DECC Laboratory, Milestones and Roadmap

Tom Rizy

Oak Ridge National Laboratory

DECC Meeting

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Oak Ridge, TN

Managed by UT-Battelle
for the Department of Energy

Topics

- **Laboratory Layout & Interface to the ORNL Distribution System**
- **Laboratory Enhancements**
- **Milestone Achievements**
- **Roadmap & Test Plan**

DECC LABORATORY LAYOUT

DECC Beginnings

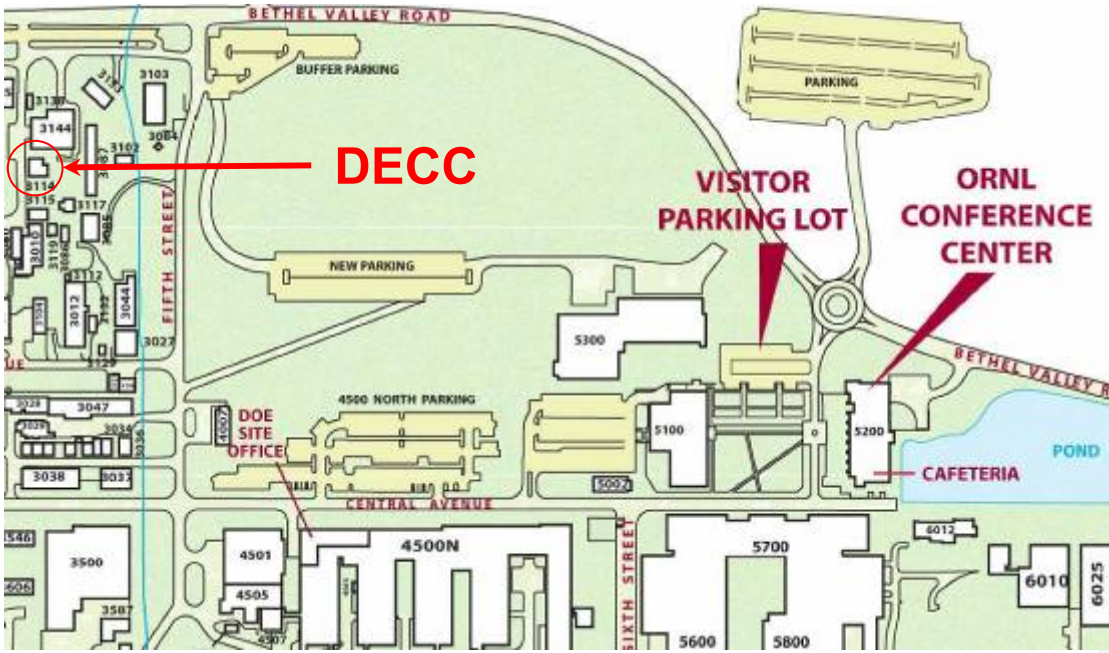
- **Gil's Visit on Feb 25, 2005**
- **Started as "Reactive Power Laboratory"**
- **Nothing yet installed or operating**
- **144kW and 6.6kW power supplies delivered**
- **250hp Synchronous Motor moved from motor shop***

Tom King, Gil Bindewald (DOE OE) & John Kueck

**Motor had been checked out as synchronous condenser (SC) at motor shop (summer '04)*

DECC Laboratory is located on North End of the ORNL Campus in Building 3114

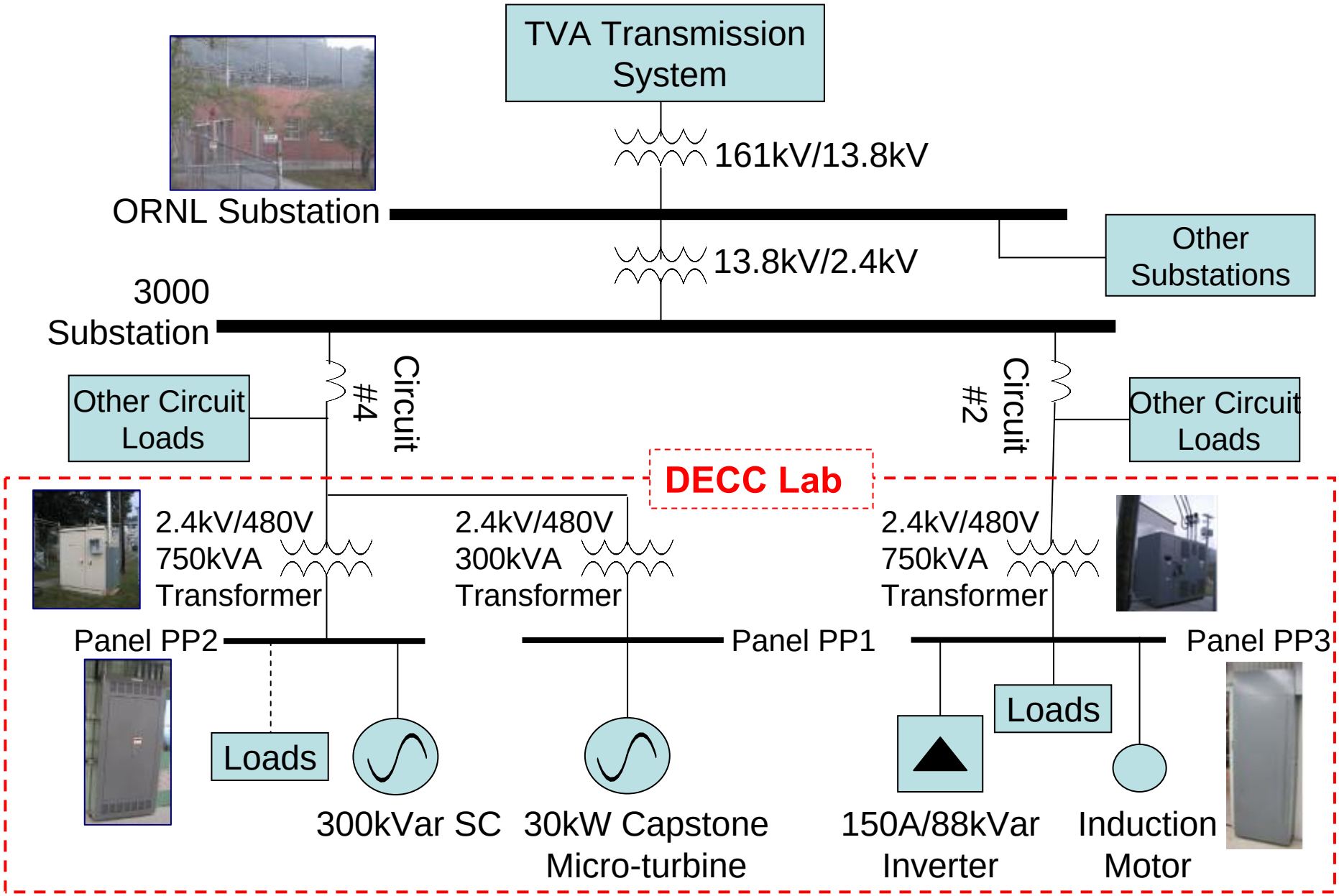
Inside



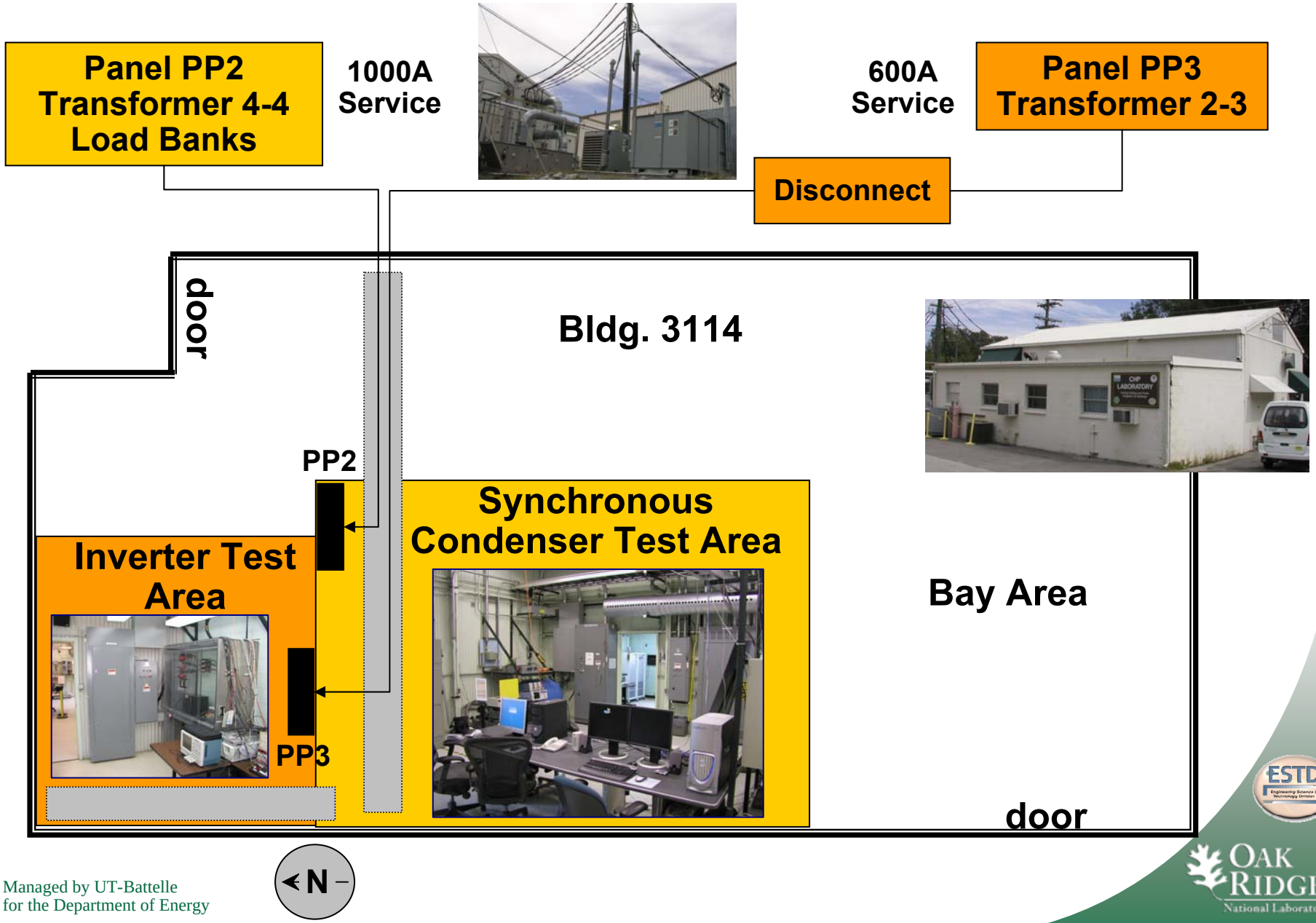
Outside Front

Outside Rear

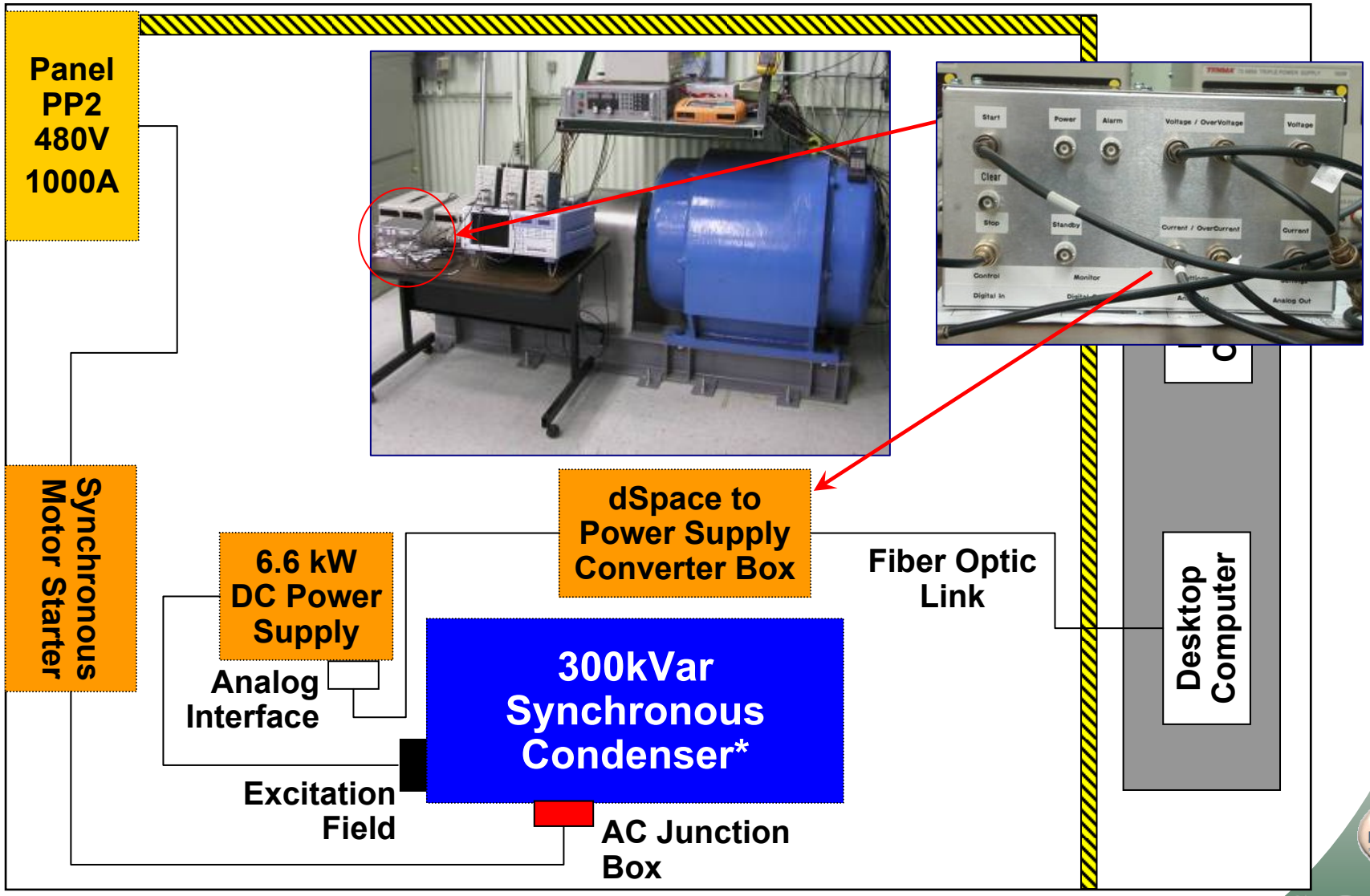
DECC Lab is Interfaced with the ORNL Distribution System



DECC Lab Layout



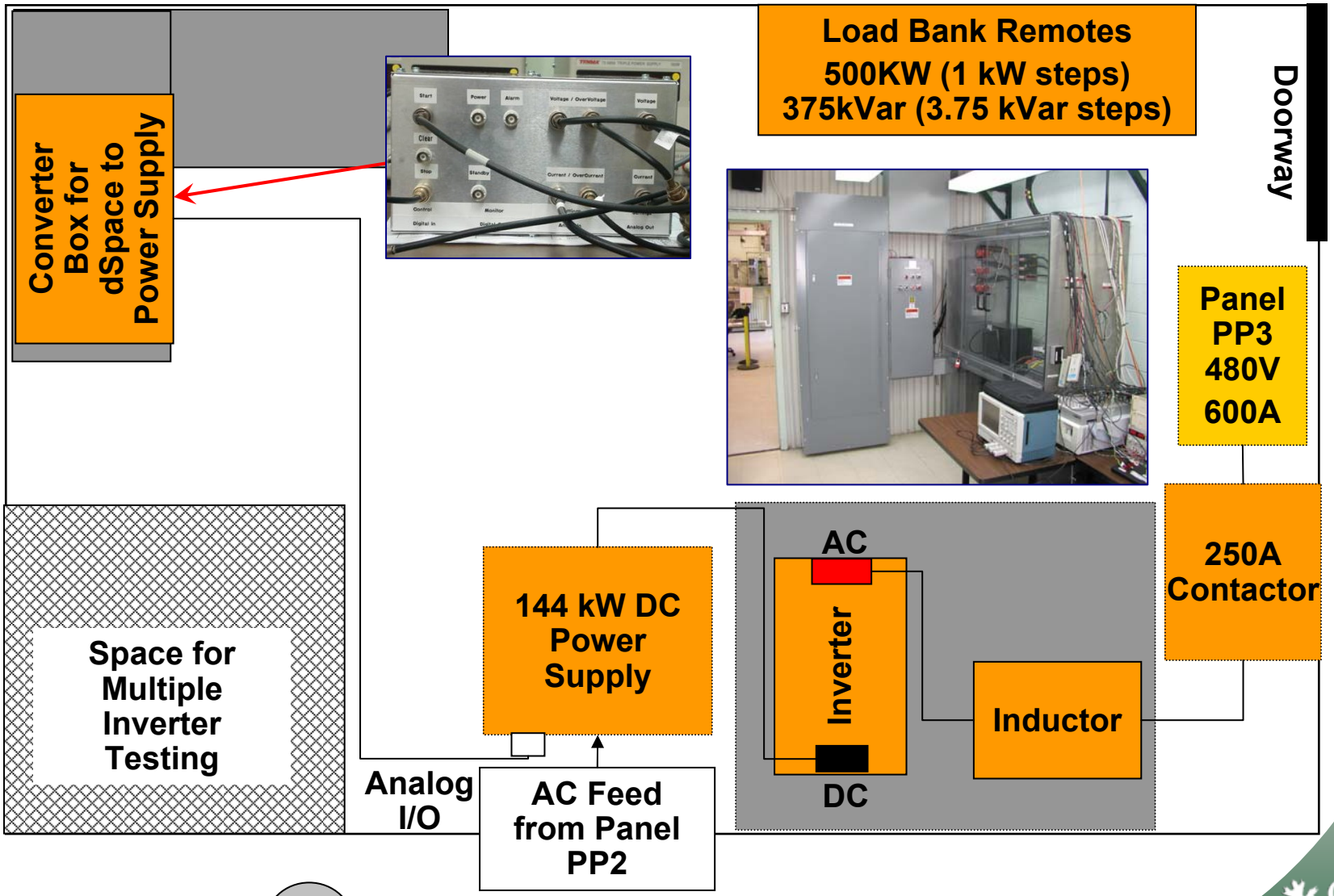
DECC Lab Layout (Cont'd)
Synchronous Condenser (SC)



*Overexcited synchronous motor

DECC Lab Layout (Cont'd)

Inverter Test Area



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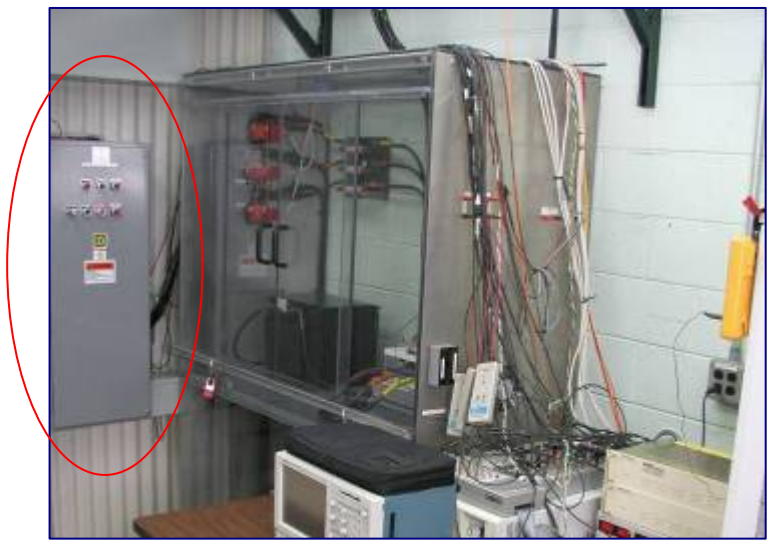
DECC Lab Layout (Cont'd)
Inverter Test Area

Fiber optic Link

dSpace System, Oscilloscope for PWM & Power Supply

Load Bank Remotes



Contactor & Inverter Cabinet

DECC Lab Layout (Outside)
Service Feeds

Transformer 2−3

Transformer 4−4

- **2.4kV/480V/750kVA transformers for both service feeds**
- **1000A/480V panel connected to circuit #4 (transf. 4-4)**
- **600A/480V panel connected to circuit #2 (transf. 2-3)**
- **Circuits fed from ORNL 3000 substation (step-down station, 13.8kV to 2.4kV)**

DECC Lab Layout (Outside)
Load Banks

Avtron Model K675A

- **500kW Load Bank**
- **1kW Step Resolution**
- **Helidyne™ resistive elements***
- **Remote Control Panel**
- **Size: 69"L, 47"W, 52"H**
- **Weight: 700 to 900 lbs**

Avtron Model K841B

- **375kVar Load Bank**
- **3.75kVar Step Resolution**
- **Non-saturating 3-phase iron core reactors**
- **Remote Control Panel**
- **Size: 116"L, 66"W, 80"H**
- **Weight: 6,000 to 9,000 lbs**

**Designed by Avtron and manufactured of corrosion resistant chromium alloy wire.*

DECC LAB ENHANCEMENTS

DECC Lab Enhancements
30kW Micro-turbine added

- **Previously used for CHP**
- **27-24kW max depending upon ambient outside temperatures**
- **Connected to Circuit #4 at 480V panel 4-1**
- **kW dispatch controls; no voltage regulation or power factor control**
- **Instrumented (spring '06) to interface with dSpace system**
- **Remote control software inside at DECC computer**

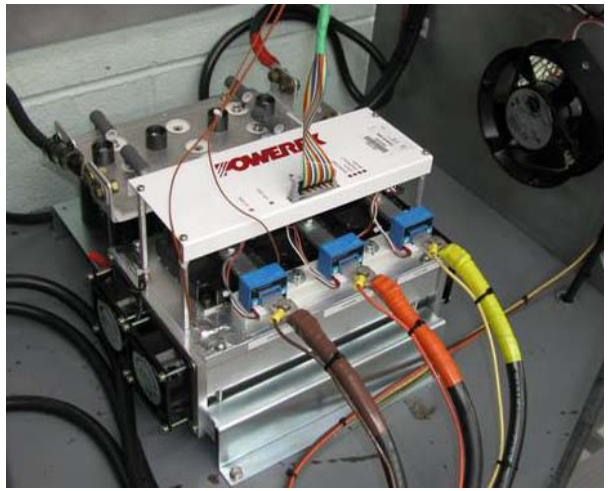
Part of Remote Control Screen

Micro-Turbine Behind 3114

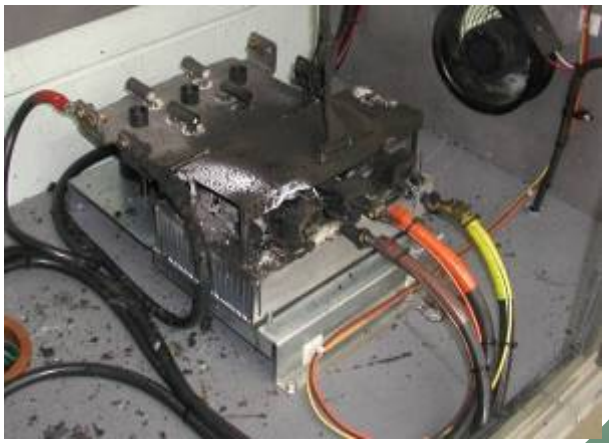
Transformer & Instrumentation

DECC Lab Enhancements (Cont'd)
Inverter Cooling

- **Exceeding the junction temperature of IGBTs is the Achilles heal of inverter operation**
- **Using heat sink limit of 76°C**
  - **Estimate IGBT junction to be another 20 to 30°C higher**
  - **100°C to 120°C is okay**
  - **Above 120°C, there can be degradation**
- **75A inverter operated at 62A (83% capacity) for several minutes**
  - **The inverter did not trip out on over-temperature (96 to 100°C) protection**
  - **However, the inverter failed catastrophically**



150A Inverter



Failed 75A Inverter

DECC Lab Enhancements (Cont'd)
Increased Cooling for Inverter

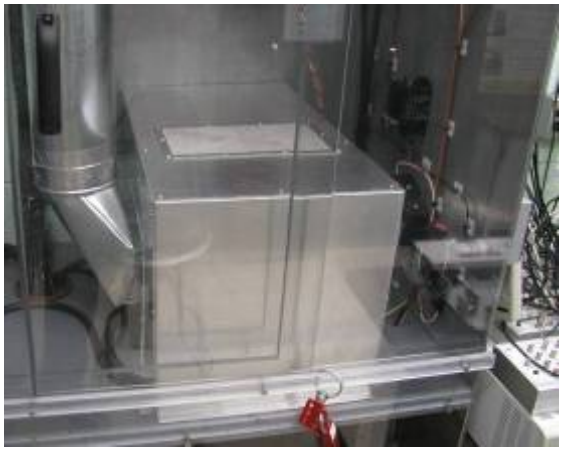
- **Inverter temperature is the limiting factor in terms of current; stay below 76°C at heat sink**
- **Ducting added pull heat away from inverter and outside of test cabinet**
- **Replaced forced draft fan on inlet with larger capacity**
  - **Increased to from 230 to 300cfm**
- **Added fan to exhaust (in addition to inlet) of piping**
  - **600 cfm induced draft fan**
- **Thermocouples (two) in addition to onboard thermistor monitor near IGBT junctions**

Air Ducting & Forced Draft Fan

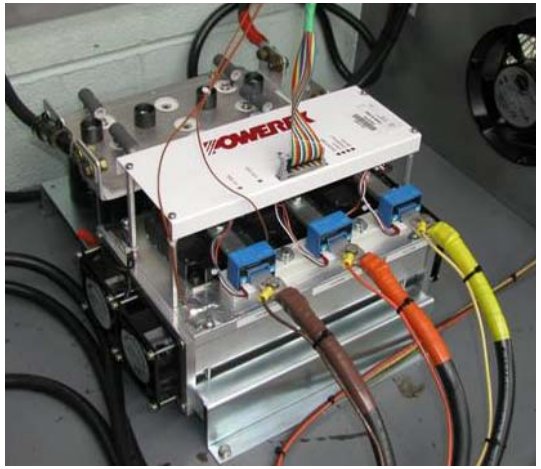
Induced Draft Fan

DECC Lab Enhancements (Cont'd)
Higher Rated Inverter & Shielding

- **2007 testing with 150A (88kVar) rated inverter**
- **Output limited to 76°C ceiling**
  - **77A peak continuous or 67% of capacity continuous**
  - **150 A peak for several cycles or 100% of capacity momentarily**
- **225A output over-current trip protection**
- **EMI shielding added to reduce interference with dSpace**
- **Plan to change to 300A (176kVar) rated inverter in the near future**



EMI Shielding in Place



150A Inverter

DECC Lab Enhancements (Cont'd)
Induction Motor

- **Added to inverter panel (PPP3)**
  - **150A Motor Starter was already in place**
- **Initially a small motor (7.5hp)**
  - **but have motor logic and fuses for larger sizes up to 75hp**
- **Using to create voltage sags**
  - **Balanced with all three-phases connected (2V sag for 0.1s)**
  - **Unbalanced with one-phase disconnected (1V sag for 2s)**
- **Startup of synchronous motor also being used to create voltage sag**
  - **Most Severe and long lasting**
  - **Translates to 3V or greater sag for 4s on inverter panel**

Fuse Blocks

7.5hp Induction Motor

DECC Lab Enhancements (Cont'd)
Induction Motors for Voltage Sag Testing

15hp Motor

40hp Motor

50hp Motor

25hp Motor

250A Motor Start

75hp Motor

Micro-Turbine Available for FY08

- **100kW Micro-turbine**
- **Donated by SCE**
- **Plan to wire up in FY08**
- **Capable of limited voltage & power factor correction**
  - **0.8 lead/lag power factor correction**
  - **±2% voltage regulation**
- **Plan to connect to circuit #4**
  - **Panel PP2 has an available 350A CB**

Elliott TA-100 Micro-Turbine

New DE Technologies to be Added

- **Photovoltaic (PV) Array**
  - **assess opportunity for non-active power compensation**
  - **50kW PV Array to be added by end of the year**
  - **Storage could be added later to provide output when it is cloudy/rainy/night**
- **Plug-in Hybrid Electric Vehicle (PHEV)**
  - **Study interface with grid**
  - **Charge while providing non-active power**
  - **Interaction with our other DE systems**
  - **Plan to add in the future**

MILESTONE ACHIEVEMENTS

Milestones & Key Achievements

"Continual improvement is an unending journey"*

2004 – Pre-Lab

- **Characterization of SC at motor shop – Aug**

2005 – Commissioning

- **Start of DECC Laboratory – Feb 2005**
- **300 kVar SC operated for first time to inject reactive power into circuit #4 – Apr 2005**

2006 – Inverter

- **Inverter (75A/44kVar) operated at 10% of output to inject reactive power into circuit #2 – Feb**
- **Inverter operated at 83% of its rated output – Mar**
- **Installed higher rated inverter (150A/88kVar) – May**
- **Developed control for both SC & inverter to regulate local voltage – June**

Lloyd Dobyns and Clare Crawford-Mason, *Thinking About Quality

Milestones & Key Achievements (Cont'd)

2006 – Simultaneous Operation

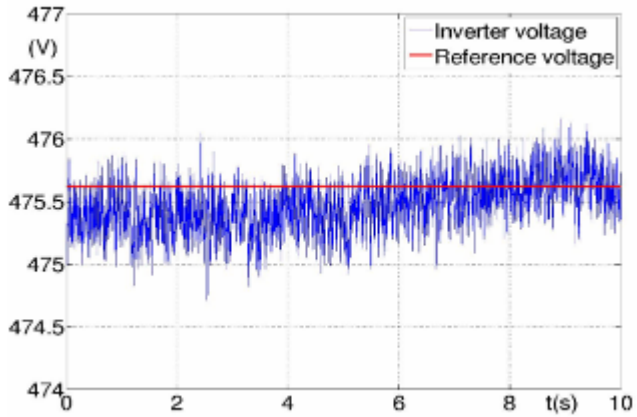
- **Output-to-temperature characterization of inverter – Summer**
  - Conducted off-grid and loaded up with our load banks
  - Inverter can output max of 77A continuously at 76°C
- **Simultaneous operation of SC & inverter – Sep**
  - Each independently controls its panel voltage
  - Inverter regulated voltage on power panel PP3 (circuit #2)
  - SC regulated voltage on power panel PP2 (circuit $4)

2007 – Simultaneous Operation with Conventional MTG

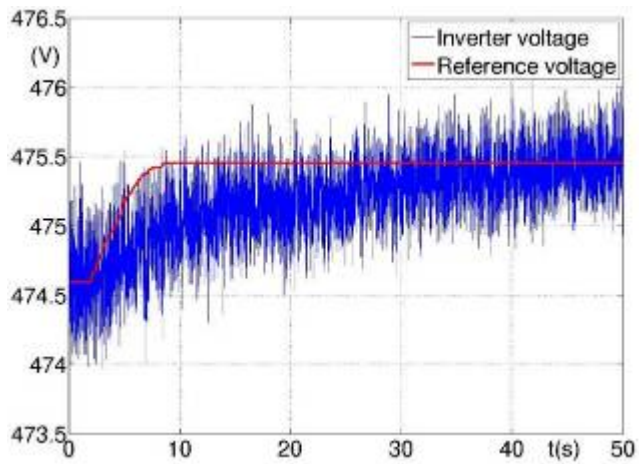
- **Simultaneous operation of inverter, SC & micro-turbine – May**
  - Dynamic response of independent controls
  - Inverter can respond to a steady-state change of 1V
  - SC can respond to a steady-state change of 5V
  - Response of inverter controls to synchronous motor start

Local Voltage Regulation on Sept 6 '06*

INVERTER

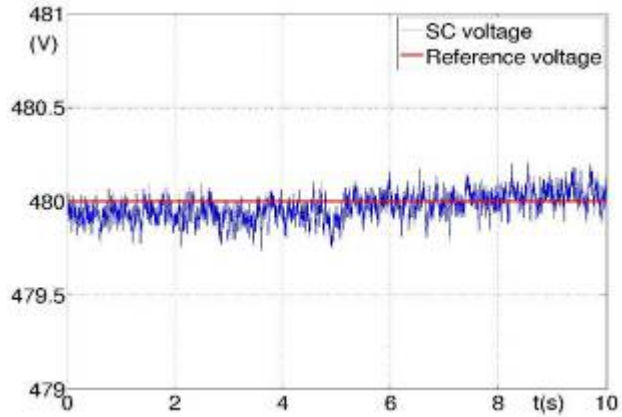


Voltage regulation at PP3

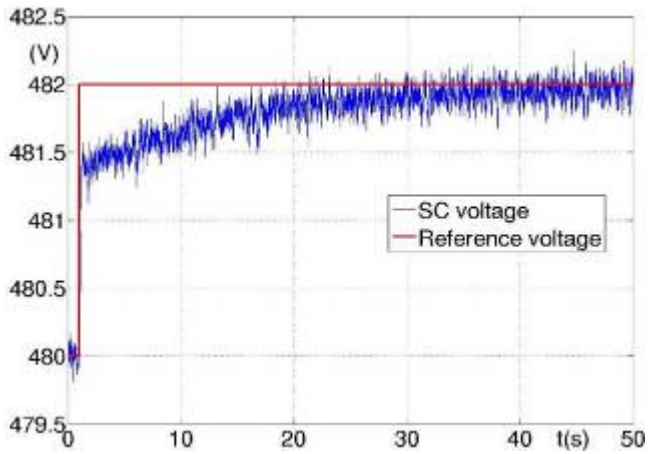


Response to 1V increase

SYNCHRONOUS CONDENSER



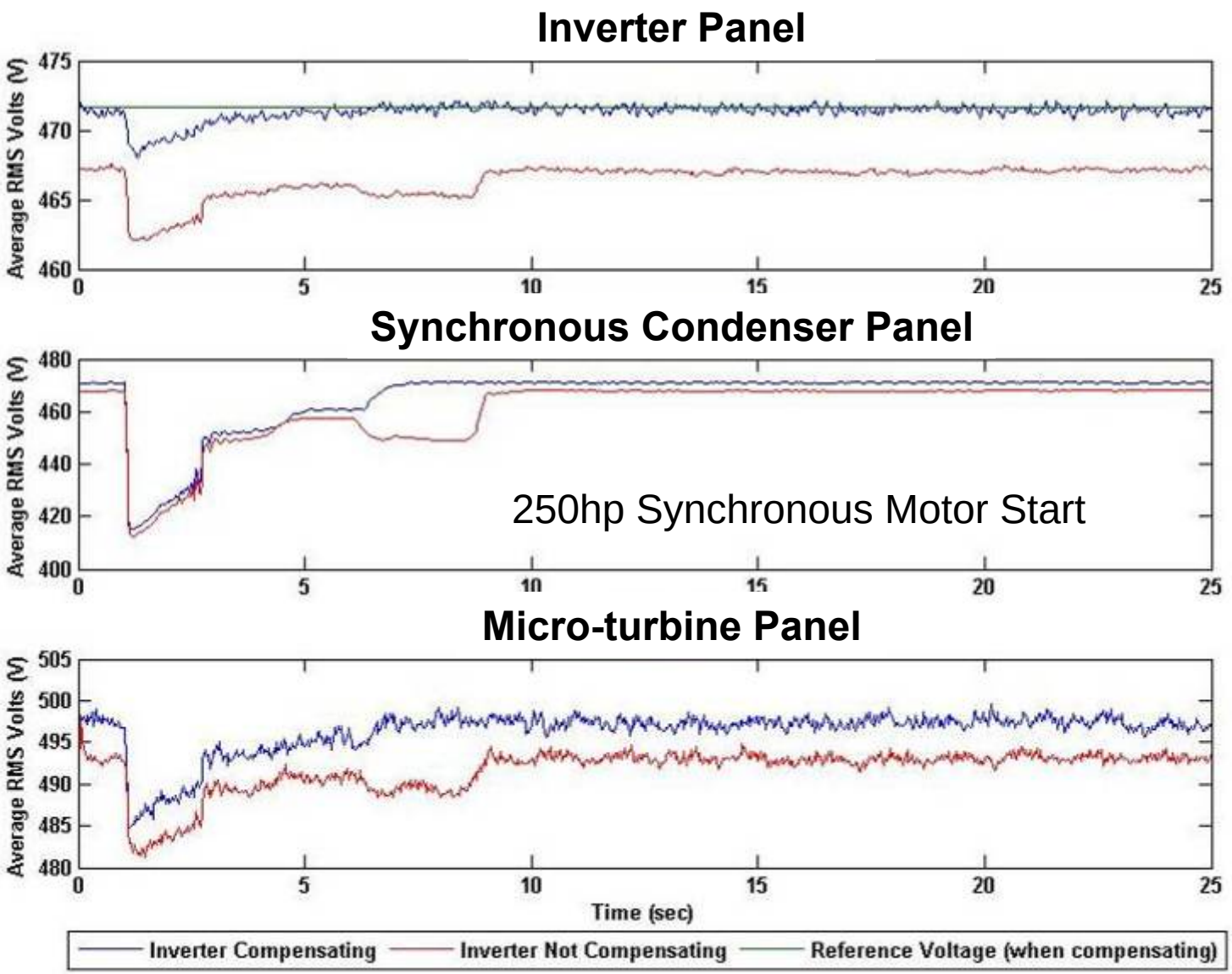
Voltage regulation at PP2



Response to 2V increase

**Used shielded BNC cables but some noise from inverter operating at 12.5 kHz still showing up on signal.*

Local Voltage Regulation on May 1, '07



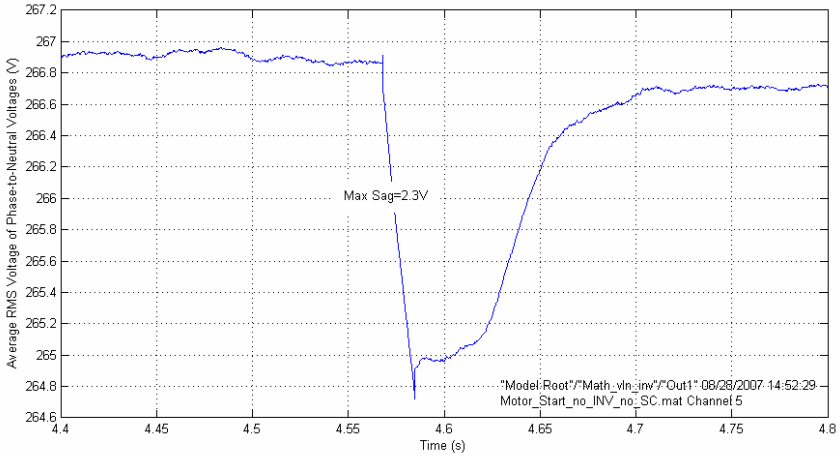
Milestones & Key Achievements (Cont'd)

2007 – Simultaneous Operation with Voltage Sags (Aug)

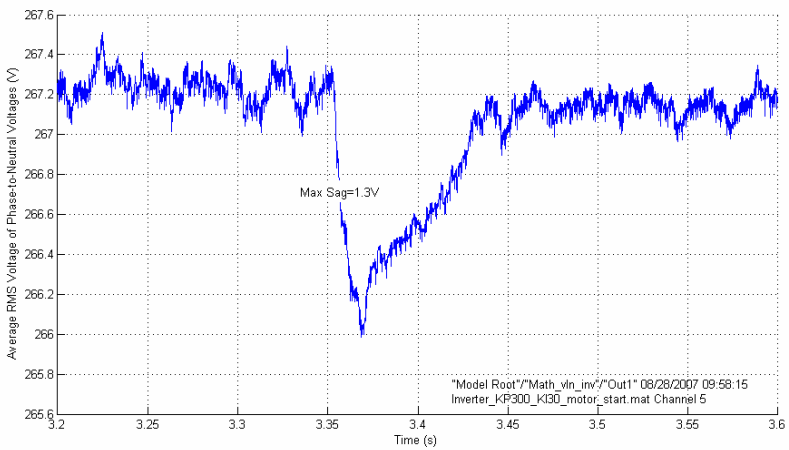
- **Operation of inverter, SC & MTG during balanced voltage sag**
  - **7.5hp induction motor start draws ~121A**
  - **Voltage sag of 2V for 0.12s**
  - **Inverter outputs ~100A for a few cycles**
- **Operation of inverter, SC & MTG during unbalanced voltage sag***
  - **Start of single-phased induction motor (phase b fuse pulled)**
  - **Motor can't start and draws ~85A peak current for 2.2s**
  - **Max 1.1V sag, 50% unbalance**
  - **Inverter outputs ~90A for the duration of the sag**
- **Operation of all DE during severe voltage sag**
  - **250hp synchronous motor start; 58V sag on PP2 (SC), 3.8V on PP3**
  - **Inverter trips out on 225A over-current protection**
    - **Suspect too much reactive power demanded to raise voltage sag**
    - **TVA & ORNL were heavily loaded due to the 90+ temperatures & drought**
  - **Same test worked in May without inverter tripping out**

**Control is configured for balanced voltages so all inverter phase currents are present*

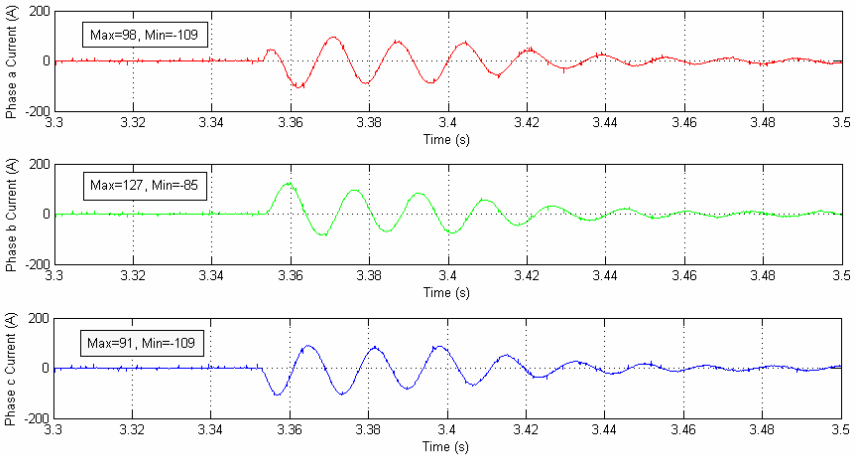
Regulation with Balanced Sag – Aug 28 '07



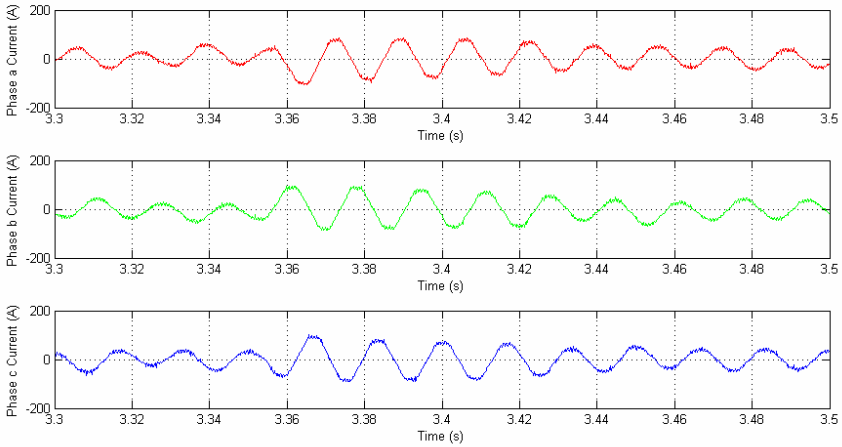
Sag for induction motor start



Inverter voltage regulation on PP3

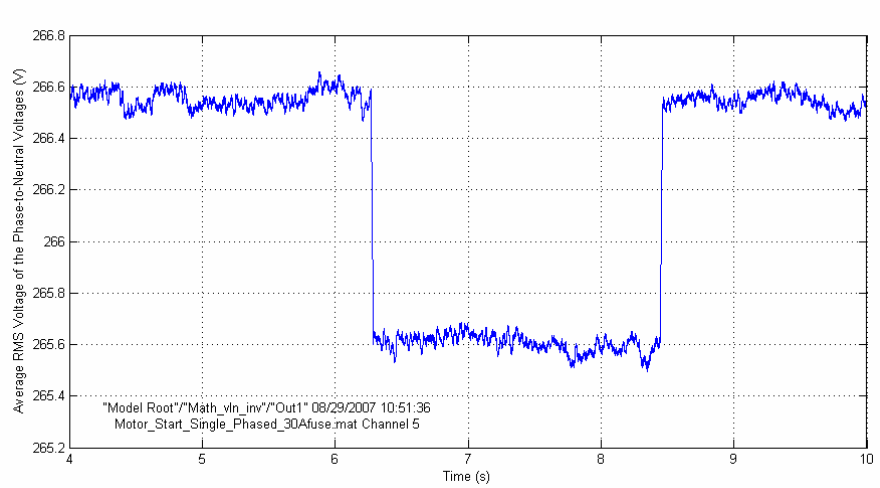


Motor Start Current

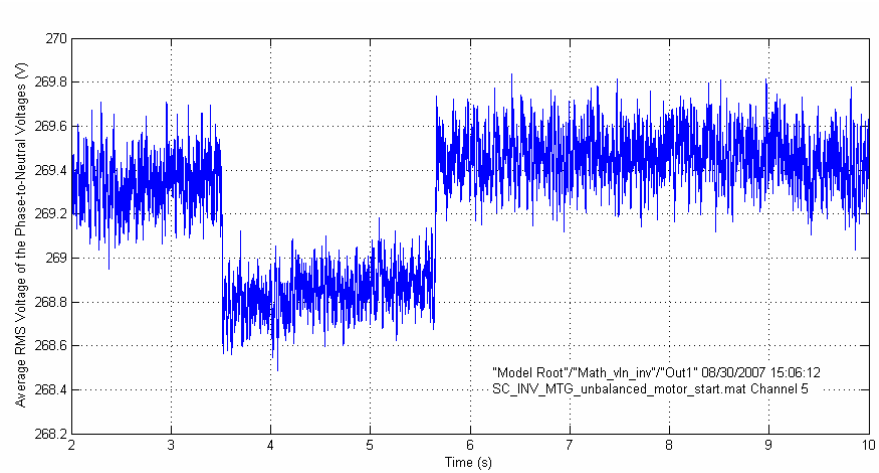


Inverter Current

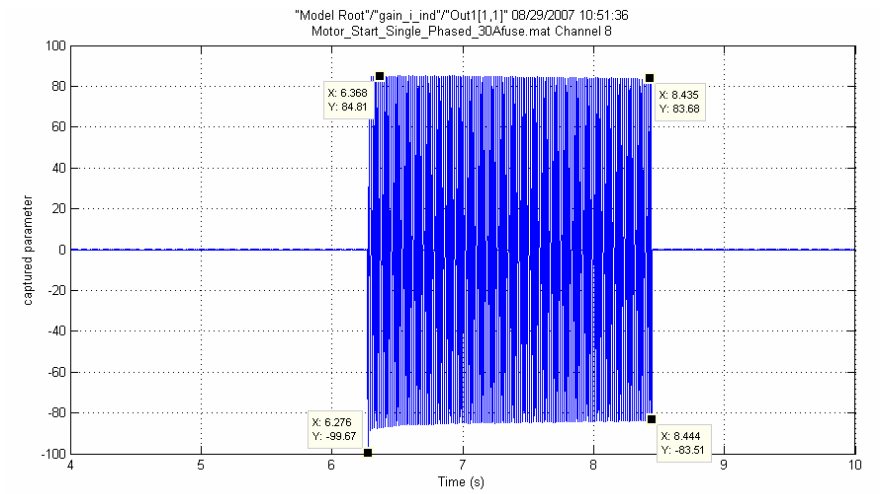
Regulation with Unbalanced Sag – Aug 30 '07



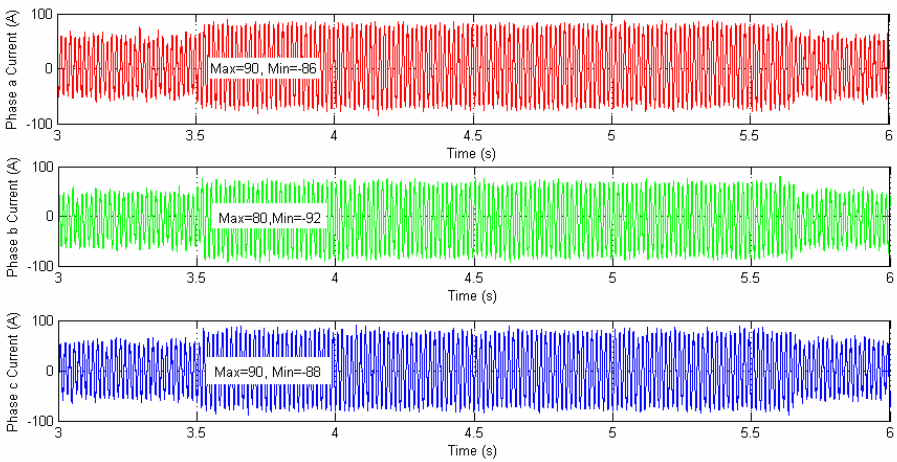
Sag for single-phased motor start



Inverter voltage regulation on PP3



Motor Start Current (Ph a)



Inverter Current

TEST PLAN & ROADMAP

Test Matrix

- **Testing of advanced controls for rotating-based and inverter (PE)-based DE**
  - **Autonomous, local control will minimal communications**
  - **Focus has been reactive power injection/absorption for voltage regulation**
  - **Future efforts include power factor and harmonics control and different control techniques**
- **Currently have 8 test items for DECC**
  1) **Temperature-dependent Inverter Rating**
  2) **Voltage Regulation**
  3) **Unbalance Voltage Regulation**
  4) **Voltage Sags**
  5) **Voltage Operating Bands**
  6) **Circuit Reconfiguration**
  7) **Circulating Currents**
  8) **Fault Clearing**

Test Matrix Elements

No	Test Category	Description
1	Temperature-dependent Inverter Rating	Characterize inverter continuous operating current level based on IGBT (Insulated-gate bipolar transistor) temperature with new cooling configuration
2	Voltage Regulation	Response of control algorithms to balanced voltage changes (i.e., shift in reference, changing load conditions, capacitor bank trip)
3	Unbalance Voltage Regulation	Response of independent phase control for unbalanced voltage (unbalanced source or loads)
4	Voltage Sags	Response to various dynamic conditions (i.e., voltage sags, load steps and motor starts)

Test Matrix Elements (Cont'd)

No	Test Category	Description
5	Voltage Operating Bands	Changing voltage schedules for the DEs which involves the use of a voltage-band based control (i.e., upper & lower references)
6	Circuit Reconfiguration	Change the substation source or impedance of the feeder circuit
7	Circulating Currents	Vary electrical distance between multiple DEs to determine how they interact and level of circulating current (i.e., DEs on different versus same circuit).
8	Fault Clearing	Severe abnormal conditions (i.e., when there is a fault)

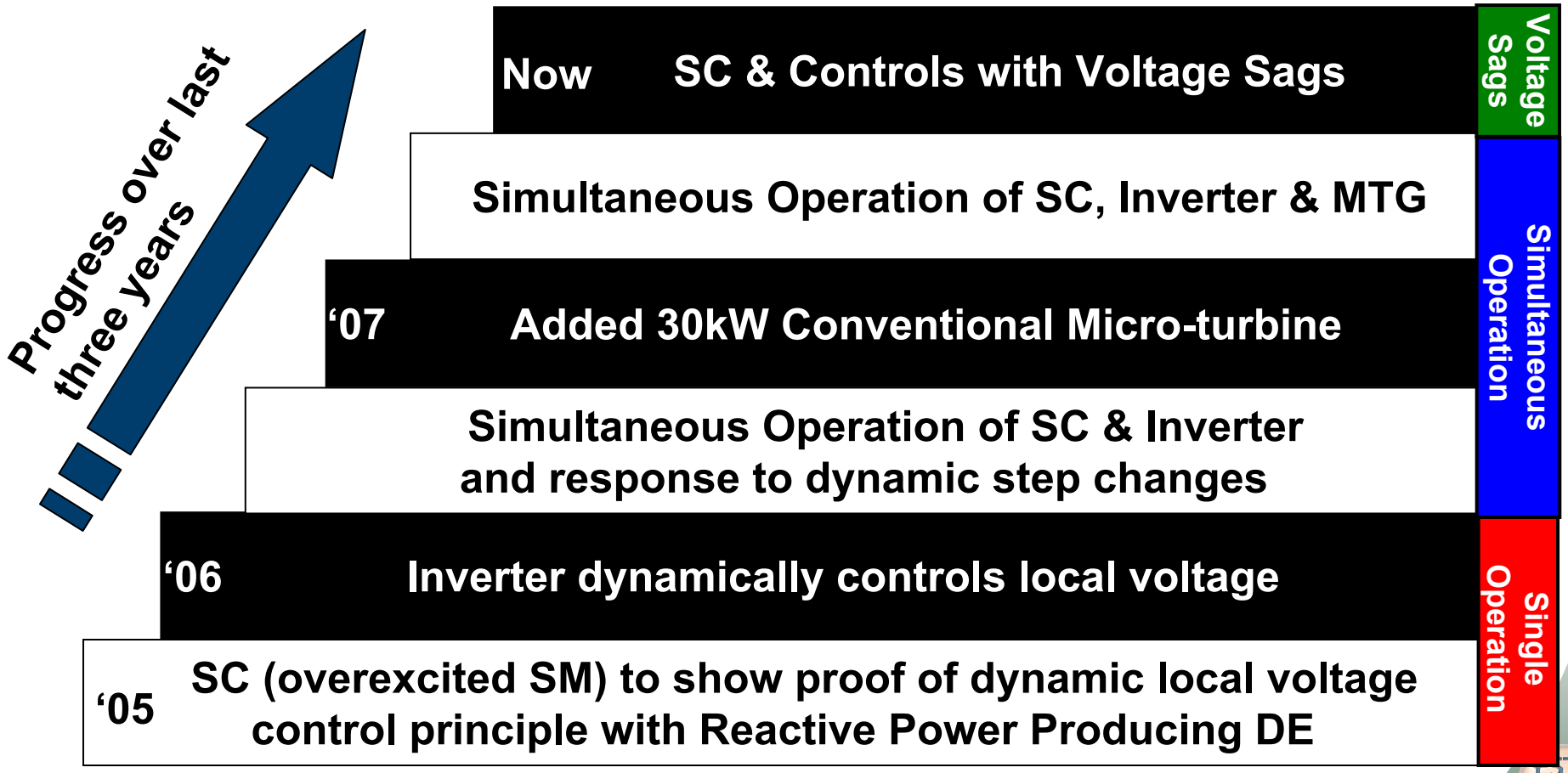
Test Matrix Items & Schedule*

No	Test Category	Description
1	Temperature-dependent Inverter Rating	FY06 & FY07
2	Voltage Regulation	FY06 & FY07
3	Unbalance Voltage Regulation	Just Started FY07
4	Voltage Sags	Just Started FY07
5	Voltage Operating Bands	FY08
6	Circuit Reconfiguration	FY08
7	Circulating Currents	TBD
8	Fault Clearing	TBD

**FY is a fiscal year, such as FY08 is from October 1, 2007 to September 30, 2008.*

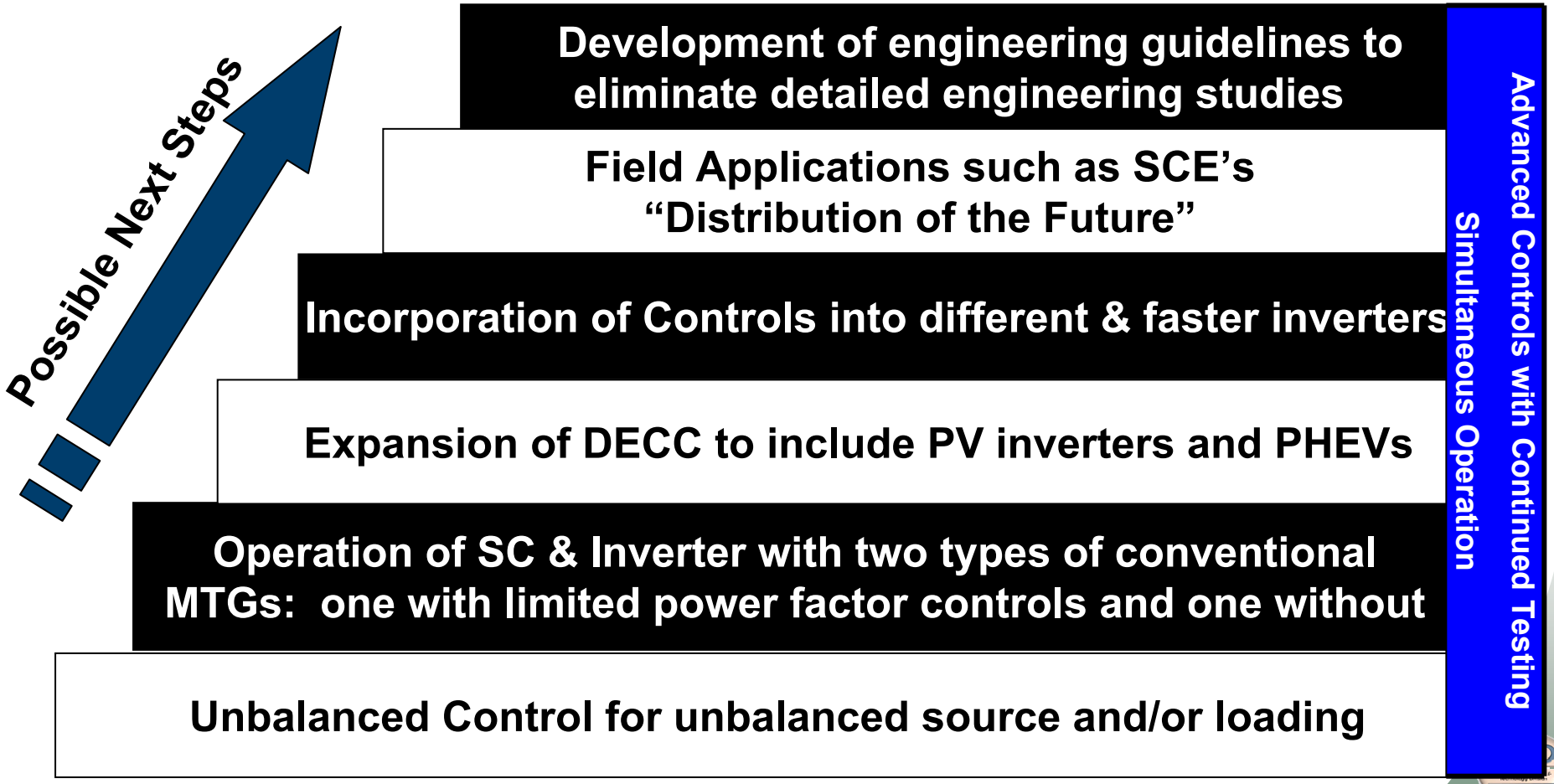
DECC Provides Building Blocks

Progress Steps at DECC



DECC Provides Building Blocks

Next Steps at DECC



CONCLUSIONS

- **DECC is an established and unique DE laboratory interfaced to an actual distribution system**
- **DECC provides a real-world environment for testing local, autonomous control of non-active power producing DE**
- **Our testing has shown positive results with our advanced voltage control algorithms**
- **We have an aggressive test matrix which we have made headway on it and will continue to follow and add to for future R&D**
- **Our next steps will focus on voltage sags and unbalanced conditions with motor starts**
- **We are proceeding to develop software simulation models in parallel to evaluate new algorithms and modifications prior to testing**

OAK RIDGE NATIONAL LABORATORY

Managed By UT-Battelle for the Department of Energy

D. Tom Rizy, Research Staff
Cooling, Heating and Power (CHP) Group
Engineering Science & Technology Division
One Bethel Valley Road, MS-6070
Oak Ridge, Tennessee 37831-6070

(865) 574-5203 Voice, 9338 Fax
(865) 207-6769 Cell
Email: rizydt@ornl.gov
www.ornl.gov, www.ornl.gov/sci/decc