Modular Power Electronics for Renewable Distributed Energy

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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

Cascaded DC-DC and DC-AC

AC-Module
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

Partially Rated PE
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

<table>
<thead>
<tr>
<th>DG Source</th>
<th>I1</th>
<th>DC-Link Generation (IPEM 1)</th>
<th>I2</th>
<th>Utility Connection (IPEM 2)</th>
<th>I3</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV, Fuel Cell</td>
<td></td>
<td><img src="image1" alt="Diagram" /></td>
<td></td>
<td><img src="image2" alt="Diagram" /></td>
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<td><img src="image3" alt="Diagram" /></td>
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<tr>
<td>Wind, Microturbine, IC Engine, Flywheel</td>
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<td><img src="image4" alt="Diagram" /></td>
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<td><img src="image5" alt="Diagram" /></td>
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<td><img src="image6" alt="Diagram" /></td>
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<tr>
<td>Battery</td>
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<td><img src="image7" alt="Diagram" /></td>
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<td><img src="image8" alt="Diagram" /></td>
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<td><img src="image9" alt="Diagram" /></td>
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</table>

* Non-operational
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

<table>
<thead>
<tr>
<th>DE Systems</th>
<th>Control Functions</th>
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<tbody>
<tr>
<td></td>
<td><strong>IPEM 1</strong></td>
</tr>
<tr>
<td>PV</td>
<td>Maximum peak power tracking</td>
</tr>
<tr>
<td>Wind</td>
<td>Generator speed, current, flux</td>
</tr>
<tr>
<td>Microturbines</td>
<td>DC bus voltage</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>DC bus voltage</td>
</tr>
<tr>
<td>IC Engine</td>
<td>DC bus voltage</td>
</tr>
<tr>
<td>Battery-Charging</td>
<td>Battery terminal voltage</td>
</tr>
<tr>
<td>Battery-Discharge</td>
<td>DC bus voltage</td>
</tr>
<tr>
<td>Flywheel</td>
<td>Generator torque, speed, DC bus voltage</td>
</tr>
</tbody>
</table>
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

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

NREL National Renewable Energy Laboratory
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
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Questions ?

Diagram of a wind turbine system with the following components:

- Wind Turbine
- Generator
- EMI Filter
- Gate Driver
- IPEM (Rectifier)
- IPEM (Inverter)
- DC Bus
- Heat Sink
- Integrated Cooling
- Utility
- Coolant In
- Coolant Out
- Computer
- System Data Bus
- Applications Data Bus
- User Commands
- Systems Manager
- Application Manager

The diagram shows the flow of data and components within the system, including the integration of cooling and data management systems.