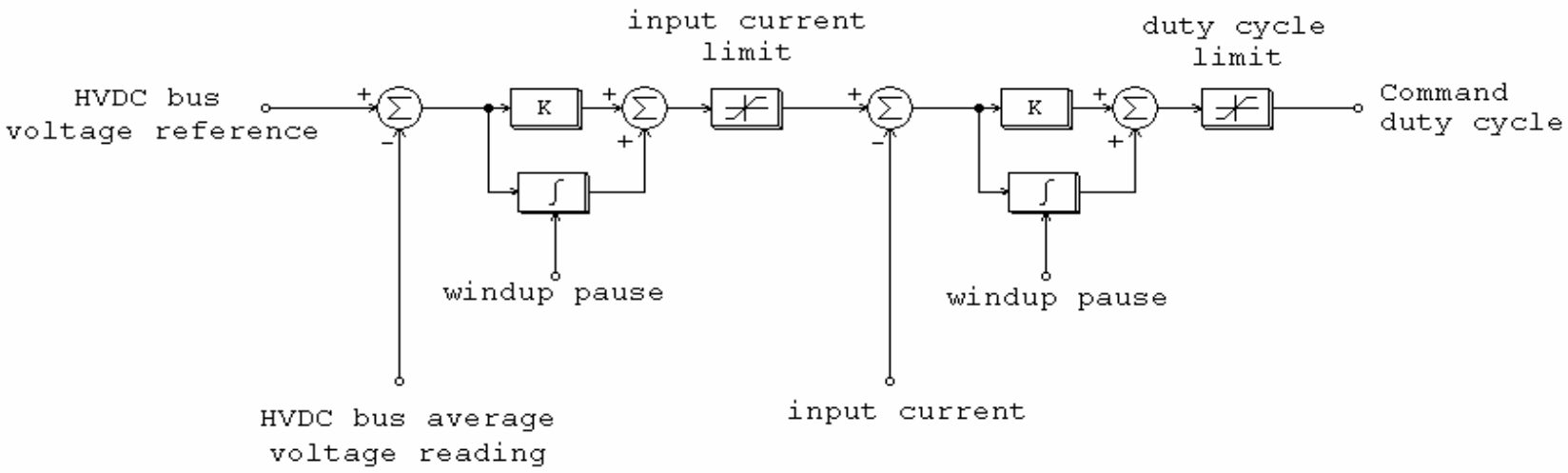
Control Electronics

- Full digital control
  - Allows highly flexible and adaptive control strategies
  - Minimal analog circuitry
  - Reduced cost
- DSP (Digital Signal Processor) based
  - General purpose microprocessor
  - Fast computational speed (150MHz)
  - Highly integrated peripherals
- Modular controller card design
  - Generic and flexible design



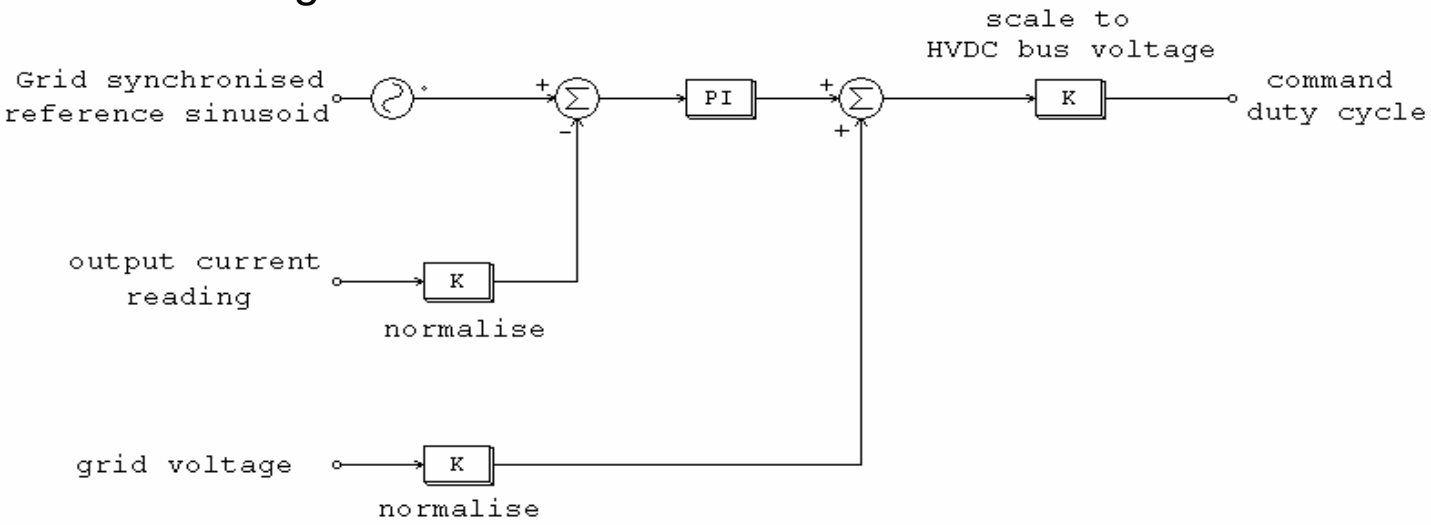
Input Stage Control (DSP #1)

- Fast inner current control loop
  - Eliminates AC fundamental input power ripple
  - Smaller energy storage components – cheaper and lighter
- Slow outer HVDC bus control loop
  - Calculates reference for inner current loop, based on bus voltage error
  - Slow-speed averaged response, does not interfere with inner loop

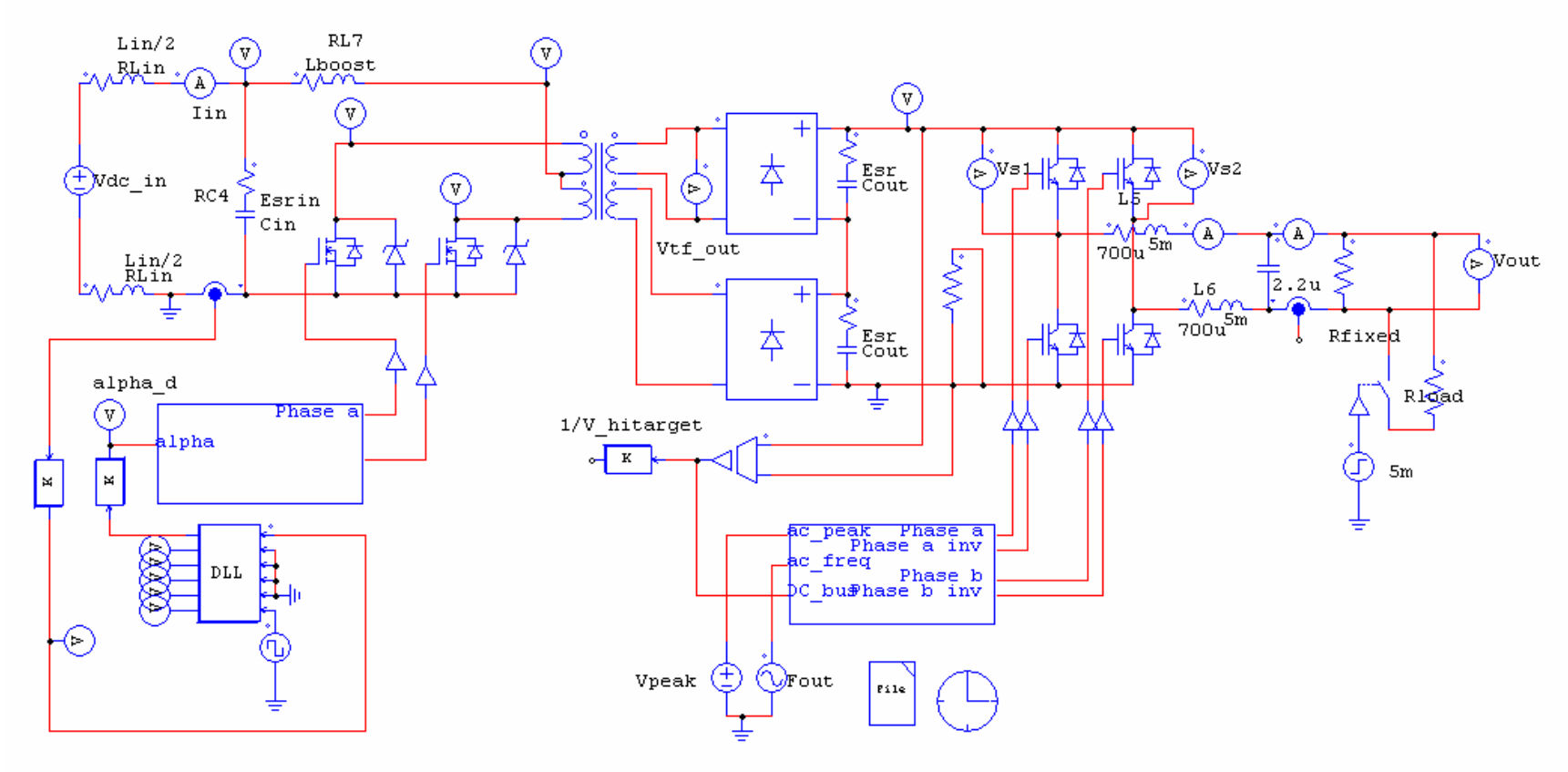


Output Inverter Control (DSP #2)

- Standalone mode: DC bus voltage compensated PWM
  - Creates a smooth AC voltage output
- Grid-connected mode: feed forward and closed loop
  - Feed forward follows grid voltage
  - PI current control makes small changes, allows power to flow into the grid
  - Insensitive to grid harmonics



Digital Control Simulation



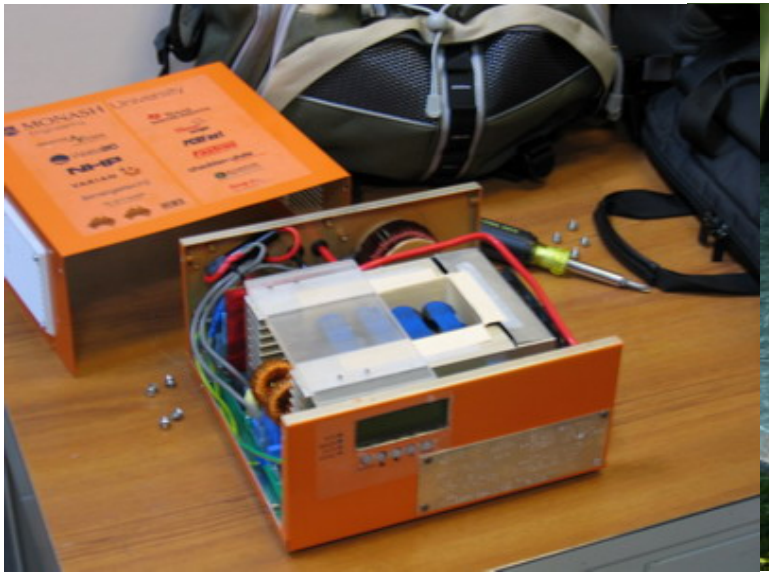
Software

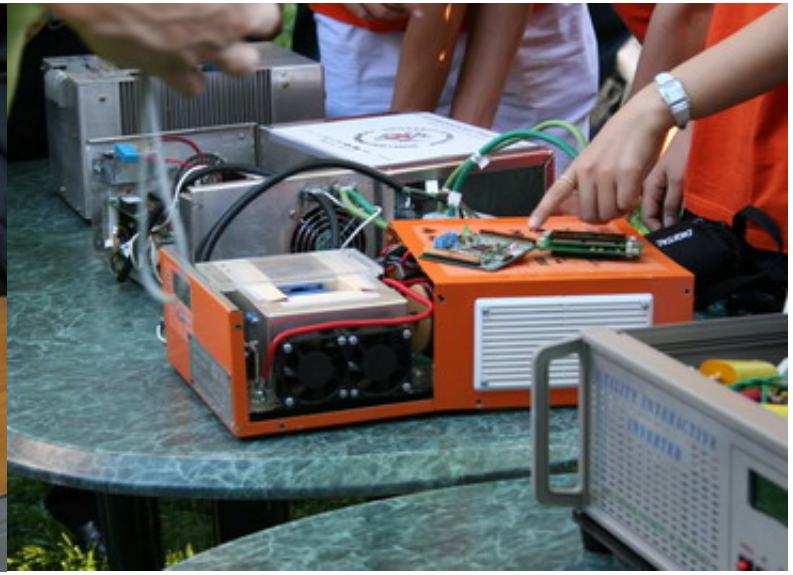
- Development tools
  - TI 281x DSP with CCS 2
- Extensive fault protection
  - Controlled and immediate shutdown responses
  - Saved our hardware on numerous occasions
- Communications protocol
  - Error detection
  - Allows 260 kbit/s transfer speed
- State based software implementation
  - Event triggered state transitions
  - Decouples software behaviour

Protection

- Hardware
  - Causes interrupts to allow immediate processing of critical trips.
- Software
  - Dual level of protection depending on severity
  - Controlled and emergency shutdowns
- Fuses

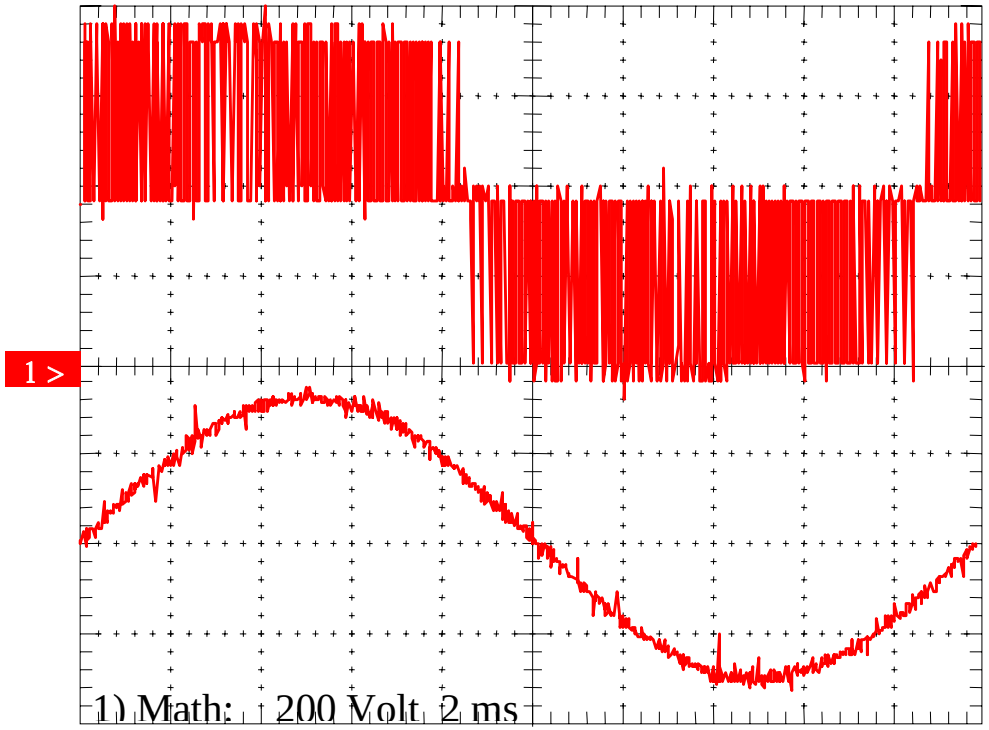
Unit Performance





Unit under test at NREL

Standalone AC Output



Switching waveform

Output waveform

Output Waveform THD = 1.9%

Efficiency

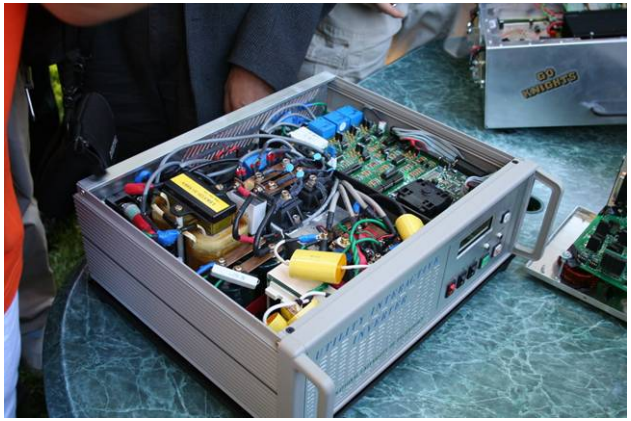
	35V	45V	55V
600W	85.2%	86.3%	86.5%
900W	84.9%	87.3%	87.8%
1000W	84.9%	88%	**88.7%**

Variation of approximately 4% over the power range and input voltage

Specifications

	Required	Achieved
• Weight	3kg	4.27kg
• Efficiency	90%	88.7%
• Volume	7.5 litres	7.2 litres
• Cost	$200	$134.38
• Galvanic Isolation	Yes	Yes
• Variable input voltage (30-60V)	Yes	Yes
• Dual output voltage (110/240V)	Yes	Yes

Winning Inverters



South Korea University of Technology

University of Illinois

Key Innovations of our Inverter

- Use of lightweight, high frequency transformer
- Fully digital controller design
- Dynamic Clamping Circuit
- Isolated digital communications
- Minimal wiring and efficient use of space
- Minimisation of parts

Questions?