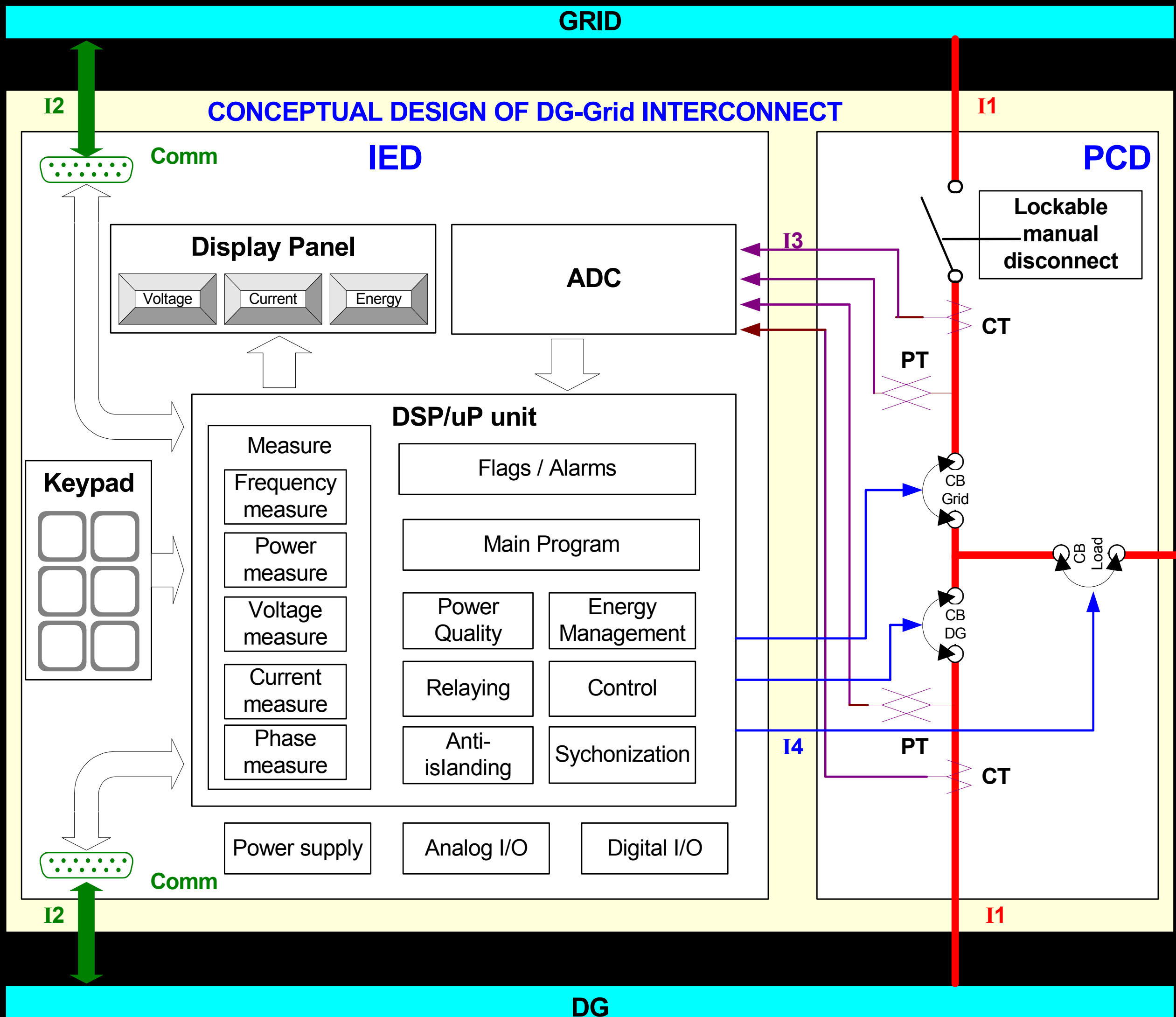
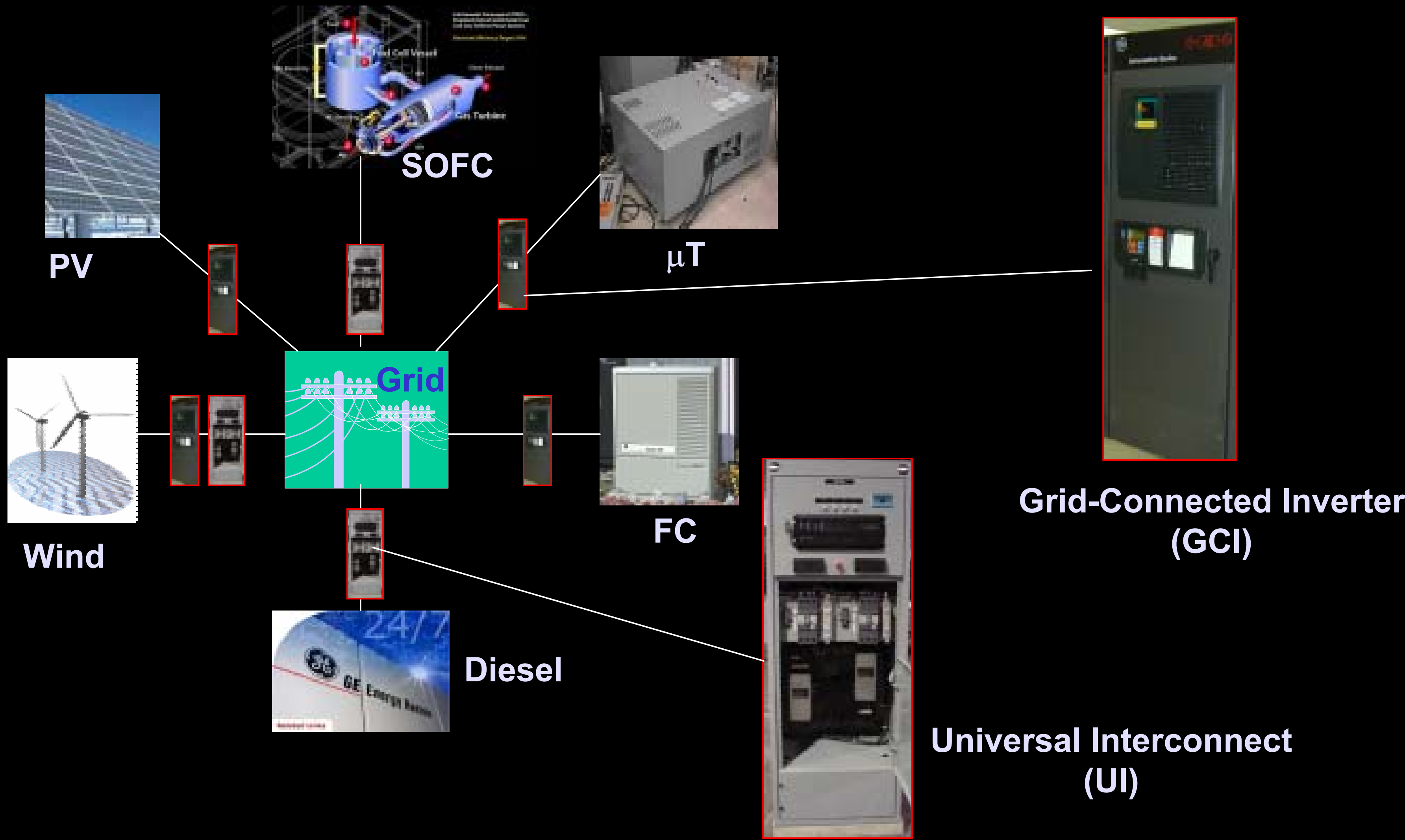
Interconnect Conceptual Design



- **Standardized modules**
  - **IED** (Intelligent Electronic Device)
  - **PCD** (Power Carrying Device)
- **Standardized/Normalized interfaces**
- **Technology neutral, suitable for interconnecting different DGs**
- **Pre-testing and pre-certification for standard compliance**
- **Scalable and upgradable**
- **Universal platform with natural progression of functionality to maximize the economic and performance benefits of DG**

DG/Grid Interconnect



- **Two interconnect platforms**
- **Functions, e.g. communications, metering, etc. are built on the platforms, depending on application scales, e.g. individual end users, aggregated dispatch/control, etc.**

IEEE 1547 Compliance Matrix

4.1 General Requirements

4.1.1	Voltage Regulation	Available	P1547 says that DG shall not actively regulate the voltage at the PCC. UI should monitor the voltage to be within the range of ANSI C84.1, Range A. G60 has voltage protection, monitoring, and data log
4.1.2	Integration with Area EPS Grounding	Available	need to consider different Transformer connections, e.g. Wye/Wye, Delta/Wye, etc. will require different protection elements. In some cases, it may need to sense primary (substation)
4.1.3	Synchronizatio		flicker effect. Flicker monitoring is not the current G60 function. G60 has sync check.
4.1.4	Distributed Resources on Distribution Secondary Grid and Spot Networks	N/A	Reverse power protection is needed to coordinate with netowrk protectors. Unclear to exactly define UI functions as the issue is not thoroughly addressed in the current standard version.
4.1.5	Inadvertent Energization of the Area EPS	Available	dead circuit check
4.1.6	Monitoring Provisions	Available	This function refers to remote monitoring by utilities operators. Therefore, communication is needed. How to communicate, however, is undertermined. P1547.3 will address communication requirements. G60 has communication capabilities. The requirement will be determined by local power control operator.
4.1.7	Isolation Device	N/A	External to UI Box. readily accessible, lockable, visible-break isolation device. It may be desirable for UI to monitor (but not control) the status of the isolation device.
4.1.8	Interconnect Integrity		
4.1.8.1	Protection from Electromanetic Interference (EMI)	Available	UI IED device meets the requirement
4.1.8.2	Surge Withstand Performance	Available	UI IED device meets the requirement
4.1.8.3	Paralleling Device	N/A	contact/CB ratings (220% of the rated voltage), not part of IED

Anti-Islanding Protection

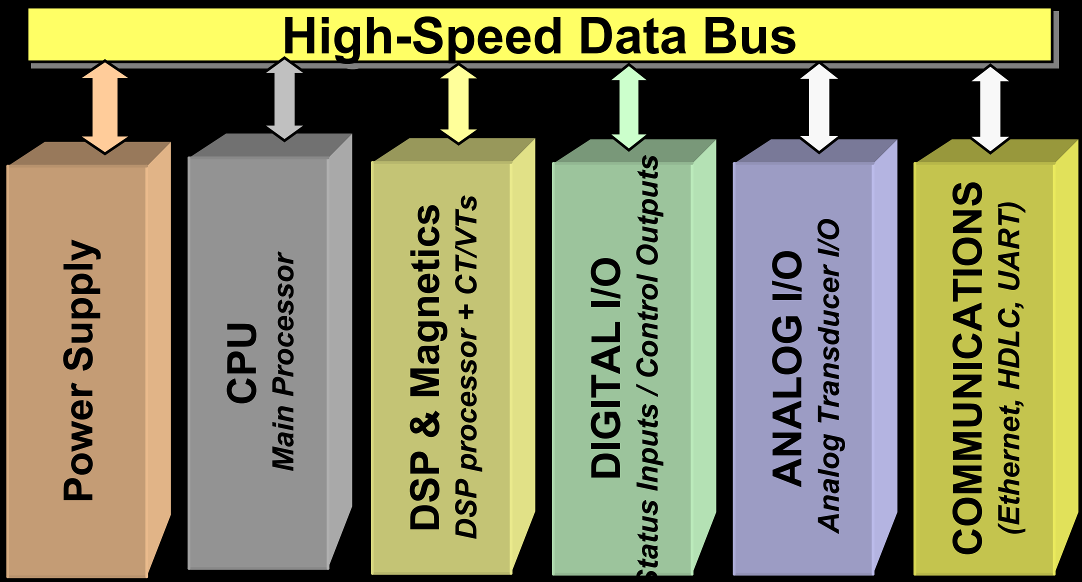
4.2 Response to Area EPS Abnormal conditions

4.2.1	Area EPS Faults	Available	G60 has some elements for fault detection
4.2.2	Area EPS Reclosing Coordination	***Anti-Islanding protection***	reclosing time varies, e.g. reclosing due to lightning is normally fast (less than 0.5s), however, reclosing due to tree fall is normally slow (up to 10s). Different utilities set the reclosing time differently, depending on their practical conditions. Therefore, the timing of AI protection should be adjustable to coordinate with recloser settings. If transfer trip (communication) is used, then it is not an issue. If not, then it is a challenging for anti-islanding detection with fast reclosing.
4.2.3	Voltage	Available	adjustable set points for DG > 30kW. Could be realized using FlexLogic
4.2.4	Frequency	Available	adjustable set points for DG > 30kW. Could be realized using FlexLogic
4.2.5	Loss of Synchronism	Available	sync check. Also need to monitor flicker. Leave it as DG design issue.
4.2.6	Reconnection to Area EPS	Available	The delay time should be user adjustable.
4.3 Power Quality			
4.3.1	Limitation of DC injection	N/A	UI could monitor it, but too costly. Need LEM current sensors, not just CTs, if want to monitor it. Leave it as DG design requirement.
4.3.2	Limitation of Flicker Induced by the DR	N/A	Monitoring flicker, SMARFI 90, 80, 70
4.3.3	Harmonics	N/A	UI could monitor it, but too costly. To monitor harmonics (up to 40th harmonic), may need additional computation resources. Leave it as DG design issue.
4.4 Islanding			
4.4.1	Unintentional islanding	***Anti-Islanding protection***	detection within 2s.
4.4.2	Intentional islanding	N/A	no requirements given yet in the standard

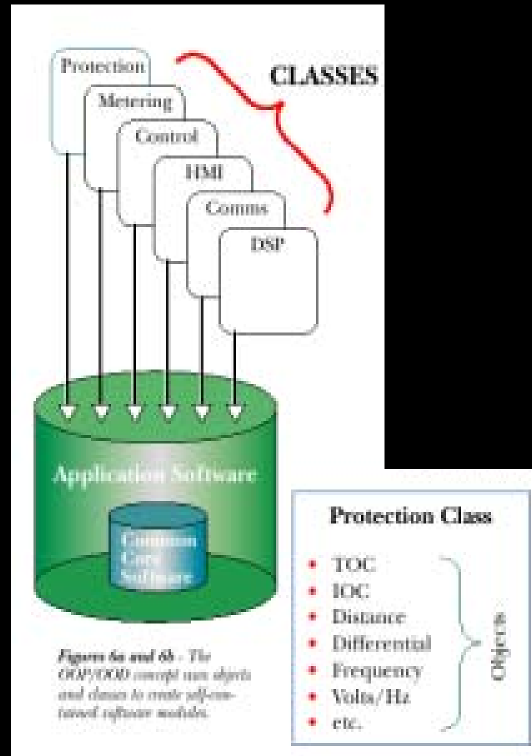
- **Most requirements can be met by today's technology**
- **Anti-islanding function is not well established, and is the key for standard and utility acceptance to DG**

UI Platform

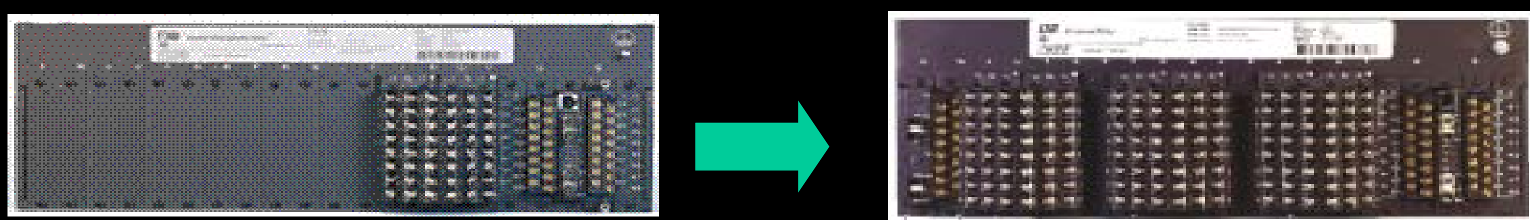
Modular Hardware



Modular Software



Scalable

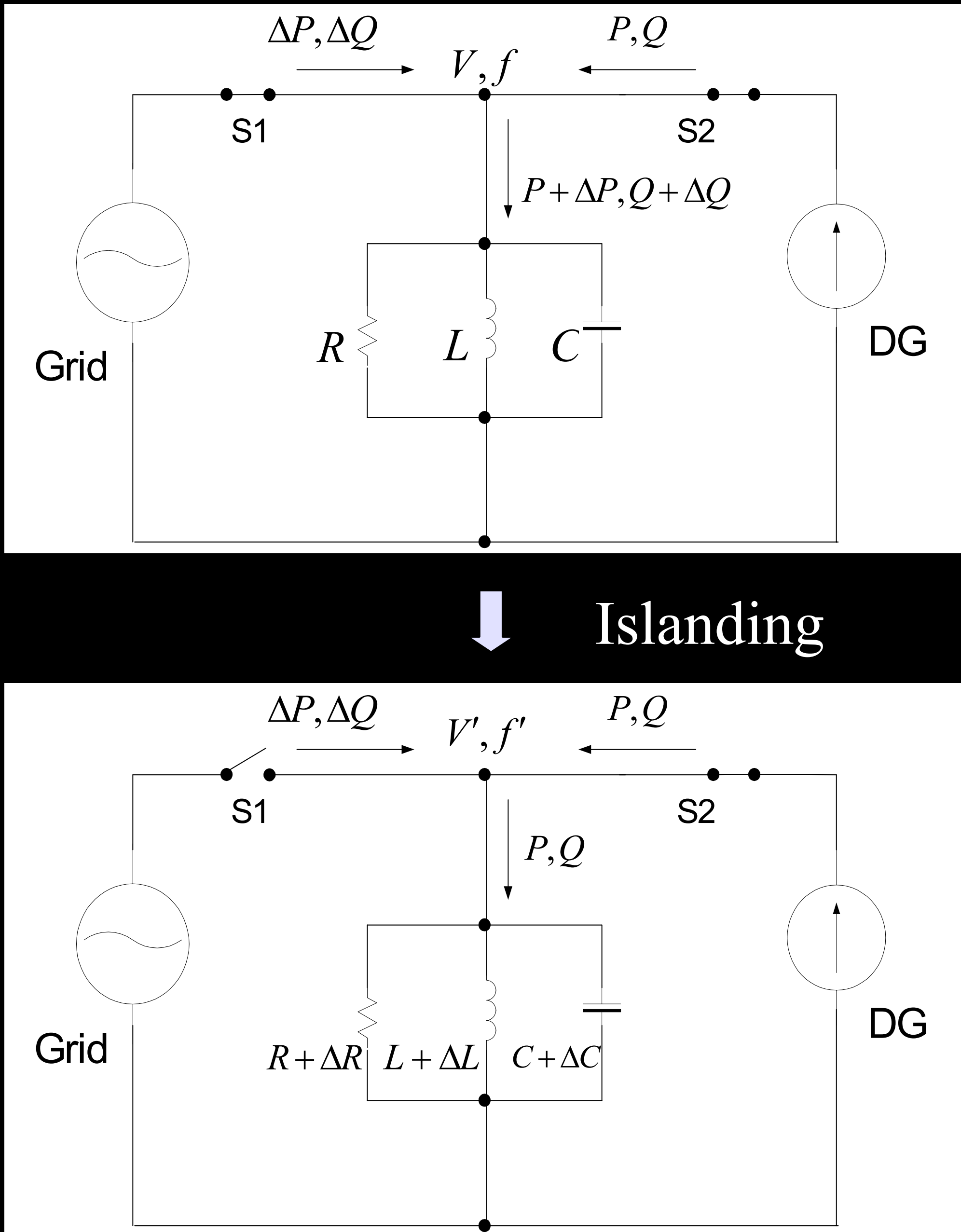


- **The Platform Family - One Common Architecture - from Feeder Protection to Generator Control, Meet UI feature requirements**

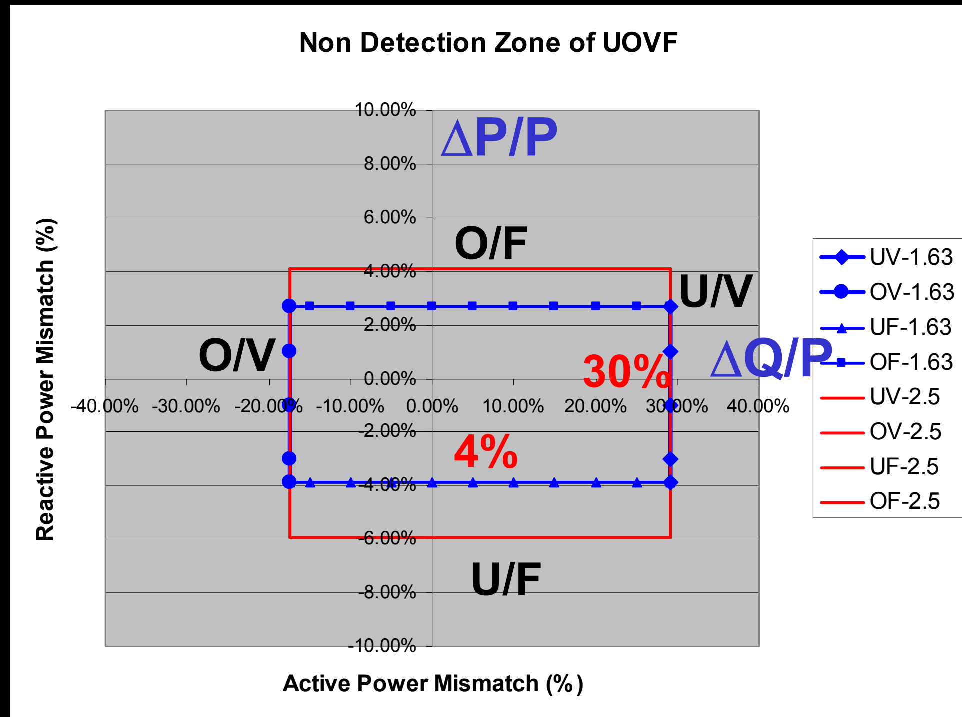
Anti-Islanding Study – Existing Schemes

	Cost	Technology Neutral	Effectiveness
Local sensing ➢ U/O V&F ➢ Phase Jump ➢ ROCOF ➢ Harmonic Monitoring	●	●	?
Perturbation ➢ Impedance monitoring ➢ Impedance insertion	◕	◕	?
Integrate with DG control ➢ SFS, SVS ➢ SMS ➢ Asymmetrical Wave.	●	◓	?
System coordinated control ➢ PLC ➢ Comm.	◓	●	●

Anti-Islanding Study – Non-Detection Zone



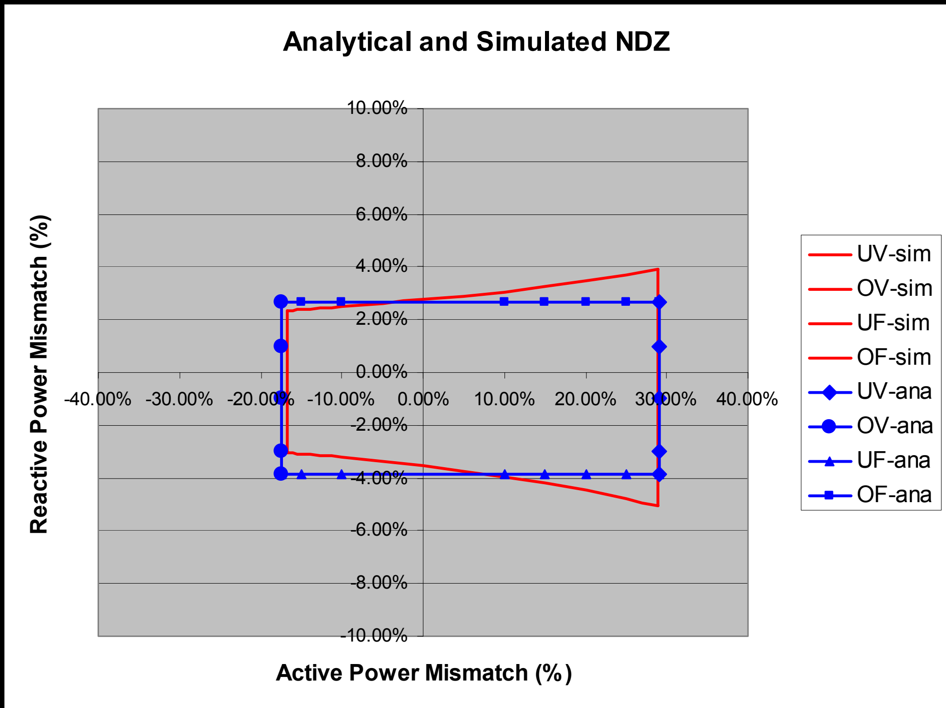
- AI performance Index: Non-Detection Zone (NDZ), defined as the region (in ΔP, ΔQ space), within which the interconnect devices cannot detect an island.

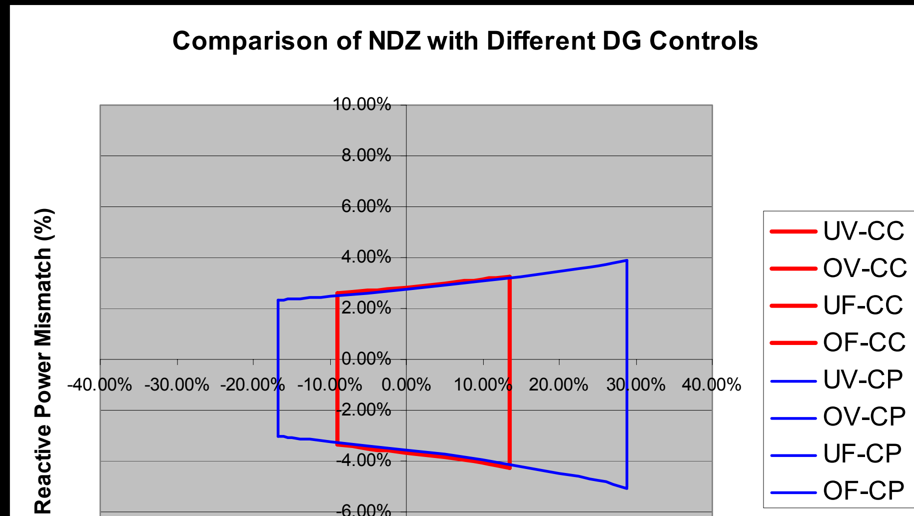


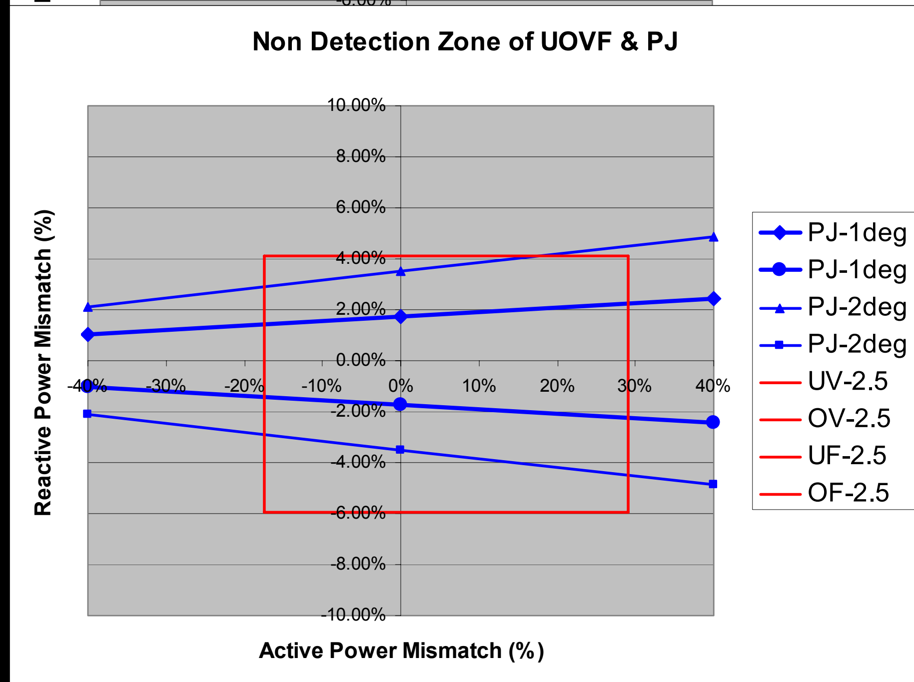
$$\left(\frac{V}{V_{\max}}\right)^2 - 1 \le \frac{\Delta P}{P} \le \left(\frac{V}{V_{\min}}\right)^2 - 1$$

$$Q_f \cdot \left(1 - \left(\frac{f}{f_{\min}}\right)^2\right) \le \frac{\Delta Q}{P} \le Q_f \cdot \left(1 - \left(\frac{f}{f_{\max}}\right)^2\right)$$

Anti-Islanding Study – Non-Detection Zone

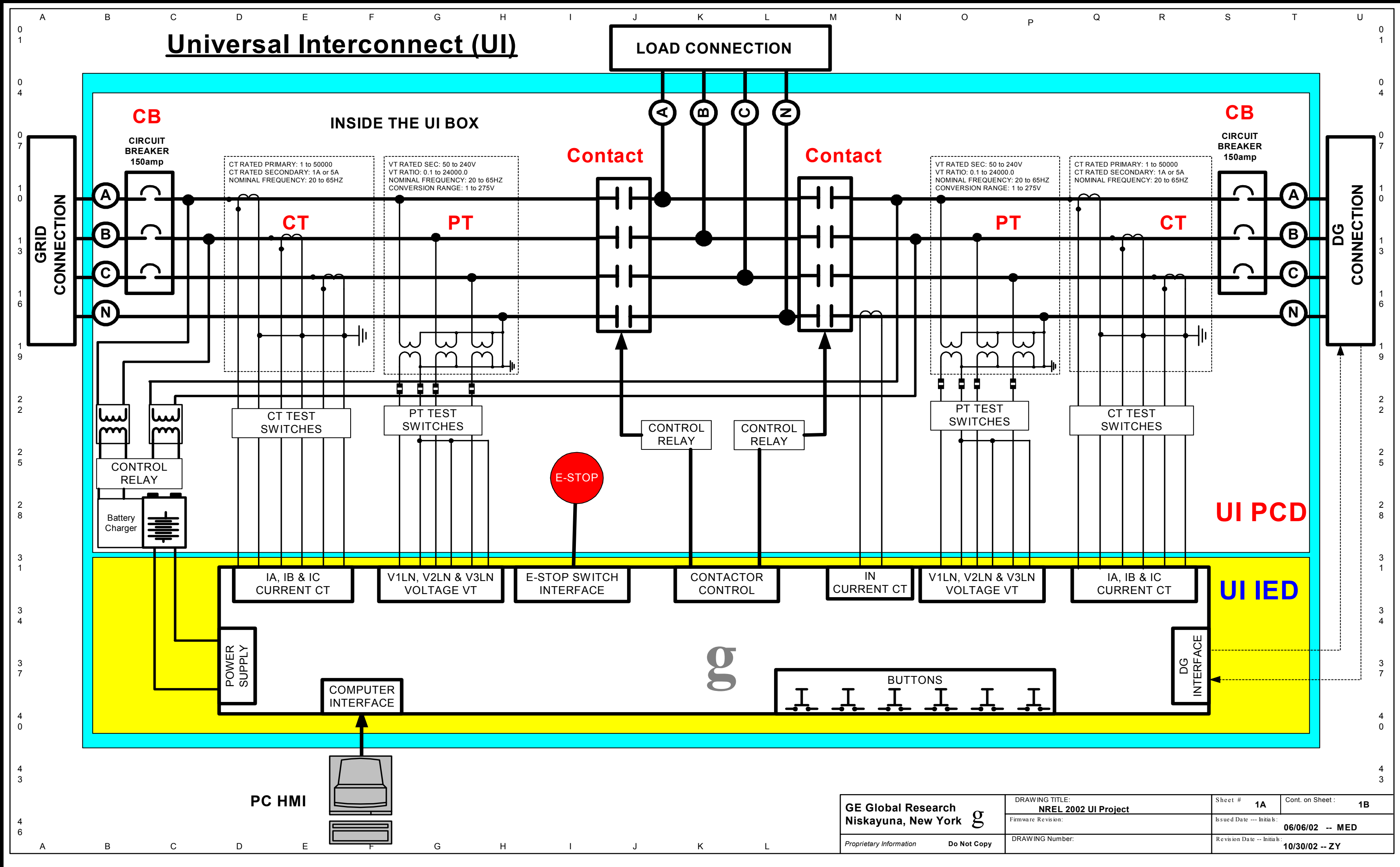






- Analyzed NDZ with different schemes and different DG controls
- Any passive scheme will have significant NDZ. Combined schemes reduce NDZ
- Proposed one scheme based on the study

Universal Interconnect (UI) Design



- Built for 100kW, but the design is scalable and re-configurable, both hardware and software

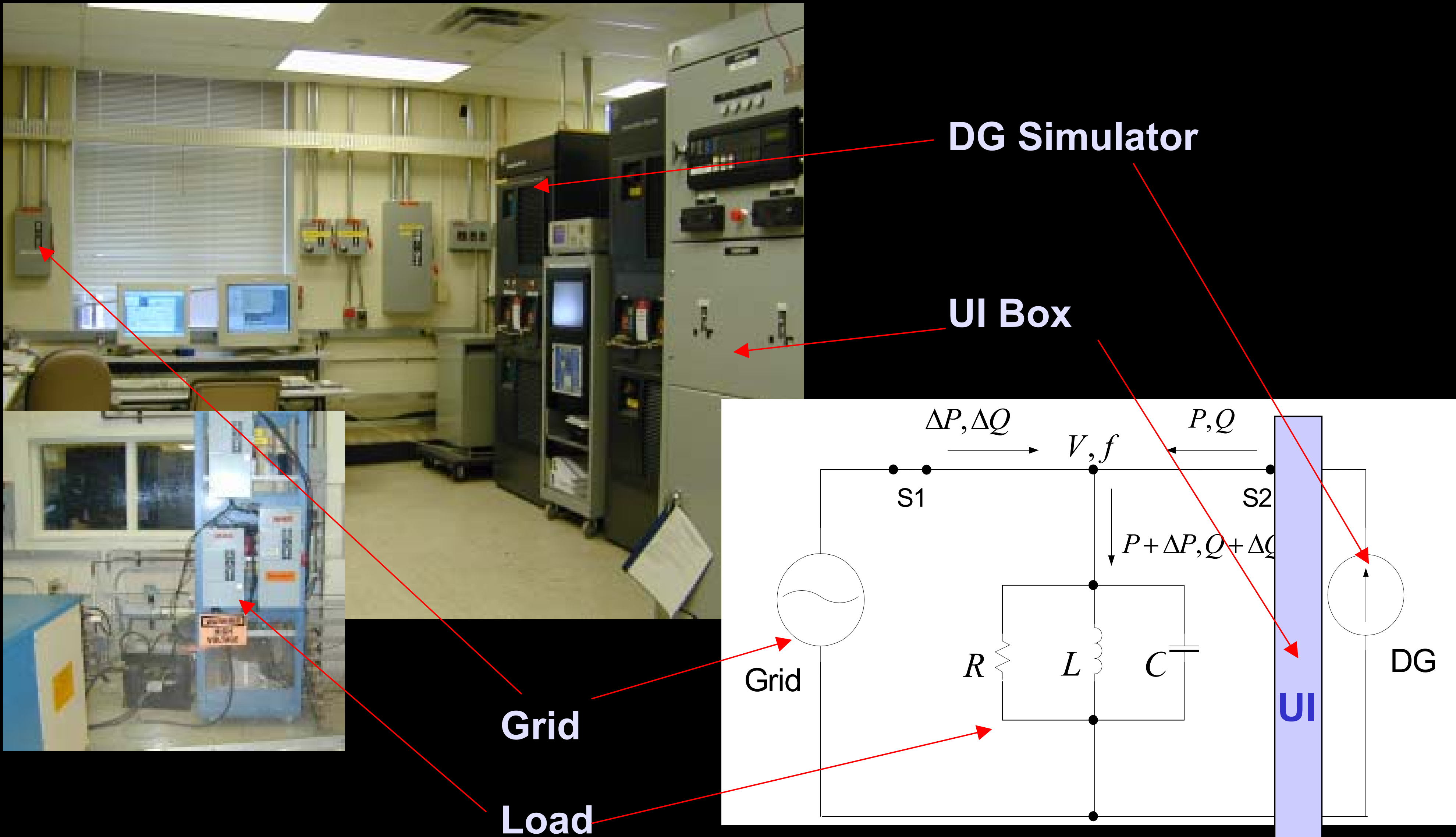
Universal Interconnect (UI) Prototype

F304B

UI

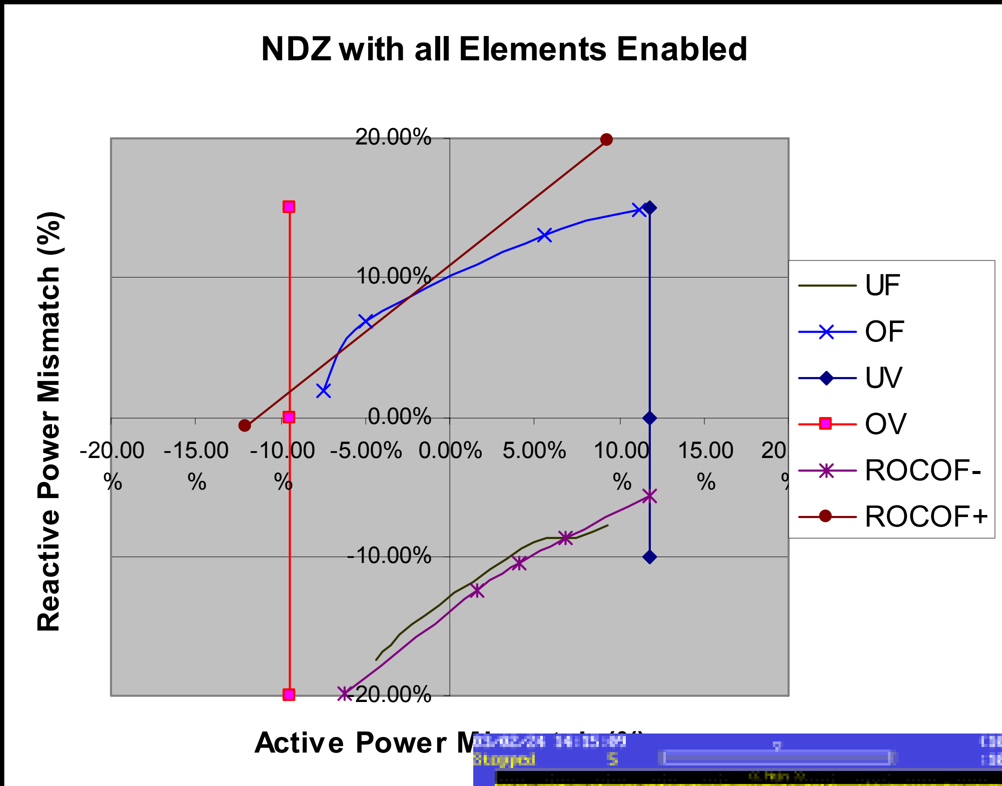
- Eliminate unnecessary redundancy
- Reduce Cost
- Easy to be pre-tested and pre-certified
- Easy to configure and integration: plug-and-play
- Could be independent product offerings: IED, PCD, or UI

UI Testing at GE - Interfacing Inverter-Based DG



A platform for proof-of-concept and technology transition

UI Testing at GE - Interfacing Inverter-Based DG



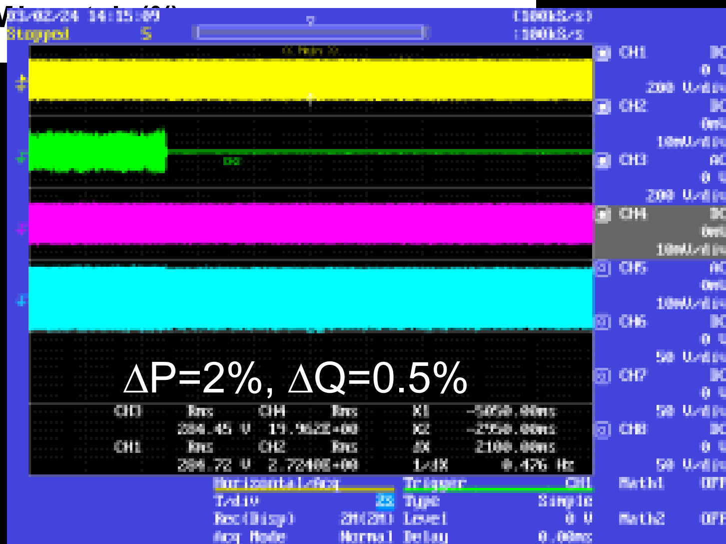
- **Tested at only low power level**
- **The tested AI based on ROCOF concept does not improve NDZ over U/O V&F for inverter-based DG at this power level**

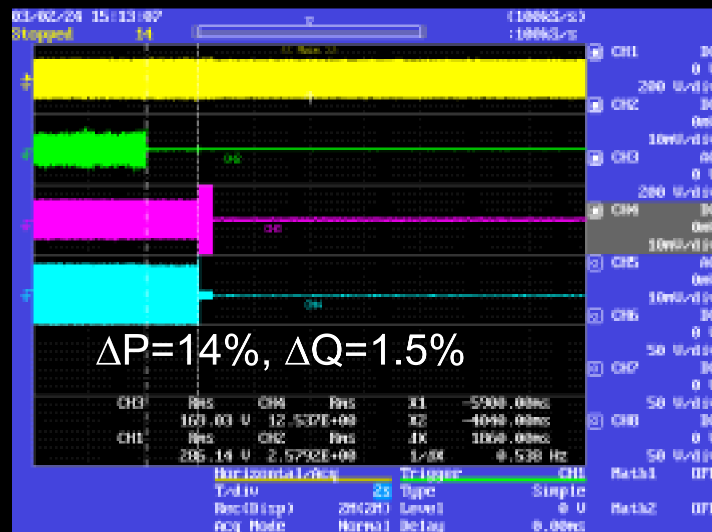
Grid voltage

Grid current

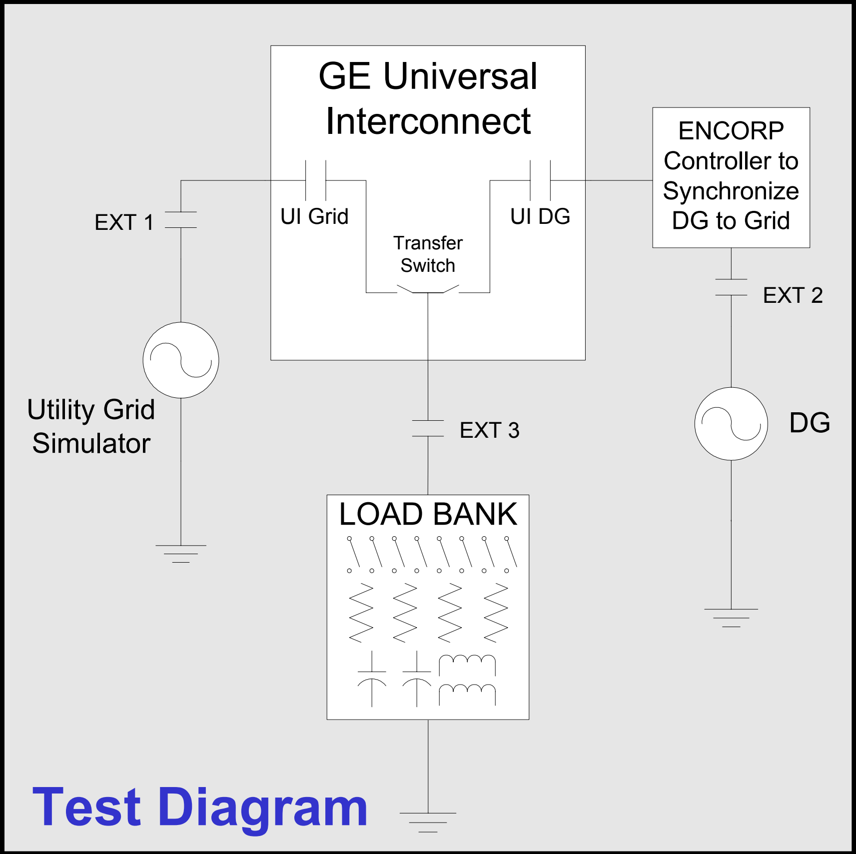
DG voltage

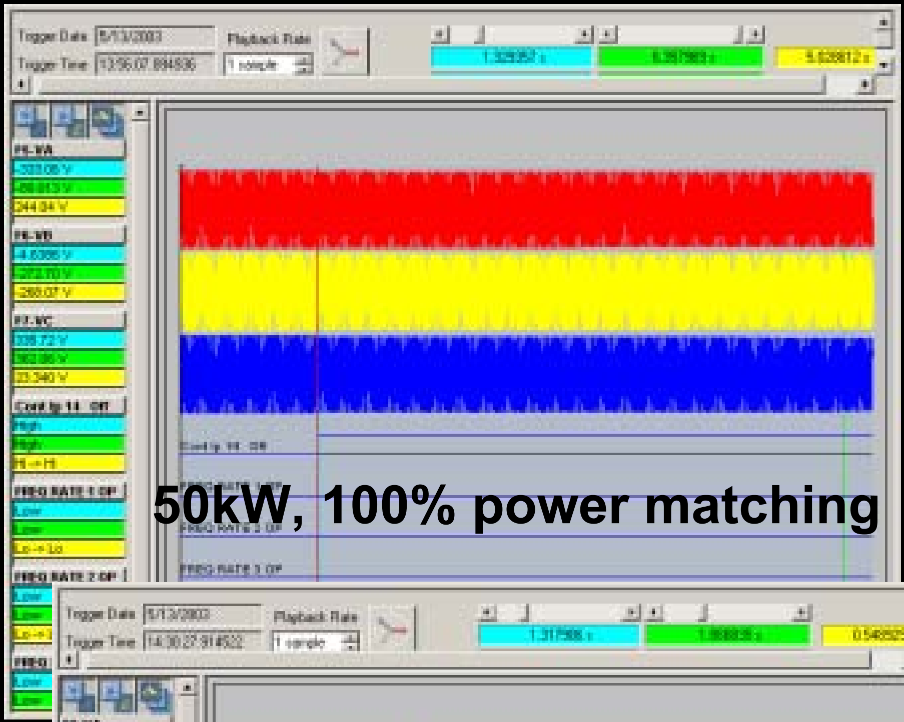
DG current

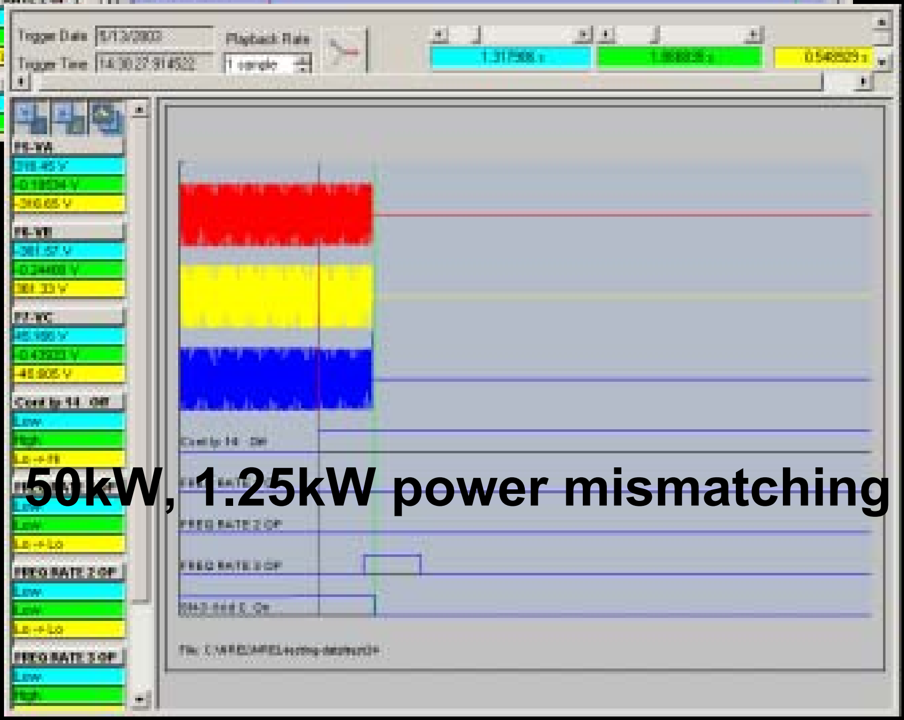




UI Testing at NREL - Interfacing Diesel Generator







- 125kW Diesel Gen.
- The tested AI is much more effective for diesel generator than for inverter-interfaced DG

UI Testing at NREL - Interfacing Diesel Generator

Tested Non-Detection Zone

DG output	Active Load (kW)	Reactive Load (kVar)	Power mismatch (kW)	NDZ (% of PDG, rated)
20	23	36	3	2.4%
35	37.5	62.5	2.5	2.0%
50	51.25	90	1.25	1.0%
80	81.5	144	1.5	1.2%

Summary:

- Total 70 tests
- All of them tripped on the tested AI, before tripping on U/O V&F
- NDZ is much smaller with respect to active power mismatch
- Never trip on reactive power mismatch for the diesel, need improvement
- Disturbance cases tested - 100% load step, cap switching, zero out one phase, or all three phases momentarily, or unbalance 48%, 120%, 120%. Not a single false trip, the tested AI is robust
- Load step change after islanding, trip on 1kW (0.8%) transient load, no trip on slow load ramping
- Minimum reverse power protection based on NDZ to ensure AI protection

Planned Activities for FY2004

- Study and develop advanced anti-islanding control for inverter-based interconnect for IEEE 1547 & UL 1741 compliance
- Study advanced anti-islanding control for machine-based interconnect
- Study interconnect control for multiple DGs, Study facility microgrid
- Test inverter-based interconnect

Grid-Connected Inverter (GCI) Development

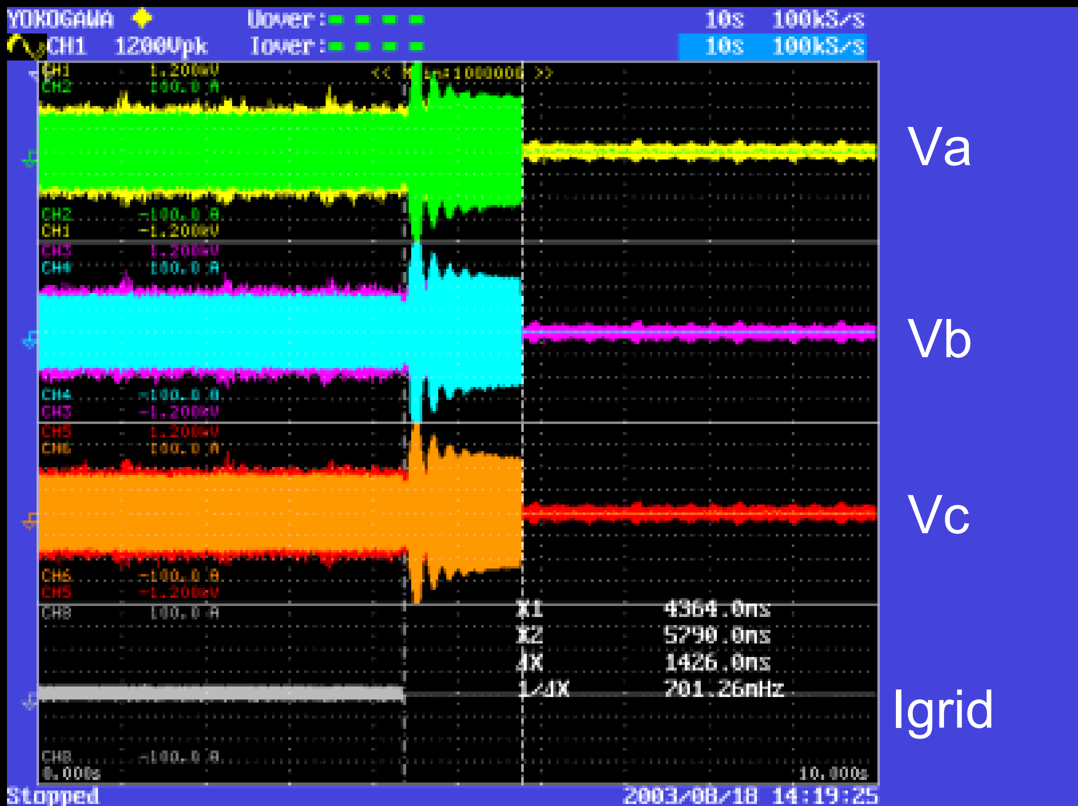
Sterling Engine

Fuel Cell

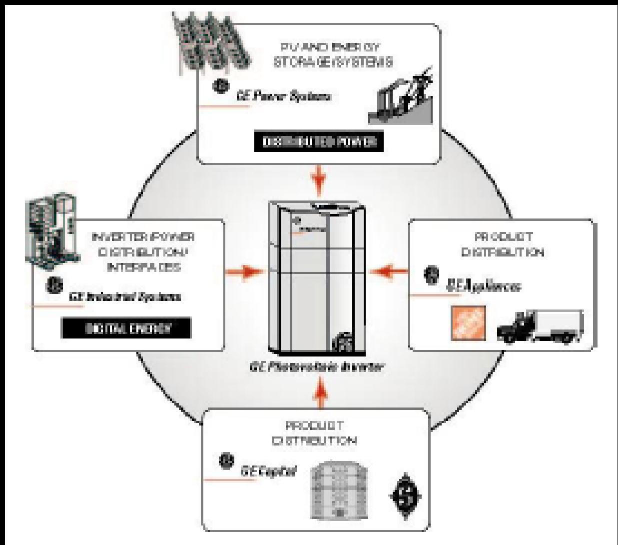
- **GE is developing GCI for two DG vendors, STM (Sterling Engine), and FCE (Direct Fuel Cells).**

Grid-Connected Inverter (GCI) Development

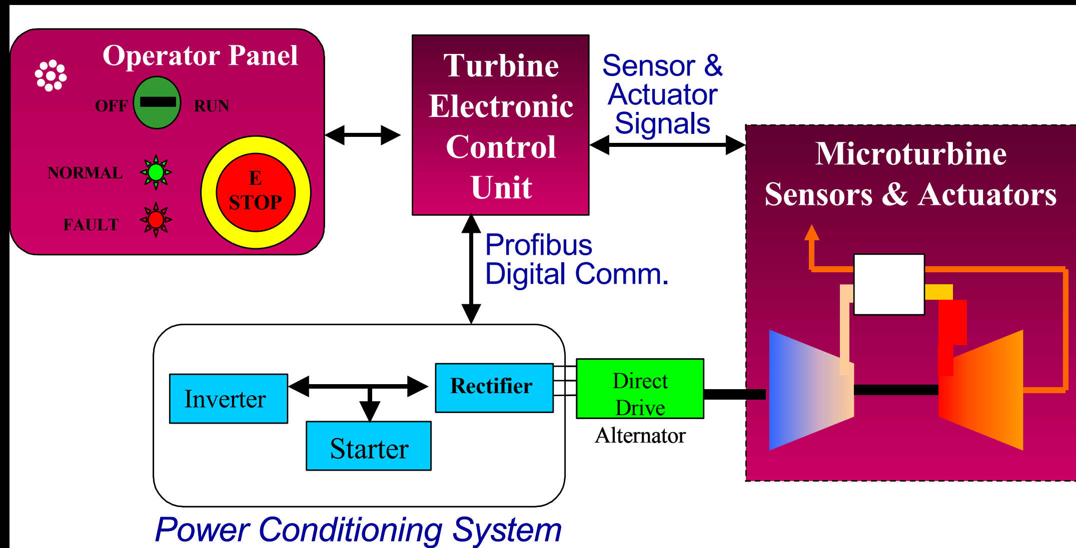
- GE Proprietary active AI family schemes, no NDZ
- Simulation and preliminary testing completed
- Results are very promising, will meet UL 1741, EON standards
- Software code only, low cost
- minimum power quality impact
- Complete design insight and guidelines available
- Penetration impact predictable
- Work for multiple DGs



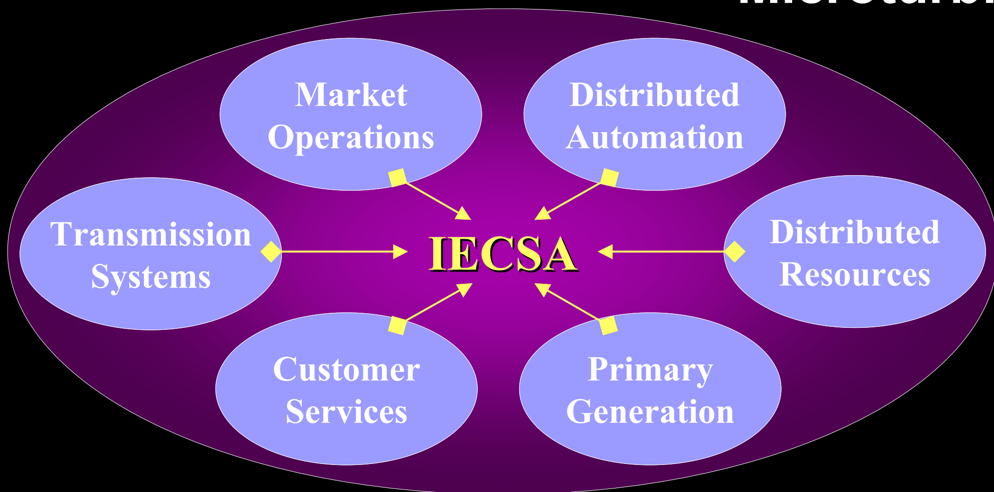
Program Interactions & Collaborations



Sandia - High Reliability Inverter



DOE - Advanced Integrated Microturbine System



EPRI - Integrated Energy and Communications Systems Architecture (IECSA)

Technology Transitions

The algorithms/functions developed by this program transitioned to a GE Multilin New firmware release (July 2003)

The algorithms/functions developed and tested by the program is transitioning to a new GE grid-connected inverter platform for use with sterling engines and fuel cells (August 2003)

Future Plans

Proposed outyear (beyond FY04) activities:

- Low cost, modular UI protection devices
- Modular cross-platform inverter-based interconnect
- Demonstration at beta test site

Summary

- GE interconnect project is performing crucial investigation of DG and Grid integration issues (Support EDT system integration goal)
- GE proposed a systematic approach to addressing interconnect solutions (Support EDT plug-n-play Interconnection goal)
- GE is taking the new technology to expand its strategic market in alternative energy and distributed generation (Support EDT mission to transform today's electric distribution infrastructure … with more distributed energy resources (DER) integration with electric power systems)