Studies of Intelligent Power Systems at OSU

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Outline

► Introduction of existing and ongoing activities
► Smart Resistor: an approach to solve the issue for constant power load
► Summary and future work
An intelligent power system for future airplanes are dc, ac, or hybrid microgrids that have hierarchical intelligence to realize optimized power flow control at both normal and failure mode conditions.

Key features of an intelligent power system include:

- Power flow and energy management optimization
- Fault prediction and fast detection
- Coordinated control and protection strategies for fault handling
Multi-layers of a Typical Intelligent Power System

Components and subsystems:
- Generators;
- Power electronics based loads;
- Circuit breakers;
- Component level faults.

System and networks:
- Network topology;
- System level faults;
- Reconfiguration and control.
Electric Power Components

- Failure mode analysis and modeling of each component and subsystem;
- Characteristic of Silicon carbide (SiC) based solid-state circuit breakers;
- Artificial intelligence and self-learning for load management and fault protection;
- Smart switching devices inside power converters, e.g., SmartFET.
Approaches/Associated Challenges in Each Layer

- Trade-off and optimization between sub-systems, e.g. sizing of generator and the energy storage units;
- Reconfiguration and redundancy;
- Impact of communication latency towards power network control and protection;
- Coordination between local intelligence and central control;
- Coordination between control strategy and protection schemes;
- System stability.
DC arcs are most dangerous type of faults that could happen in aviation power systems.

- A low impedance (parallel) arc can cause severe damage and requires fast detection.
- A high impedance (series) arc resembles a sudden load reduction and is more difficult to be detected.

### Experimental Condition

<table>
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<tr>
<th>DC source voltage (V)</th>
<th>75, 120, 175, 240, 300</th>
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<tr>
<td>Load current (A)</td>
<td>3, 6, 15, 25</td>
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<tr>
<td>Gap length (in)</td>
<td>0.04, 0.06, 0.08, 0.10, 0.12</td>
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A wavelet based detection method based on dc arc signature synthesis [1]

Interactions between droop control and high impedance arc fault [2]

- If the dc arc happens at the input side of the source converter, droop controller will increase arc current
- If the dc arc happens at the output side of the source converter, droop control will try to maintain the arc current
- If the dc arc happens at the load connection point, current sharing ratio between source converters can not be maintained


Developing new hierarchical control framework to enable systematic design of aviation electric power systems

Key: developing supervisory control strategies that

• Detect and isolate faults.
• Adapt to measurements, the droop gains and voltage reference values of individual converters.

To be validated on the microgrid testbed and built-in simulation modules.

Preliminary Results

Stability analysis and robust controller design [Herrera, Zhang, Wang, 2015]
  – Developed method to analyze robust stability for any given operating point
  – Designed controllers to enlarge the set of such states

Distributed control for inverter-based island AC microgrid [Chang & Zhang 2015]
Converting an AC Microgrid into a DC Microgrid

Power Hardware-in-the-Loop Unit
► Emulate several subsystems of the microgrid.
► Emulate a scaled-down utility grid, and study the interaction between the microgrid and the utility grid.

Real Time SCADA and System-in-the-Loop Unit
► Low latency communication between control center and distributed local controller.
► Emulation of different communication network topologies and events in real time.

A constant power load (CPL) connected to a power electronics based source.

The constant power load exhibits negative impedance when the bus voltage changes which leads unstable oscillation.

Examples:
- Shipboard power systems
- Aircraft power systems
- Utility microgrids
Motivations:
- Solve the CPL problem with a clear physics oriented concept;
- Fully utilize capabilities of distributed energy storage units and high bandwidth of emerging wide bandgap power devices.
Features and Potentials of “Smart Resistor”

- Converting all power electronics based loads into adjustable resistance, “Rdroop”;

- Achieving ultimate microgrids/smart grids by coordinating adjustable smart resistors and smart sources, which are both based on droop control.

The first paper on the concept of Smart Resistor is accepted by APEC2017.
The Bandwidth and Current Requirement

$P_{\text{CPL}} = 50 \text{ kW}, V_{\text{bus}} = 400 \text{ V with 10\% step change}$

High bandwidth and high current call for wide bandgap power device based circuits.
Stability Comparison

Phase portrait of CPL.

Phase portrait of Smart Resistor

\[ P_{CPL} = 50 \text{ kW}, \ V_{bus} = 400 \text{ V with 10\% step change} \]
Test Setup

The first validation was performed at the 60 V DC microgrid.

The OSU 400 V, 10 kW GaN based power converter.
Experimental/Simulation Results

CPL without compensation.

Performance of the Smart Resistor.
Summary and Future Work

► Intelligent power system needs studies at both component and system level

► Preliminary results on DC arc fault and the construction of a hybrid microgrid test bed will benefit the future study

► Two integrated projects will be continued to address
  ▪ Fault analysis, system modeling, and test bed
  ▪ Hierarchical control and protection strategies

Collaborations on new concepts and future projects are welcome.
To save a life, be a doctor.

To save the world, be a power electronics engineer!

Thank you!

Questions?