Accidental Islanding of Distribution Systems with Multiple Distributed Generation Units of Various Technologies

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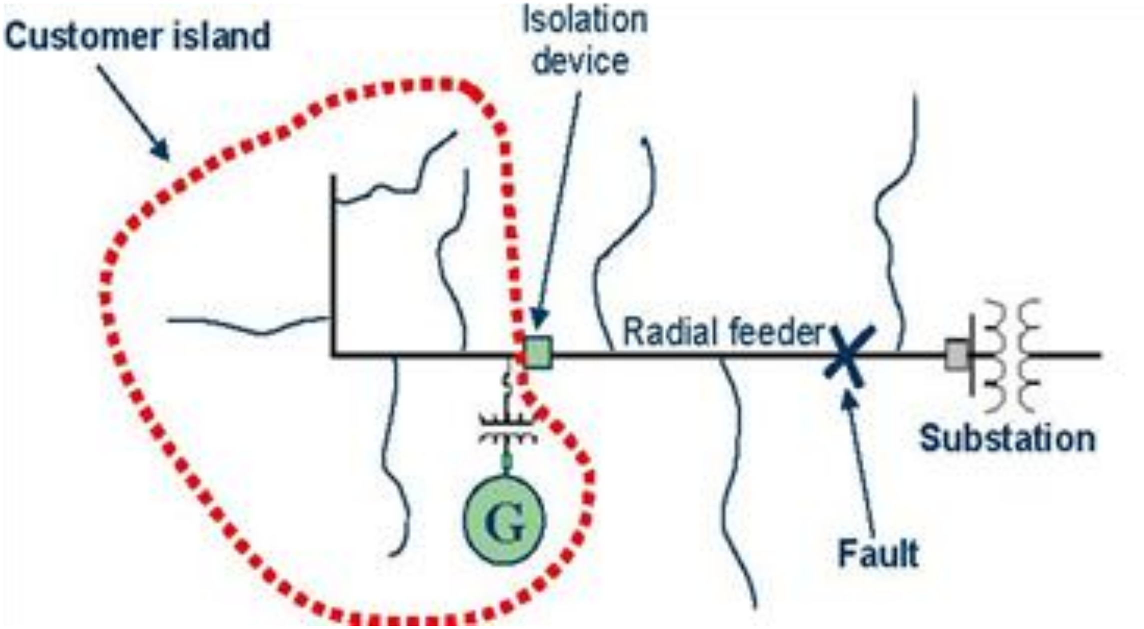
Grid of the Future 2013 Symposium
Boston, MA - Oct. 22, 2013

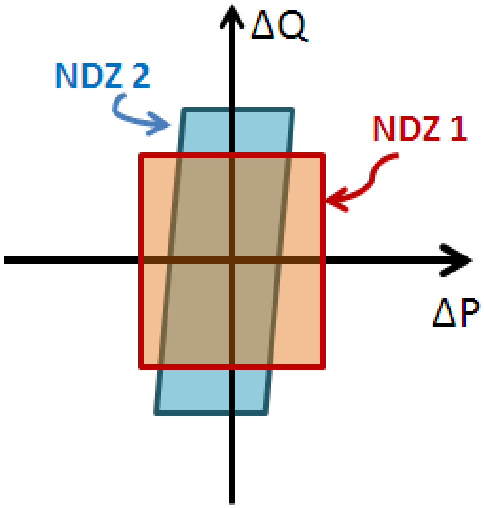
Outline

- Introduction
- Problem Statement
- Studies
- Conclusions



Introduction – Anti Islanding (AI)

- Requirements:
  - DG capability to detect an unintentional islanding of a feeder and cease to energize in less than 2 seconds
- Impact:
  - Power quality concerns (damaging overvoltage), slowing down reclosing or out of synch reclosing, and safety matter (some utilities)
- Main Issue with anti-islanding schemes:
  - Non-Detection zone
  - Tested for single DG



1) Constant power loads,
2) Impedance or voltage dependent load

Islanding Detection Methods

	DG technology	Pros	Cons
Passive	**All**	**• Uses locally measured signals** **• Simple, cheap**	**Non-detection zones for some cases**
Active	**Inverters**	**• Integral part of inverter control** **• High reliability**	**Impact of perturbation unknown for multiple DG**
Communication based	**All – but mostly for large capacity DG**	**High reliability**	**Expensive**

Note: DG Size, Technology, and Location are determinant factors in selection of anti-islanding scheme

Passive AI Schemes

Example Schemes	Basic Principal of Operation
Conventional under/over voltage and frequency protection	Imposing thresholds on acceptable level of voltage and frequency deviations
Rate of change of frequency	Measuring the rate of variation of frequency
Vector Shift	Measuring a sudden change in the phase angle of a generator voltage vector
Directional real and reactive power	Imposing thresholds on Real/Reactive power directions (only importing or exporting)
Impedance measurement	Using local voltage and current to measure variations in impedance seeing from the grid

- Advantages:
  - Low-cost add-on solutions at PCC
  - available on commercial protective relays from different vendors
- Disadvantages:
  - NDZ is highly dependent on load and generation
  - Requires testing and evaluation for minimum load to generation ratios of less than 3 to 1 (2 to 1)

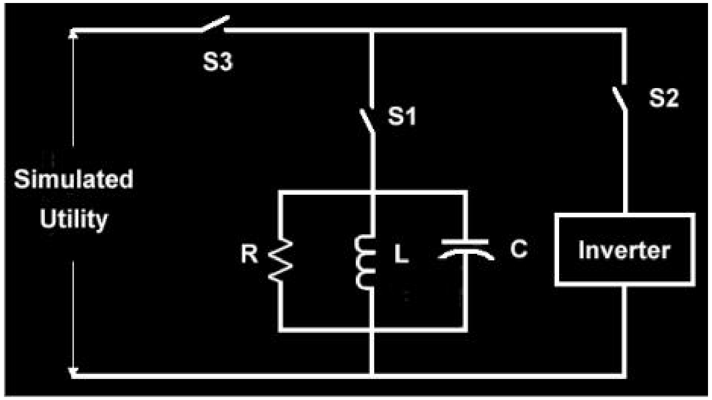
Active AI Schemes

Example Schemes	Basic Principal of Operation
Slip-mode Frequency Shift (SMS)	The current and/or voltage phase angle of the inverter, instead of always being controlled to be zero, is made to be a function of the frequency of the PCC voltage
Sandia Frequency Shift (SFS)	Applies positive feedback to the frequency of the inverter voltage at PCC.
Sandia Voltage Shift (SVS)	Applies positive feedback to the amplitude of the voltage at PCC.
Frequency Jump – Zebra Method	Dead zones are inserted into the output current waveform.

- Primarily used with Inverter-Based DGs (PV, wind, energy storage inverters)
- Proprietary schemes – large variety of patented methods (hard to model and study)
- Some concerns with deterioration of the power quality (signal injection)
- Unknown interactions among schemes from different vendors (single unit compliance testing)

Anti Islanding Test – UL Certification

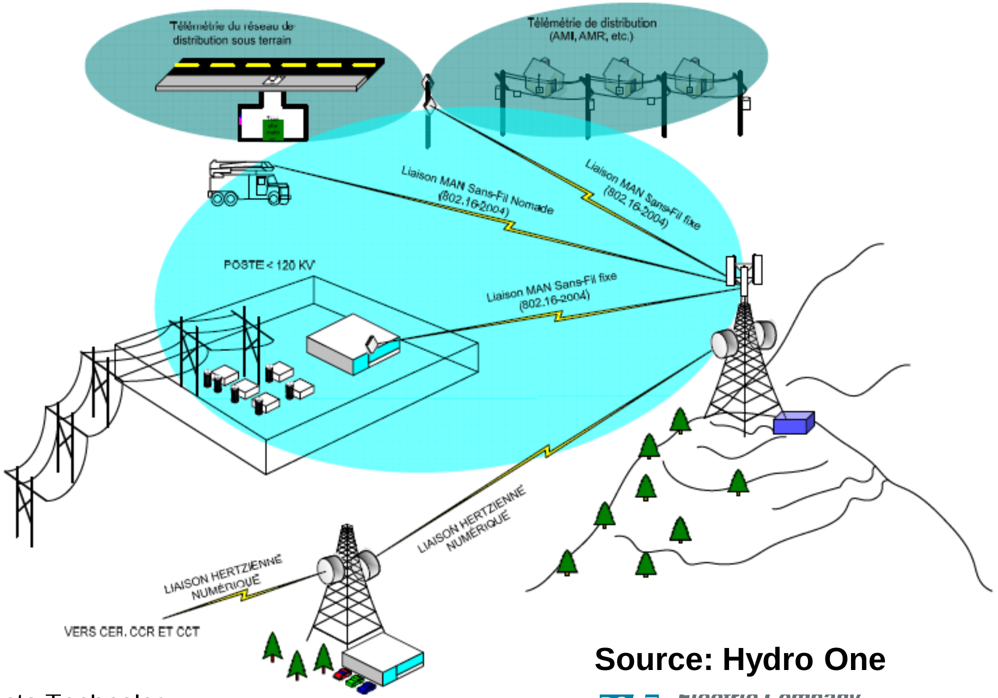
- UL-1741 certification for utility interactive inverters
  - Test is performed on single inverter at a timer
  - Using a power quality factor (Q) of 1.0 (+/- 0.05)
  - Balancing load condition (current flowing to the grid < 2% rated)
  - Repeating for 33%, 66%, and 100% of the rated output power



- Limited knowledge of interactions among:
  - Multiple inverters, e.g. roof-top PVs
  - Various DG technologies: Inverter + Synchronous Generator

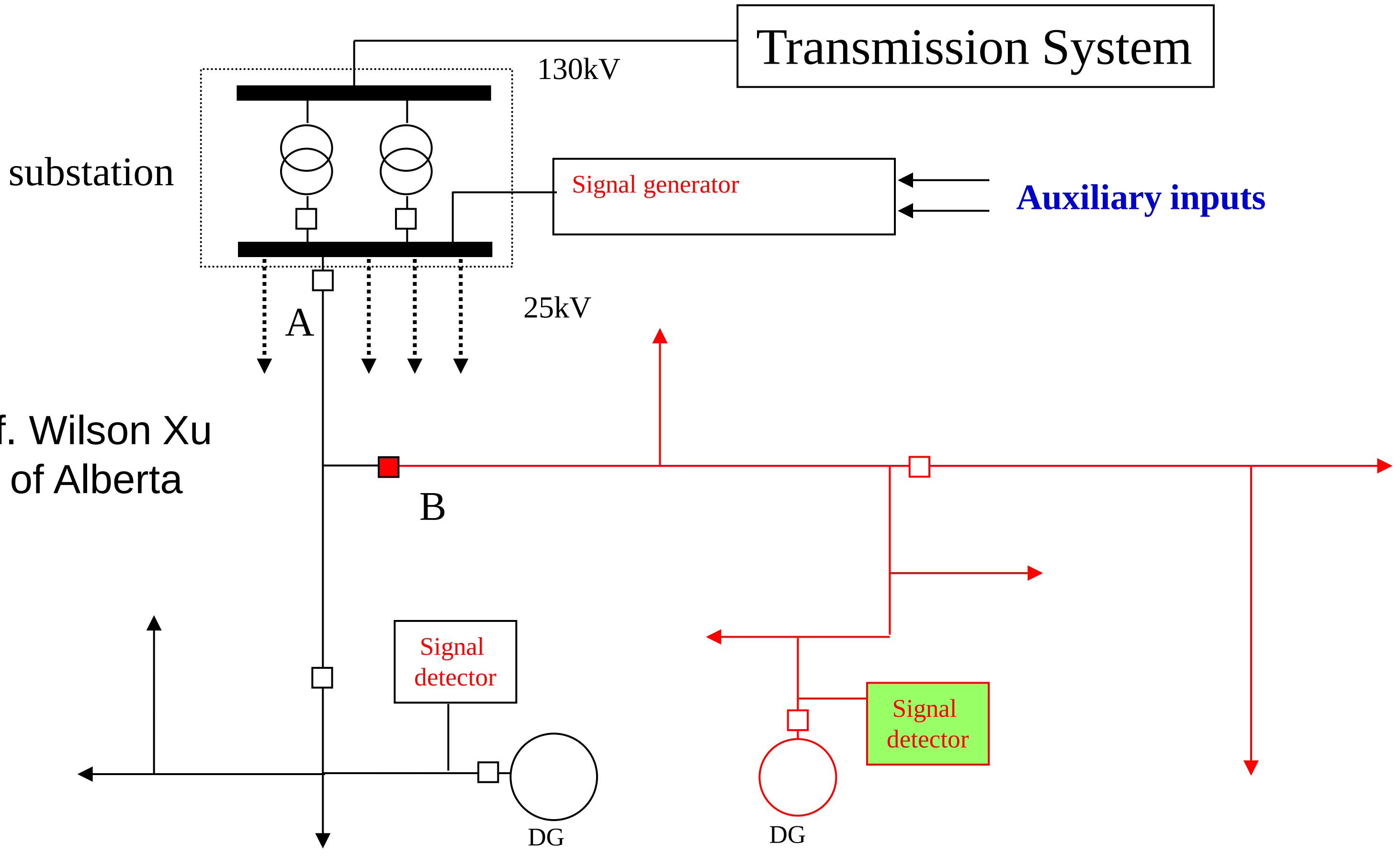
Transfer Trip Methods

- A reliable solution if communication infrastructure is available
- Typically is required for DG>500 KW and P(DG) greater than half of minimum load
- Required at each recloser or disconnect switch on the feeder
- Cost effective technologies:
  - 900MHz radio freq. transfer trip: line of sight
  - WiMAX and/or Broadband wireless: multiple DGs



Source: Hydro One

Power Line Signaling Method

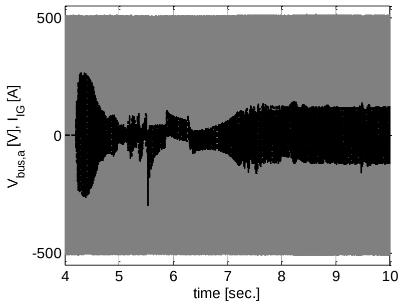


Source: Prof. Wilson Xu
University of Alberta

- Two components:
  - Signal Generator at Substation & Signal Detector at DG location
- Multiple DGs can share same signal generator

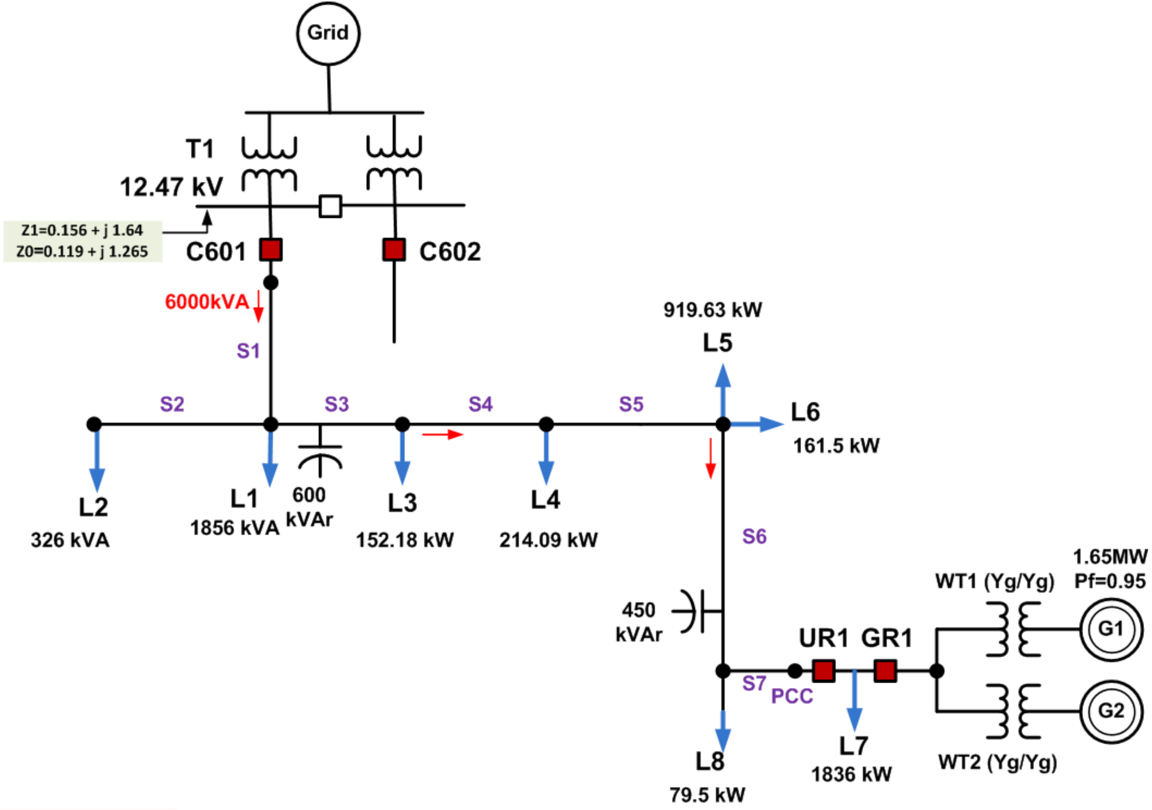
Anti-Islanding Evaluation Methods

- Apply screening criteria
- Transient simulation studies
  - Model feeder and DG with conventional AI schemes and/or Generic active schemes
  - Use vendor-specific Inverter model with Active AI (if available)
- Laboratory (field) evaluation
  - Comtrade playback of captured phenomena (event record) into devices
  - Real time digital simulation (RTDS) test setup (hardware in the loop)
  - Field testing of the schemes



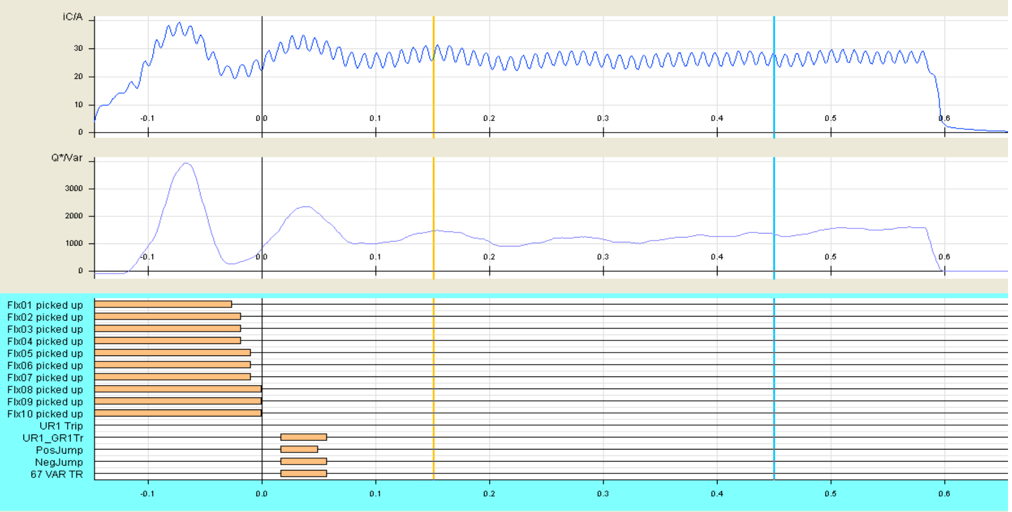
RTDS Evaluation of a Passive AI Scheme

- Two doubly fed asynchronous generators on a 12 kV feeder
- Reactive power compensation (leading power factor) for voltage control
- Passive (relay based) or communication based anti-Islanding (conventional or advanced schemes)



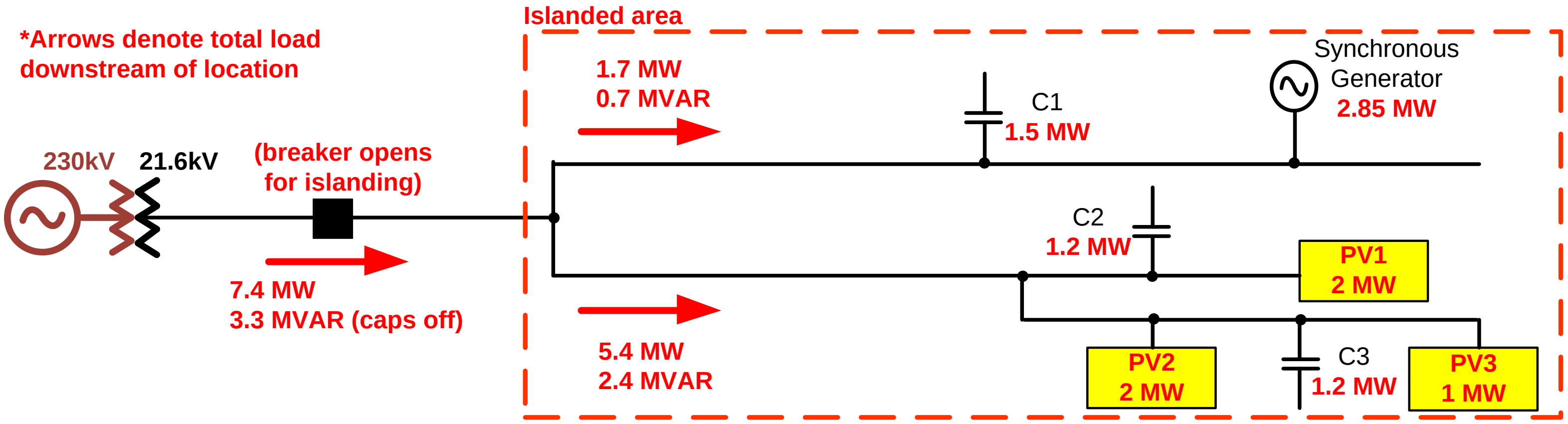
Test Cases and Evaluation

Test Cases		Function Picked up
Case 1	Max L, Zero Gen	**27 undervoltage**
Case 2	Min L, Zero Gen	**27 undervoltage** **32R reverse power**
Case 3	Max L, Max Gen	**27 undervoltage** **32R reverse power**
Case 4	Min L, Max Gen	**59 Overvoltage**
Case 5	Max L, Matching Gen	**32R reverse power** **27 undervoltage**
Case 6	Min L, Matching Gen	**32R reverse power** **67Var protection** **27 undervoltage**
Case 7	Min L, Matching Gen with P(Load)	**59 Overvoltage** **32R reverse power**
Case 8	Min L, Limiting P(UR1) to 500 kW	**27 undervoltage**



Transient (EMTP) Studies - Benchmark

- Building an electromagnetic transient model of the system:
  - Frequency/voltage dependent component models (lines, transformers, loads, shunt elements)
  - DG interface and controls (vendor specific or generic)
  - Protection elements and switching sequences
- Evaluate various realistic operating scenarios (P/Q mismatch)



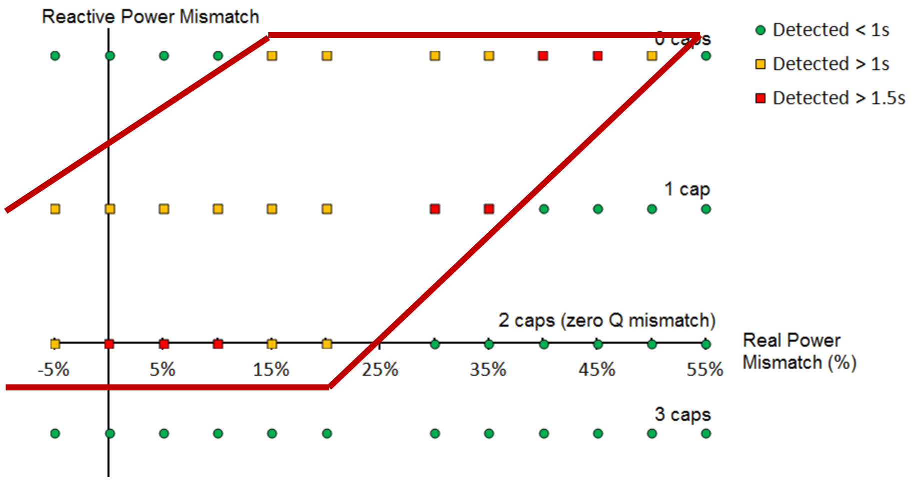
- Benchmark:
  - A 21.6 kV distribution system with synchronous generator (landfilled gas) and solar PV facilities
  - Multiple switched capacitors
  - Total DG > Load

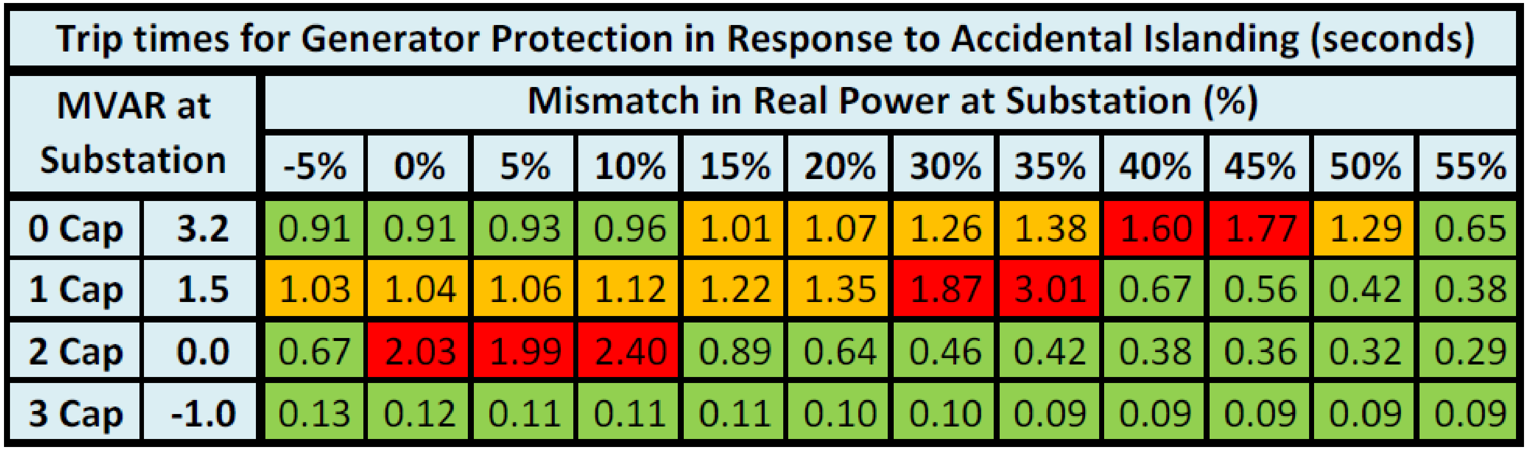
Study Objectives and Cases

- Determine voltage and frequency response of the system
  - What is the effect of power mismatch (both ΔP & ΔQ)
  - When can synchronous generator sustain an island?
  - Impact of capacitor switching
- Evaluate performance of typical (voltage/freq. based) and new (reactive power, power factor, vector shift) intertie protection schemes
- Study cases:
  - **Active Power mismatch** (Load – Generation): 55%, 50%, 45%, 35%, 20%, 10%, 5%, 0% and -5%
  - **Reactive power mismatch**: a) no capacitor (3.2 Mvar flow downstream at substation), b) single capacitor (1.5Mvar flow), c) two capacitor (no Mvar flow), and d) three capacitor compensation (1Mvar flow upstream)

Study Results – Generator Trip Time

- Islanding detection (trip time) varies significantly with the power mismatch
  - Fast trip: t<1 sec
  - Slow detection: 1 < t < 1.5 sec
  - Very slow detection: t > 1.5 sec
- Synchronous generator supplied Q
- More sensitive to Q surplus

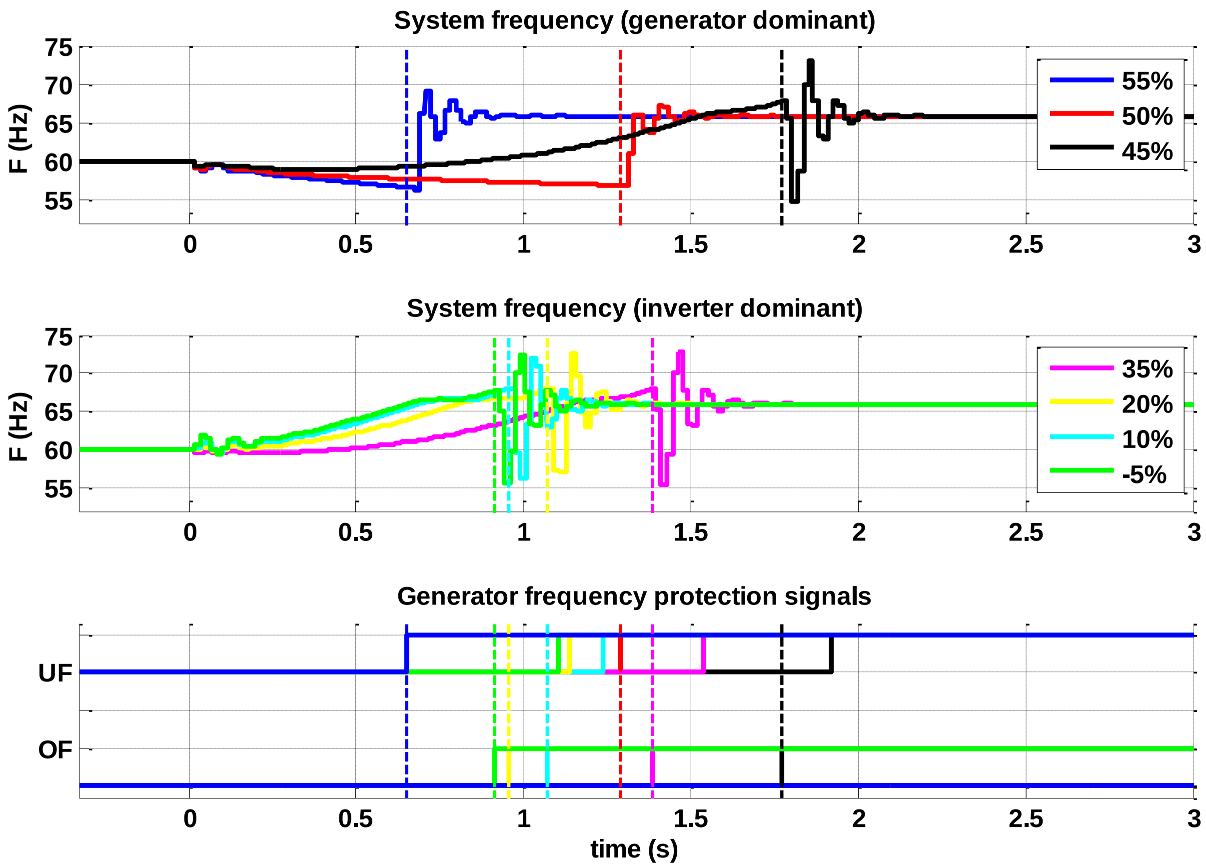




Trip times for Generator Protection in Response to Accidental Islanding (seconds)													
MVAR at Substation		Mismatch in Real Power at Substation (%)											
		-5%	0%	5%	10%	15%	20%	30%	35%	40%	45%	50%	55%
0 Cap	3.2	0.91	0.91	0.93	0.96	1.01	1.07	1.26	1.38	1.60	1.77	1.29	0.65
1 Cap	1.5	1.03	1.04	1.06	1.12	1.22	1.35	1.87	3.01	0.67	0.56	0.42	0.38
2 Cap	0.0	0.67	2.03	1.99	2.40	0.89	0.64	0.46	0.42	0.38	0.36	0.32	0.29
3 Cap	-1.0	0.13	0.12	0.11	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.09

System Frequency Responses

- Positive active power mismatch:
  - Synchronous generator dominated: Frequency decreases
  - PV Inverter dominated: Frequency increases



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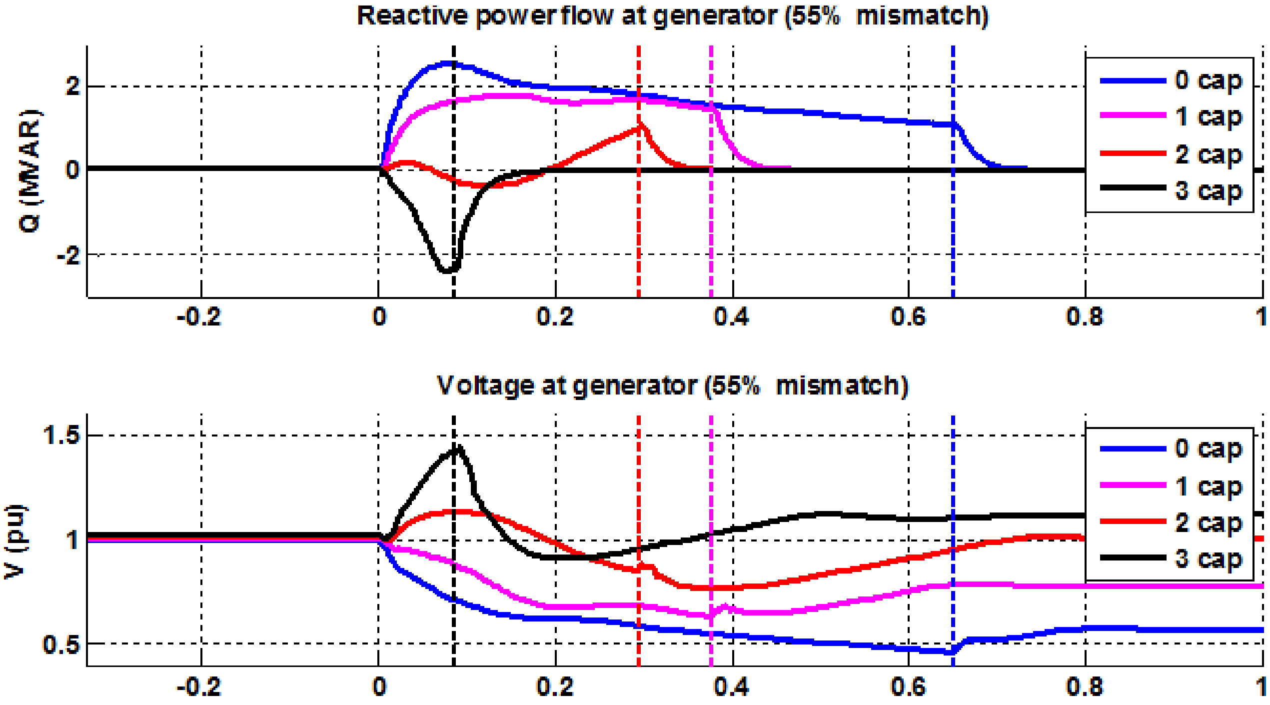
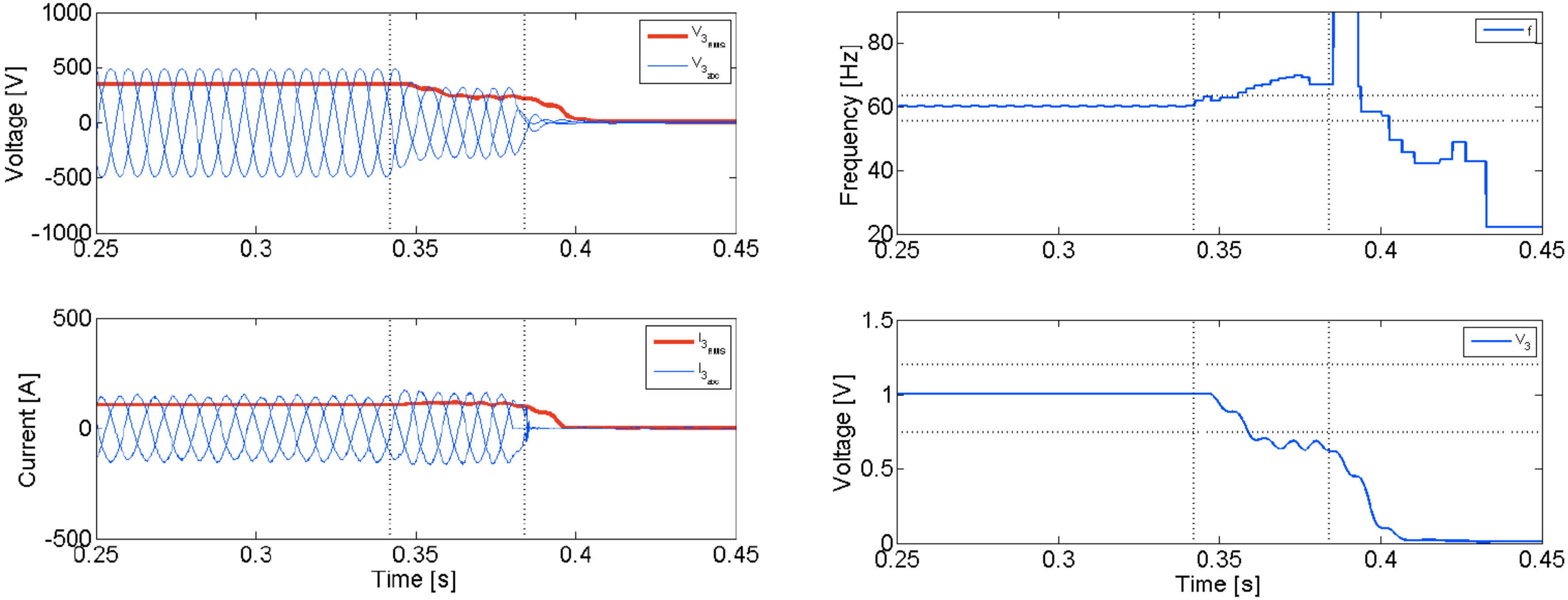
Synchronous Generator Responses

- At large positive P or Q mismatch:
  - Generator trips on under frequency or under voltage
- At medium P mismatch:
  - Generator trips on over frequency
- At low P or negative Q: Trip on Over frequency or Over voltage



Example Field Results – Inverter Islanding



- 40% power mismatch (Load > Gen)
- Voltage collapses
- Frequency pushed out of range

Ref: M. Ross et. al., “Photovoltaic Inverter characterization Testing on a Physical Distribution System”, IEEE PES General Meeting, San Diego CA, July 2012

Summary

- Anti-islanding with multiple inverters and synchronous generators:
  - Both active and reactive power mismatches are determinant
  - Include protection schemes based on large reactive power excursion as part of intertie protection at synchronous generator
  - Reactive power surplus in the islanded area results in fast trip
- Inverter domination: frequency changes depend on reactive power mismatch (excess Q, Freq goes down)
- UL certified single inverter unit even at low power mismatch would trip fast enough, based on active anti-islanding methods

Thanks

- Questions?

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