Modular Power Electronics for Renewable Distributed Energy

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IEEE Colorado Symposium on Electronics for Sustainable Energy
Marriot Hotel, Boulder, Colorado
May 17, 2008

Outline

- Background
- PE for distributed energy resources (DER)
  - PV, fuel Cell
  - Wind, microturbines, IC engines
  - Battery, flywheel
- Modular power electronics
  - Integrated power electronics modules
  - Topologies for distributed resources
  - Control requirements
- Conclusions

Background

- Increasing importance of distributed resources
- Renewable portfolio standards
- DER consists of
  - Renewable sources (PV, wind)
  - Non-renewable sources (Fuel cell, microturbines, IC engines)
  - Storages (Battery, flywheel)
- Requirements for specific power electronics (PE) for consumer applications and/or grid connection

Barriers for PE

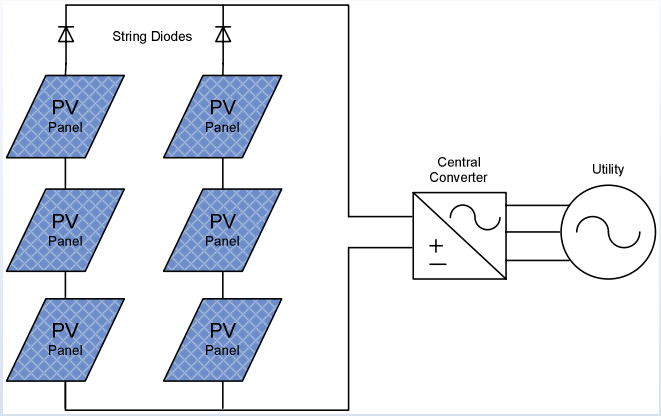
- Addition of PE with distributed resources
  - Increased cost (up to 40% of capital cost)
  - Decreased reliability (typically 5 years life)
- Technology challenges
  - Lack of standardization
  - Lack of modularity and scalability
  - Lack of DER system package
- California Energy Commission (CEC) PIER program

Power Electronics for DER

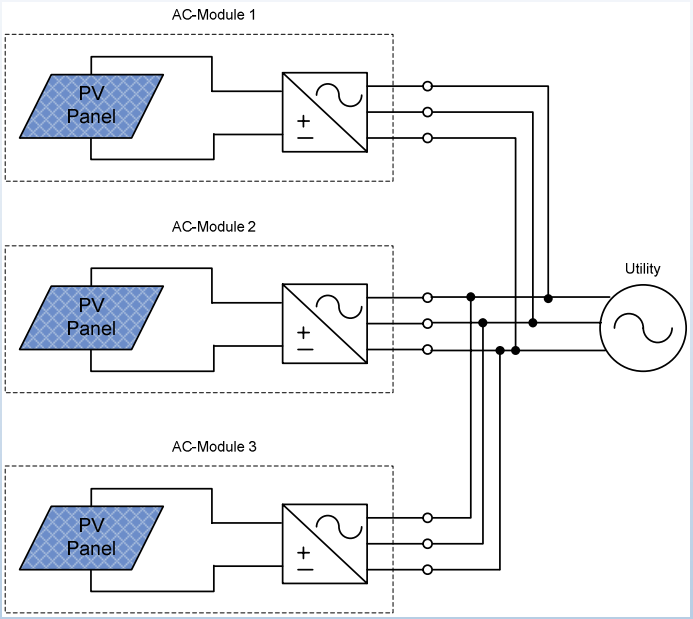
- Depends on specific DER
  - Type of generation (DC or variable AC)
  - Bidirectional (storages)
- Different PE topologies
  - DC – DC (Buck, Boost, Isolated)
  - DC – AC (Inverter)
  - AC – DC (Rectifier)
  - AC – AC (Cycloconverter, Matrix converter)
  - Combinations AC-DC-AC, DC-DC-AC

PV Topologies

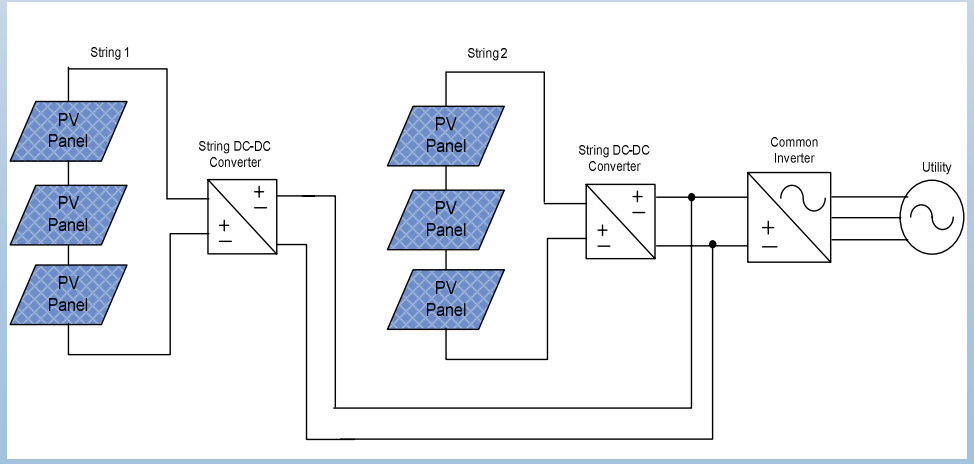
Centralized PV



AC-Module

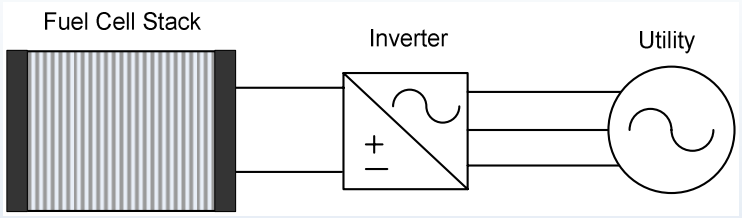


Cascaded DC-DC and DC-AC

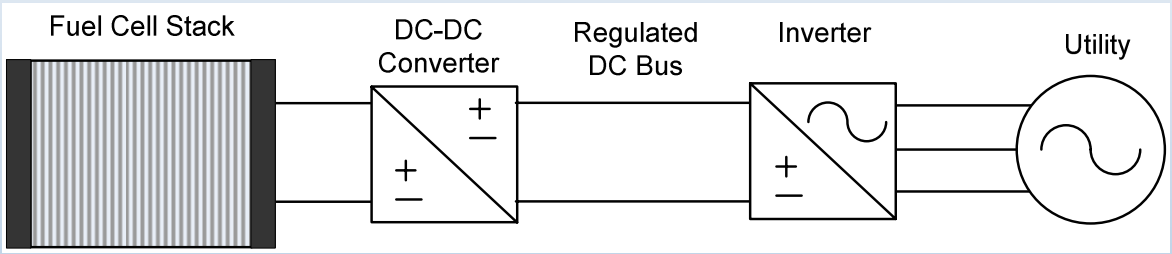


Fuel Cell Topologies

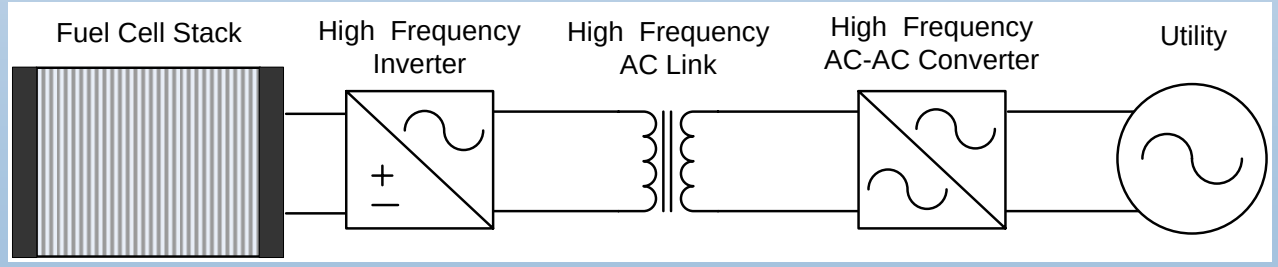
Central Inverter



Cascaded DC-DC and DC-AC

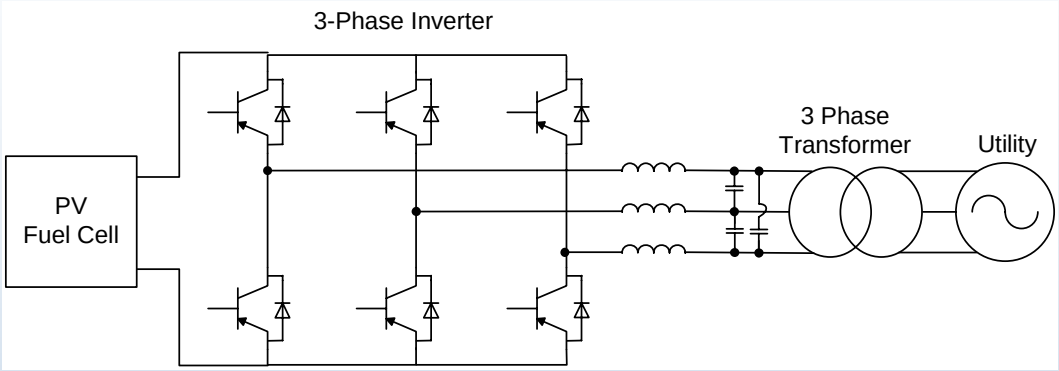


Cascaded DC-AC and AC-AC

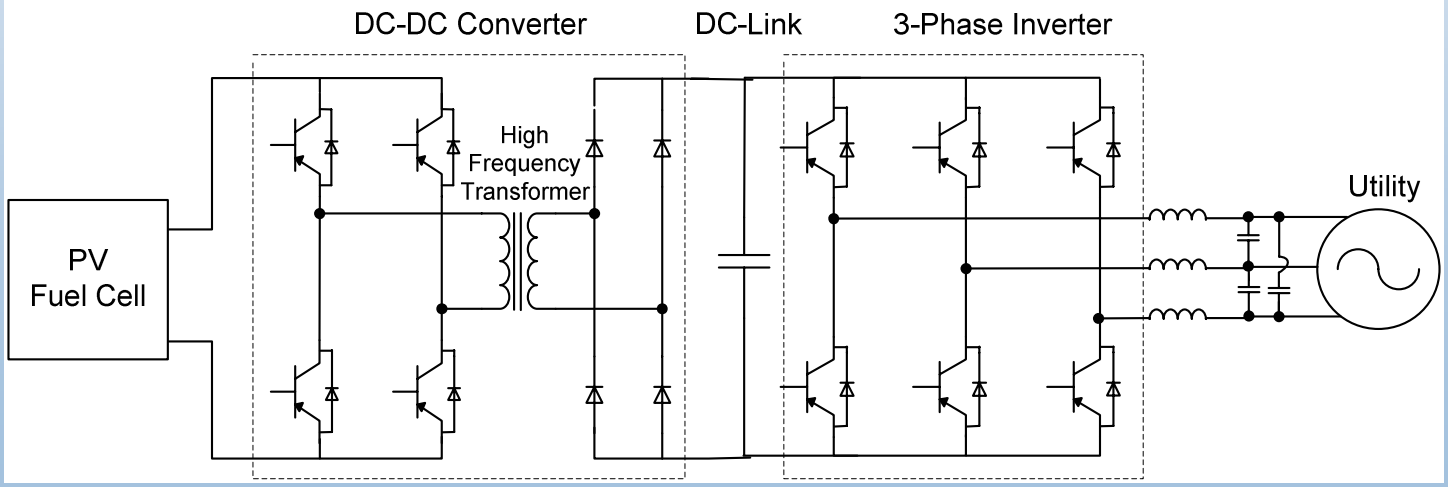


PE for PV and Fuel Cell

Single Inverter

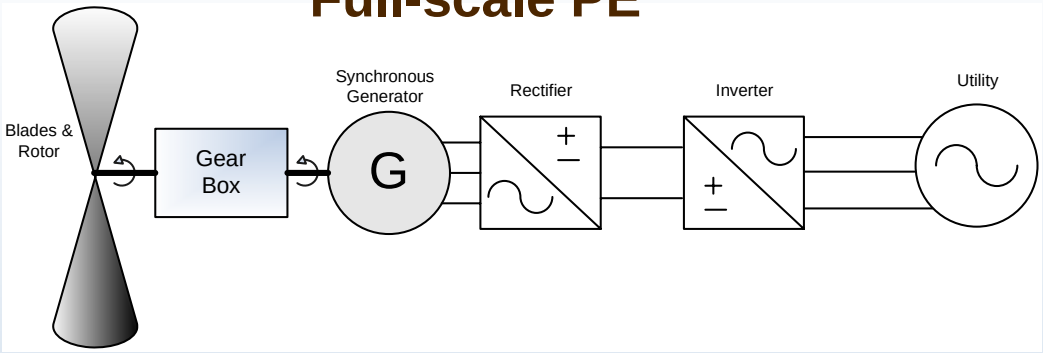


Isolated DC-DC Converter and Inverter

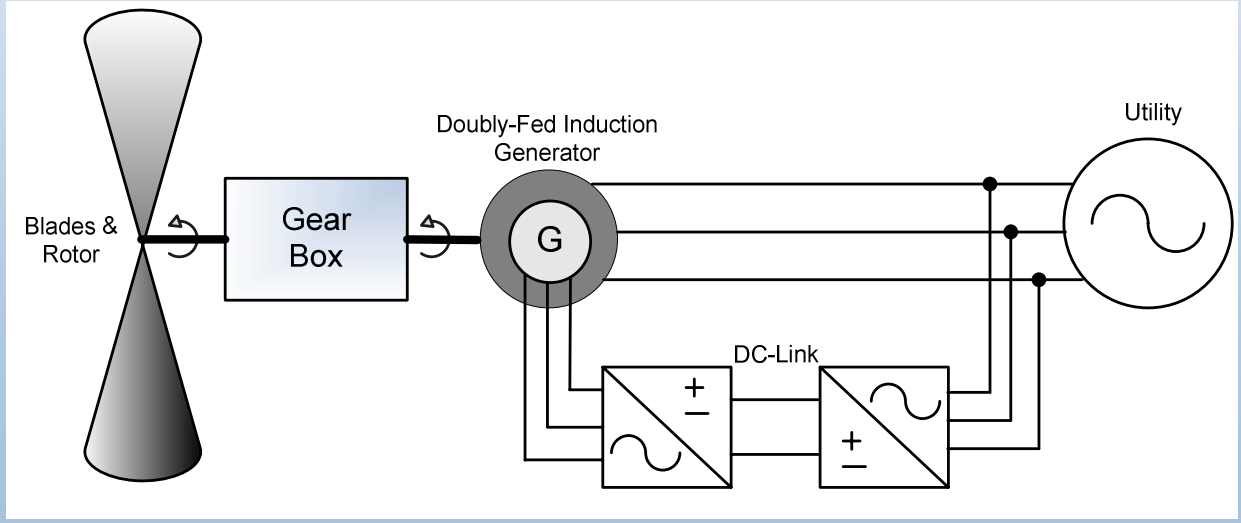


Wind Topologies

Full-scale PE

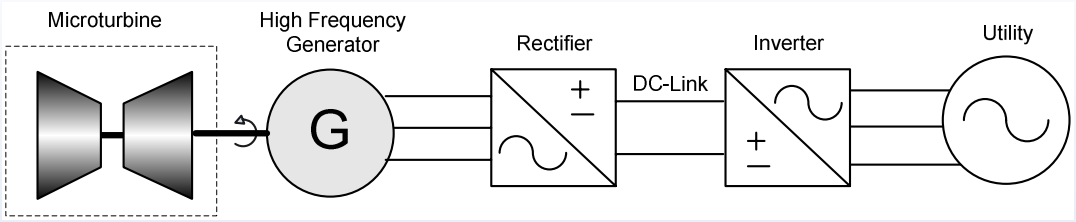


Partially Rated PE

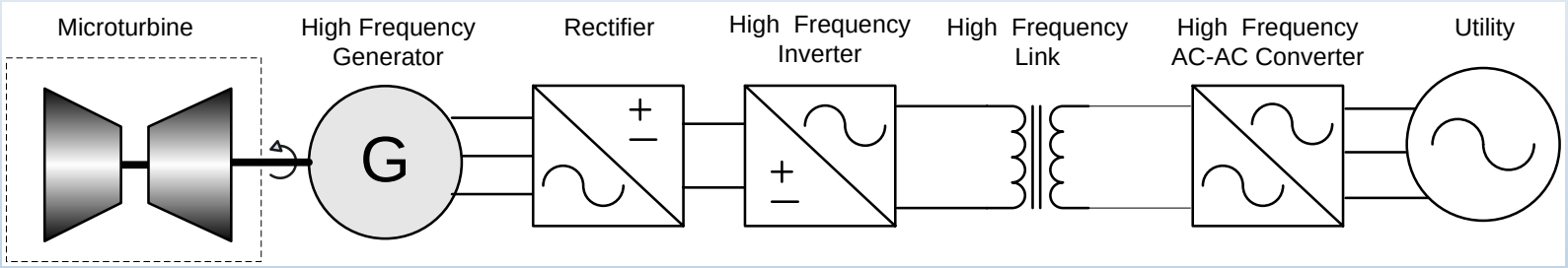


Microturbine Topologies

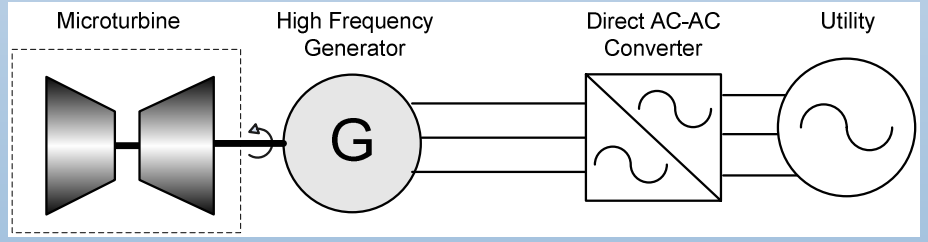
DC-link Power Converters



HFAC-link Power Converter



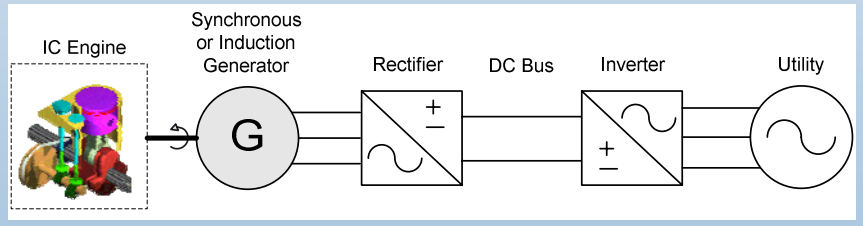
Direct AC-AC converter



IC Engine Topologies

- IC engines typically connected by fixed speed synchronous generator
- PE offers the advantage of having variable speed operation - optimizes fuel usage for varying loads

Full-scale PE



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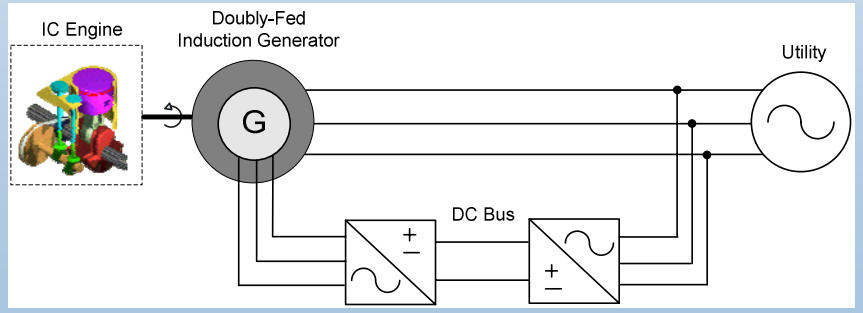
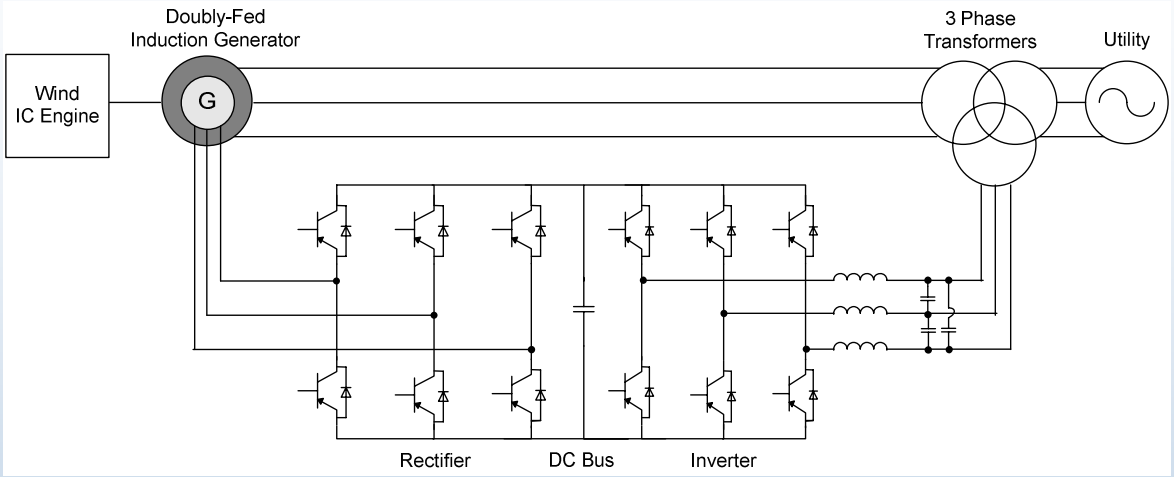
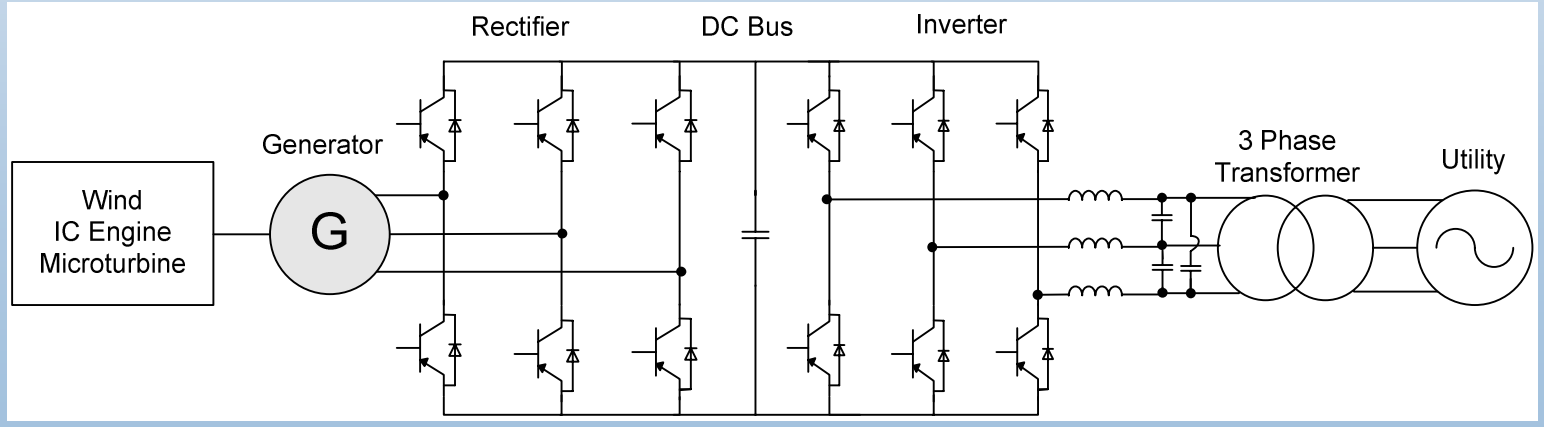


PE for Wind, Microturbine, IC Engine

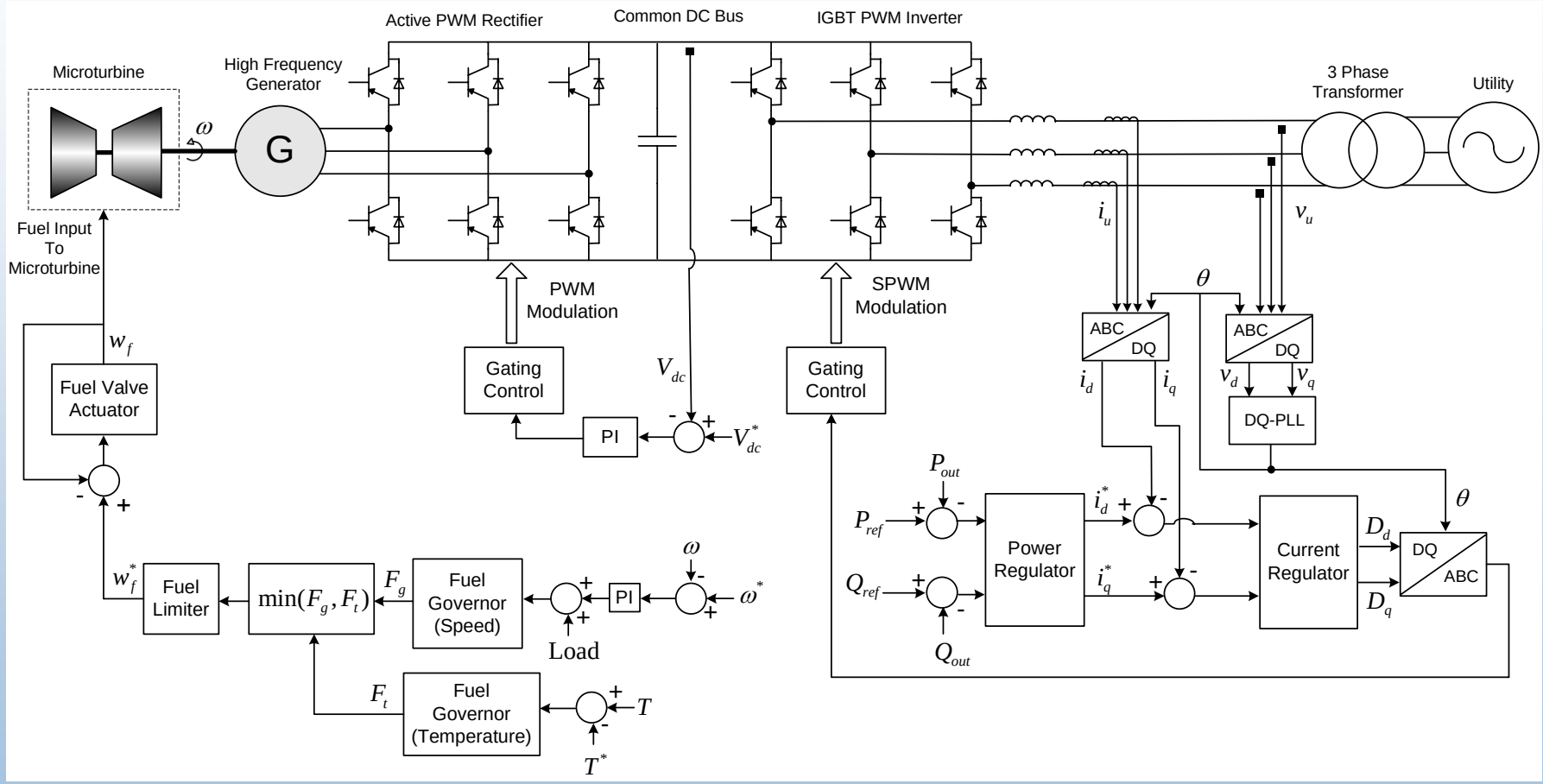
Partially Rated Back-to-back Converters



Full-scale Back-to-back Converters

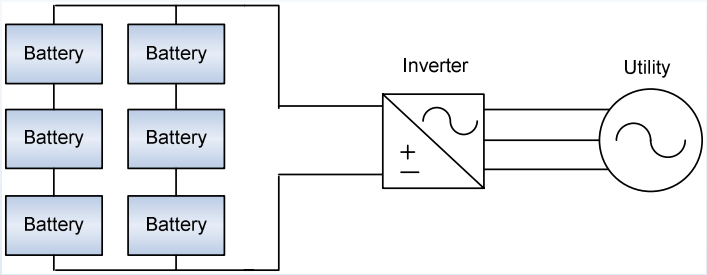


Controller Example

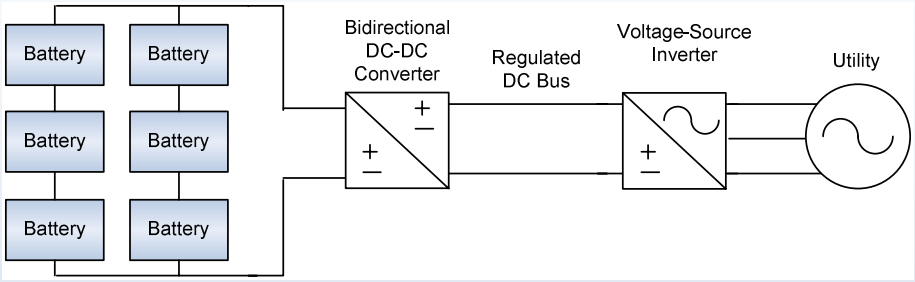


Battery Storage Topologies

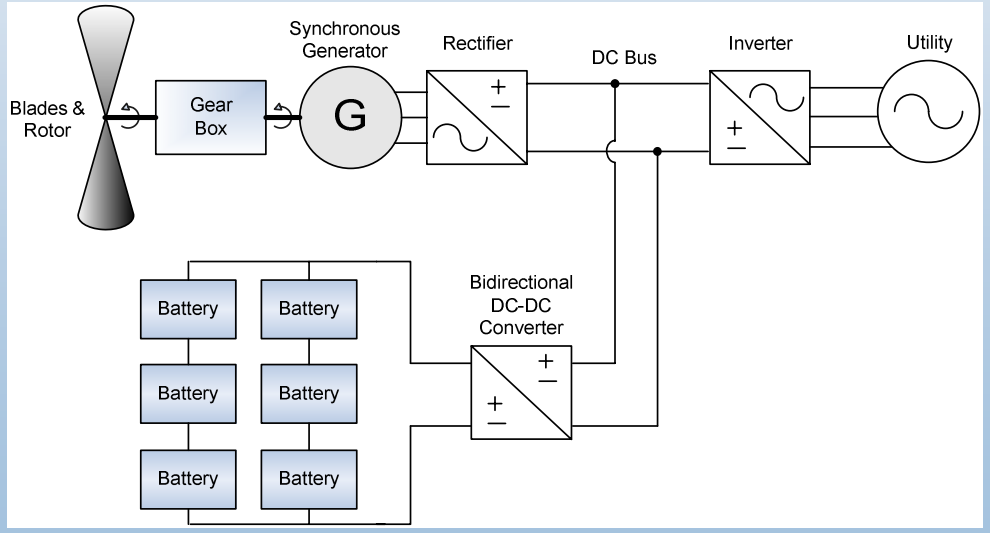
Single Inverter



Cascaded DC-DC and DC-AC

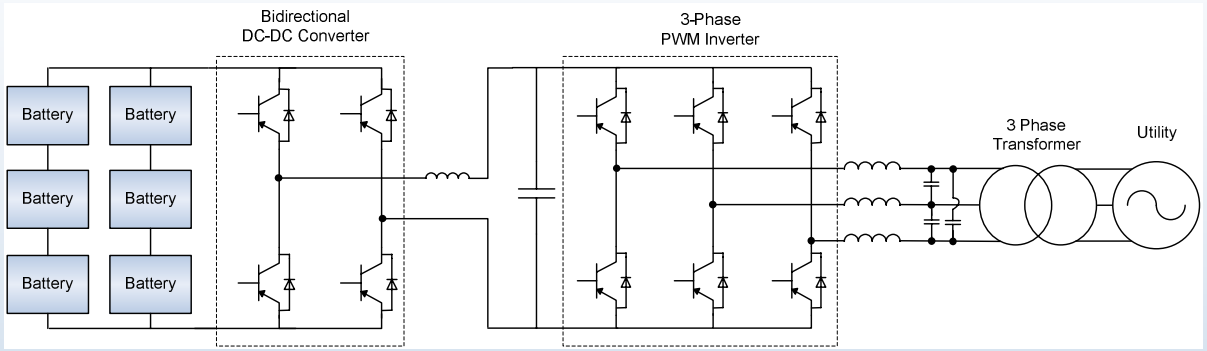


Hybrid System with Battery and Wind

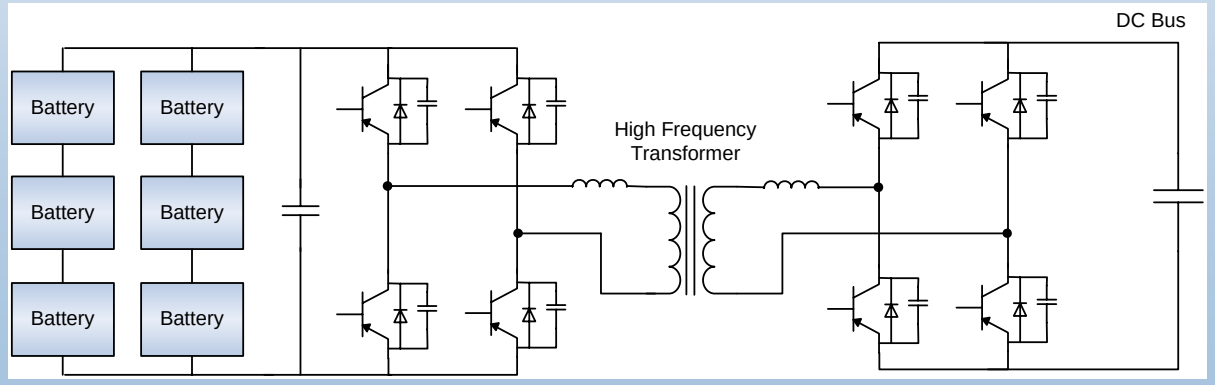


PE for Battery Storage

Bidirectional DC-DC Converter and Inverter

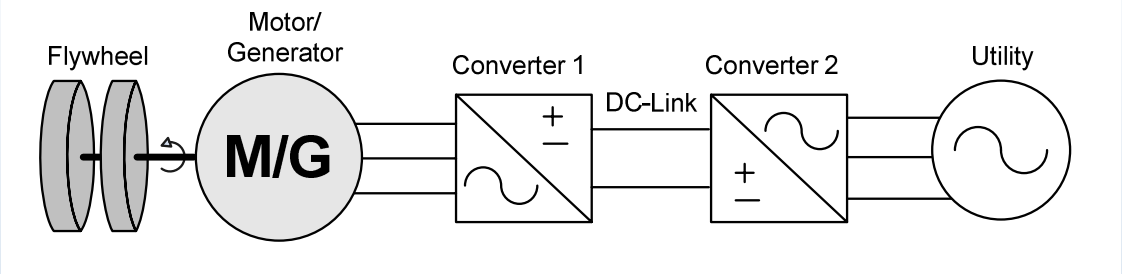


Isolated Bidirectional DC-DC Converter

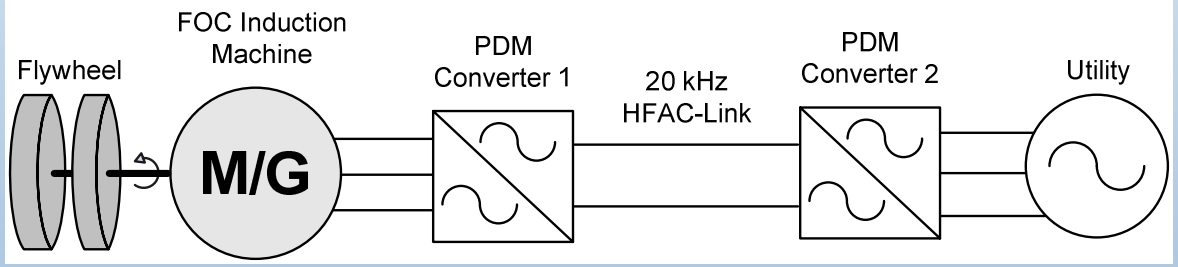


Flywheel Storage Topologies

DC-link Power Converters

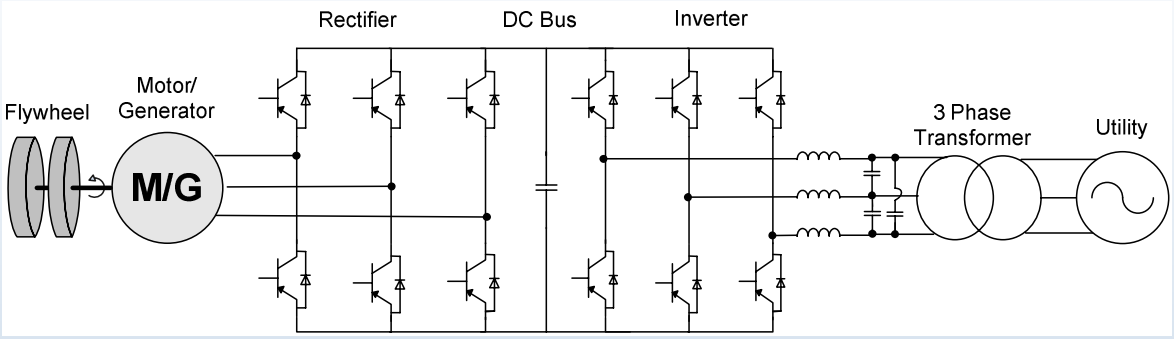


HFAC-link Power Converter

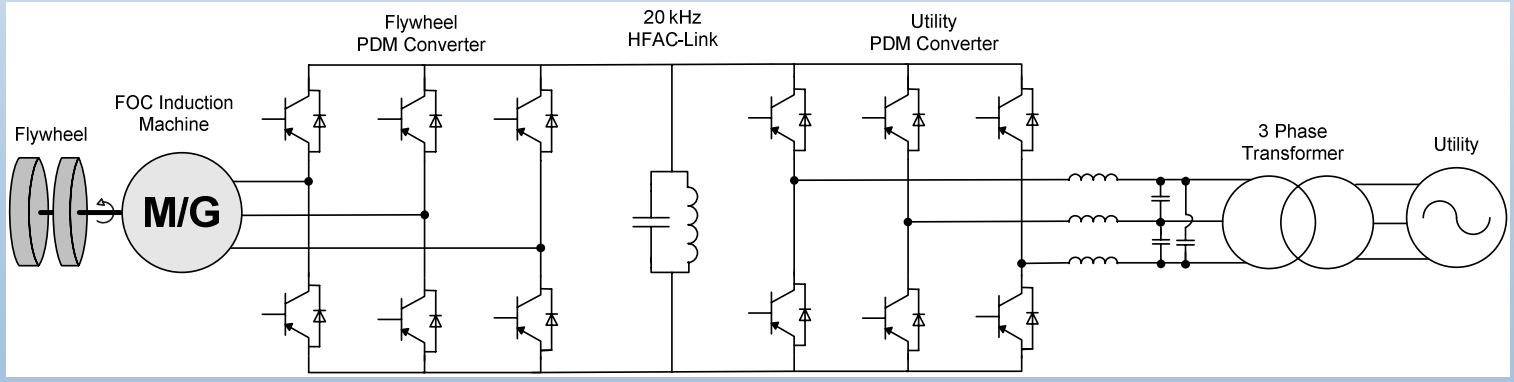


PE for Flywheel Storage

Back-to-back Converters



Back-to-back PDM Converters

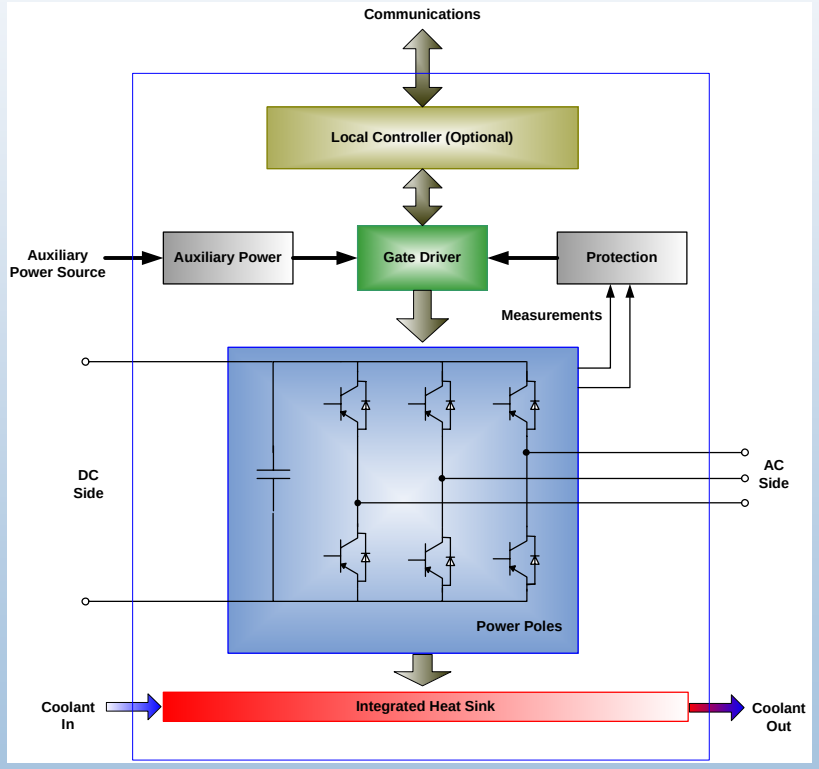


Modular Power Electronics

- Power Electronics Building Block (PEBB)
  - Integration of power devices, gate drives, and other components to functional blocks
- Adoption of functional building blocks that can be used for multiple applications results in
  - High volume production
  - Reduced engineering effort
- The value of integration can be enhanced with the standardization of interfaces of the power blocks, control and communications

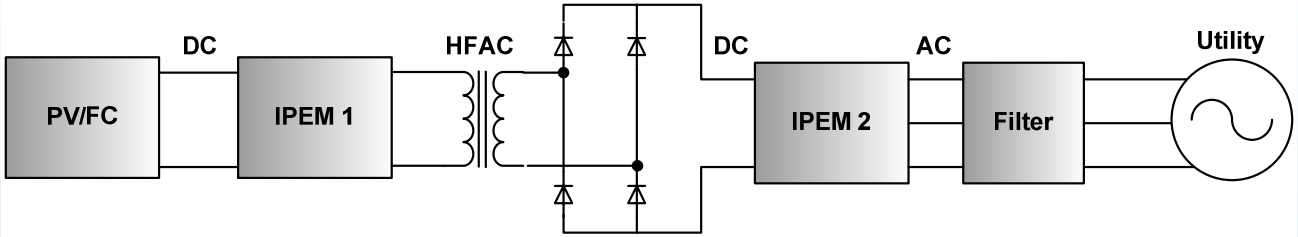
Integrated PE Modules

- Modular design approach revolves around integrated power electronics modules (IPEM)
- IPEM consists of
  - PE switches
  - DC-link capacitors
  - Sensors
  - Gate drivers
  - Heat sink
  - DSP controller
- Semikron SKAI
- American Superconductor PM1000

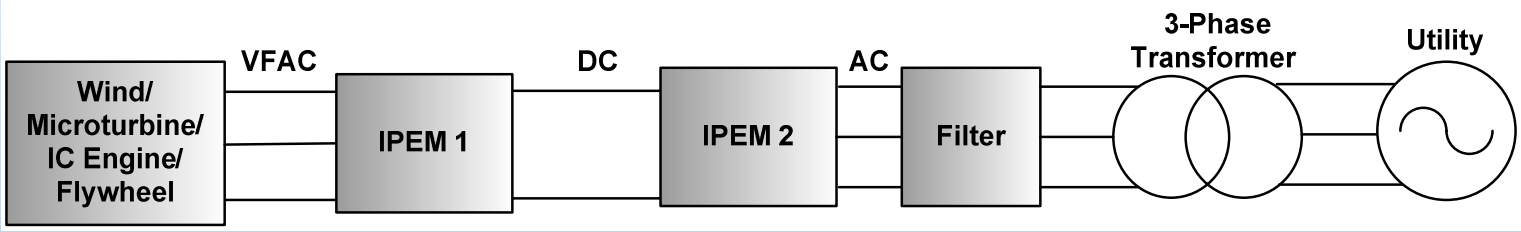


Modular Topologies for DER

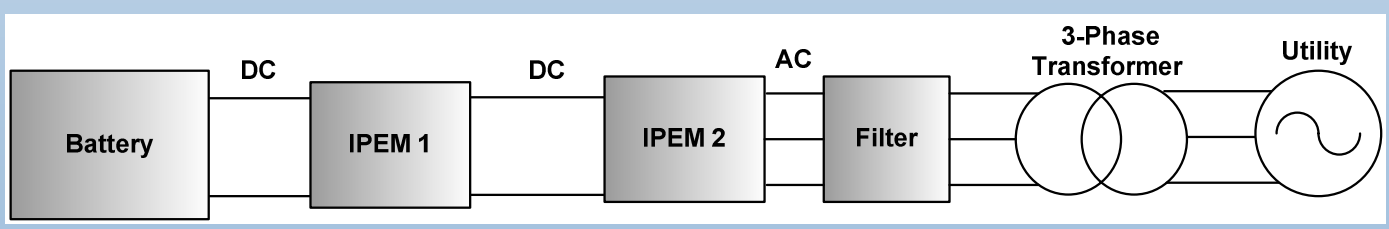
Cascaded DC-DC and DC-AC Converters



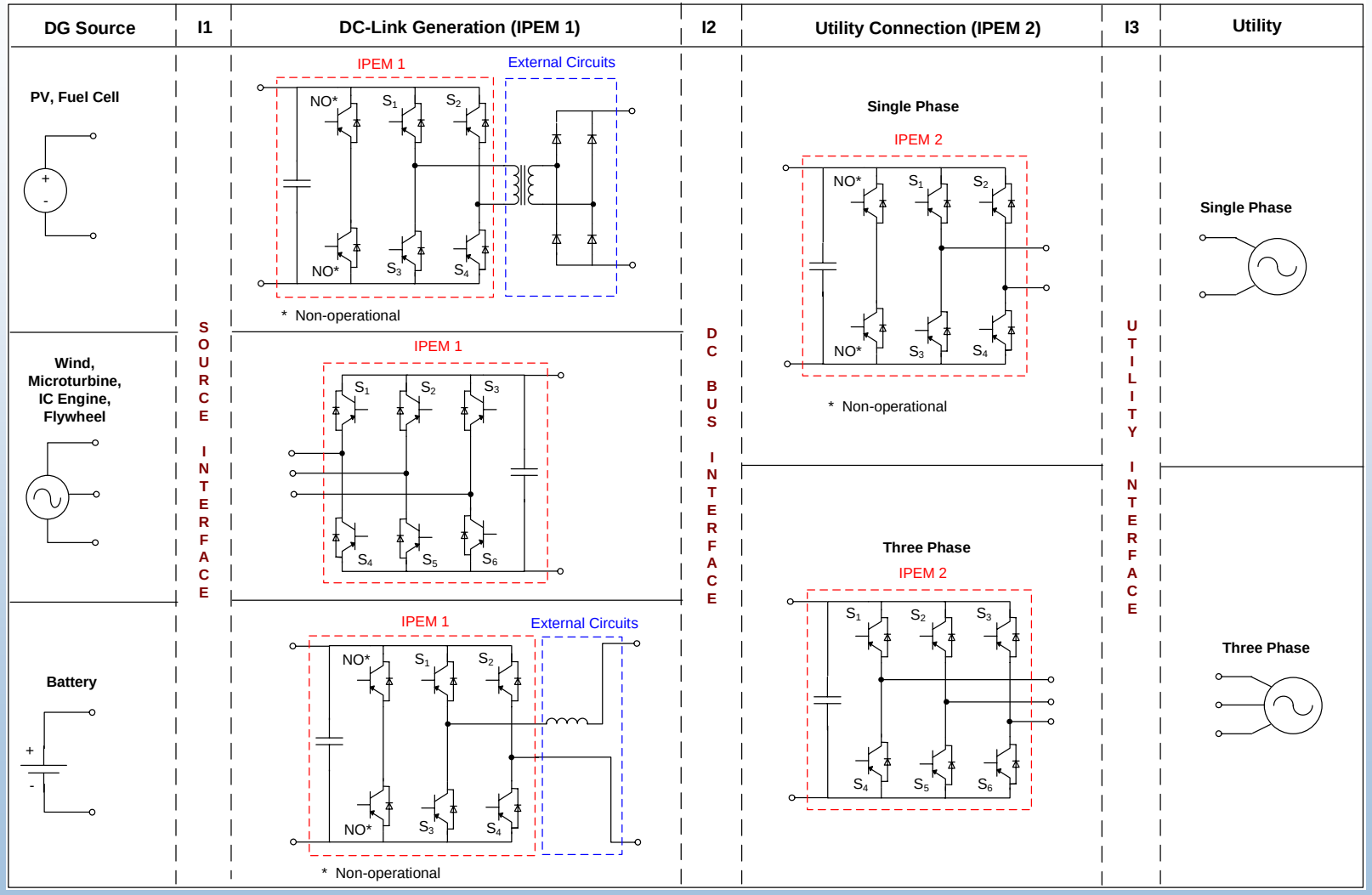
Back-to-back Converters



Bidirectional DC-DC and DC-AC Converters



Generalized IPEM-based PE



Controller for Modular PE

- Dual converters provide flexibility of designing comprehensive control objectives
- In general, the source converters are used for DC bus voltage control
- Grid connected converters are used in constant current control or constant power control
- DC bus voltage regulation is also frequently used for grid converters
- Additionally, for the fuel based systems, such as microturbines, fuel cells and IC engines; external controller can be designed for optimization of fuel

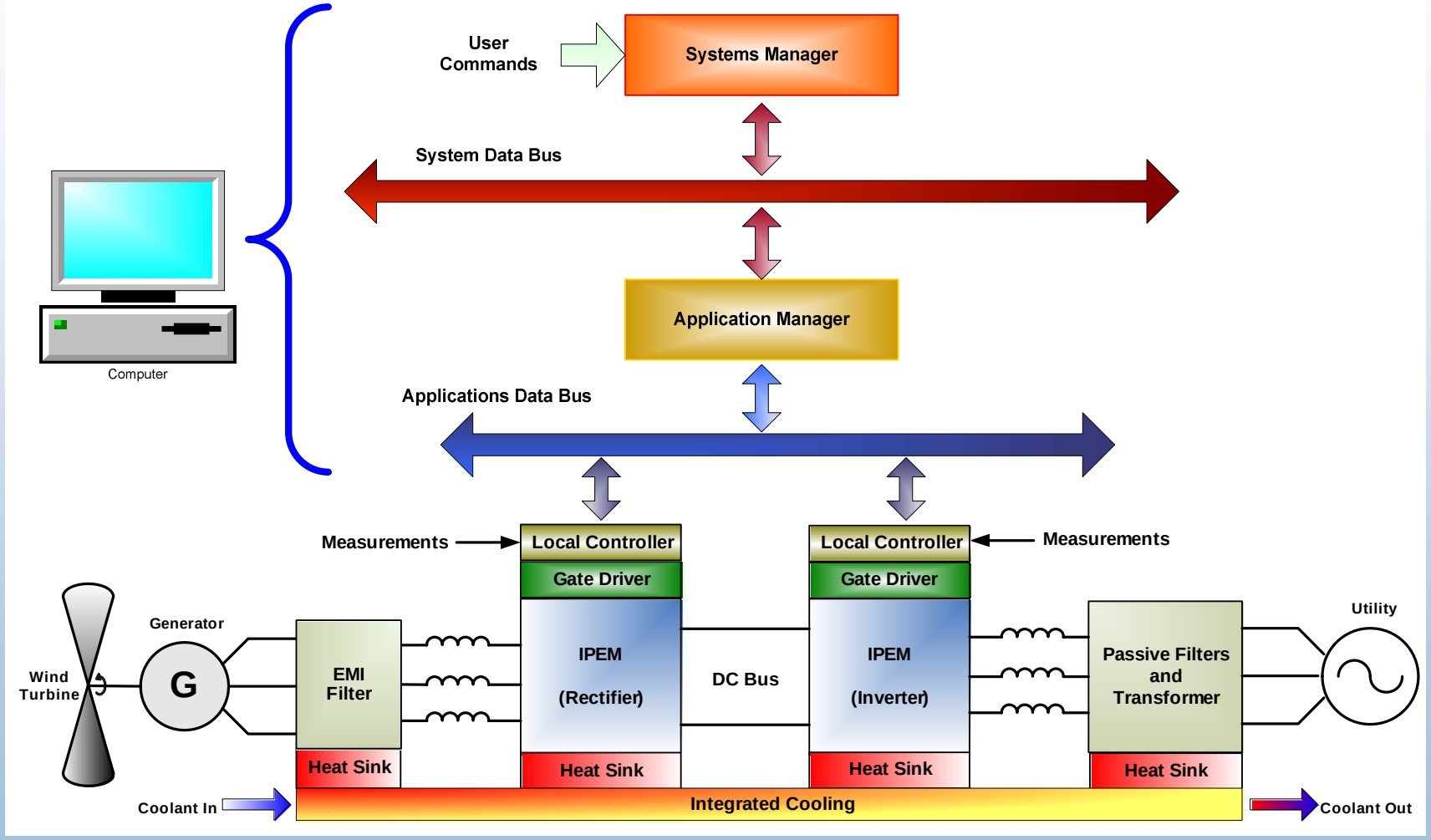
Typical Control Functions

DE Systems	Control Functions		
	IPEM 1	**IPEM 2**	**Additional**
PV	Maximum peak power tracking	Power flow to grid	n.a.
Wind	Generator speed, current, flux	DC bus voltage, current to utility	n.a.
Microturbines	DC bus voltage	Power flow to grid	Fuel usage
Fuel Cell	DC bus voltage	Power flow to grid	Fuel usage
IC Engine	DC bus voltage	Power flow to grid	Fuel usage
Battery-Charging	Battery terminal voltage	DC bus voltage	Operational mode
Battery-Discharge	DC bus voltage	Power flow to grid	Operational mode
Flywheel	Generator torque, speed, DC bus voltage	Power flow to grid	n.a.

Standardization Requirements

- Standardization is required for power flow and signal distribution network
- This in turn allows for distributed controller approach
- By using control software that is functionally divided into hierarchical levels and by standardizing interfaces between levels
  - application software becomes independent of the hardware specifications of power stage
- The standardization of communication interface allows division of PE system into flexible, easy-to-use, multifunctional modules, which can significantly ease the task of system integration

Conceptual Modular PE System



Conclusions

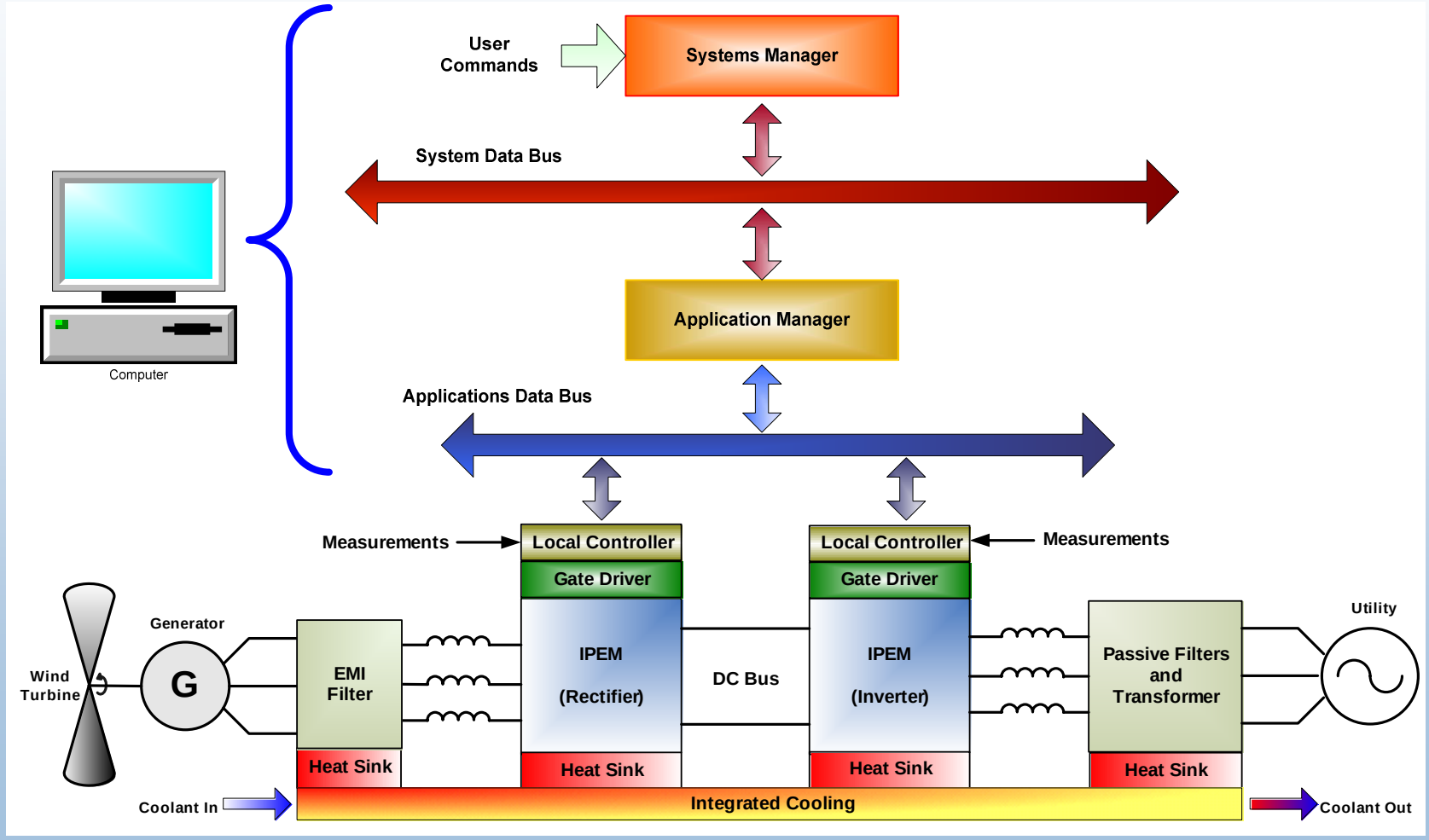
- PE adds large installation costs for DER system
- PE designs are specific to the DE technology, still they possess some common functionalities
- IPEM based back-to-back converter topologies
  - a viable PE interface that can operate with different DE systems with small or no modifications
- However, to reach the goal of modularity, challenges in defining the power and communication interfaces, are to be addressed

Acknowledgements

- **California Energy Commission (CEC)**
- **National Renewable Energy Laboratory**

The National Renewable Energy Laboratory is a national laboratory of the U.S. Department of Energy (DOE) managed by Midwest Research Institute for the U.S. Department of Energy under Contract Number DE-AC26-99GO10337. This report was prepared as an account of the work sponsored by the California Energy Commission and pursuant to the M&O Contract with the United States Department of Energy (DOE). Neither Midwest Research Institute, nor the DOE, nor the California Energy Commission, nor any of their employees, contractors or subcontractors, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacture, or otherwise does not necessarily constitute or imply is endorsement, recommendation, or favoring by Midwest Research Institute, or the DOE, or the California Energy Commission. The views and opinions of authors expressed herein do not necessarily state or reflect those of Midwest Research Institute, the DOE, or the California energy Commission, or any of their employees, or the United States Government, or any agency thereof, or the State of California. This report has not been approved or disapproved by Midwest Research Institute, the DOE, or the California Energy Commission, nor has Midwest Research Institute, the DOE, or the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

Questions ?


User Commands
Systems Manager
System Data Bus
Application Manager
Applications Data Bus
Computer
Measurements
Local Controller
Gate Driver
Local Controller
Gate Driver
Measurements
Utility
Generator
Wind Turbine
G
EMI Filter
IPEM (Rectifier)
DC Bus
IPEM (Inverter)
Passive Filters and Transformer
Heat Sink
Heat Sink
Heat Sink
Heat Sink
Coolant In
Integrated Cooling
Coolant Out