Reliable, Low Cost Distributed Generator/Utility System Interconnect

Subcontract No. NAD-1-30605-01

GE Global Research Center
GE Power Systems Energy Consulting
GE Multilin
Puget Sound Energy

DOE Distributed Power Program
Quarterly Review Meeting
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Madison, WI

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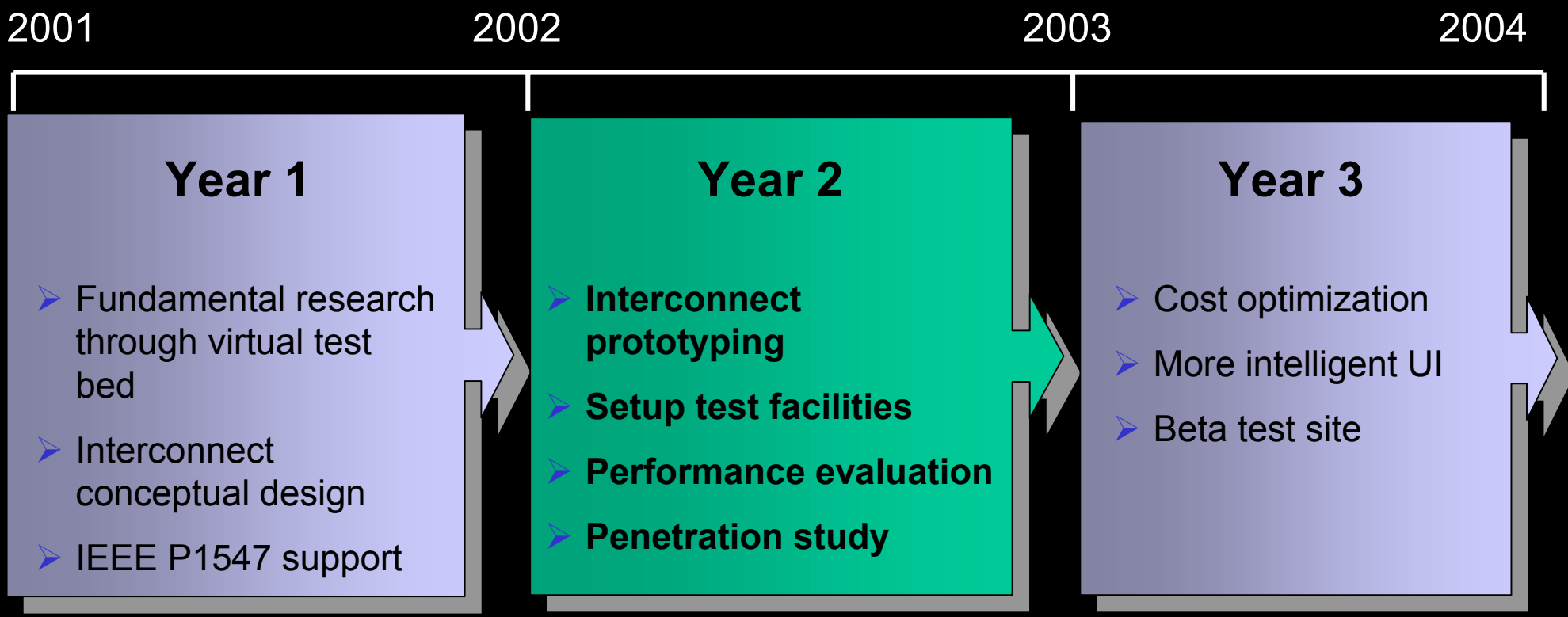
Outline

- Program Overview / Gantt Chart
- Voice of Customer Survey
- Universal Interconnect Needs and Roadmap
- Anti-Islanding Study
- Test Facilities Setup
- Universal Interconnect Platform Features
- Universal Interconnect Business Path
- Penetration Study
- Summary / Next Step

Program Overview

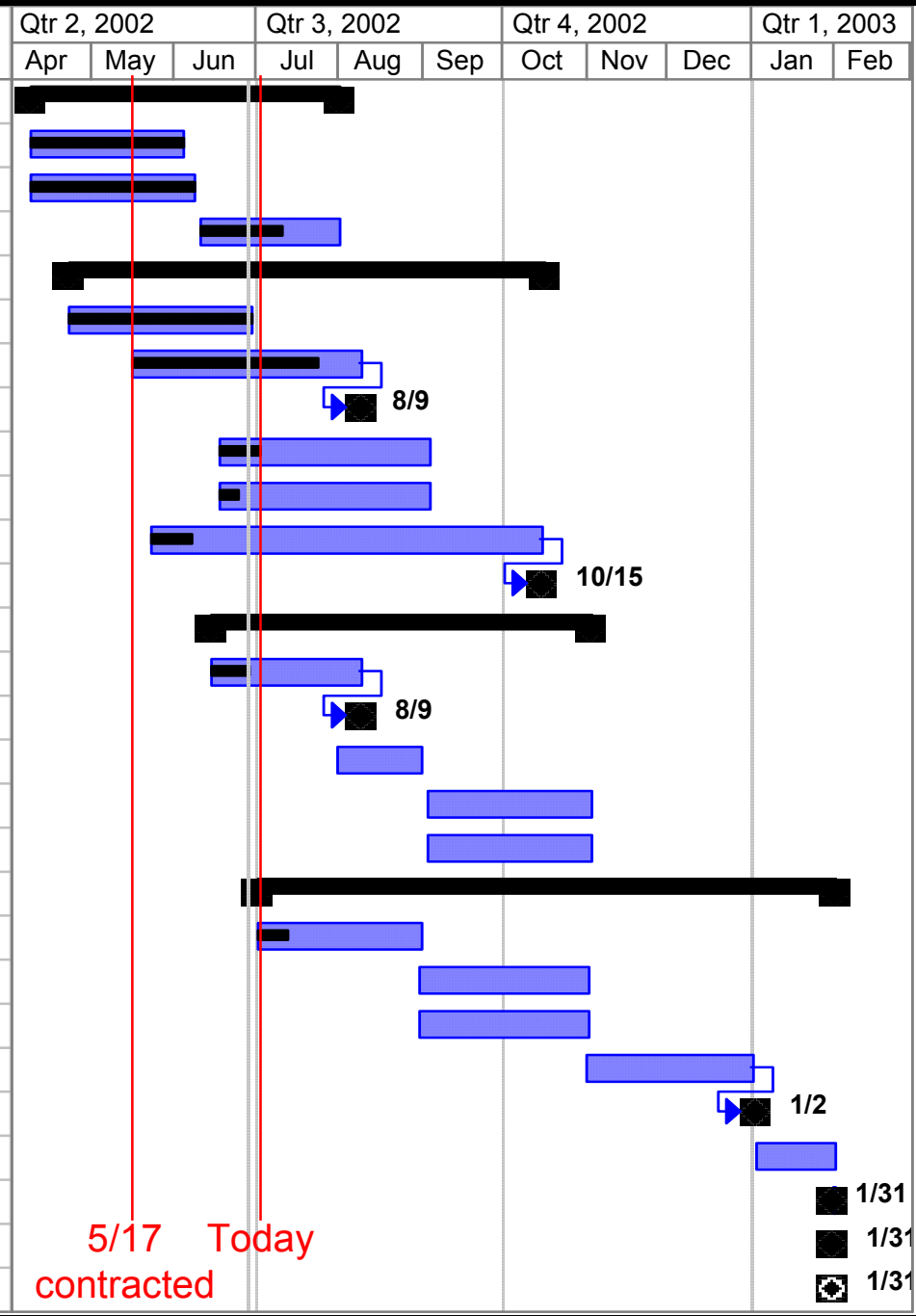
Program Goals:

- Explore DG/EPS system interconnection issues
- Develop DG/EPS universal interconnect that allows reliable system operation and plug-and-play, meanwhile maximizes DG values.



Gantt Chart (Apr. 1, 2002 – Jan. 31, 2003)

% Complete	Task Name
88%	**UI Requirements**
100%	Voice Of Customer (VOC)
100%	Competitive Survey
60%	Draft UI Requirements Doc
38%	**UI Study**
100%	Model Test Systems in PSCAD
80%	Setup Test Facilities
0%	Deliverable: Test Facility Setup Desc.
20%	Study Anti-Islanding
10%	Study Other UI Functions
10%	Study DG Penetration Issues
0%	Deliverable: Penetration Study Report
7%	**UI Implementation**
25%	UI Detailed Design Documentation
0%	Deliverable: Detailed Design of UI
0%	Model System in RTDS
0%	Impl. Anti-Islanding
0%	Impl. Other UI Functions
4%	**UI Testing**
20%	Develop Packaging/Testing Plan
0%	Testing UI using RTDS
0%	UI Packaging
0%	Testing UI using Grid Simulator
0%	Deliverable: UI for NREL
0%	Testing UI at NREL
0%	Deliverable: Prelim Test/Eval Report
0%	Deliverable: Annual Report
0%	End of Project - Original Schedule



Voice of Customer (VOC)

Purpose: To gather input from Universal Interconnect customers along the entire distribution chain

- GE is a participant in most energy industry segments
- GE Businesses and non-GE customers provided input to VOC

Key Findings:

- The DisCo is the hidden or influencing customer in all interconnection installations - must have DisCo buy-in
- Current DG users driven by need for critical power, not economics of DG
- Current: DisCo is in reactive role w.r.t. DG installation

End Users	Packager / Service	Original Equip. Mfgr.
DisCo • Puget Sound Energy • Customer 1 **IPPs** • GE Aircraft Engines - Lynn, MA • Customer 2 **Commercial (w/ DG)** • Customer 3	**Energy Rental** • GE Energy Rentals **Energy Services** • GE Energy Services • GE Digital Energy **Packagers** • GE AEP • GE Distributed Power • GE Zenith **Consulting / Services** • GE Power Systems Energy Consulting	**Diesel Generators** • GE Trans. Systems **Microturbines** • Customer 4 • GE Power Systems **Aero-derivatives** • GE Aircraft Engines **Fuel Cells** • Plug Power/GE **Gas Turbines** • GE Power Systems **Wind** • GE Power Systems

Interconnect Needs and Trends

Local Protection (P1547 Functions)

- o/v, u/v
- u/f, o/f
- o/c
- sync check
- dead circuit check
- fault detection
- anti-islanding

Local Control

- Voltage Regulation
- Frequency Regulation
- Synchronizing Control
- Local EPS pf Control
- Power Quality

Enterprise Energy Control

- Building Energy (Heat/Cooling)
- Process Energy
- Load Management

Commerce Functions (metering)

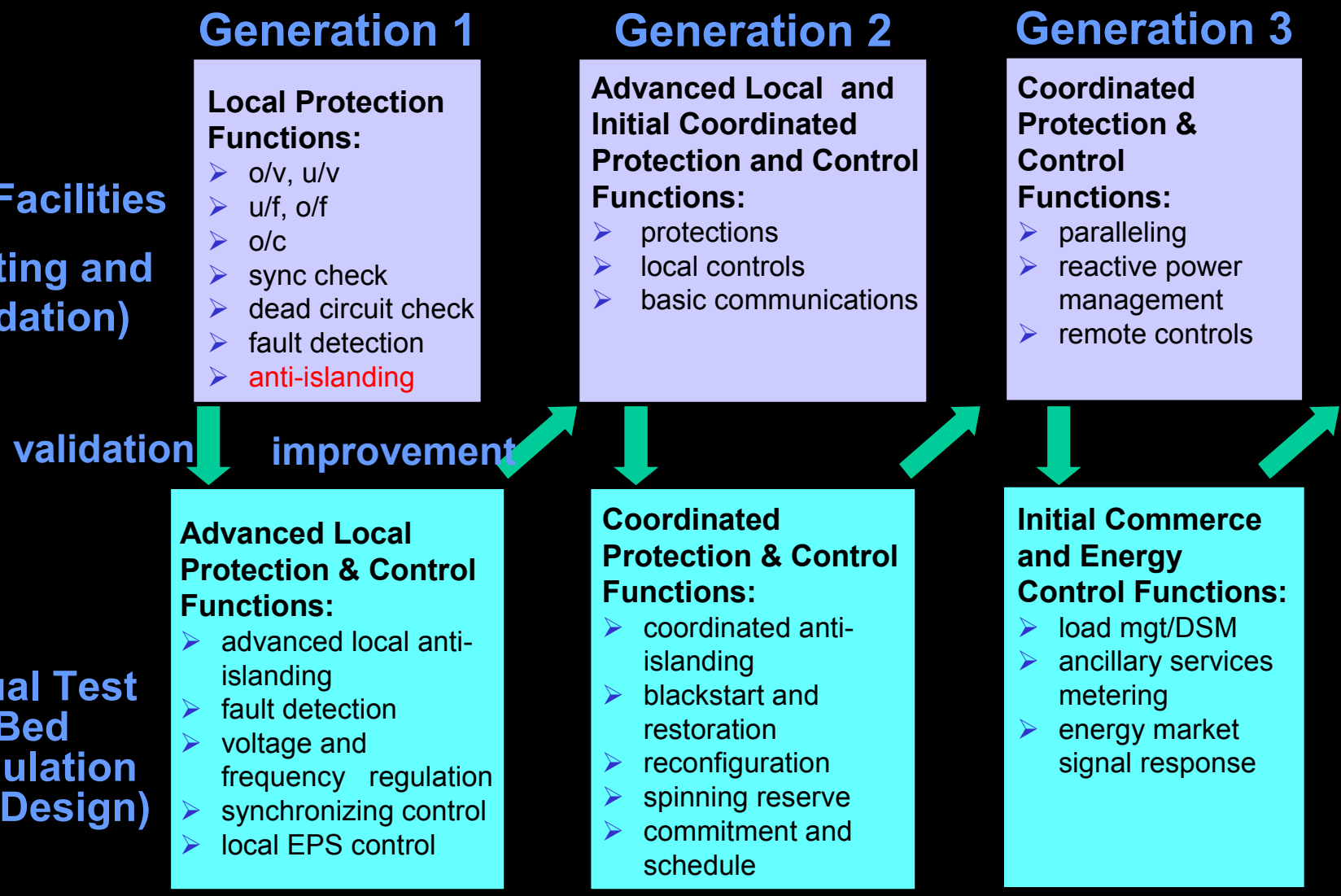
- Power (time)
- Reactive Power (time)
- Energy (time)
- Ancillary Services
  - Spinning reserve (t)
  - Voltage support (t)
- Real-time/spot price
- Other Market signals
- Power Quality Metering

Coordinated Protection and Control (requiring communications)

- Advanced anti-islanding
- Advanced voltage regulation
- Blackstart
- Restoration
- Reconfiguration
- Spinning reserve
- Commitment/ decommitment
- Schedule/Dispatch

- There is a natural progression of functionality
- Requirements expand at higher penetrations
- Economic benefits increase with higher functionality

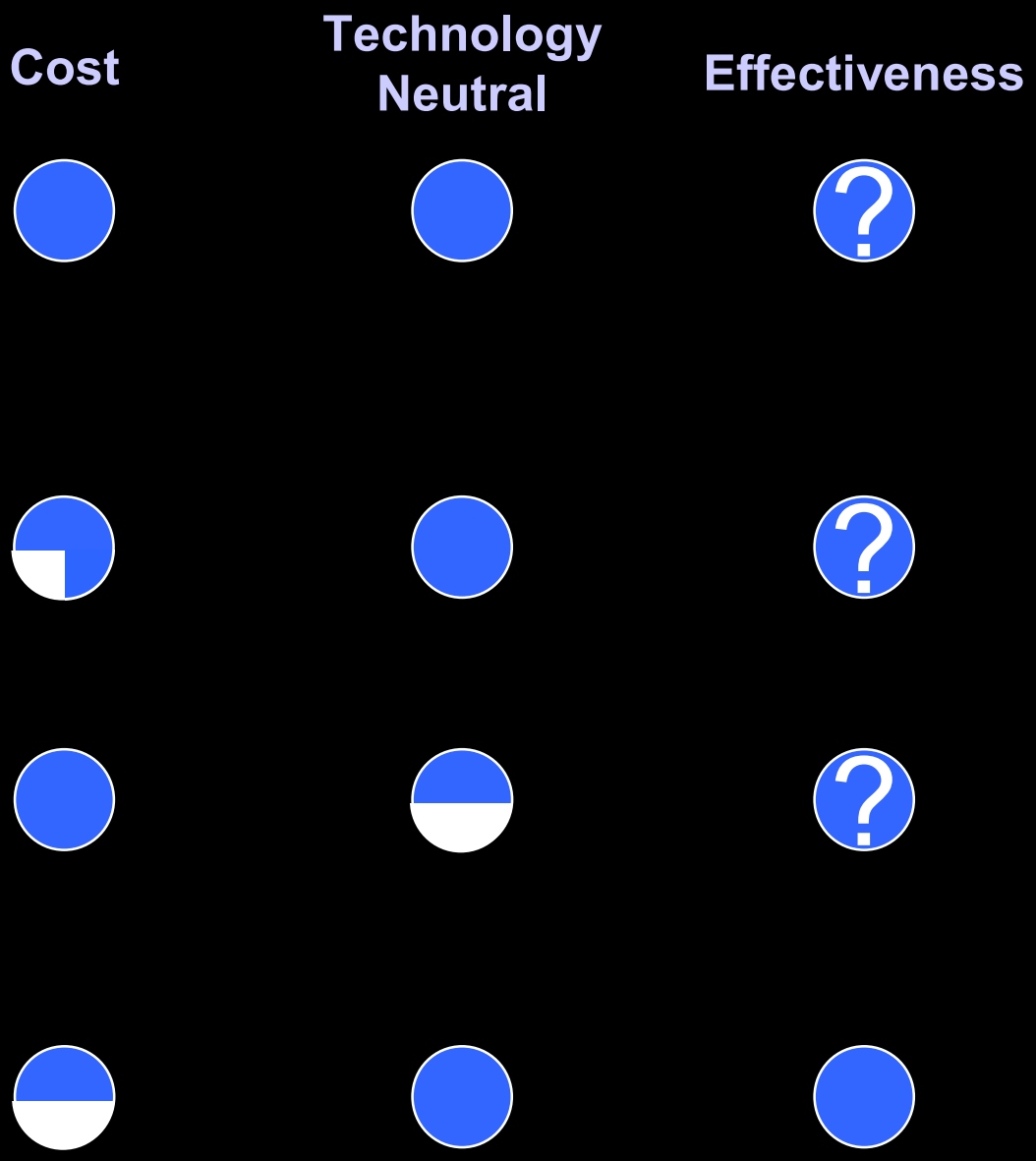
Interconnect Technology Roadmap



Two vehicles, which interact & support each other, to drive the interconnect technology:

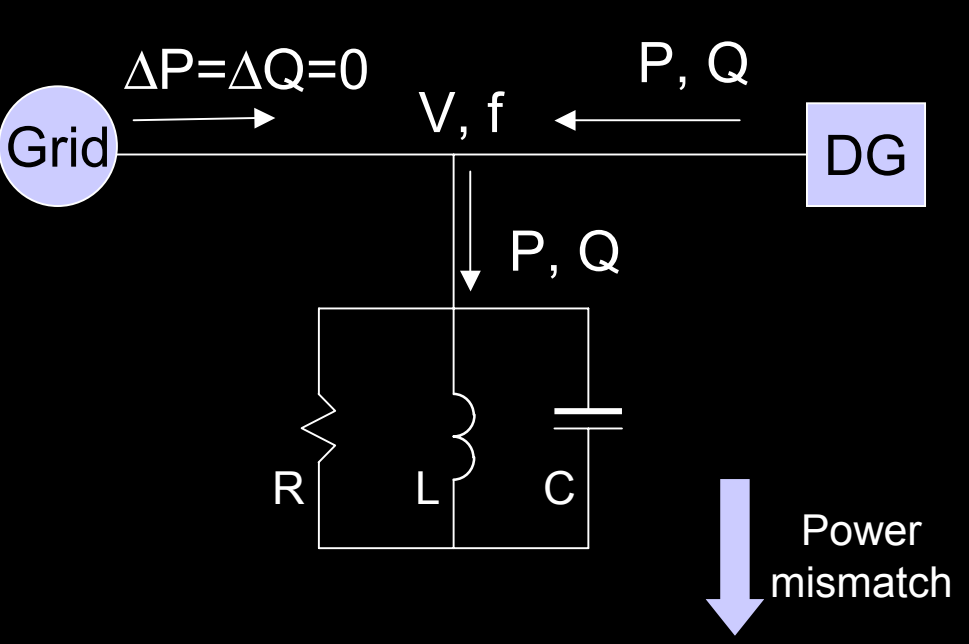
- Test Facilities for the interconnect prototyping and testing;
- Virtual Test Bed (VTB) for design, analysis and case studies.

Anti-Islanding Study

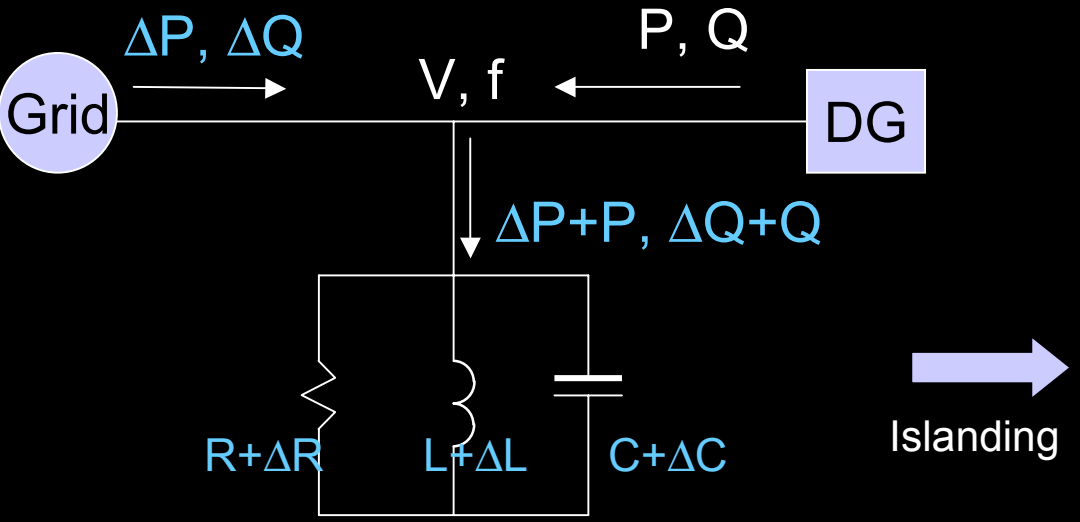


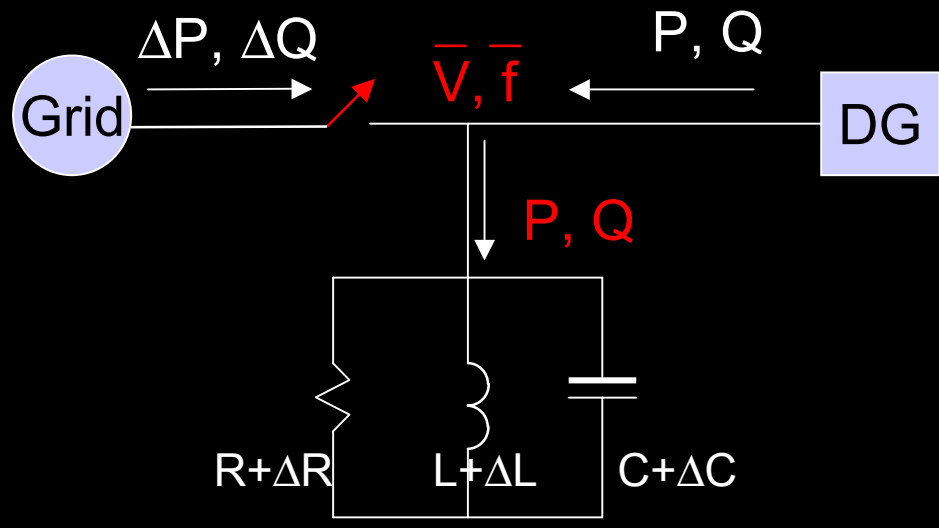
- Local Sensing is much better-off in terms of UI implementation

Anti-Islanding Study

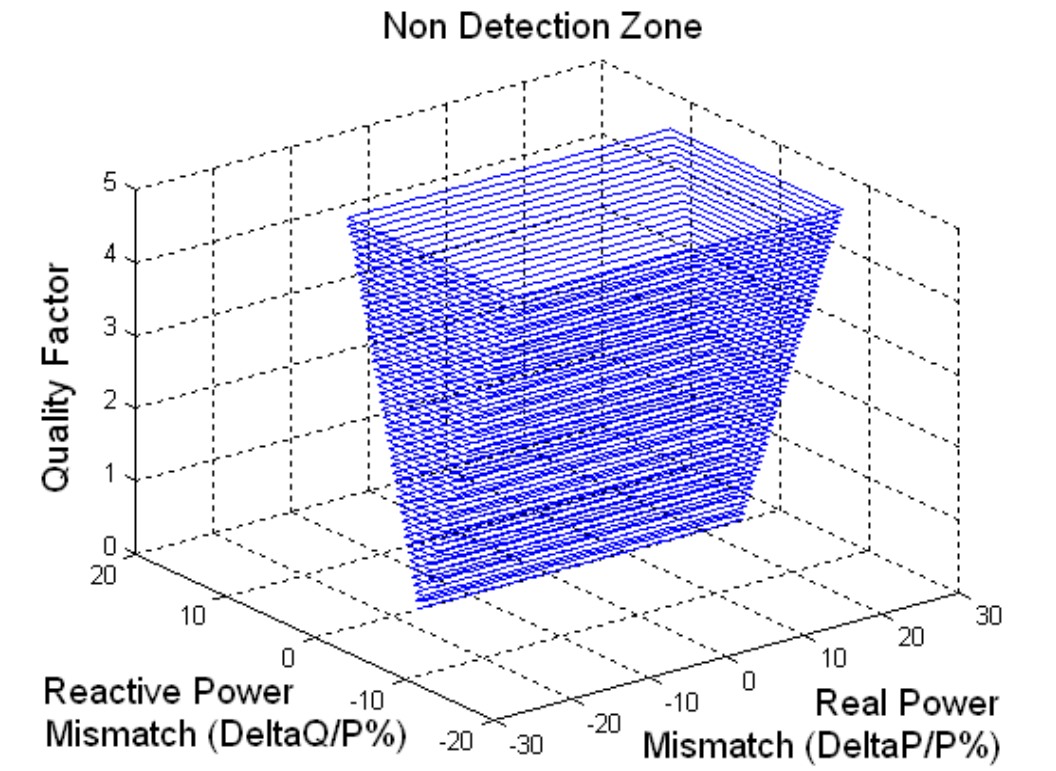


- AI performance Index: Non-Detection Zone (NDZ)
- NDZ defined in Power Mismatch Space (ΔP and ΔQ)
- When ΔP=ΔQ=0, an island is likely to occur
- NDZ is defined as the region (in ΔP, ΔQ space), within which the DG or interconnection devices cannot detect an island.



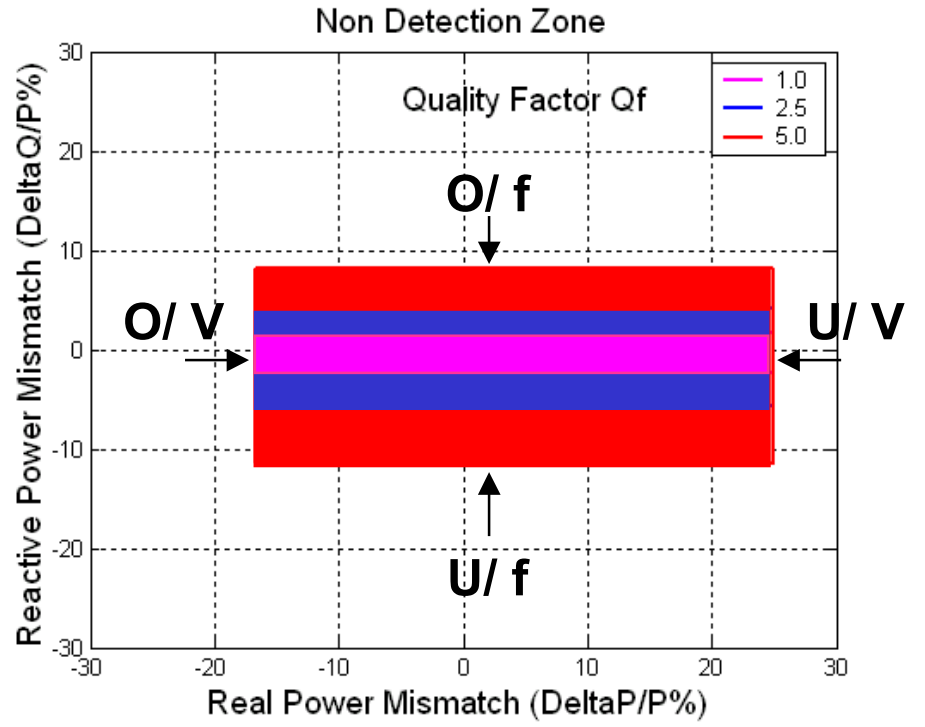


U/O Frequency and Voltage NDZ

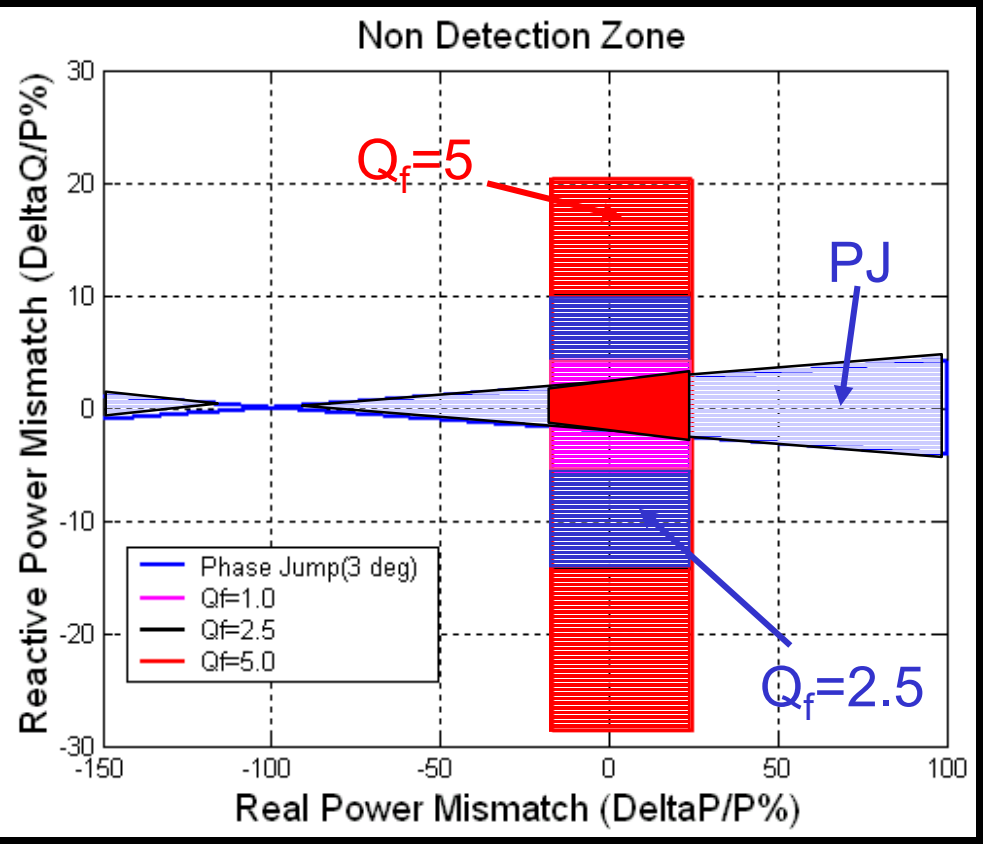


- Steady state result
- Power is normalized
- 3-dimension: ΔP/P, ΔQ/P, Qf
- Qf: quality factor. Reactive power stored in L or C is Qf*P.
- When Qf increases, U/O f NDZ becomes larger, while U/O V is nearly unchanged.

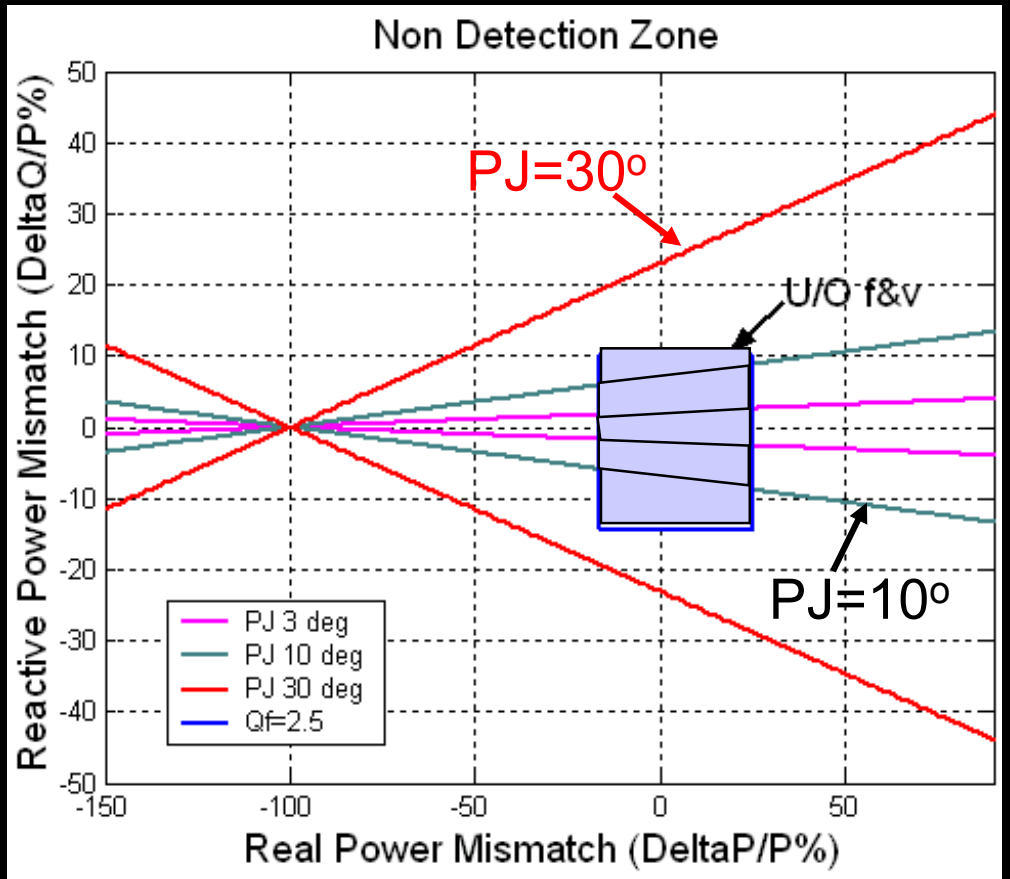
- For a constant power DG (e.g. inverter type), U/O f NDZ is dominated by reactive power mismatch, U/O v NDZ is dominated by active power mismatch.
- Reactive power mismatch is more sensitive than active power mismatch, given a typical threshold settings (e.g. P1547)



Phase Jump NDZ



- Instantaneous result
- PJ NDZ is independent from Qf. In other words, in a system with large Qf, PJ may be more effective than U/O f&v.
- The combined methods could cover Qf variation better

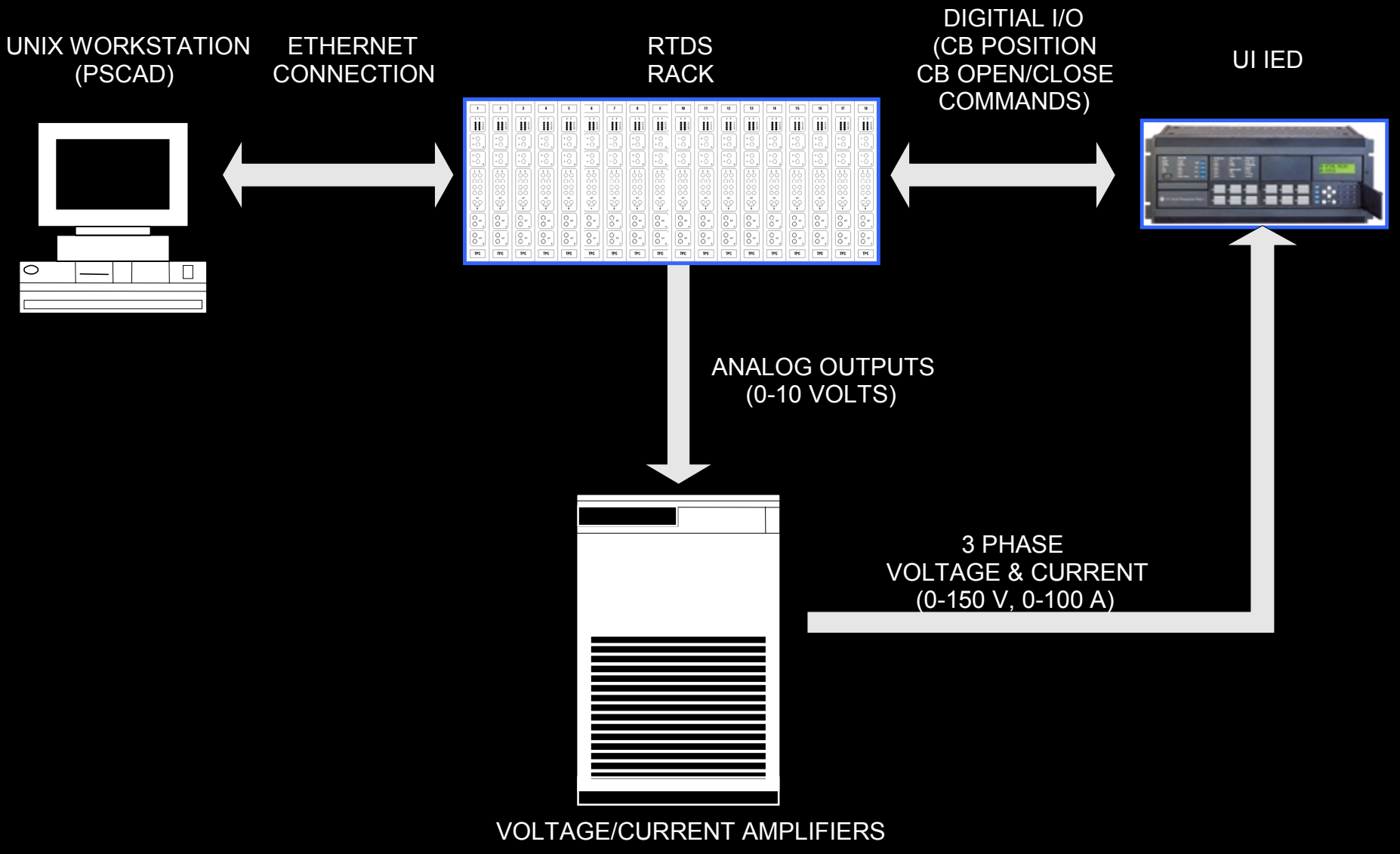


- If PJ threshold is large (it may have to be in practical situations), then the PJ NDZ may not help to reduce overall NDZ

AI Study Next Step

- Expand the results to non-unity power factor case.
- Map other AI schemes NDZ
- Map NDZ with dynamic load (e.g. motor load) and dynamic DG (inverter and machine) using PSCAD simulation (numerical method)

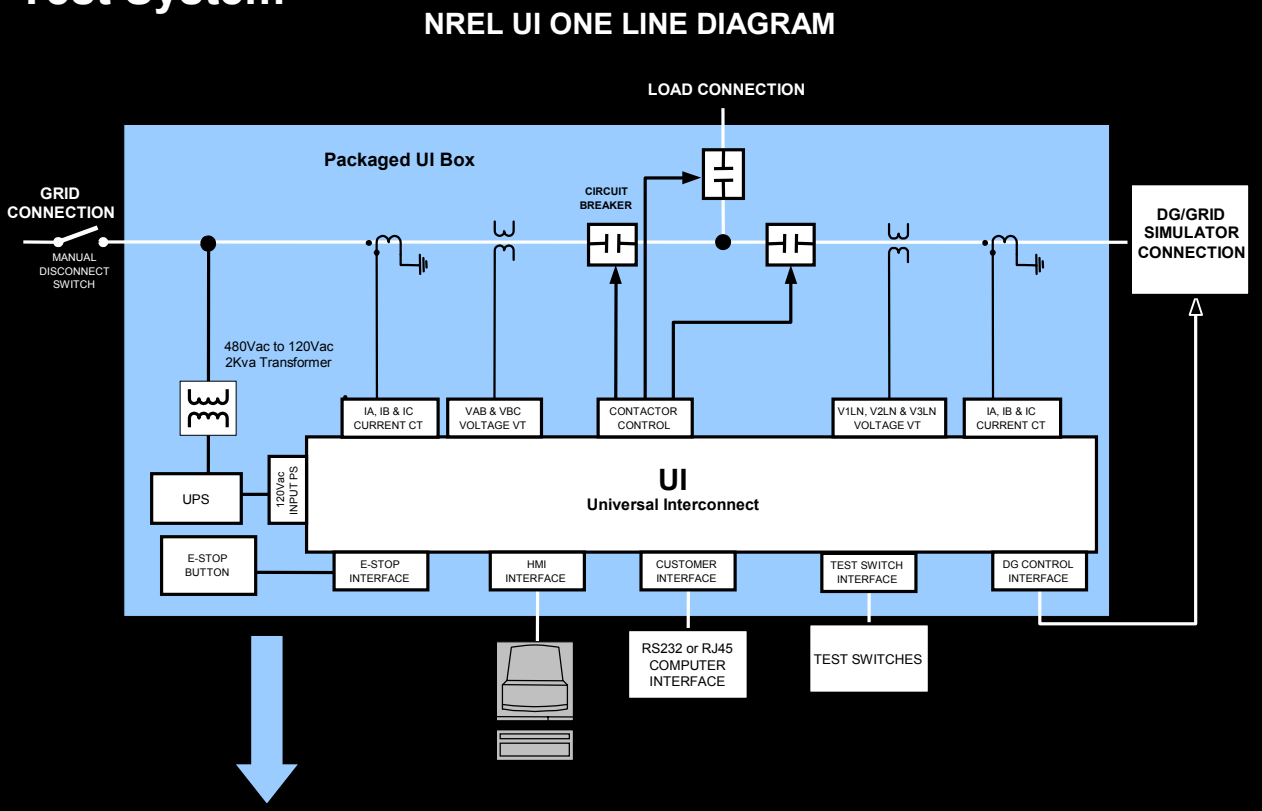
Test Facilities Setup – RTDS System

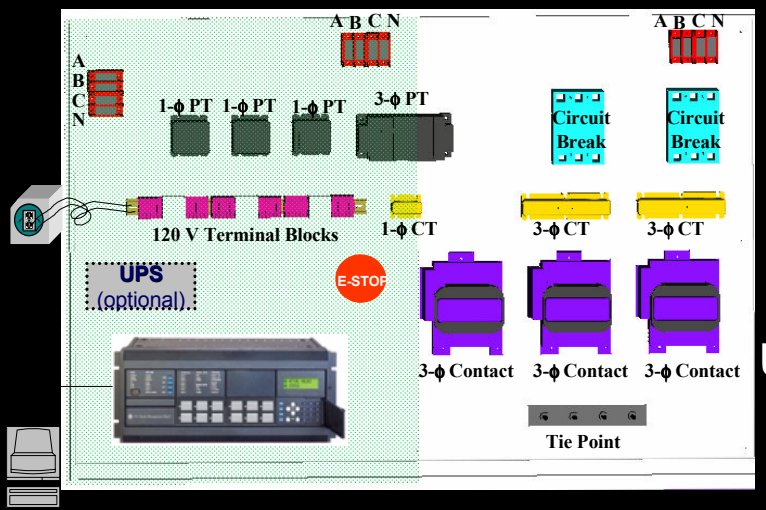


UI IED functional testing

UI Panel Package

Test System





UI Panel Package

- **Standardized modules**
  - **IED** (Intelligent Electronic Device)
  - **PCD** (Power Carrying Device)
- **Standardized/Normalized interfaces**
  - **Power**
  - **Sensor**
  - **Control**
  - **Communication**
- **Technology neutral, suitable for FC, uTurbine, Getset, etc.**
- **Pre-testing and pre-certification for 1547 compliance**
- **Scalable and upgradable**
- **Universal platform with natural progression of functionality**
- **Ability to maximize the economic and performance benefits of DG**

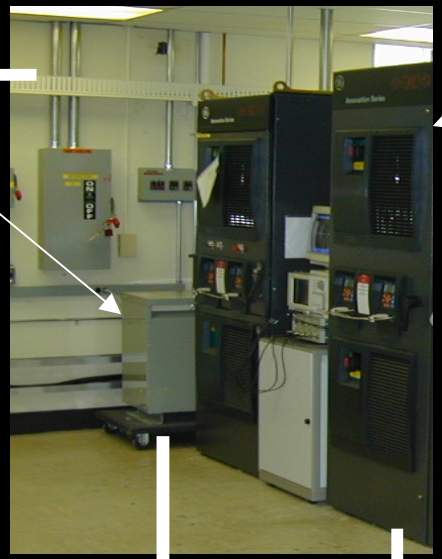
Test Facilities Setup – Grid Simulator System

Grid

Output Filter

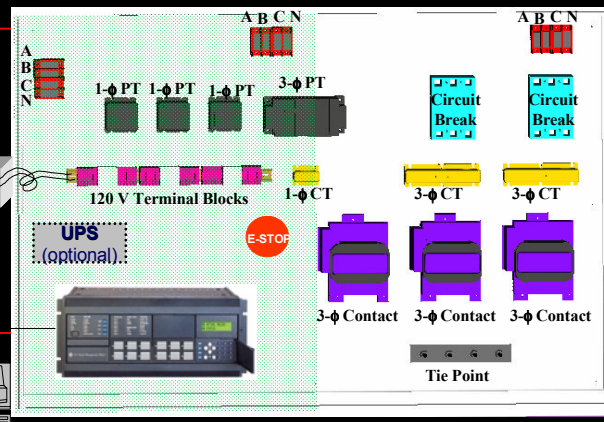
GE Innovation Drive Toolbox (HMI)

Control Room



GE Innovation Drive (DG/GRID Simulator)

Universal Interconnect Package



Test Room

Isolation Transformers

Load Bank

UI Panel (IED+PCD+etc) power testing

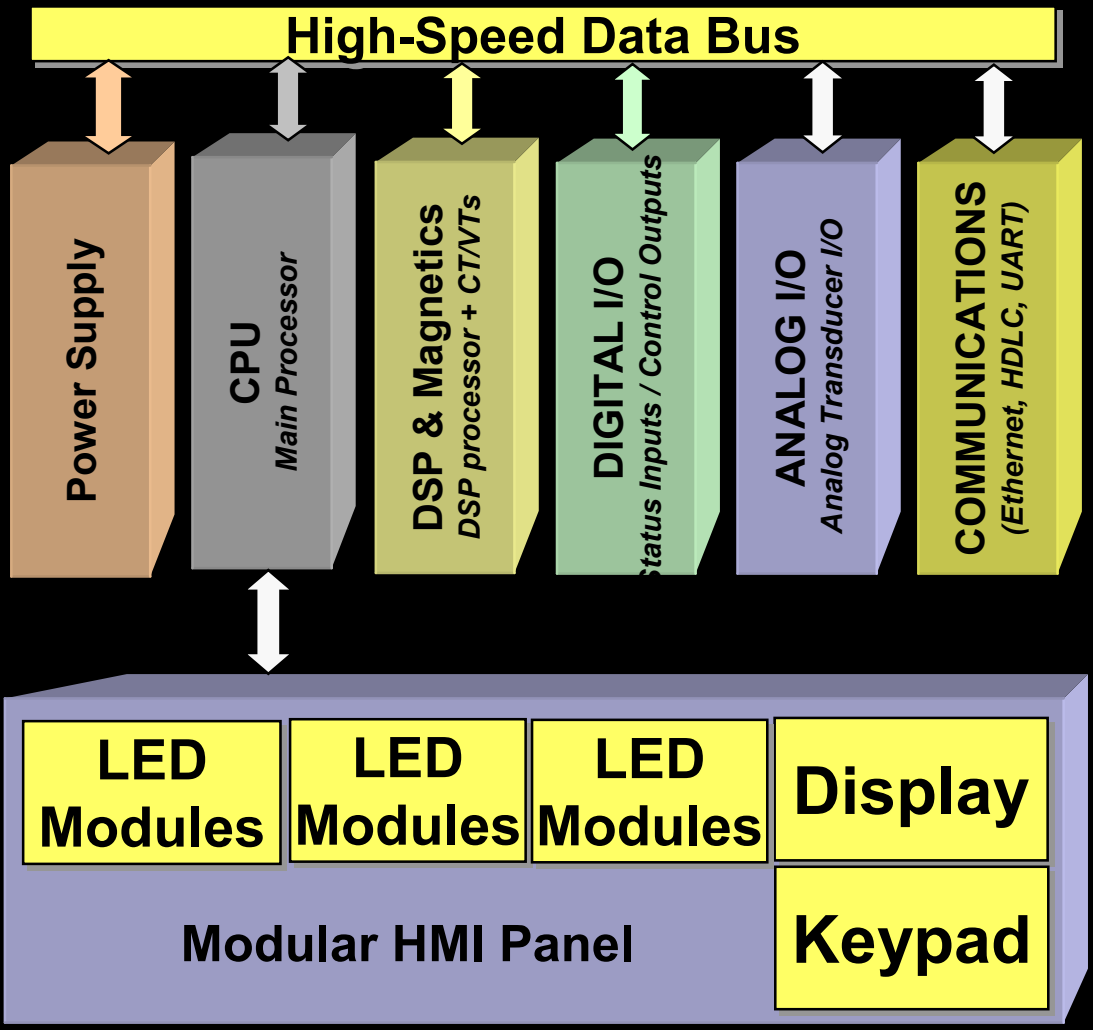
Universal Interconnect Platform

Current Available Functional Modules

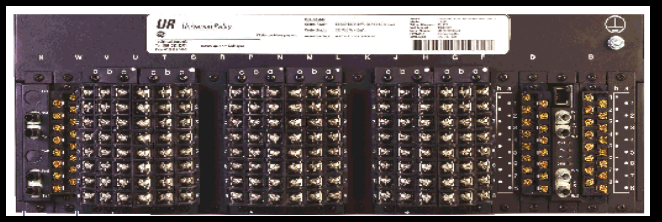
- Protection Elements
- Metering Elements
- Monitoring Elements
- Programmable Logic and I/O control
- Data and Event capture/storage
- HMI programmability
- Communications: multiple protocols

Some Features of the UI Platform

Universal Interconnect Architecture - 'Modularity'



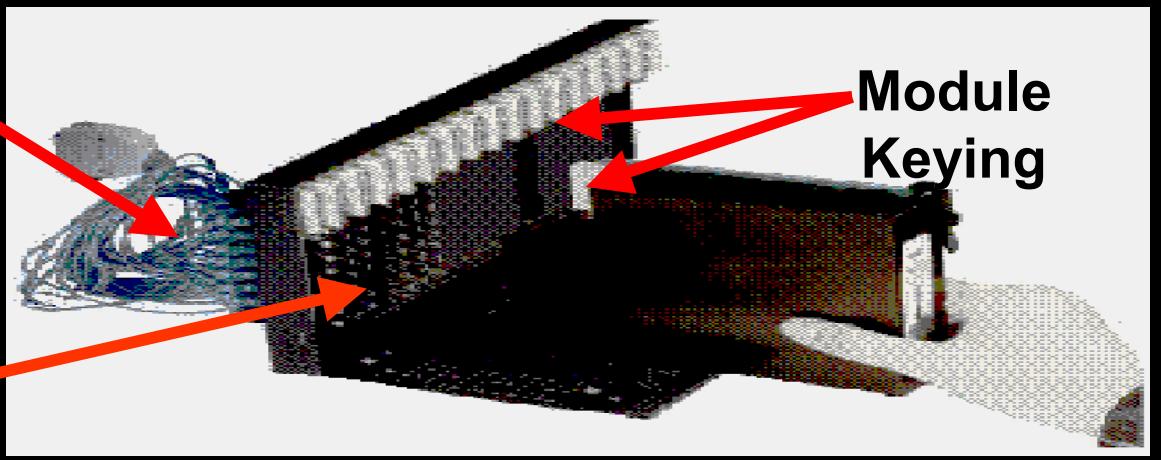
Scalability



Some Features of the UI Platform

'Upgradeability' / Serviceability

Easy Module Draw-out



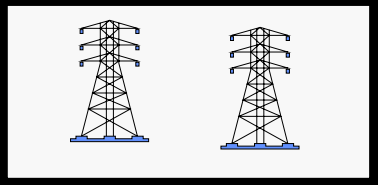
Field Wiring Undisturbed

CT Shorting 'Clips'

Some Features of the UI Platform

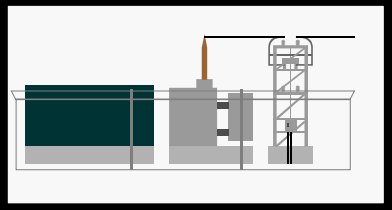
The Platform Family - One Common Architecture - from Feeder Protection to Generator Control

TRANSMISSION



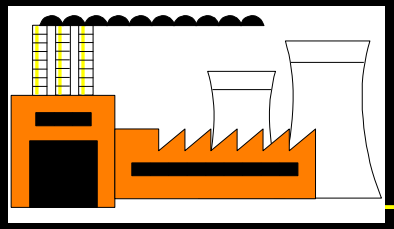
- L60 (Transmission Line: Phase Comparison)
- L90 (Transmission Line: Current Differential)
- D60 (Transmission Line: Distance)
- B30 (Busbar: Basic 6 Feeder)
- *B90 (Busbar: Comprehensive up to 24 Feeders) - Future*

DISTRIBUTION



- F35 (Feeder: Multiple Feeders - Basic Protection)
- F60 (Feeder: Comprehensive w Hi-Z)
- T35 (Transformer)
- T60 (Transformer: Comprehensive)
- C30 (Control IED)
- C60 (Breaker Management IED)

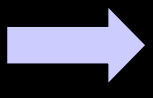
GENERATION / MOTOR



- G60 (Generator)
- M60 (Motor)

UI Business Path – GE at Play!

UI



LV

LV

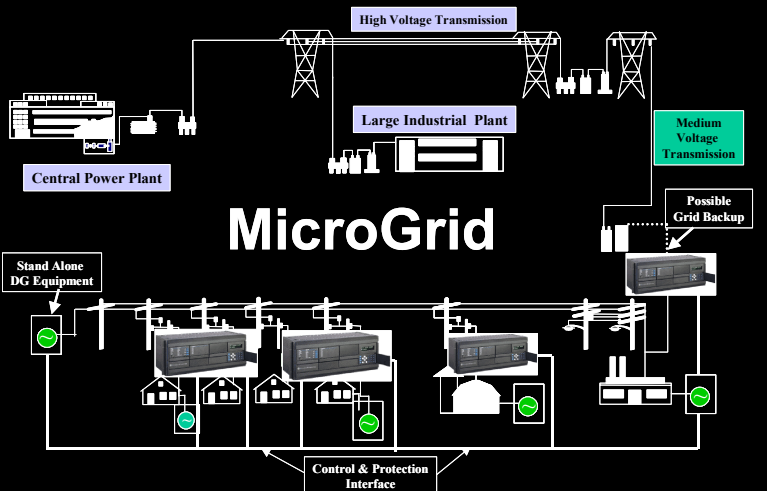
MV

Recip

Fuel Cell

Wind

SOFC



Penetration Study - 2nd Year

- 1st Year of GE interconnect project provided crucial investigation of DG and EPS integration issues
  - Quantitative insight into the critical issues
  - Results are useful to the industry in defining interconnection standards
- One conclusion: "surface has been scratched"
  - Fertile ground for further investigation
- 2nd Year: Extend System Studies to add to application domain knowledge

Guidance and Perspective for Host DisCo Engineering

Penetration Study - 2nd Year

2nd Year: Extend System Studies to further populate application domain knowledge

- Need: Application guidelines based on penetration
- Scope: Performance/System impact issues
- Not Scope: Regulatory, commercial, liability, economics
- Approach:
  - Distill insights from year 1
  - Review and include insights from other experience and research
  - Add quantitative analysis to fill gaps
  - Develop applications key/decision tree
  - Aim for balance between accuracy and simplicity
  - Map to Functionality for UI
  - Document in white paper
- Compliments: NARUC, P1547, EEI

Another *Step* in Bridging the Gap

Summary

- Voice of Customer (VOC) survey provides important input to UI requirements definition,
- Anti-Islanding – one of key UI functions – is being studied with a systematic approach.
- The UI platform is served as a vehicle for further UI development.
- Defined penetration study focus: application guide.

Next Step

- (VOC): Continue obtaining input from UI stakeholders, within and outside GE.
- Anti-Islanding: The study will include dynamic DG and load, identify key factors that impact AI.
- Two test facilities are being setup for UI prototyping and testing.
- Develop and implement UI functions.
- Penetration Study / Application Guide: The results will be reported out with a white paper.