Power Electronics Research at Ryerson

Bin Wu
Professor
Dept. of Elec & Comp Eng
Ryerson University

350 Victoria Street, Toronto, Canada M5B 2K3

Research Areas

- **Power Electronics (High Power)**
- **Electric Drives (Medium Voltage, 2.3kV – 13.8kV)**
- **Renewable Energy Systems (Wind, PV)**
- **Urban Energy Systems (Energy Storage Systems, EV Charger/Charging Stations, Microgrid)**

Research Laboratories

LEDAR

Laboratory for Electric Drive Applications and Research

CUE Lab

Centre for Urban Energy Laboratories

WindTech

WindTech/Microgrid Research Lab

LEDAR

Laboratory for Electric Drive Applications and Research

CFI

NSERC CRSNG

Rockwell Automation

Honeywell

Ontario Innovation Trust

The best electric drive research facility in a Canadian university

LEDAR (Lab A)

Laboratory for Electric Drive Applications and Research

ENG327 Lab

LEDAR (Lab B)

Laboratory for Electric Drive Applications and Research

EPH120 Lab

CUE Lab

For Urban Energy Research

hydro One

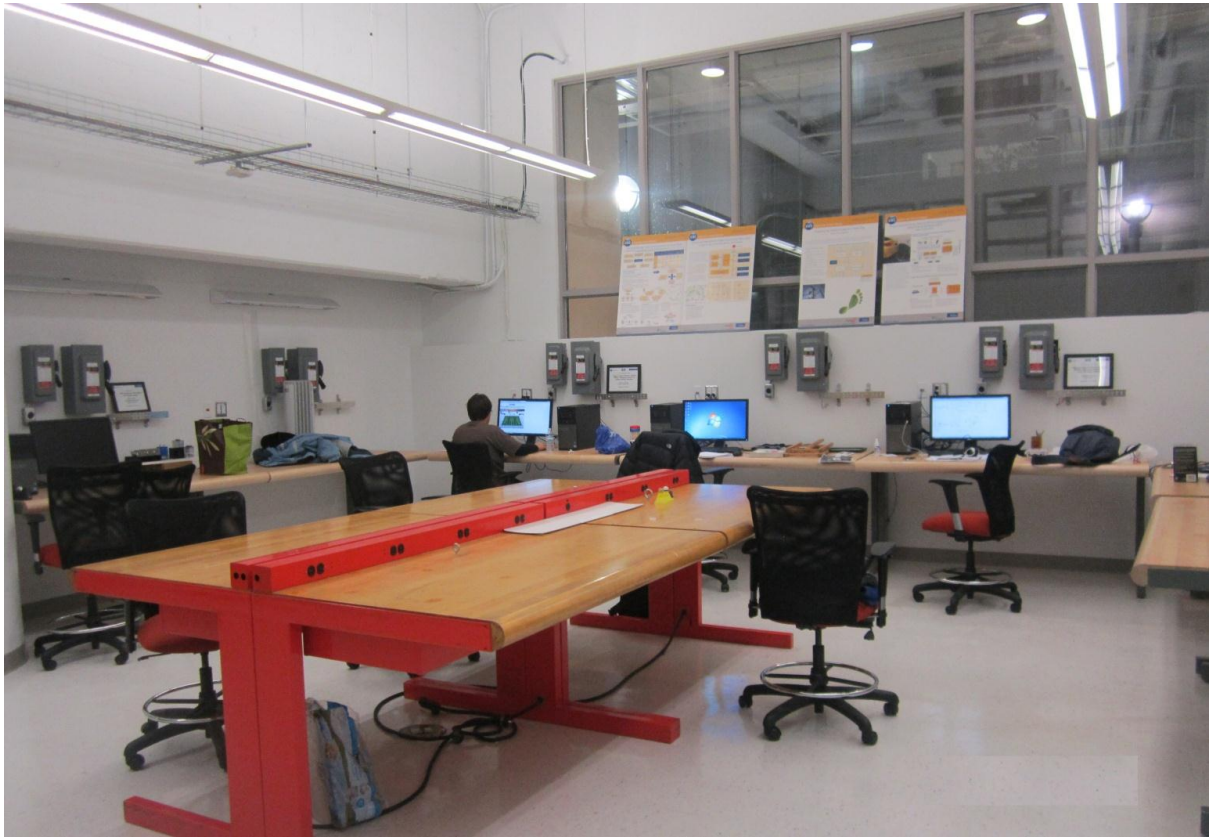
ONTARIO POWER AUTHORITY

toronto hydro corporation

CUE

CUE Lab

For Urban Energy Research



CUE108 Lab

WindTech

WindTech/Microgrid Research Laboratory

Sponsors

CFI

Canada Foundation for Innovation

Rockwell Automation

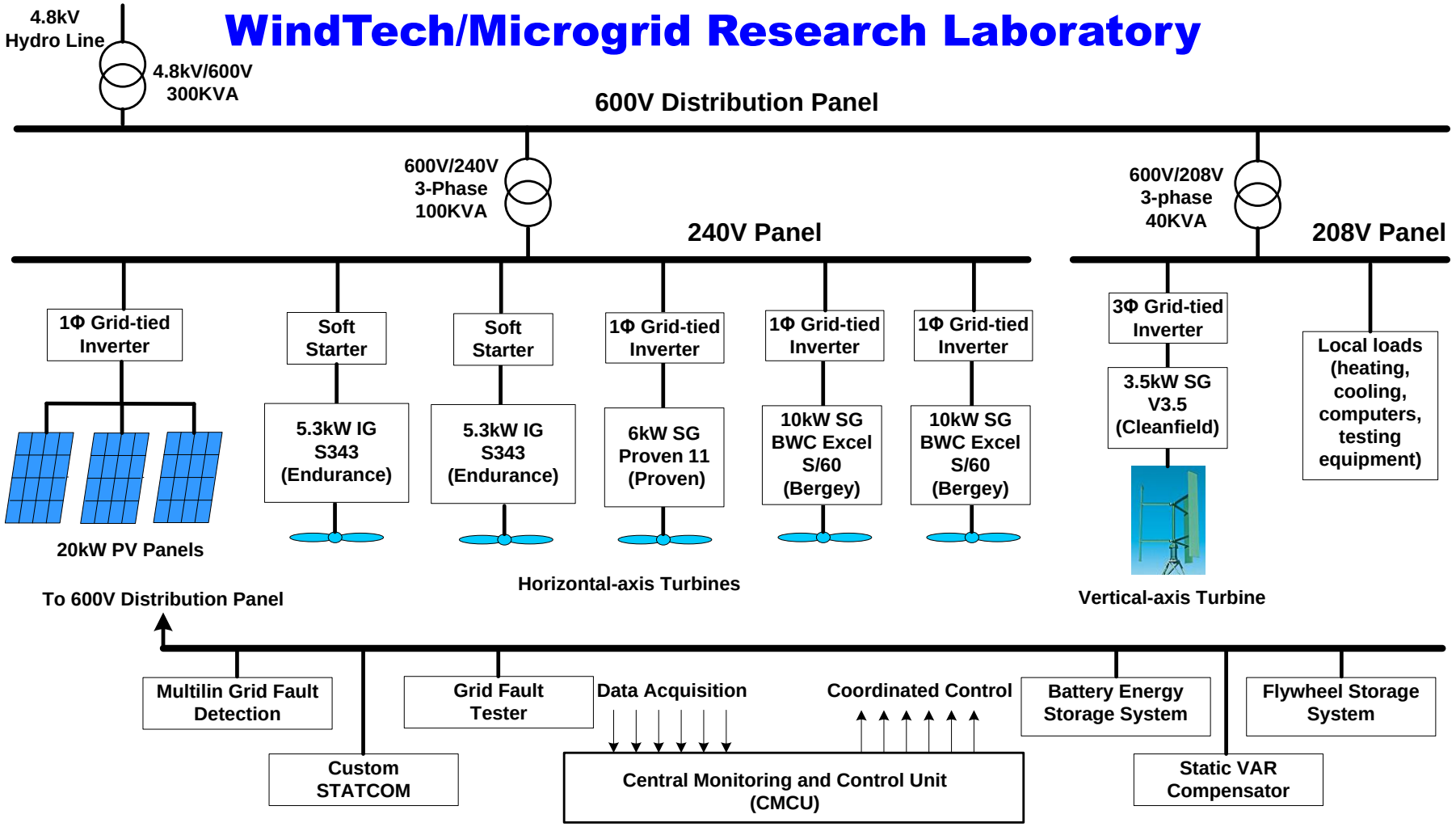
Ontario

Ministry for Research and Innovation

RYERSON UNIVERSITY

WindTech

WindTech/Microgrid Research Laboratory



WindTech

WindTech/Microgrid Research Laboratory

Six wind turbines to be erected

WindTech

WindTech/Microgrid Research Laboratory

PV panels on one of the two buildings

Electric Drive Research

Long-Lasting Collaboration with Rockwell Automation Canada (since 1994)

Medium Voltage (MV) Drive: 2.3KV to 7.2KV, 0.5MW to 15MW

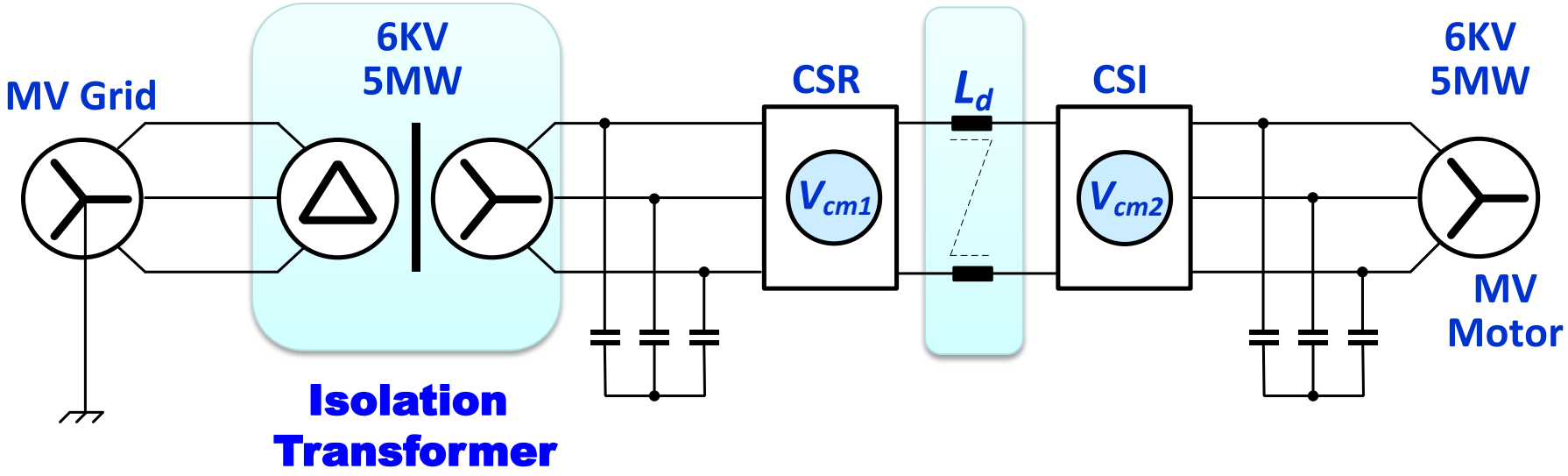
Electric Drive Research

Long-Lasting Collaboration with Rockwell Automation Canada (since 1994)

- From 1994 to 2005:
  Three Collaborative Research & Development (CRD) Programs
- From 2006 to 2017:
  Two Industrial Research Chair (IRC) Programs
- 25 US/European patents granted/filed
- The developed research results and technologies have been used in Rockwell's drive products
- Rockwell has become one of the top three MV drive manufacturers in the world

Electric Drive Research

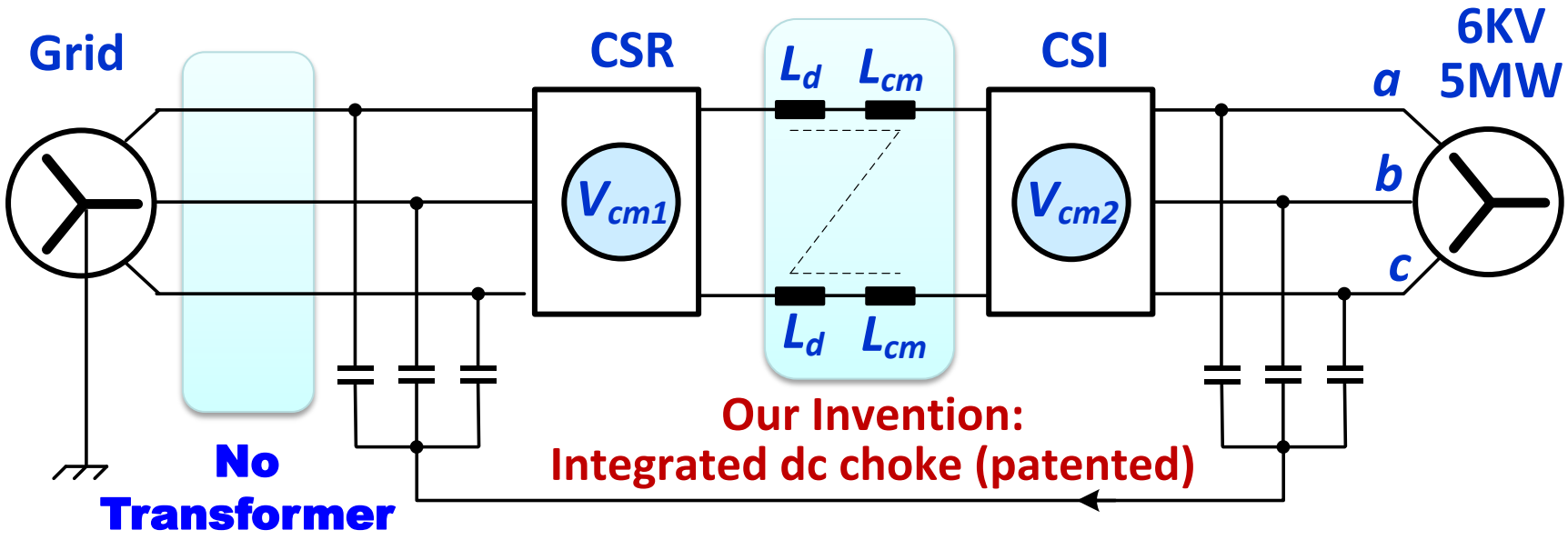
An Example - Transformerless Technology Developed for Rockwell Automation Canada



Rockwell's 1st generation MV drive with isolation transformer in early 1990's

Electric Drive Research

An Example - Transformerless Technology

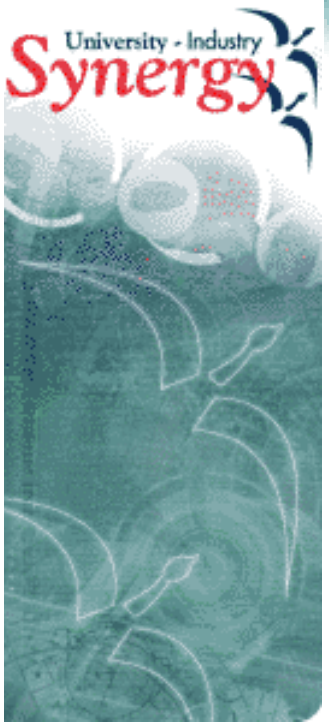


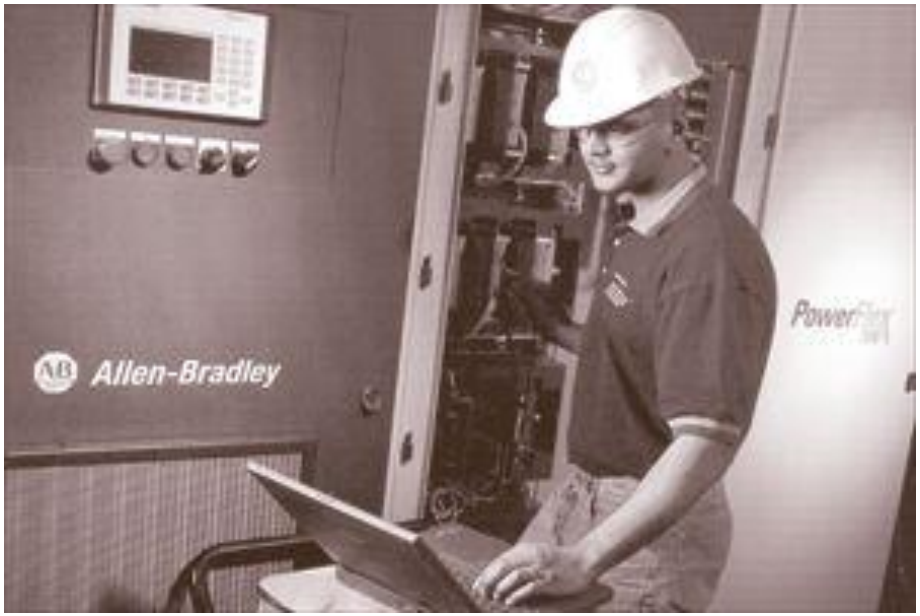
- World's 1st transformerless MV drive
- Save manufacturing cost by 30%
- Save physical size by 25%
- Increase system efficiency by 50%

US Patent, #6,617,814 B1, 09/09/2003,
B.Wu, S.Rizzo, et al, "Integrated dc Link Choke and Method"

Electric Drive Research

Award-winning Partnership with Rockwell Automation Canada

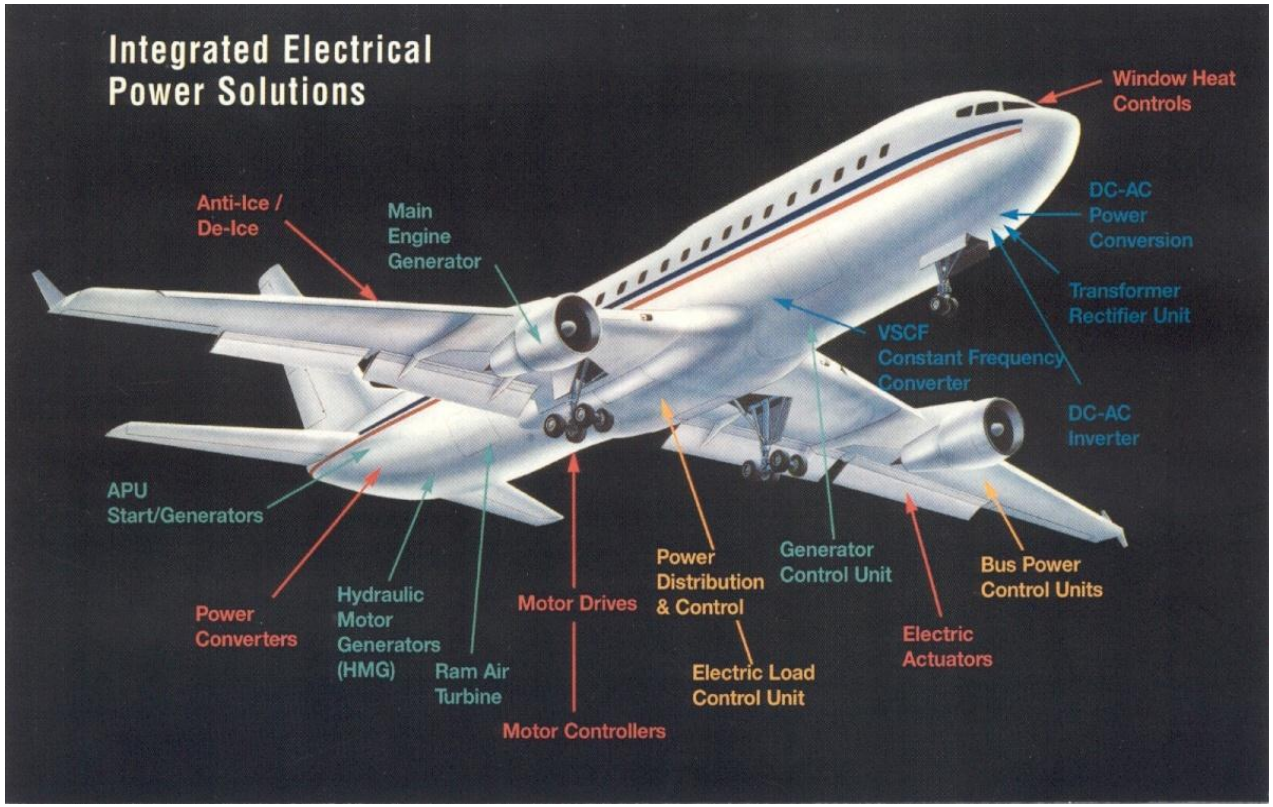




National Award - NSERC Synergy Award for Innovation

Electric Drive Research

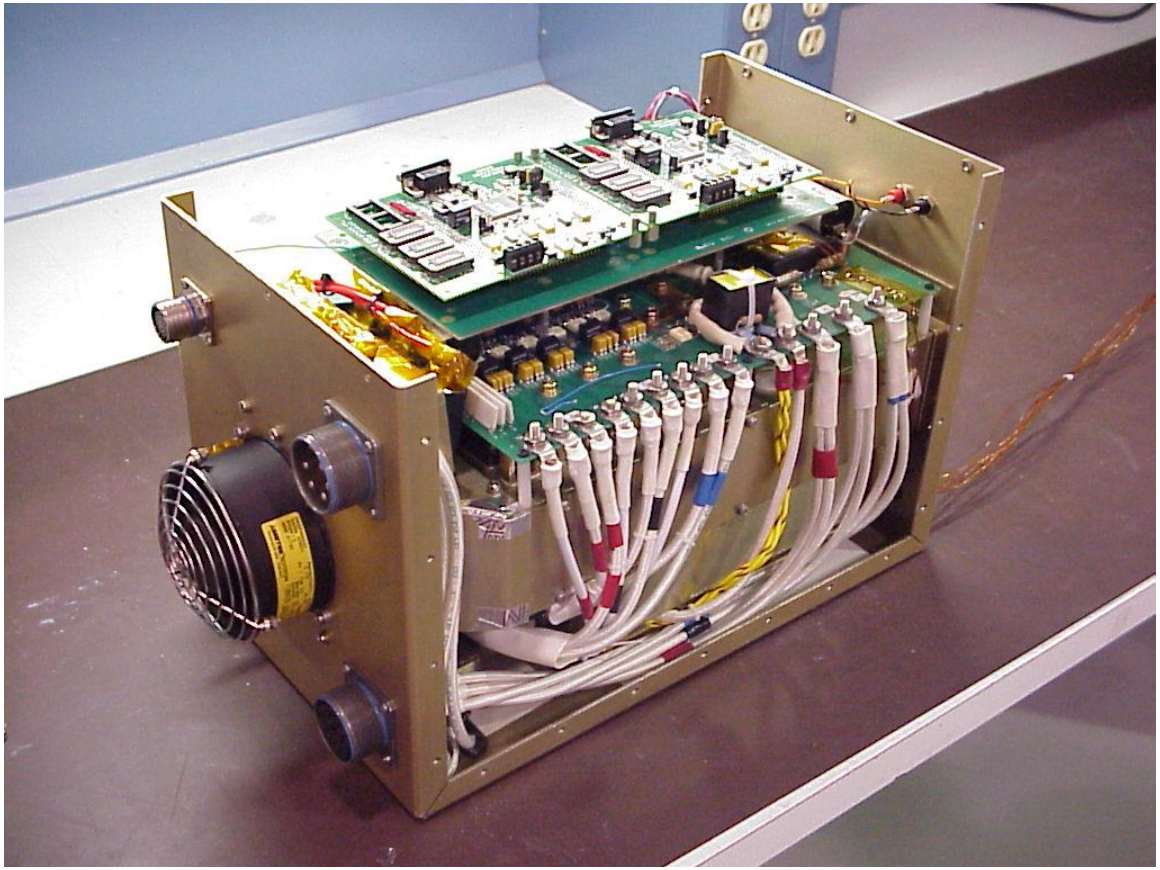
More than 10 years of research collaboration with Honeywell Aerospace Canada



More Electric Aircraft

Electric Drive Research

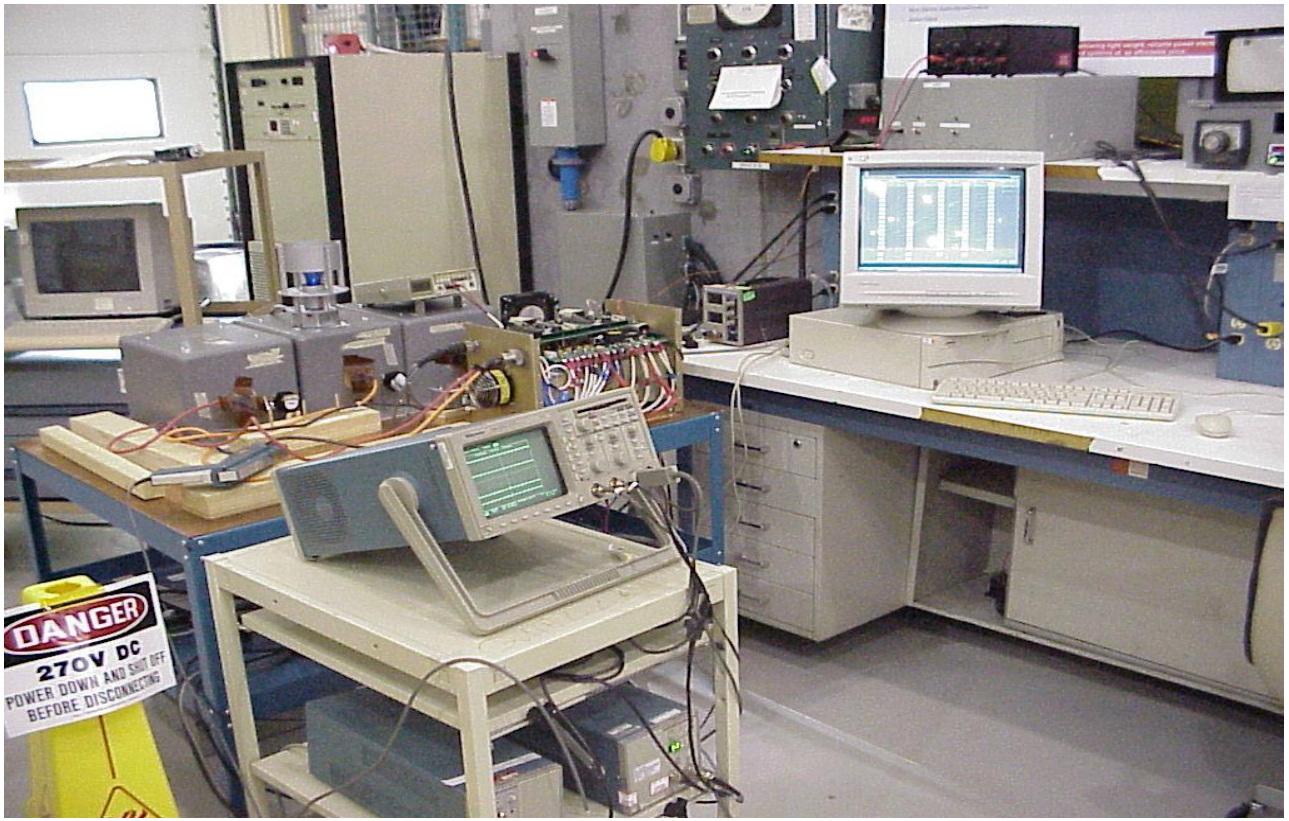
Next Generation Motor Controller (20HP)



Final Prototype (9” x 11”x 15”) for Honeywell Aerospace

Electric Drive Research

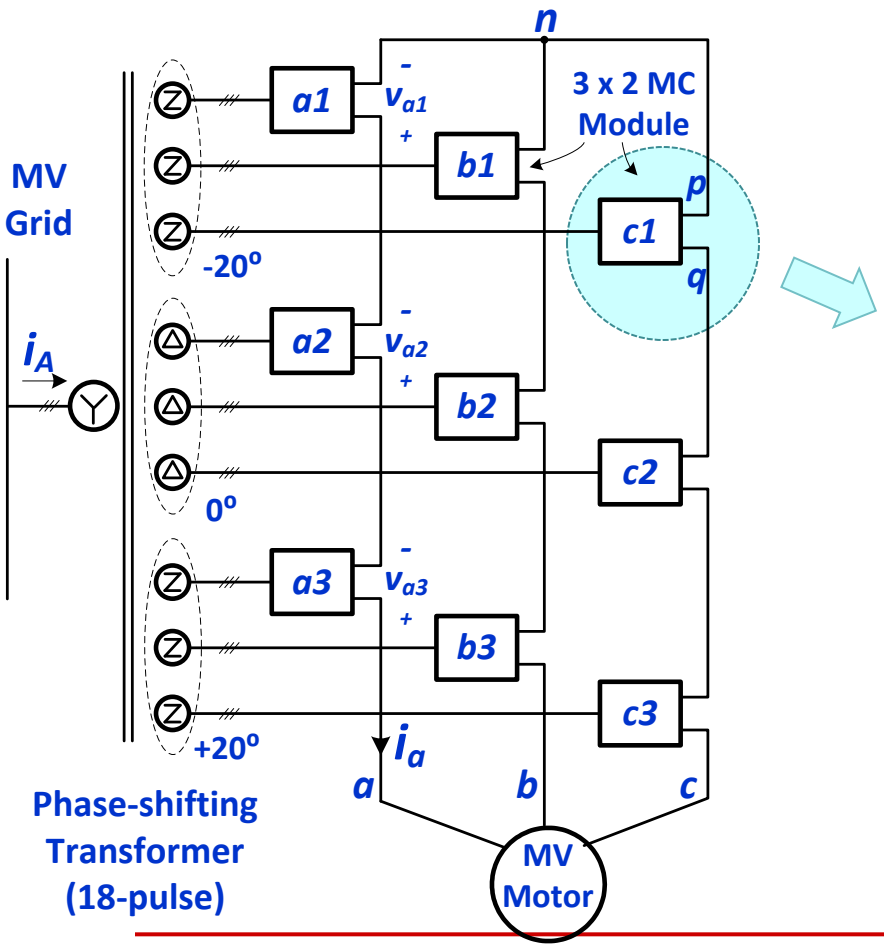
Next Generation Motor Controller

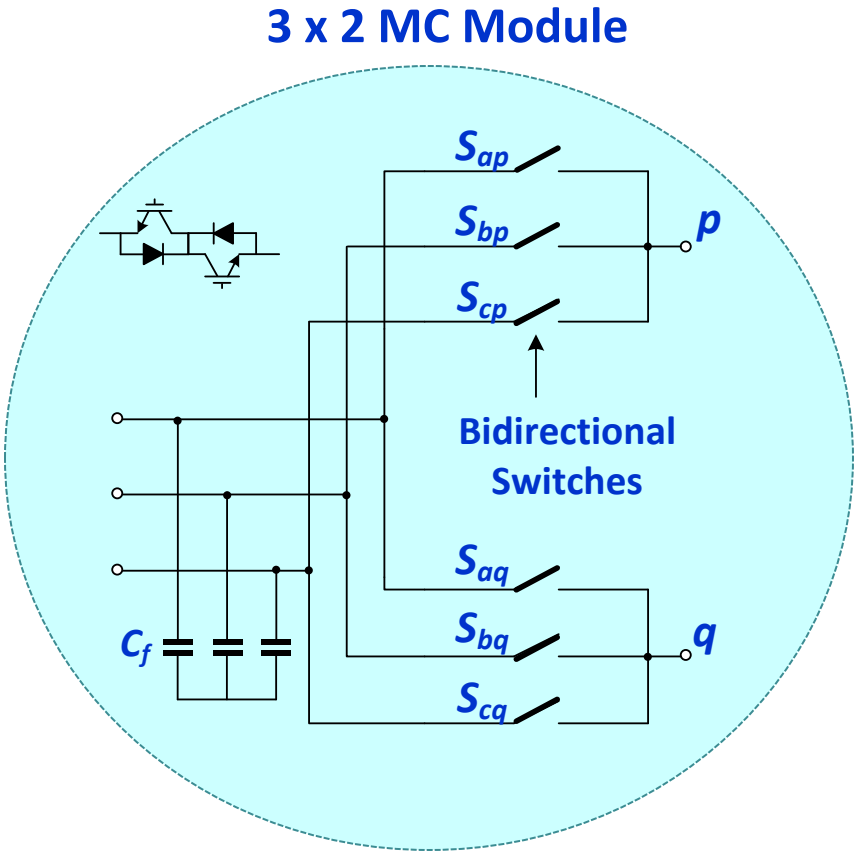


EMI Testing at Motor Speed of 24,000rpm at Honeywell Aerospace

Electric Drive Research

Multi-modular Matrix Converter

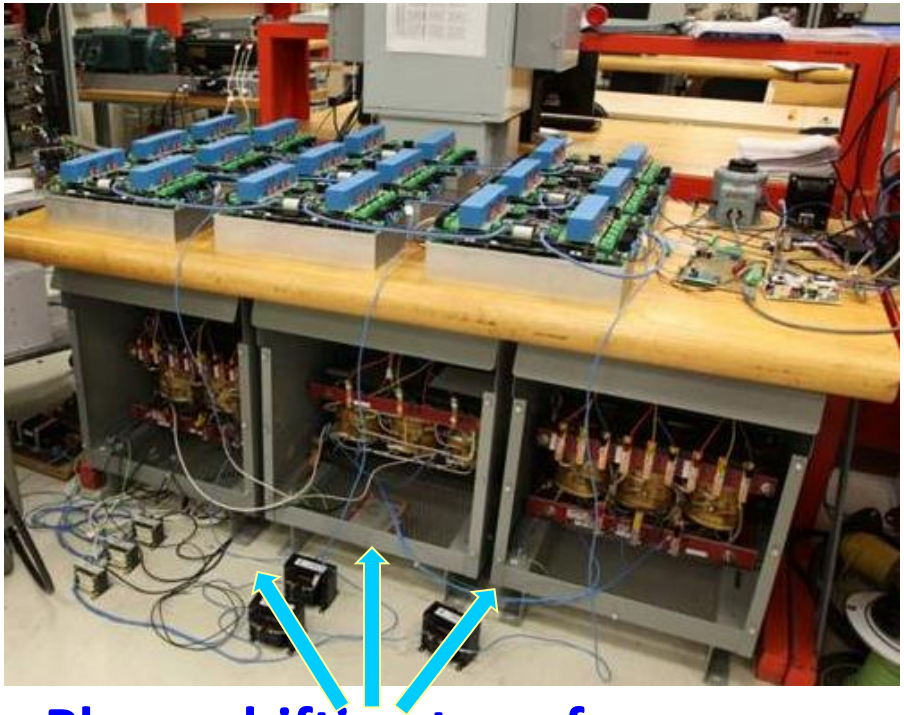




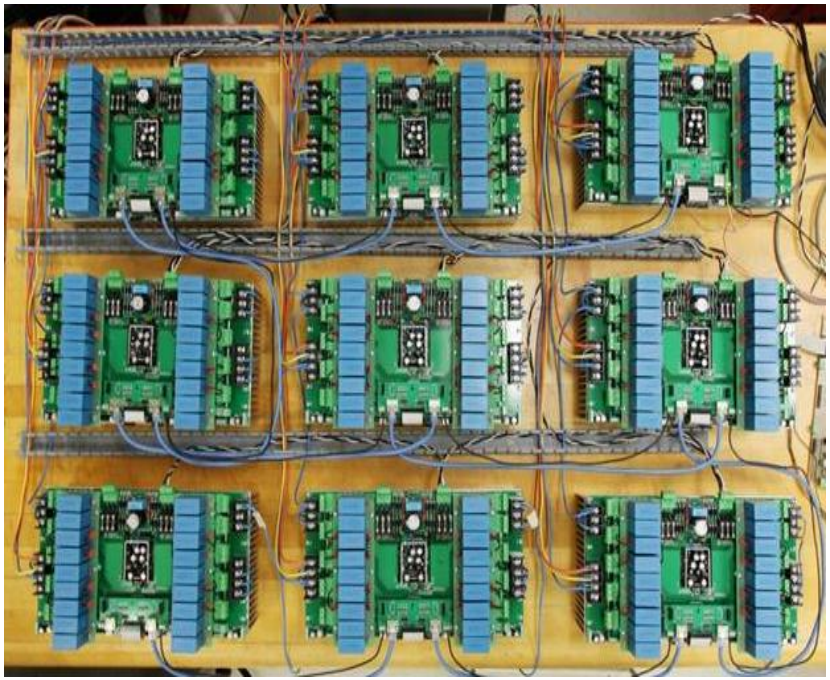
Electric Drive Research

Multi-modular Matrix Converter

Research focus: advanced switching schemes for the MMMC



Phase shifting transformer with 9 secondary windings



MC modules

Electric Drive Research

Small-Scale Laboratory Prototype for 50,000HP Drive

Parallel converters for Rockwell Automation

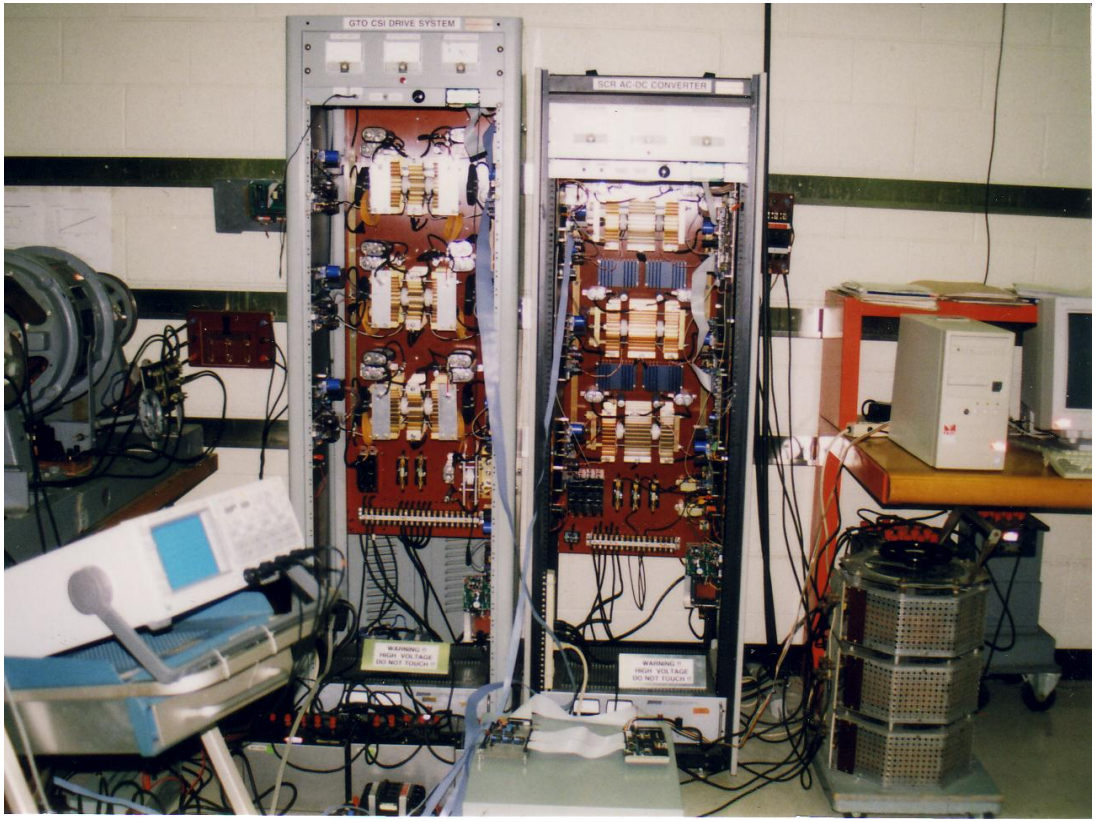
Electric Drive Research

IGCT Fed Current Source Converter Fed Drive

for Rockwell Automation

Electric Drive Research

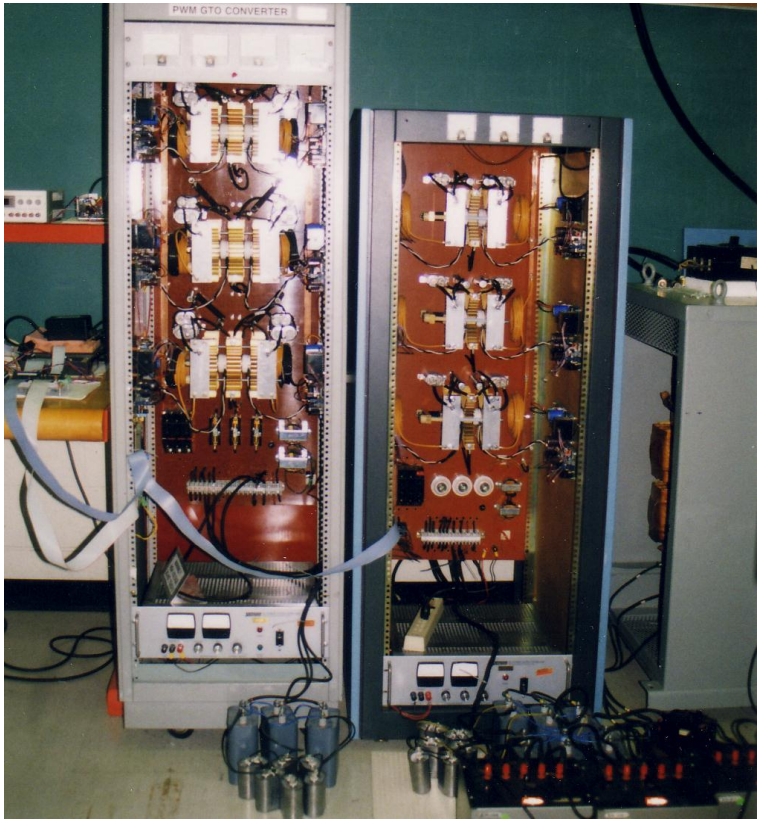
Advanced Drive Control Schemes



US Patents: #6,166,929, 2000; #6,269,010 B1, 2001; #6,366,483 B1, 2002.

Power Converter Research

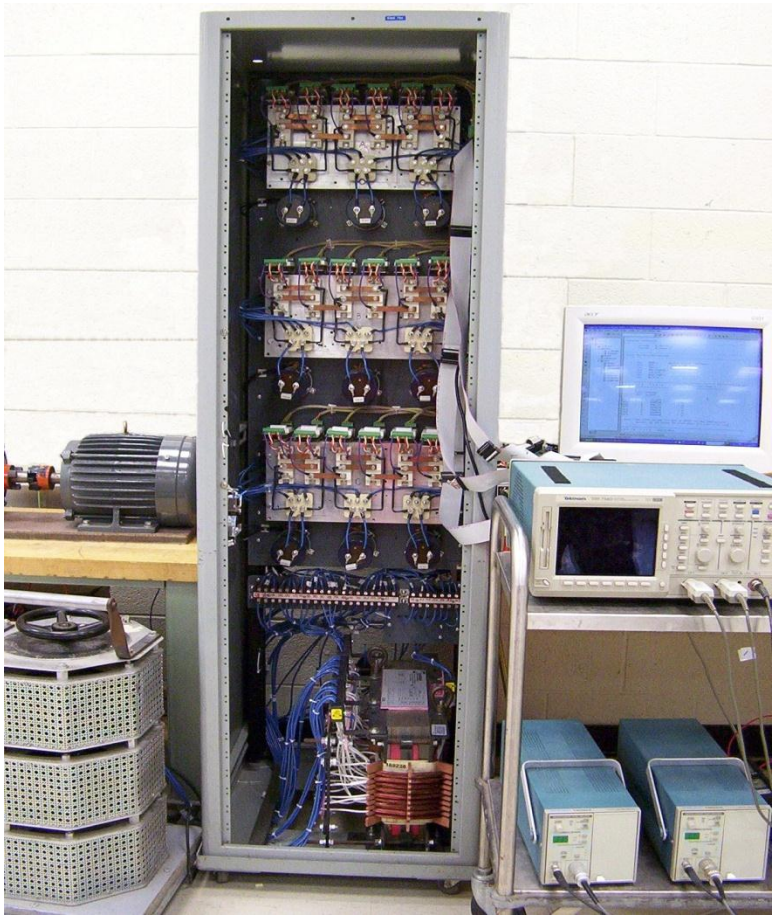
Harmonic-Eliminating Current Source Rectifier

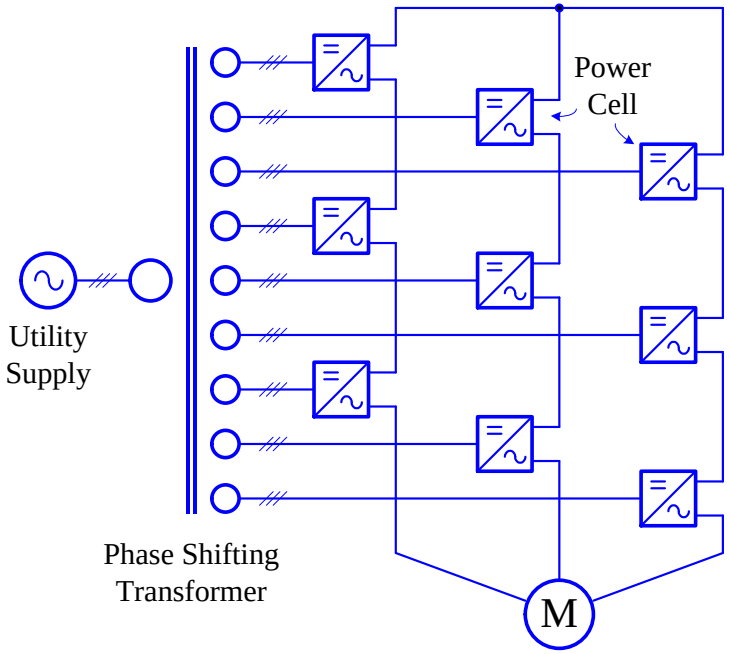


US Patent #5,835,364, 1998

Power Converter Research

Multilevel Cascaded H-Bridge Inverters

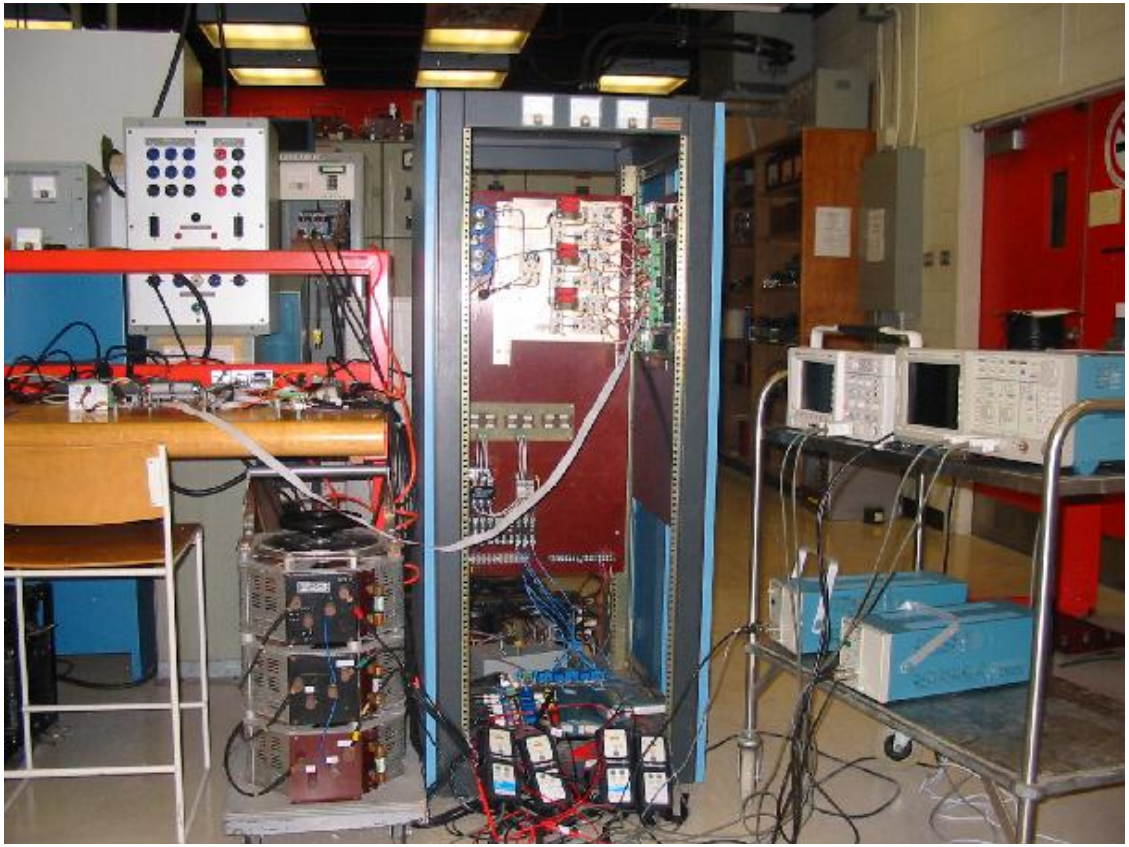




Seven-Level CHB Inverter

Power Converter Research

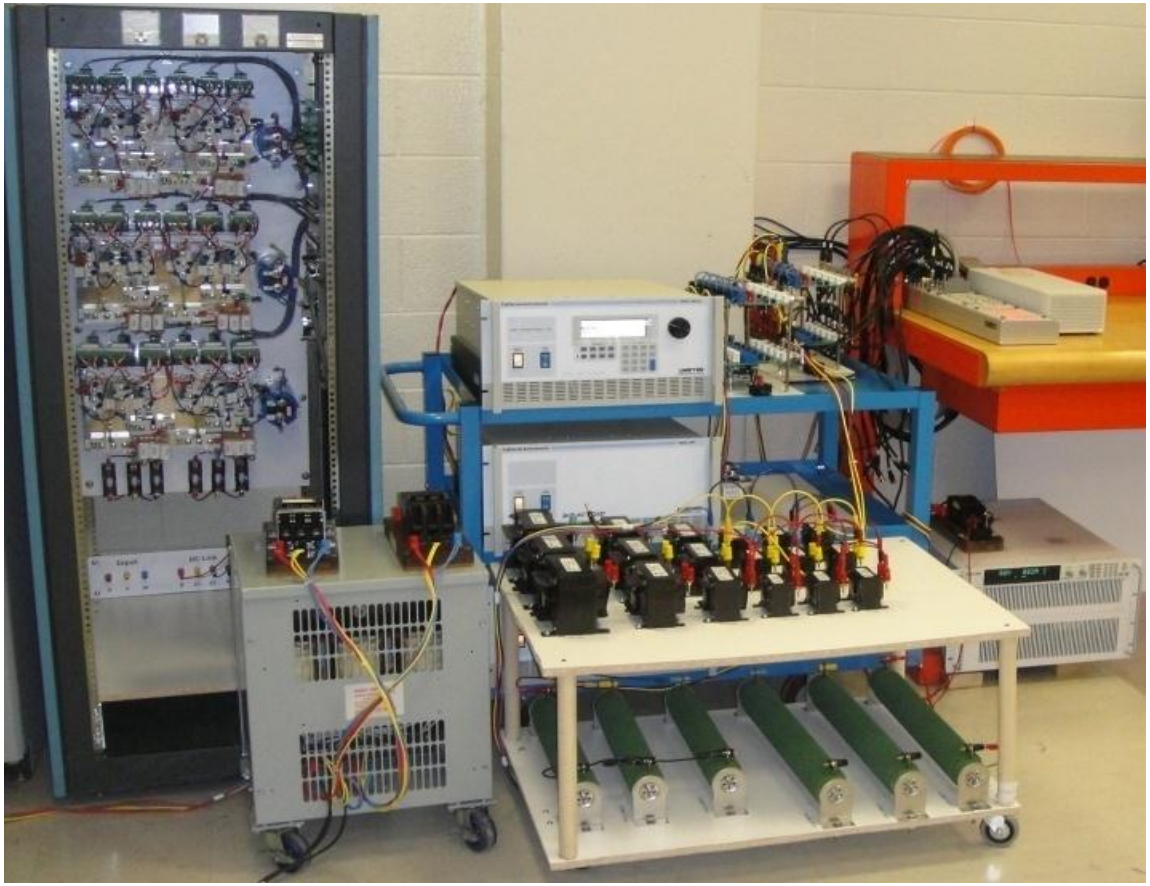
Three Neutral Point Clamped (NPC) Inverters



US Patent #7,495,938 B2, February 24, 2009
European Patent Publication: # 06007880.5-2207, 2006

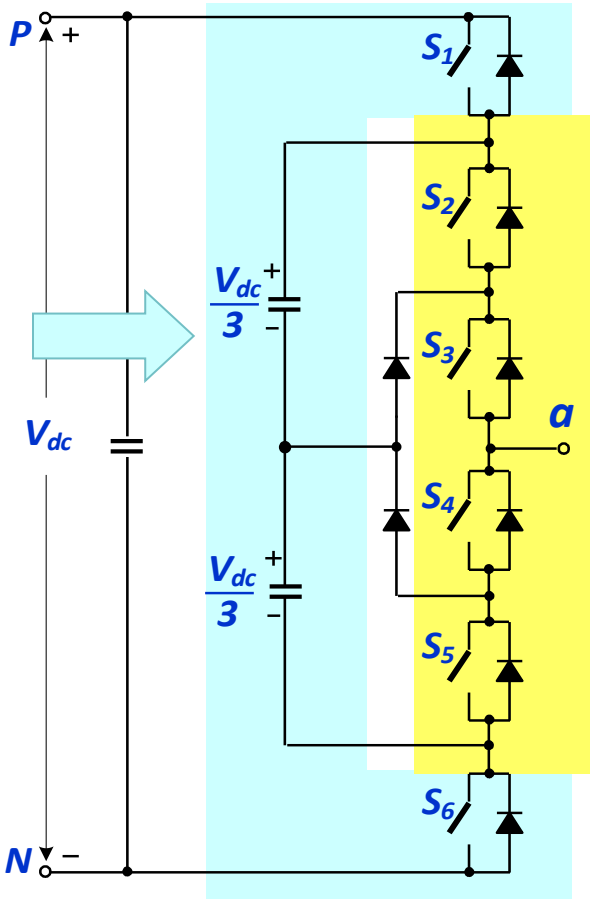
Power Converter Research

Multilevel diode-clamped converter system



Power Converter Research

Four-level Nested Neutral Point Clamped (NNPC) Inverter



Flying Capacitor (FC) converter

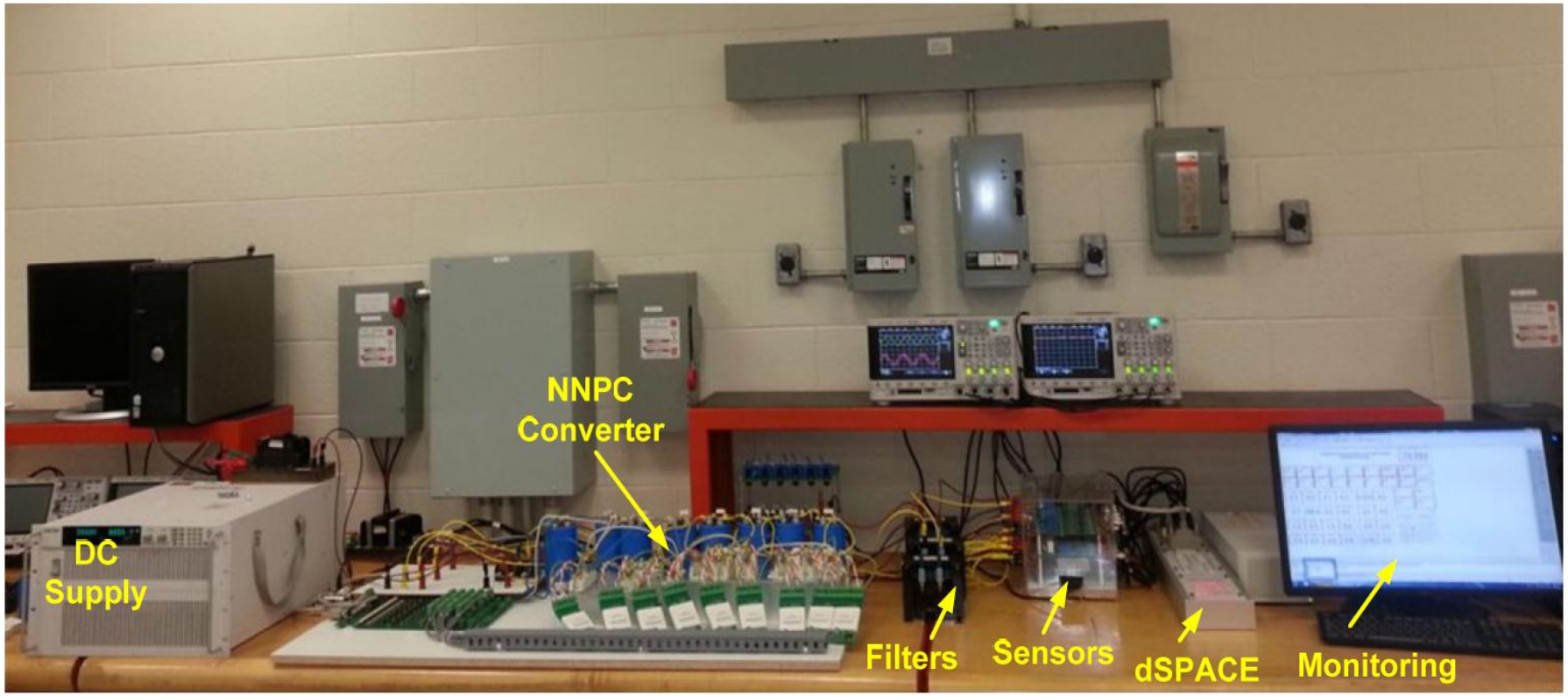
NPC converter

NNPC = NPC + FC converters

1) US Patent Application Serial #14/153,103, filed Jan 13, 2014
2) European Patent Application #14167709.6, filed July 2, 2014

Power Converter Research

Four-level Nested Neutral Point Clamped (NNPC) Inverter

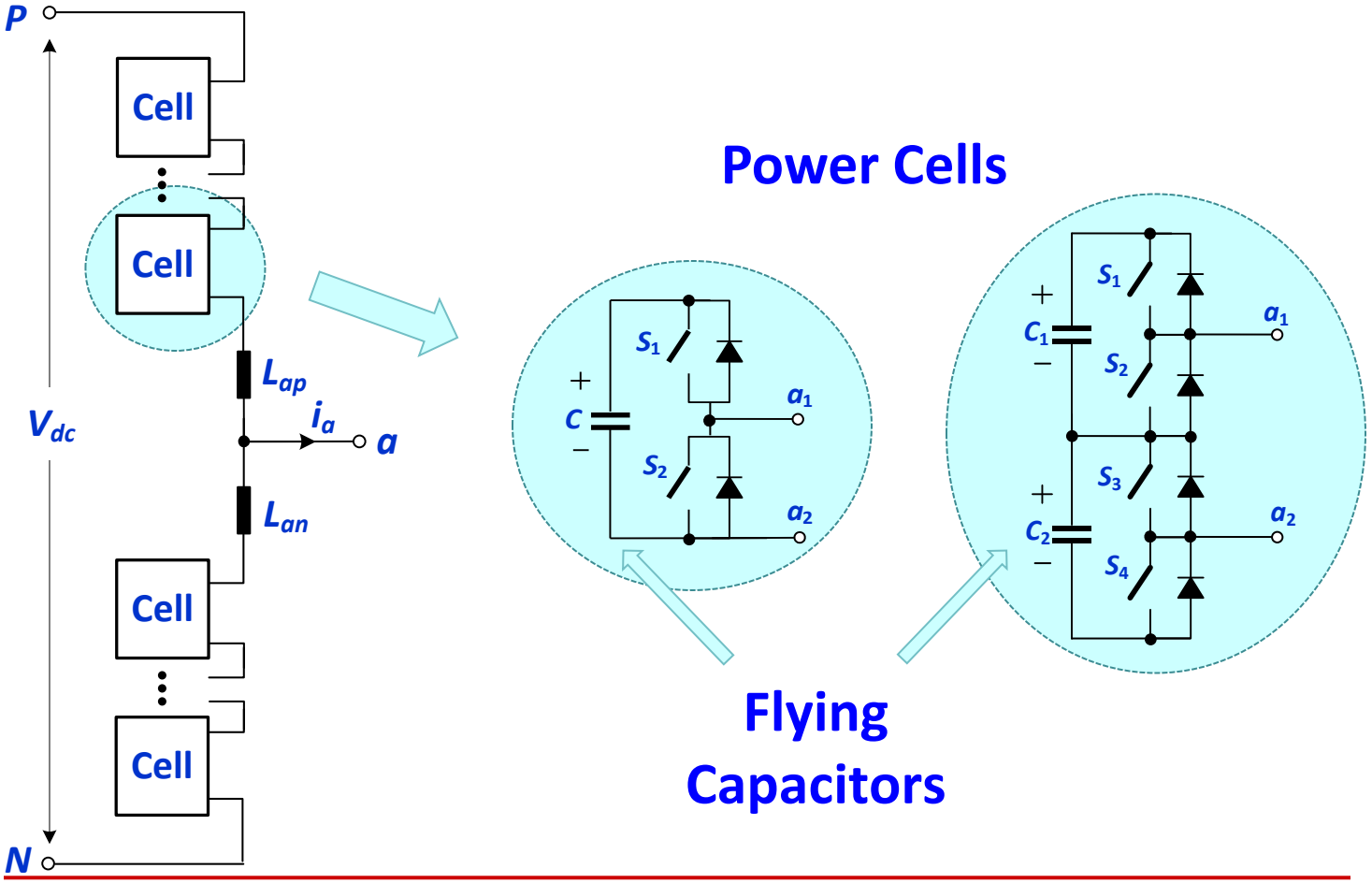


Experimental Setup

3) European Patent Application Serial #15150396.8, filed January 8, 2015

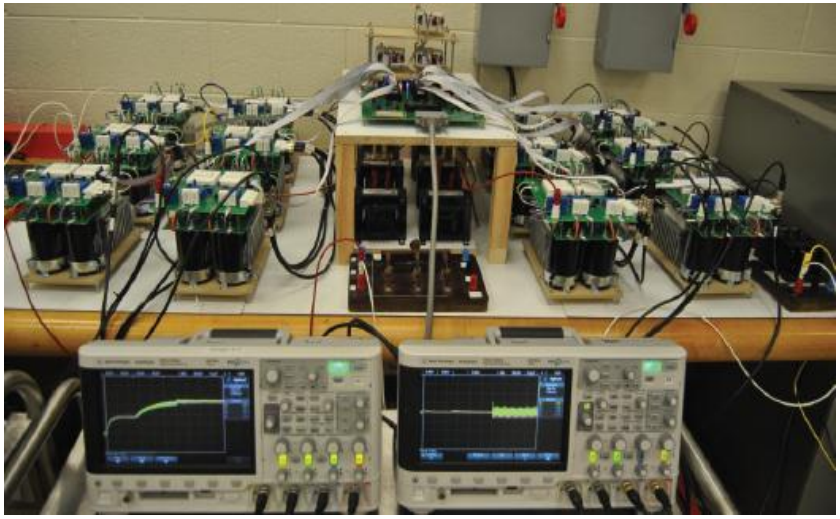
Power Converter Research

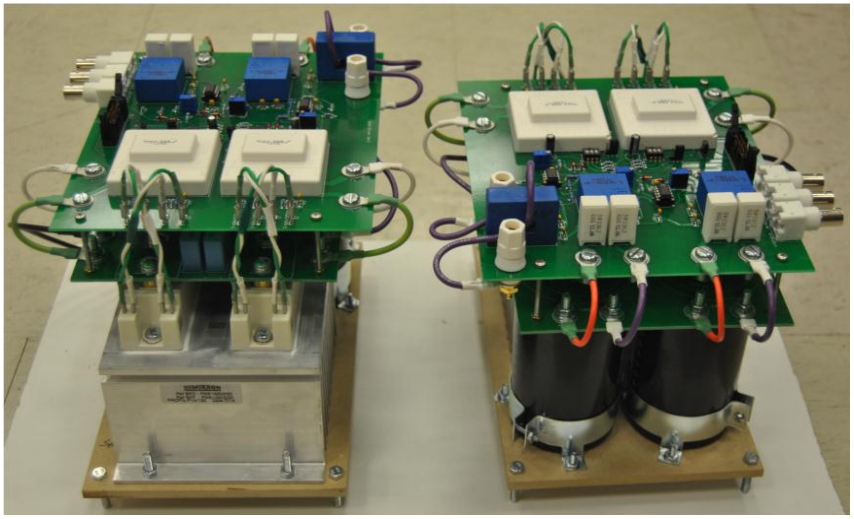
Multilevel Modular Converters (MMC) for MV Drives



Power Converter Research

Multilevel Modular Converters (MMC) for MV Drives





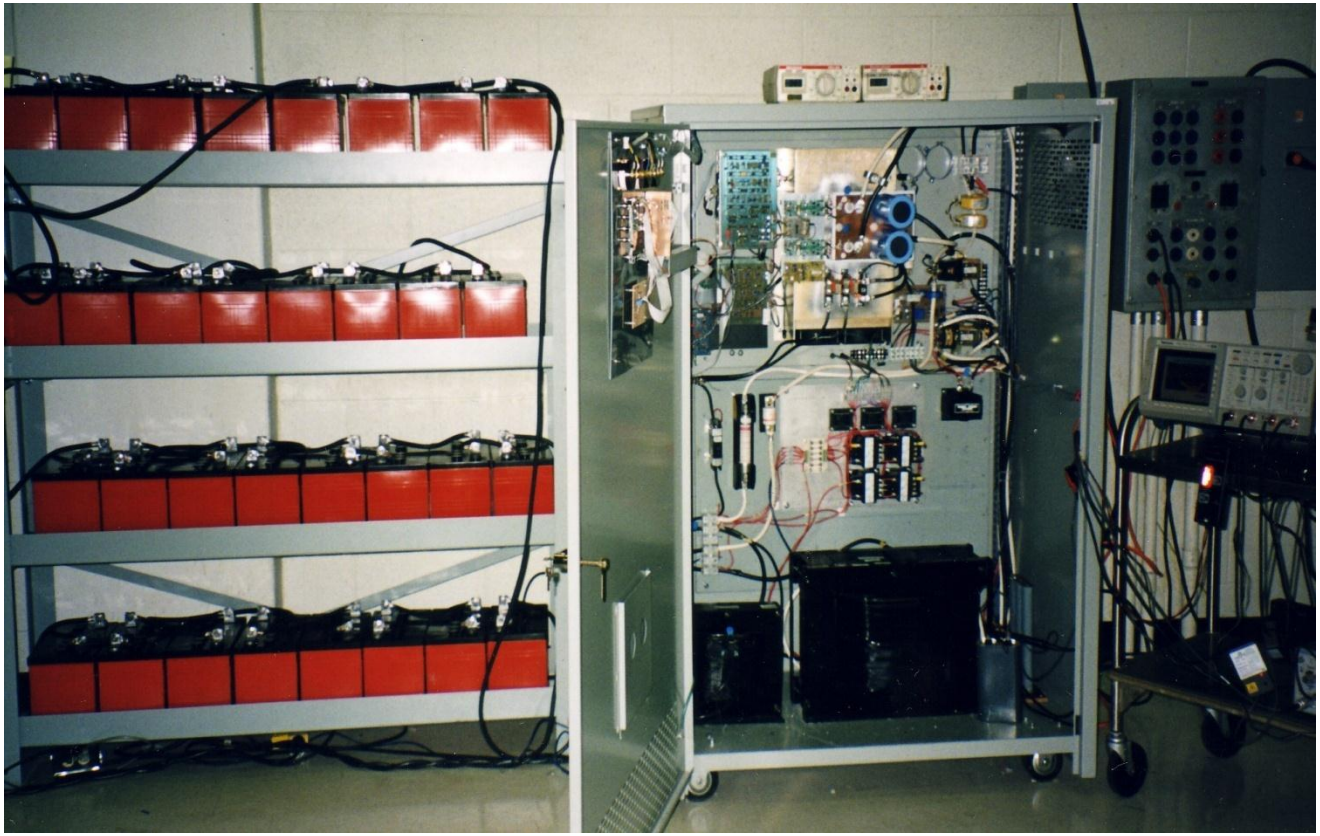
Research topics

1) Simple cost-effective precharging circuits for flying capacitors
2) Low and zero speed operation without common-mode voltage injection for transformerless MV drives

1) US Patent Application, 14/597,261, filed Jan 15, 2015
2) US patent filing currently under preparation

Uninterrupted Power Supply (UPS)

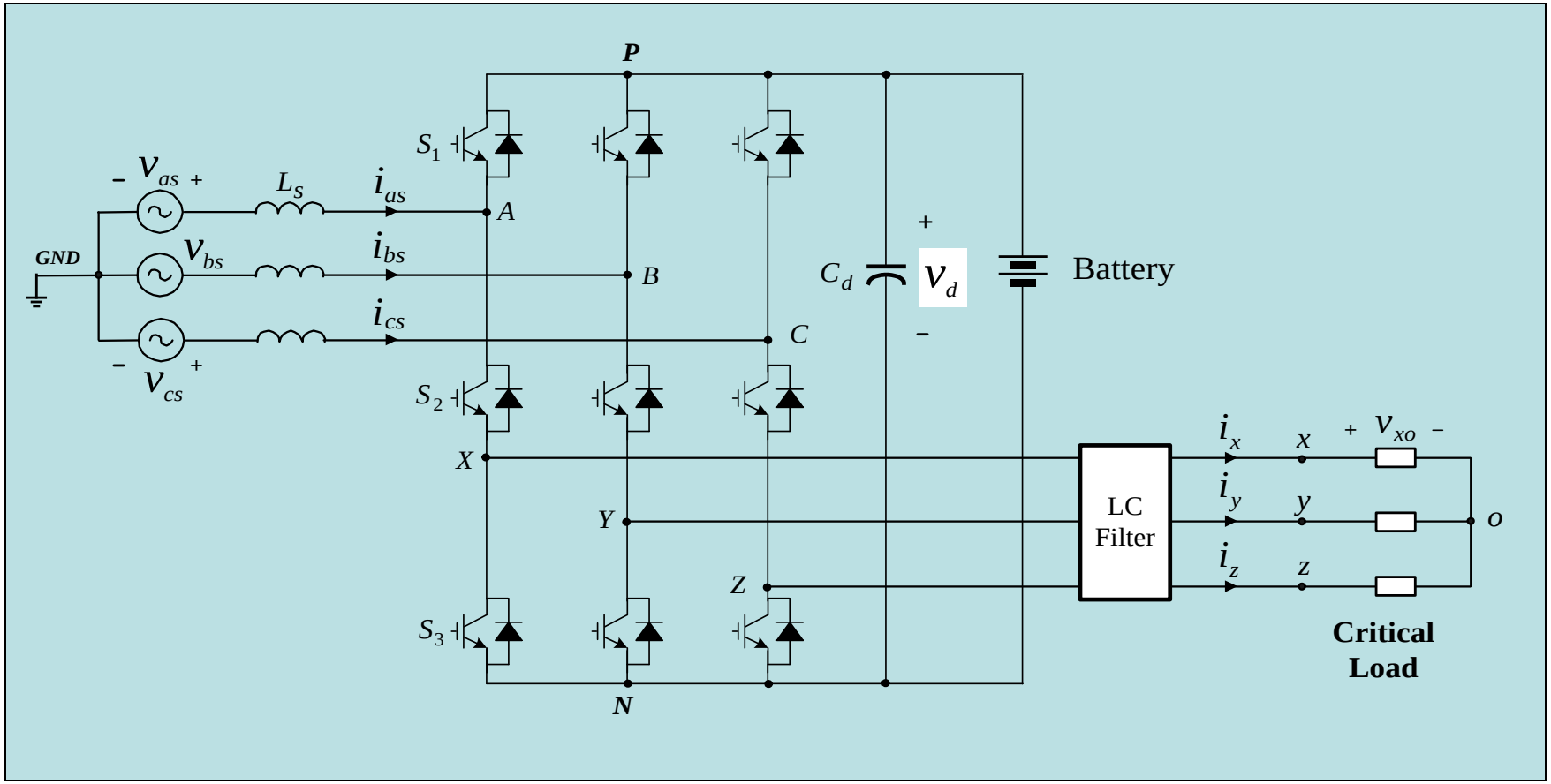
Off-line UPS for Emergency Lighting Applications



20KW Final Prototype – For Lumacell Inc

Uninterrupted Power Supply (UPS)

On-line UPS with a Novel Nine-Switch Converter



US Patent #7,310,254 B2, Dec. 18, 2007

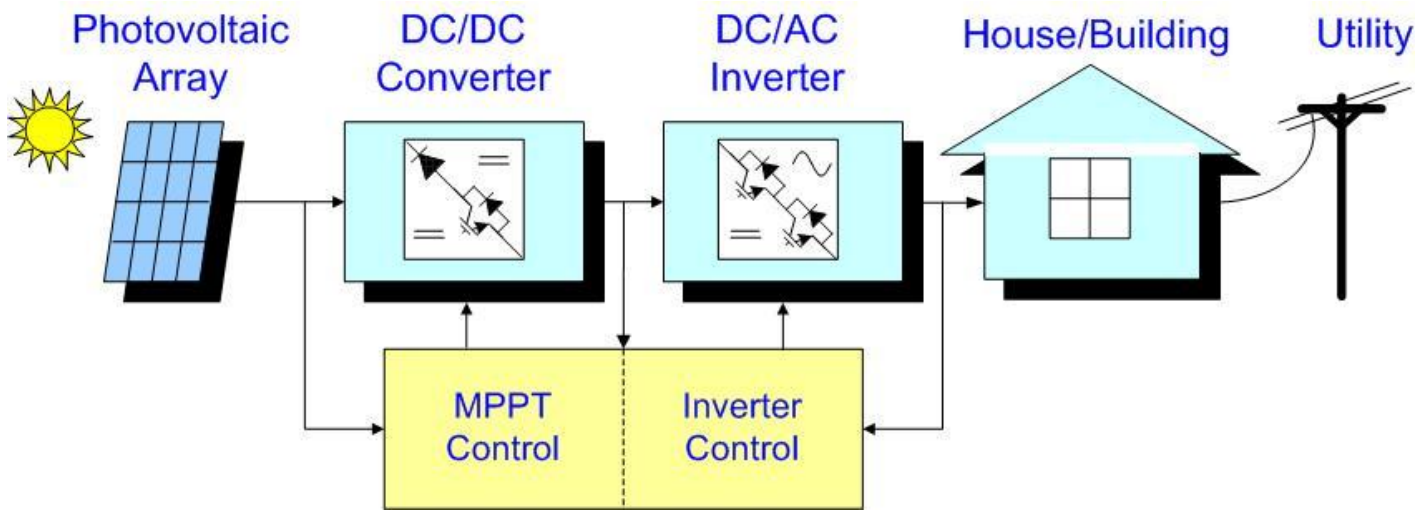
Renewable Energy Research

Solar Energy

Photovoltaic (PV) Arrays

Renewable Energy Research

Solar Building Research Network Program



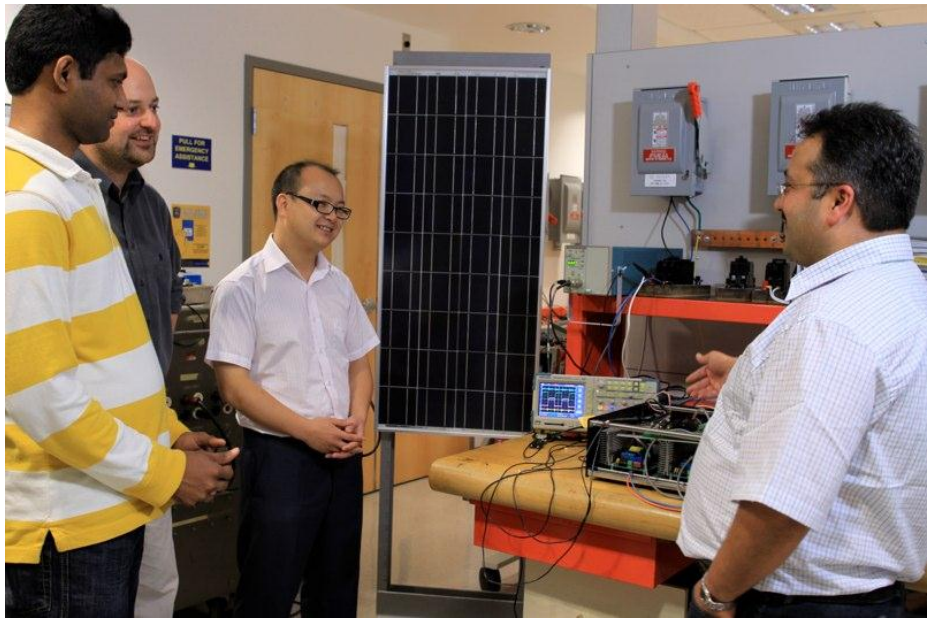
Renewable Energy Research

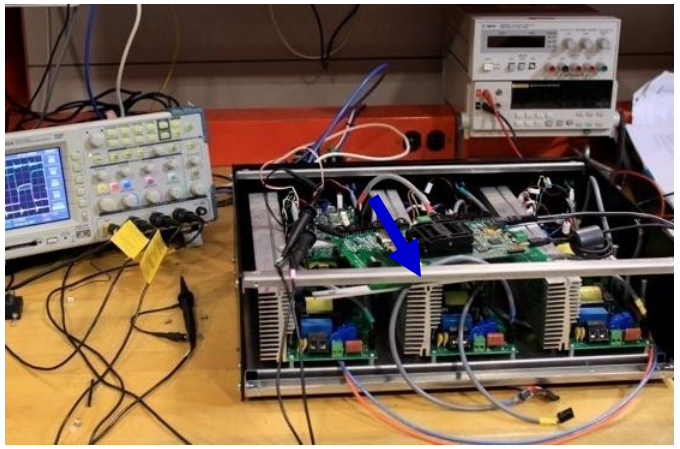
1kW PV Converter System

Laboratory Prototype – 1kW PV converter with MPPT control

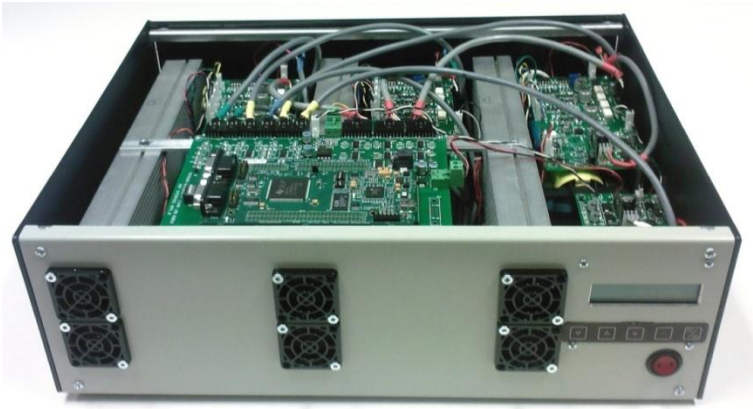
Renewable Energy Research

5.4kW Multichannel Interleaved PV Converter System



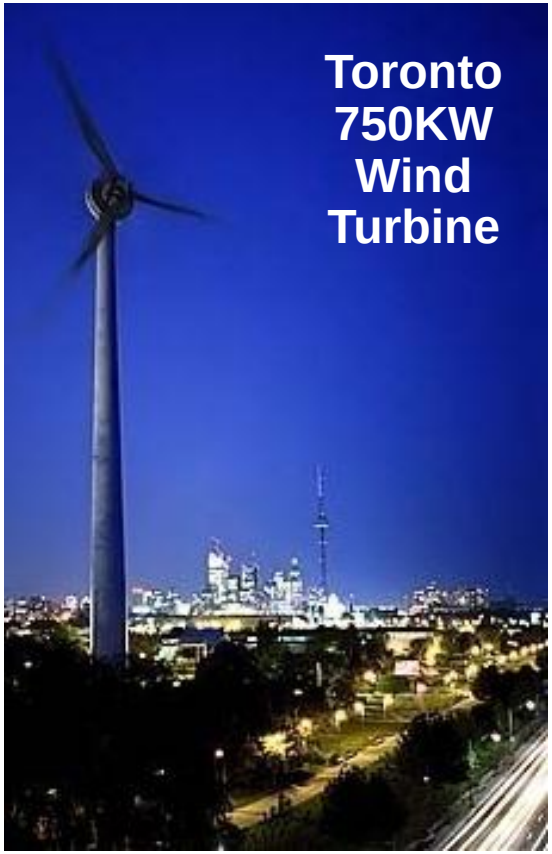


1.7kW x 3 channel prototype →

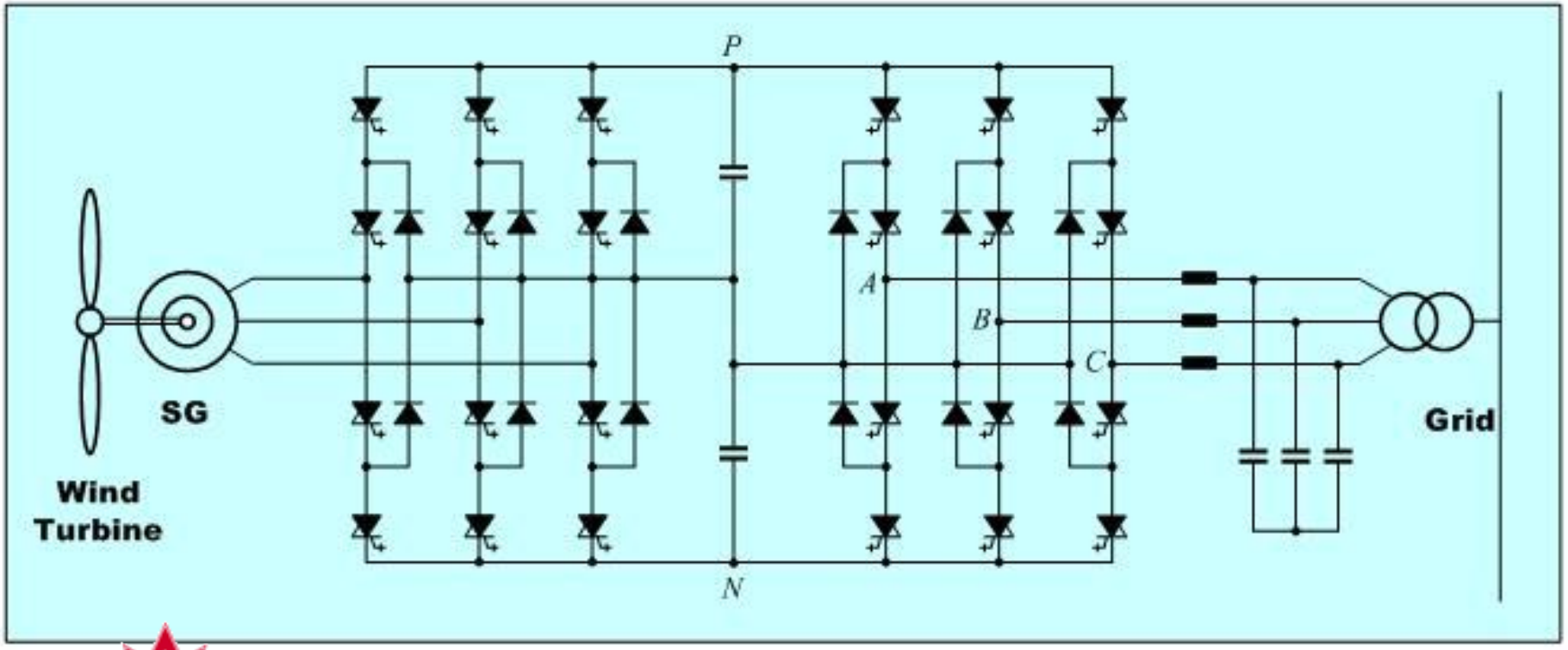


Renewable Energy Research

Wind Energy



Wind Energy Research

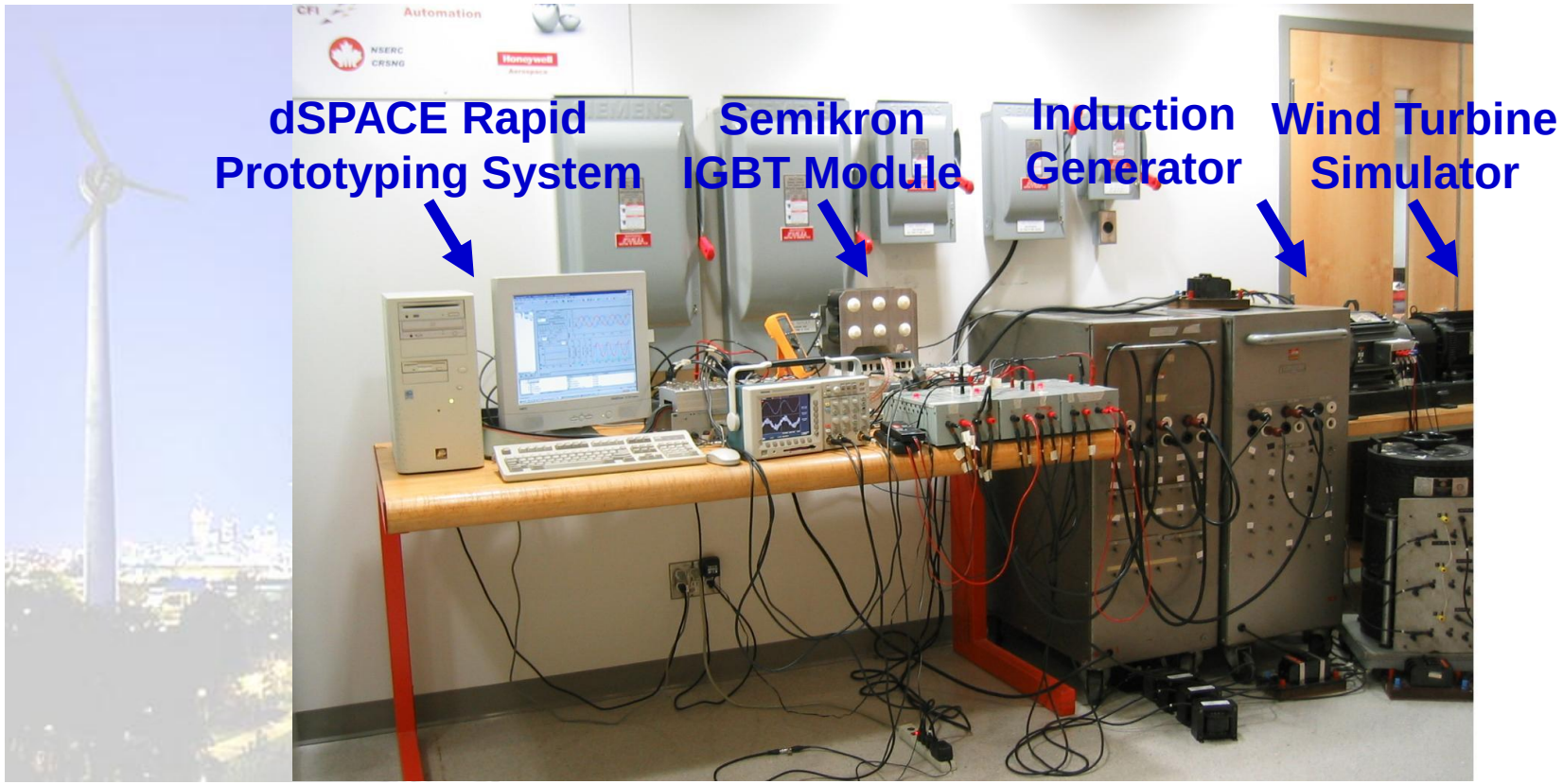


WESNet

NSERC WESNet Project 3.1

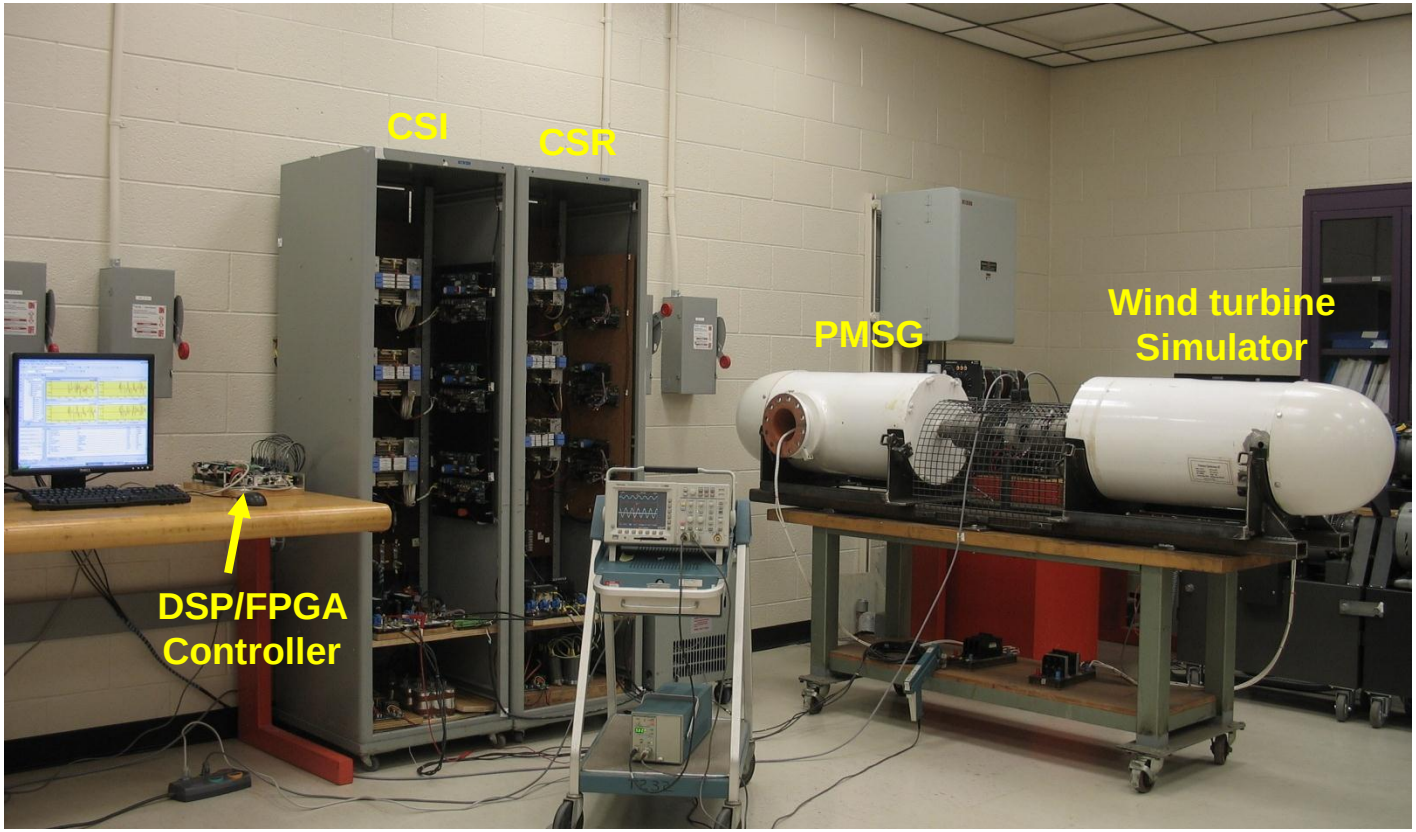
Wind Energy Research

Induction Generator Based Wind Energy System



Wind Energy Research

PM Synchronous Generator CSI Wind System



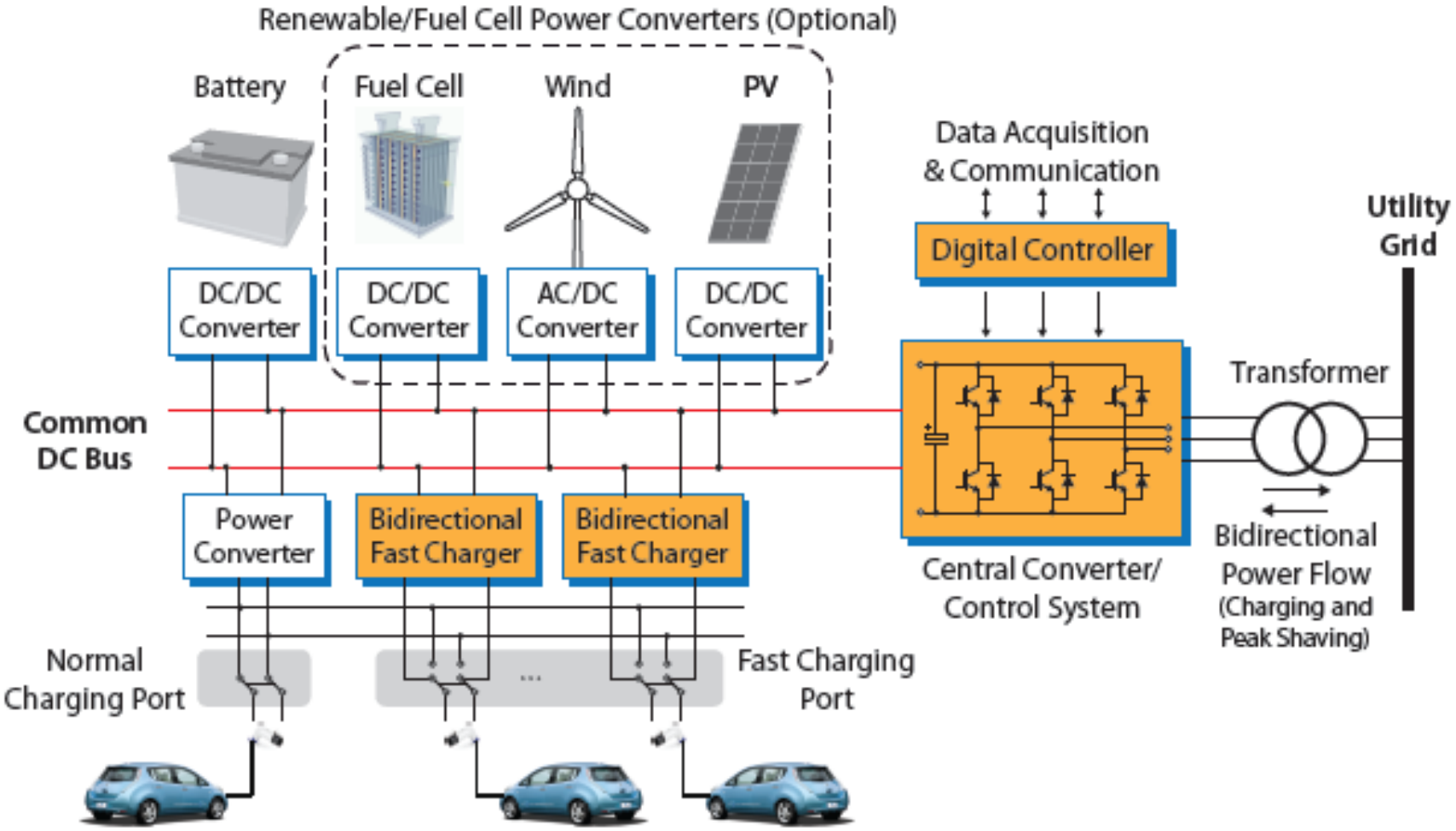
Electric Vehicle Charging Station

Research areas:

- **Charging station architecture**
- **Slow and fast chargers**
- **Renewable energy integration**
- **Optimal energy management**

Electric Vehicle Charging Station

Proposed architecture with common DC bus



International Collaborations

- **Universidad de Sevilla, Spain:**
  Drs. Leopoldo Franquelo, Jose Ignacio Leon
- **Universidad Técnica Federico Santa María, Chile:**
  Drs. José Rodríguez, Samir Kouro
- **Hefei University of Technology, China:**
  Drs. Meiqing Mao, Xing Zhang
- **University of Tehran, Iran**
  Dr. Hassan Monsef
- **Nanyang Technological University, Singapore:**
  Drs. King Jet, Samini Choi

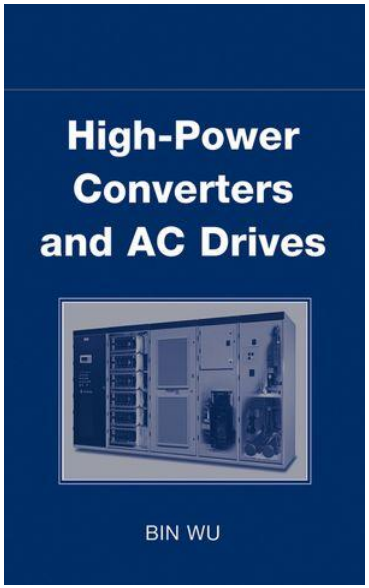
International Collaborations

- **Technical University of Catalonia, Spain:**
  Dr. Salvador Alepuz
- **Aalborg University, Denmark:** Dr. Zhe Chen
- **University of Hertfordshire, UK:**
  Dr. Reza Sotudeh
- **Chungbuk National University, Korea:**
  Dr. Jaeho Choi
- **Universidad Nacional de Asunción, Paraguay:**
  Dr. Raúl Gregor Recalde
- **Tsinghua University, China:**
  Drs. Yongdong Li, Zhengming Zhao

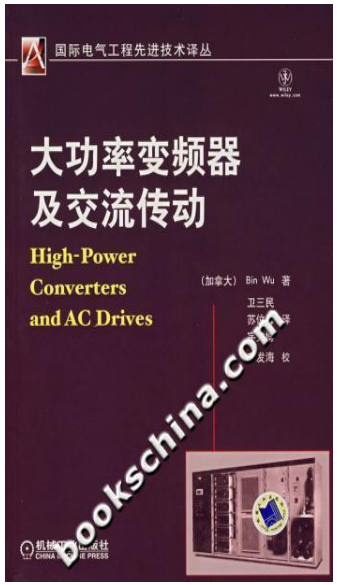
International Collaborations

- **Rajamangala University of Technology, Thailand:**
  Dr. Napat Watjanatepin
- **Wroclaw University of Technology, Poland:**
  Dr. Waldemar Rebizant
- **Universidad de Talca, Chile:**
  Dr. Marco Rivera
  - Very successful and fruitful collaboration since 2010
  - Provided leadership in research directions and projects
  - Published about 30 IEEE transactions and conference papers jointly

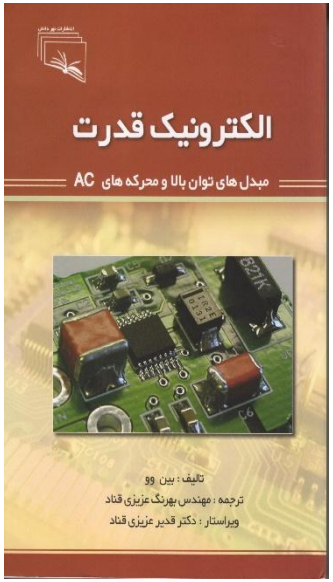
Books



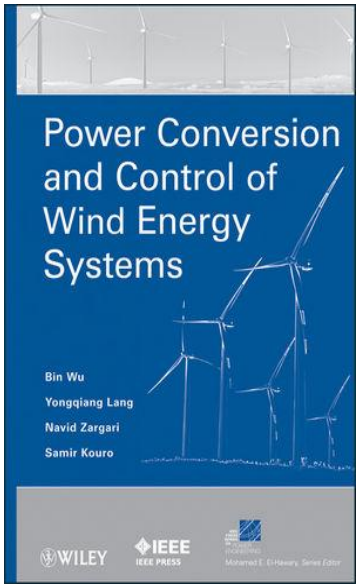
B. Wu
352 pages, 2006
Wiley-IEEE Press



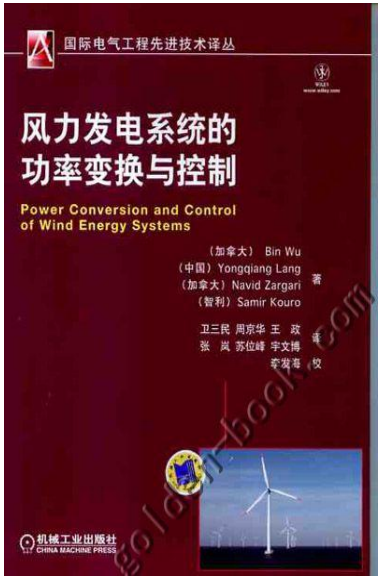
Chinese
Translation



Persian
Translation



B.Wu, Y.Lang
N.Zargari, S.Kouro
480 pages, 2011
Wiley-IEEE Press



Chinese
Translation

Patents

US/European Patents: 30 (issued/pending)

(12) **United States Patent**
Wu et al.

(10) **Patent No.: US 6,617,814 B1**
(45) **Date of Patent: Sep. 9, 2003**

(54) **INTEGRATED DC LINK CHOKE AND METHOD FOR SUPPRESSING COMMON-MODE VOLTAGE IN A MOTOR DRIVE**

(75) Inventors: **Bin Wu**, Toronto (CA); **Steven C. Rizzo**, Cambridge (CA); **Navid R. Zagari**, Cambridge (CA); **Yuan Xiao**, Kitchener (CA)

(73) Assignee: **Rockwell Automation Technologies, Inc.**, Mayfield Heights, OH (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/832,389**

(22) Filed: **Apr. 11, 2001**

JP 19810163459	19811015	4/1983
JP 19810180011	19811110	5/1983
JP 19810180020	19811110	5/1983
JP 19870096587	19870420	10/1988
RU	706887	12/1979

OTHER PUBLICATIONS

Bin Wu and Frank DeWinter, "Voltage Stress on Induction Motors in Medium Voltage(2300–6900V) PWM GTO CSI Drives", IEEE Transactions on Power Electronics, vol. 12, No. 2, Mar. 1997 pp. 213–220.

E. Cengelci, P. Enjeti, C. Singh, F. Blaabjerg and J. K. Pederson, "New Medium Voltage PWM Inverter Topologies for Adjustable Speed AC Motor Drive System", 1998, 7 pages.

RYERSON UNIVERSITY

Ryerson Campus

Thanks