



Microgrid Control

PSERC Tele-Seminar
Presentation

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CERTS Microgrid Project by CEC



● CERTS Research Team

- ▶ LBNL, SNL
- ▶ University of Wisconsin (Lasseter)
- ▶ Northern Power Systems
- ▶ Tecogen
- ▶ Youtility Inc.
- ▶ American Electric Power



Presentation Overview

- **Basic Microgrid**
 - ▶ **Overview of Distributed Generation**
 - ▶ **Proposed Microgrid Architecture**
 - ▶ **Final Control Concepts**
- **Hardware System Implementation**
 - ▶ **Setup Description**
 - ▶ **Hardware Tests**
- **Future Work**



State of the Art on Prime Movers

● Non-Renewables:

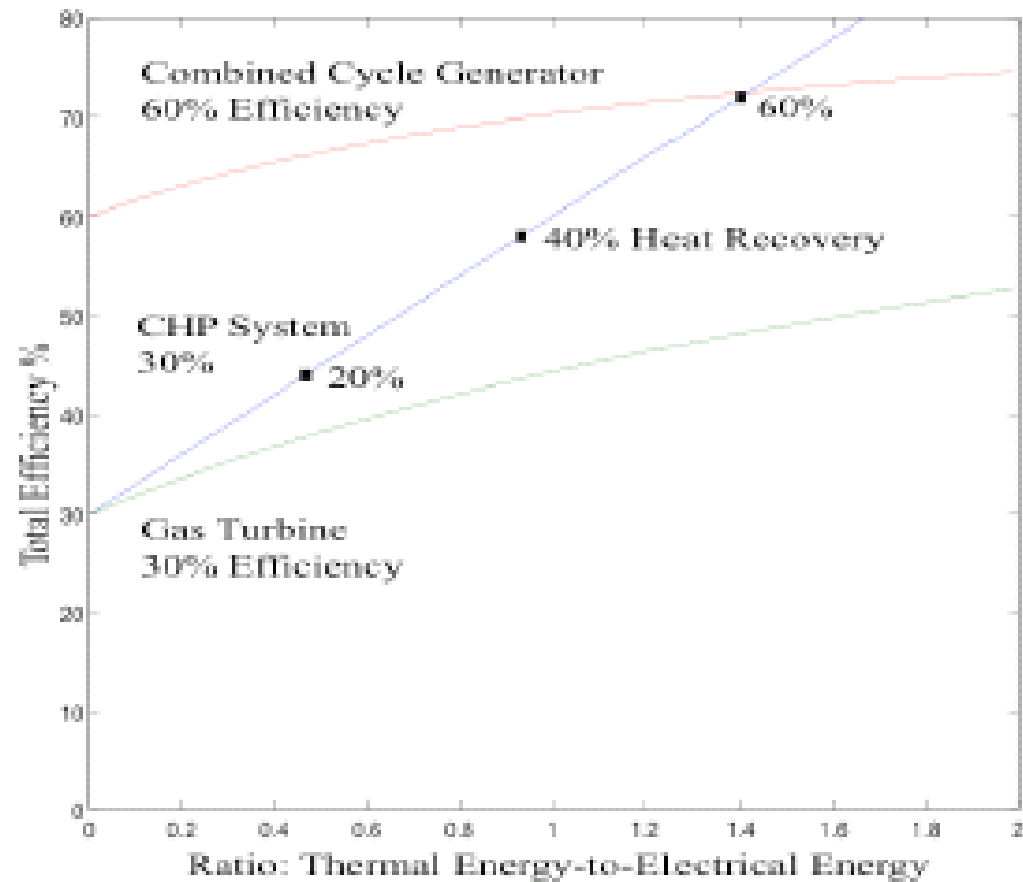
- ▶ Internal Combustion Engines
- ▶ Combustion Turbines
- ▶ MicroTurbines
- ▶ Fuel Cells

● Renewables:

- ▶ Photovoltaic
- ▶ Wind
- ▶ Biomass

Combined Heat and Power (CHP)

- Unlike electricity, heat cannot be efficiently transmitted over long distances
- Heat can be used in space heating, desiccant dehumidification, water heating, process heat
- Total efficiency (electric + heat) increases as heat demand increases





Distributed Generation Issues

- **California has set a goal of achieving 20% of new generation additions with distributed generation by year 2010: nearly 50,000 new small generators could populate the grid in California alone**
- **All these new units cannot be centrally controlled, they must be clustered with loads**
- **Interconnection Standards**
 - ▶ **IEEE P-1547, CA Rule 21: Disconnect on V, f deviations and source shutoff**
- **Barriers**
- **System Issues**
 - ▶ **Protection**
 - ▶ **Stability**



Basic Microgrid

- **Northern Power, GE, EPRI, NextEnergy, CERTS-UW define microgrid as a cluster of sources and loads configured in a radial network capable of operation in parallel or independent from the grid**
- **Intentional islanding to ensure power quality to sensitive loads**



Basic Microgrid Issues

- Northern and NextEnergy approaches heavily rely on communication system for providing a real-time picture of the loading condition in the microgrid
- Approach requirements:
 - ▶ Extensive site analysis
 - ▶ Metering and data collection
 - ▶ Custom-based design of the system
- Installation of additional unit after design is difficult



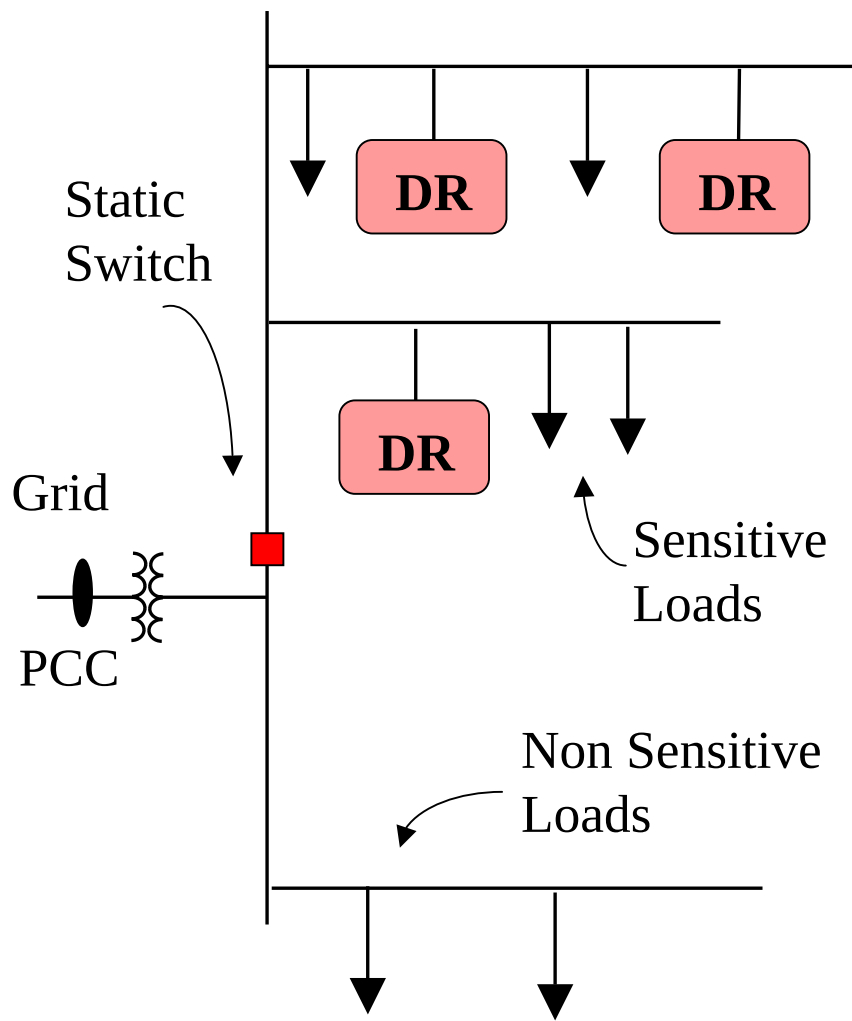
CERTS-UW Expanded Microgrid Concept

- **One-point connection with the rest of the system**
 - ▶ **Interconnection equipment and requirements are relegated to a single location**
 - ▶ **Single dispatchable unit from the utility**

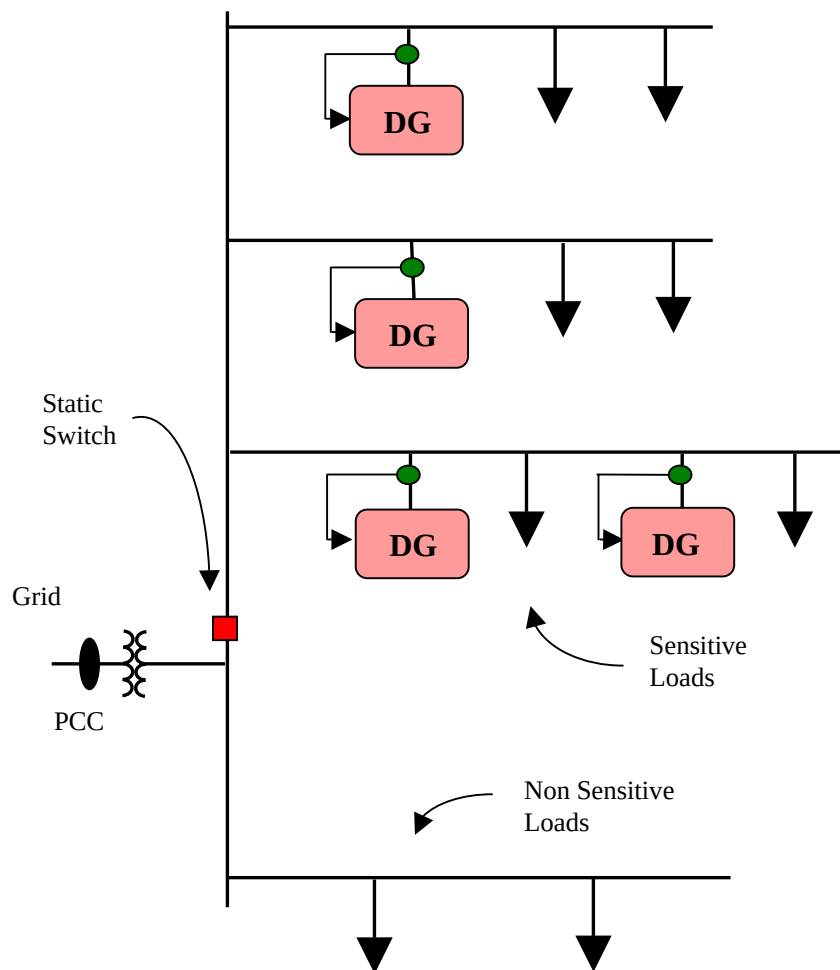
- **Peer to peer configuration**
 - ▶ **No critical unit failure**
 - ▶ **Increase of system reliability (n+1)**
 - ▶ **No critical system of communication**

- **CHP applications to take advantage of waste heat**
 - ▶ **Plug and play required to install units near heat demand**

Proposed Microgrid Architecture

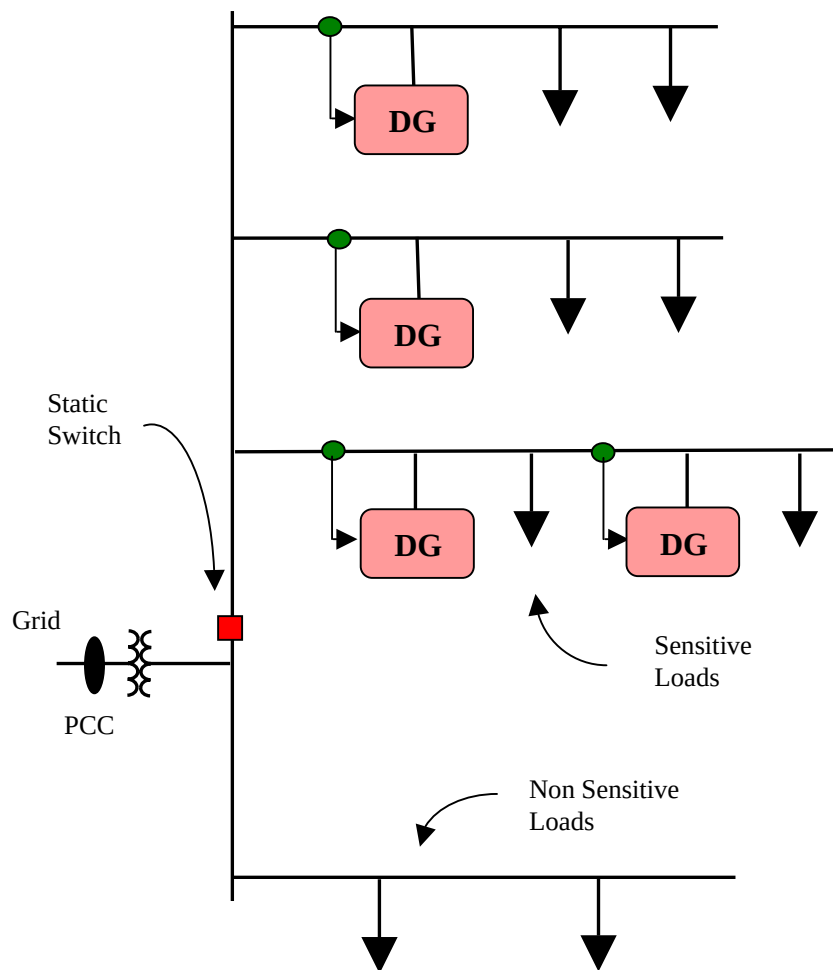


- PCC is the location where interconnection standards are enforced
- Sensitive loads are clustered together with distributed generation behind the static switch
- Non sensitive loads are on separate feeders
- Units must have key features to ensure p&p and p2p functionality:
 - ▶ Use of local information only
 - ▶ Independent setpoints choice
 - ▶ Stored energy at each unit
 - ▶ Ability to autonomously and independently readjust output power following islanding



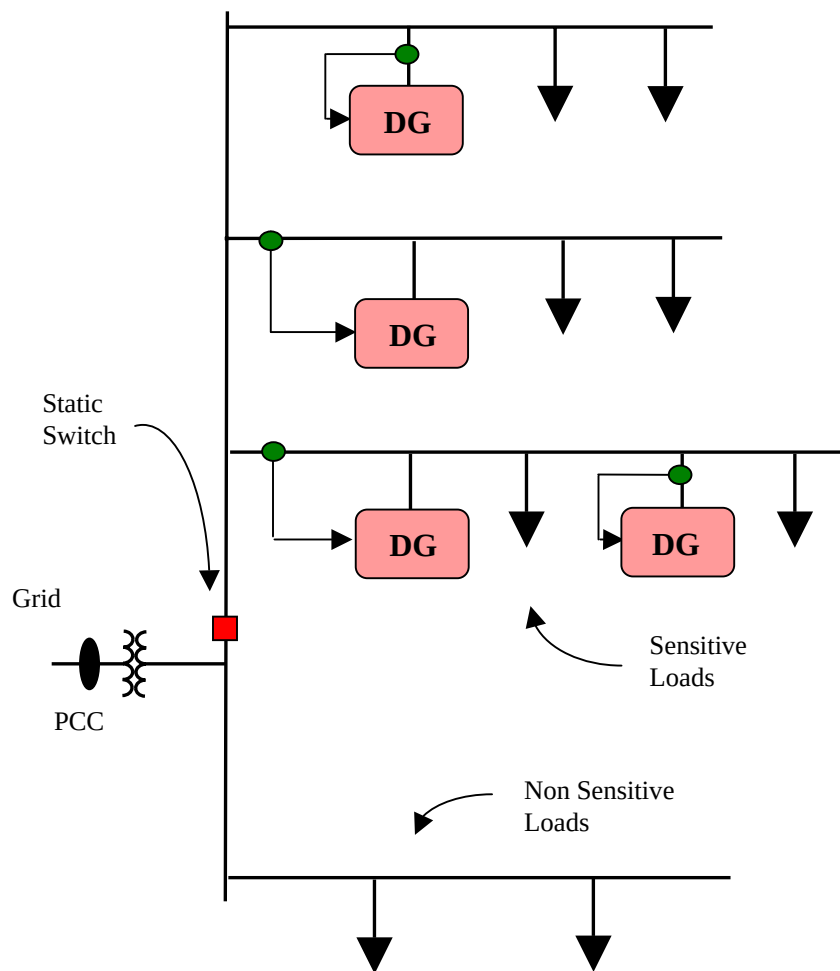
Unit Power Control

- Tracks request of P
- Extra demands from loads are provided by the grid
- Fits CHP applications, where $P=f(H)$



Feeder Flow Control

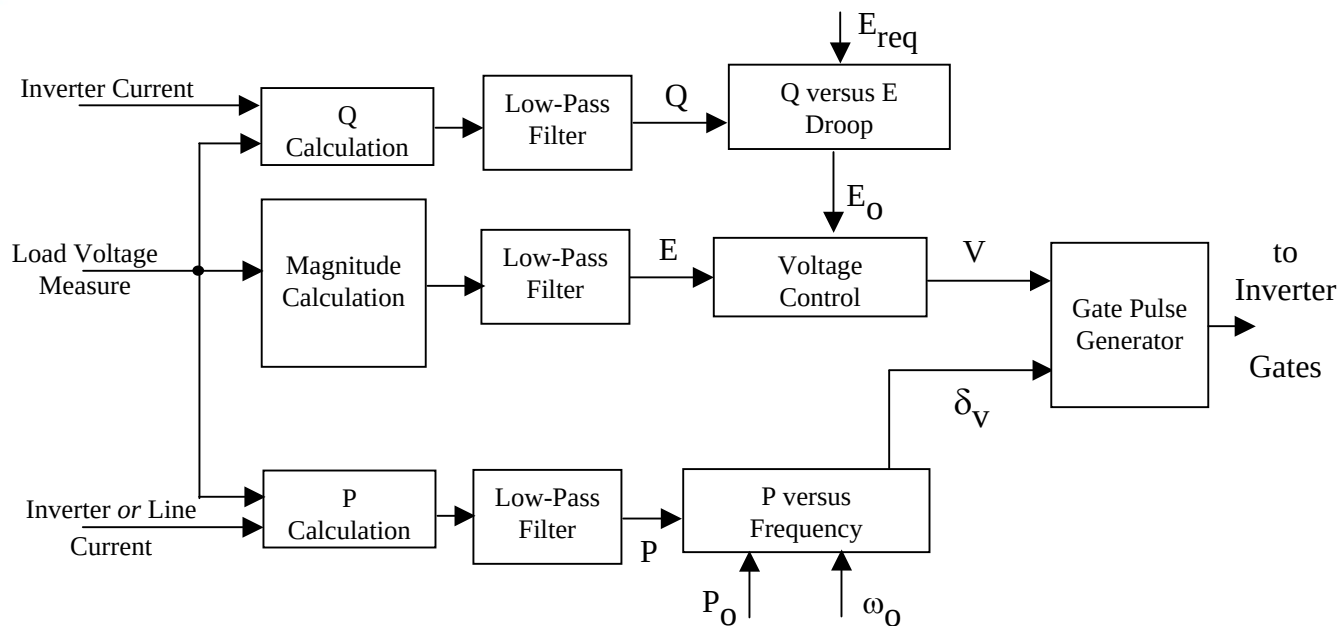
- Tracks requests of F
- Extra demands from loads are provided by sources
- Microgrid becomes a true dispatchable load as seen from the grid
- Allows particular pricing contracts to be signed



Mixed System

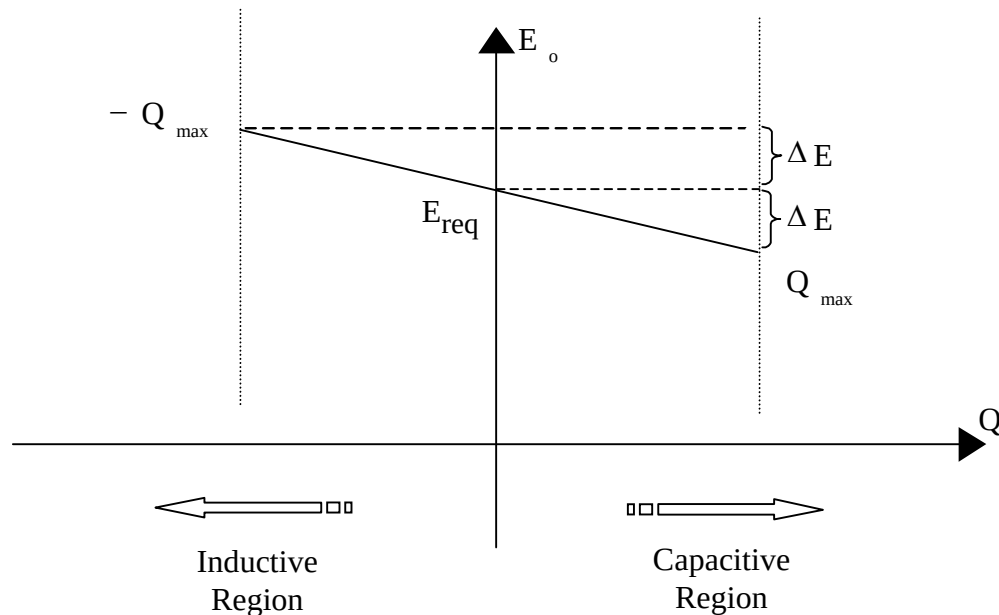
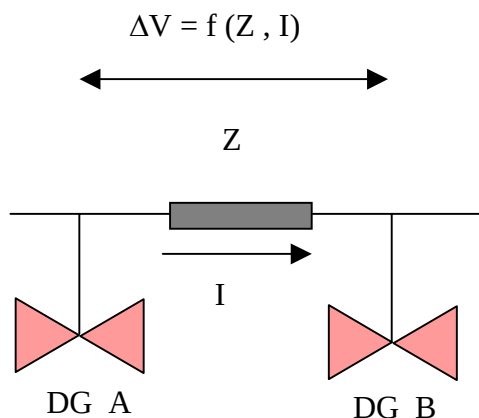
- Some units track P, other F requests
- Hybrid system could enjoy the best of both worlds
- Same unit may operate in one mode or the other, switching modes at any point in time

Final Control Concepts



- Control regulates voltage magnitude and power
- Power vs frequency droop to redispatch during island
 - ▶ Fixed slope and active power limits
- Reactive power droop to limit reactive current injection
 - ▶ Voltage setpoints can be independently chosen
 - ▶ Units can be installed in parallel

Q versus E Droop

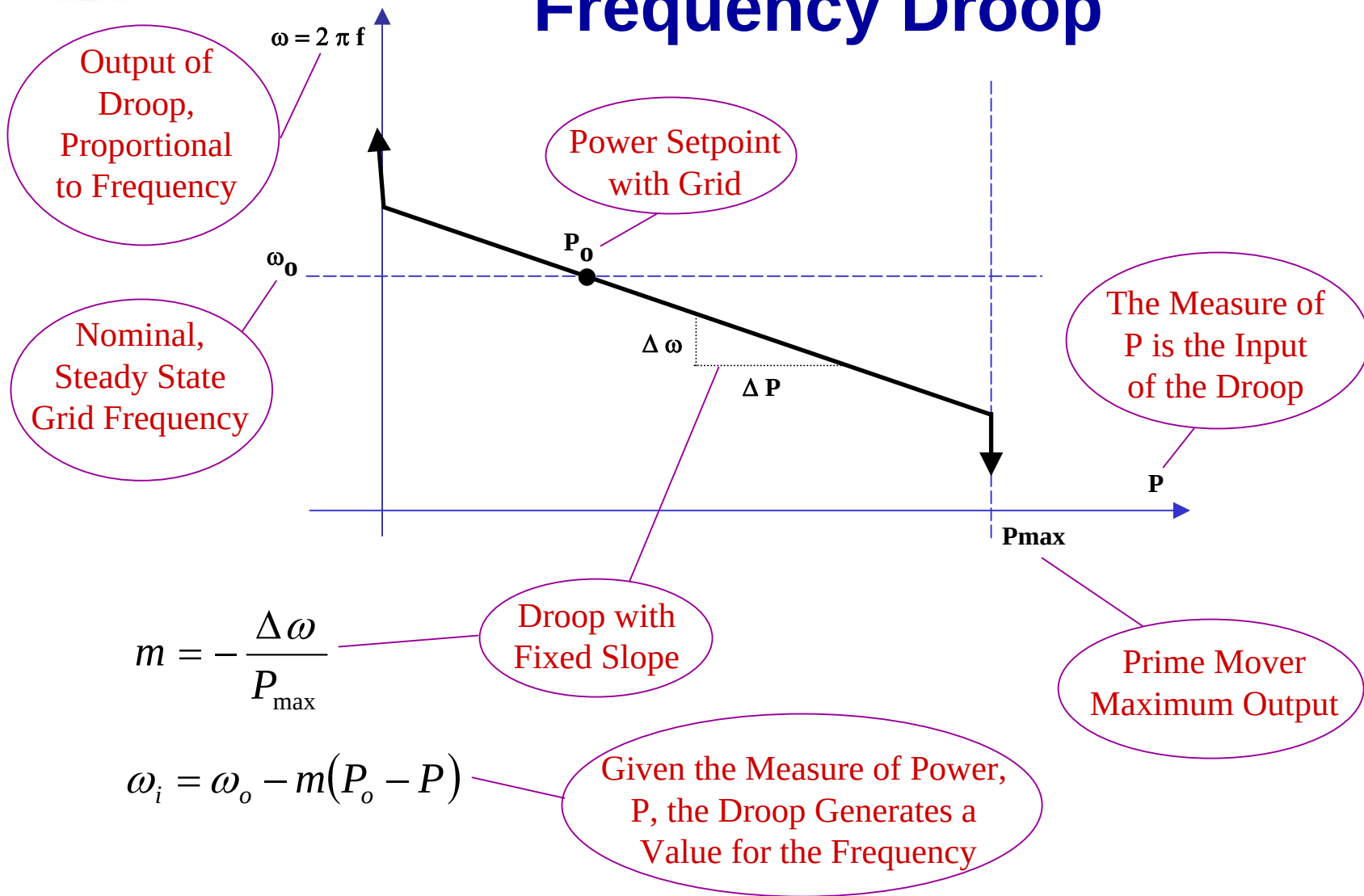


$$E_o = E_{req} - m_Q Q$$

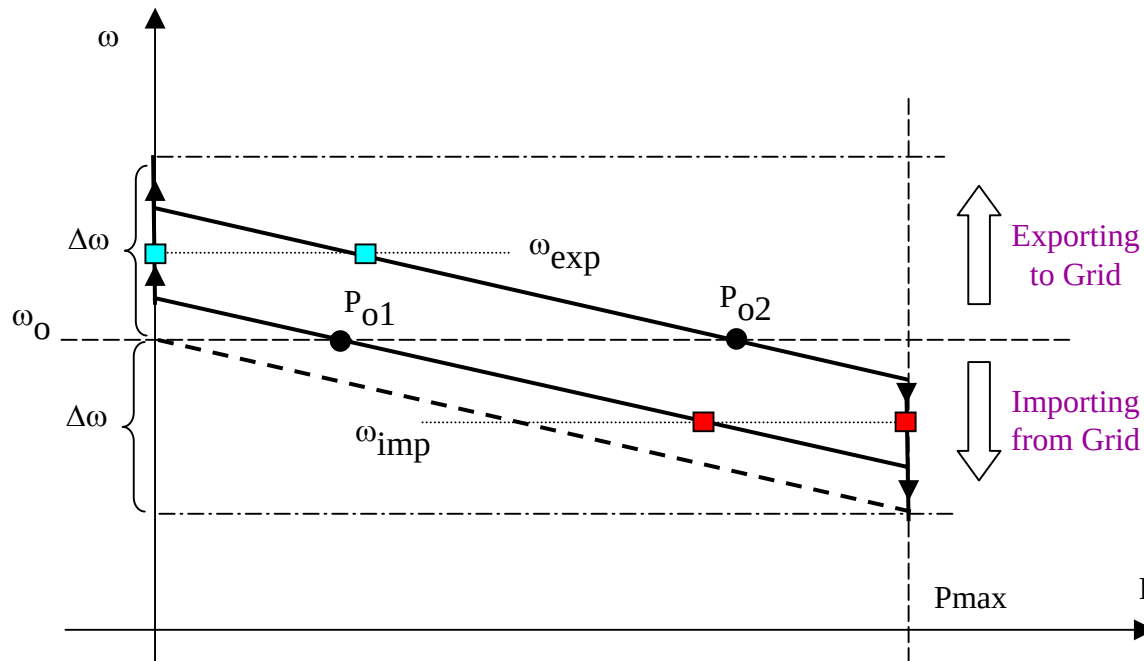
$$m_Q = \frac{\Delta E}{Q_{max}}$$

- Voltage difference between sources is function of impedance and current between them.

Description of P versus Frequency Droop

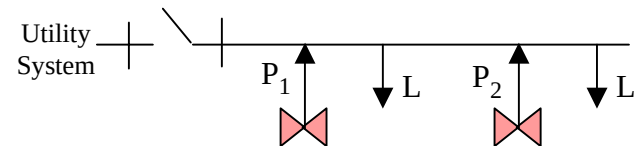


P versus Frequency Droop

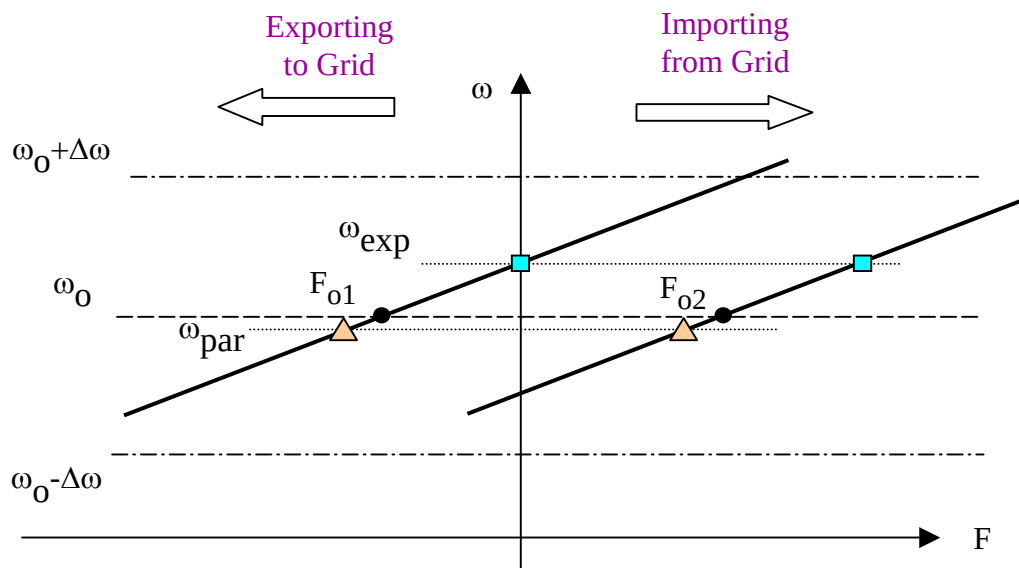


$$m = -\frac{\Delta\omega}{P_{max}}$$

$$\omega_i = \omega_o - m(P_{o,i} - P_i)$$

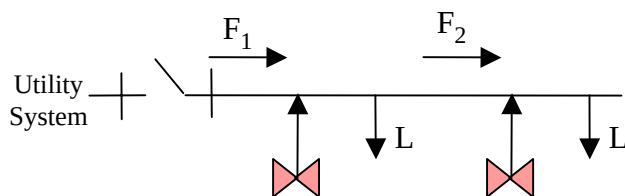


P versus Frequency Droop

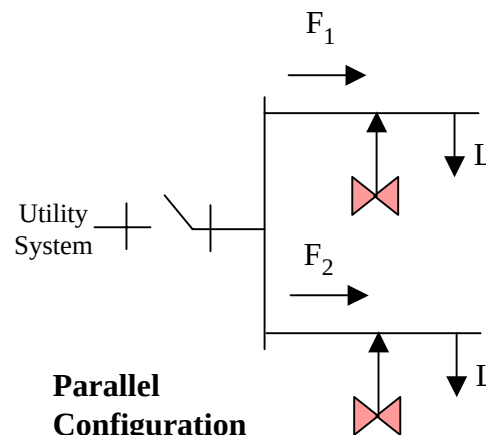


$$m_F = \frac{\Delta\omega}{P_{max}}$$

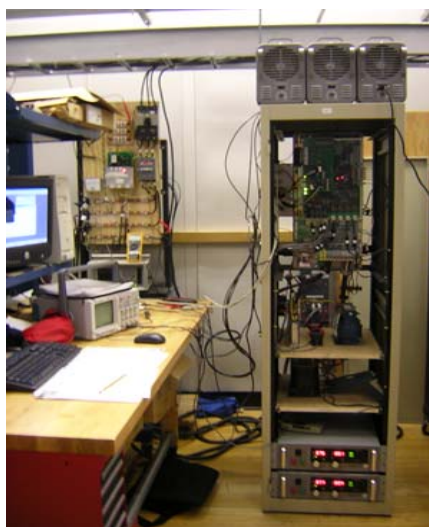
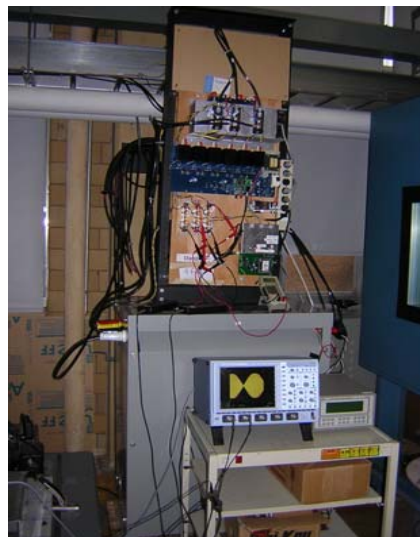
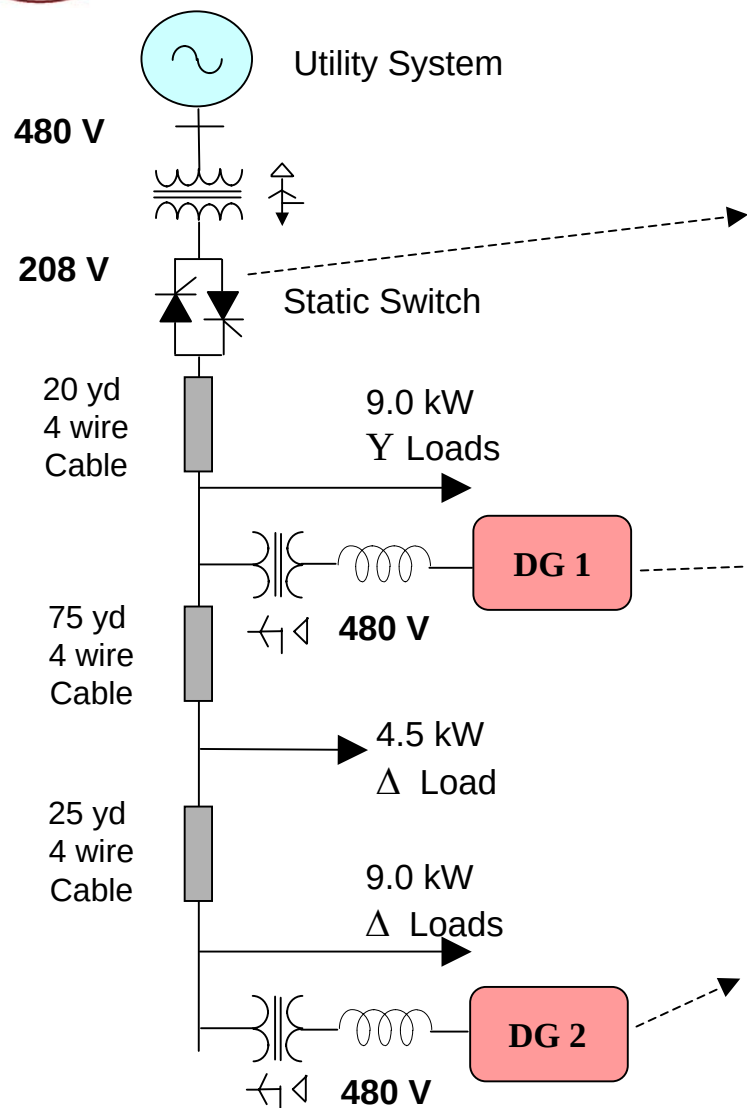
$$\omega_i = \omega_o - m_F (F_{o,i} - F_i)$$



Series Configuration



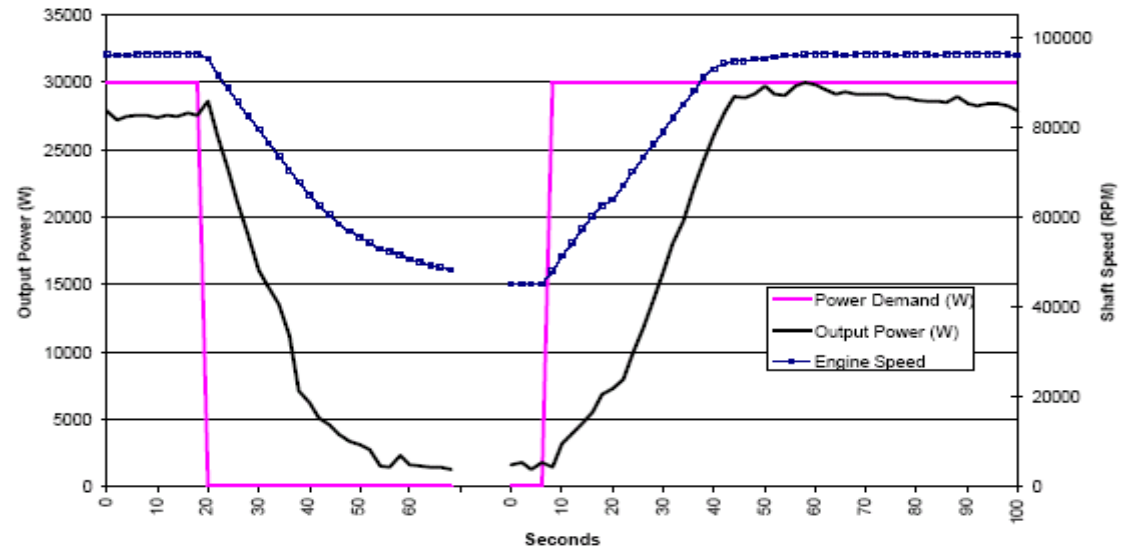
Parallel Configuration



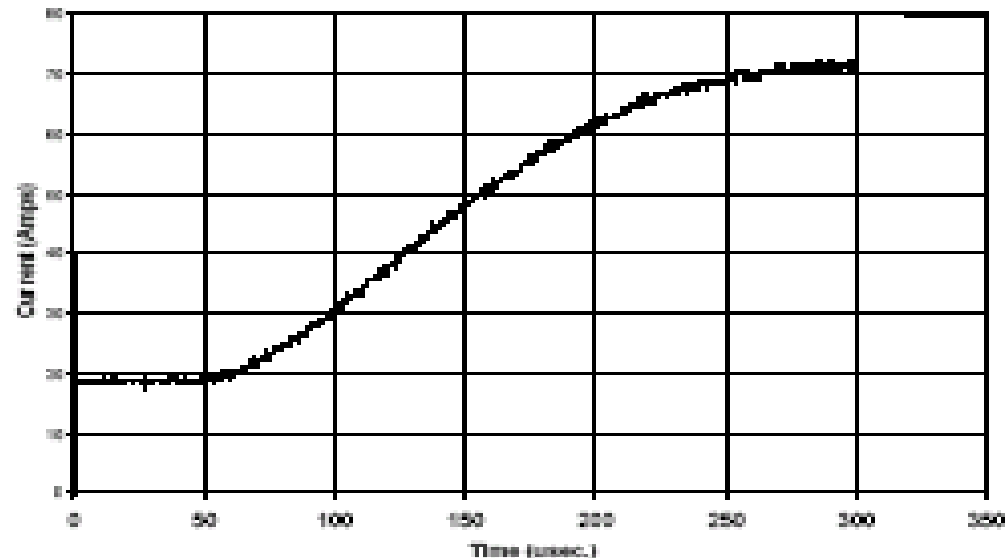


Storage Issue

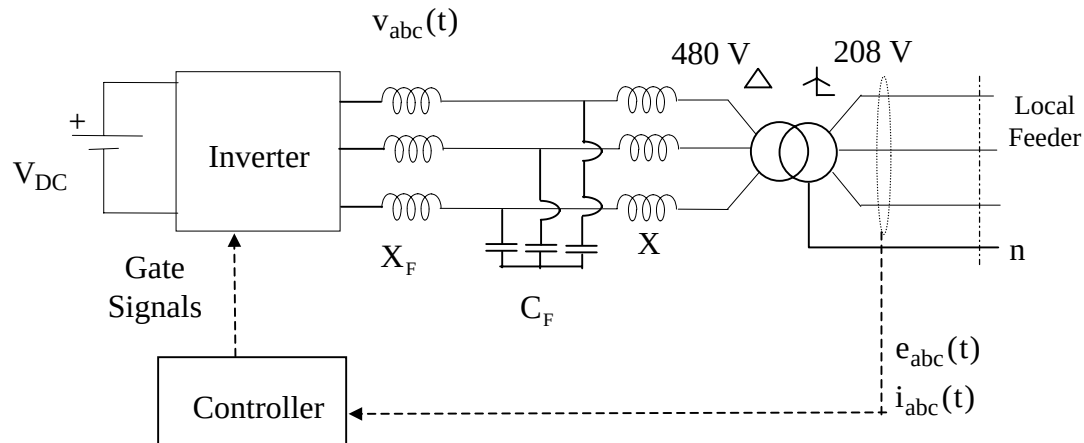
**Capstone
Microturbine**



**3.5kW Fuel
Cell Stack**

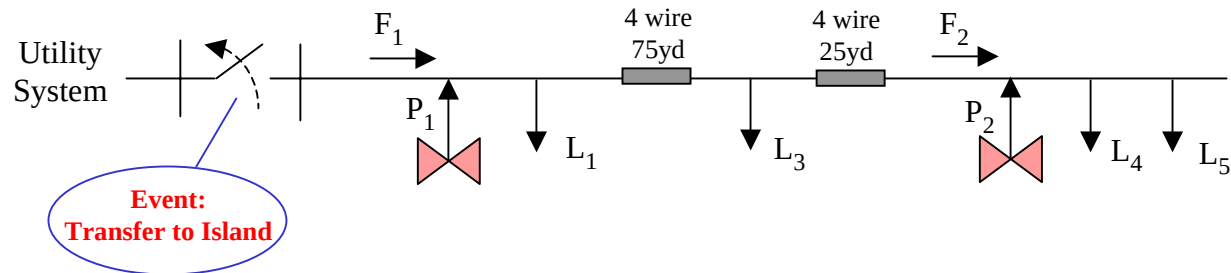


Hardware Microsource Diagram



- Ideal DC bus of 750V
- 15kW inverter at PF=0.8, with switching frequency of 4kHz
- Filter to eliminate harmonics at switching frequencies
- Inductance sized for maximum power angle of 7 degrees
- 45 kVA transformer
- DSP board that implements the control

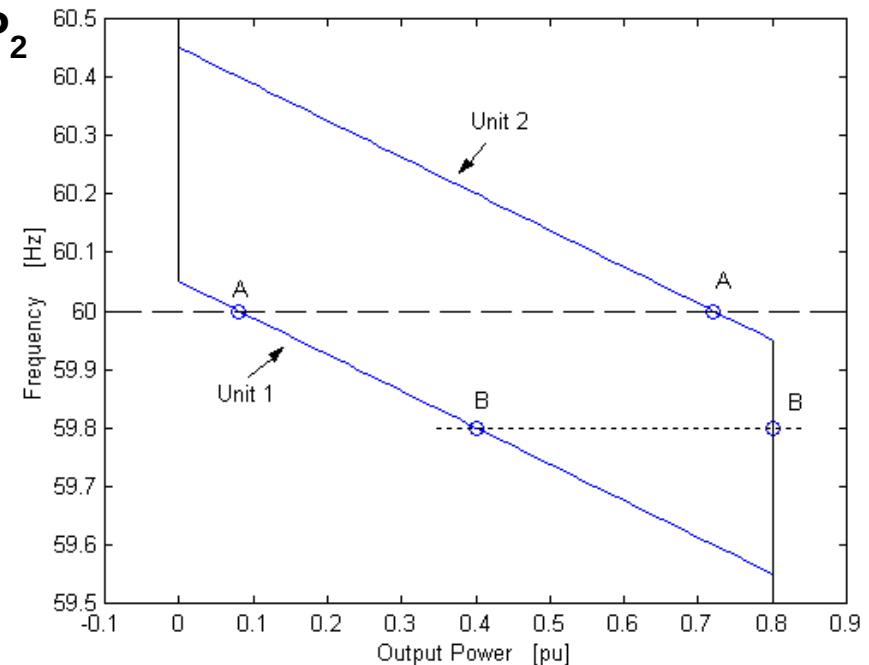
Unit Power Control: Reaching Maximum Power



Event shows Unit 2 reaching maximum output power after islanding.

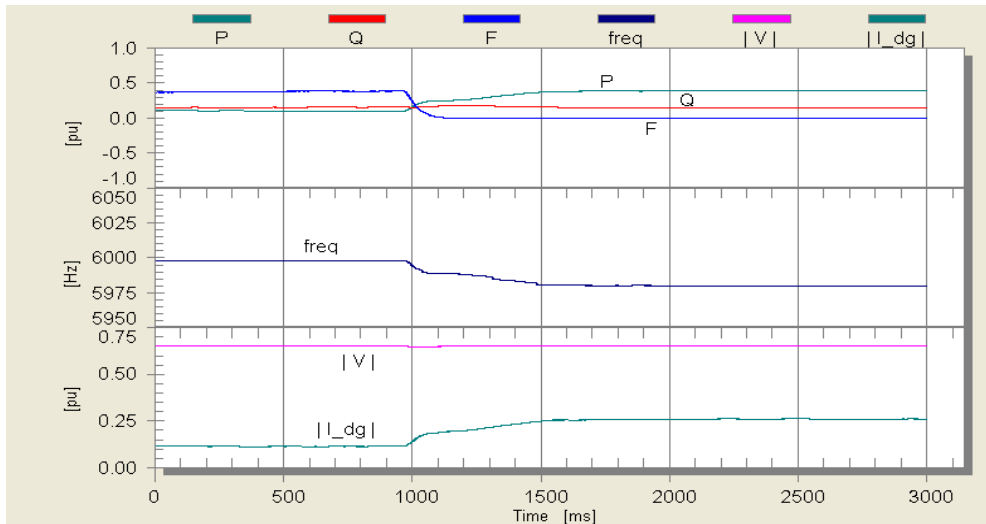
Series Configuration, Control of P_1 and P_2

	A – Grid	B – Island
P_1 [pu]	0.08 = 10%	0.4 = 50%
P_2 [pu]	0.72 = 90%	0.8 = 100%
Frequency [Hz]	60.00	59.8
Load Level [pu]	1.2 = 150%	1.2 = 150%
Grid Flow [pu]	0.4 = 50%	0.0

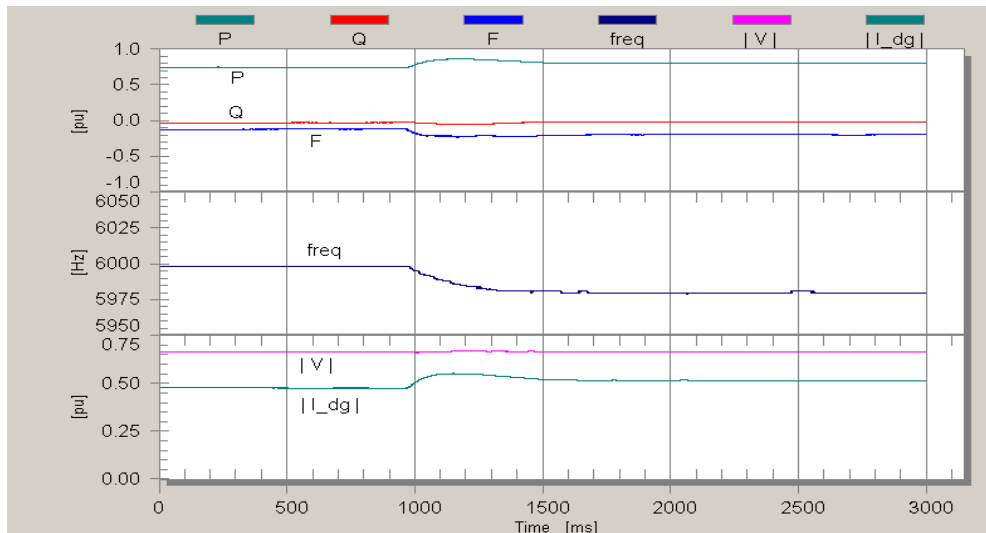




Unit Power Control: Reaching Maximum Power

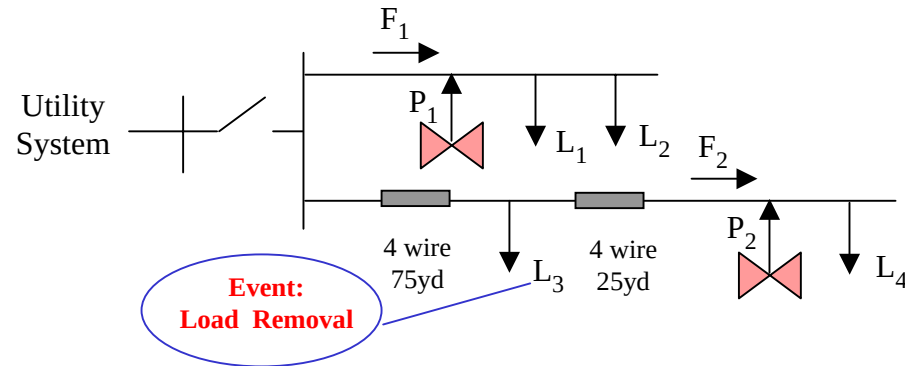


Unit 1



Unit 2

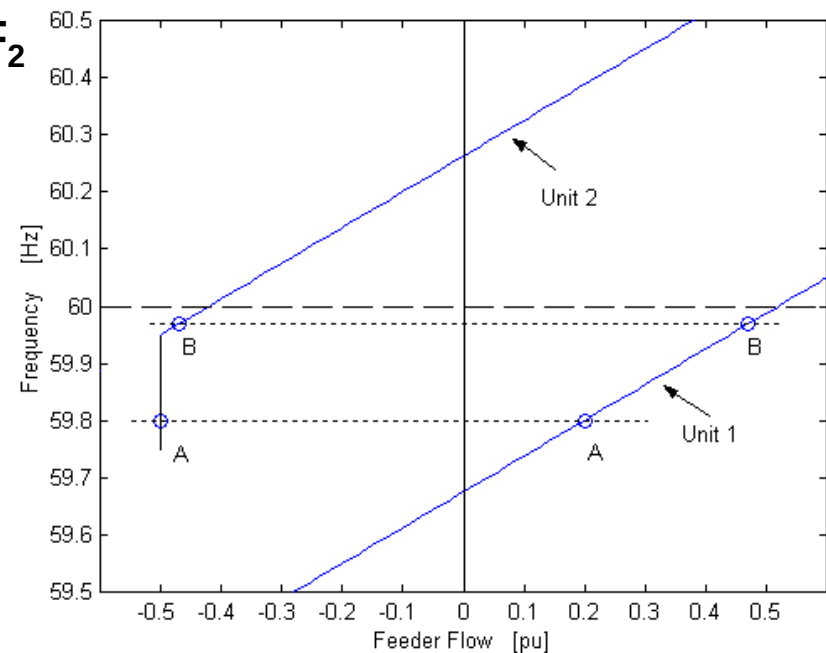
Zone Power Control: Classic Parallel Solution: $F_1 = -F_2$



Event shows Unit 2 backing off from maximum output power after a load is removed.

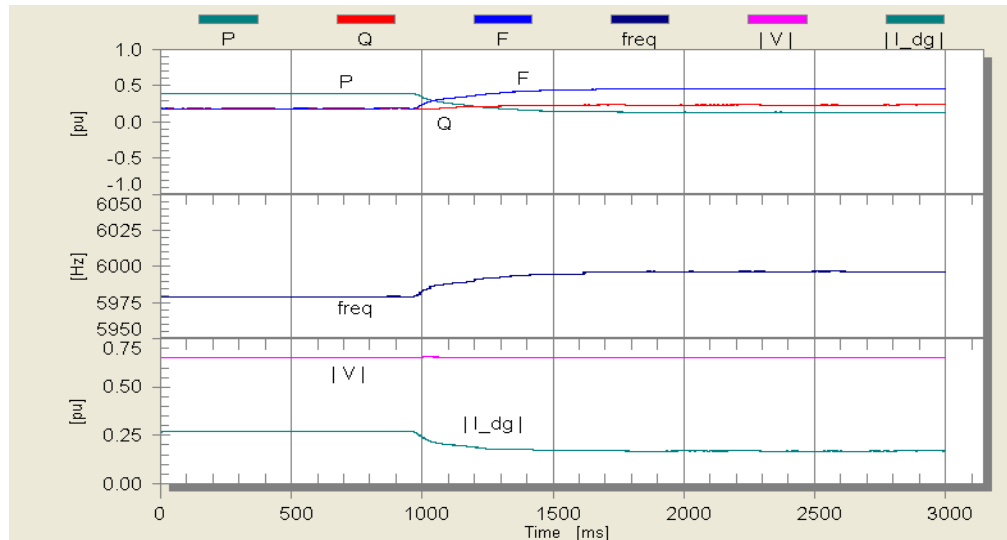
Parallel Configuration, Control of F_1 and F_2

	A – L_3 on	B – L_3 off
P_1 [pu]	0.4 = 50%	0.13 = 16%
P_2 [pu]	0.8 = 100%	0.77 = 96%
Frequency [Hz]	59.80	59.968
Load Level [pu]	1.2 = 150%	0.9 = 112%
Grid Flow [pu]	0.0	0.0

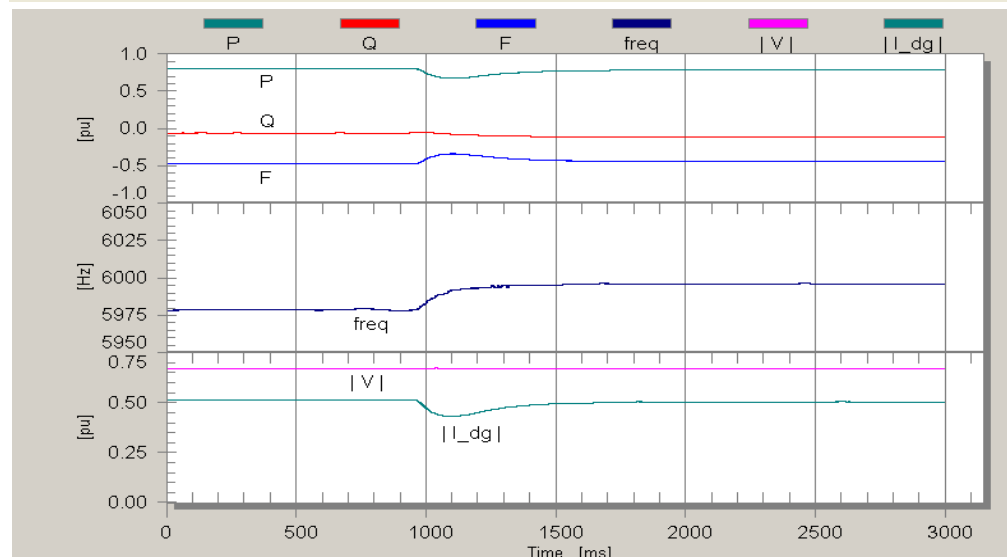




Zone Power Control: Classic Parallel Solution: $F_1 = -F_2$



Unit 1



Unit 2



CEC/CERTS Test Microgrid



● Northern Power Systems:

- ▶ Designed the test microgrid (no inverters) and protection
- ▶ Building and testing static switch

● Tecogen:

- ▶ Prime mover (natural gas fired IC engine) with inverter

● Youtility:

- ▶ Building inverter and controls for Tecogen microsource

● American Electric Power:

- ▶ Provides test site (Ohio)