Future Directions in Wind Power Conversion Electronics

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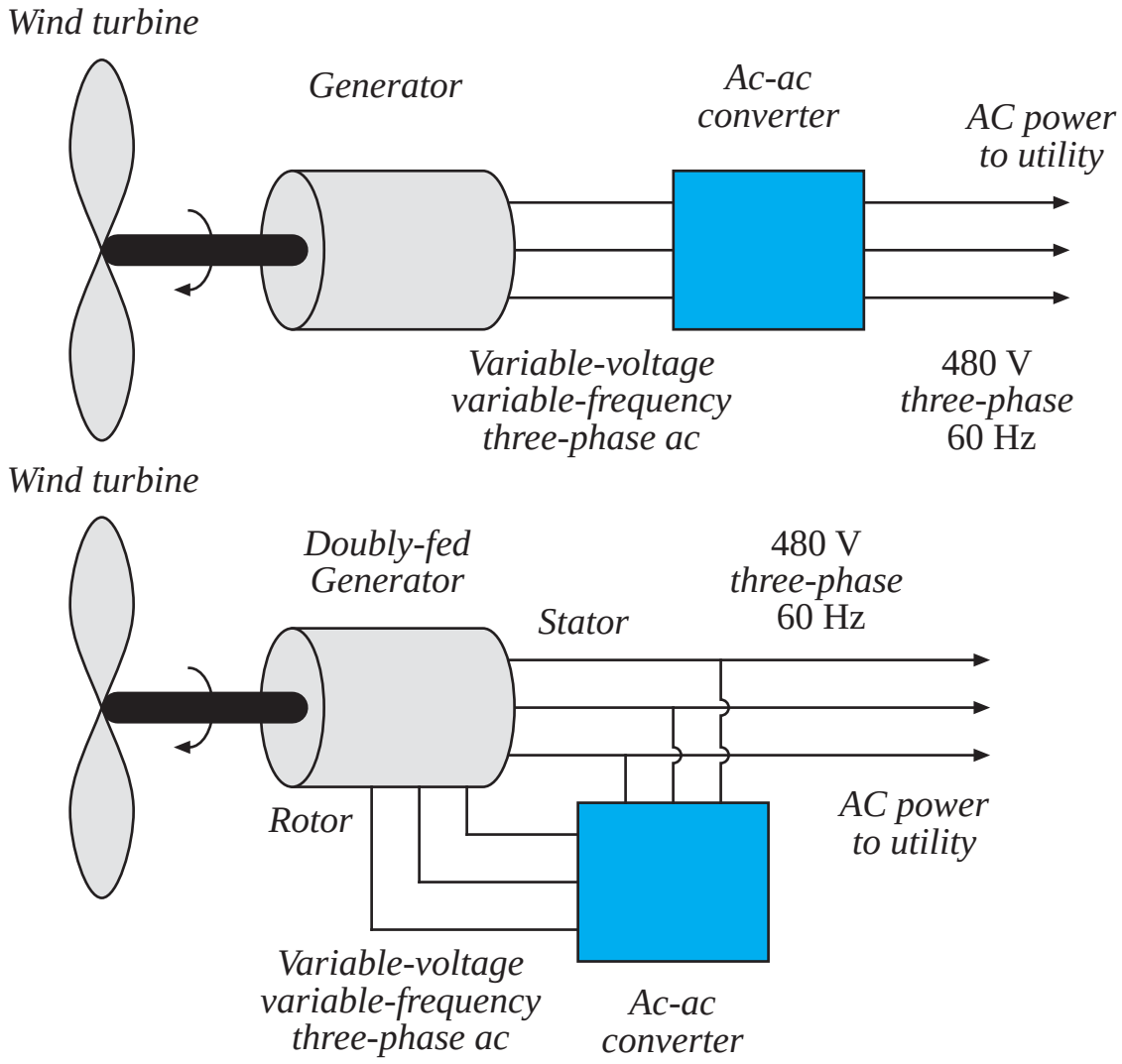
Power Conversion in Variable-Speed Wind Power Systems

Critical issues:

- Maintaining high efficiency over a wide range of voltages and wind speeds
- Reduction of capital cost
- Quality of electrical waveforms injected into utility and generator



About Power Electronics Technology

- Evolution of magnetics and capacitor technology is slow
- Evolution of microprocessor/microcontroller technology is rapid
- Evolution of power semiconductor technology is rapid
  - Low voltage (< 1kV) power semiconductors are inexpensive and exhibit high performance
  - Progress in high voltage controlled devices such as HVIGBT's
- Major gains in packaging technology

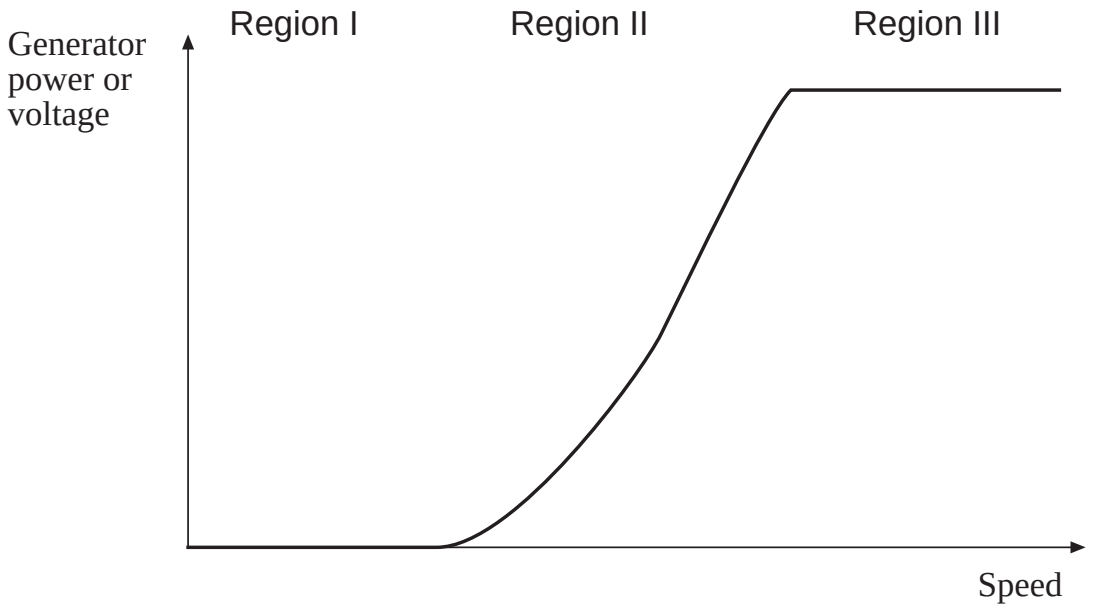
Conclusion— where to focus research thrusts:

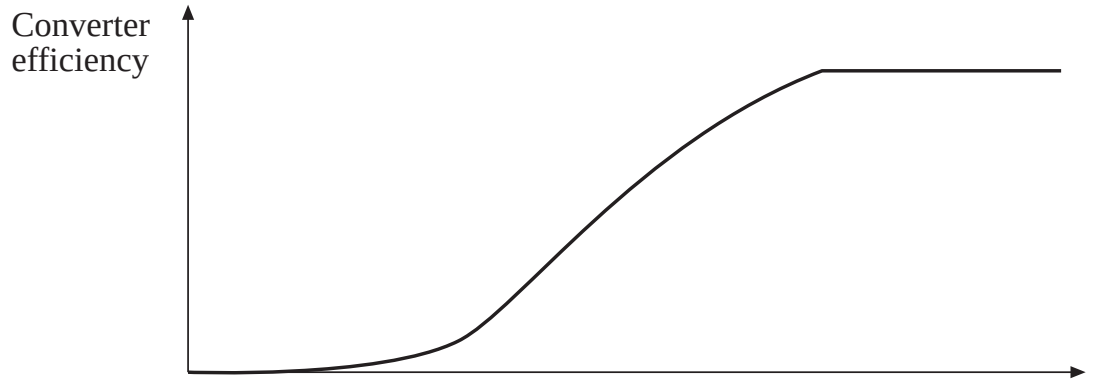
Use of silicon to make significant gains in converter performance, size, and/or cost

- Use silicon to improve performance
- Increased intelligence and complexity; finer structure
- Improve efficiency, reduce capital cost, improve waveform quality, improve reliability

Conventional converters are not optimized for variable-speed wind power applications

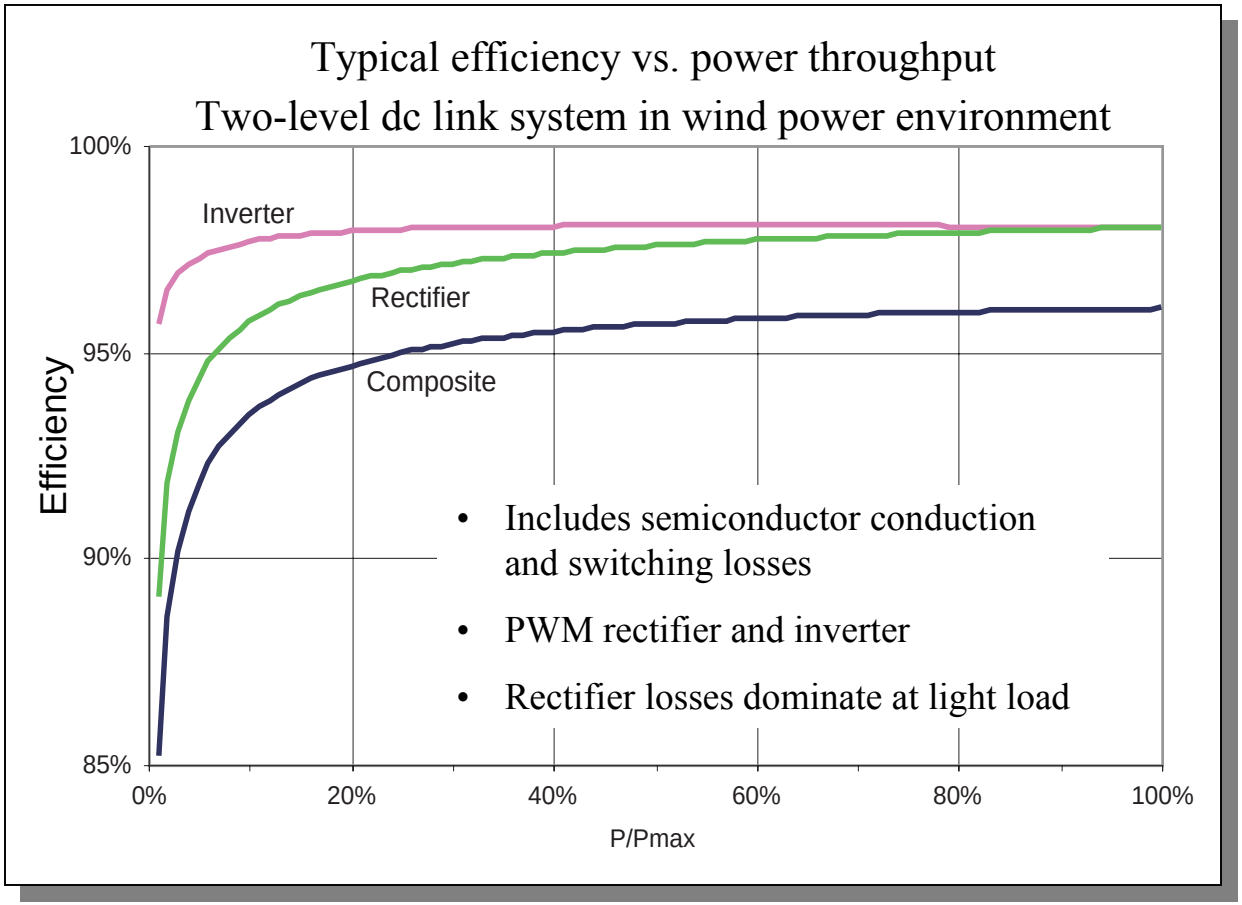
- Poor efficiency in Region II reduces energy captured
- A smaller converter could attain higher efficiency at low wind?





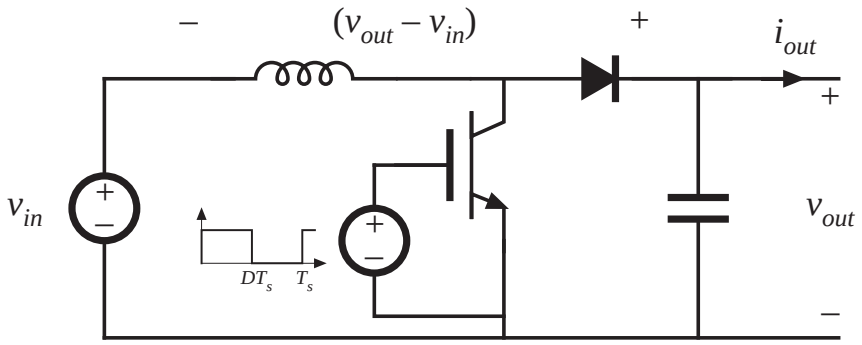
The Problem of Poor Converter Efficiency at Low Wind Speed

- Typically observed in variable-speed wind generator systems
- We showed that the origin of this problem is the reduction of converter efficiency that occurs when the generator voltage is reduced
- Other mechanisms, such as circulating currents in resonant converters or in doubly-fed systems, can also contribute to this phenomenon

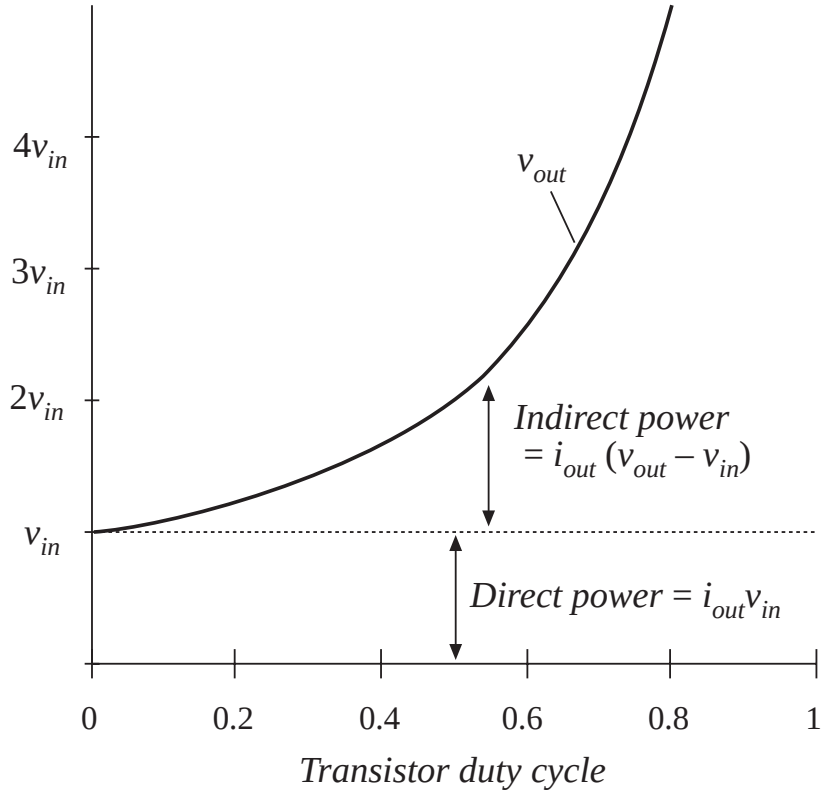


Indirect Power in PWM Boost Rectifier

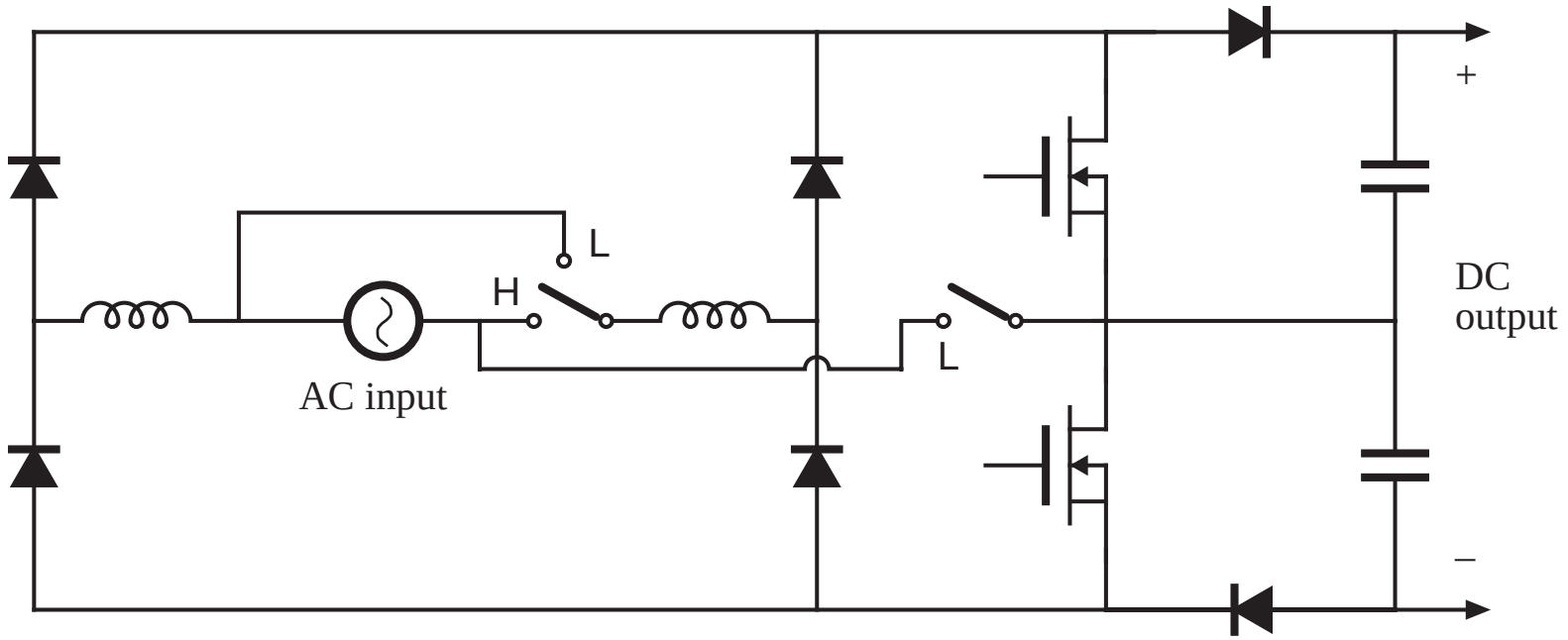
Input of conventional DC link system reduces to boost rectifier:



When the converter is required to process substantial indirect power, efficiency is degraded. This mechanism explains the observed problems in variable-speed wind power applications



Reconfigurable AC-DC converters

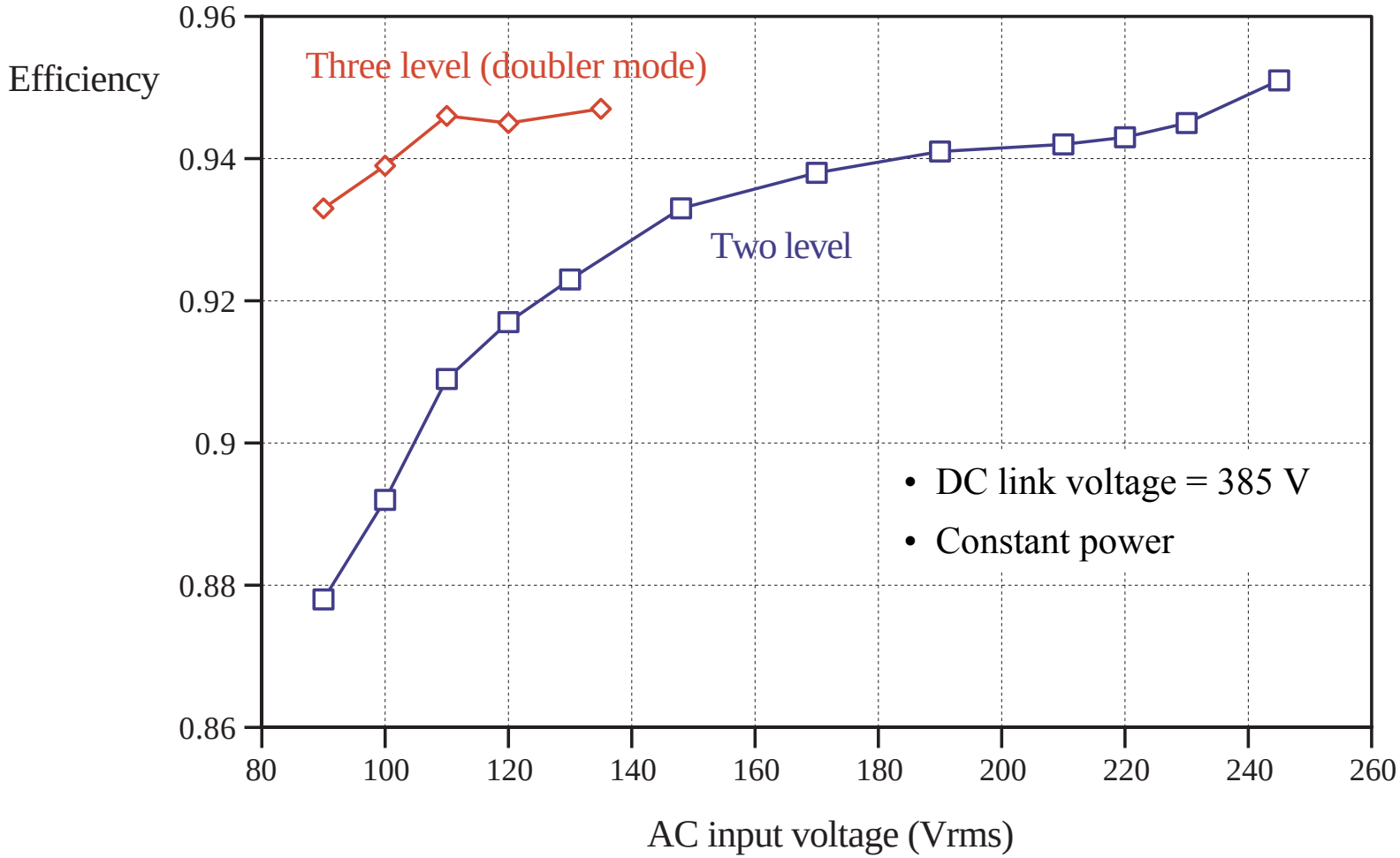


Single-phase PWM boost converter example

Reconfigure converter to improve efficiency at low input voltage, while maintaining high output voltage

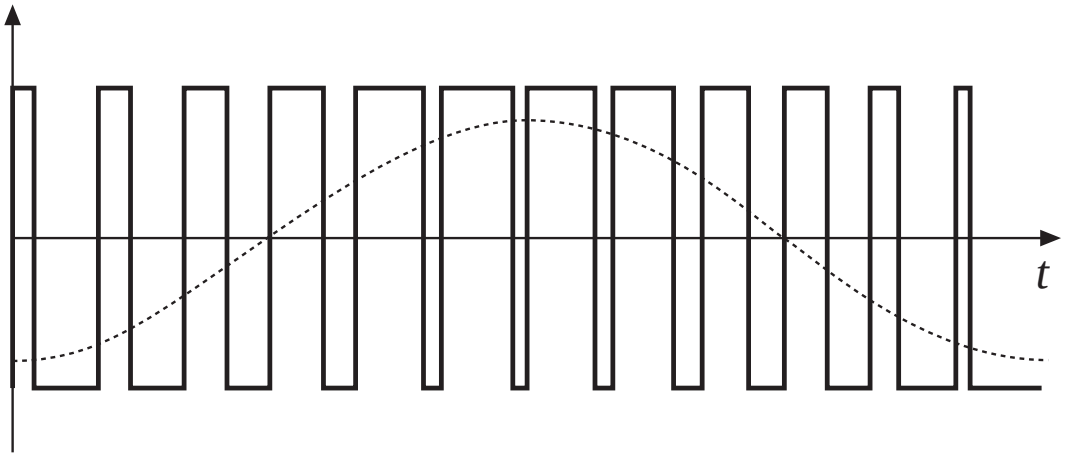
Measured Efficiencies of Single-Phase PWM Boost Rectifiers

Two-Level vs. Reconfigurable Three-Level PWM

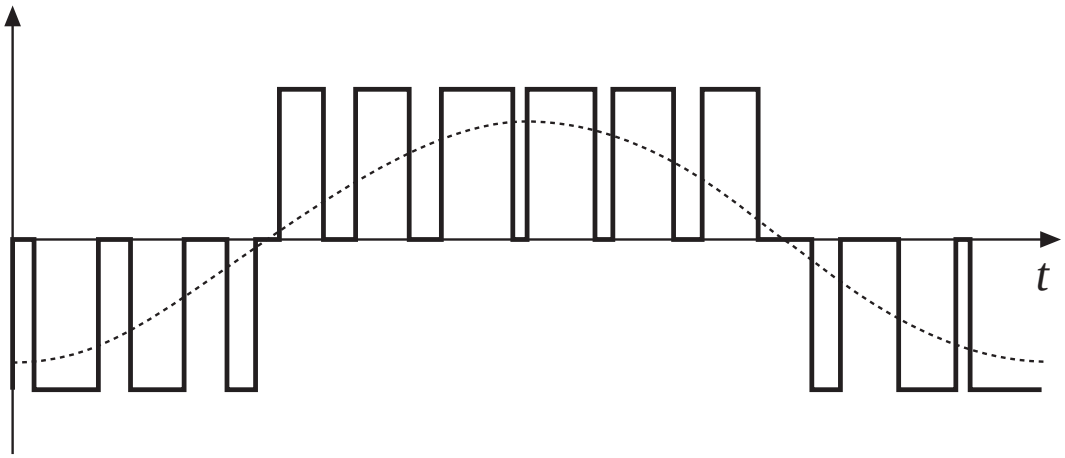


Multi-Level Switching

Two-level switching

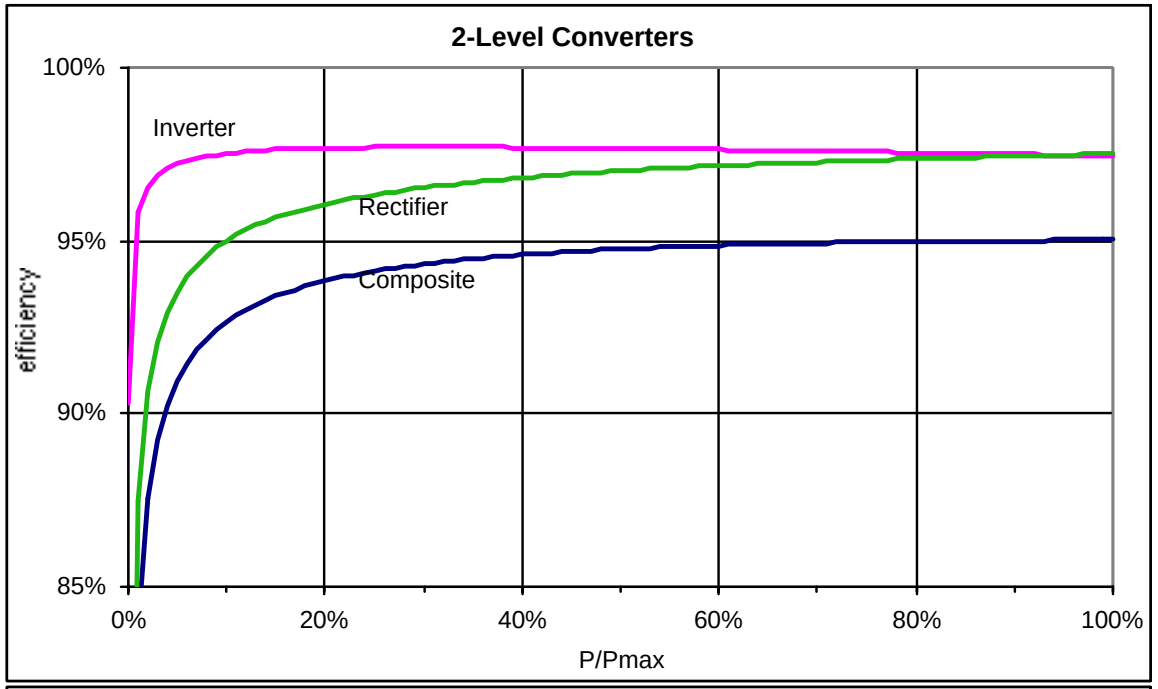


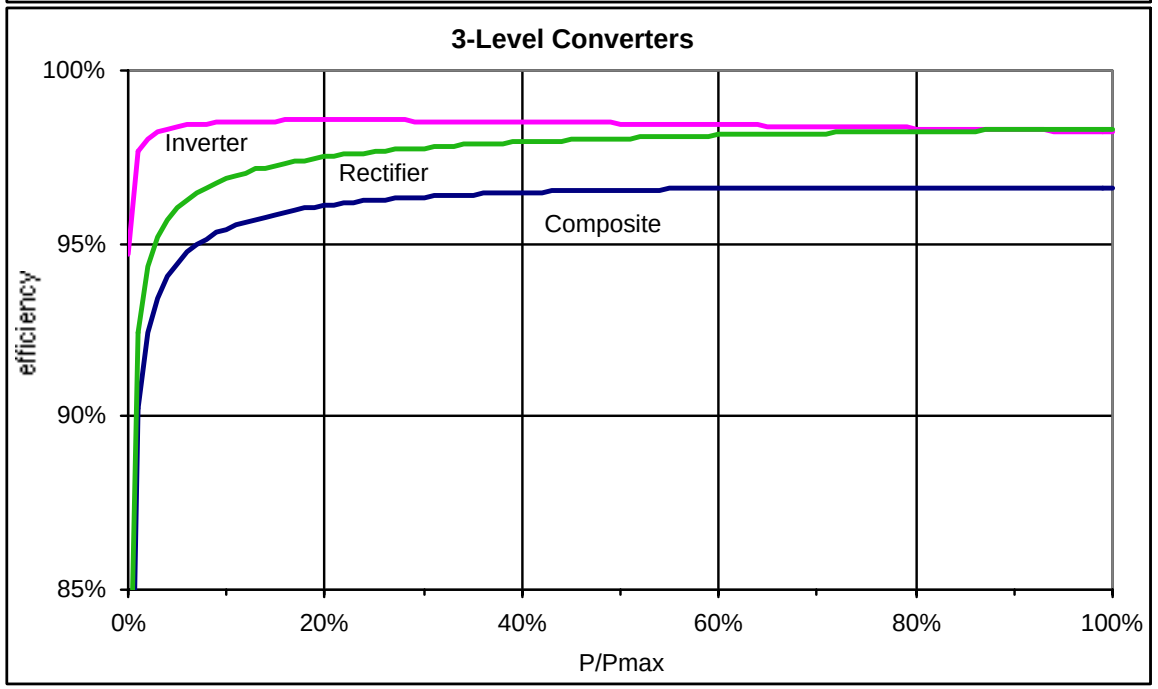
Three-level switching



Improvement of Converter Efficiency via Three-Level Switching

Predicted by experimentally-verified model of semiconductor conduction and switching loss





Discussion

- Switching loss can be modeled by equations of the form

  $$P_{sw} = (\Delta v)\, Q\, f_{sw}$$

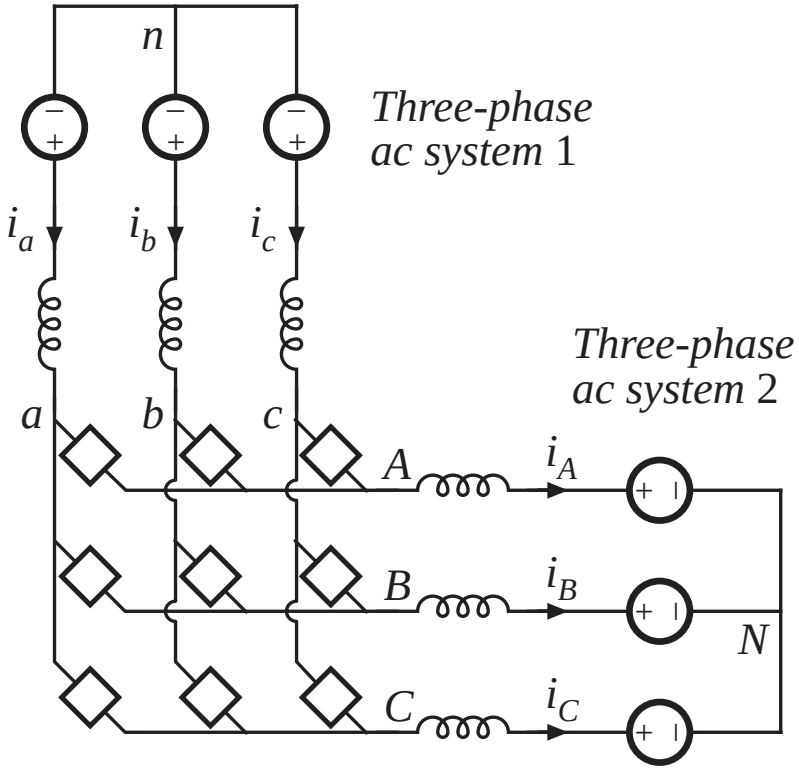
  Multilevel switching reduces the voltage step (Δv), and hence improves efficiency at full load
- Multilevel switching reduces the indirect power at low input voltage
- Efficiency at light load is improved, and the knee of the efficiency curve is shifted to the left
- Resonant conversion and/or soft switching techniques may be unnecessary
- How to realize multilevel switching?

The Case for Small Module Size

- Low-voltage IGBT's have very low cost
  - Less than $1 in high volume for 600V 50A 100KHz IGBT: specific cost of $0.03/KVA
  - Higher voltage IGBT modules typically have specific costs of $0.50/KVA
- Built by machine on printed circuit boards: low manufacturing cost
- High quality utility and machine waveforms
- Lower switching loss and better utilization of silicon
- Improved efficiency at low wind speed

A new family of ac-ac matrix converters capable of multilevel switching

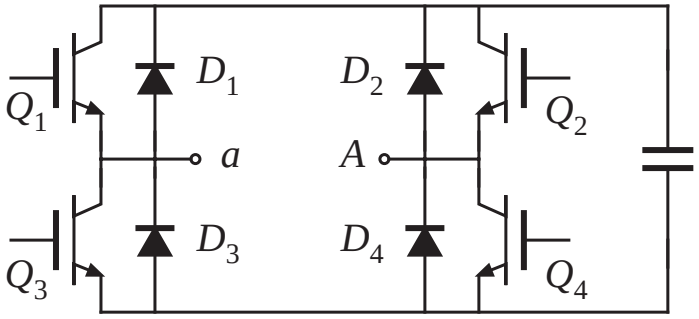
Basic converter



Modular switch cell

Symbol

Realization



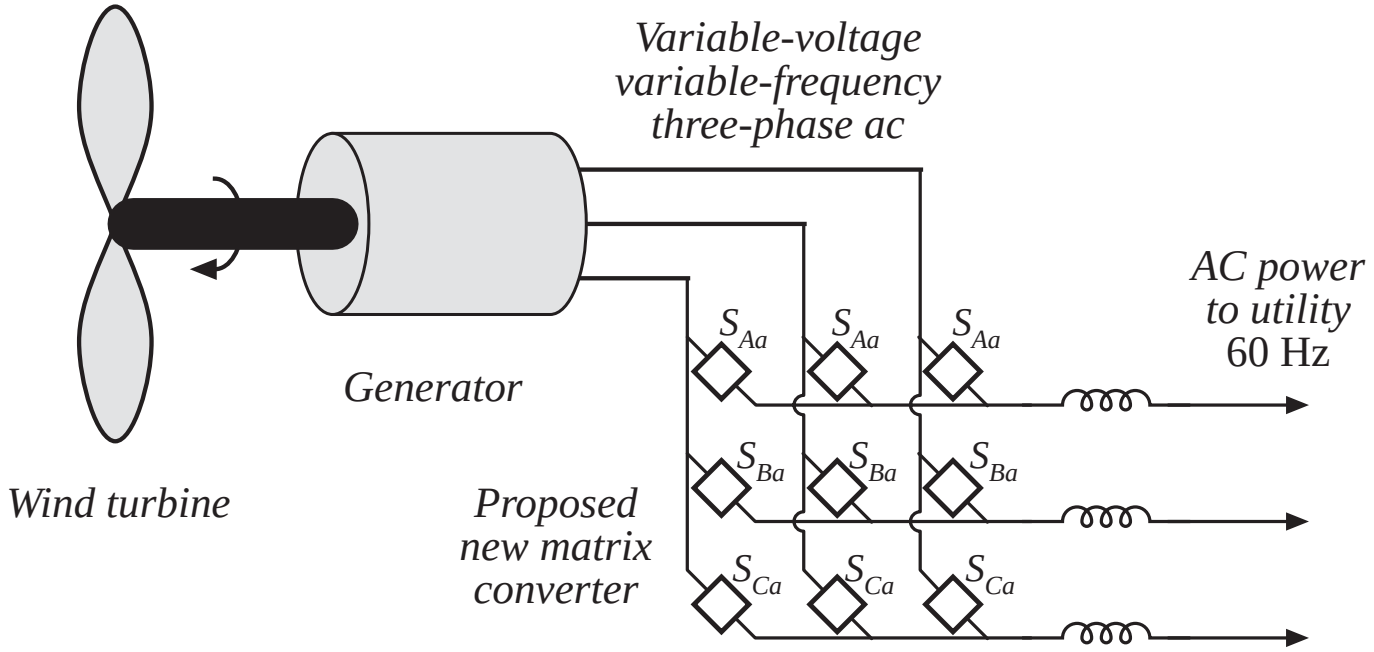
At rated voltage: two-level operation

At low voltage: three-level operation

Advantages of Proposed Converters

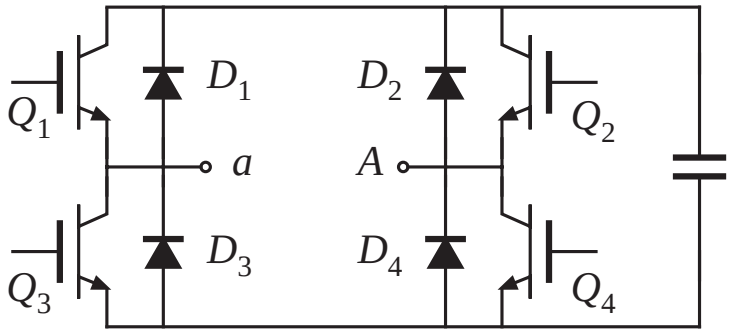
- Multilevel conversion is possible, even in the basic version. This enables improvement of the low-wind efficiency of the converter, without sacrificing performance at rated power
- The converter can both step up and step down the voltage magnitude
- Switch commutation is simple
- Modular construction allows scaling to higher voltage and current levels, using inexpensive low-voltage silicon
- Simple bus bar structures
- High quality waveforms

New Modular Multilevel Matrix Converter in a Wind Power Application

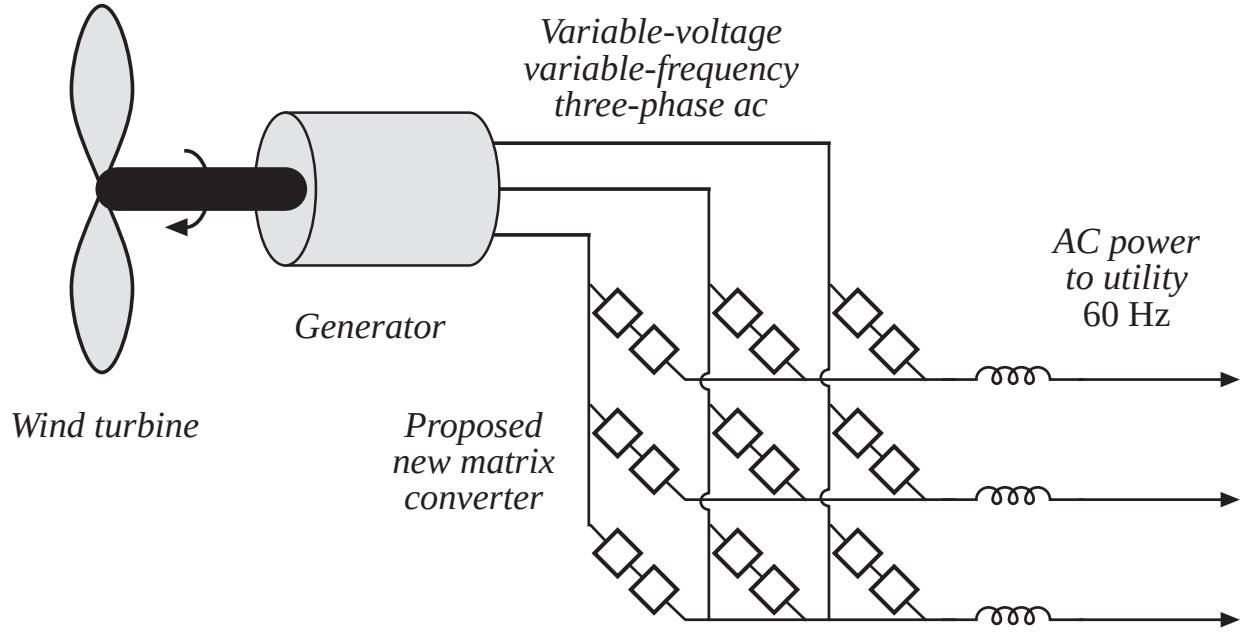


Switch cell:

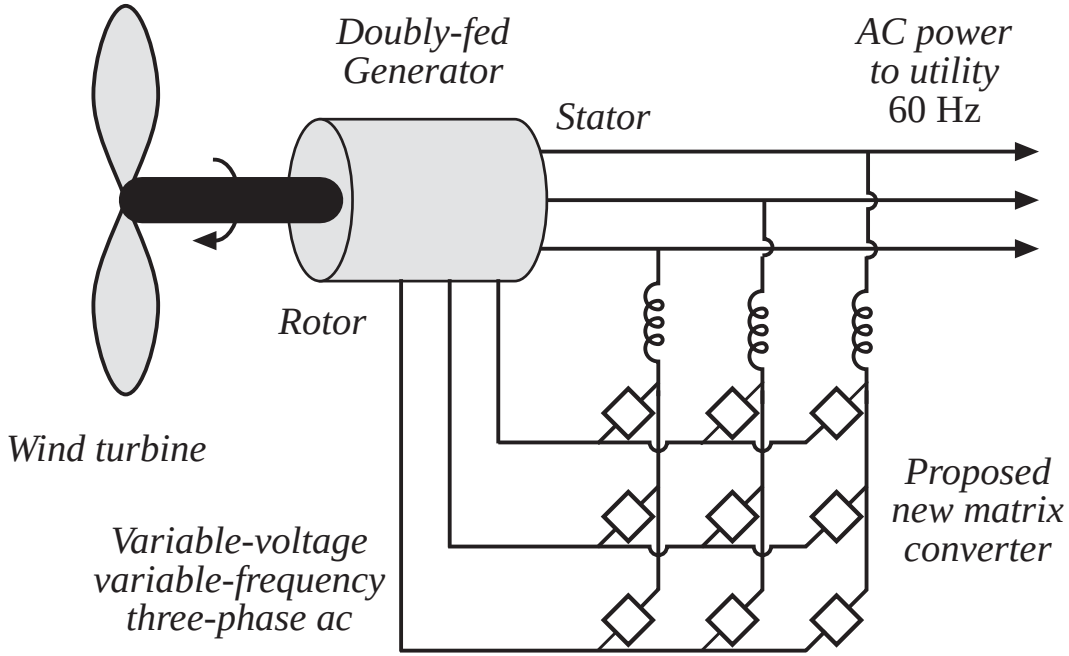
Converter contains a matrix of switch cell modules

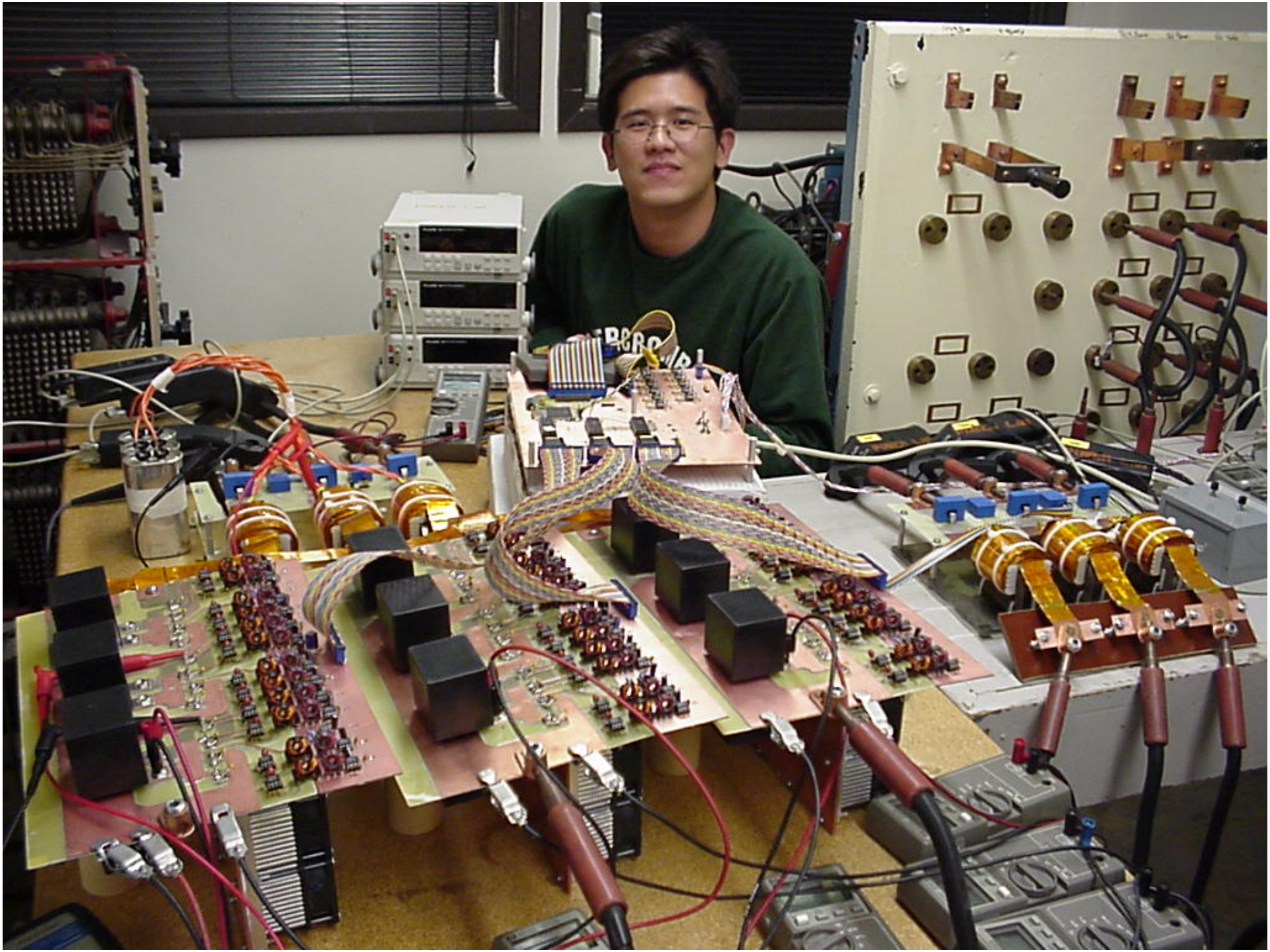


Increasing the number of levels



Doubly fed system

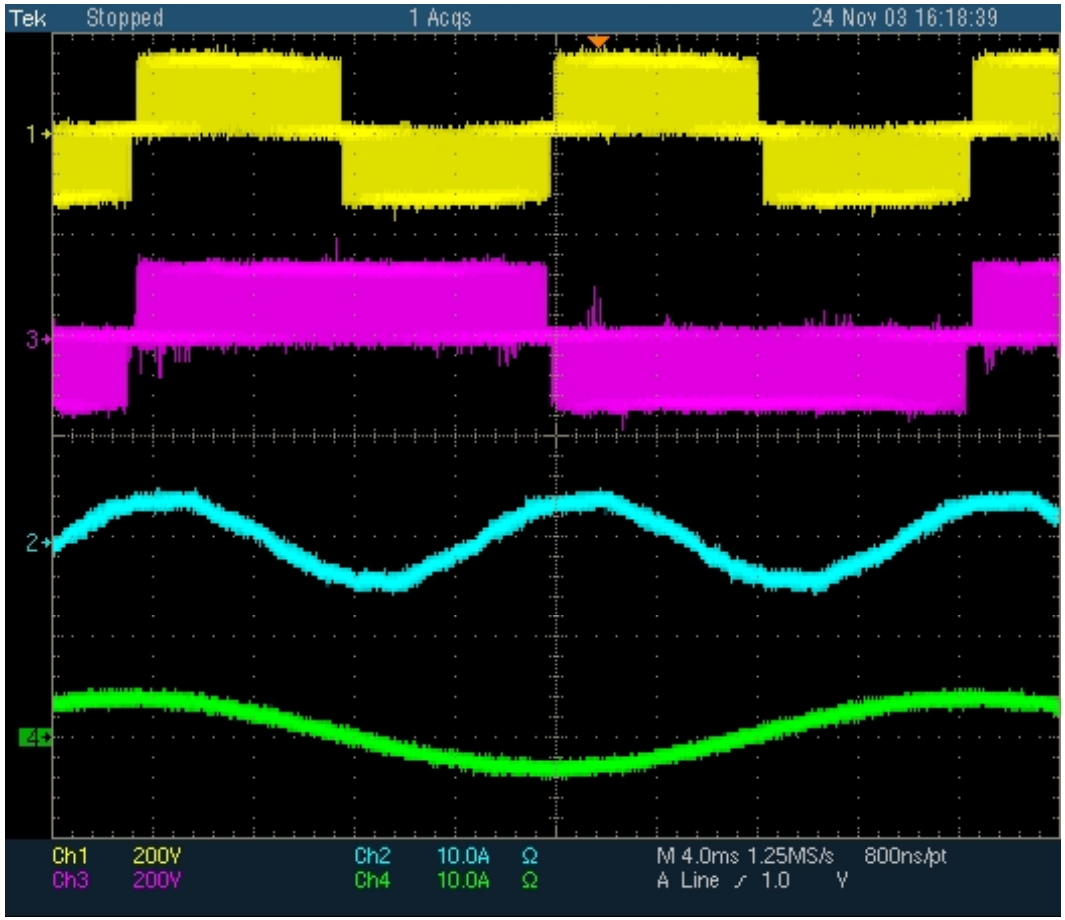




Experimental Data

Utility-side AC voltage and current (60 Hz)

Machine-side AC voltage and current (30 Hz)

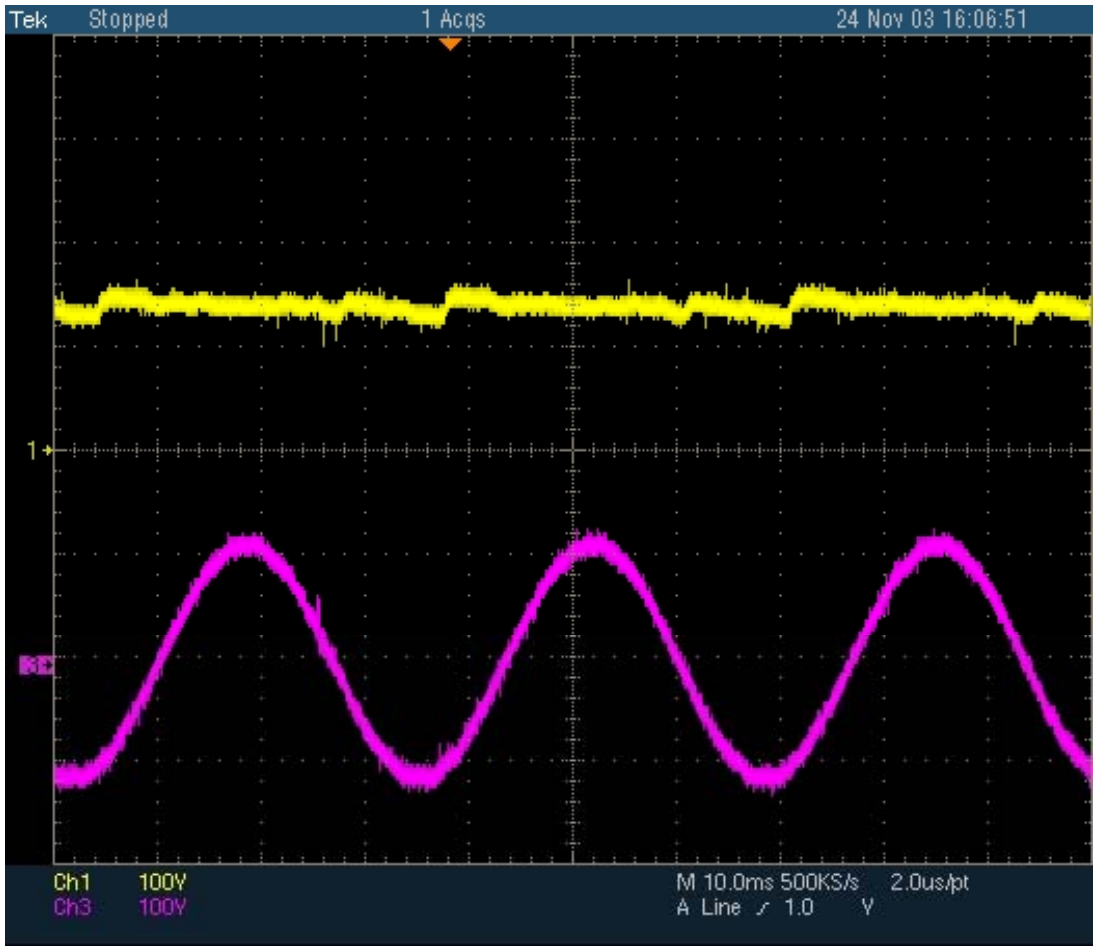


60 Hz to 30 Hz Data

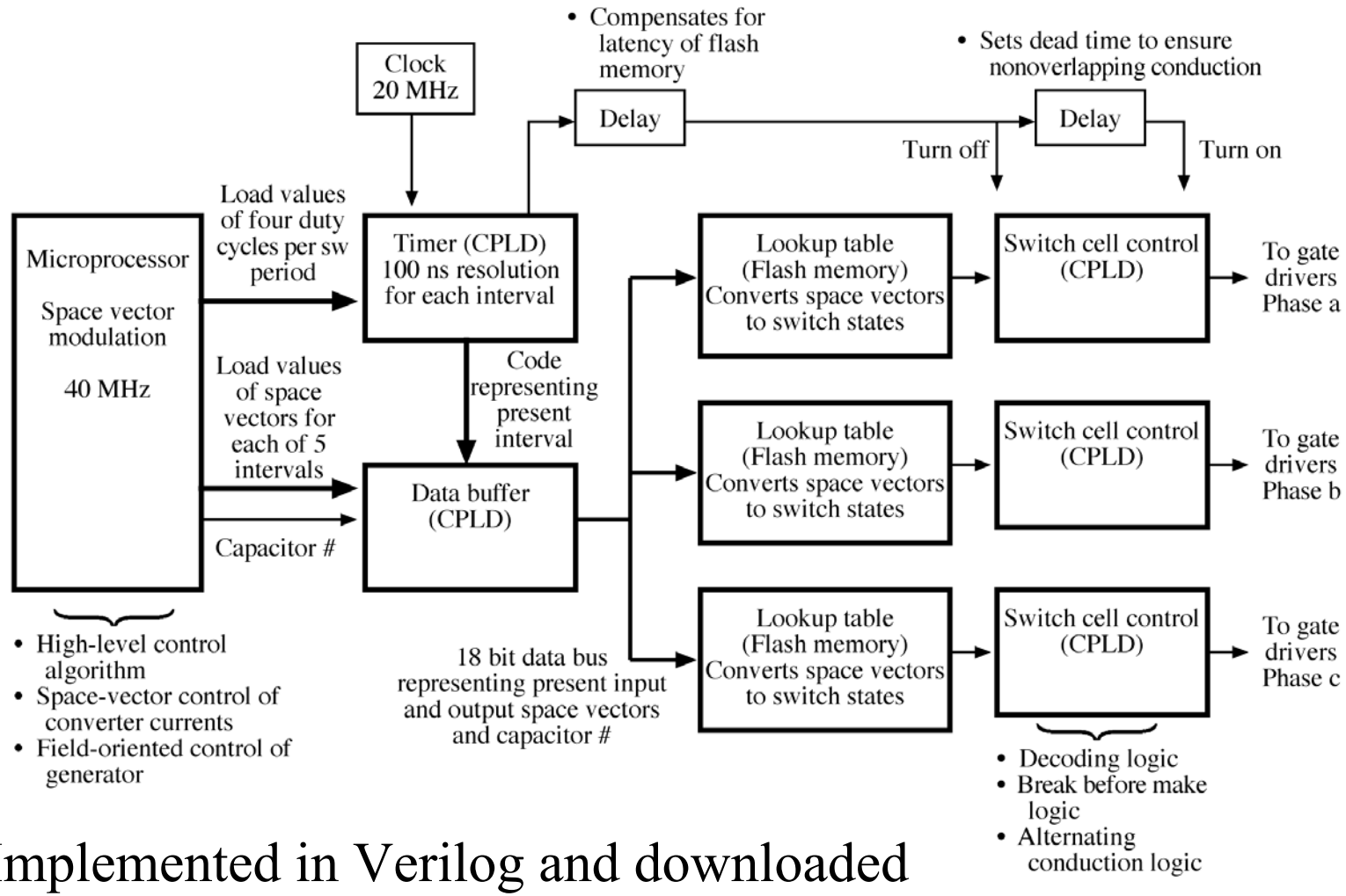
Maintenance of DC capacitor voltage

Upper trace: capacitor voltage of one switch module

Lower trace: 60 Hz current injected into utility



Controller Block Diagram



Implemented in Verilog and downloaded into programmable logic arrays

Issues: Multilevel Modular Converters

- Complexity of control of individual module voltages and currents
  - Centralized control algorithm not feasible as number of modules is increased
  - Requires new decentralized control approaches
- Topologies: interconnection of modules
  - Other modular topologies may allow better control
  - Effect on efficiency

Conclusions

- The variable-speed wind power application requires better ac-ac converters having
  - Lower capital cost
  - Improved efficiency over a wide range of wind speeds and generator voltages
  - Better terminal waveforms
- Electronic power converters having finer structure are becoming feasible:
  - Inexpensive, high performance silicon switches
  - Sophisticated controllers
  - High level of packaging technology

Conclusions
Continued

- Multilevel switching can address the issues of variable speed wind power
  - Reduced switching loss improves efficiency without need for resonant techniques
  - Improved efficiency over wide range of wind speeds
  - Improved waveform quality
- New modular converter topologies
  - Allow scaling to higher powers and higher voltages
  - Could allow use of advances in packaging and low-voltage silicon in megawatt applications
  - Need additional work in decentralized control and modular topologies