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Analysis and Testing of Optimal Power Control Strategy for NASA Moon Base Interconnected DC Microgrid System

9/15/23

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Lee Rashkin, Sandia National

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Overview

- Introduction
- System Description
- Secure Scalable Microgrid Testbed (SSMTB)
- Control System
- Scaled Test System
- Results
- Conclusions

Introduction

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- NASA's plans for the Artemis missions is the construction of a habitation and mining base on the lunar surface
- High consequences loads must remain powered during interruptions
  - Control system governing the power flow
- System consists of several load centers separated by 9-12 km primarily sourced by photovoltaic (PV) and energy storage systems (ESS)
  - Independent DC microgrids with their own loads, sources, and controls
  - Grid tie lines to connect microgrids allowing for controlled power flow between grids
  - Required to transport power between grids in cases of anticipated or non-anticipated shortfalls between power generation and load demands

System Description

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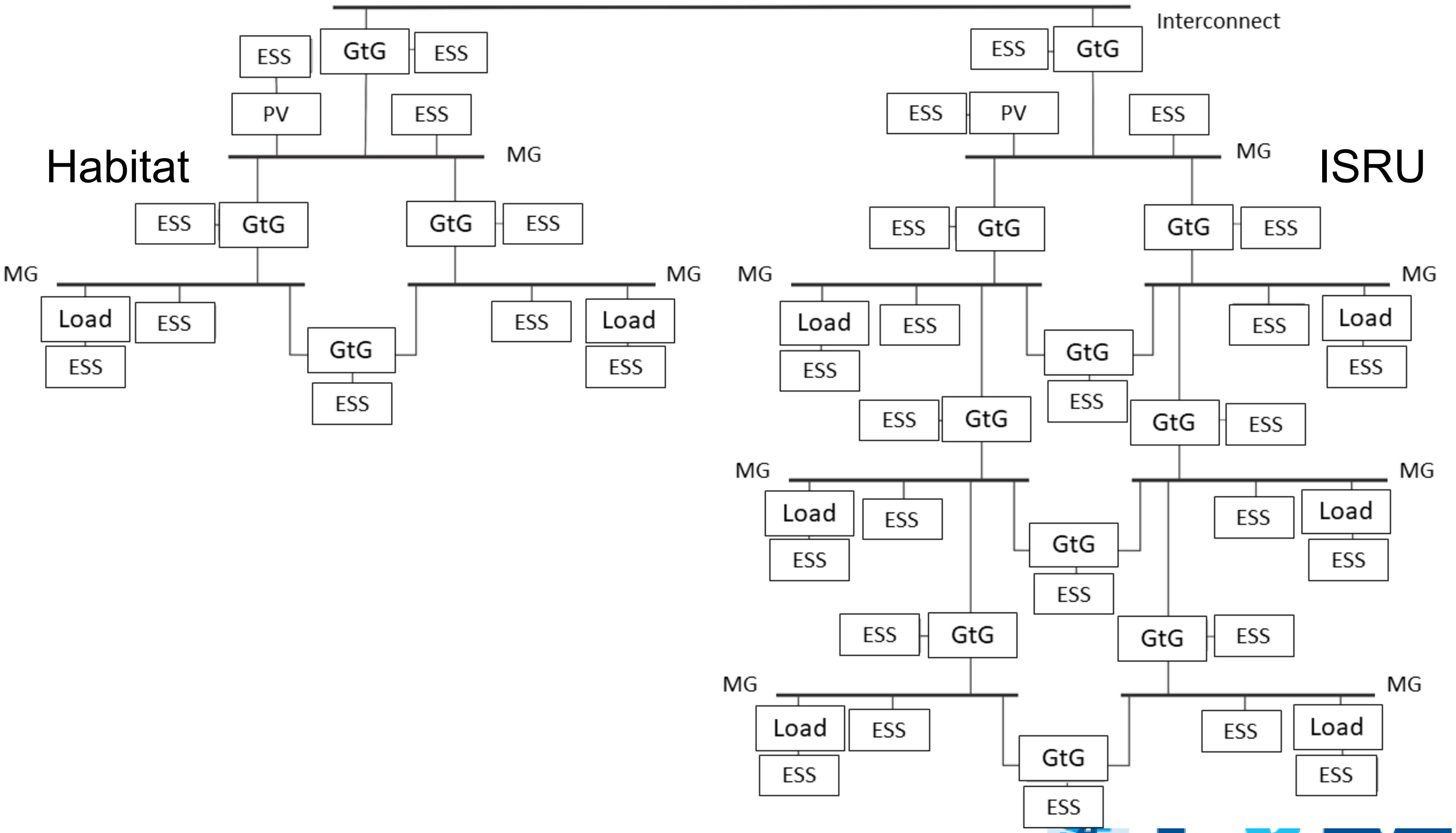
- The full scale system consists of:
  1. Habitat module
  2. In-situ resource utilization (ISRU) mining module
  3. Interconnection



Sandia's microgrid testbed was used for hardware validation

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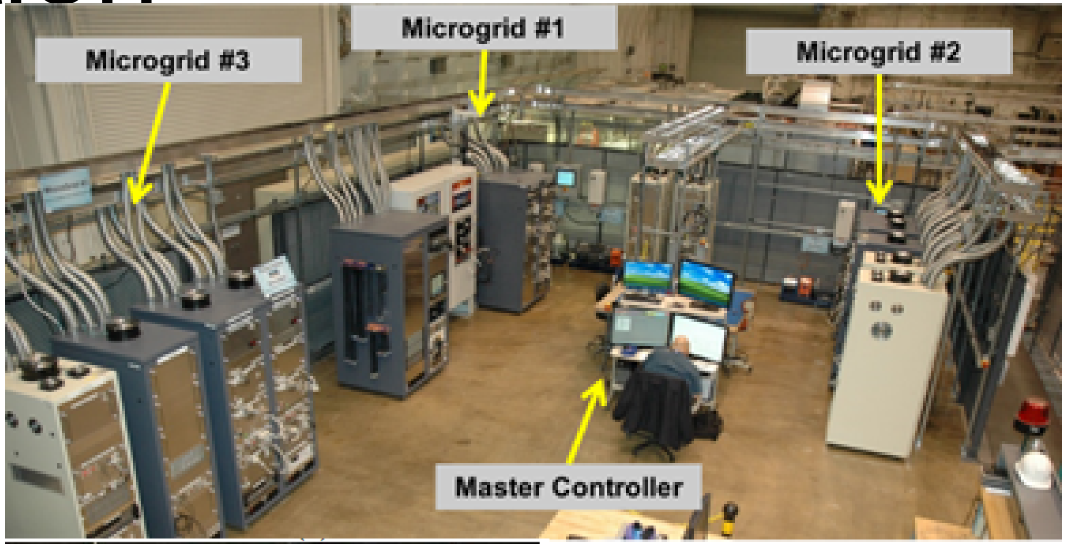
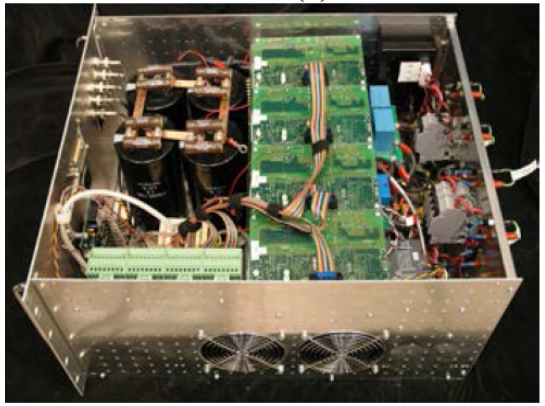
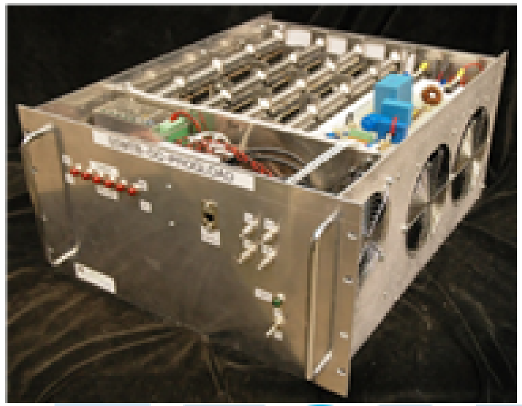
- Design scaled to hardware bed
- The Secure Scalable Microgrid Testbed (SSMTB) was configured to represent scaled moon base power system with multiple buses
- The testbed components used include
  1. 3 DC microgrid systems
  2. Arbitrary response energy storage emulators (ARESE)
  3. High-power digital resistors (0-6.7 kW)
  4. Power electronics based grid-to-grid converters







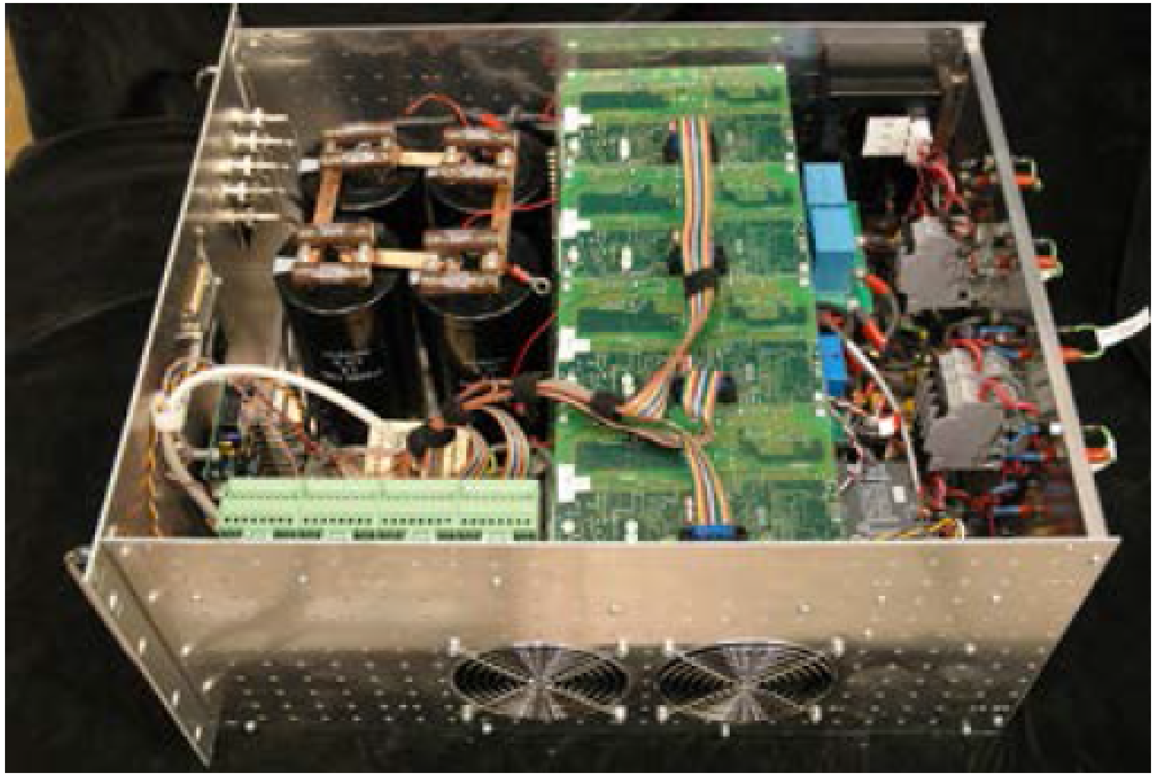
ARESE and Photovoltaic Emulator

ARESE units consist of:

1. Power electronics hardware and capacitors
2. 600 V / 5 kW power supply
3. Resistive dump load
4. Versilogic industrial control board with 10 kHz control loop

Energy storage units use ARESE unit set up for voltage control

Photovoltaic (PV) resources are emulated by using an ARESE unit setup for current control



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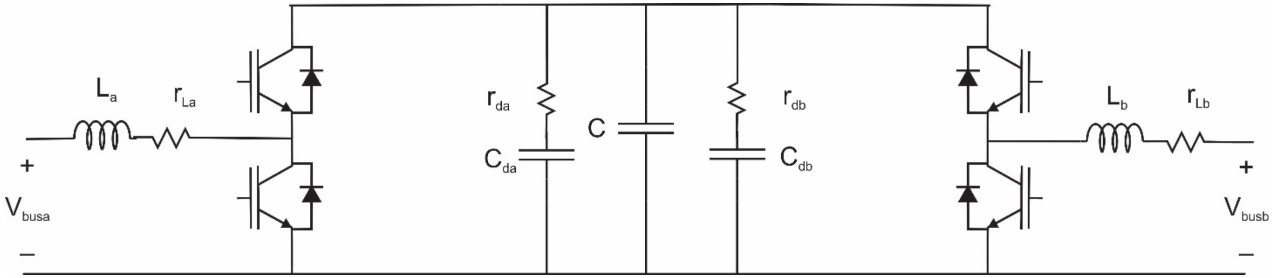
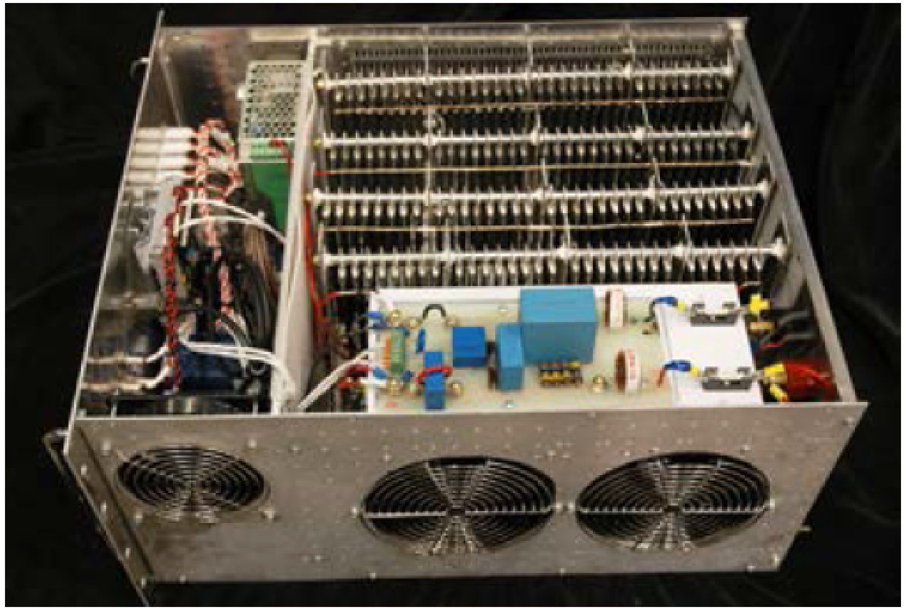
Grid-to-Grid Converters and Digital Loads



- Power electronics grid-to-grid converters control power flow between grids.
- Back to back boost converter topology
- Controller manages the voltage of the internal capacitor and responds to power flow set points
- Digital loads simulate loads
- Bank of parallel 1500 Ω
- Allows for a wide range of resistance settings
- Profiles for generation and load levels can be sent to each component in the SSMTB



Software Agents and Optimal Controls

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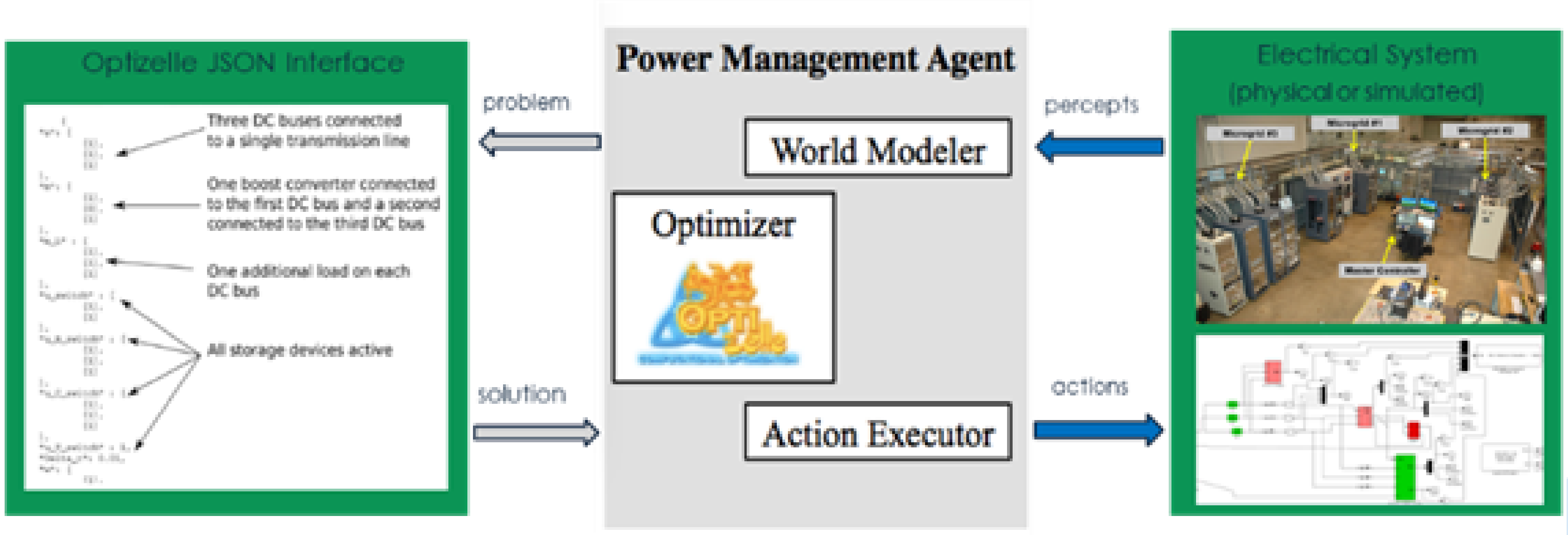
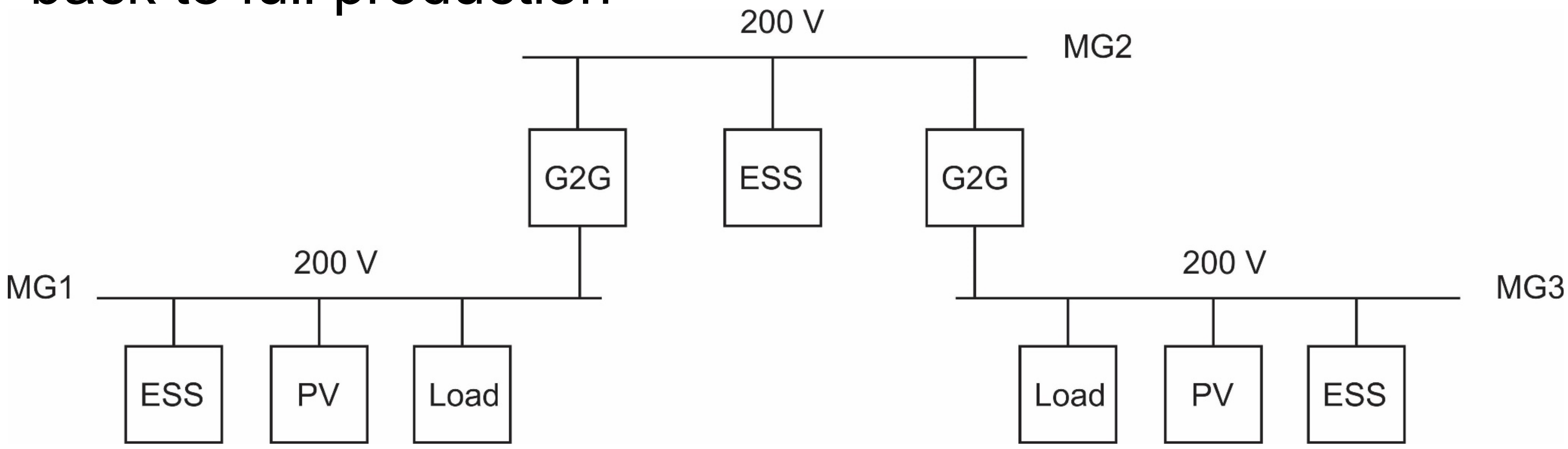
- Software agents may be situated throughout the power system to support local and global resource management
- IP based, UDP and TCP, communication links and protocols enable information exchange between the optimizer, agents, and represented power system
- Agents monitor system state through sensor instrumentation and send control updates to particular resources in a closed loop fashion
- Agents support various control techniques (optimization, physics based models, and nonlinear control techniques), along with extensions for rule based actions and team level coordination



[REF] Cook, M., Young, J., and Wilson, D., Agedillo Agent-based Control, Sandia Copyright Assertion #2265, granted March 13th 2018.
[REF] Young, J., Optizelle [op-tuh-zel] is an open source software library designed to solve general purpose nonlinear optimization problems, OptimoJoe, LLC, https://www.optimojoe.com/uploads/reports/Optizelle-1.2.1-letter.pdf

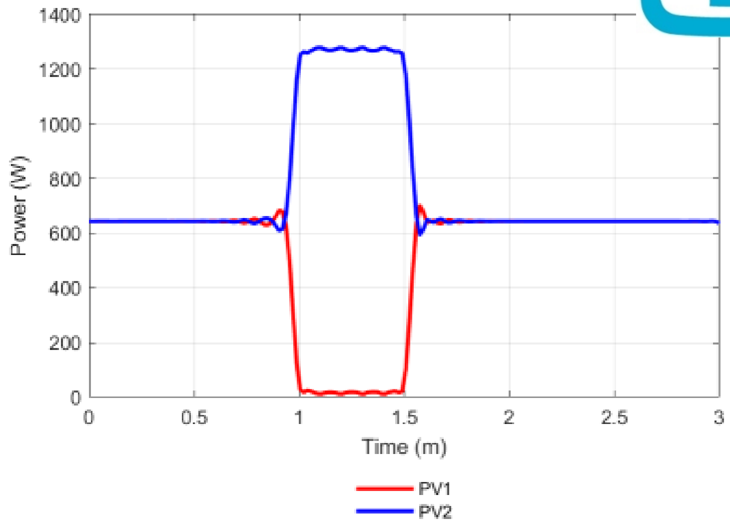
Scaled Hardware Test System

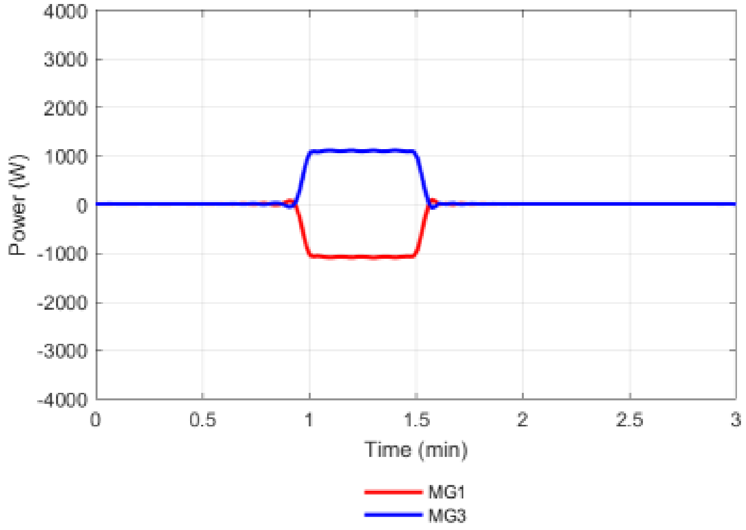
- Representative moon base system on SSMTB shown below
- Examines the control of the power transfer between grids
- All loads, PV generation, and energy storage systems (ESS) on a grid were condensed into single units
- Optimal controller monitored the load demands and PV generation
- PV1 profile causes a significant decrease in generation, then increased back to full production



Supervisory Optimal Control Results

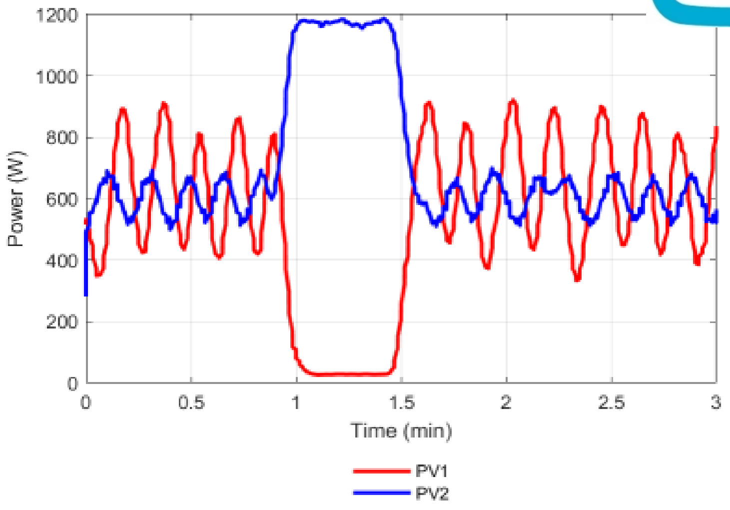
- Optimal control used a simulated reduced order model of the hardware
- Bus voltages were set to 200 V ±5%
- Loads set to a constant 1066 W
- PV power generation has generation in one grid drop to 0
- The optimal controller determined the power flow through the grid-to-grid converters connected to the interconnect line



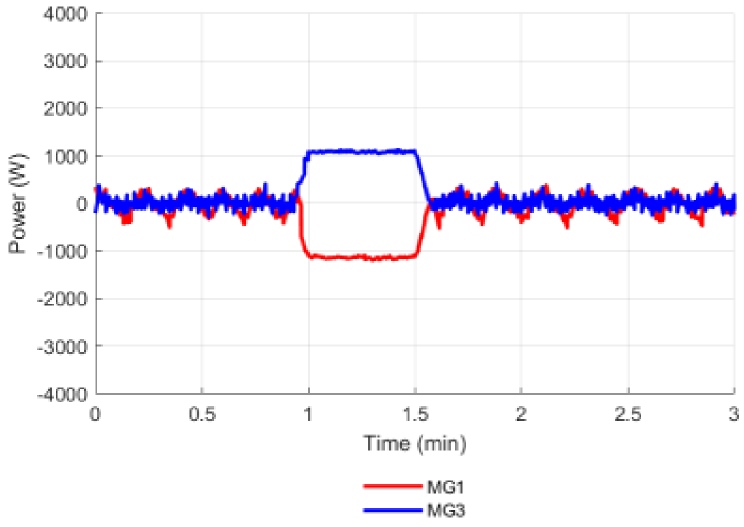


SSMTB Hardware Results

- Average value of hardware behavior match simulated



- Large oscillations when zero-power-flow between grids due to under damping



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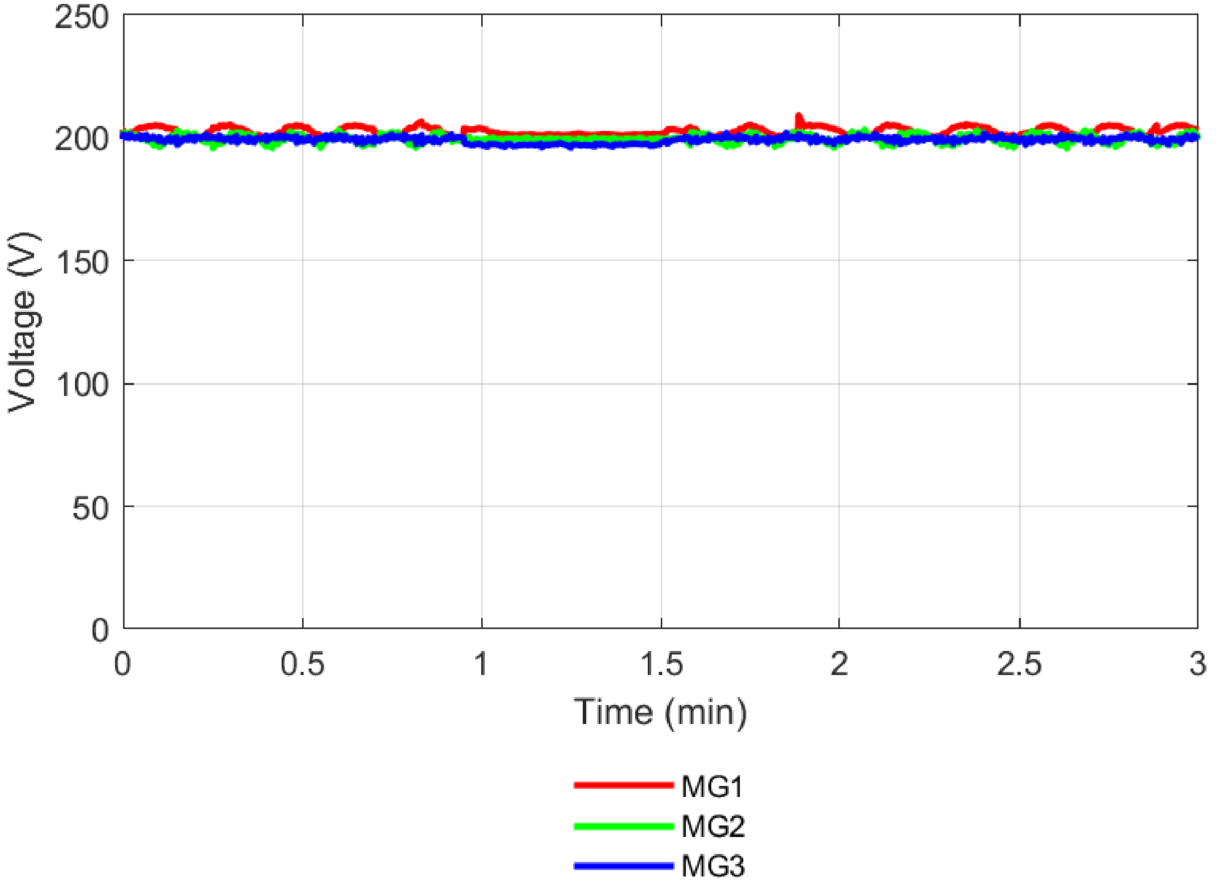
Grid Voltages Remain Constant During the Disturbance



Bus voltages are held within ±5% of the 200 V regulation voltage

Conclusions

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- Moonbase design with isolated DC microgrids and a tie line examined
  - Power transport between microgrids in the case of a generation short fall
  - Controller determines power flow between the grids and power electronics
  - An optimal control method using a simulated system to determine power flow was implemented
- Tested using the SSMTB hardware testbed
- Results show that the controller is capable of determining the power flow required to maintain the bus voltages.

Future work

- Tuning Reduced Order Models
- Raising the voltage of the tie line
- Longer line
- Full system simulation studies
- Online Controller

Thank You