Customer-driven microgrids and enabling technologies

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Outline of presentation

- State of electricity infrastructure in US
- Smart Grid Initiative (SGI)
- Customer-driven microgrid (CDM)
  - Philosophy
  - Relation to SGI
- Architectural aspects of a CDM
  - A basic building block of the CDM
- Operational aspects of a CDM
- A path forward

State of electricity infrastructure in US

- Electricity demand to grow from ~3800 BkWh to ~4750 BkWh in next 2 decades
- 260 GW of new generation to supply this demand growth and to replace retirements (~30 GW) planned
  - ~53% from natural gas
  - ~24% from renewables/others
  - ~18% from coal
  - ~5% from nuclear

Source: Energy Information Administration. "Annual energy outlook 2009 with projections to 2030. [Online] {Available} http://www.eia.doe.gov/oiaf/aeo/electricity.html (Sep 2009)

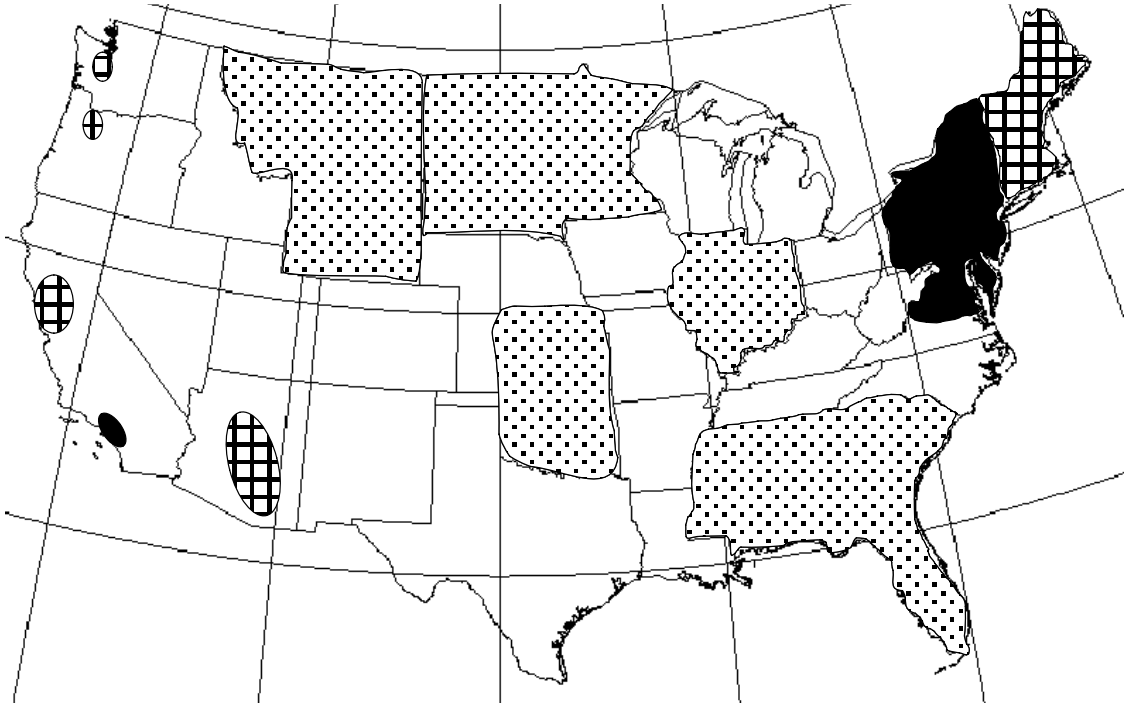
State of electricity infrastructure in US

- Transmission system is "fragmented, inadequate," and unable to maximize renewable resources spread across the US [1]
  - US DOE projections of 20% Wind by 2030 relies on $60B transmission investments [2]
  - Finding sites for new grid infrastructure - a major obstacle for expanding renewables' reach [3]
- Analysts expect $300B from 2009-2030 to modernize the grid [1],[2]
- Deterred by regulatory barriers vis-à-vis planning, siting, and cost allocation [1]
  - Particularly, interstate transmission regulations
  - Only 14 interstate transmission lines built since 2000 [1]

[1] (Mar 09) B. L. Dorgan. Democratic Policy Committee. "The case for a 21st century electricity transmission system" [Online] {Available} http://dpc.senate.gov/dpcdoc.cfm?doc_name=fs-111-1-34 (Oct 2009)
[2] (Nov 08) M. W. Chupka, R. Earle, P. Fox-Penner, R. Hledik, "Transforming America's power industry: The investment challenge 2010-2030" [Online] {Available} http://www.brattle.com/_documents/UploadLibrary/Upload725.pdf (Oct 2009)
[3] (Sep 09) I. Talley. "Interior department to approve seven renewable-energy projets" [Online] {Available} http://online.wsj.com/article/SB125434790460153875.html (Oct 2009)

State of electricity infrastructure in US

Nature of crisis in transmission system



critical congestion area where near term action is essential

congestion area of concern where additional analysis and information is required

conditional congestion areas where additional generation will introduce major problems

Source: US Dept. of Energy "National electric transmission congestion study," [Online] Available: http://nietc.anl.gov/documents/docs/Congestion_Study_2006-9MB.pdf (Sep 2009)

State of electricity infrastructure in the US

CONJECTURE

- A more congested transmission system, due to disproportional load and transmission assets growth rates, may be simply unable to deliver the demand due to severely inflated prices of congestion and lack of infrastructure
- This situation represents a compromise of security and reliability of the electric grid in the US

The Smart Grid Initiative

- Title XIII of Energy Independence and Security Act of 2007
- US policy for modernization of electricity T&D infrastructure
- Smart grid defined by following characteristics [1]:
  - Self-healing from power disturbance events
  - ***Enabling active participation by consumers in demand response***
  - Operating resiliently against physical and cyber attack
  - ***Providing power quality for 21st century needs***
  - ***Accommodating all generation and storage options***
  - Enabling new products, services, and markets
  - ***Optimizing assets and operating efficiently***

[1] US DoE, Office of electricity delivery and energy reliability. "Smart Grid" {Online] {Available}: http://www.oe.energy.gov/smartgrid.htm (Oct 2006)

http://www.oe.energy.gov/DocumentsandMedia/smartgrid_diagram.pdf

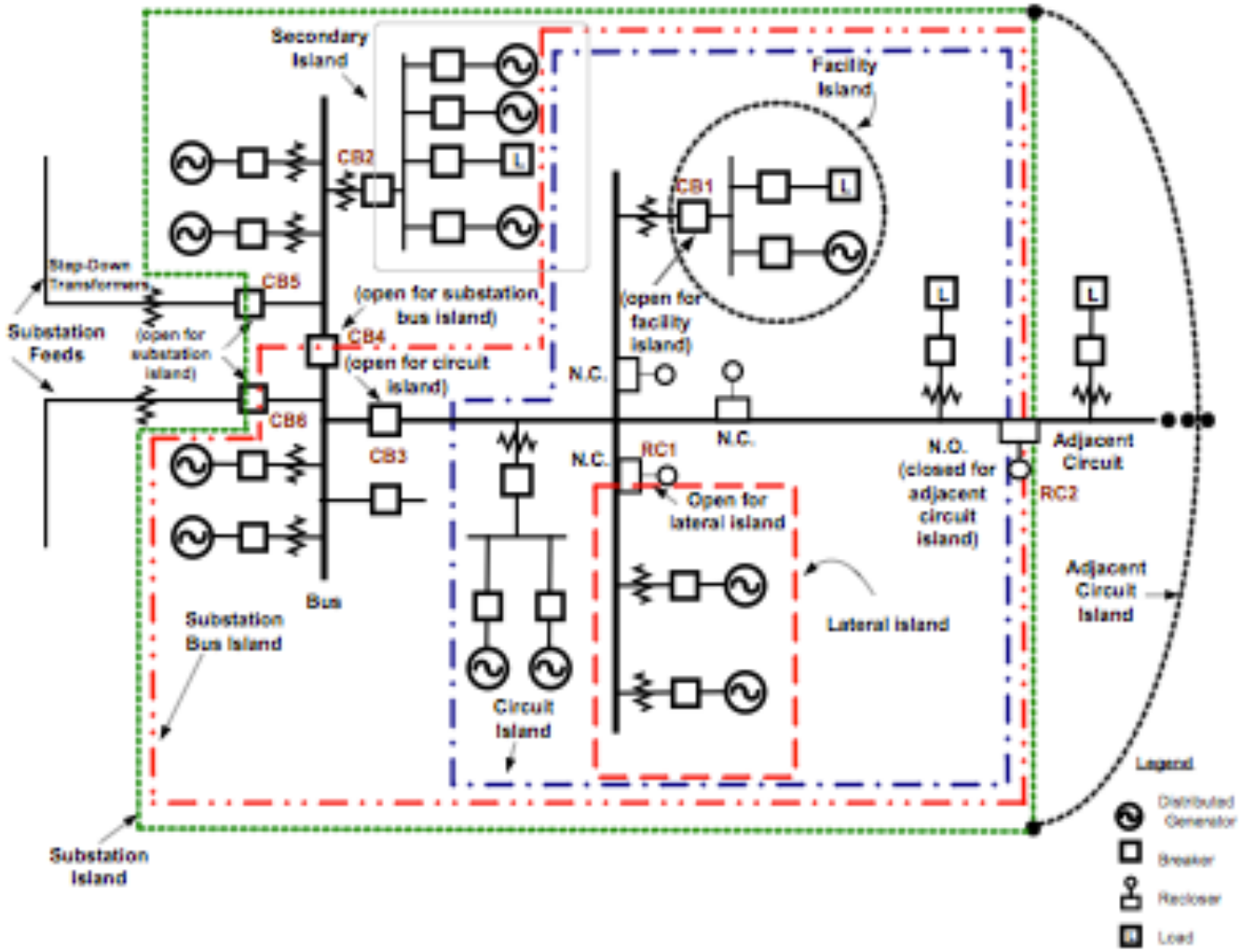
Smart Grid and distribution engineering

- Smart Grid more likely to impact distribution than transmission systems in the US
- Smart meter installation is gaining traction
- Energy-aware buildings
- Home energy management
  - Google Power Meter ™ http://www.google.org/powermeter/
- Goals of the Smart Grid and Microgrids are aligned
- Utilities are beginning to see the opportunities of microgrids [1]
- From 2009-2015, over 3.1GW of new microgrids to come online worldwide [1]
  - ~75% of that will be in North America, representing $5.8 billion of the market [1]
- "The goals of both the Smart Grid and the microgrid are the same: *to maximize generation assets through embedded intelligence while dramatically boosting efficiencies, thereby minimizing costs.*"(a direct quote from [1])

[1] P.Asmus, "Microgrids: Why some utilities see a threat where others see opportunity," SmartGridNews, Oct 2009, [Online] {Available} http://www.smartgridnews.com/artman/publish/Delivery_Microgrids_News/Microgrids-Why-Some-Utilities-See-a-Threat-and-Others-See-Opportunity-1327.html (Nov 2009)

What is a microgrid?

- An autonomous self-sustainable subset of an area electric power system that can operate independent of the grid or in connection with the grid
- Applications in civilian and military milieus



Source: IEEE P1547.4 "Draft Guide for Design, Operation and Integration of Distributed Resource Island Systems with Electric Power Systems,," Work Group web site http://grouper.ieee.org/groups/scc21/1547.4/private/stddrafts.html

Some characteristics of the microgrid

- Designed to enhance reliability to loads
- Provides a panoply of ancillary services
- Potential for economic incentives
- May incorporate renewable energy sources
  - Avenue for meeting renewable portfolio standards (RPS)
- Types: remote, industrial, utility-owned
- **New paradigm: customer-driven microgrids**

Customer-driven microgrids

- Enable active participation of consumers in demand response
- Advances the state-of-the-art in interactions between customers and grid
  - Governed by common rules
- Trading real power and reactive power with grid
  - Additionally, other ancillary services provided on-demand
- Islanded operation for reliability and economics
- Possible path for projected high penetration of PVs in distribution systems
- Constituents possess enabling technologies

Customer-driven microgrids

- Two modes of operation: grid tied and isolated
- Grid tied mode:
  - CDM participates as a single entity in interactions with grid
  - A central entity (agent) arbitrates within the CDM and with the grid
- In isolated mode:
  - Central entity determines mix of loads and generation in CDM
  - Issues signals for load shedding or generation services
- In either mode, central entity removes unwilling participants from its purview

Customer-driven microgrids

- Customer Driven Microgrid (CDM) is formed by contractual agreement among small utility customers
- Most members of a CDM will have their own distributed generation
- CDM will be formed to minimize required electrical system modifications
- CDM will be operated to maximize the benefits to the CDM members
- CDM will use market mechanisms to develop set points for native generation and loads
- CDM will be able to operate in islanded mode for *extended periods* as in the case of a utility grid outage

Topology of a CDM

- The CDM has the following characteristics:
  - single-phase, low voltage (120 V)
  - based on existing distribution architecture
  - Point of common coupling (PCC) established at low voltage terminals of existing distribution transformer
    - Existing utility customer drops from a single distribution transformer are connected to CDM bus
    - CDM bus is connected to the distribution transformer by a PCC breaker
  - Customers have PV-sourced DG (assumption)
  - Basic building block of CDM is the '*smart inverter*' (SI)

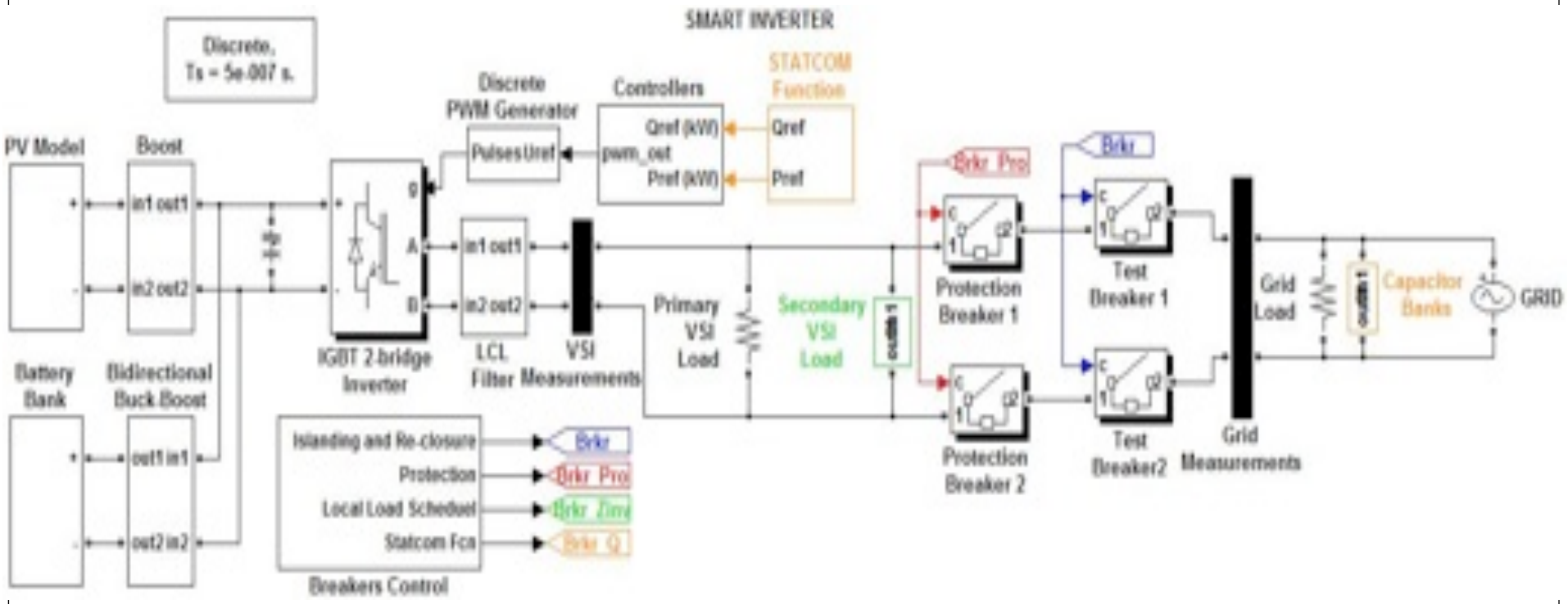
Distribution System Characteristics

- The distribution system used in CDM model testing has the following characteristics:
  - a weak distribution system with 2000 A fault current available at 120 V terminals of distribution transformer
  - customer drops 4/0 AWG Al triplex buried conductor with 0.100-j0.046 Ω/1000 feet impedance and 205 A capacity
  - drops from distribution transformer to the SIs are 90 feet long for half of the SIs and 160 feet long for the others
  - 20.1 KVA, 0.99 lagging power factor load external to the CDM connected at distribution transformer terminals

Smart Inverter characteristics

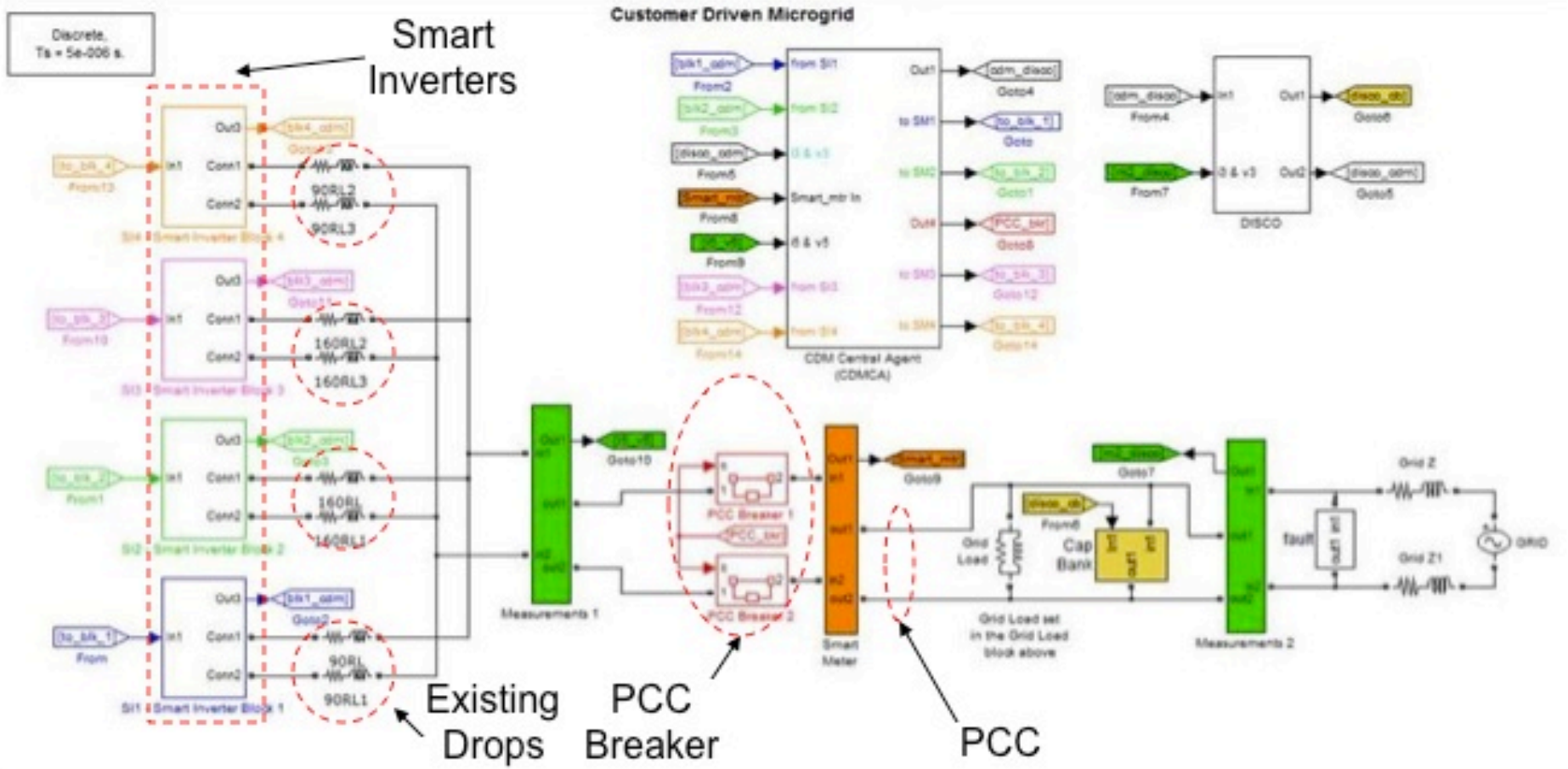
- Voltage source inverter rated at 5 kVA 1-phase operating at 120 V 60 Hz AC
- Current control for grid connected mode; and voltage control for islanded mode
- Enables efficient interconnection and economical operation for dispersed PV-based DG installations to utility grid
- Enabling technologies and paradigms: smart metering, incorporation of smart appliances, provision of pricing information to consumers, provision of some control options to consumer, and information exchange on a fully networked system enabled by massively deployed sensors

A smart inverter for the Smart Grid



R. Carnieletto, S. Suryanarayanan, M. G. Simões, F. A. Farret, "A multifunctional single-phase voltage source inverter in perspective of the smart grid initiative," in Proc. 2009 IEEE Industry Applications Society Annual Conference, Houston, TX, Oct. 2009, pp. 1-7.
R. Carnieletto, D. Brandaõ, S. Suryanarayanan, M. G. Simões, F. A. Farret, "A multifunctional single-phase voltage source inverter in perspective of the smart grid initiative," in press, IEEE Industry Applications Magazine, Jun. 2010.

Customer-driven microgrid (CDM)



S. Suryanarayanan, R. K. Rietz, J. Mitra, "A framework for energy management in customer-driven microgrids," accepted, 2010 IEEE Power & Energy Society (PES) General Meeting, Minneapolis, MN, Jul 2010.

Customer Driven Microgrid Structure

- CDM incorporates four Smart Inverters (SIs)
- One SI per dwelling unit or small business (Unit)
- Each unit has native loads (SI Loads) and metering
- Each unit has enabling technologies – smart meter, PV with energy storage (Pb-acid batteries and interface), minimally redundant communication network
- CDM has a CDM Central Agent (CDMCA)
  - performs market operations for CDM
  - provides set points and operational modes to SIs based on market operations
  - single point of interface with agent for utility grid

Customer Driven Microgrid Operation

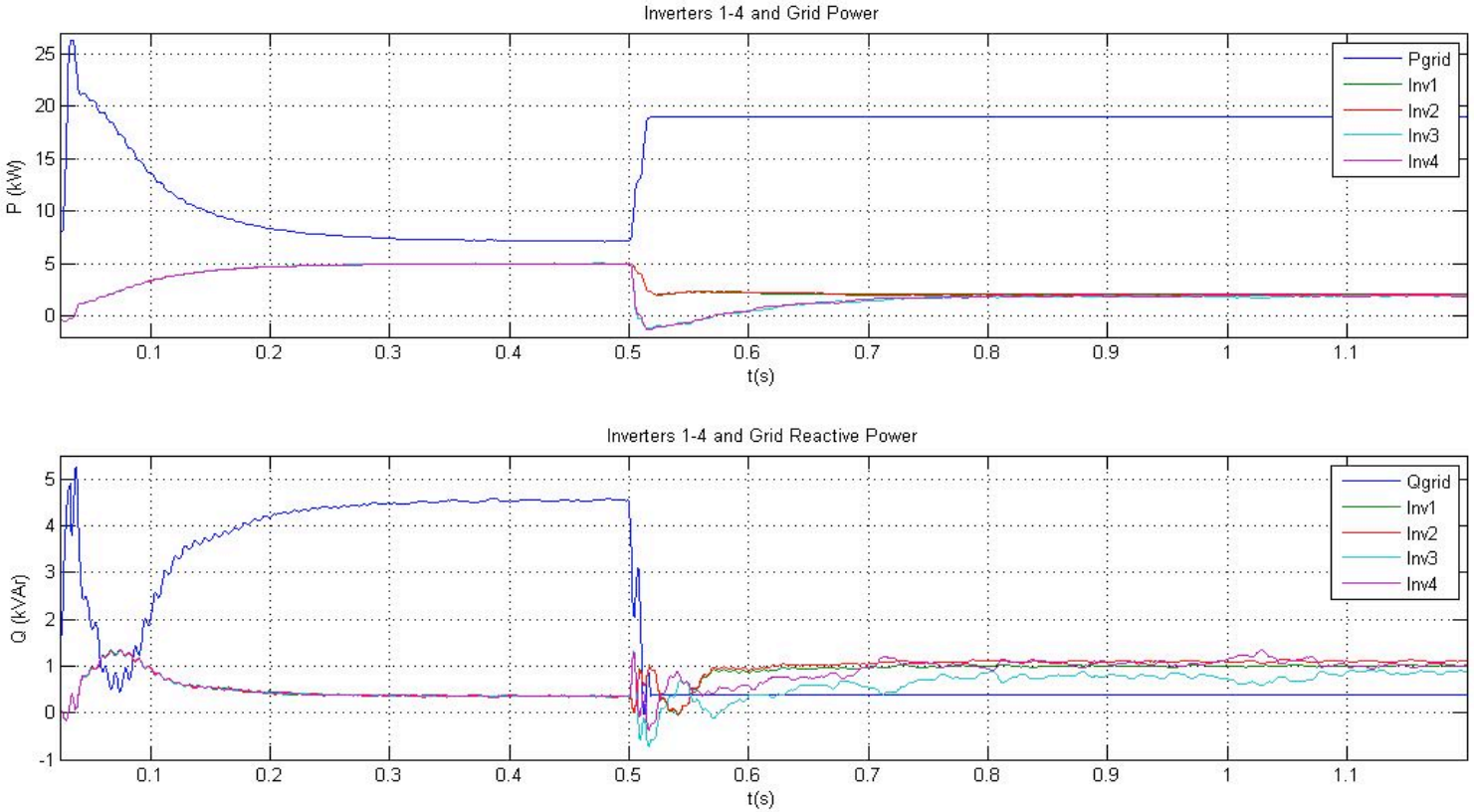
- The CDM and Units can function in four modes:
  - Units connected to CDM bus, CDM bus connected to grid (On Grid)
  - Units Connected to CDM bus, CDM bus disconnected from grid (Islanded)
  - all Units disconnected from CDM bus (Individually Islanded)
  - Some but not all units connected to CDM bus, CDM bus On Grid or Islanded (Hybrid)
- SIs retain capabilities developed for the single SI
  - can provide power and reactive power based on set points
  - Can individually operate in STATCOM mode to provide voltage support at the PCC

Customer Driven Microgrid Operation

- The set points from the CDMCA to the SIs currently can be established by:
  - auction
  - a central CDM STATCOM function within the CDMCA
  - hard coded set points

An example

- 4 smart inverter CDM transitioning from grid connected STATCOM mode to islanded mode:



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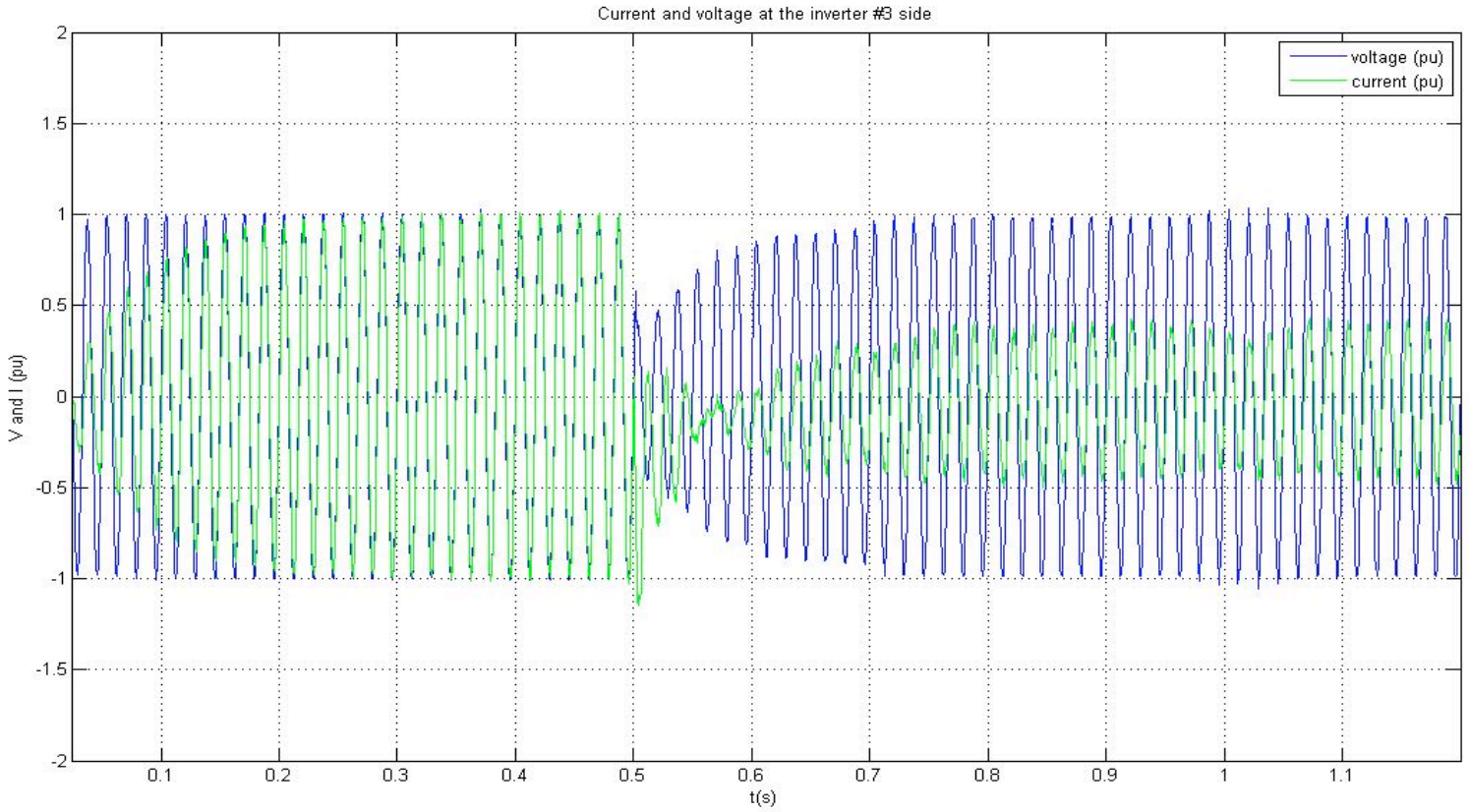

A path forward

- Investigate prototype of SI being developed in Colorado School of Mines for variety of '*what-if*' scenarios
- Investigate CDM architectures for additional functionalities
- Implement a Nash equilibrium based operational methodology for maximizing the utility of the CDM

Thank you