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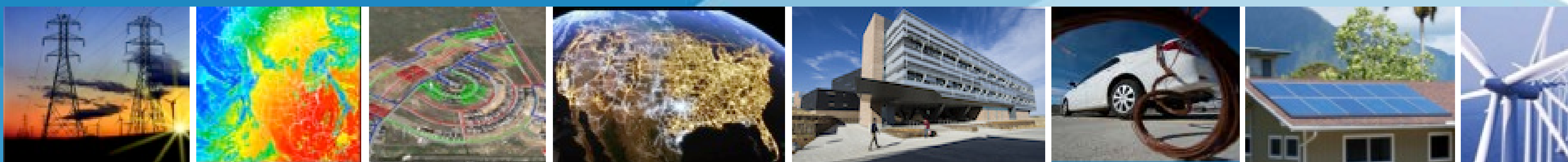


Prevention of Unintentional Islands in Power Systems with Distributed Resources

Ben Kroposki

National Renewable Energy Laboratory

Webinar - August 24, 2016

NREL/PR-5D00-67185

A seminar with audio is posted at NREL's YouTube channel: https://www.youtube.com/watch?v=-xjprcbFK3Q

Presentation Outline

- Types of islands in power systems with DR
- Issues with unintentional islands
- Methods of protecting against unintentional islands
- Standard testing for unintentional islanding
- Advanced testing of inverters for anti-islanding functionality
- Probability of unintentional islanding
- The future of anti-islanding protection
- References

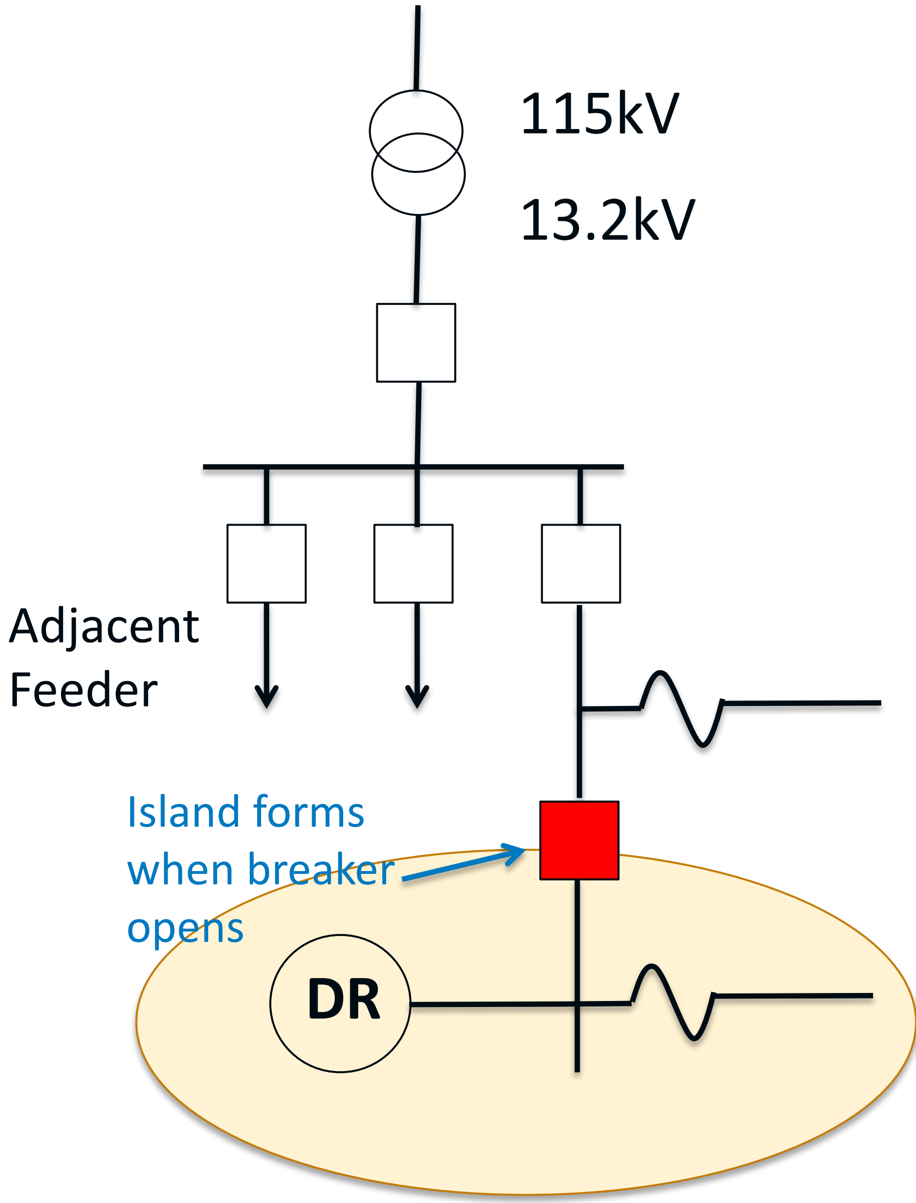
Terms

- **Area EPS** – Area Electric Power System
- **Local EPS** – Local Electric Power System
- **PCC** – Point of Common Coupling
- **DR** – Distributed Resource (e.g. distributed generation (DG), distributed energy resource (DER))
- **DER** – Distributed Energy Resource (The IEEE 1547 Working Group voted and decided to change DR to DER in the next version. DER will NOT include Demand Response as it does in some countries)
- **Anti-islanding** (non-islanding protection) – The use of relays or controls to prevent the continued existence of an unintentional island

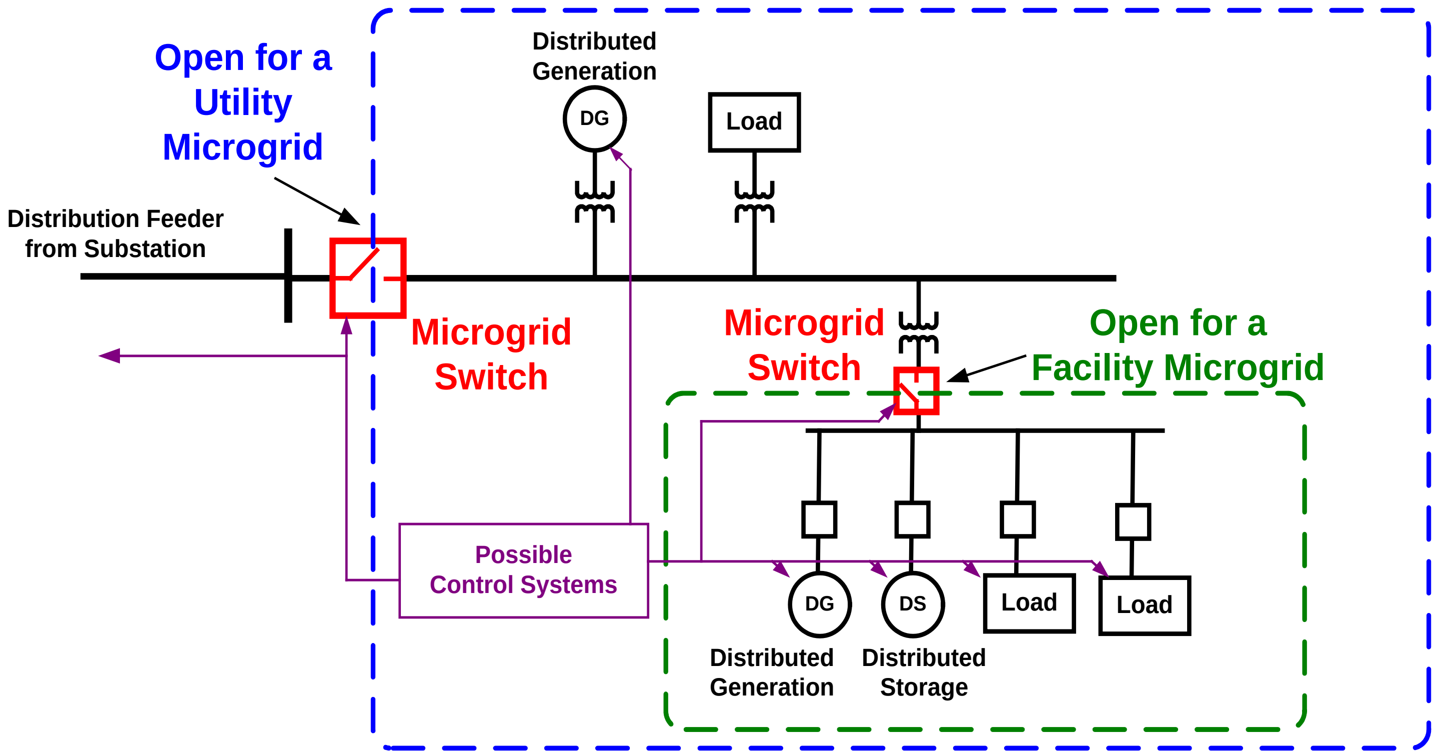
Island Definition

Island: A condition in which a portion of an Area EPS is energized solely by one or more Local EPSs through the associated PCCs while that portion of the Area EPS is electrically separated from the rest of the Area EPS.[1]

- Intentional (Planned)
- Unintentional (unplanned)



Intentional Islands (Microgrids)



Source: *Making microgrids work* [2]

IEEE 1547.4 is a guide for Design, Operation, and Integration of Intentional Islands (e.g. Microgrids) [3]

(1) have DR and load

(2) have the ability to disconnect from and parallel with the area EPS

(3) include the local EPS and may include portions of the area EPS, and

(4) are intentionally planned.

IEEE 2030.7 and 2030.8 – In development and cover microgrid control design and testing

Issues with Unintentional Islanding

- **Personnel Safety** – Unintentional islands can cause hazards for utility workers if they assume downed lines are not energized during restoration
- **Overvoltages** – Transient overvoltages due to rapid loss of load are possible. If an adequate ground source is not present in the island, a ground fault can result in voltages that exceed 173% on the unfaulted phases.
- **Reconnection out of phase** - This can result in large transient torques applied to motors connected to the islanded area EPS and their mechanical systems (e.g., shafts, blowers, and pumps), which could result in damage or failure.
- **Power Quality** – Unplanned island area EPS may not have suitable power quality for loads
- **Protection** – Unintentional islands may not provide sufficient fault current to operate fuses or overcurrent relay protection devices inside island

References [4]-[7]

Understanding DR Sources

- **Synchronous generators** are voltage source devices that can support islanded grid operations. Synchronous generators are typical in diesel or natural gas powered engine-generators.
- **Induction generators** usually will not be able to support an island but will instead cease to produce current because of the loss of reactive power, which is necessary to support a rotating magnetic field within the generator. If sufficient capacitive reactance is available to supply the reactive power requirements of the induction generator field, either through the installation of power factor correction capacitors or the presence of considerable cable-type power conductors, it may be necessary to provide for direct detection of faults in a manner similar to that of synchronous generators.[4] Induction generators are found in some engine-gen sets and wind turbines.
- **Inverter-Based DR** are typically current-source devices that require a voltage-source (typically the utility grid) to synchronize to. Voltage-source (e.g. grid forming) inverters do have the ability to support islanded operation. Inverters are found in PV systems, wind turbines, microturbines, fuel cells, and battery energy storage.

References [4]

IEEE 1547: Unintentional Islanding Requirement

IEEE 1547-2003: 4.4.1 Unintentional Islanding Requirement

For an unintentional island in which the DR energizes a portion of the Area EPS through the PCC, the DR interconnection system shall detect the island and ***cease to energize the Area EPS within two seconds*** *of the formation of an island.* [1]

Unintentional Islanding Requirement Background

IEEE 929 [8]– Early PV Interconnection Standard that has been replaced by IEEE 1547

- Defined **nonislanding** inverter as an inverter that will cease to energize the utility line in ***ten cycles or less*** when subjected to a typical islanded load in which either of the following is true:

    a) There is at least a 50% mismatch in real power load to inverter output (that is, real power load is < 50% or > 150% of inverter power output).

    b) The islanded-load power factor is < 0.95 (lead or lag).

- If the real-power-generation-to-load match is within 50% and the islanded-load power factor is > 0.95, then a nonislanding inverter will cease to energize the utility line ***within 2s*** whenever the connected line has a quality factor of 2.5 or less.

IEEE 1547-2003 (Early Drafts)

- **Draft 5** – 2 second to detect and cease to energize
- **DRAFT 6/7** - For an unintentional island in which the DR and a portion of the Area EPS remain energized through the PCC, the DR shall cease to energize the Area EPS ***within ten seconds*** of the formation of an island. Ten seconds was recommended by synchronous generator manufactures as a reasonable value.
- **Draft 8 and beyond** – changed unintentional islanding requirement to 2 seconds to get closer to instantaneous recloser settings. Inverters were already seen as capable from IEEE 929 requirement.

Footnote to IEEE 1547 Requirement[1]

Some examples by which this requirement may be met are:

- The DR aggregate capacity is less than one-third of the minimum load of the Local EPS.
- The DR installation contains reverse or minimum power flow protection, sensed between the Point of DR Connection and the PCC, which will disconnect or isolate the DR if power flow from the Area EPS to the Local EPS reverses or falls below a set threshold.
- The DR is certified to pass an applicable non-islanding test.
- The DR contains other non-islanding means, such as a) forced frequency or voltage shifting, b) transfer trip, or c) governor and excitation controls that maintain constant power and constant power factor.

DR Aggregate Capacity

The DR aggregate capacity is less than one-third of the minimum load of the Local EPS.

- If the aggregate DR capacity is less than one-third of the local EPS load, it is generally agreed that, should an unintentional island form, the DR will be unable to continue to energize the load connected within the local EPS and maintain acceptable voltage and frequency. [4]
- The origin of this 3-to-1 load-to-generation factor is an IEEE paper [9] based on simulations and field tests of induction and synchronous generation islanded with various amounts of power factor-correcting capacitive kilovoltamperes reactive.
- It was shown that as the pre-island loading approached three times the generation, no excitation condition could exist to support the continued power generation.

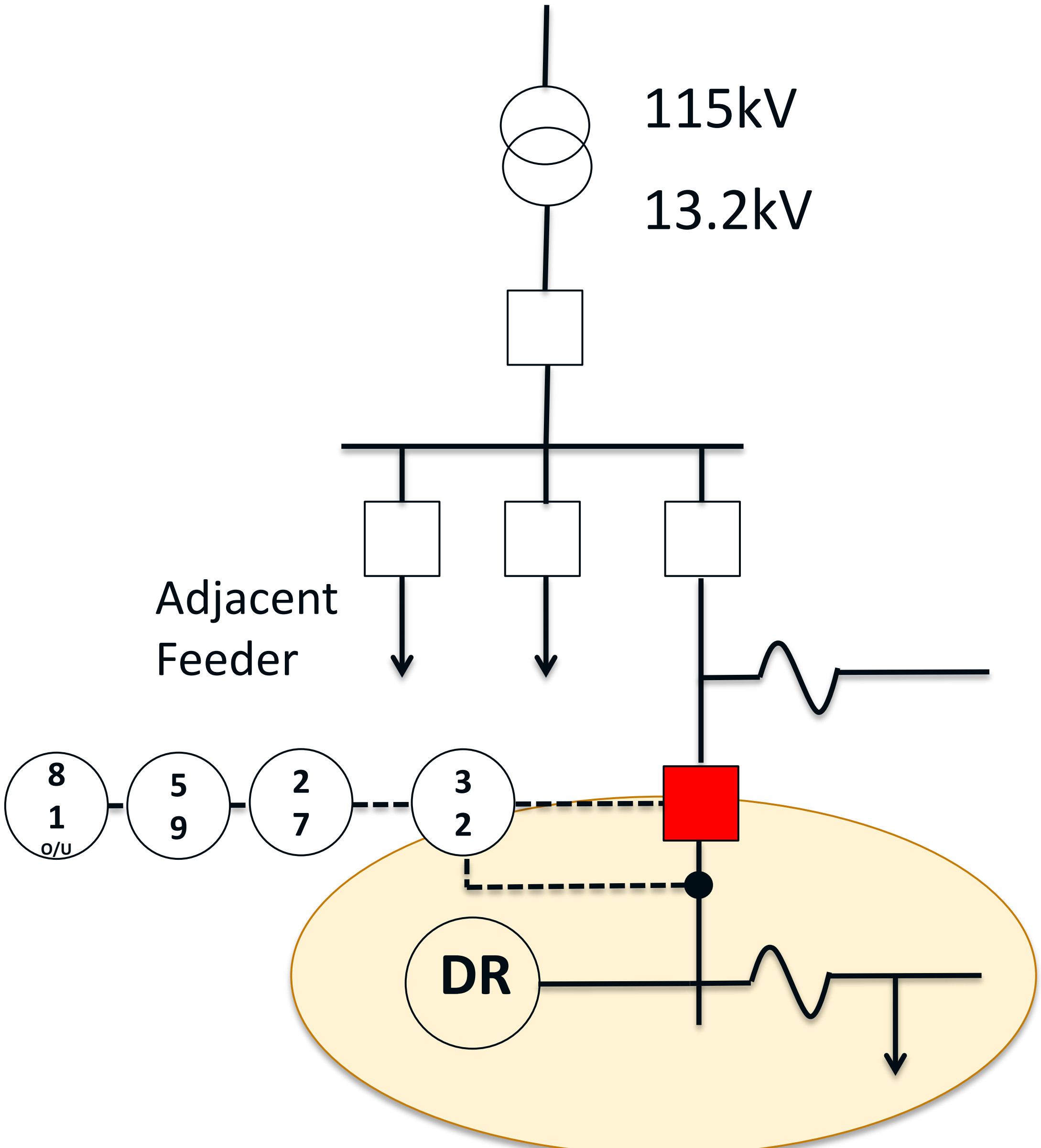
Methods of protecting against unintentional islands

- Reverse/Minimum Import/Export Relays
- Passive Anti-islanding
- Active Anti-islanding
  - e.g. instability induced voltage or frequency drift and/or system impedance measurement coupled with relay functions
- Communication-Based Anti-Islanding
  - Direct transfer trip (DTT)
  - Power line carrier (PLC)
  - Impedance Insertion
- Methods Under Development
  - Phasor-based anti-islanding

References [10]-[37]

Reverse/Minimum Import/Export Relays

- Protective Relay Function (Reverse Power = 32)
- Used in cases where the DR is not exporting to the grid
- Local loads are typically larger than DR



Passive Anti-islanding

- Over/under voltage and frequency trip settings
- Voltage and frequency relay functions (81o, 81u, 27, 59)
- Set a V/F window – if conditions are outside window, then DR trips
- Non-detect zone (NDZ) exists between trip points
- Amendment 1 (IEEE 1547a) allows for adjustable clearing times

New Voltage and Frequency Trips Settings from Amendment 1 of IEEE 1547-2003 [38]

Table 1—Interconnection system default response to abnormal voltages

Default settings[a]		
Voltage range (% of base voltage[b])	Clearing time (s)	Clearing time: adjustable up to and including (s)
V < 45	0.16	0.16
45 ≤ V < 60	1	11
60 ≤ V < 88	2	21
110 < V < 120	1	13
V ≥ 120	0.16	0.16

[a] Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted

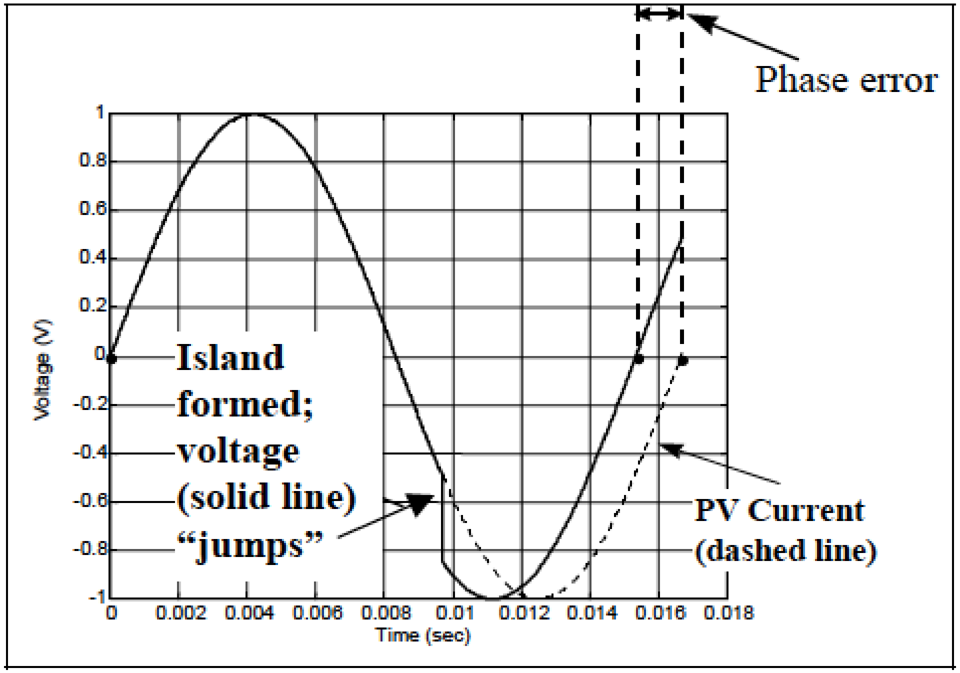
[b] Base voltages are the nominal system voltages stated in ANSI C84.1-2011, Table 1.

Table 2—Interconnection system default response to abnormal frequencies

	Default settings		Ranges of adjustability	
Function	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s) adjustable up to and including
UF1	< 57	0.16	56 – 60	10
UF2	< 59.5	2	56 – 60	300
OF1	> 60.5	2	60 – 64	300
OF2	> 62	0.16	60 – 64	10

Other Passive Anti-islanding

- Rate-of-change-of-frequency (ROCOF)
- Voltage or Current Harmonic Monitoring – monitor voltage harmonic distortion
- Voltage Phase jump - detect a sudden "jump" in phase displacement between inverter voltage and output current



Voltage Phase Jump [15]

Active Anti-islanding

- Impedance Measurement
- Detection of Impedance at a Specific Frequency
- Slip-mode Frequency Shift
- Frequency Bias
- Sandia Frequency Shift
- Sandia Voltage Shift
- Frequency Jump
- ENS or MSD (a device using multiple methods)

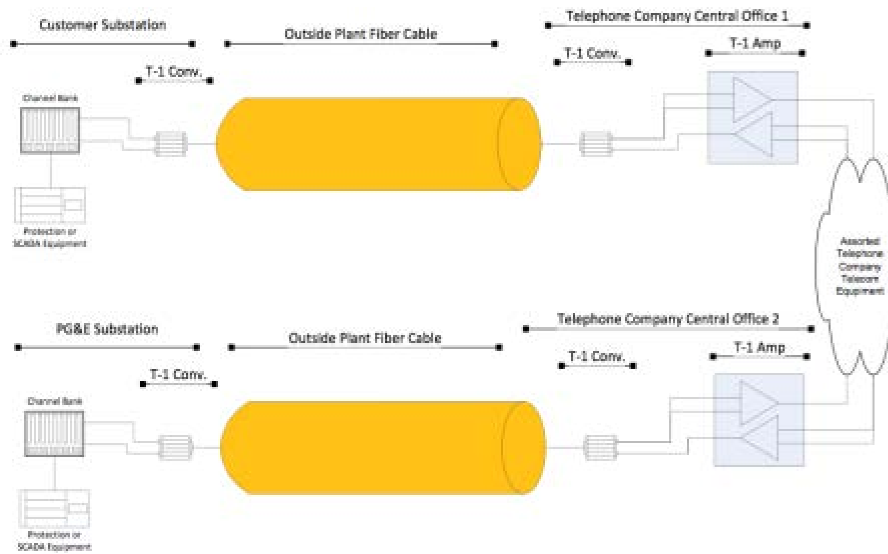
Active methods generally attempt to detect a loss in grid by actively trying to changing the voltage and/or frequency of the grid, and then detecting whether or not the grid changed.

Communications-based Methods

- Power Line Carrier – Provide a permissive run signal, when signal goes away, the DR ceases to energize circuit
- Impedance Insertion – Remotely add capacitors that cause a large enough voltage change to trip O/U voltage protection
- DTT – next slide

Direct Transfer Trip (DTT)

- Direct Transfer Trip (DTT) provides a communications signal from the Area electric power system component such as a feeder breaker or automatic line sectionalizing devices to the DR or the addition of sync-check relaying or undervoltage-permissive relaying at the feeder breaker or automatic line sectionalizing devices. [4]
- DTT scheme is used to avoid accidental paralleling of larger DR to the grid.
- DTT may require communications not only from the substation breaker but also from any automatic line sectionalizing devices upstream from the DR.

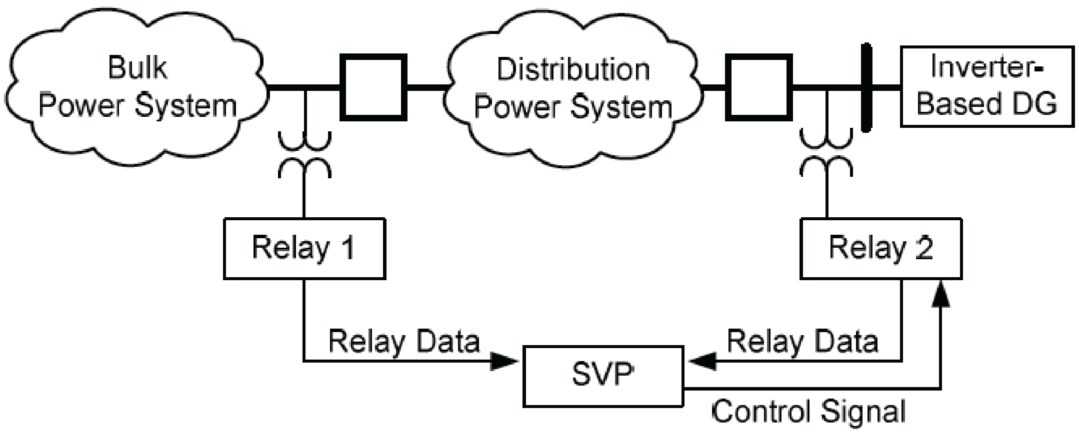


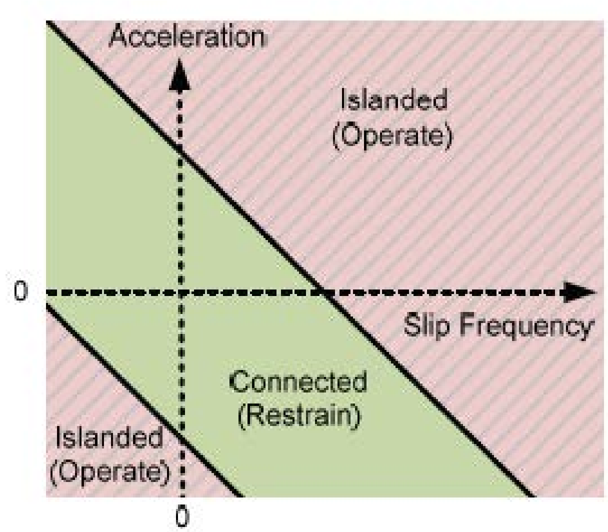
All Fiber DTT Protection Circuit [39]

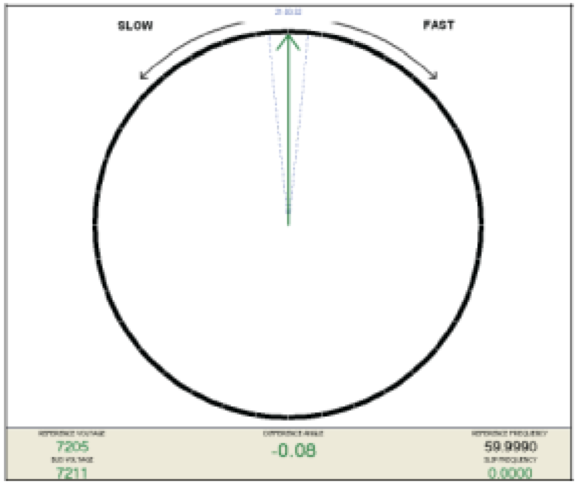
- Examples of DTT (from PG&E interconnection requirements [39]:
  - Direct Fiber to Substation with proper interface provisioning
  - Licensed Microwave with proper interface provisioning
  - Class A DS0 4-Wire Lease Line provisions by Local Exchange Carrier (LEC)
  - additional Direct Transfer Trip (DTT) Telecommunication Options via the new Class B, T1 Lease Options
- **Drawback:** DTT often uses a dedicated fiber or other communications infrastructure which is costly to install and operate.

Methods under development

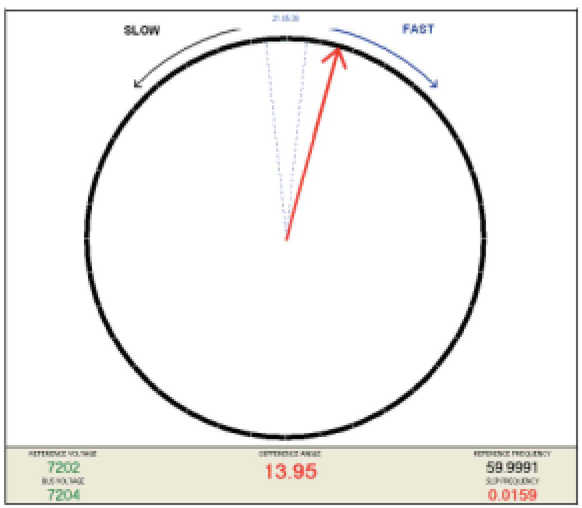
- Phasor-based anti-islanding [31]







Phasors when Grid-connected



Phasors when Islanded

Standard Unintentional Islanding Testing

IEEE 1547.1 – Unintentional Islanding Test

- IEEE 1547.1 details testing requirements for unintentional islanding [40]
- Uses a matched RLC load and measures trip times when island condition occurs
- The RLC load is set to a Quality factor (Q_f) = 1.0
- Q_f of 1.0 is equivalent to a load displacement power factor of 0.707.
- Distribution circuits typically operate at a value greater than 0.75 p.f.
- Conducted at 100%, 66%, and 33% rated power
- The test is to be repeated with the reactive load (either capacitive or inductive) adjusted in **1% increments** or alternatively with the reactive power output of the EUT adjusted in 1% increments from 95% to 105% of the initial balanced load component value. If unit shutdown times are still increasing at the 95% or 105% points, additional 1% increments shall be taken until trip times begin decreasing.

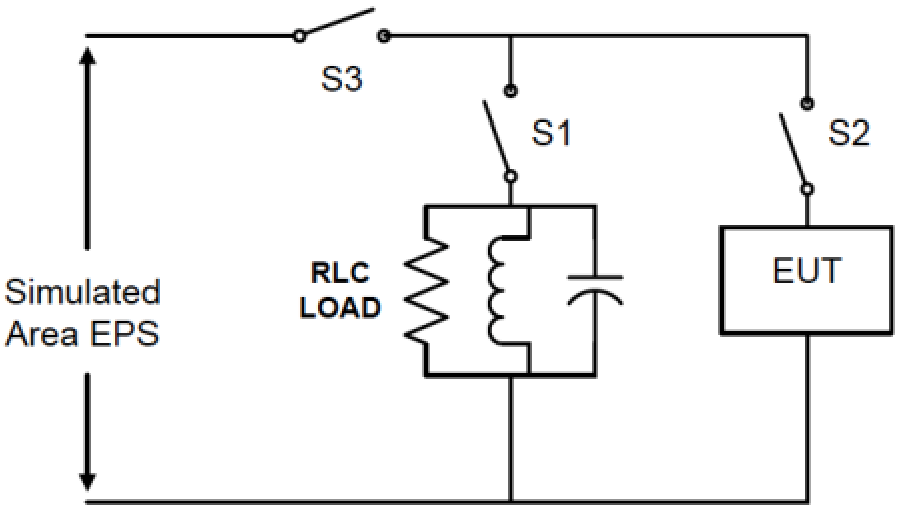


Figure 2—Unintentional islanding test configuration from IEEE 1547.1

$$Q_f = R\sqrt{\frac{C}{L}}$$

- A Q_f of 2.5 was used in IEEE 929-2000 and is equivalent to a load displacement power factor of 0.37. [8]
- Q_f was reduced to 1.0 during evaluation of IEEE 1547.1 to reduce testing burden since run on times were not significantly longer at 2.5

Unintentional Islanding Test for Synchronous Generators

- Load is matched in real and reactive power [40]
- Tested at:
  - Minimum Load at unity 1.0 p.f.
  - Maximum real load at unity 1.0 p.f.
  - Maximum real load at rated p.f. lagging
  - Maximum real load at rated p.f. leading

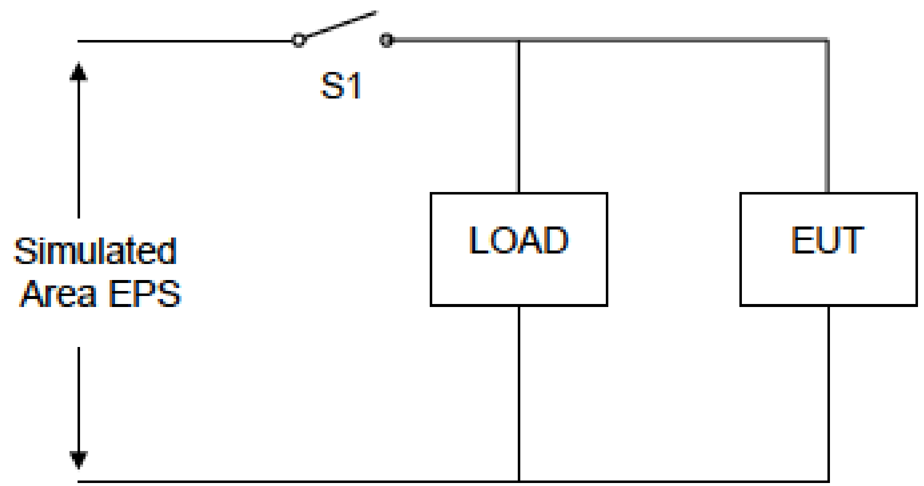


Figure 3—Unintentional islanding test for synchronous generators configuration from IEEE 1547.1

Reverse Power Flow (for unintentional islanding)

- To meet the unintentional islanding requirement in 1547, the DR installation may contain reverse or minimum import power-flow protection [40]
- Sensed between the point of DR connection and the PCC, it disconnects or isolates the DR if power flow from the area EPS to the local EPS reverses or falls below a set threshold.
- IEEE 1547.1 tests evaluate the magnitude and time of the reverse/minimum power flow protective device.

Advanced Testing

Energy Systems Integration Facility (ESIF)

http://www.nrel.gov/esif

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Unique Capabilities

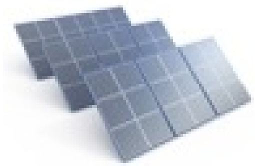
- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation and loads
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced communications and control
- Interconnectivity to external field sites for data feeds and model validation
- Petascale HPC and data mgmt system in showcase energy efficient data center
- MW-scale Power hardware-in-the-loop (PHIL) simulation capability to test grid scenarios with high penetrations of clean energy technologies

Shortening the time between innovation and practice

Energy Systems Integration Facility (ESIF)

http://www.nrel.gov/esif/

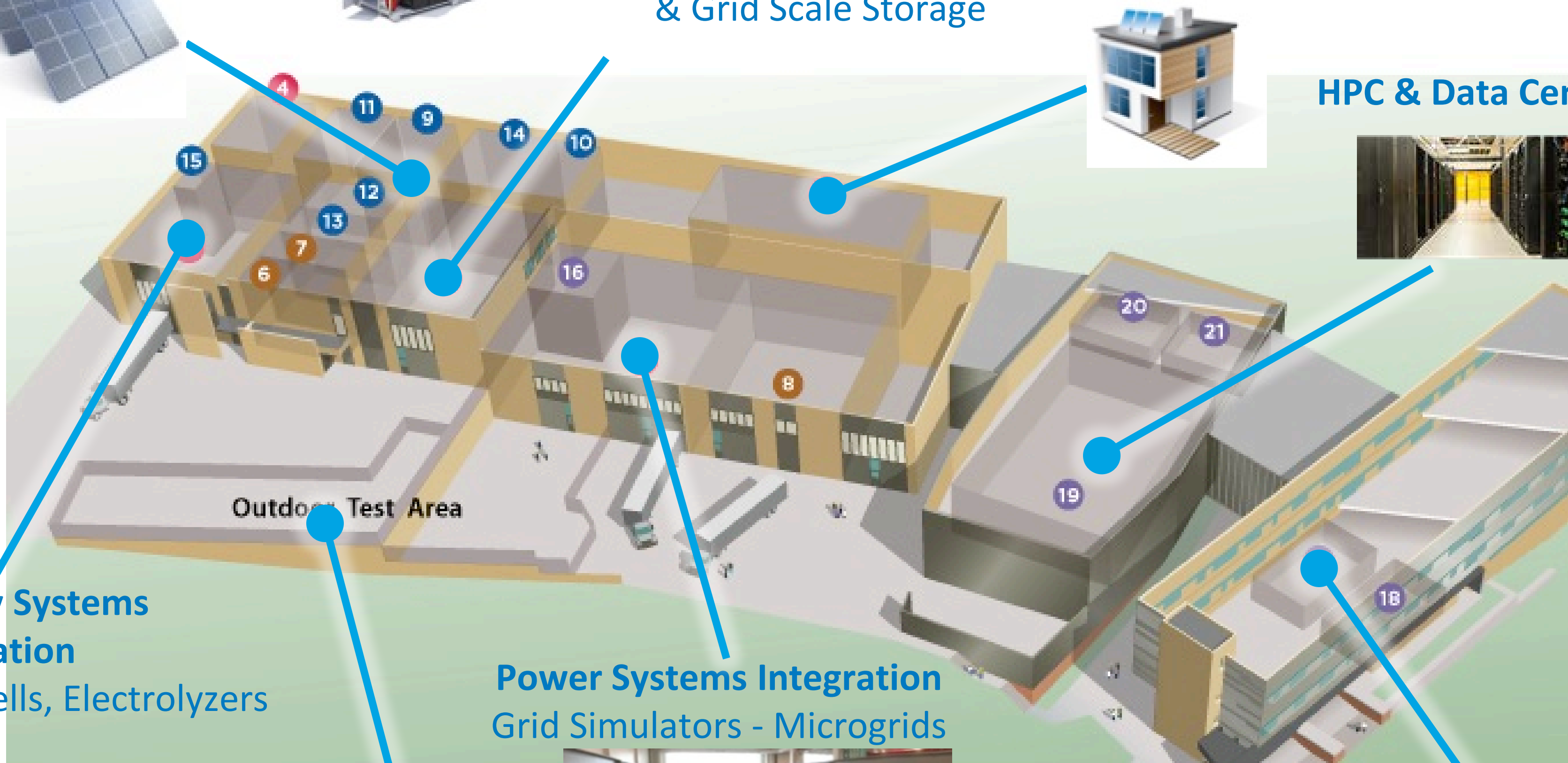
Rooftop PV



Energy Storage -
Residential, Community & Grid Scale Storage

Smart buildings & controllable loads

HPC & Data Center



Energy Systems Integration
Fuel Cells, Electrolyzers

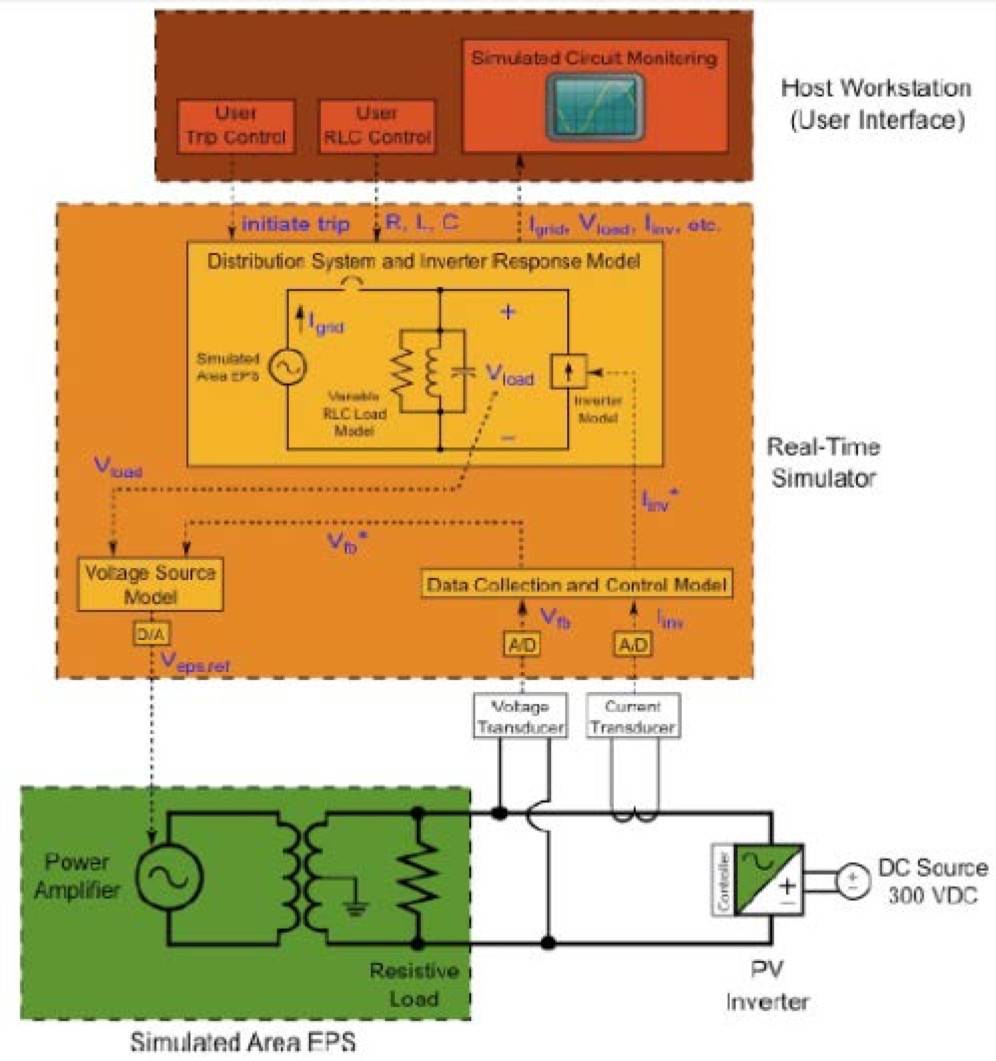
Power Systems Integration
Grid Simulators - Microgrids

Outdoor Test Areas
EVs, Transformers, Capacitor Banks, Voltage Regulators

Advanced Distribution Management Systems

Advanced Testing - PHIL

- Power Hardware in the Loop (PHIL) – replicate loads and some grid component of the test in simulation
- The variable RLC load PHIL approach is effective for achieving conditions that are difficult to replicate with discrete hardware [42][43]
- May not work on all active AI methods



Multiple Inverter Testing

- Sandia Testing [44] – examined 4 inverters/single PCC (demonstrated that multiple inverters still meet 2 sec requirement).

- NREL Testing with SolarCity & HECO [45] - examined 1) the impacts of both grid support functions and 2) multi-inverter(3)/multi PCC islands on anti-islanding effectiveness.
    - Showed that with grid support functions (volt/var and frequency/watt) enabled, the 2 sec requirement is still met.
    - Showed that multiple PCCs did not cause trip times beyond 2 seconds (regardless of system topology)
    - Results only valid on inverters/designs that were tested

Probability of Unintentional Islands

Probability of Islanding

- To create an electrical island, the real and reactive power flows between DR and loads must be exactly matched
- What is the probability of this happening?

- IEA PVPS Task 5 – Study [46]
  - The "benchmark" risk that already exists for network operators and customers is of the order of 10^{-6} per year for an individual person
  - The risk of electric shock associated with islanding of PV systems under worst-case PV penetration scenarios to both network operators and customers is typically $<10^{-9}$ per year
  - Thus, the additional risk presented by islanding does not materially increase the risk that already exists as long as the risk is managed properly
  - Balanced conditions occur very rarely for low, medium and high penetration levels of PV-systems.
- The probability that balanced conditions are present in the power network and that the power network is disconnected at that exact time is virtually zero.[47][48]

Suggested Guidelines for Assessment of DG Unintentional Islanding Risk – Sandia Report [49]

- Cases in Which Unintentional Islanding can be Ruled Out
  - Aggregated AC rating of all DG within the potential island is less than <u>some fraction of the minimum real power</u> load within the potential island
  - Not possible to balance reactive power supply and demand within the potential island.
  - DTT/PLCP is used
- Cases in Which Additional Study May Be Considered
  - Potential island contains large capacitors, and is tuned such that the power factor within a potential island is very close to 1.0
  - Very large numbers of inverters
  - Inverters from several different manufacturers
  - Include both inverters and rotating generators

The Future of Anti-islanding Protection

- Passive islanding often has a NDZ, but it is hard for power systems to maintain a generation/load balance for extended periods of time (beyond 10s)[50]
- Active anti-islanding techniques are fast and work best on "stiff" grids. Most techniques work when a significant change in system characteristics occur because of island formation.
- New integration requirements are opening up voltage and frequency trip points to enable grid stability at high DR penetrations
- Multiples of active anti-islanding techniques may or may not work against each other.
- Future power systems may not be as stiff with reduced use of synchronous generators.

Items for Discussion

- 2s requirement – Is this the right number?
  - Too slow for instantaneous/fast reclosing
  - Too fast for some communications based AI methods
  - Need active AI to achieve this with matched load

- Active Anti-islanding – Is it needed?
  - What happens when you have thousands of different techniques and deployed DR?
  - Should there be 1 method that everyone must use? (tried before, but patents got in the way)
  - Will active AI work against maintaining grid stability at high penetration levels?

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