Micro-grid

Mid-term Project

ECE421/521

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Micro-grid Topics

- History and basic theory
- State of the art designs and products
- Technical and social impacts
- Challenges and R&D
- Applications and demonstrations
- Anti-islanding detection method

Micro-grid

History and Basic Theory

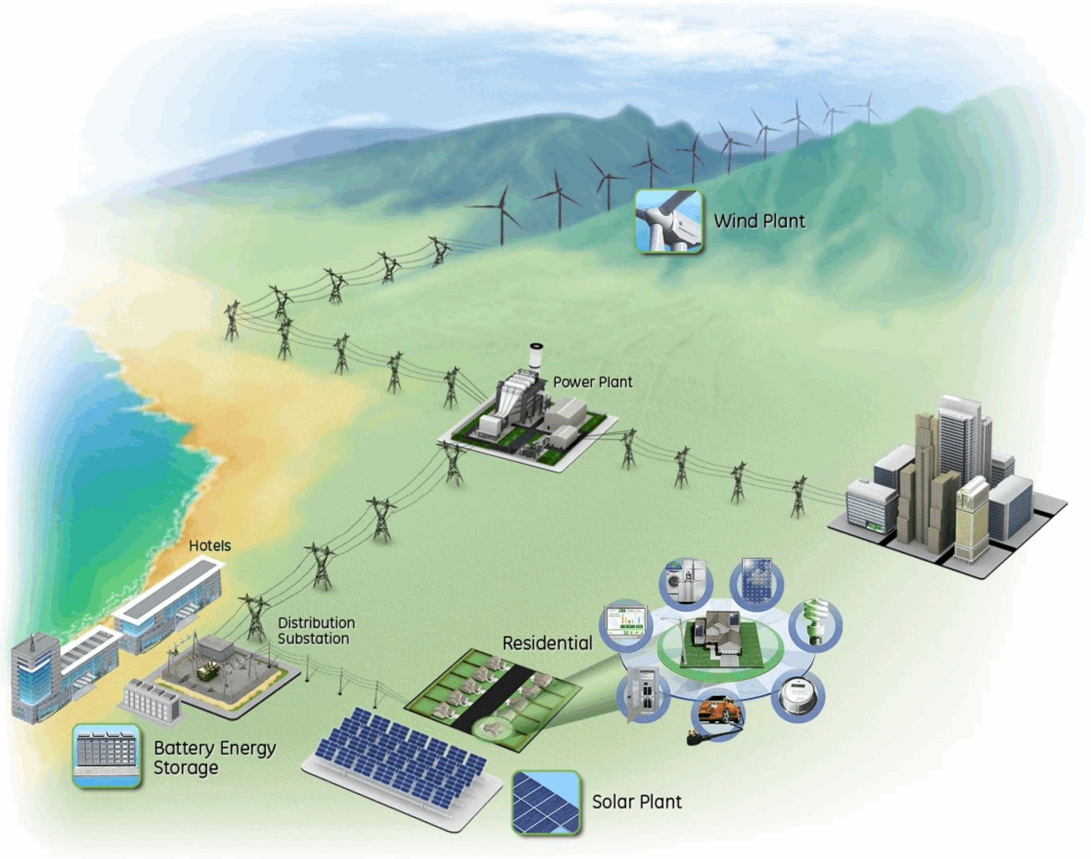
Definition of Micro-grid

- The micro-grid concept is a natural evolution of distributed resources that may be used to serve energy customers.
- It is a small-scale power supply network that is designed to provide power for a small community.
- It enables local power generation for local loads.
- It comprises of various small power generation sources that makes it highly flexible and efficient.

What is a Micro-Grid?

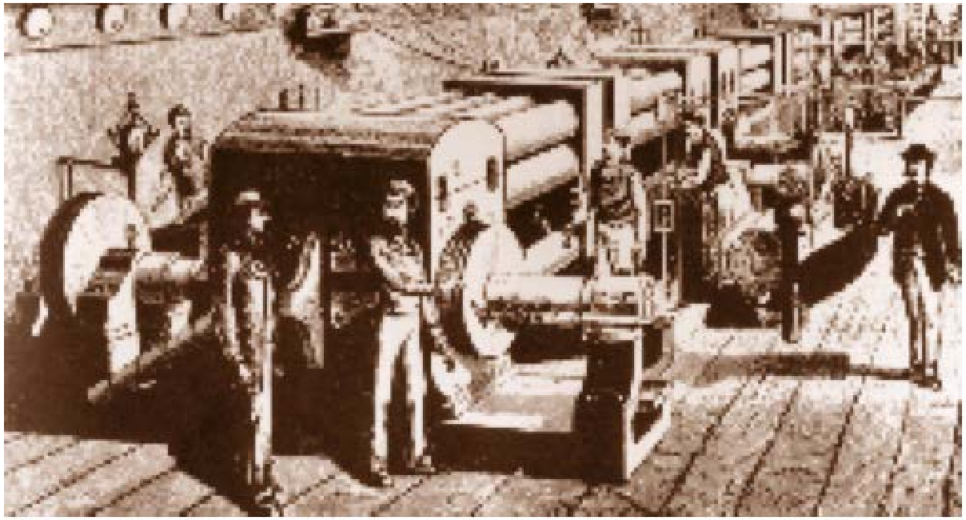
Example of a Micro-grid creating a power quality park.

- Renewable energy sources.
- Conventional distributed generators.



History of Micro-grid

- The concept of Micro-grid it is a modern of reformulation of the origins of the power systems.
- The early power industry(1880-1910) had already implemented micro-grid architectures.



⇨ Problem?

Edison`s Pearl Street Statin in New York City in 1882 serving as a small part of the financial district.

The demise of early Micro-grids

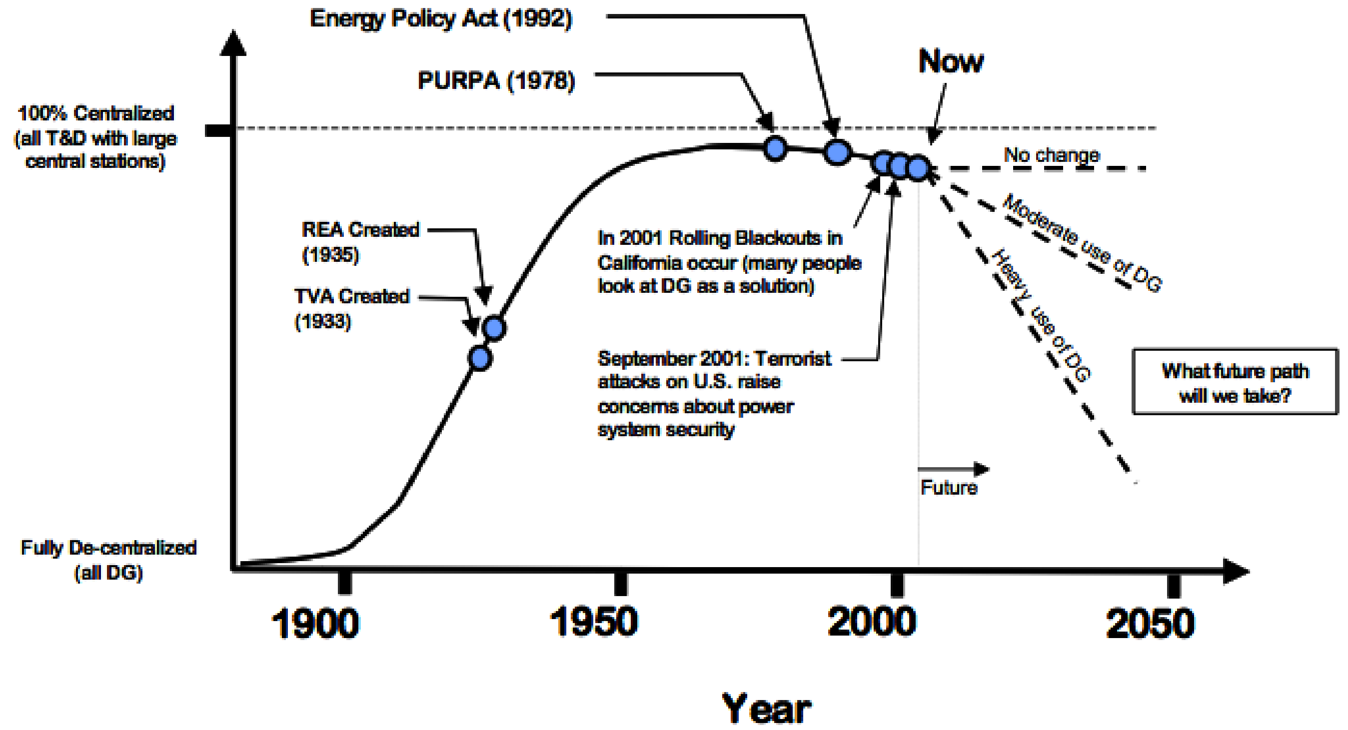
Problem Many early micro-grids were not particularly reliable because only one power plant supplied all of the energy.

Solution Interconnecting some systems to improve reliability.

Technological and economical factors:

- Developments of large-scale hydro-electric resources located significant distances from urban load centers required the utilization of transmission lines.
- Newly developed transmission and distribution networks.
  (150 KV transmission voltage)
- Increasing use of standardized 60-Hz frequency.
- Steam and hydroelectric power plants had significant economies of scale.

- **Government also plays a role.**



Degree of centralization of the US power system.

State-of-art designs/products

Micro-grid service area

- ***Single-Customer Micro-Grid***
- ***Radial Customer Group***
- ***Full Substation -Based Micro-Grid***
- ***Micro-Grids Operating with Multiple Dispersed Resources***
- ***Adaptable Micro-Grid That Breaks Into Sub-Grids***
- ***Networked Primary Micro-Grid***

Micro-grid service area

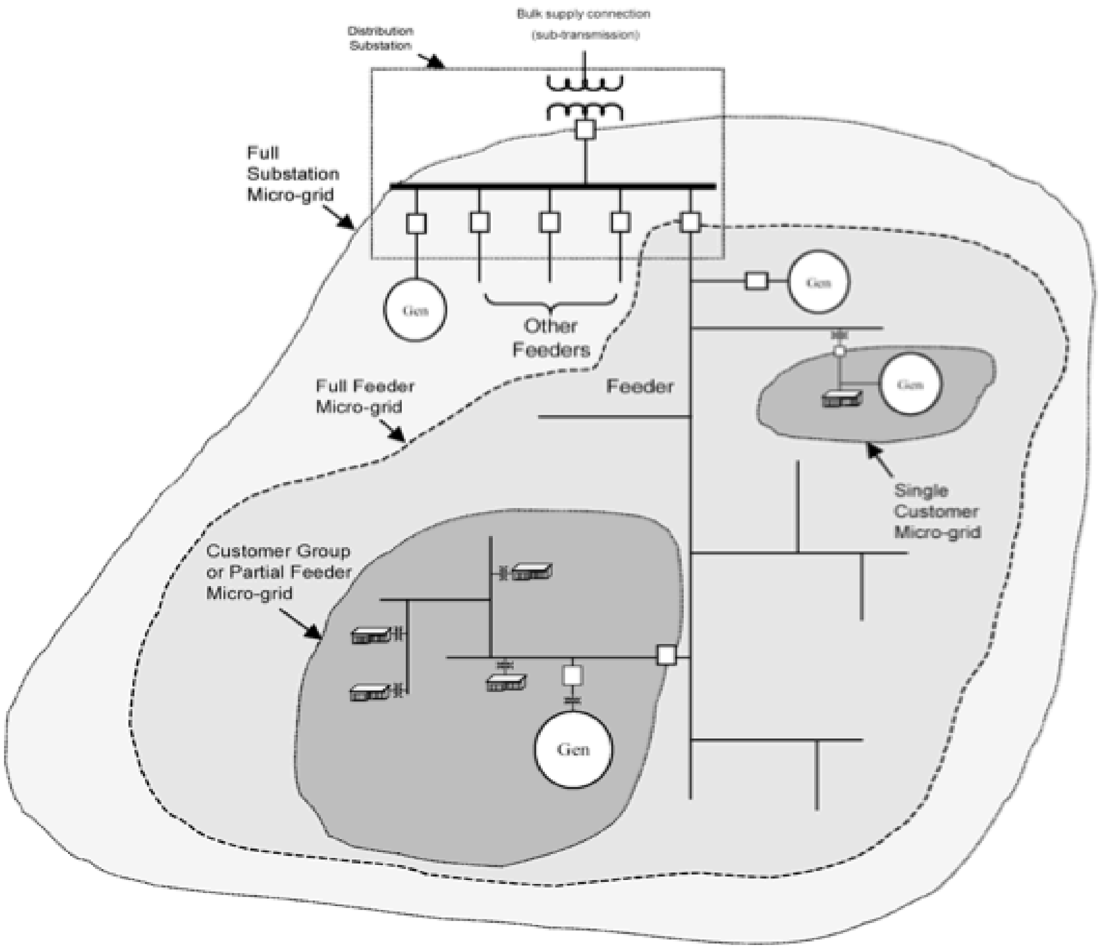


Figure 2-1
Examples of Micro-Grids on a Radial Distribution System – From Single Customer Up to Entire Substation

Micro-grid service area

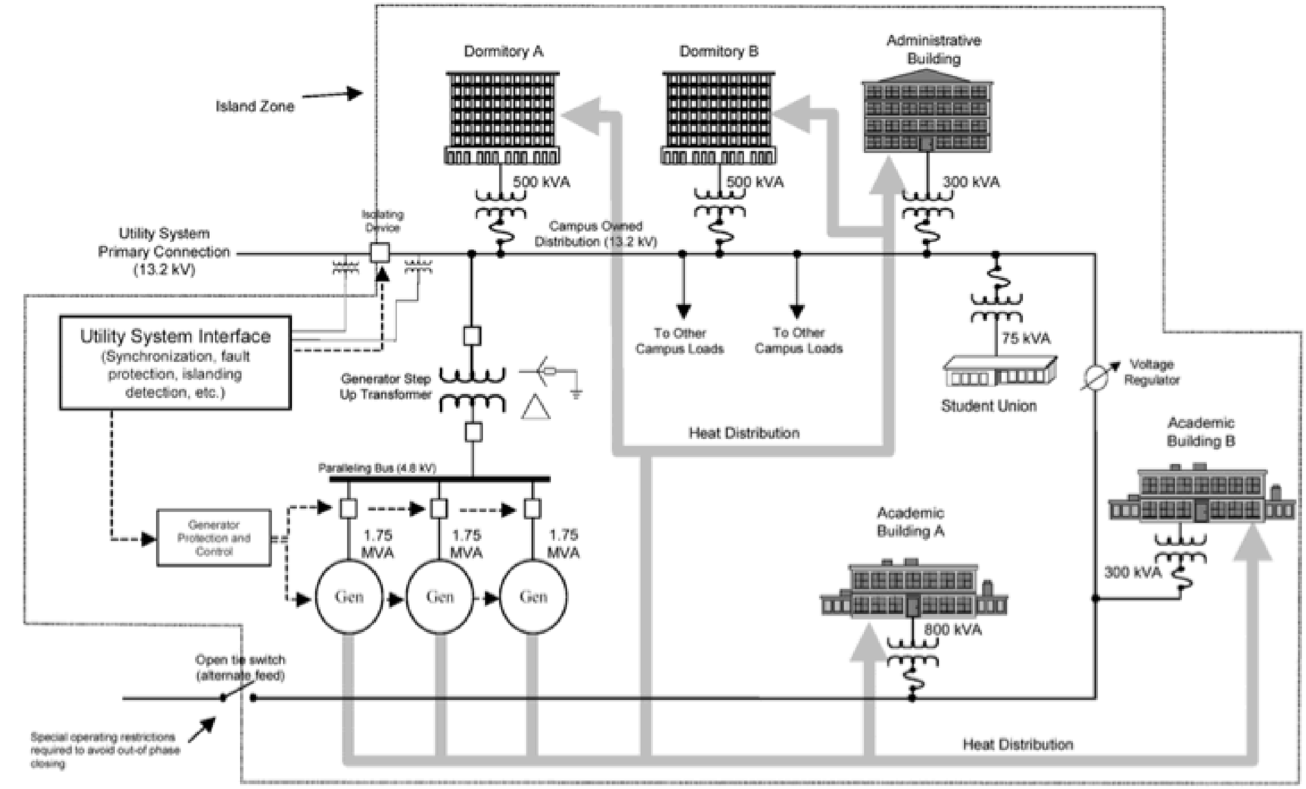


Figure 2-6
Example of a Radial Business Park or Campus -Based Micro-Grid

Micro-Grids Operating with Multiple Dispersed Resources

There is considerable interest in developing micro-grids with multiple generators at widely dispersed locations and with a variety of generation types, including various combinations of solar, wind, fuel cell, reciprocating engine,

combustion turbines, and energy-storage devices.

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Adaptable Micro-Grid That Breaks Into Sub-Grids

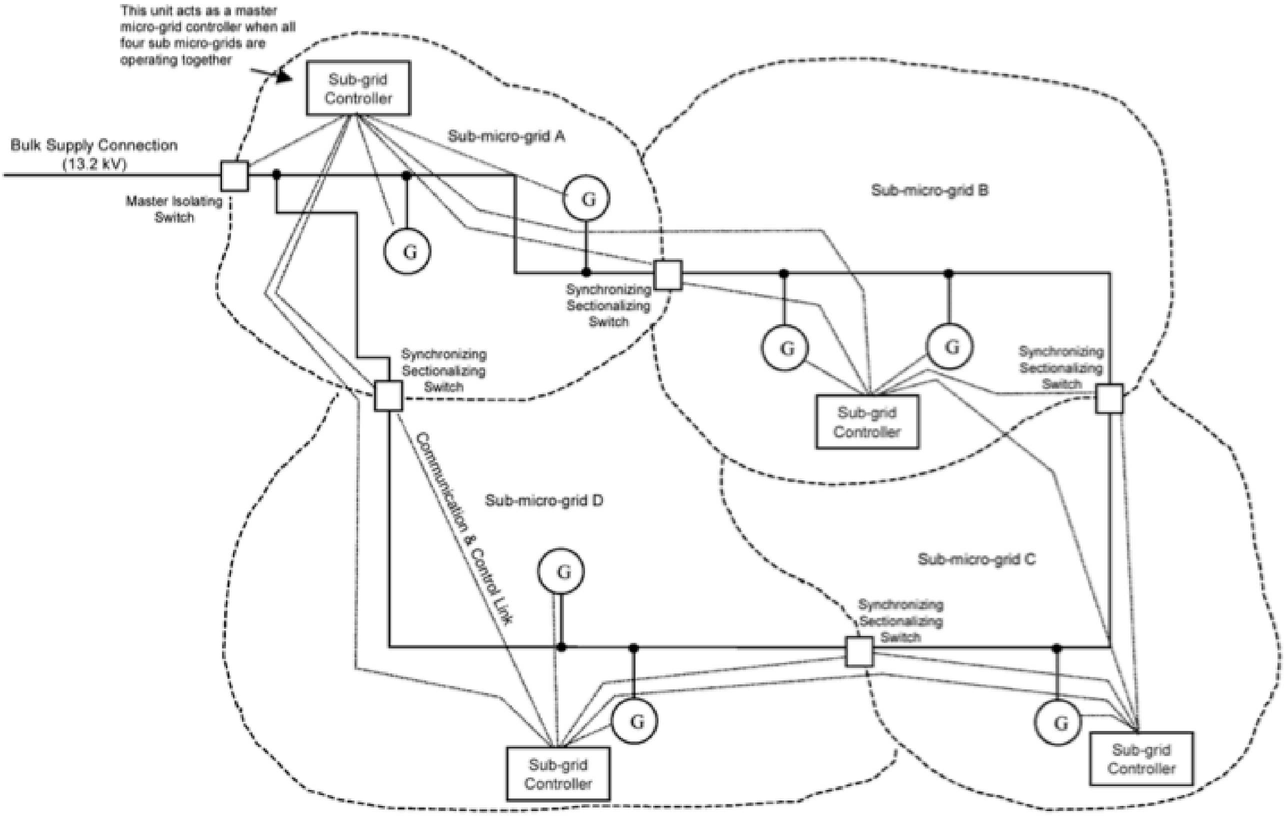


Figure 2-9
A Micro-Grid Configured to Break Apart into Numerous Sub-Grids

Networked Primary Micro-Grid

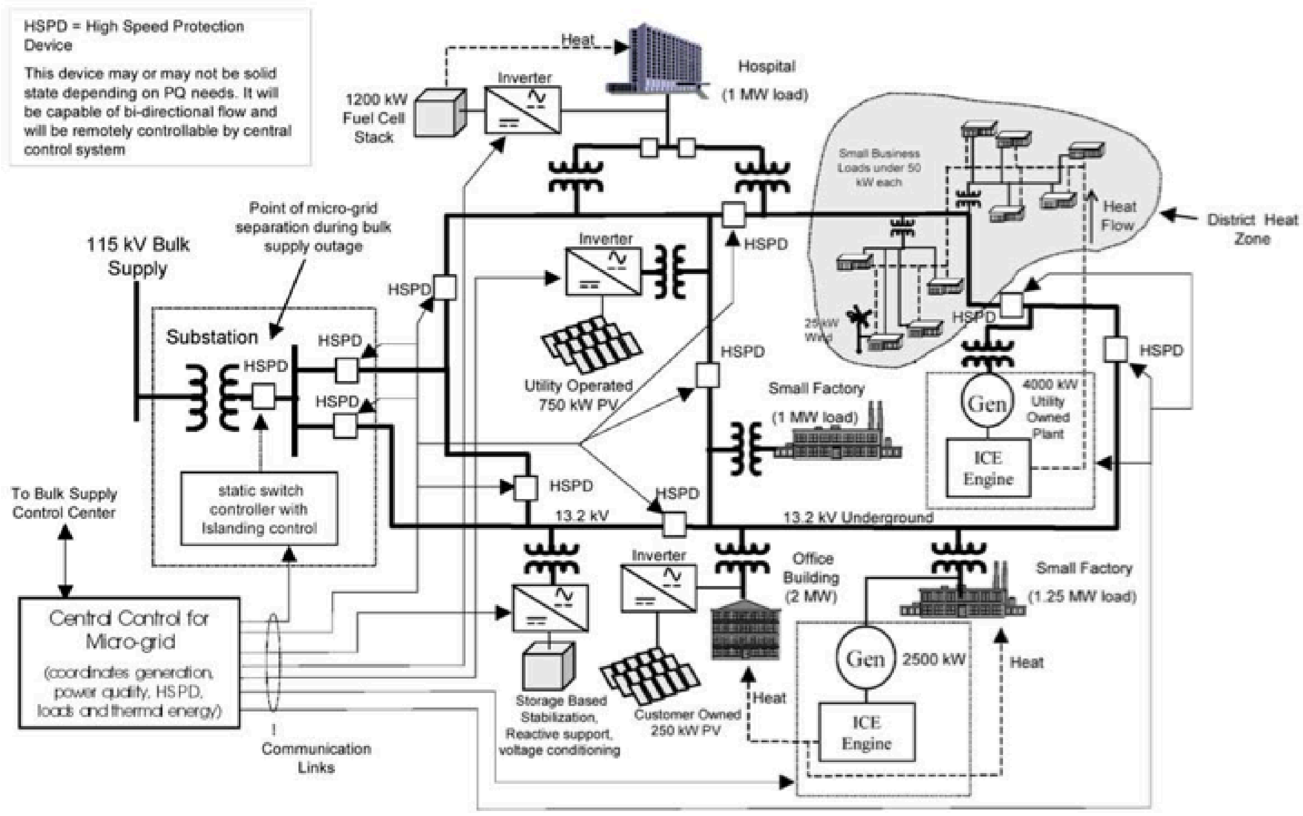


Figure 2-10
Networked Primary-Based Micro-Grid Adapted for Power Quality Business Park Application

AC versus DC Micro-Grids

DC in Micro-Grids

- Today, there is much interest in the possibility of revisiting DC as a means for distributing power on such systems.

DC in Micro-Grids

- Many distributed generation sources generates their energy as DC sources
- Avoid synchronization issues
- Avoid the reactive voltage drop
- Many loads can operate satisfactorily from DC power
- Improved inverters and power electronics allow DC power to be converted easily and efficiently to different voltage levels and to AC power.
- ....etc

DC in Micro-Grids

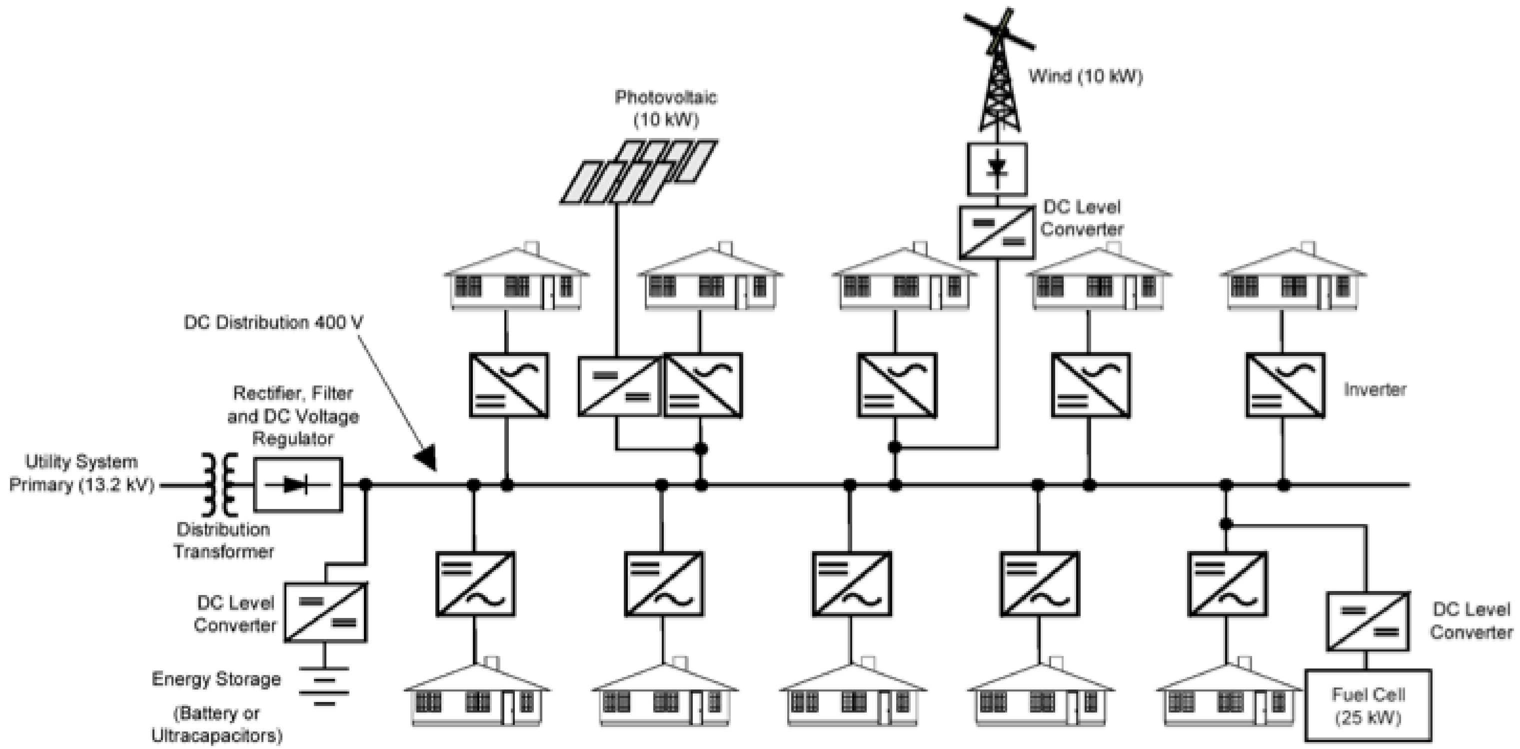
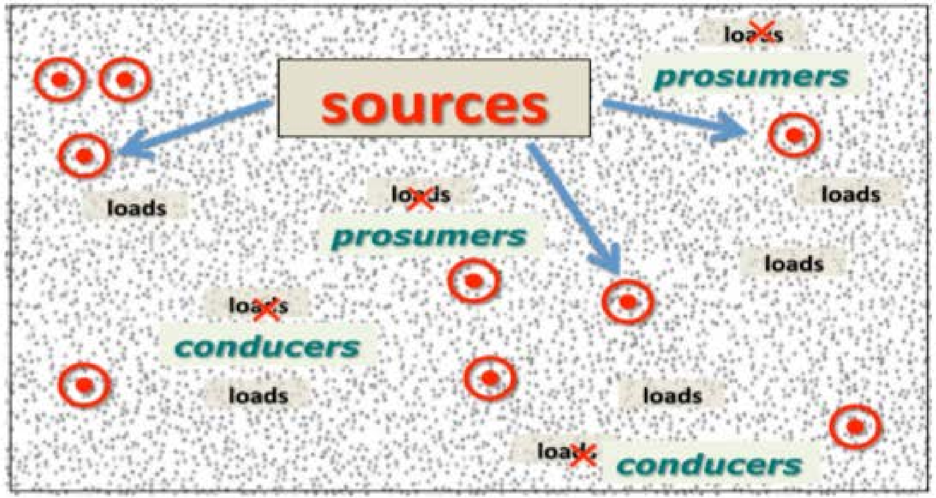


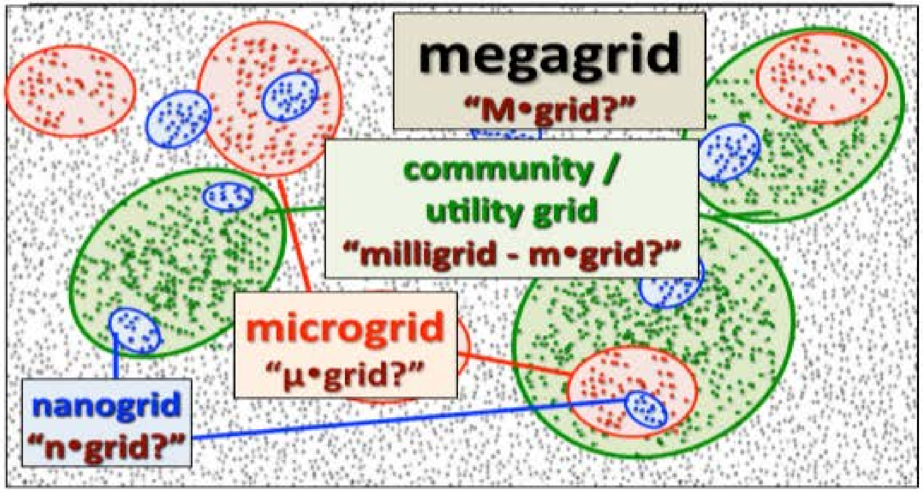
Figure 2-14
A Simple DC Micro-Grid Employing Renewable and Fuel Cell Sources

Micro-grid

Impact of Micro-grid

Impact of micro-grid

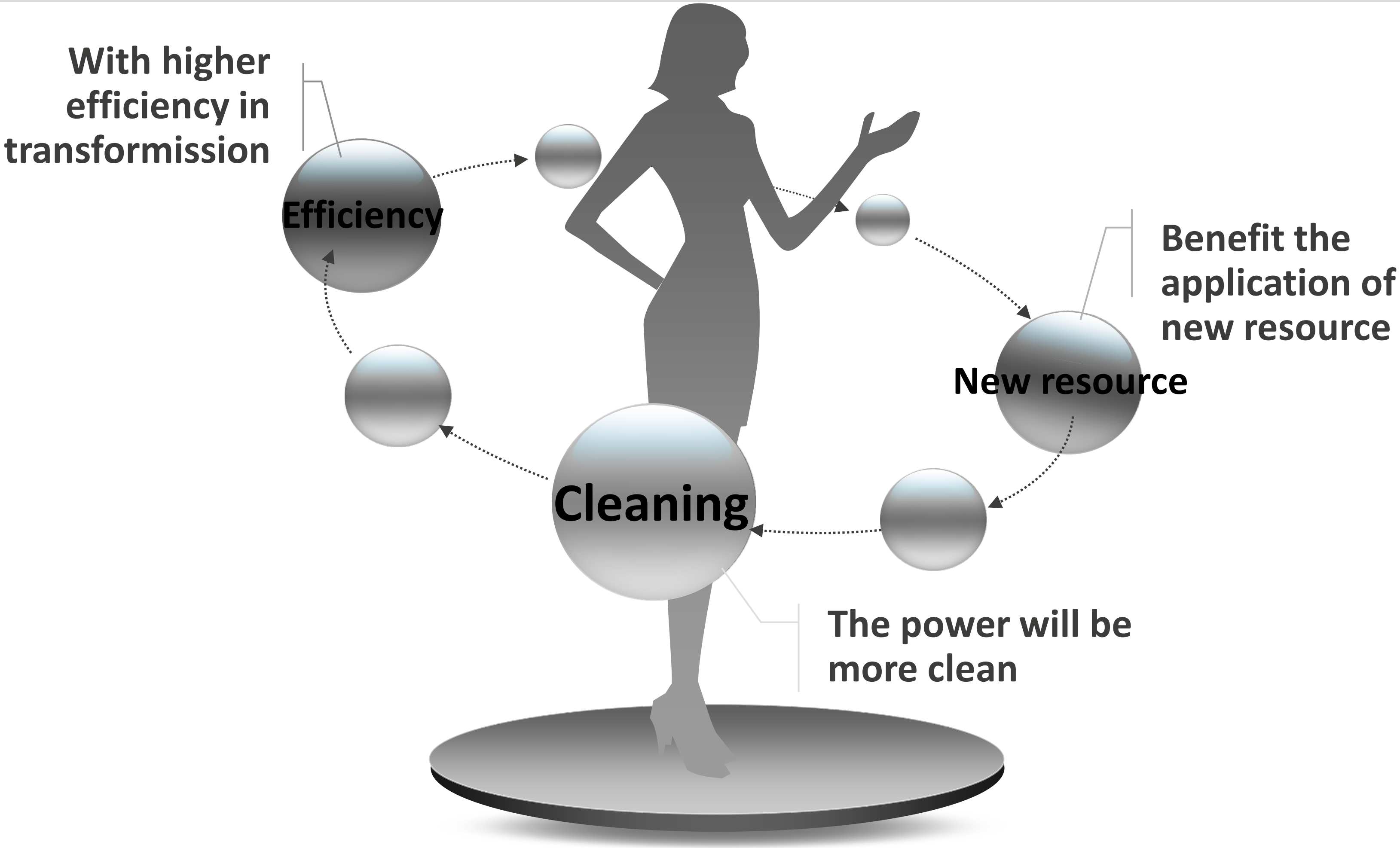




Traditional Large Grid

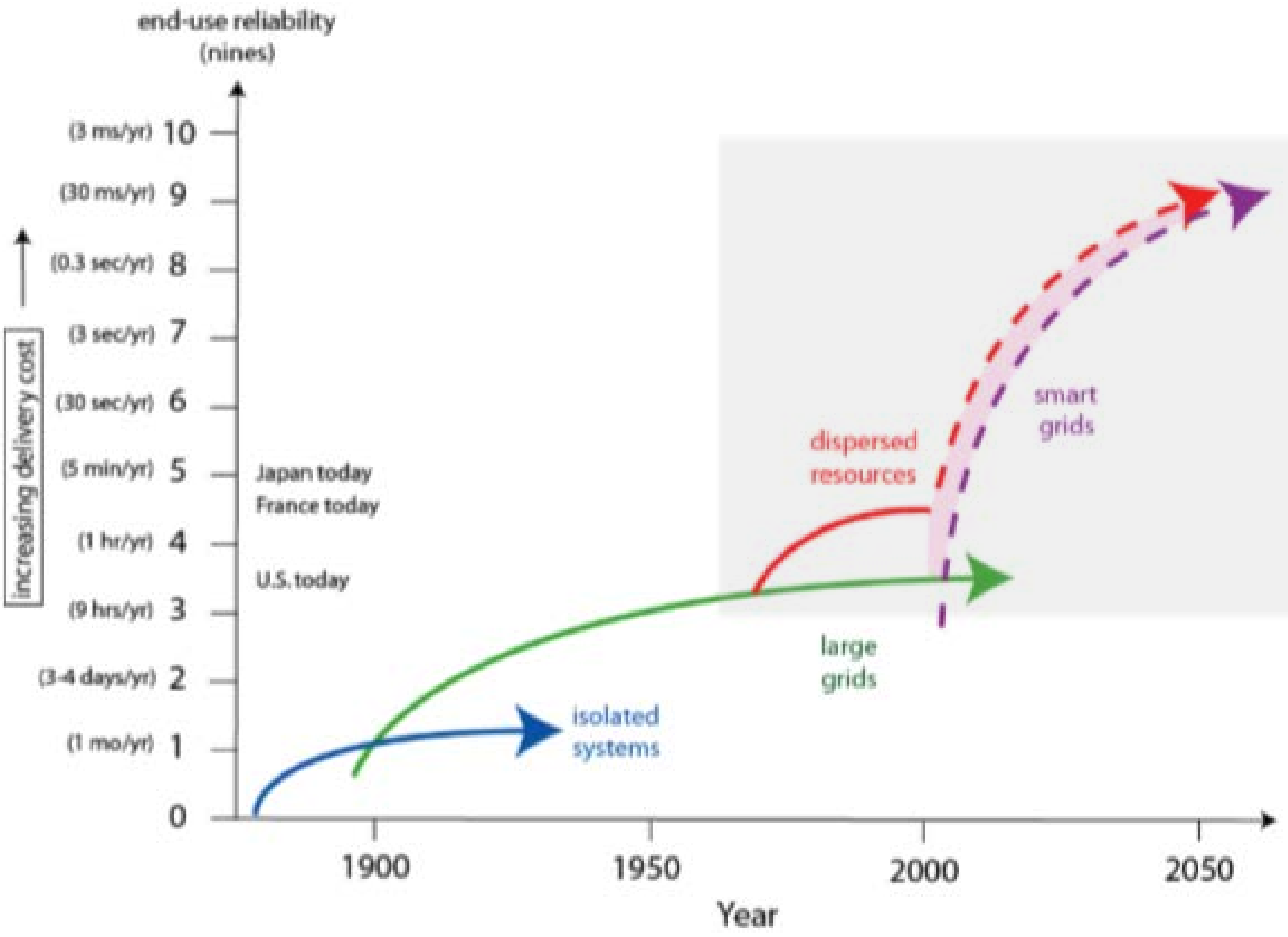
An alternative new grid

Impact of micro-grid

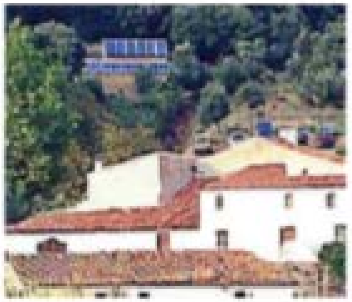


μgrids is rising with several advantages

Rising new type of grid



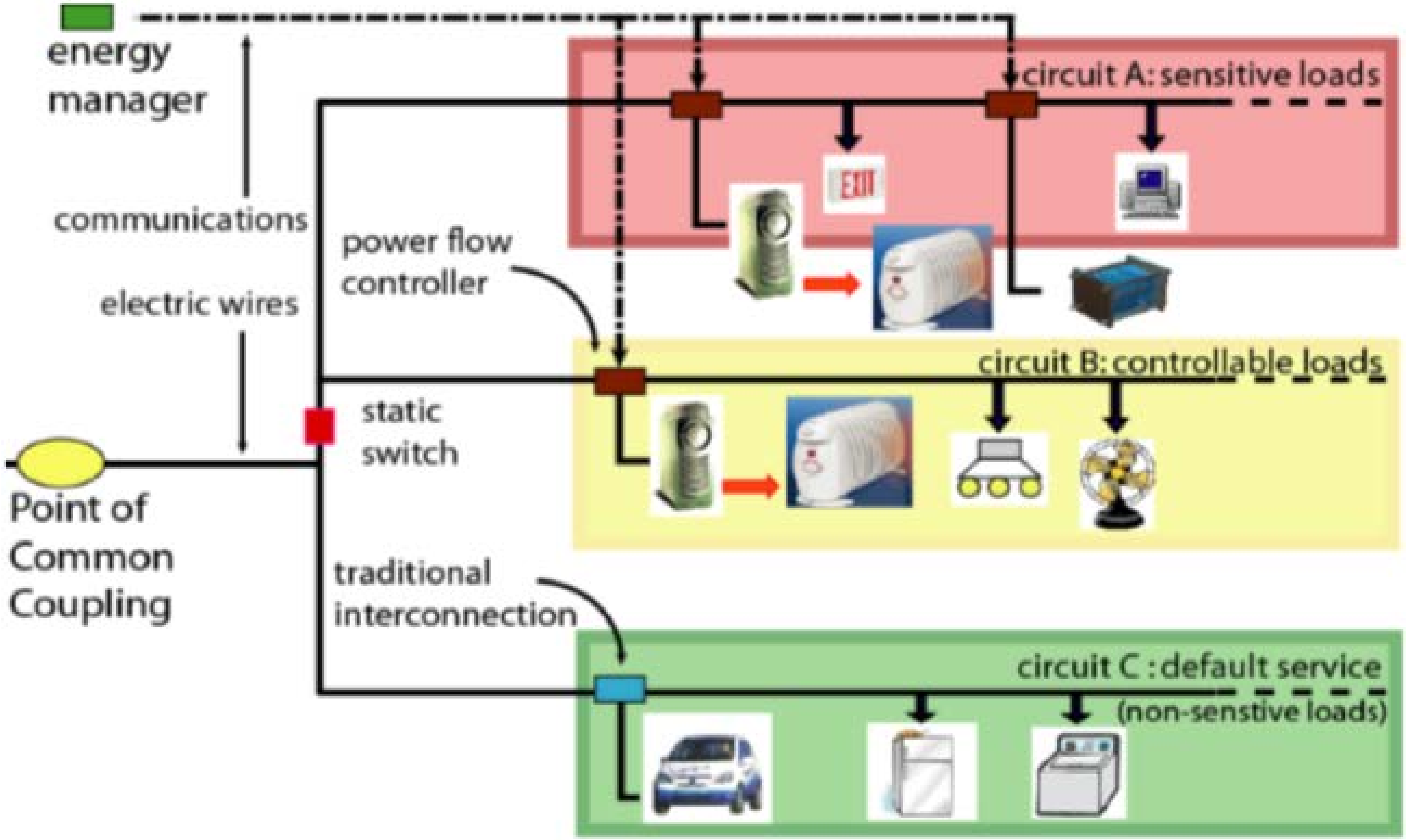
Widely applied in developed world



Duration	Since 2003
Pilot profile	▪ DG capacity el. — 22 kWp ▪ DG Technology — PV, battery, diesel-gen ▪ Classification — rural, off-grid ▪ Grid Operator — CRES
Tasks	▪ Microgrid operation ▪ Multi master control method for improvement of available peak power and system reliability

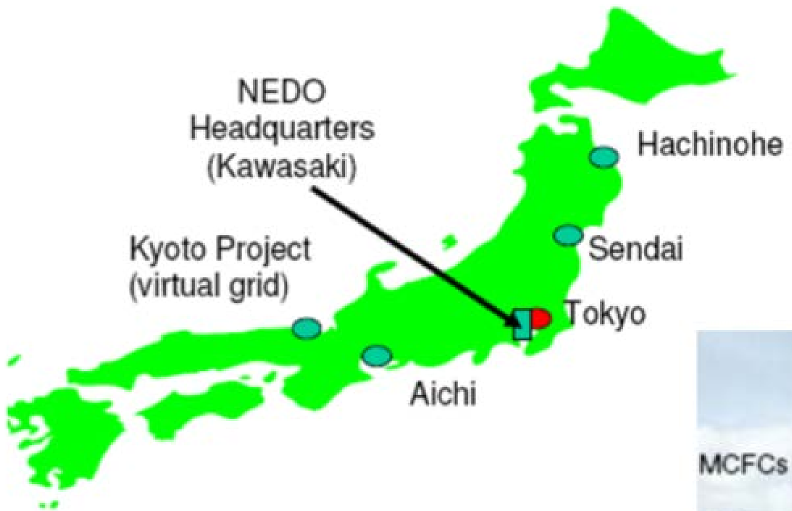
The Kythnos Microgrid

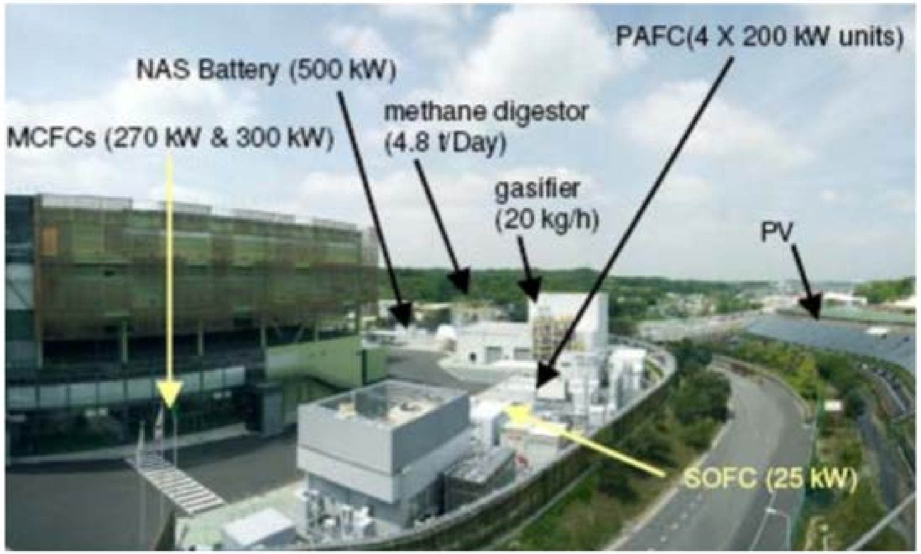
Widely applied in developed world



Schematic of CERTS Microgrid

Widely applied in developed world

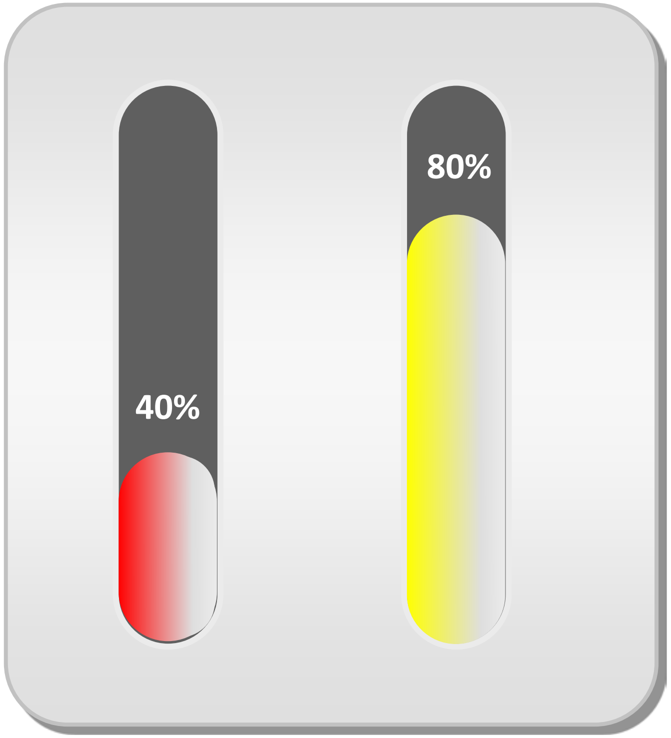




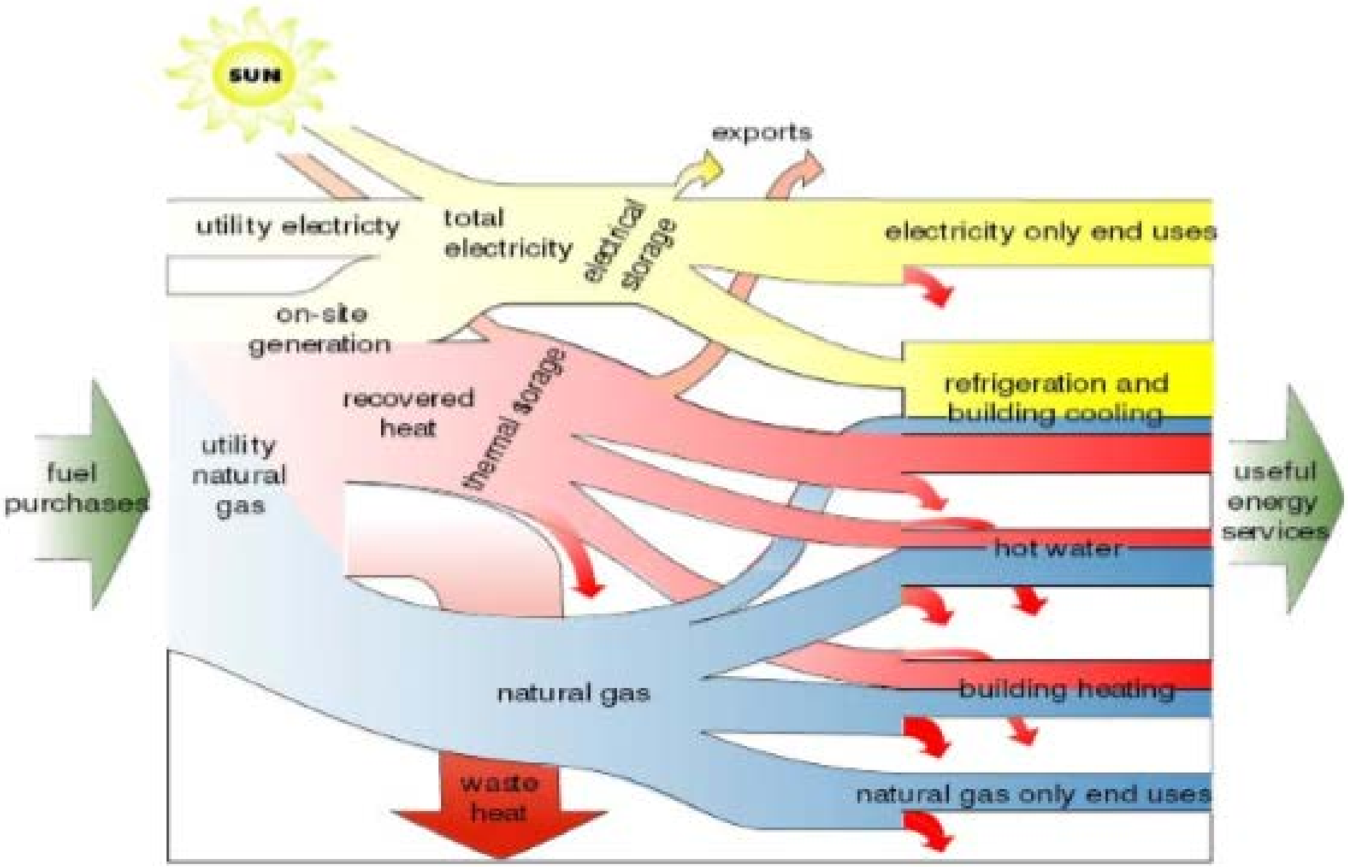
NEDO Microgrid

With Higher Efficient

- Take China as an example:
- Nowadays: 33% rate without application of µgrids, 40% for Supercritical coal-fired thermal power units
- Future(if apply µgrids):can be partially enhanced to 80% for coal-fired units



Support the development of new source



Cleaner Power

Traditional way

- Centralized
- High power
- Long transmission with more losses
- Usually using coal-fired and some other fossil fuel

Microgrids

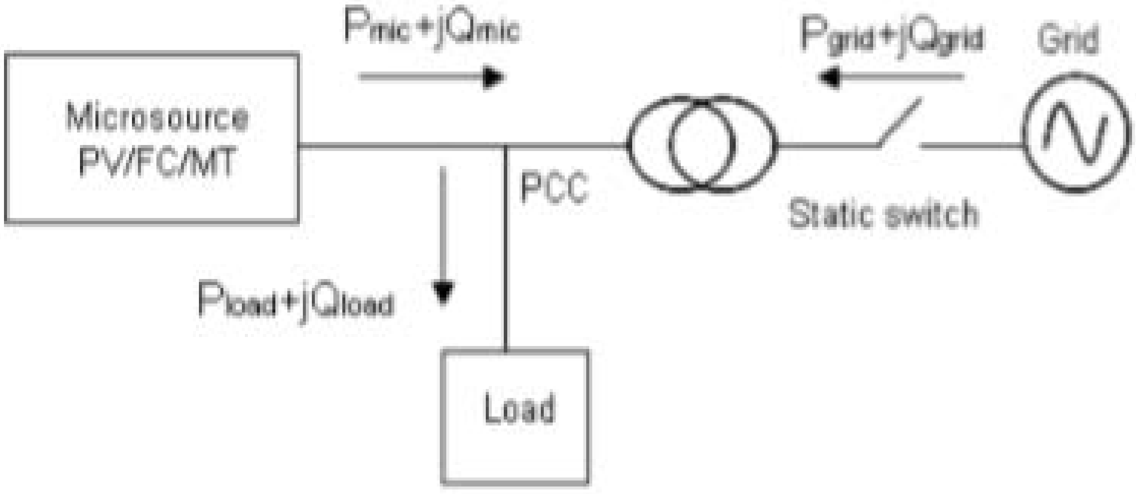
- Distributed
- Locally satisfied
- Transmission with less losses
- Usually using solar and wind power
- Smart control

Problems

- Old facility
- Cost of new tech
- Human resource
- Operation mode
- ……

Problems: Technics

- Its control and protection functions become more complicated
- Micro grids can cause several technical problems in its operation and control when operated as autonomous systems.
- Problem of protection as an example



Problems: Markets

- Take China as an example:

- The attitude for the development of the microgrid from the State Grid is "strengthening management".

- The microgrid's cost is not competitive with the rest of the market.

Micro-grid

Challenges / Research and Development

R & D Goals

- Increase autonomy for "islanded" and parallel operation
- Improve operations and control of interconnected, semi-independent micro-grids
- Improve small-scale power source technologies
- Reduce peak load demand from the macro-grid

Increased Autonomy

- Semi-independent operation benefits:
  – Can be more cost-effective
  – More reliable due to islanding capability
  – Not dependent on macro-grid fluctuations
  – Optimization of power sources for renewability
  – Optimization of power use for critical loads
- DOE's smart grid
  – Important for resiliency of the grid

Operational Challenges

- Operational Challenges
  - Managing multiple semi-independent entities on an interconnected macro-grid
  - Developing a procedure for appropriate fault detection
  - Developing a procedure for separation and subsequent islanding of a micro-grid
  - Developing a procedure for resynchronization and reconnection to the macro-grid infrastructure
  - Control and mitigation of transients during separation and reconnection

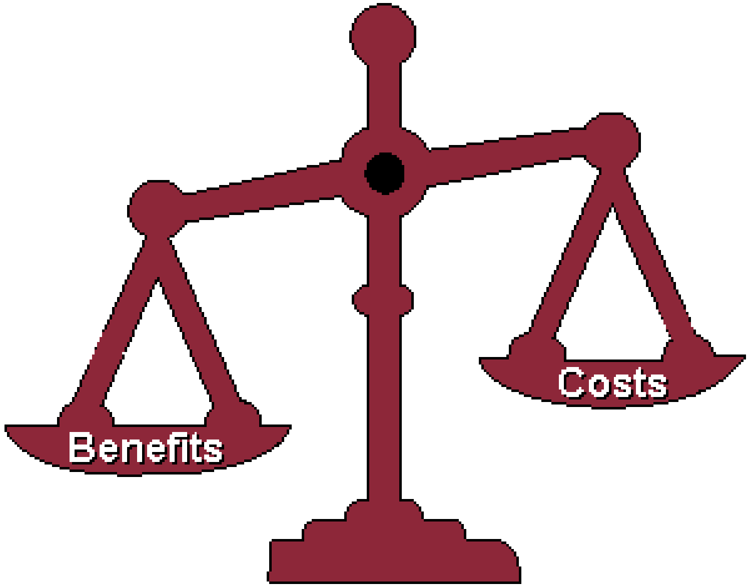
Technologies

- Development of small-scale power sources:
  - Solar cells
  - Fuel cells
  - Reciprocating engine
  - Small wind turbines
  - Waste heat recovery
  - Cogeneration sources for heat and electricity

Example: Fuel cell power plant for 250 homes

Cost Challenges

- High upfront cost of micro-grids can be prohibitive for many organizations
- Research into more efficient renewable sources will help



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Peak Load Reduction

- Micro-grids have been studied in hopes of reducing the peak load on the macro-grid
  - Transmission losses are avoided with power generation and usage occurring in the same vicinity
  - Additional power is supplemented from micro-grid power generation
  - U.S. DOE is supporting 9 RDSI (Renewable and Distributed Systems Integration) projects to attain a goal of 15% peak demand reduction

Micro-grid

Application:
FortZED Project

FortZED Background

- Fort Collins Zero Energy District
  - Approx. 7200 customers
  - 200GWh annual energy usage
  - 45 MW peak load
- Project Funding
  - $6.3 million from DoE
  - $5.1 million from state and local

FortZED Participants

- City of Fort Collins
- Fort Collins Utilities
- Public Entities
  - Colorado State University
  - Larimer County
- Private Businesses
  - Advanced Energy
  - Brendle Group
  - Eaton
  - New Belgium Brewing
  - Spirae
  - Woodward

Original Test Goals

- Demonstrate a working system of DG resources
- Reduce peak load demand
  - 2 feeder lines (distribution system)
  - 15% minimum
  - 20-30% desired

Power Generation

- Photovoltaic Systems (700kW)
  - Monitored, but not controlled
- Generators (2830kW)
  - 9 diesel, 5 natural gas, 2 bio-gas generators
- Issues
  - Emissions, reliability, commissioning

<u>Total</u>

3.5 MW

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Power Demand Resources

- 11 asset groups (650 kW)
  - Temporarily reduced and controlled if needed
  - Ice thermal storage (310 kW)
- Issues
  - Interfacing with control systems
  - Response time

FortZED Project Timeline

- 2009 – 2011
  - 2009: paperwork and system design
  - 2010: individual parts built and tested
  - 2011: system-wide demonstrations and tests
- Final test (log performance results)
  - August 15th to September 1st, 2011
  - 51 operational hours
  - 27 assets at 6 sites (3.17 MW capacity)

FortZED Results

- Peak load reduction of 9 – 25%
  - 9-12% when using 2 feeder lines
  - 15-25% when using 1 feeder line (only twice)
  - 17 min response
- Issues
  - Algorithms
  - Control of resources

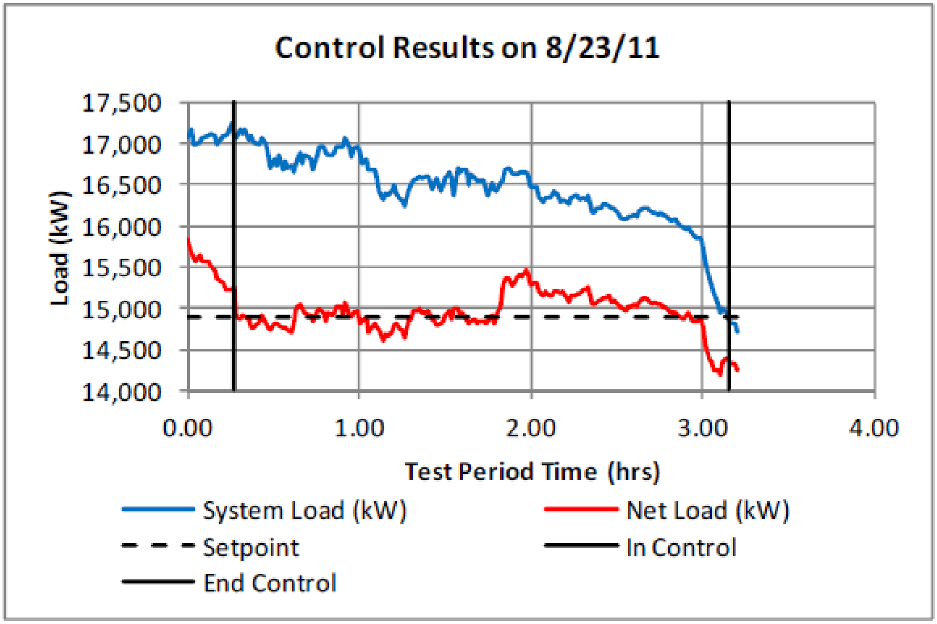


Figure from "A Community-Scale Microgrid Demonstration: FortZED/RDSI" by Daniel Zimmerle

FortZED Future Work

ENGINES & ENERGY CONVERSION LAB

- Phase II
  - Smaller operational micro-grid
    - CSU EECL
    - Northside Aztlan Community Center
  - Incorporate cyber security safeguards
- Smart Metering
- Public building upgrades and PV installs

Technology Application

Microgrid: Power Generation at the University of California in San Diego

Cogeneration: Impetus

- Deregulation of utilities in California
  - Elimination of "parting load charges"
  - Loss of "anti-cogeneration" incentives
- Opportunity to utilize existing on-campus steam production

Cogeneration Power Plant

Equipment	
Prime movers	2 Solar Turbines Titan 130 13.5-MW combustion turbine generators (combined cycle)
	1 Dresser-Rand 3-MW steam turbine
Emissions control	Solar Turbines SoLoNO$_x$ (dry low emissions)
Chilled water	Murray-Tuthill steam-driven centrifugal chiller
Thermal storage	3.8 million gallon cold water storage tower from PDM to meet peak cooling needs
Operation	
NO_x emissions level	1.2 ppm annual average (permitted level is 2.5 ppm)
Gross thermal efficiency	70%
Net efficiency	66%
Costs	
Capital cost	$27 million
Avoided electricity purchase costs per year	$8,040,000
Payback (years)	5

Cogeneration Power Plant

Cogeneration Power Plant

Photovoltaic Modules

- Total installation of 1.2 MW
- $200 annual operations and maintenance cost
- Solar output forecasting techniques in development
  - Ceilometers: produce 1-hour-ahead forecast for 1 MW of PV for supply/load/storage adjustments based on dynamic market price signals

Photovoltaic Modules

Additional System Components

- 3 MW molten carbonate fuel cell
  - Uses waste methane
- Energy Storage
  - Flow battery utilizing lead-acid technology
  - Novel materials increase power, resist corrosion
  - Scalable to grid-level storage capabilities

Controls

- DynaElectric Control System
  - Integrated with campus energy management system and automated by Johnson Controls equipment
  - Metasys graphical control user interface
  - SCADA systems

Controls

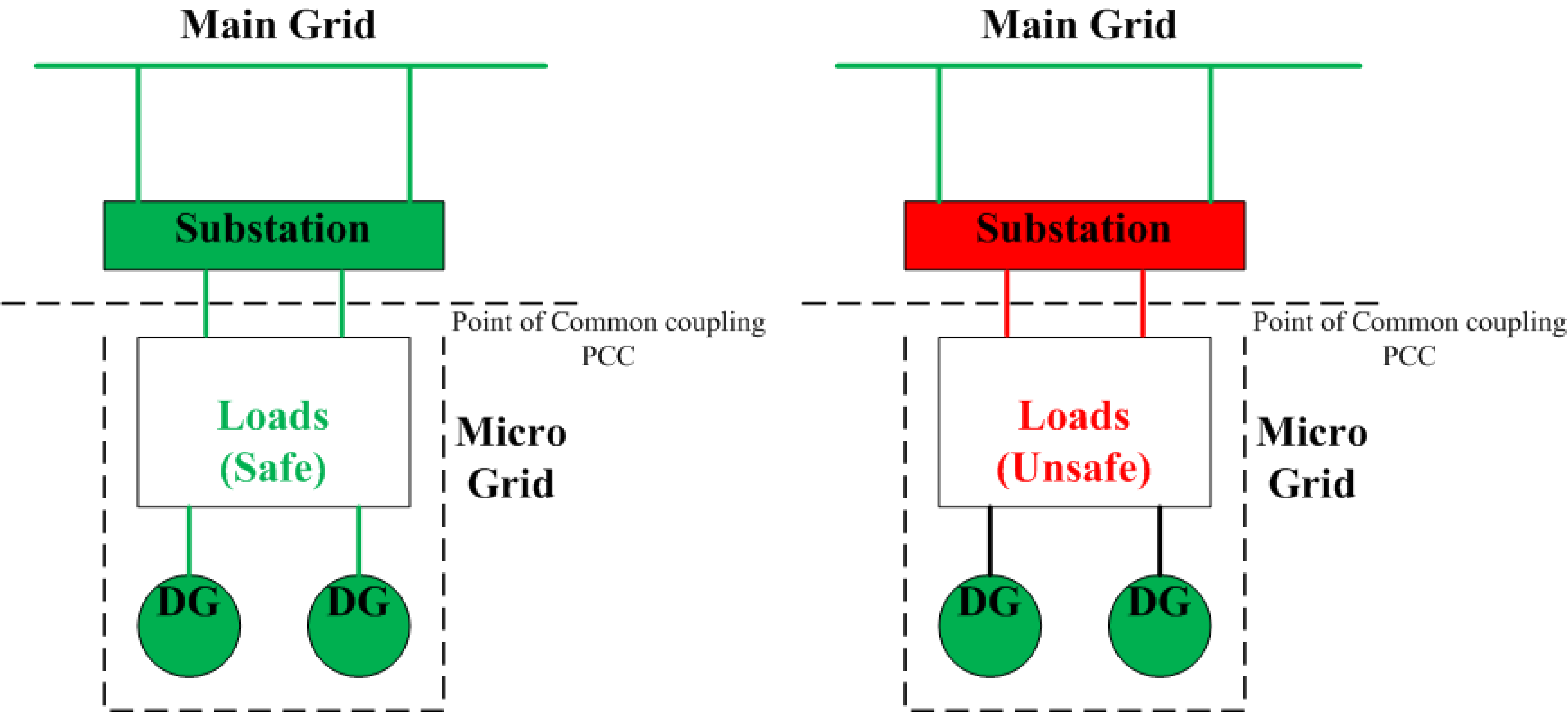
References

- http://ssi.ucsd.edu
  - Search “smart power”
  - “Smart Power Generation at UCSD – November 1, 2010”
- http://www.youtube.com/watch?v=GdprHw1JACw

Micro-grid

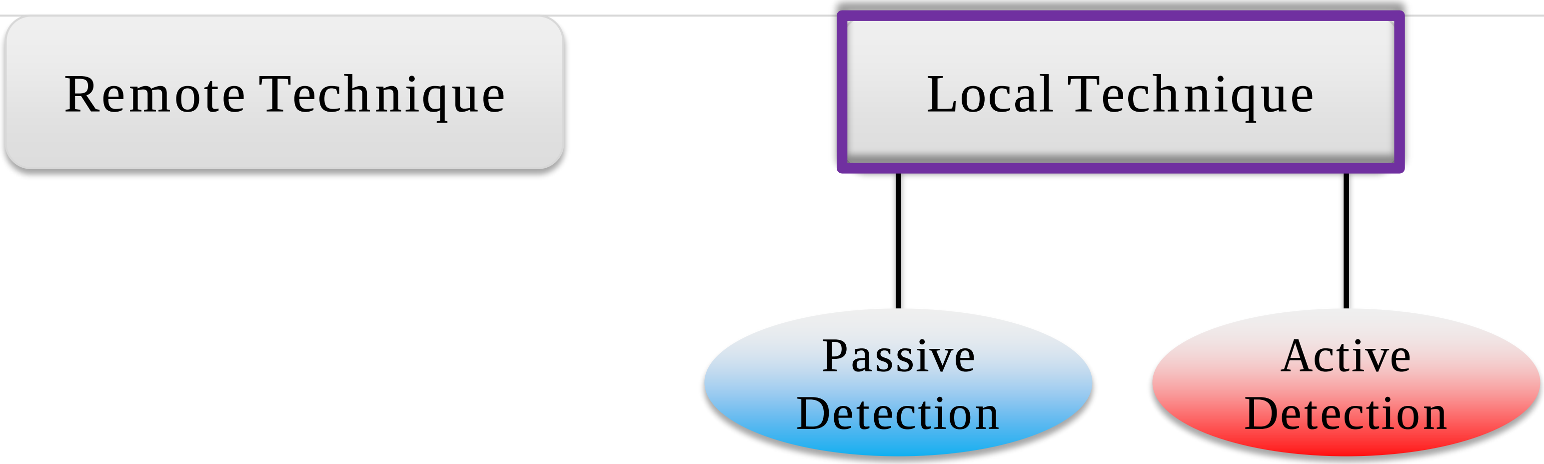
Anti-islanding detection method

What is “Islanding”?

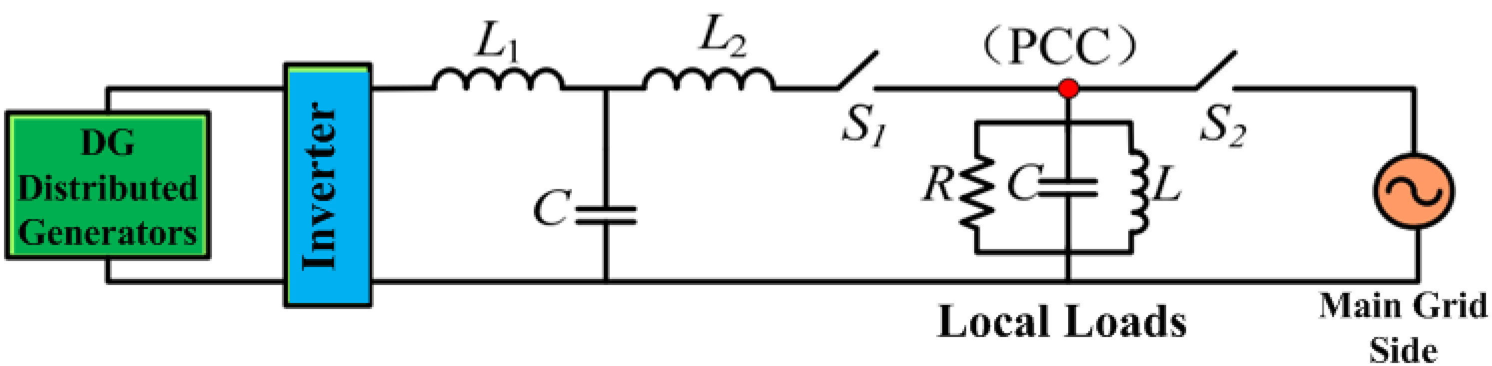


- Hazard to equipment, maintenance personnel
- Poor power quality

Anti-islanding Detection Methods [1]



Detecting Test Circuit [2]



1. Velasco D, Trujillo CL, Garcera G, et al. Review of anti-islanding techniques in distributed generators[J]. Renewable & Sustainable Energy Reviews, 2010, 14 (6): 1608-1614.
2. IEEE Std 929-2000 IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems[S]. 2000.

Local Detection Technique

Passive Detection

- Over/under-voltage and over/under-frequency
- Phase jump detection
- Detection of voltage and current harmonics
- Detection based on state estimators

Active Detection

- Impedance measurement
- Harmonic injection/detection of impedance
- Sliding mode frequency shift (SMS) o active phase shift (APS)
- Sandia voltage shift (SVS) [3]
- Sandia frequency shift (SFS) [3]

3. John V, Ye ZH, Kolwalkar A. Investigation of anti-islanding protection of power converter based distributed generators using frequency domain analysis[J]. IEEE Transactions on Power Electronics, 2004, 19 (5): 1177-1183.

Pros & Cons of Local Detection

	Passive Detection	*Active Detection*
Pros	● Short detection time ● Do not perturb the system	● Small NDZ ● Easy implementation for digital control
Cons	● Relatively large NDZ ● If thresholds is not appropriate then it could result in nuisance tripping	● Introduce perturbation in the system ● Relatively slow detection time

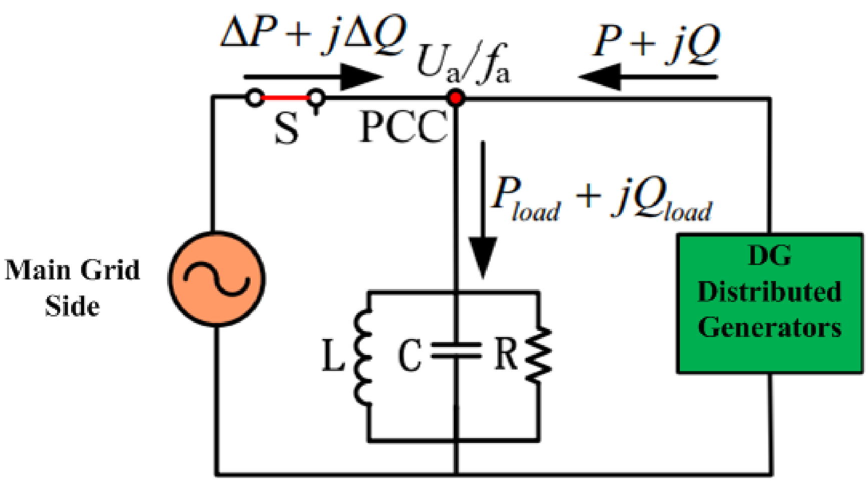
Over/under-voltage and over/under-frequency

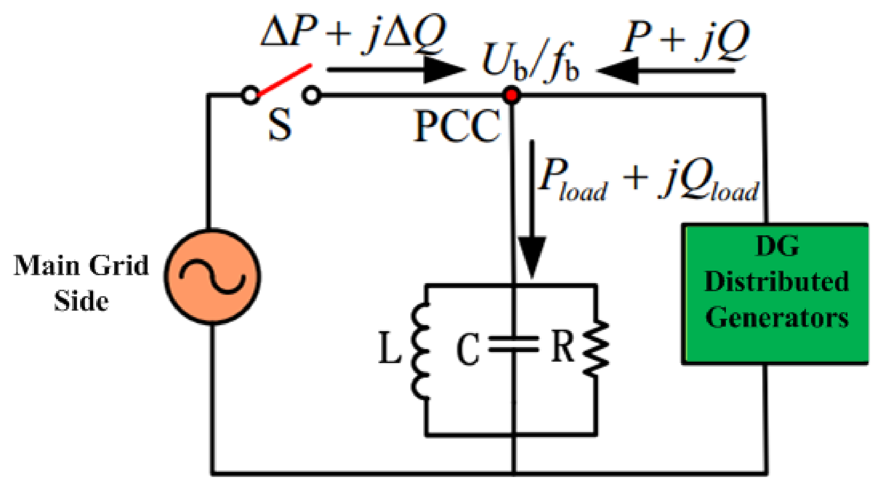
Grid parallel condition

$$P_L = P_{DG} + \Delta P$$

$$Q_L = Q_{DG} + \Delta Q$$

Islanding condition





OV/UV

OF/UF

$$\frac{U_a}{U_b} = \sqrt{1 + \frac{\Delta P}{P_{DG}}}$$

$$|\Delta P| \le \varepsilon \Rightarrow U_a \approx U_b = U$$

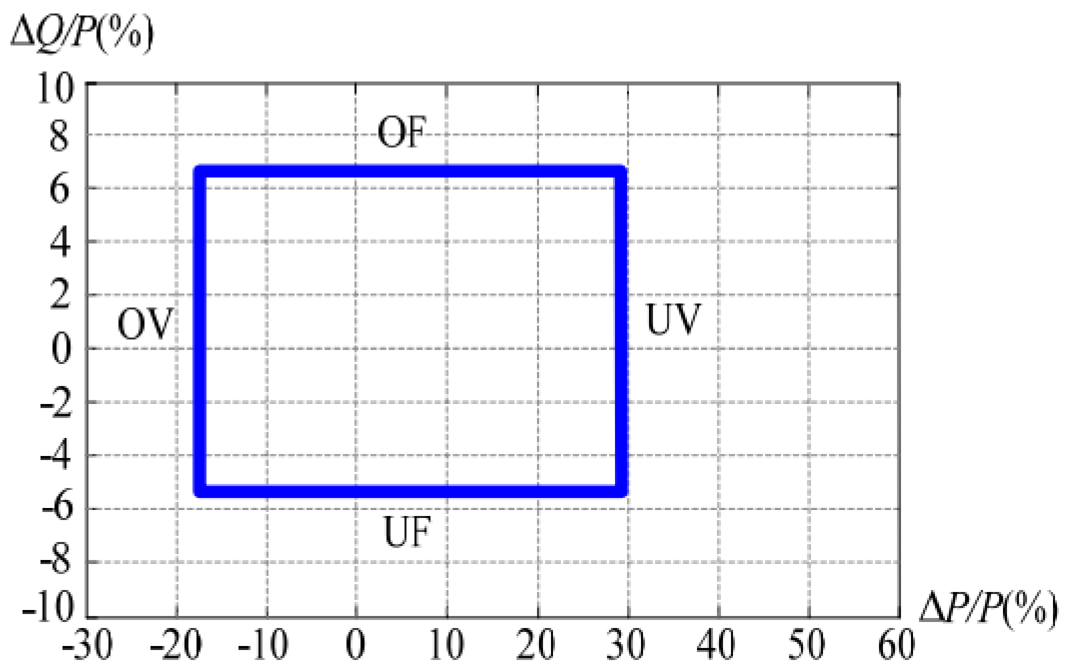
$$(\omega_a - \omega_b)(1 + \omega_a \omega_b LC) = \frac{\omega_a \omega_b L \Delta Q}{U}$$

$$|\Delta Q| \le \lambda$$

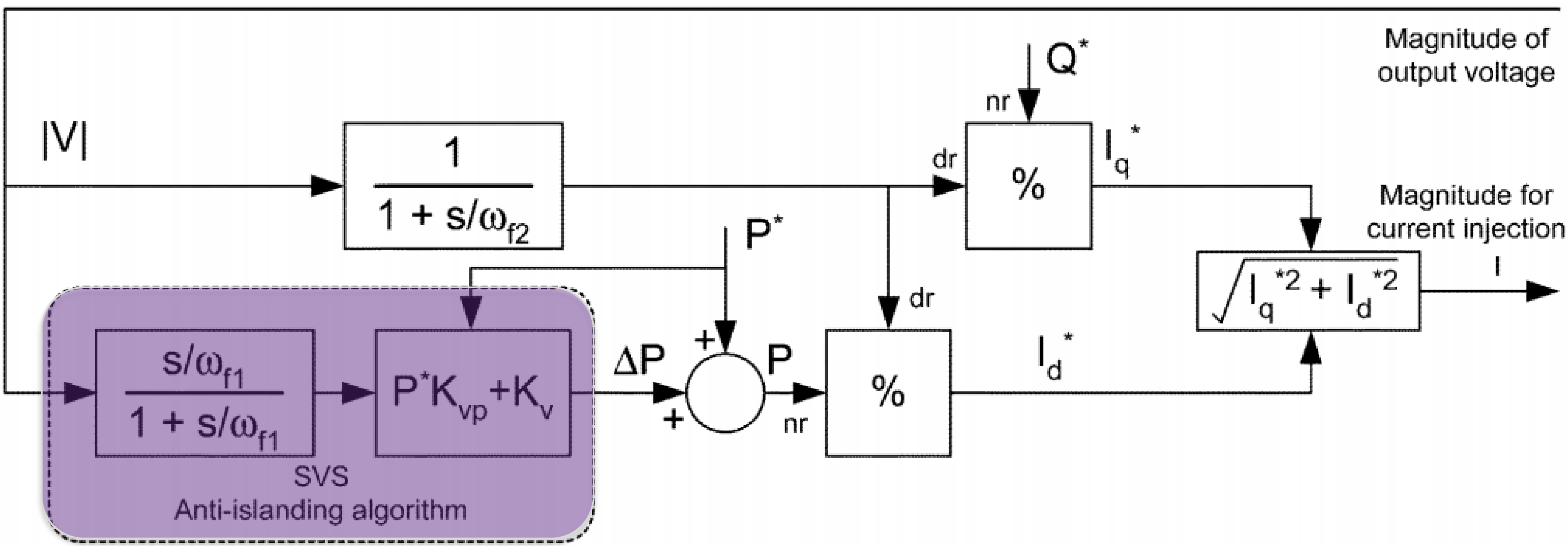
Disadvantages: Not Detection Zone, NDZ

$|\Delta P| \leq \varepsilon$

$|\Delta Q| \leq \lambda$



Sandia voltage shift (SVS)



Sandia Voltage Shift

$$I_{inv}[k] = I_{inv}[k-1] + A\{U_a[k-1] - U_a[0]\}$$

$$U_a[k-1] - U_a[0] \quad \begin{array}{ll} \text{Main grid on} & = 0 \\ \text{Islanding} & \neq 0 \end{array}$$

Simulation Results [4]

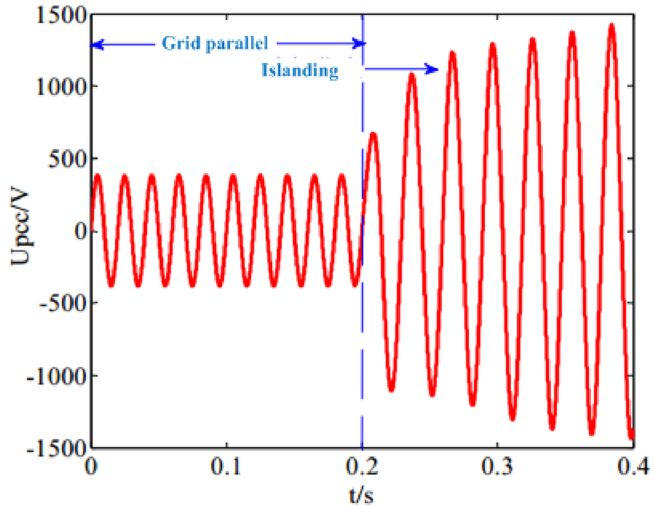


Fig. PCC voltage change when islanding happen

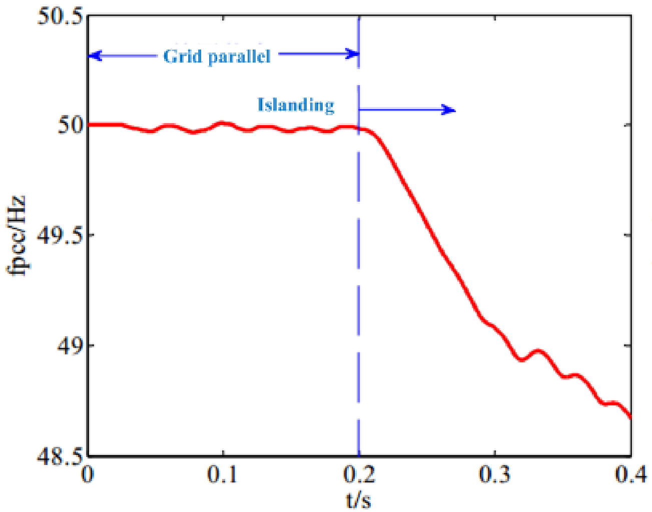


Fig. Frequency change when islanding happen

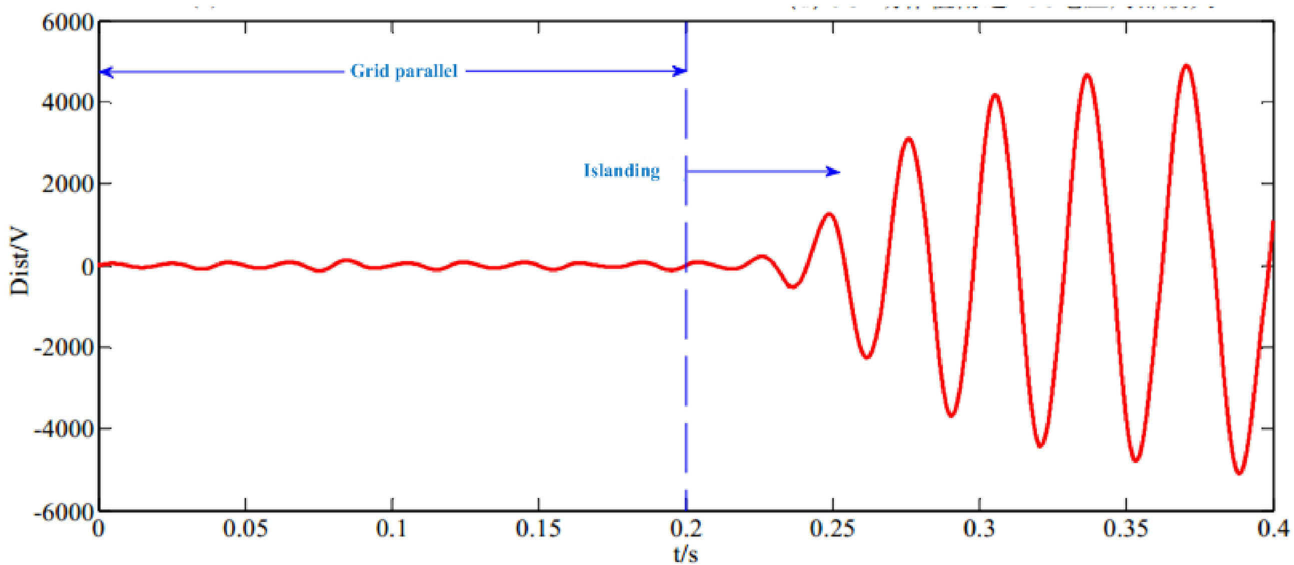
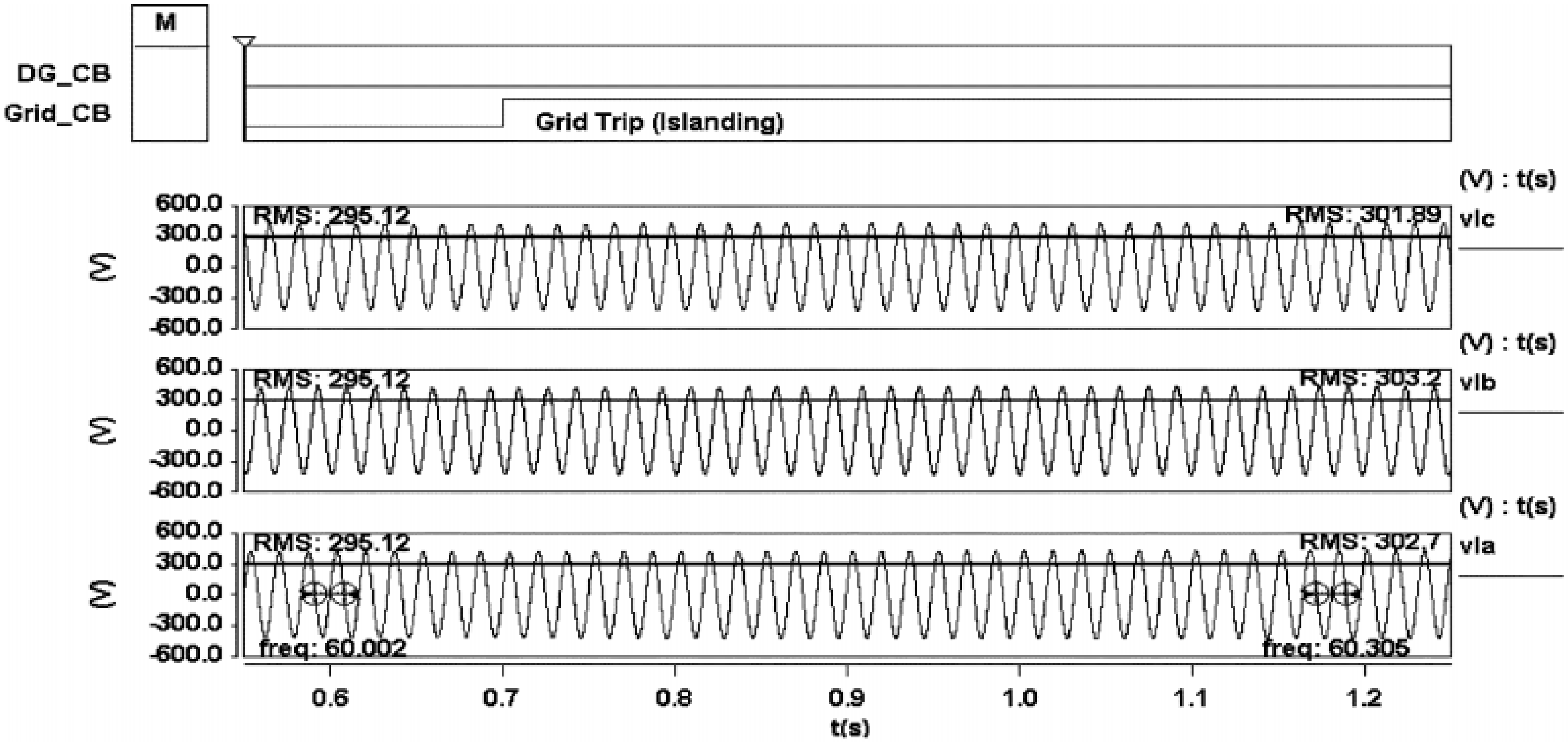


Fig. Disturbance change when islanding happen

Simulation Results [3]



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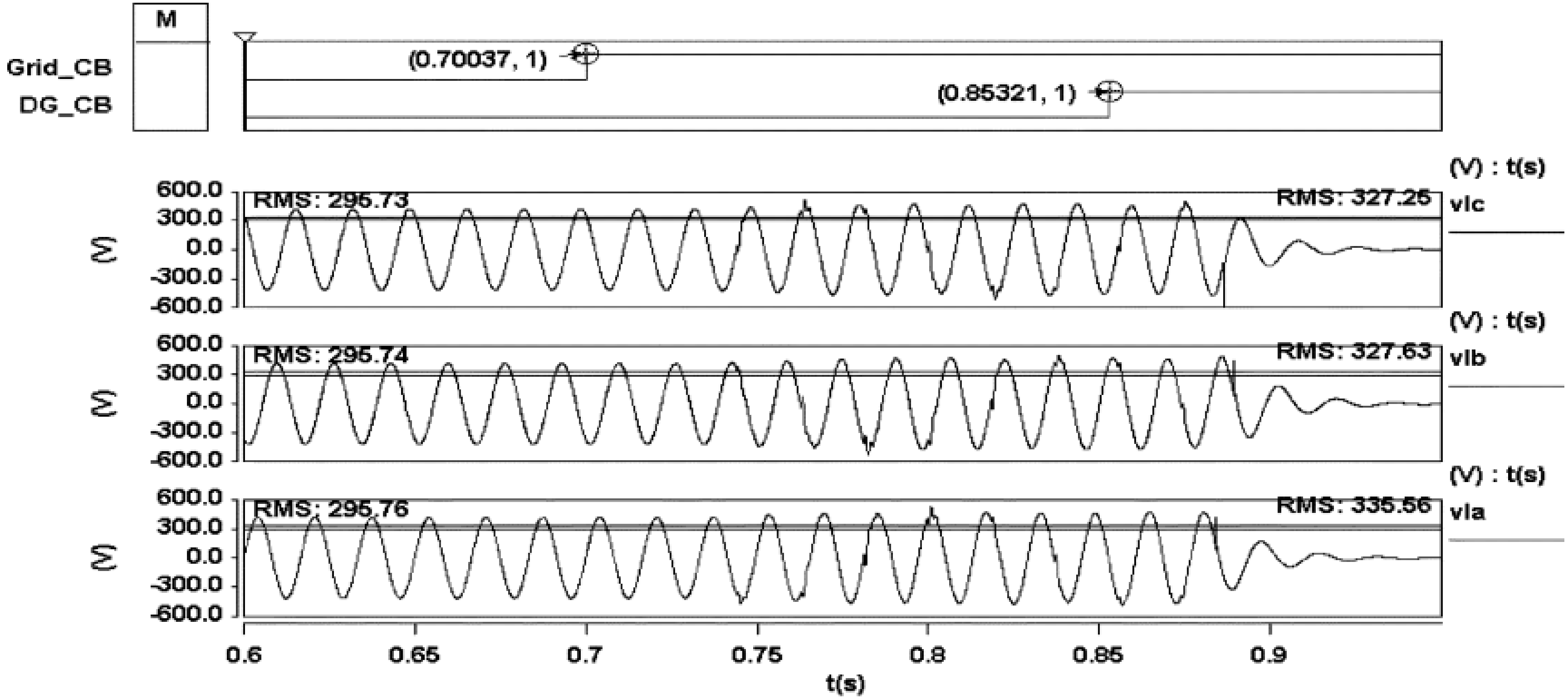

References

1. Velasco D, Trujillo CL, Garcera G, et al. Review of anti-islanding techniques in distributed generators[J]. Renewable & Sustainable Energy Reviews, 2010, 14 (6): 1608-1614.
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3. John V, Ye ZH, Kolwalkar A. Investigation of anti-islanding protection of power converter based distributed generators using frequency domain analysis[J]. IEEE Transactions on Power Electronics, 2004, 19 (5): 1177-1183.
4. Fengyue Hao. Two Classes of Anti-islanding Detection Method in Microgrid-connected Inverters Based on Duality Principle[D]. Xi'an Jiaotong University, 2012