CERTS Microgrid Technology; Where are we now?

ADVANCED DISTRIBUTION AND CONTROL FOR HYBRID INTELLIGENT POWER SYSTEMS

- Phase II STTR Program

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University of Wisconsin-Madison

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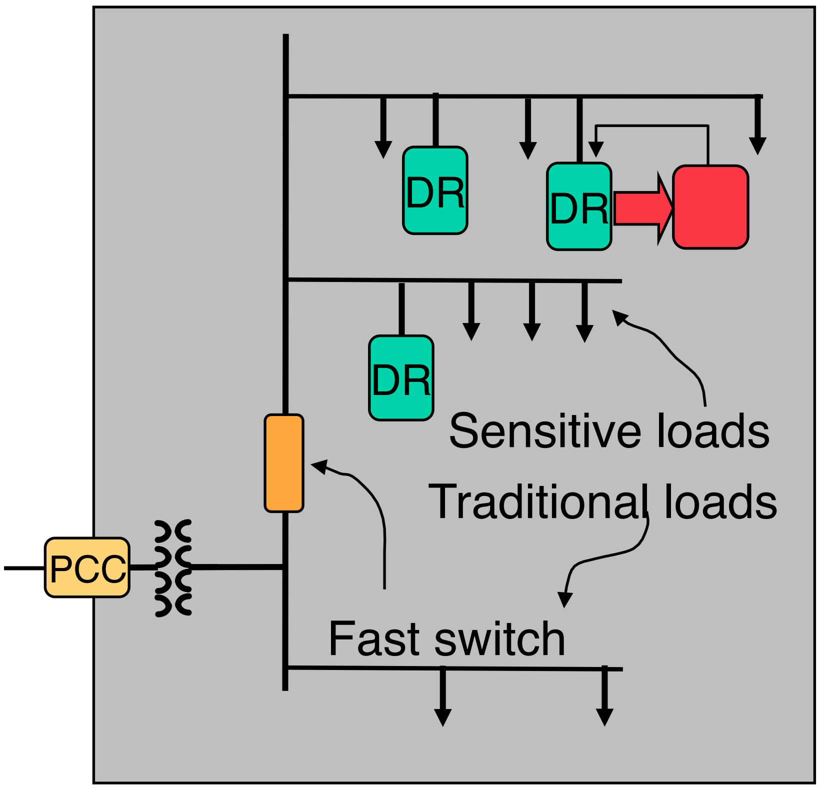
CERTS Microgrid Architecture



Objectives

- Promote CHP
- Provide for high power quality
- Allow non-compliant sources behind the PCC

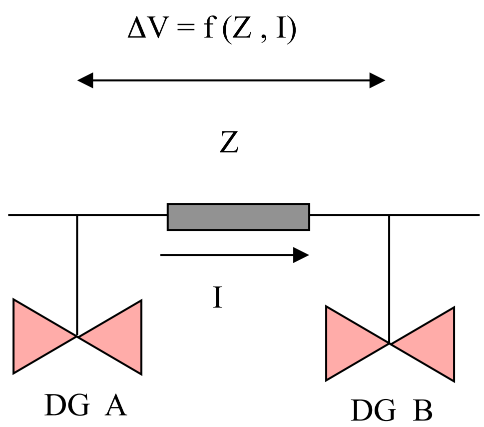
Configuration

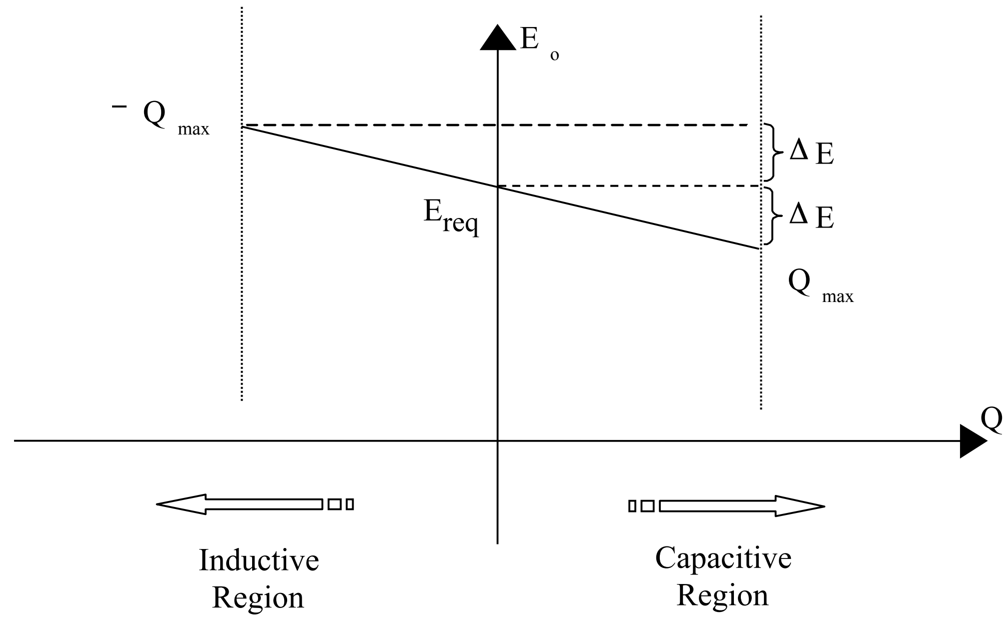
- Sources clustered with loads
- Smart switch
- Plug & Play sources

Control

- Stable for all events
- Autonomous (no central controller)
- Automatic power balance (P vs. Fq)
- Voltage control (V vs. Q)
- Intentional islanding
- Automatic re-synchronizing

CERT's Q versus E droop for stability





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

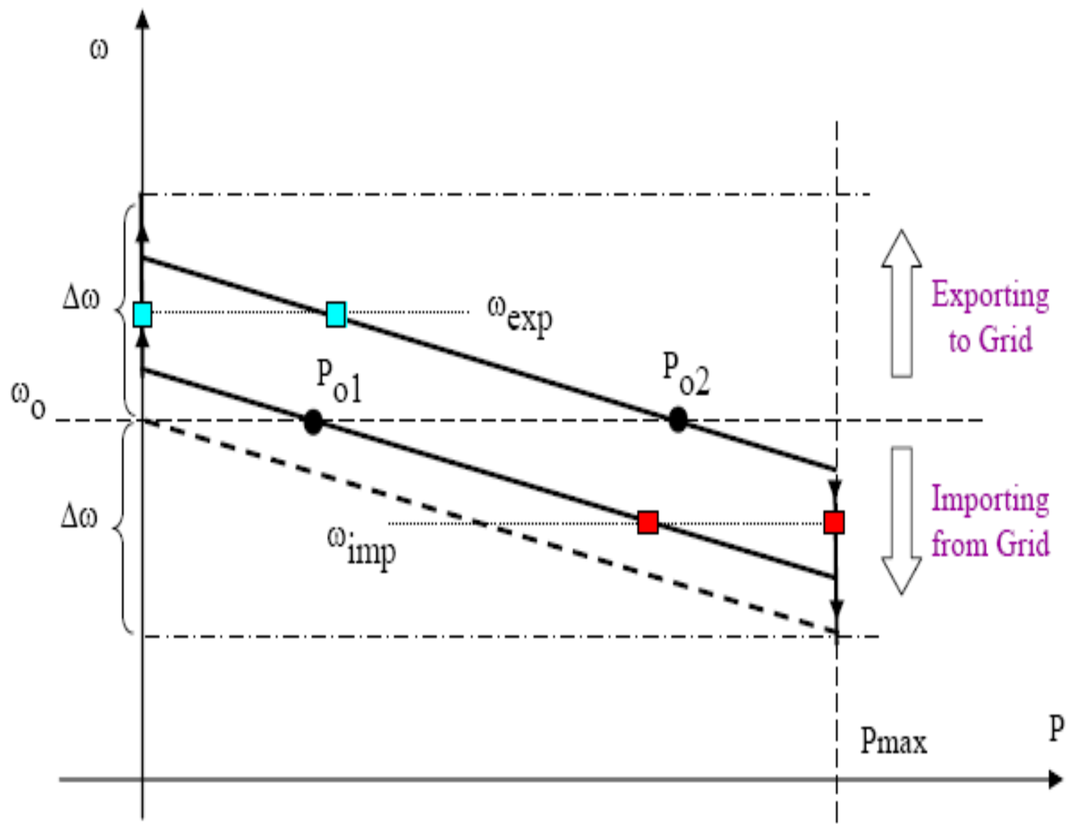
$$m_Q = \frac{\Delta E}{Q_{max}}$$

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

power *vs.* frequency droop

Assume two DER sources

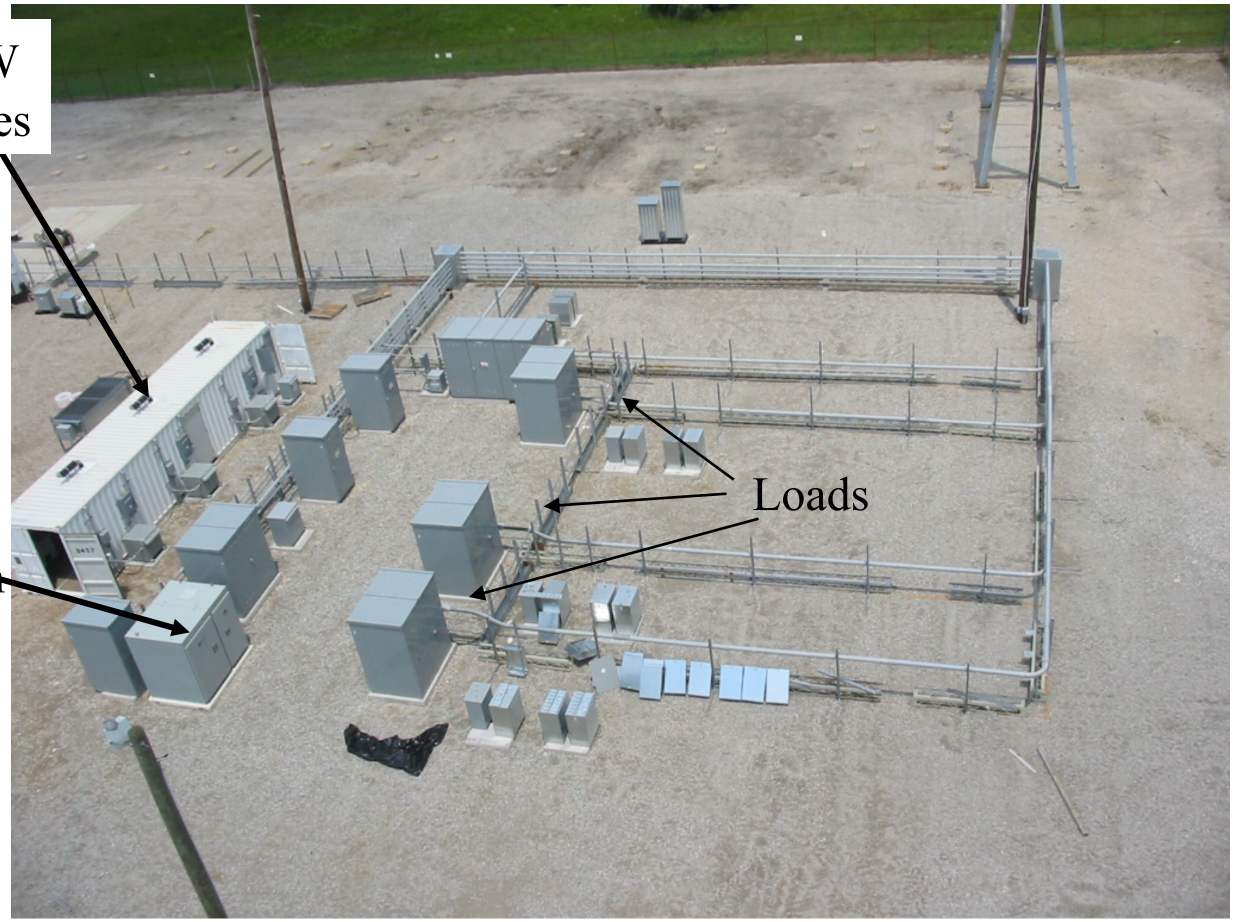
- P_{01} & P_{02} are dispatched powers while grid connected
- Square ■ indicts the new operating points after islanding if there is loss of power from the grid.
- Square ■ indicts the new operating points after islanding if the microgrid was exporting power.



CERTS Concept

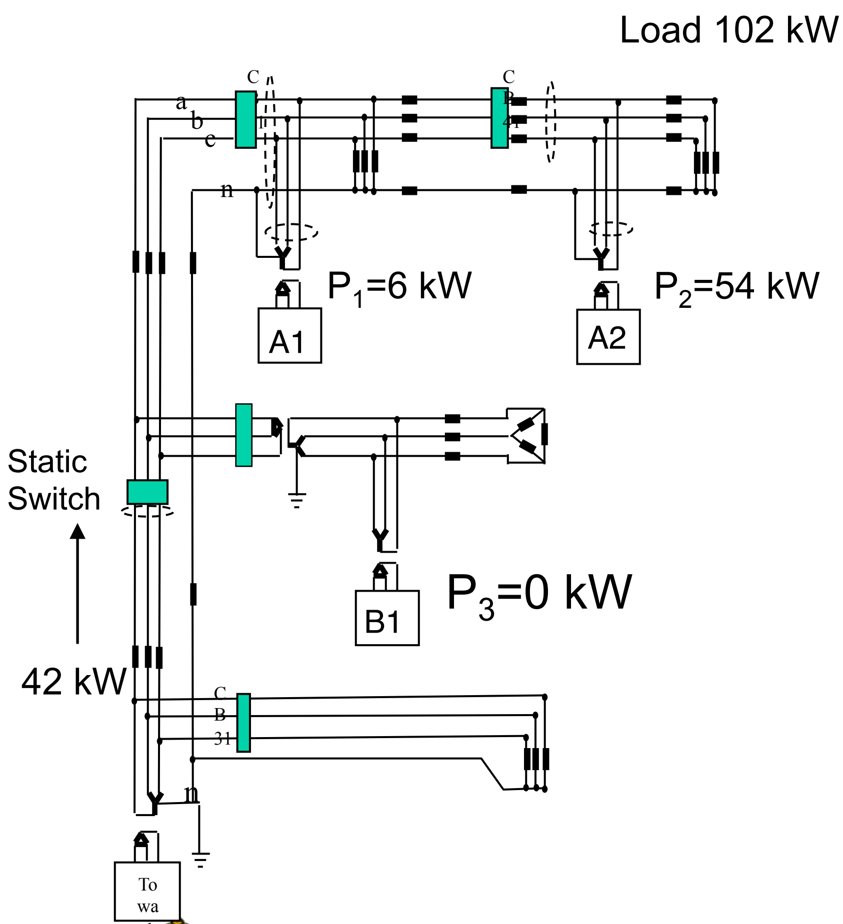
- Each DER unit is a voltage source.
- Multi-unit stability is insured through voltage vs. reactive power control.
- Communication between components is through *frequency*.
  - DER output control uses power vs. *frequency* droop.
  - Track load through frequency
  - Intelligent load shedding on low *frequency* and source shedding on high *frequency.*
  - Automatic re-synchronizing using *frequency* difference between the island and Utility network.

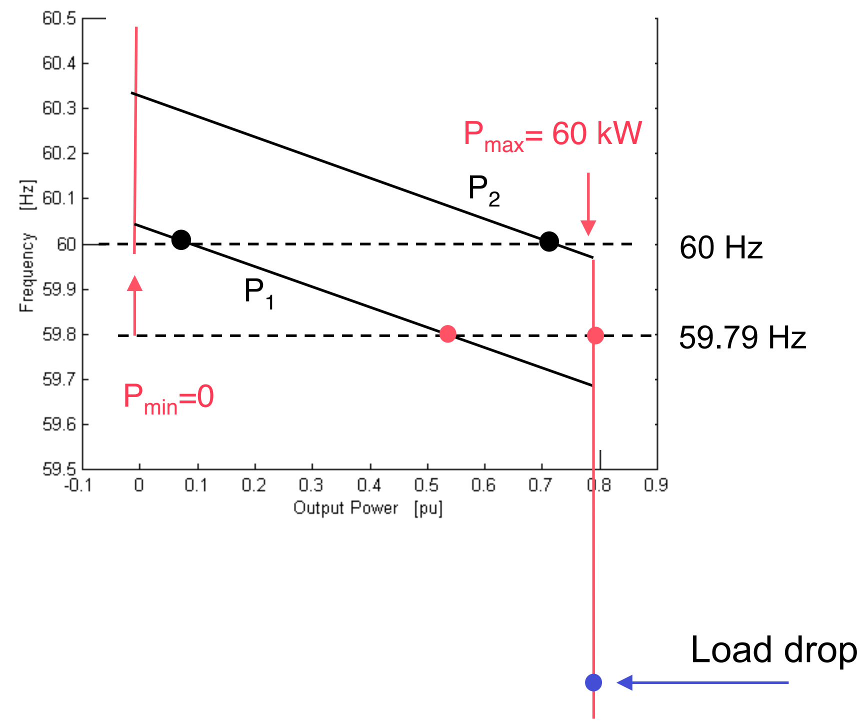
These concepts have been tested at the AEP/CERTS Microgrid test site



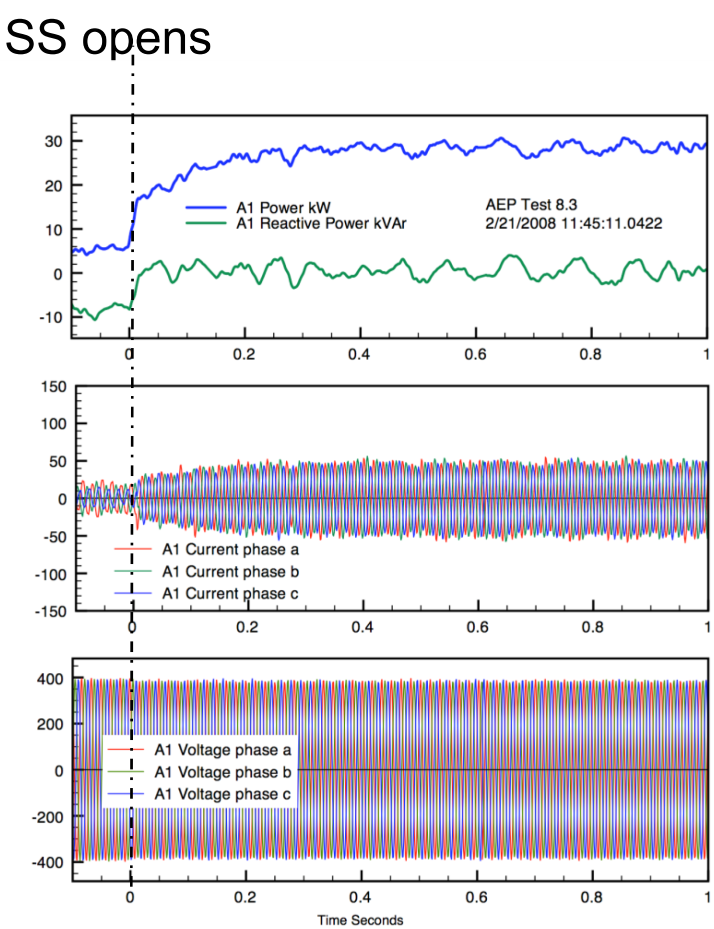
DOE TRP	1999-2002
CEC PIER	2001-2006
DOE RDSI	2006-2009
DOE HQ	2010-2011

AEP Islanding Microgrid with A2 near P_{max}

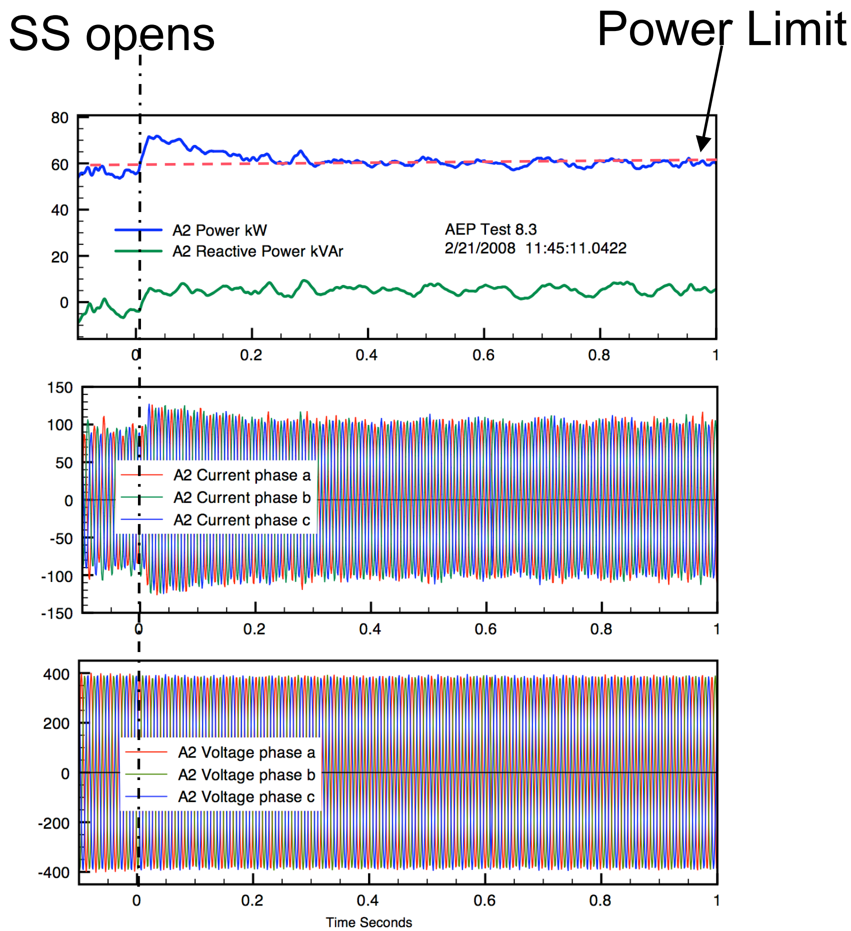




TEST 8.3: A2 Power Limit

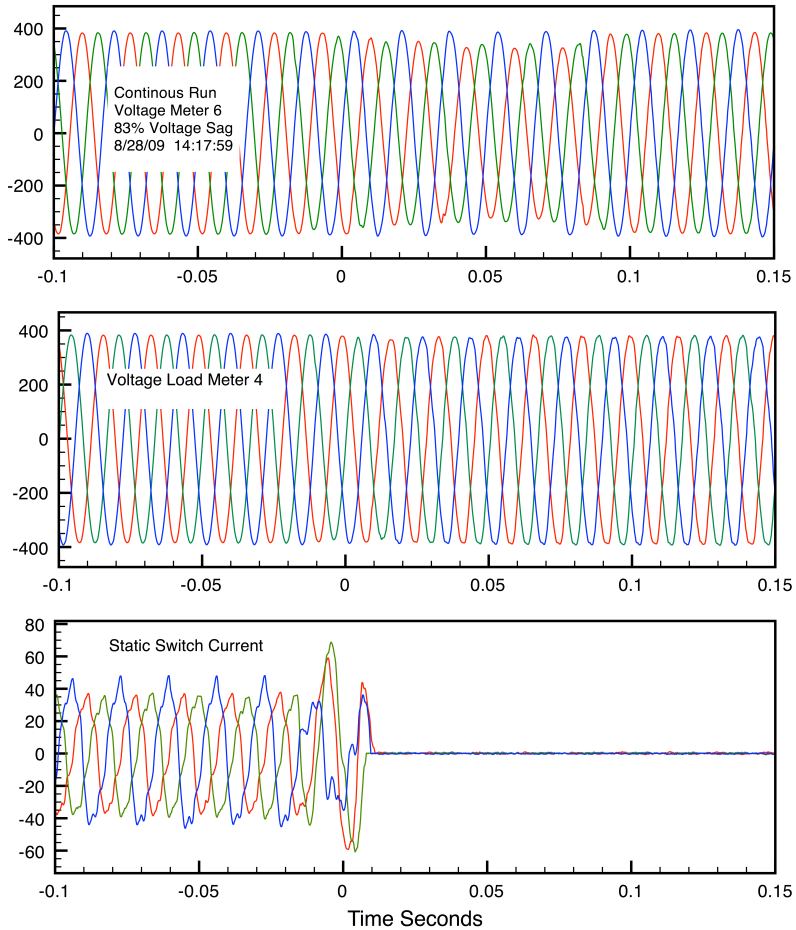


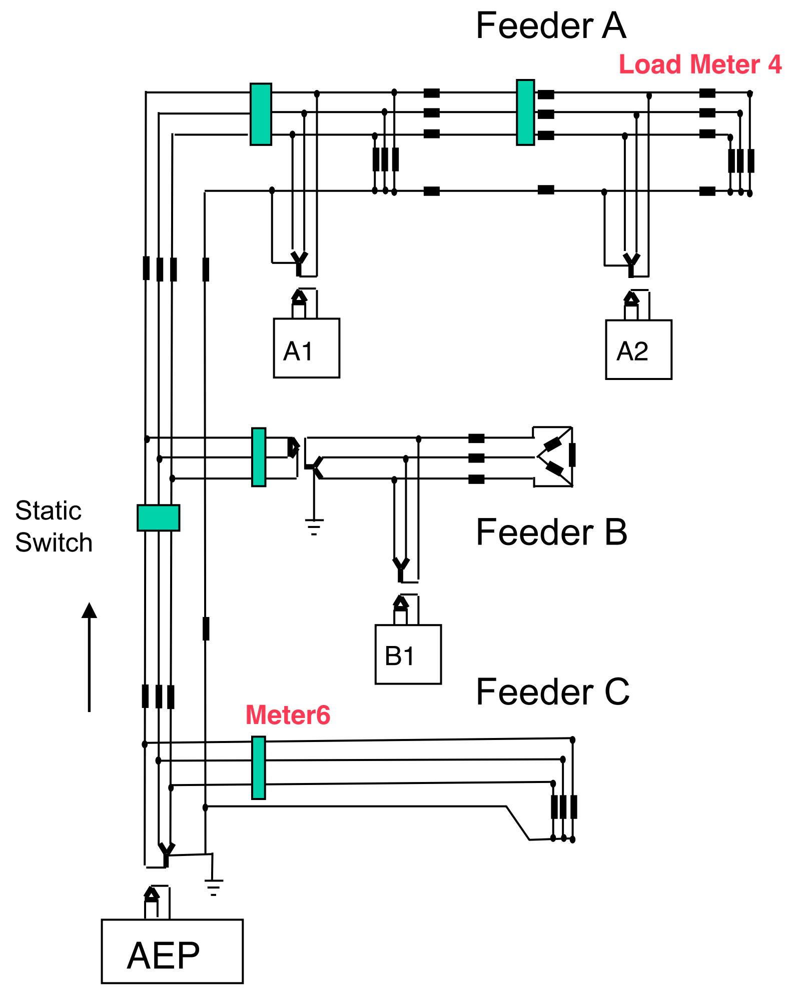
Source A1



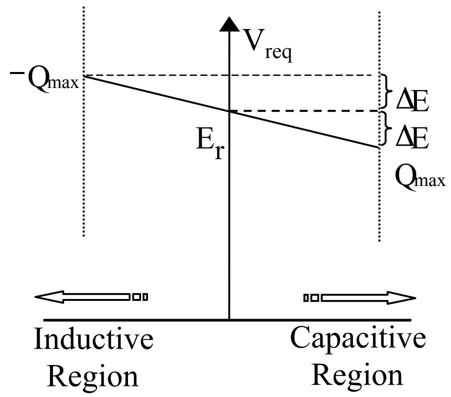
Source A2

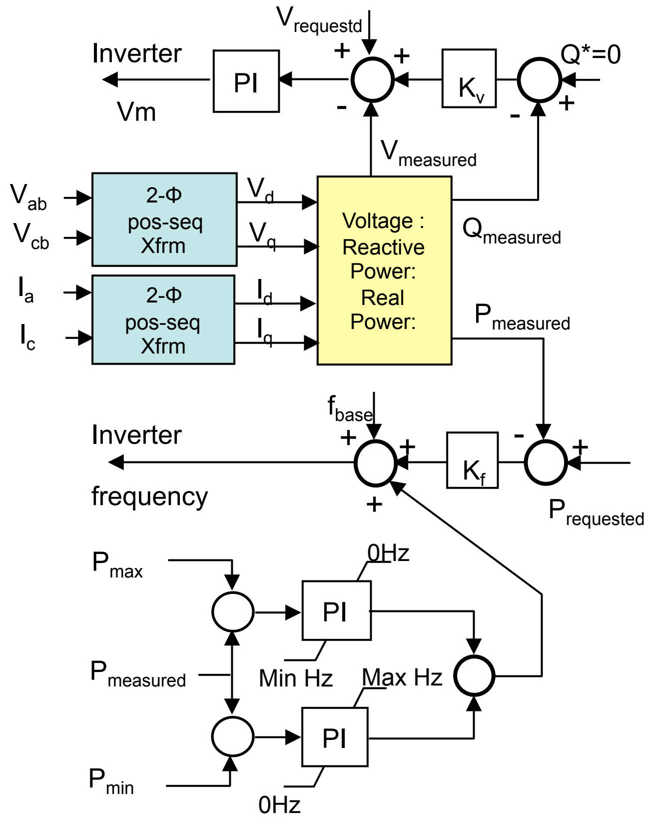
Voltage Sag AEP/CERTS Microgrid





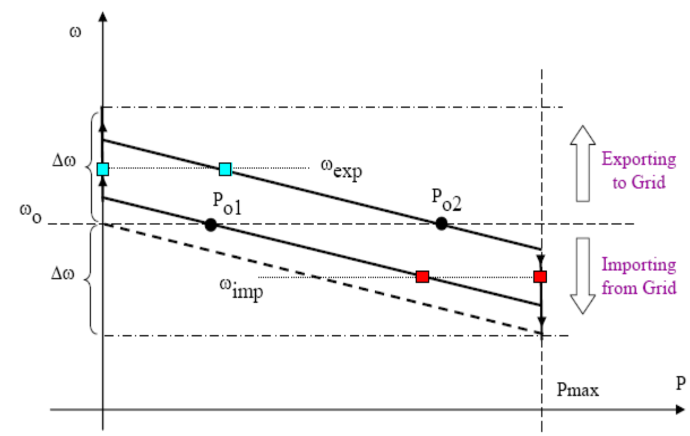
inverter controller



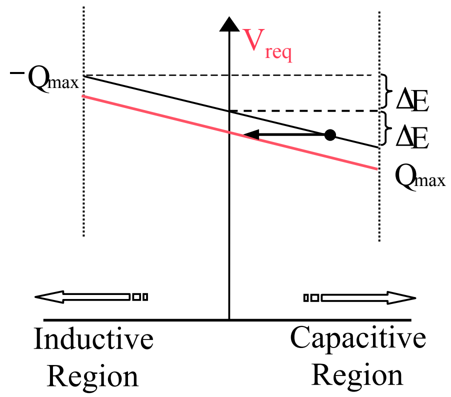


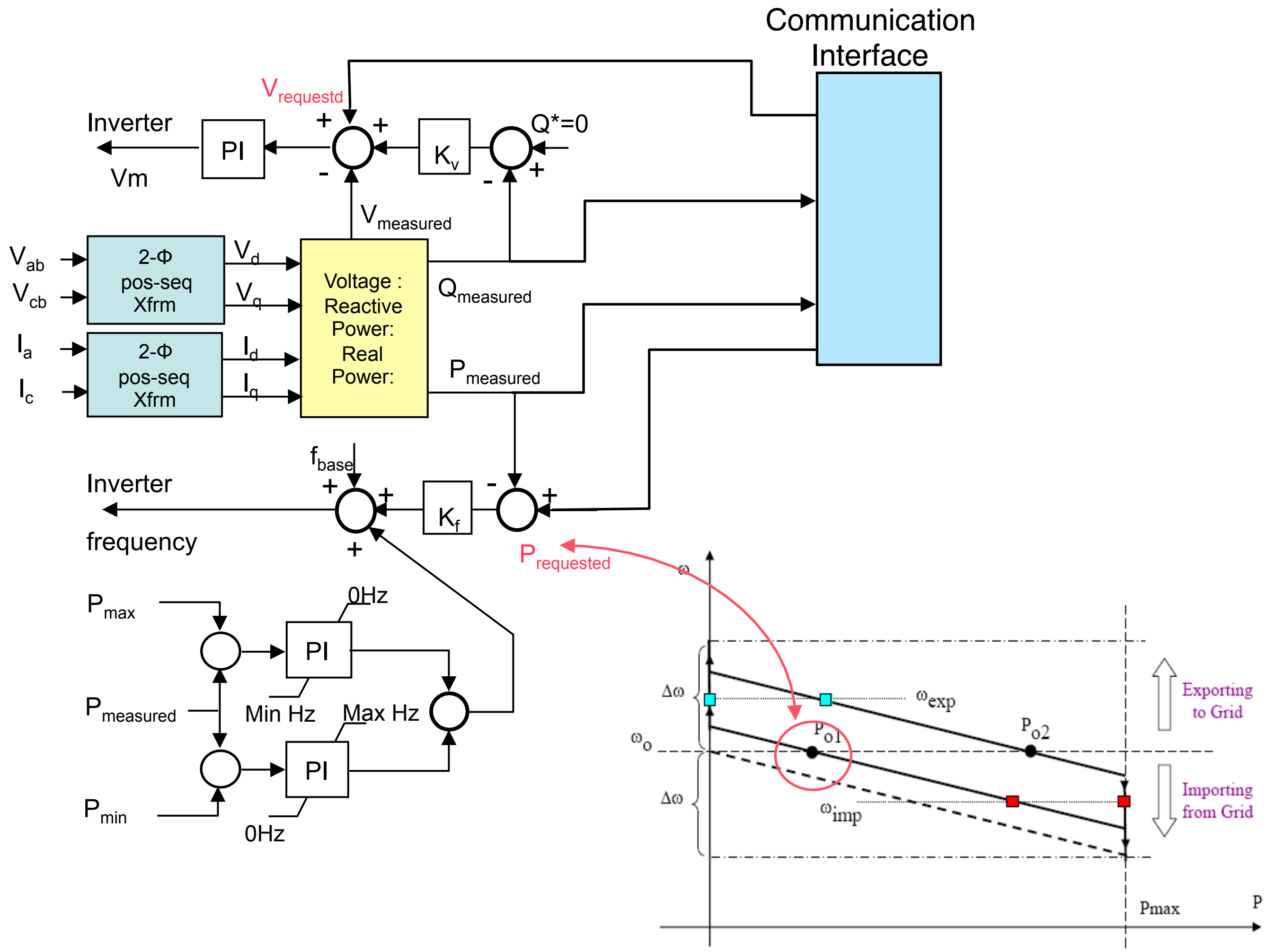
Inverter model is 3 voltage sources in delta

$$V_{ab} = V_m Cos(\omega t)$$
$$V_{bc} = V_m Cos(\omega t + \vartheta_1)$$
$$V_{ca} = V_m Cos(\omega t + \vartheta_2)$$

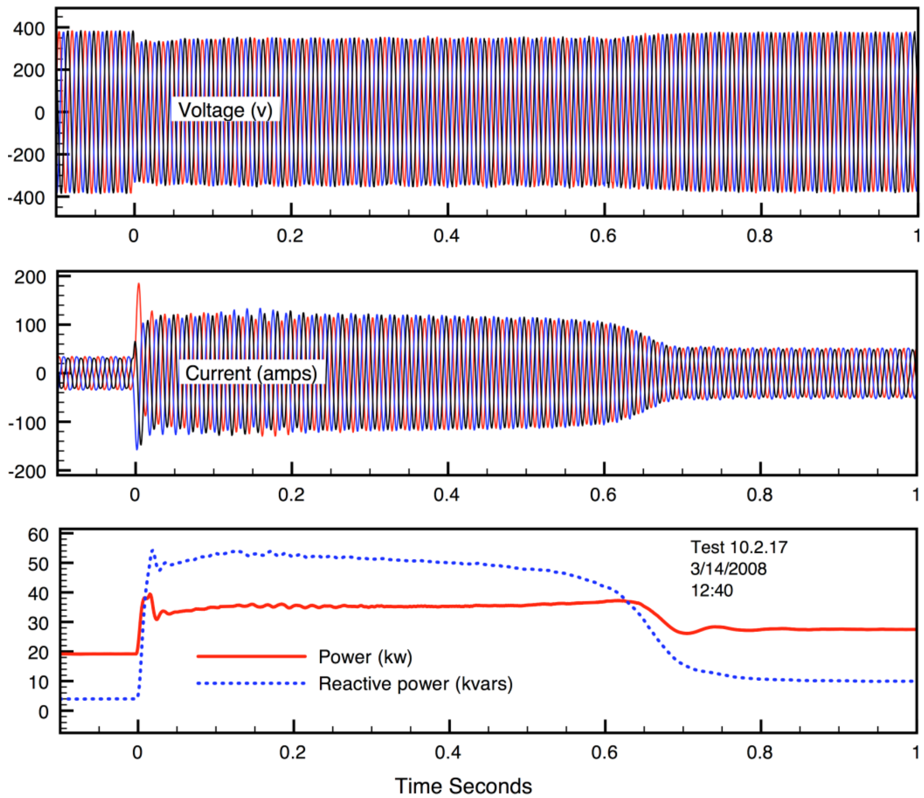


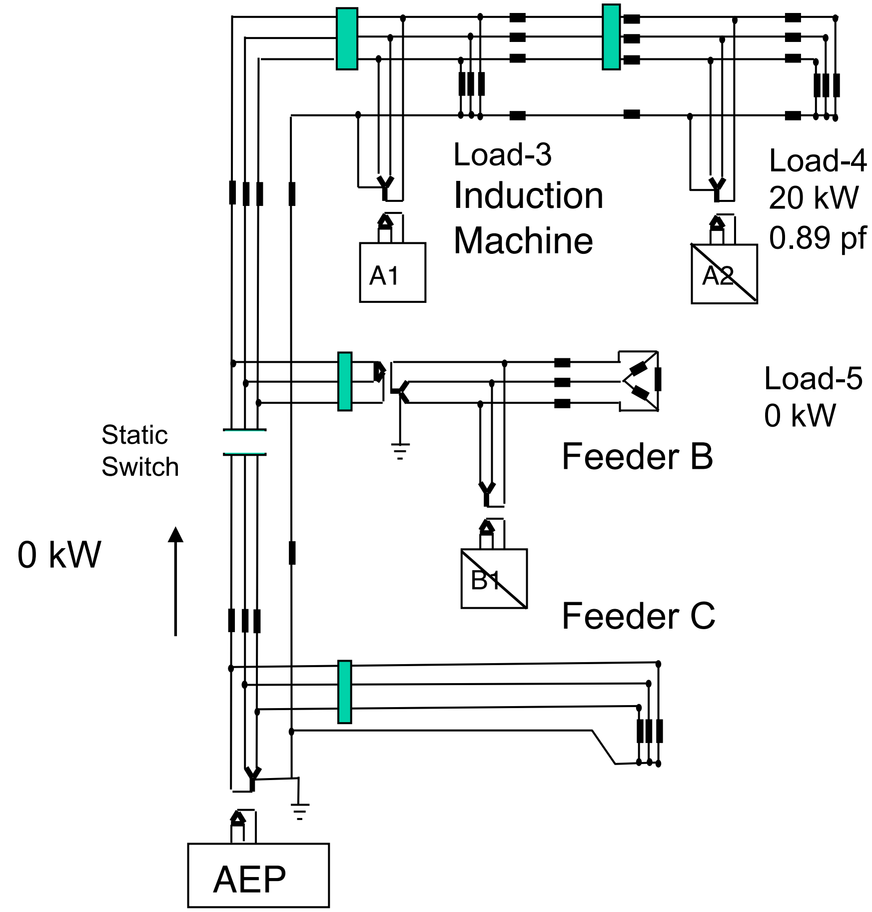
inverter interface





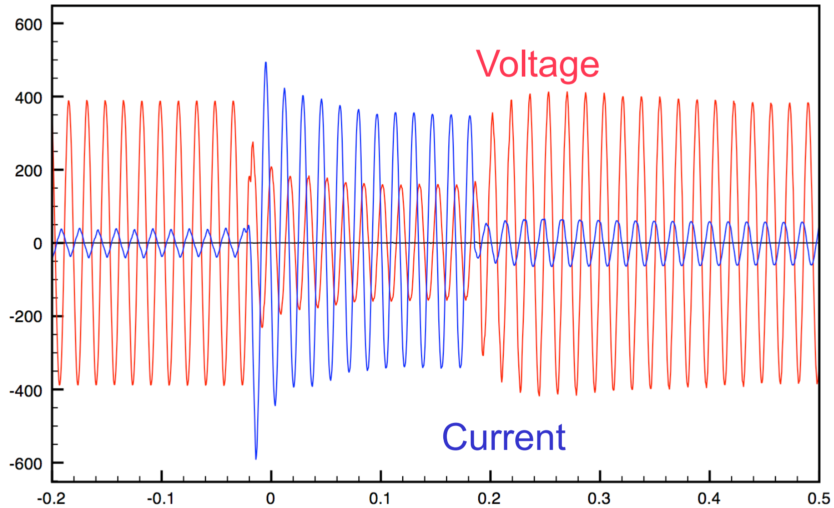
Induction Machine Starting while Islanding: Test 10.2.17

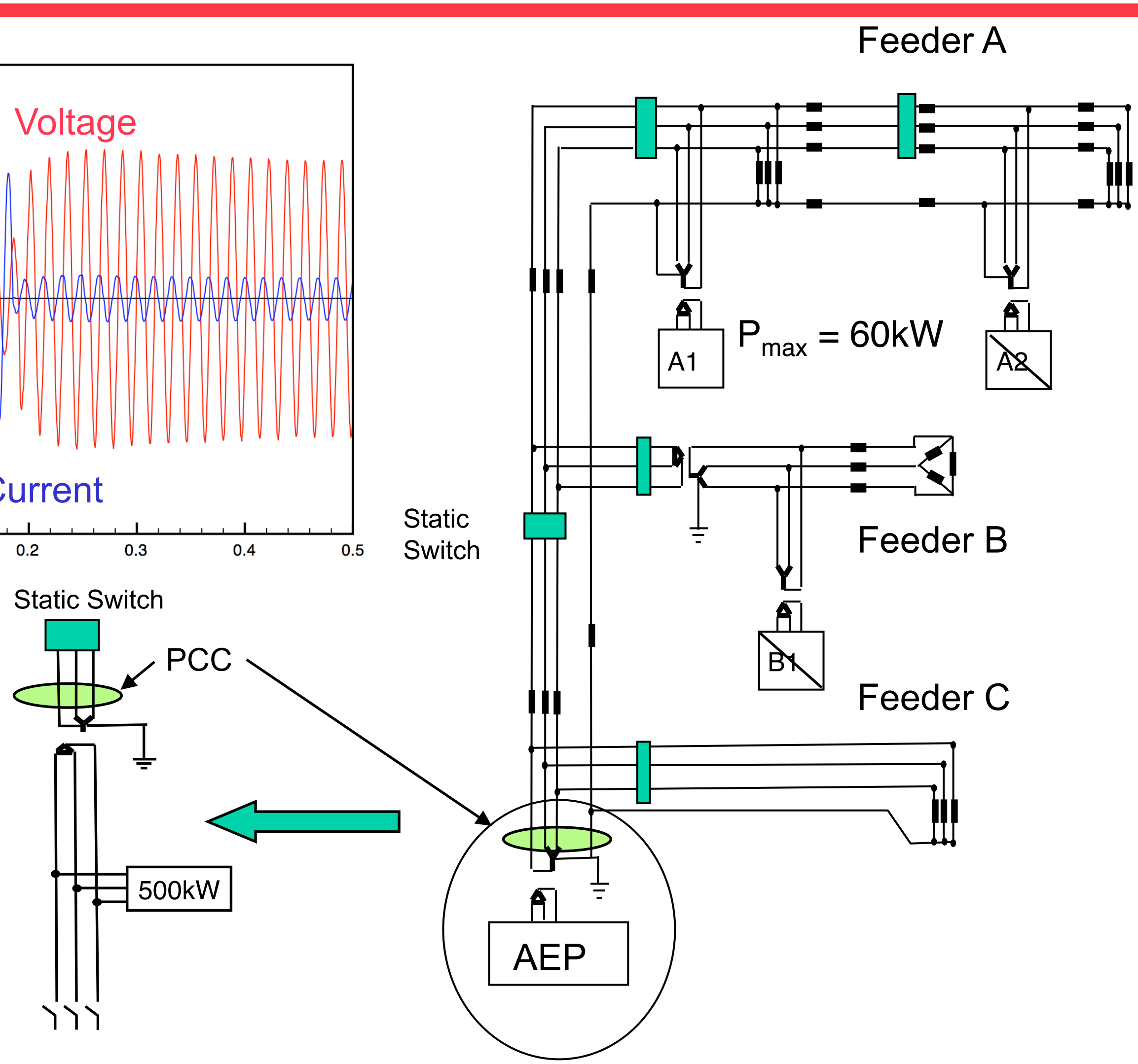




20 HP motor
60 KW , 60 Kvar inverter

Large Disturbance: A1 voltage and current





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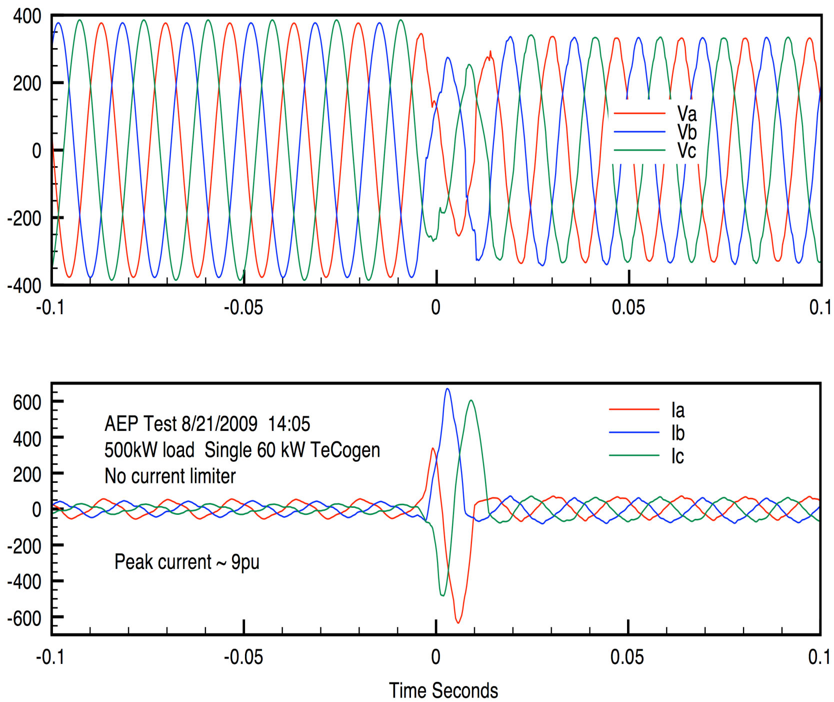
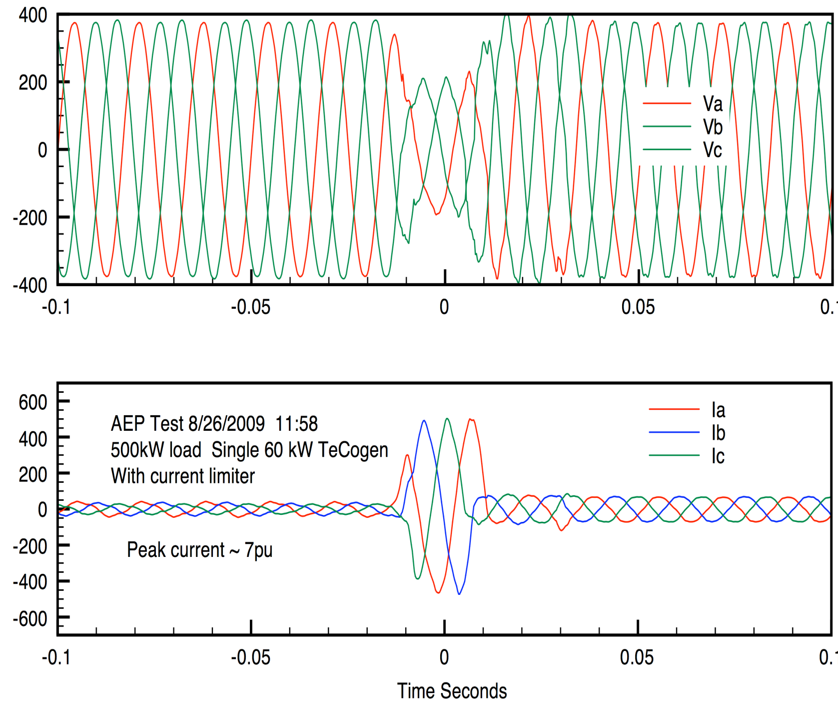
Control of overcurrents at AEP

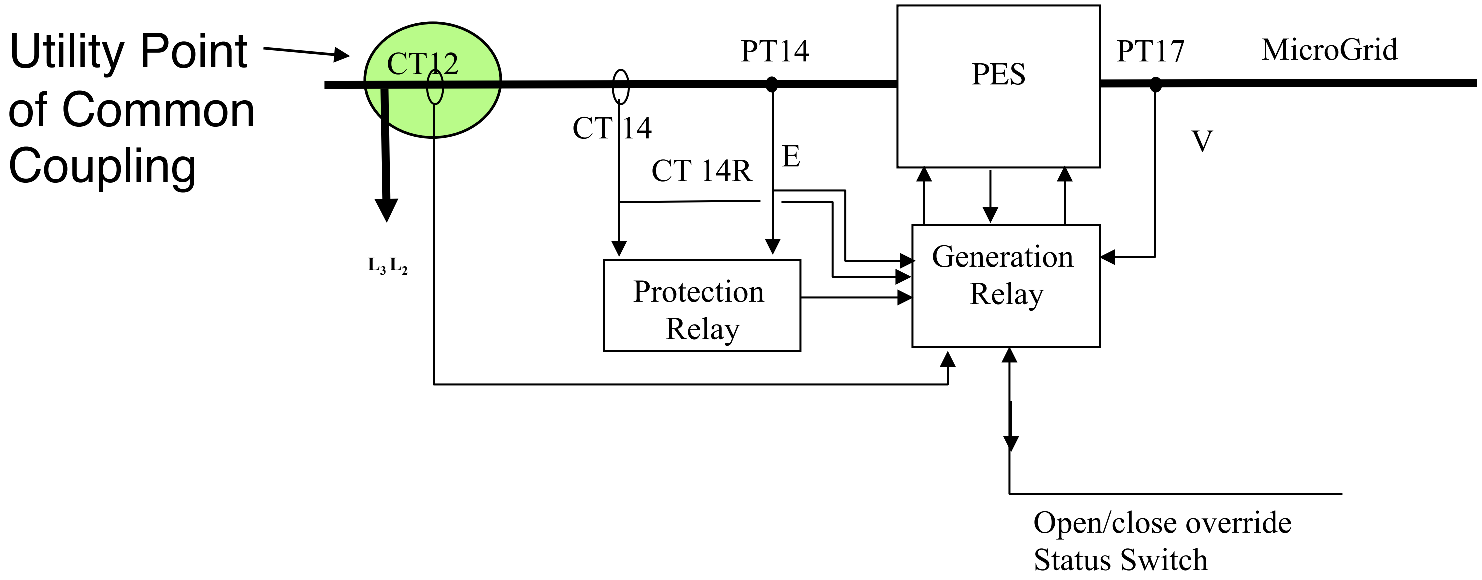


No current control



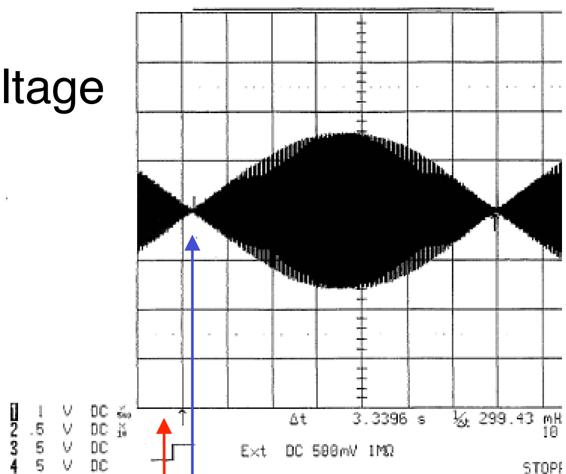
With current control

AEP Static Switch



Smart Switch Test: Seamless Re-closing

Beat Voltage

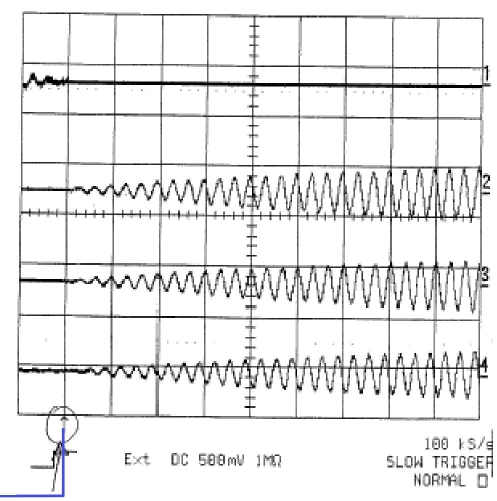


Beat Voltage

Current Phase A

Current Phase B

Current Phase C



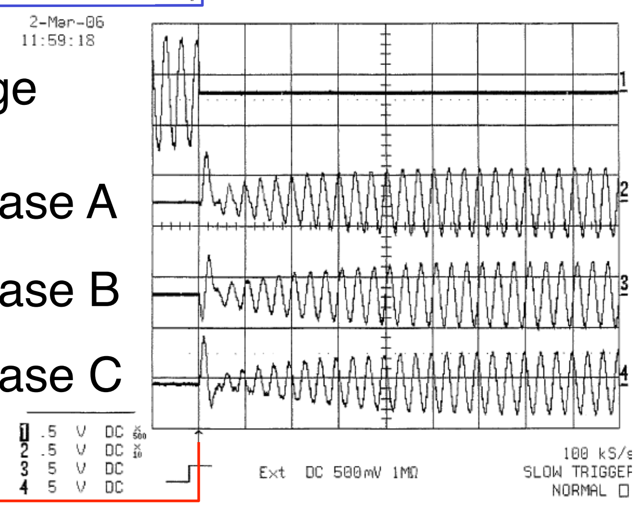
Correct closing
ΔØ~0°

Beat Voltage

Current Phase A

Current Phase B

Current Phase C



Early closing
ΔØ~27°

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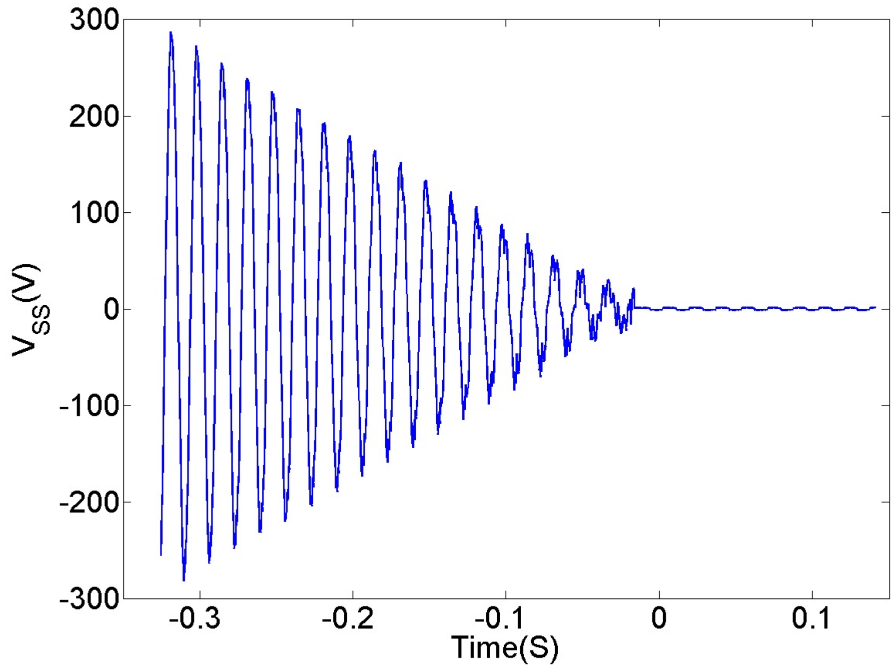
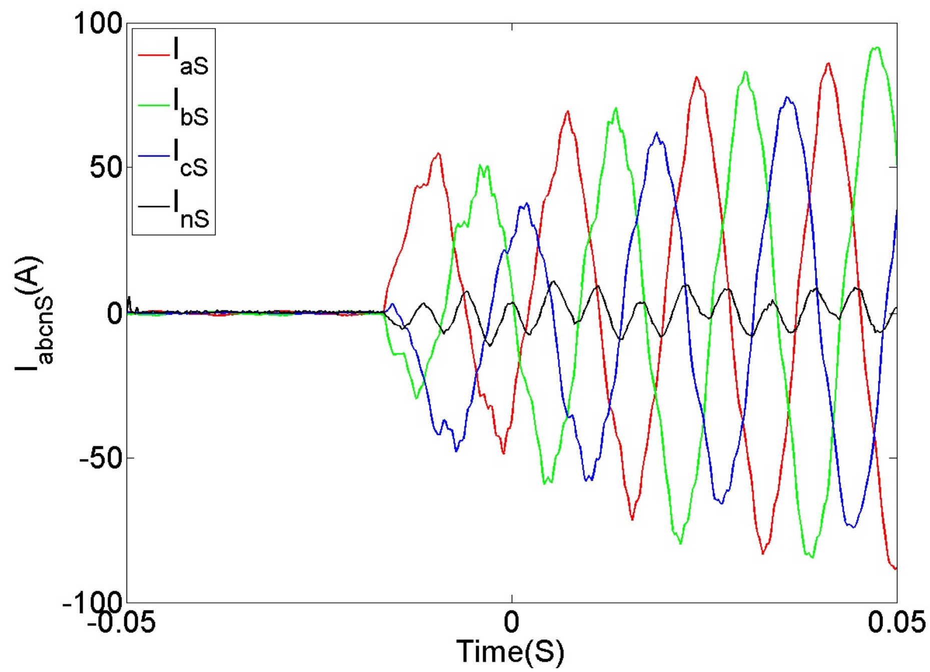
SS Synchronization site test



Voltage across SS

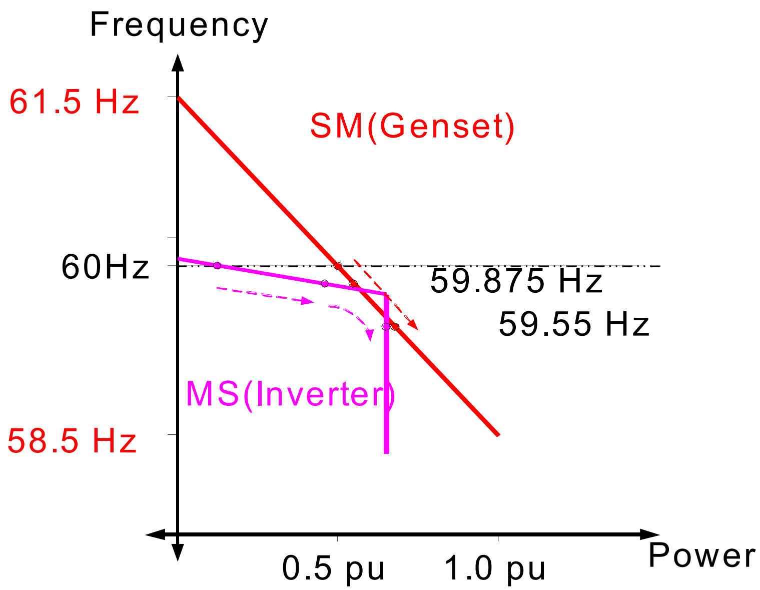


Current through the SS

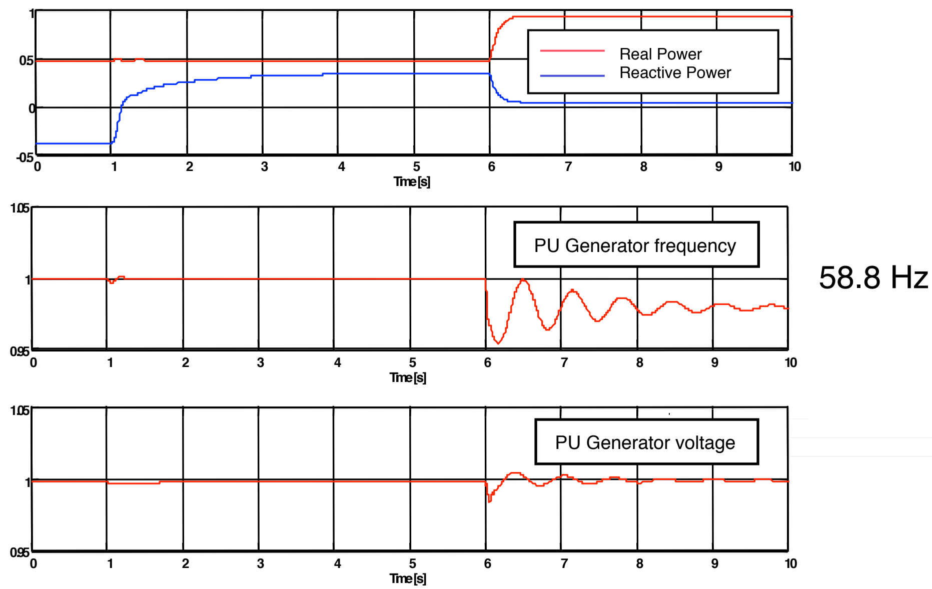
CERTS/AEP test site

- Each DER unit is a voltage source inverter.
- Multi-unit stability is insured through voltage vs. reactive power control.
- No controller needed for stable operation and load tracking
- No oscillations in freq., voltage , P and Q

Synchronous generator issues: Kohler

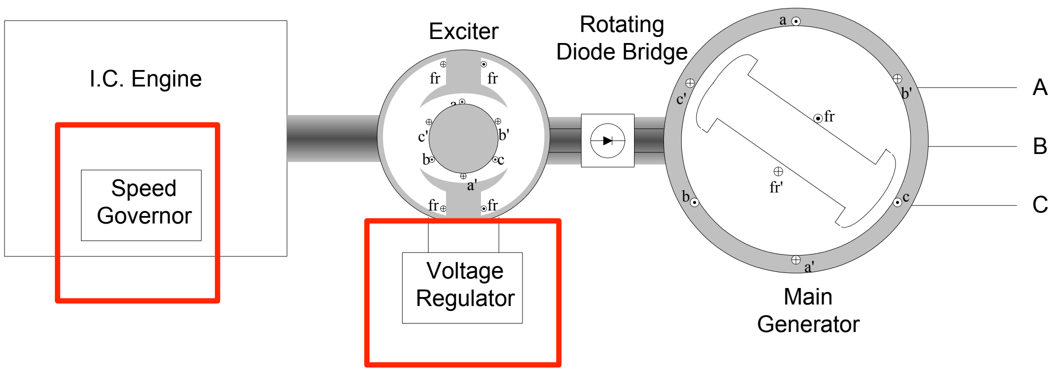


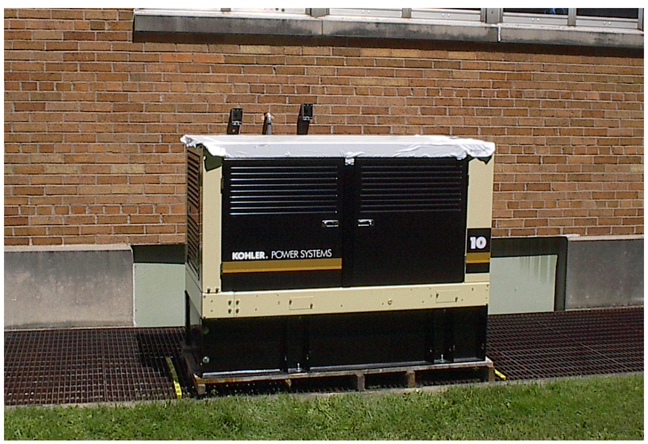
Problem of Power vs. frequency droop

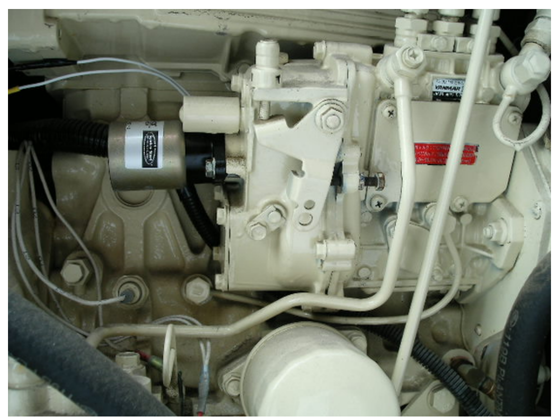


Kohler synchronous genset
3 cylinder diesel engine

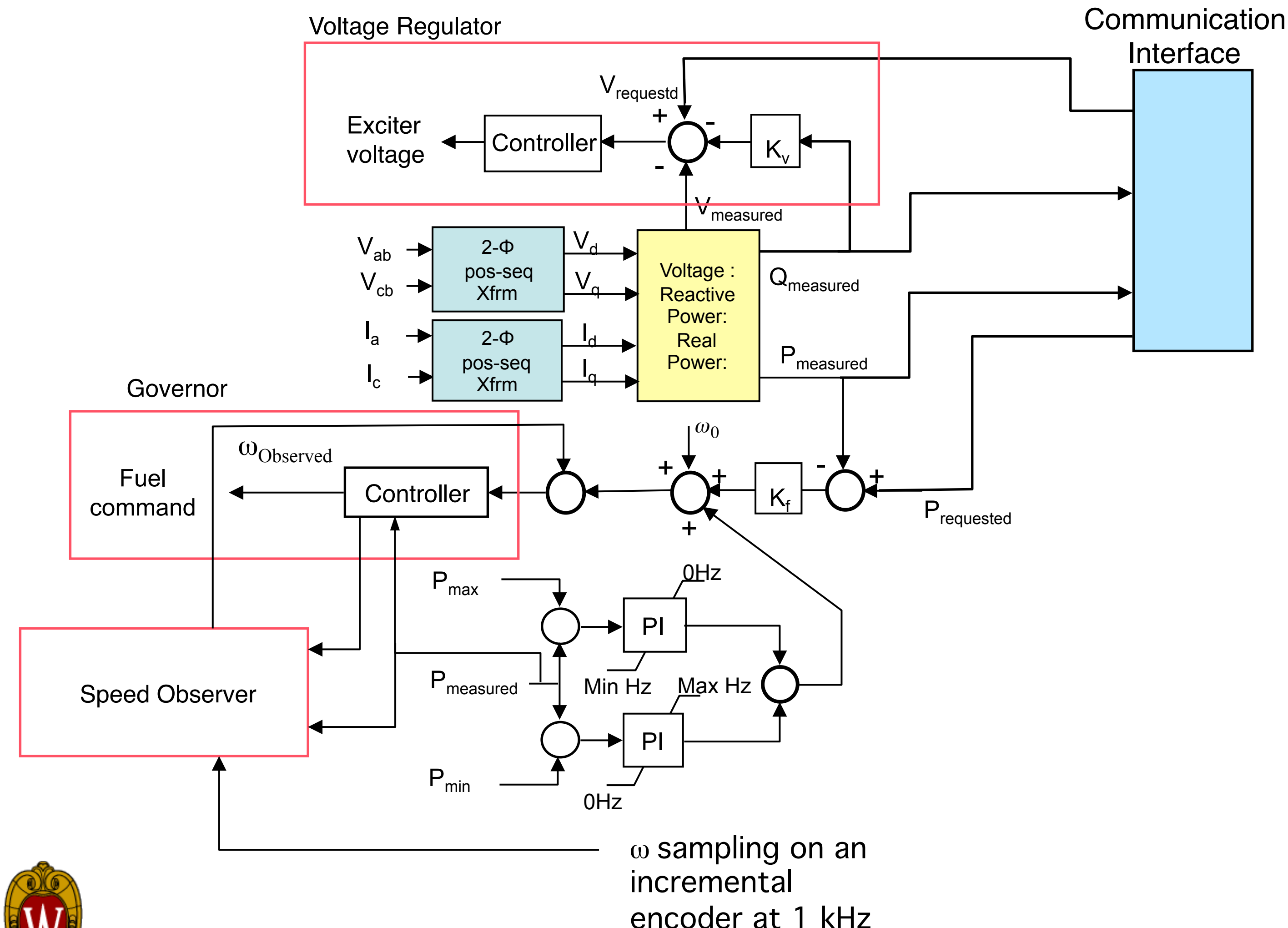
Physical Modifications





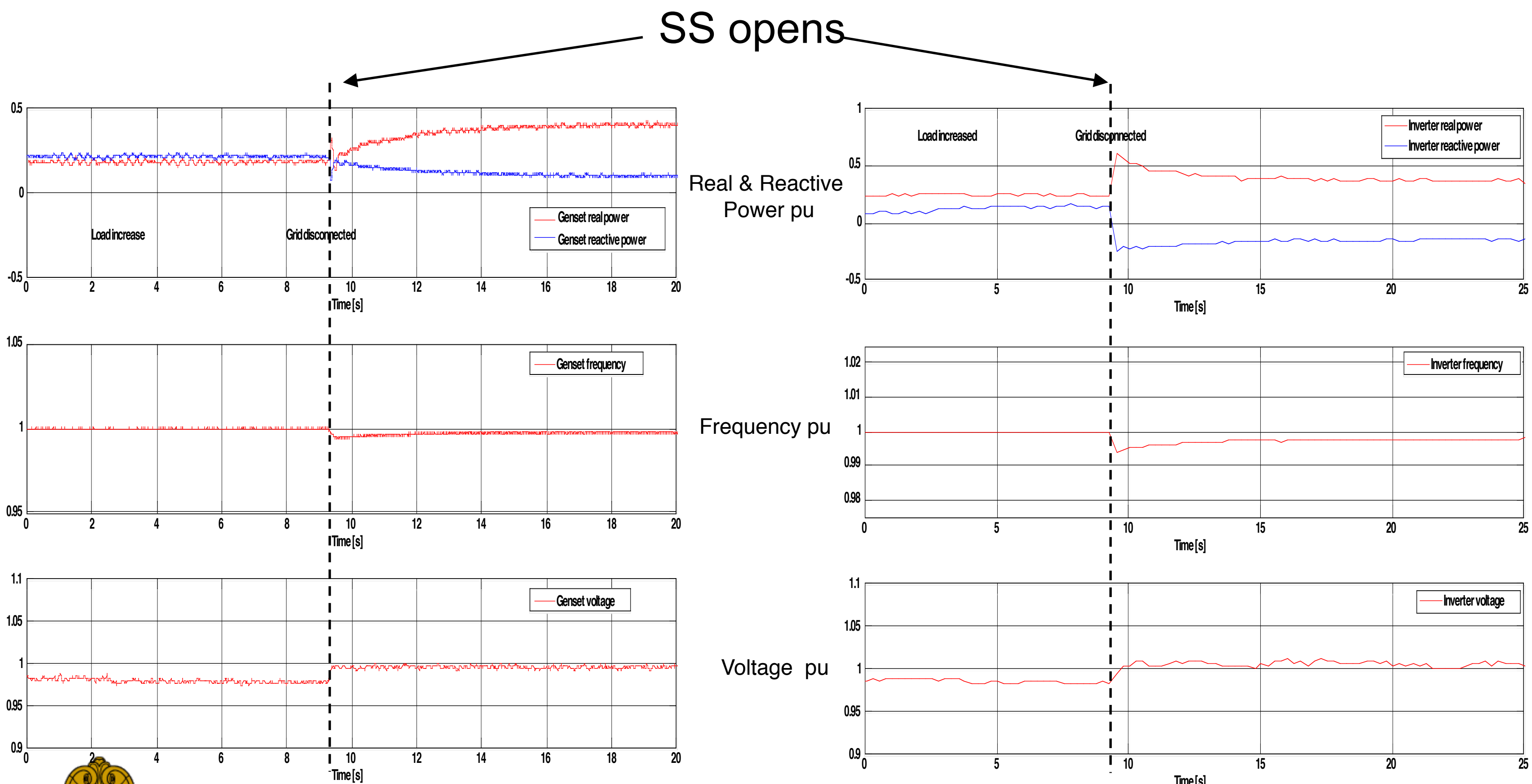


Synchronous Generator controller



Synchronous generator and Inverter : UW

Islanding of two Sources on UW Microgrid

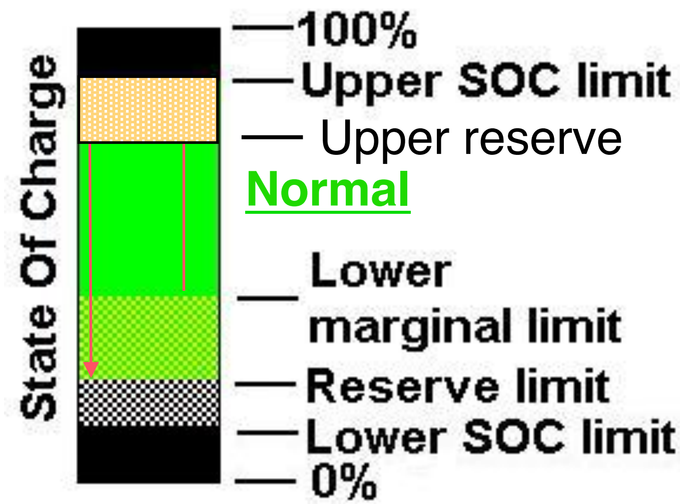


Kohler Genset

Inverter based source

Storage and SOC Management

- Upper-reserve controller reduces P_{min} to zero when SOC reach upper reserve limit
- Lower-limit controller forces converter to charge batteries when SOC reaches reserve limit



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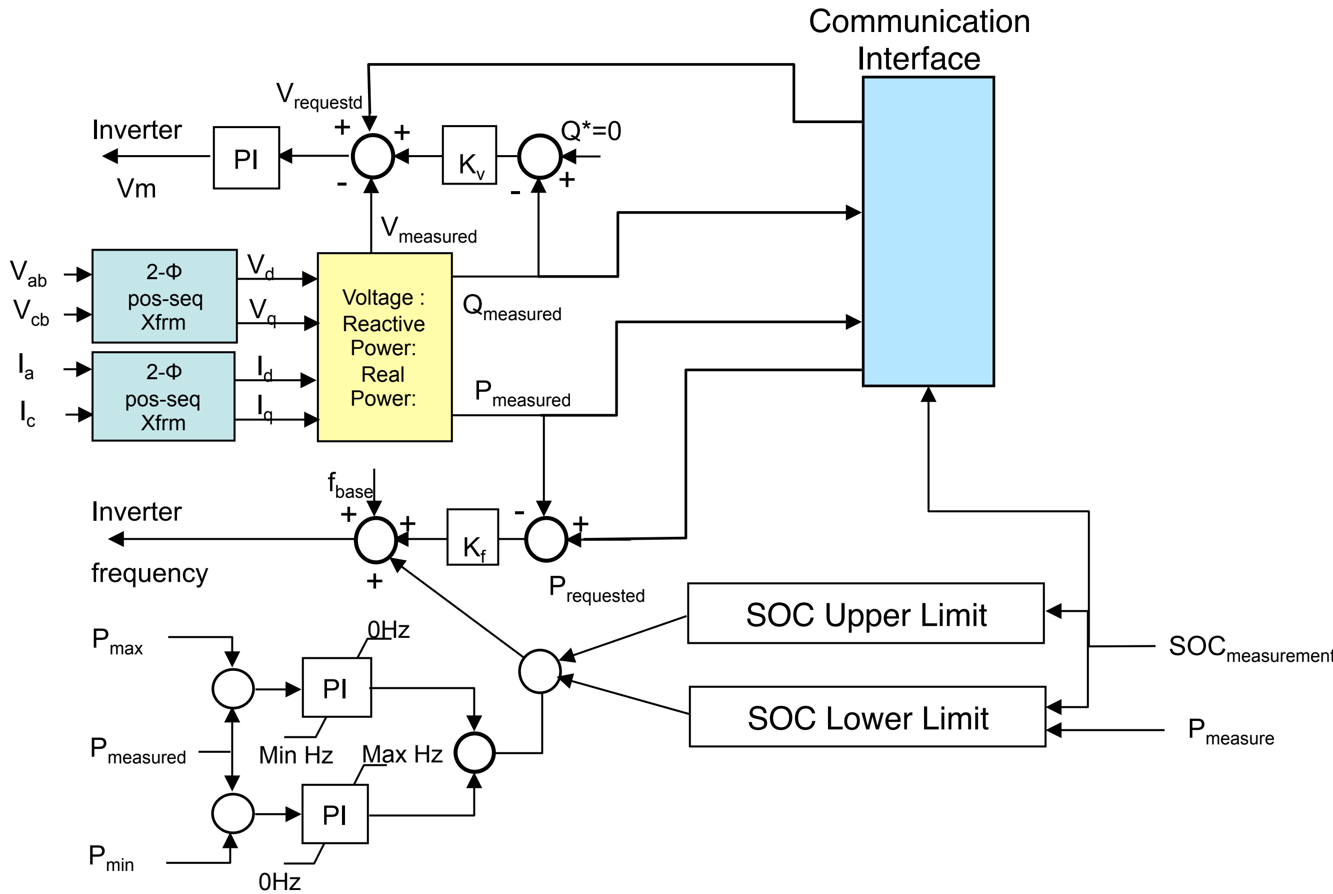
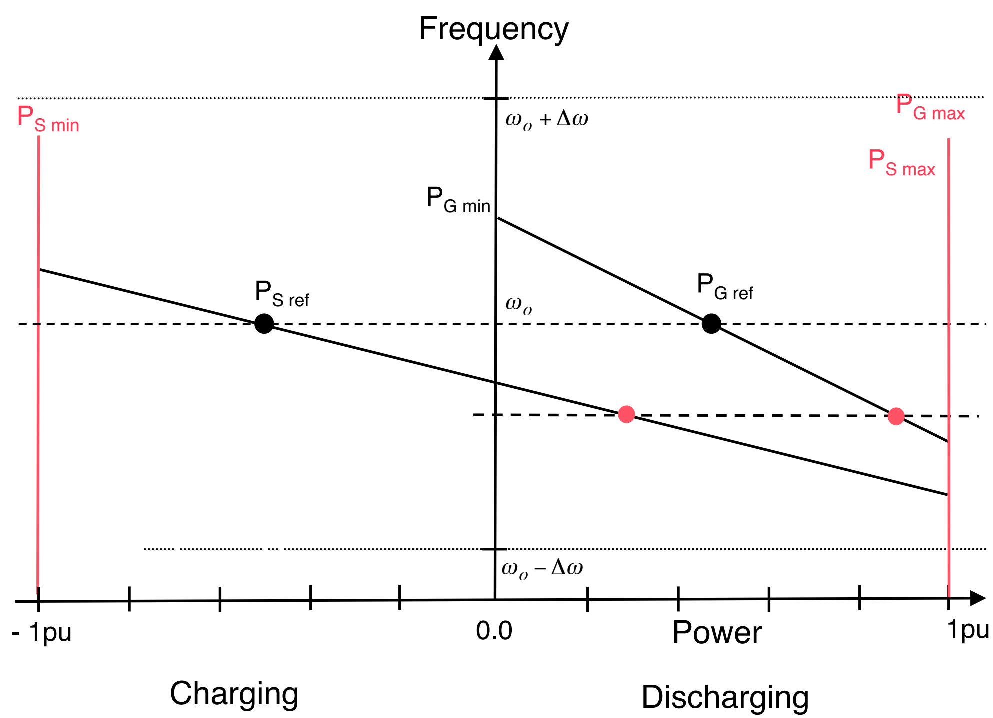
Storage with SOC controller



Storage and Generation droop

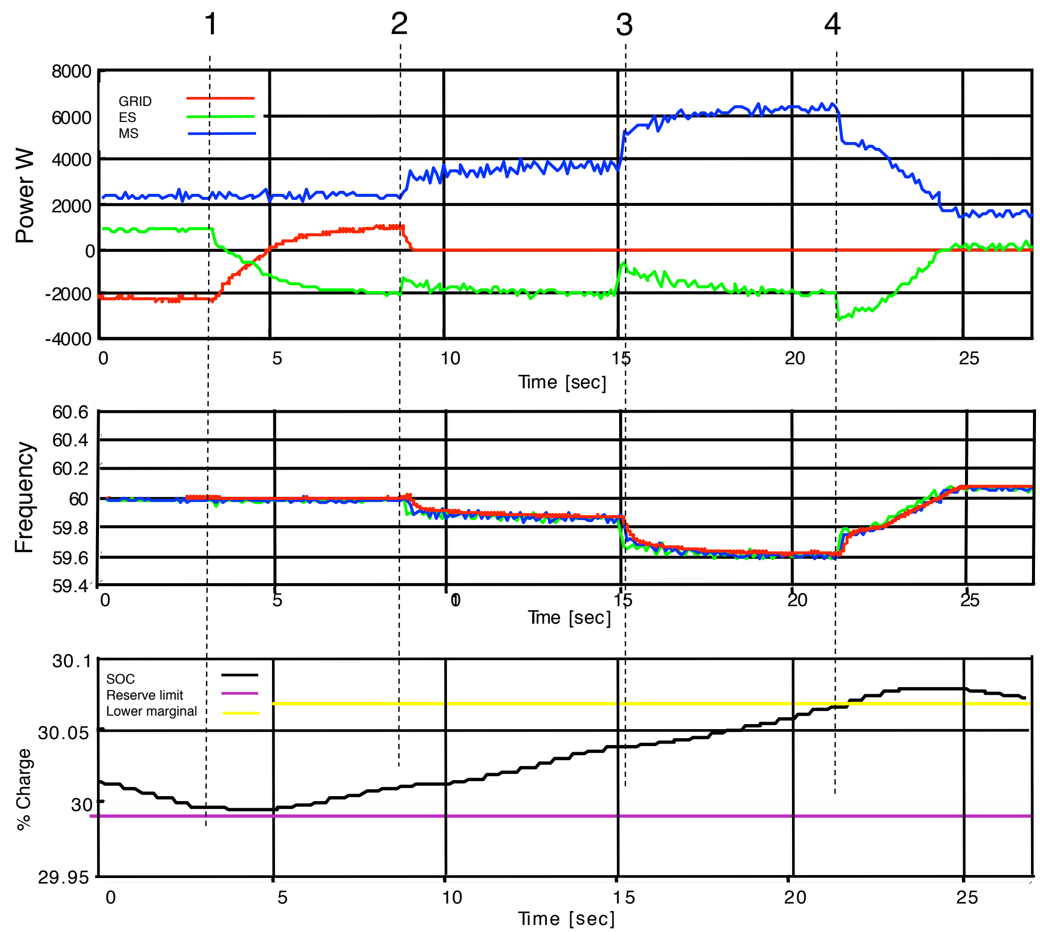
Genset and storage

1. $P_{S\ ref}$ & $P_{G\ ref}$ are dispatched powers while grid connected
2. Red circles indicts the new operating points after islanding if there is loss of power from the grid.
3. Note different slopes.

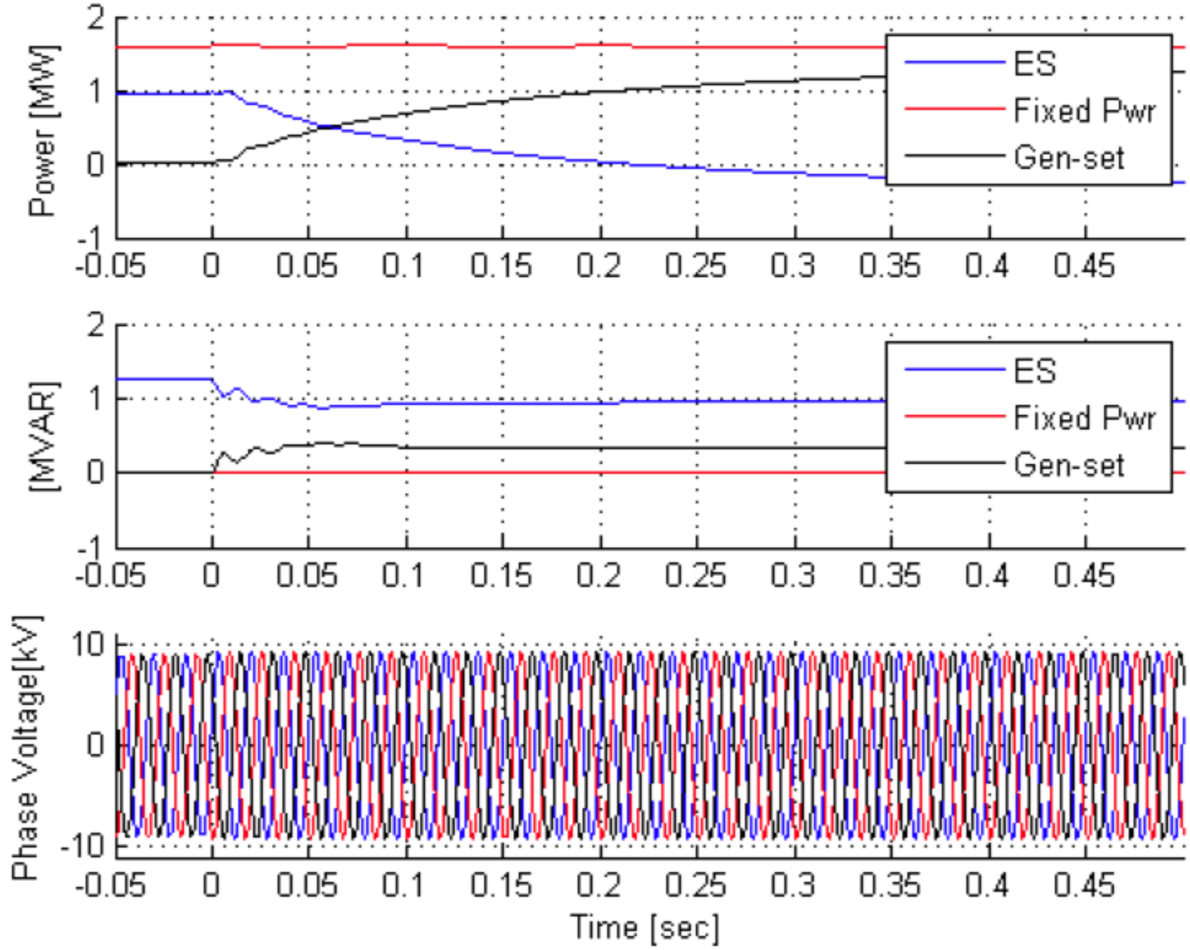


UW Microgrid test of storage and microsource

1. Storage response when batteries reach lower reserve limit SOC at t=3s
2. Islanding at t=9s
3. Step increase in load at t=15s
4. Response when batteries reach marginal voltage limit



Starting Diesel due to low SOC: Chevron



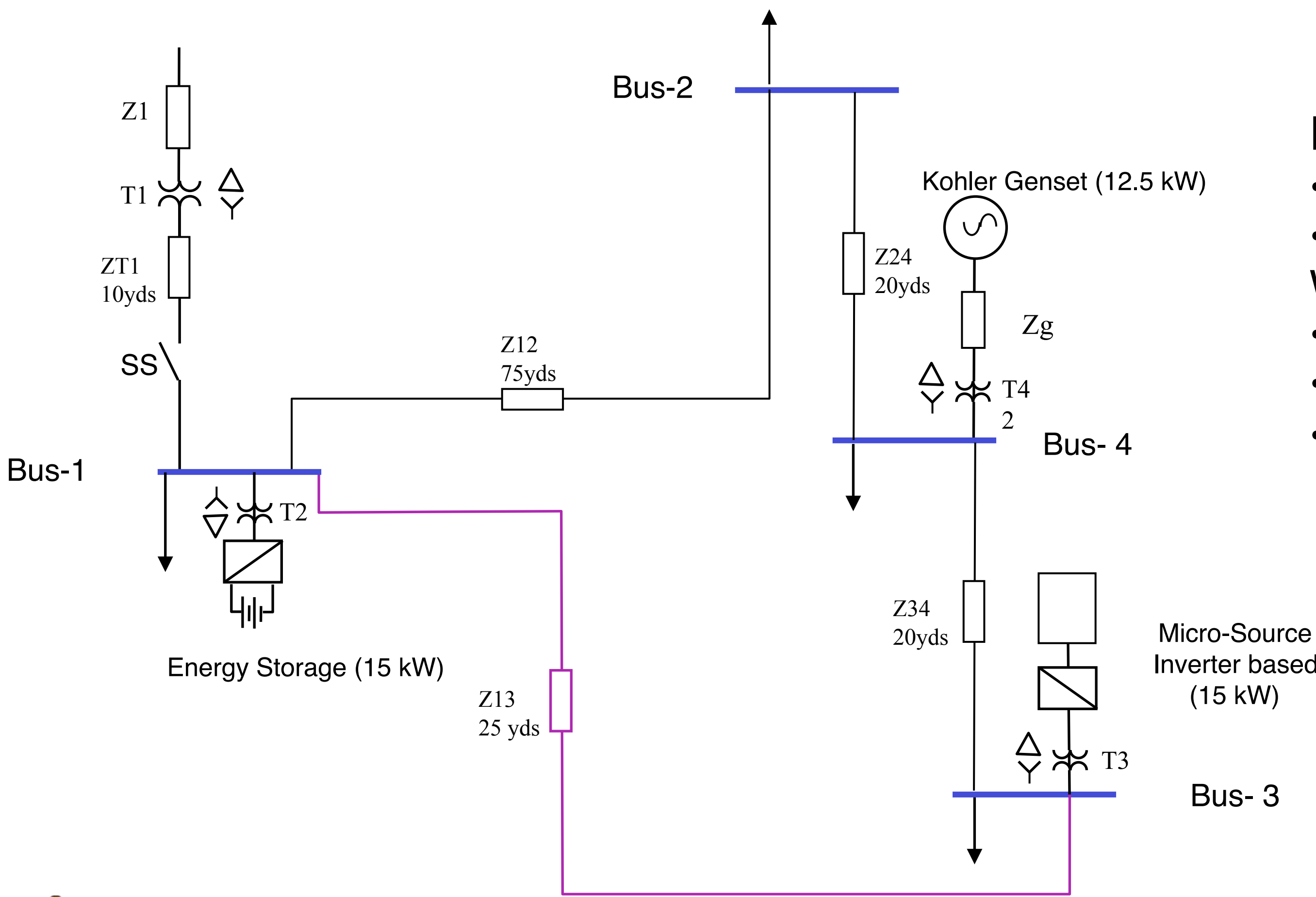
MVAR sharing
Function of V_0 for storage and genset

Summary system controller

System Controller interface

- Provides V_{set}, P_{set} and load shedding freq
- Dispatch/control bi-directional real & reactive power to the utility
- Information needed from each DER unit are P,Q, status
- SOC managed locally and/or through the system controller.

UW Microgrid Model



Events
- Islanding
- Re-close While Islanded
- Load change
- Loss of cable
- Loss of Kohler

Modeling Data Network

4-wire Cables

4-w Cables	Length yds	R Ω	X Ω
Z1		0.0934	0.0255
ZT1	5	0.0028	0.00068
Z12	50	0.0274	0.0066
Z24	30	0.0168	0.0041
Z34	30	0.0168	0.0041
Z13	25	0.0137	0.0033
Zg		0.0656	0.0021

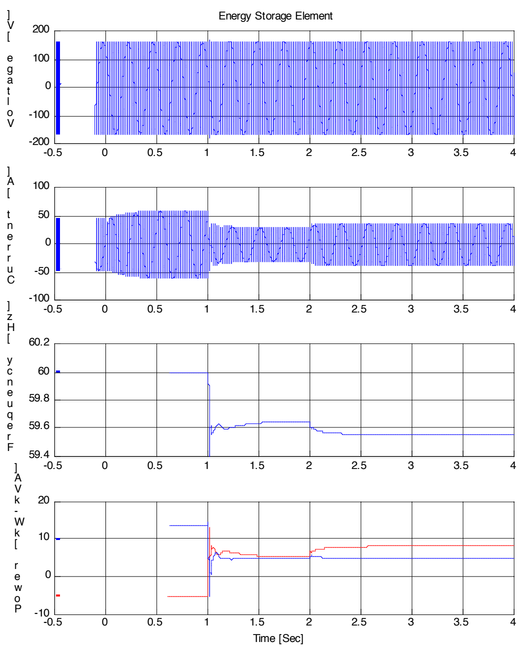
Transformers

xform	voltage	KVA	% impedance	Primary R Ω	Primary X Ω	Secondary R Ω	Secondary X Ω
T1	480-208	75	4.40	0.0169	0.0676	0.0003	0.0127
T2-T4	480-208	45	4.20	0.0269	0.1075	0.0050	0.0201

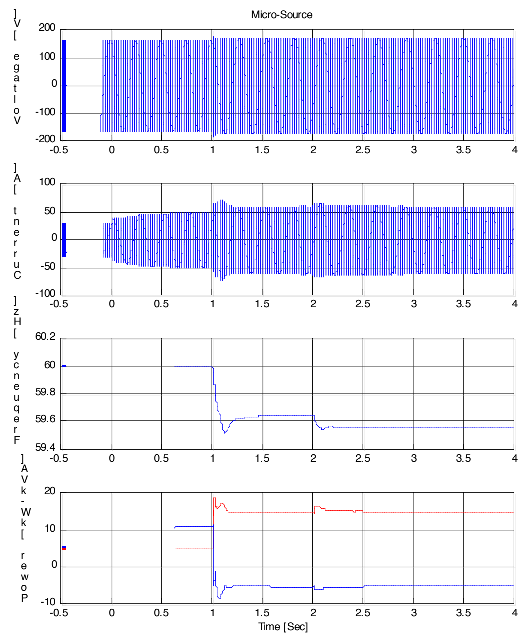
Islanding of Mesh with load change

- On-Site load 35kW: Importing 15kW
- **Island event at t=1.0sec**
- **Additional 3kW load at t=2.0sec**

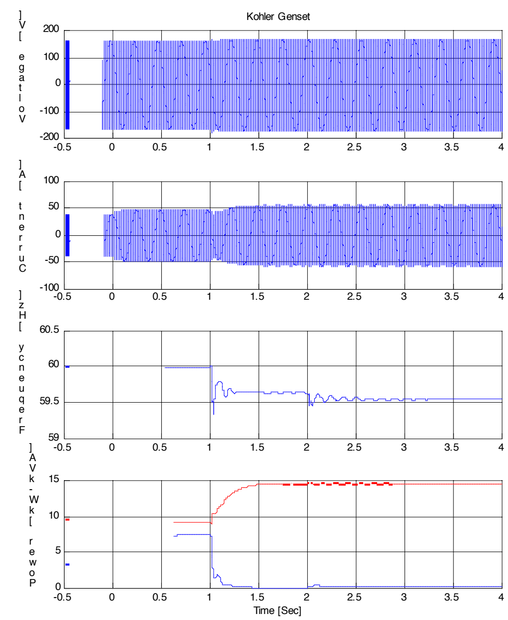
ES: Set to -5kW of 15kW rating



MS: Set to 5kW of 15kW rating



SM: Set to 10kW of 12.5kW rating



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Loss of Kohler while Islanded

- On-Site load 35kW
- **Islanded system**
- **Kohler lost at t=0 seconds**
- **Load L4 (12.5kW) low frequency trip at t~0.2 seconds**

ES: Set to -5kW of 15kW rating

MS: Set to 5kW of 15kW rating

SM: Set to 10kW of 12.5kW rating