Inverde e+ CHP Module Incorporating the CERTS Microgrid System

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Co-CEO

Tecogen

Outline

- Introduction and Background
  - Product Background and Research Sponsorship
- Basic Product Design
  - Generator and Power Converter
  - Benefits
- CERTS Microgrid
  - Principle of Operation
  - Advantages
  - Field Operation
    - Hurricane Sandy
    - Sacramento Municipal Utility District

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Introduction and Background

- Early Decades of Small CHP
  - Reciprocating Engines Highly Favored
    - Significant Advantages
- Mounting Challenges Evident in Recent Years
  - Tightening Emissions Standards
  - Utility Interconnection Difficulties
    - Engines Precluded From Simplified Interconnection Rules/Certification
    - Certification Prerequisite to Net Metering/FIT
  - Utility Outage Capability
    - Increasingly Valued Feature
    - Difficult to Implement

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Confluence of 3 Publicly Funded R&D Projects

- Collectively Resulted in Successful Commercial Product
  - Qualifies for Simplified Interconnection (UL 1741 Certified)
  - Incorporates “CERTS” Microgrid
    - Innovative Plug and Play” Approach to Islanded Operation
  - CARB 2007 Compliant Emissions

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Funded R&D Projects

- Base Machine
  - California Energy Commision PIER* Program
  - Southern California Gas Co.
- Microgrid
  - California Energy Commision PIER* Programs
    - Multiple Phases (Laboratory to Field Demo)
  - US DOE Funding Some Phases
- Emissions
  - California Energy Commision PIER* Program
  - Southern California Gas Co.

The Public Interest Energy Research (PIER) program is the state's premier energy RD&D program, advancing science and technology in the fields of energy efficiency, renewable energy, advanced electricity technologies, energy-related environmental protection, and transmission and distribution, and transportation technologies.

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Partnerships

- Sponsors
  - CA Energy Commission, SoCal Gas, DOE
- Participants
  - University of Wisconsin
  - American Electric Power (AEP)
  - DE Solutions
  - Sacramento Municipal Utility District (SMUD)
  - Lawrence Berkeley National Laboratory (LNBL)
  - The National Renewable Energy Laboratory (NREL)
  - Tecogen Inc.

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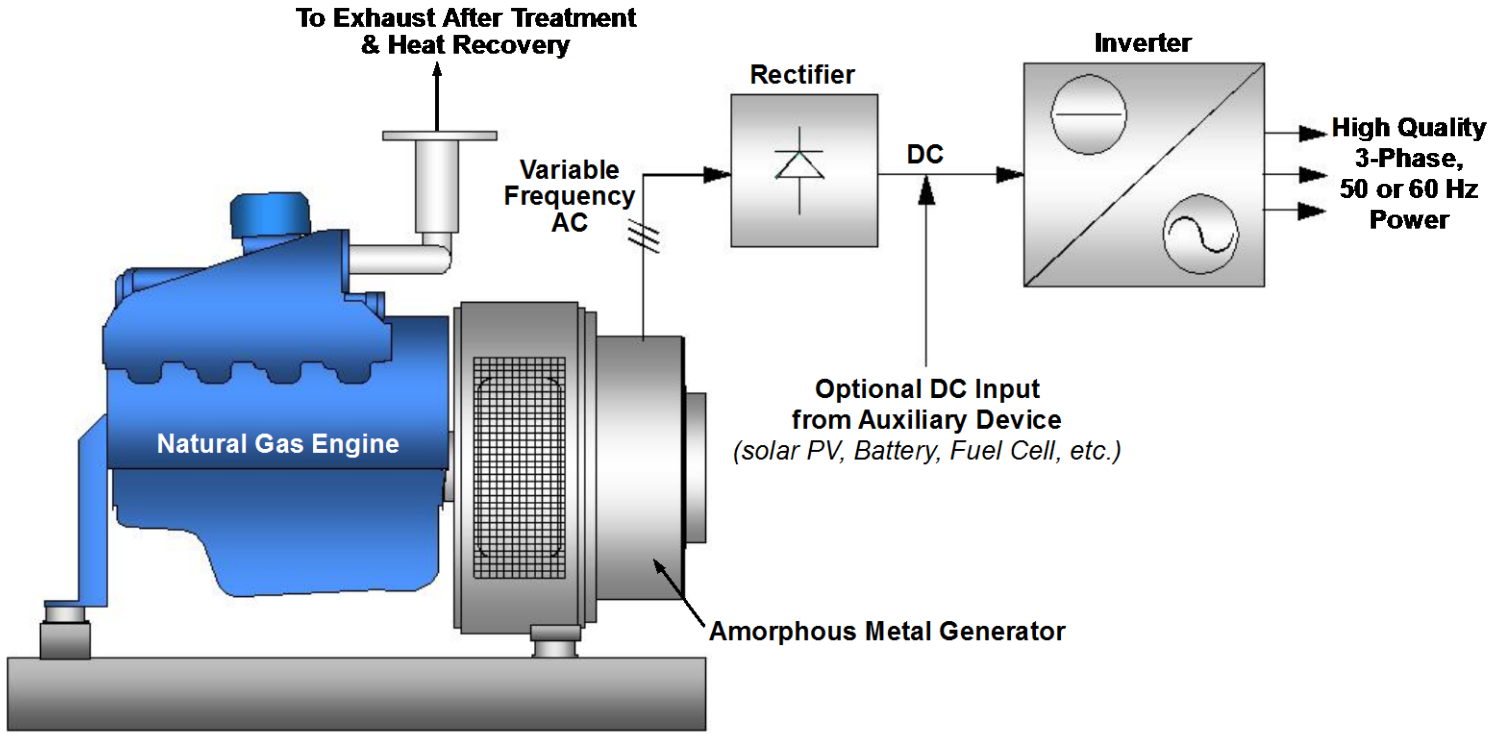
Basic Module Design

Power Conversion System



Engine/Generator Output

RPM	Volts	Freq (hz)	KW
1000	98	135	39
2200	207	297	93
3000	258	405	130

Power Conversion

Delivered kW

Volts	Freq (hz)	KW
480	60	37
480	60	88
480	60	123

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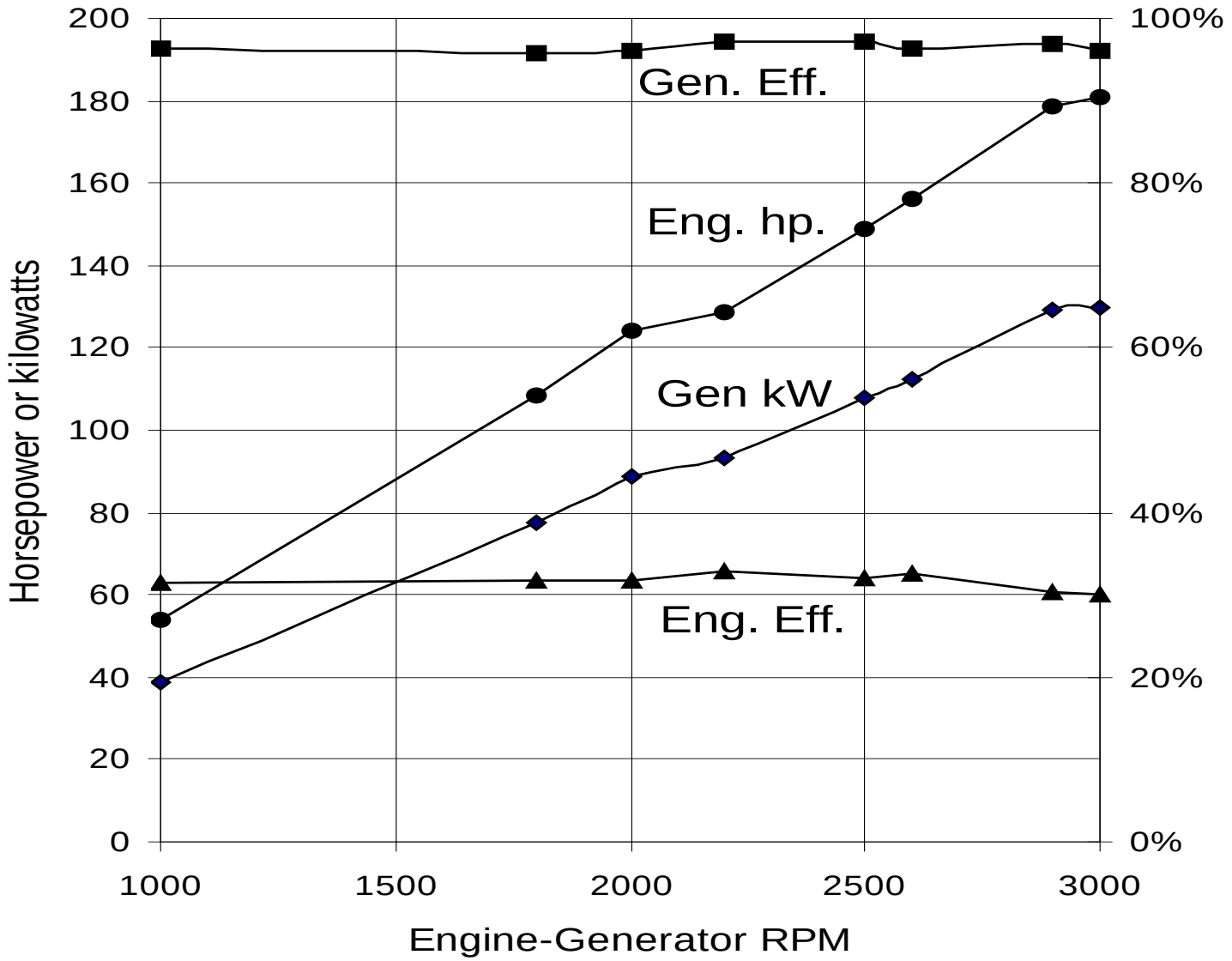
Variable RPM Performance



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Inverter-Based Features

- Qualifies for Standardized Interconnection
  - UL1741 Certification
  - Includes Anti-Islanding Feature
  - Prerequisite to Qualify for Feed-In Tariffs/ Net Metering
- Power Quality
  - No Reactive Power Use
- Power Boost for Demand-Side Response
  - High RPM Operation
- Enhanced Efficiency at Part Load
- Internationally Adaptable with Minor Changes
  - 50/60 Hz
- Potential for Outage Operation…

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Incorporation of CERTS* Microgrid

*The Consortium for Electric Reliability Technology Solutions (CERTS) was formed in 1999 to research, develop, and disseminate electric reliability technology solutions in order to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structure. The founding members include four DOE National Labs (Lawrence Berkeley National Laboratory (LBNL), Sandia National Laboratory (SNL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL); NSF's Power Systems Engineering Research Center; and the Electric Power Group.

CERTS Test Facility at AEP's Dolan Lab

Technical Challenges of Utility Outage Operation

- Requires Two Distinct Operating Modes
  - Grid-Tie
  - Islanded Operation
- Grid-Tie Common/Straightforward
  - Utility Provides Foundation
- Outage Operation More Difficult, Especially with Multiple Units (which is Typical)
  - Requires Control Basis for Establishing Frequency
  - Real and Reactive Power Must be Shared
    - Not Inherently Stable
  - Conventional Approaches Fairly Complex
    - Impractical in Small Module Applications
- CERTS System Provides Solution…

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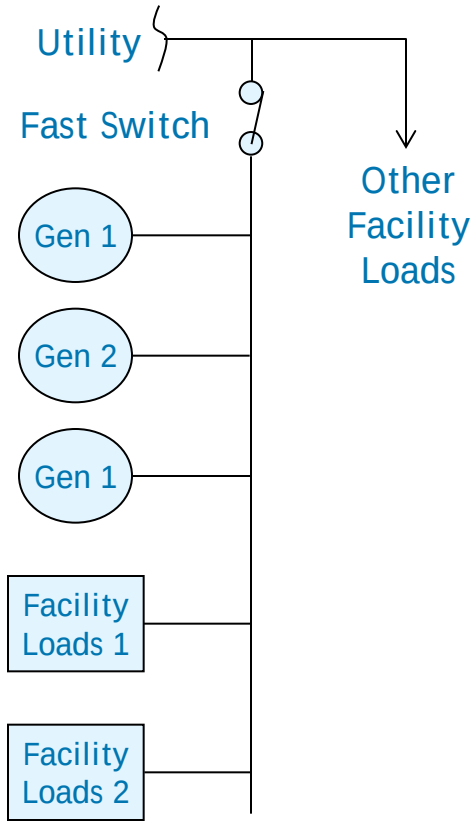
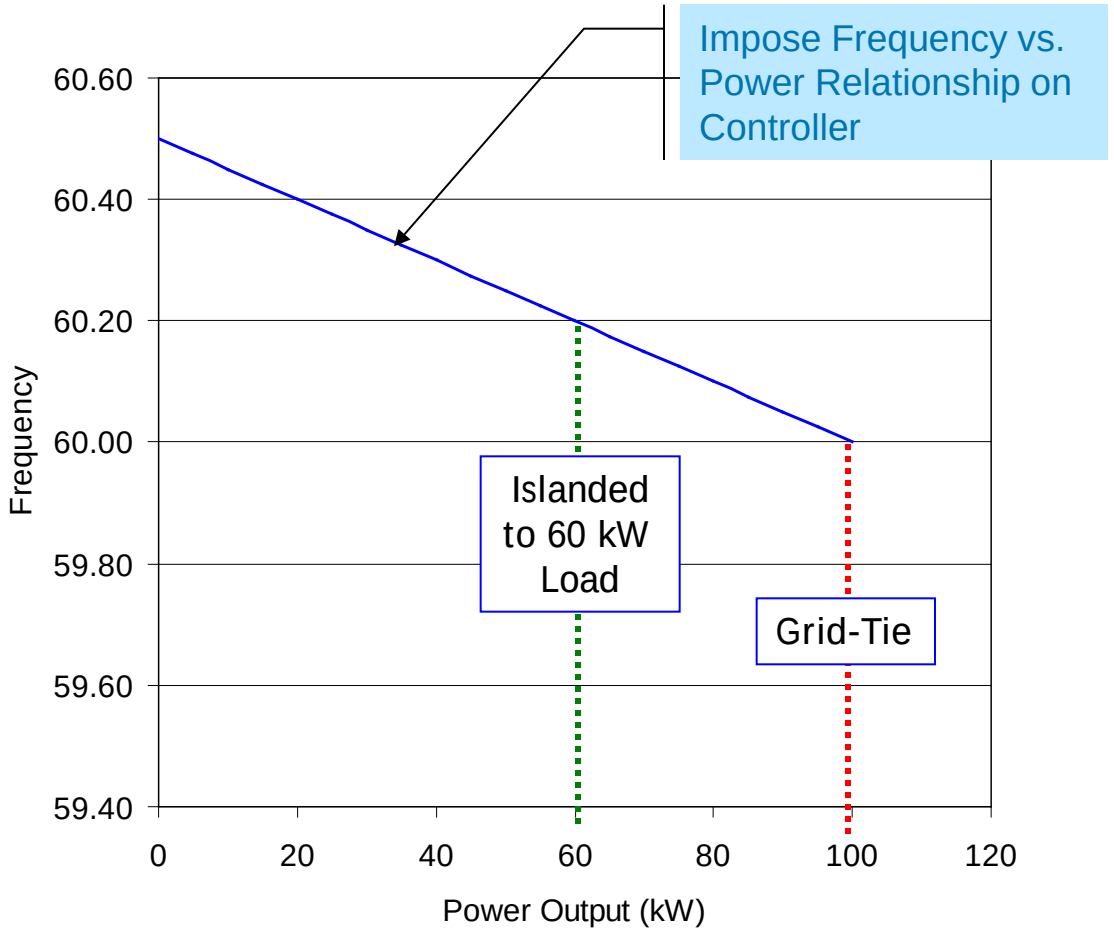
Microgrid Concept

- What is a Microgrid?
  - Collection of Distributed Energy Resources
    - CHP, PV, Wind, Batteries, Fuel Cells
  - Integrated into Single System
  - Can operate in Grid-Tie or As an Intentional Island
- Features and Benefits
  - Supports Utility Grid
  - Customer Outage Capability
    - Upon Power Quality Event, Connect/ Reconnect Seamlessly (UPS)



Hypothetical Microgrid

Droop Control



- Grid Tie
  - Frequency is Fixed 60 Hz
  - kW Output Per Function

- Islanded Operation
  - Frequency = f(load)
- Example
  - Load = 60 kW
  - Frequency = 60.20 Hz

Droop shown is for illustration only

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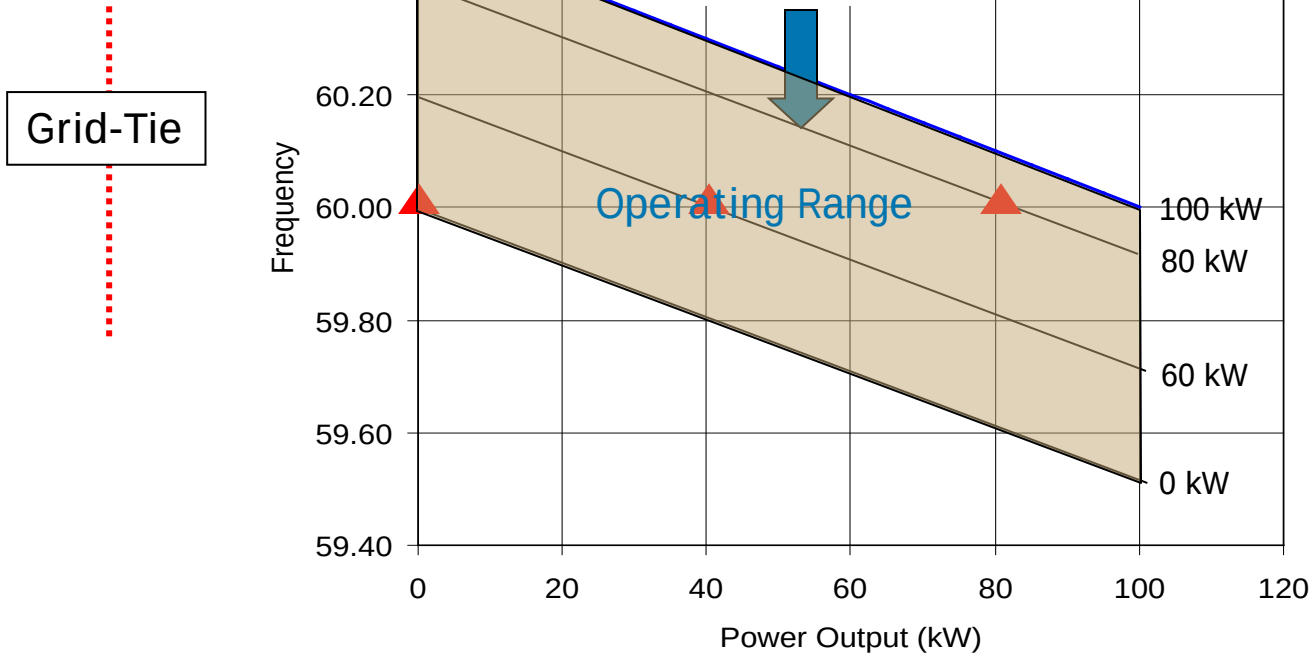
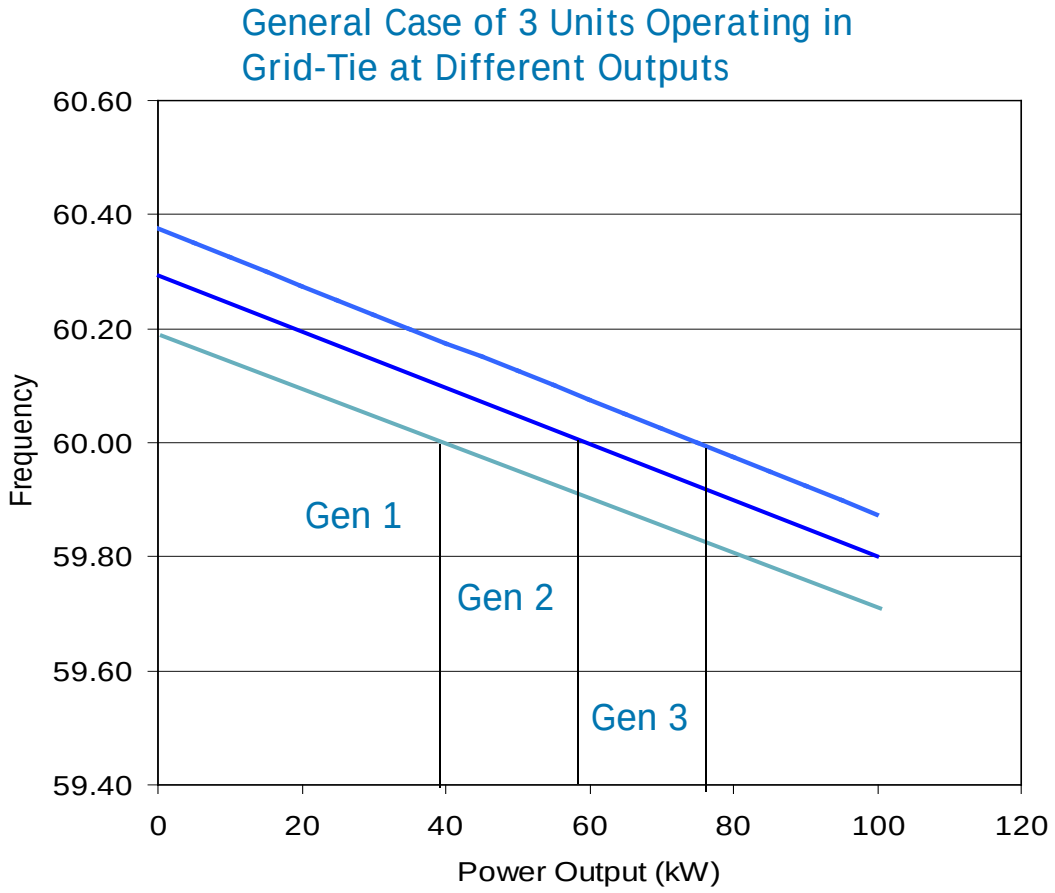
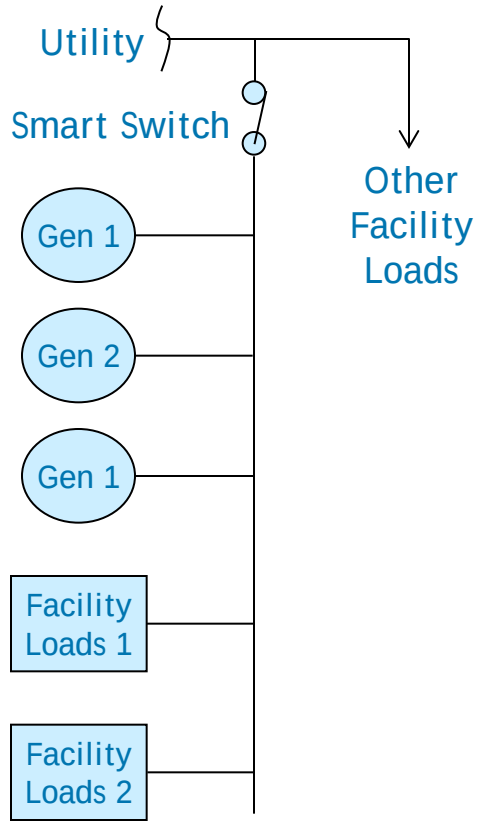
Droop Control in Grid-Tie



- Frequency Fixed at 60 Hz
- Output Changed by Changing Control algorithm
  - Droop is Depressed
- Operating Range as Shown

Consequences of Imposed Droop Control on Island Operation





Hypothetical Microgrid

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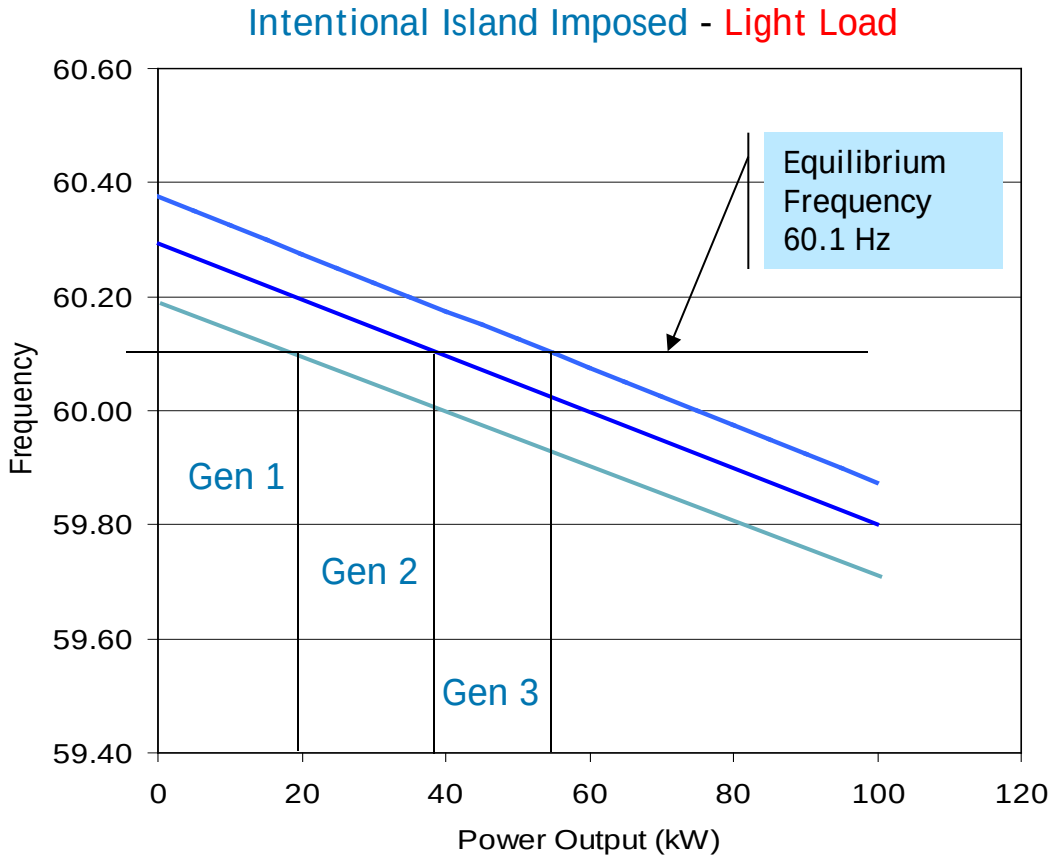

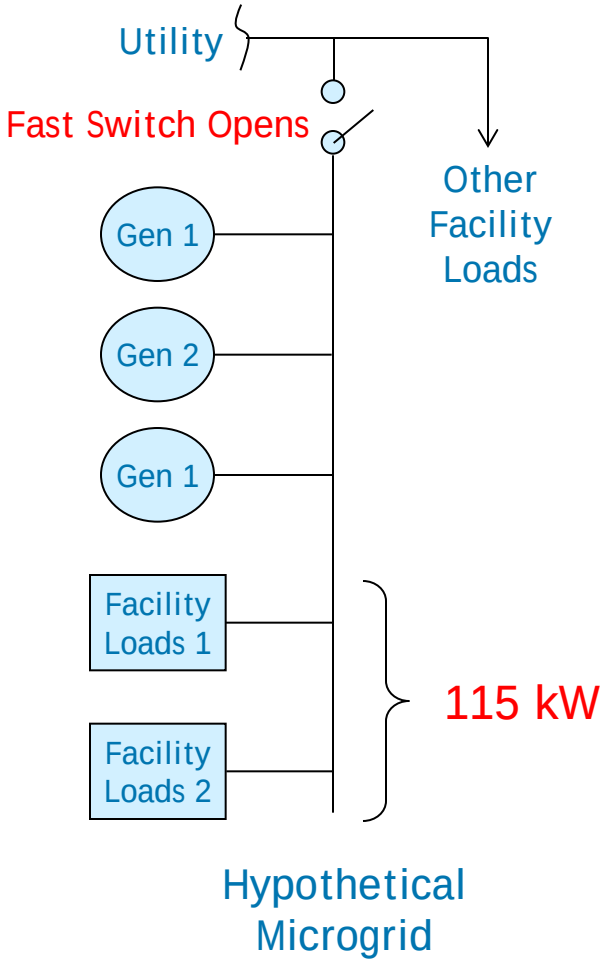

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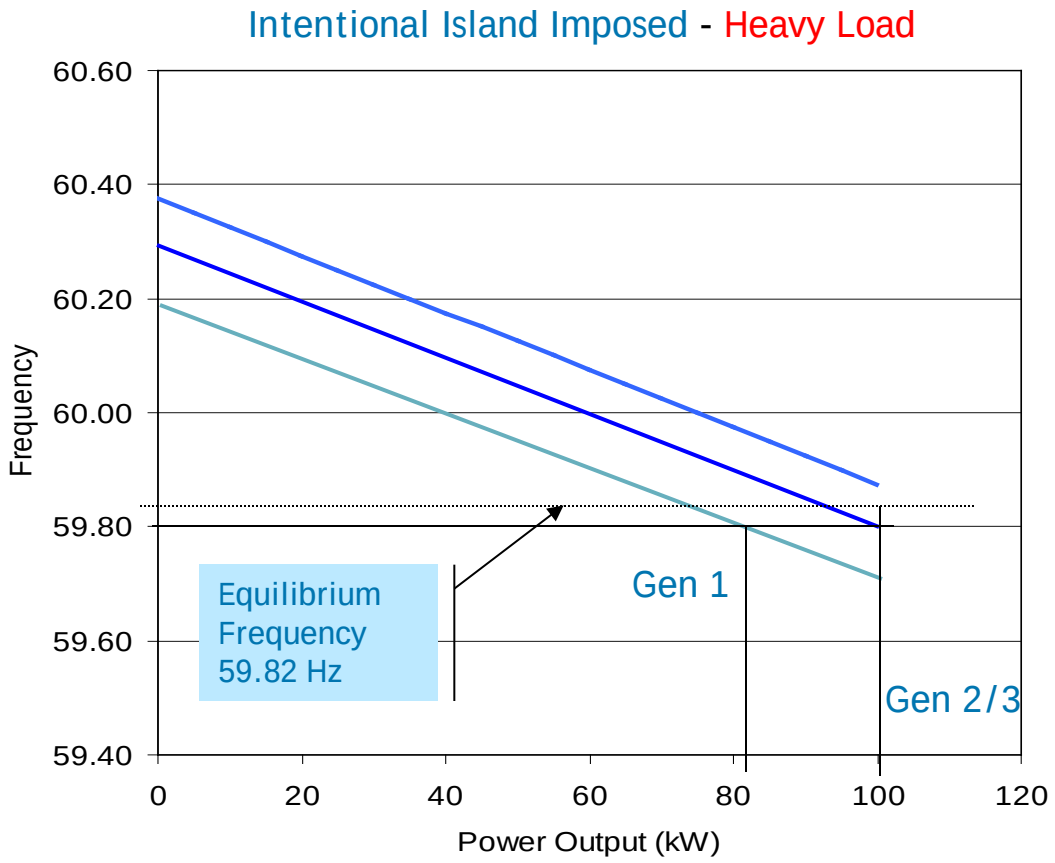
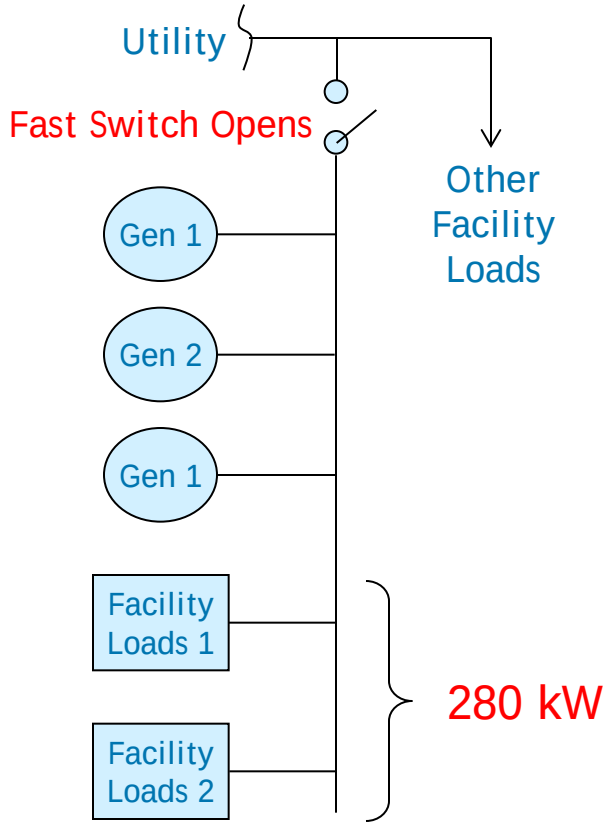
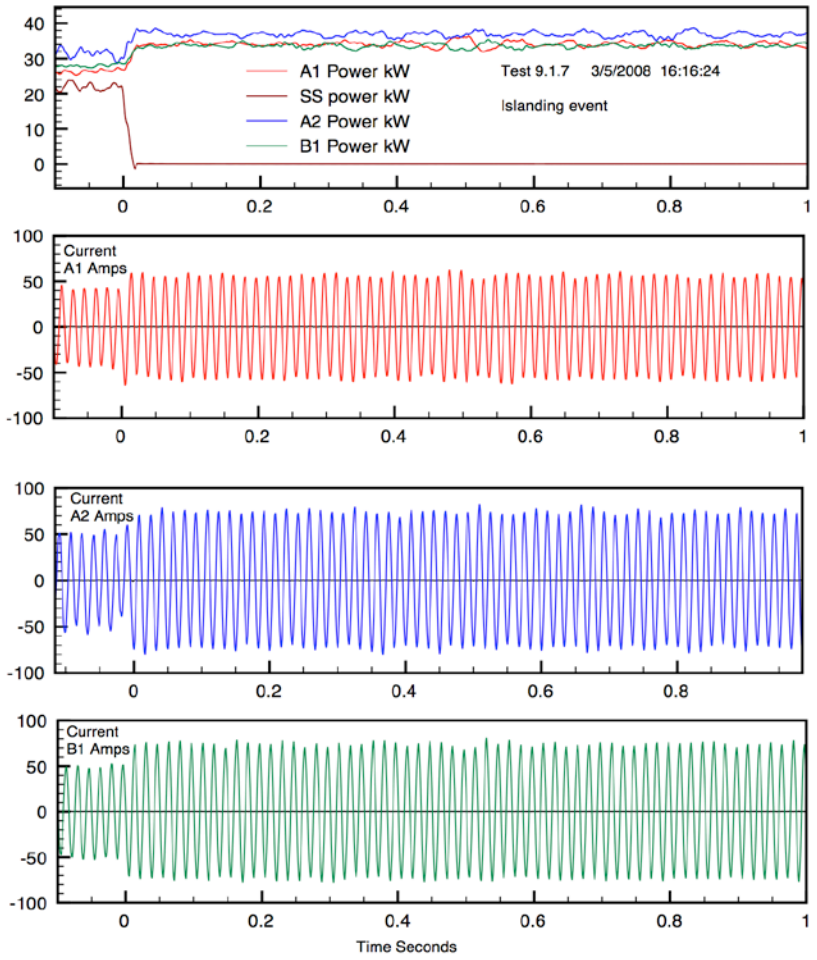




Hypothetical Microgrid

Island Event (CERTS Phase I Test)

- Initial Condition
  - Three Units Grid Tie
  - ~ 120 kW Load
    - 30 kW/ Module
    - 30 kW Utility Import
- Intentional Island Imposed (t=0)
  - Utility Import Ceases
  - kW/kVAR Balanced
  - Stable in Several Cycles



CERTS Microgrid Features/Benefits

- Solves Control Problems Inherent in Controlling Multiple Power Sources in Isolated Circuit
  - No External Controllers Required
  - Control Resides Within Factory Firmware
    - No Field Set-up/Tuning (Plug and Play)
  - Each Module is Entirely Autonomous
    - No single Point Failure
    - Units are Truly Modular…Future Machines Have No Control Impact on Others
- Extremely Stable/Rapid
  - With Fast Switch Can Serve UPS Function
    - Seamless Transfer/ Excellent Power Quality
  - Integrate With Other Technologies
- Applicable to Simpler Standby Schemes
  - Non-Seamless Transfer (Common Tecogen Application)

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SMUD Microgrid Project Overview

- California Energy Commissioned funded project
- Partners
  - Include DE Solutions, Tecogen, NREL, CERTs, Univ. of Wisconsin
- System
  - 310kW demo of CEC/DOE/CERTS Microgrid concept
    - Three 100 kW Units
    - 10 kW PV System
  - Thermal Output from CHP Plant
    - 120 Ton Absorber
    - Space Heat/ Domestic Water
  - Extremely Large Chilled Water Storage Tank (existing)
- Operation
  - General Operating Mode: Grid-Tie/ Full Output
  - Island During Utility Fault

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System Operation

- Grid Connected
  - Connected to 21 kV Feeder supplying loads in the Central Utility Plant (CUP) and Field Reporting Facility (FRF)
  - Excess electricity exported back to grid
  - Conventional Waste Heat Utilization: Absorption Chilling/ Space/ DHW
- Islanded Operation
  - Microgrid CHP system will “seamlessly” transition to islanding mode during grid disturbance
  - Non-critical loads in the CUP/FRF will be tripped
  - Remaining sensitive and critical loads will be prioritized and tripped off line as required (load shedding)
  - CUP will be served from three INV-100 units through a 480 volt bus
  - Smart Switch will automatically resynchronize microgrid
- Status
  - Commissioning in Process

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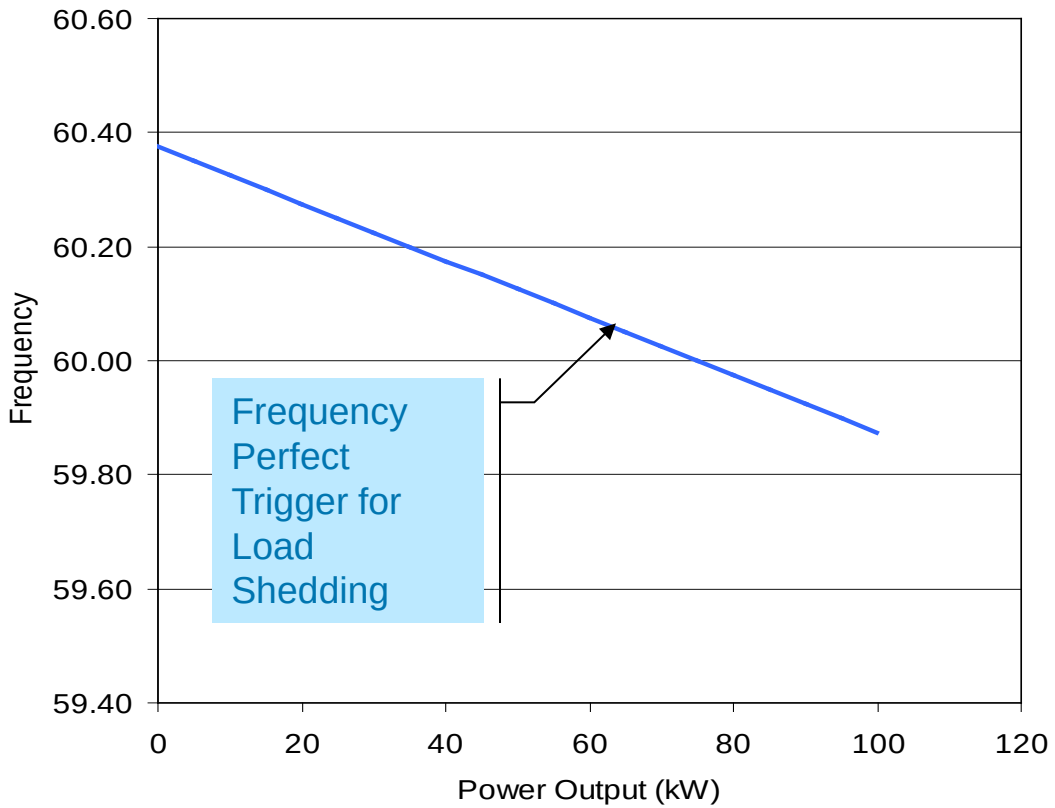
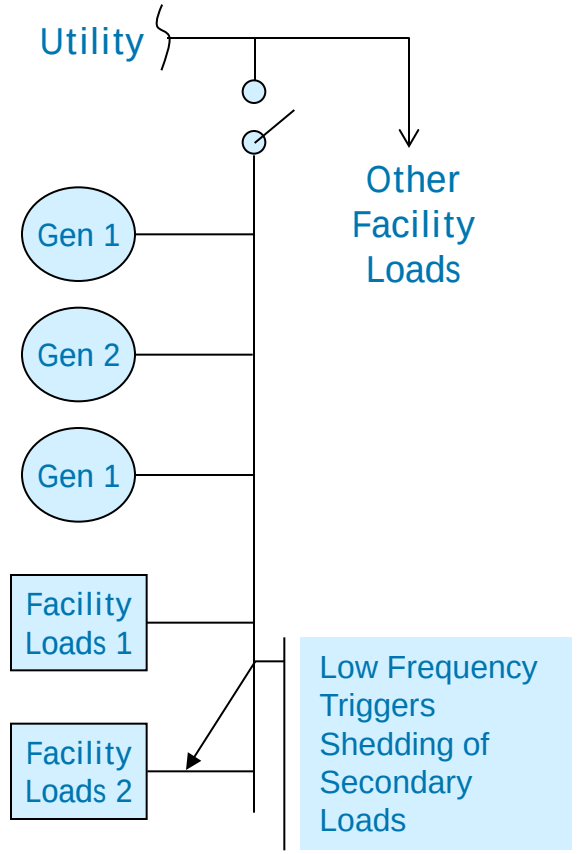
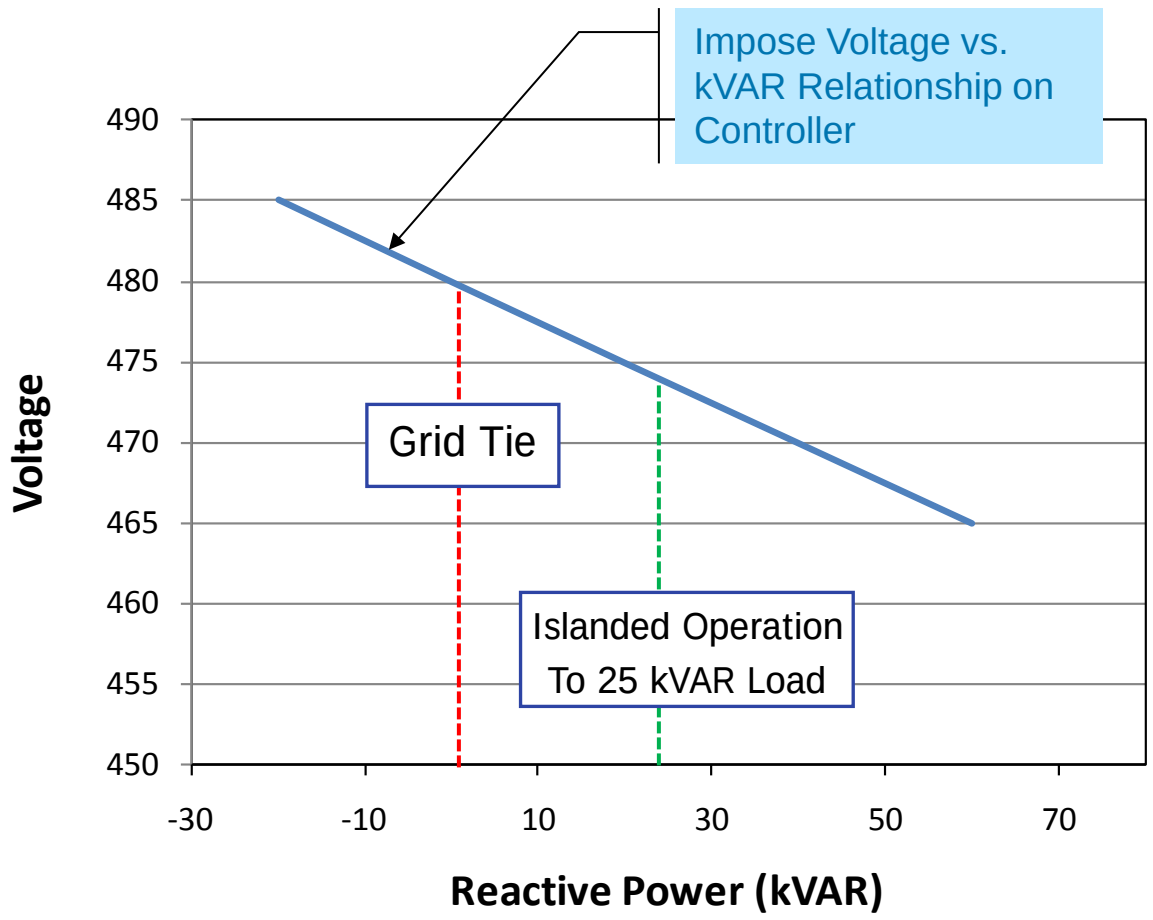
Load Shedding (When Islanded Load Exceeds Available Output)





Droop Control (Power Factor)



- Grid Tie
  - kVAR output set by Droop (1 typical)
  - Units Generally Share Identical Droop

  EMS Feedback Needed to Avoid Drift

- Island Operation
  - Load Sets Reactive Power Requirement
  - Voltage of Unit(s) will Equilibrate Per Droop

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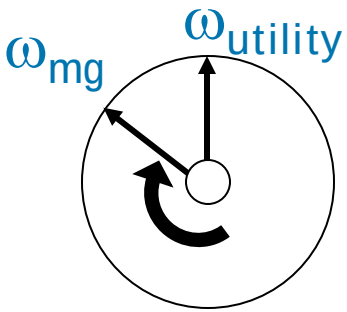
Resynchronization to Utility

- Droop System Assures Frequency Offset Between Grid & Microgrid
- Active Synchronization Unnecessary
- Relative Angular Velocity
  - $\omega_{mg} - \omega_{utility} < 0.5$ Hz
- Smart Switch Closing can be Controlled by Simple Relay (R)
- No Feedback to Generators Required



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Operational Experience NYC Area (Sandy)

- Considerable NYC Population of CERTS Enabled Units
- Majority Unaffected by Hurricane
- Three Commissioned Sites Lost Power
  - Site 1 (6 Modules/ Warehouse)
    - Maintained Islanded Operation Until Water Flooded
  - Site 2 (4 Modules/ 400-Unit Condo)
    - Fully Powered Facility Until Utility Restored (5-6 Days)
  - Site 3 (4 Modules/ 400-Unit Condo)
    - Units Well Above Street Level
    - Switchgear in Basement Flooded

Questions?

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