
ECE 333 – Renewable Energy Systems

19. Microgrids

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OUTLINE

- ❑ Definition of a microgrid – μg
- ❑ Evolution of the *US* grid
- ❑ μg concepts and salient features
- ❑ Examples of μg implementations
- ❑ μg benefits and roles
- ❑ μg s issues

OBJECTIVES

- ❑ To assess the motivation behind μg s
- ❑ To get an overview of the concept of μg
- ❑ To look at the technical advancements that took place since the early 20th century
- ❑ To identify the salient features of a μg
- ❑ To view some of the working models of a μg
- ❑ To view the μg benefits and roles
- ❑ To discuss the future of μg s

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MICROGRID - DEFINITION

A microgrid is a network of interconnected loads and distributed energy resources, within clearly defined geographic boundaries, with the properties that it is a single controllable entity with respect to the grid and that it operates either connected to or disconnected from the grid, *i.e.*, in either the *grid connected* or in the *islanded* mode.

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EVOLUTION OF THE *US* GRID

- ❑ At the beginning of the 20th century, most cities operated their own grids islanded from each other
- ❑ As late as 1918, half the *US* customers were still receiving power from small scale isolated power systems with small total capacity – below 10 *MW*
- ❑ The power systems in individual towns were not interconnected with each other and were confined to a few square miles

EVOLUTION OF THE *US* GRID

- ❑ These early power systems were generally not too reliable as the power was supplied by, typically, a single power plant or, in some cases, two plants
- ❑ Power system engineers soon learned that the interconnection of small systems with the pooled resources increases power system reliability
- ❑ The numerous technological innovations in the 1910s and 1920s, together with the changing regulatory scene, set the grid on a path that spurred the interconnection of many smaller systems

EVOLUTION OF THE *US* GRID

- ❑ In the interconnected system, large-scale central plant generation output was distributed via the grid transmission lines to the loads
- ❑ Large systems handled, typically, supply-demand balance more efficiently than smaller networks and provided improved economies of scale
- ❑ A broad range of generation options allowed for fuel flexibility and resulted in improved economic dispatch

MOTIVATION TOWARDS A μg

- ❑ As the economy expands, the need for additional electricity generation and transmission resources arises to meet the increased demand
- ❑ Today's transmission system is heavily stressed during peak hours with extensive grid congestion
- ❑ The integration of the deeper penetration of renewable resources further increases the need for transmission expansion – a major challenge in terms of the environmental and cost barriers that must be overcome

MOTIVATION TOWARDS A μg

- ❑ The antiquated *US* grid is increasingly subject to weather incidents, such as storm *Sandy* in 2012, and cyber attacks, which may result in major social and financial impacts
- ❑ Given the status of the grid and the difficulties in the implementation of grid expansion plans, there is a need to drive the generation resources further down into the distribution system to ensure reliable electricity supply

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THE MICROGRID CONCEPT

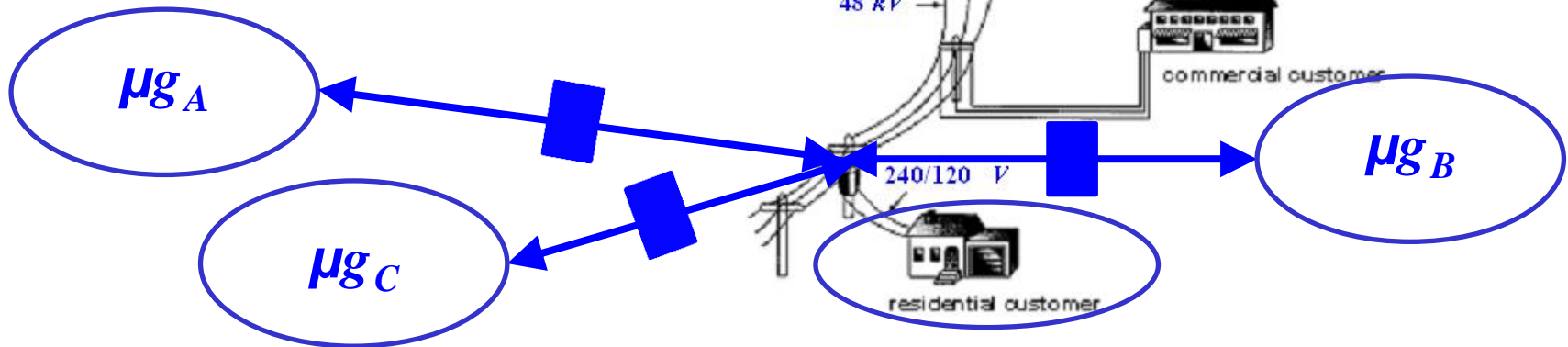
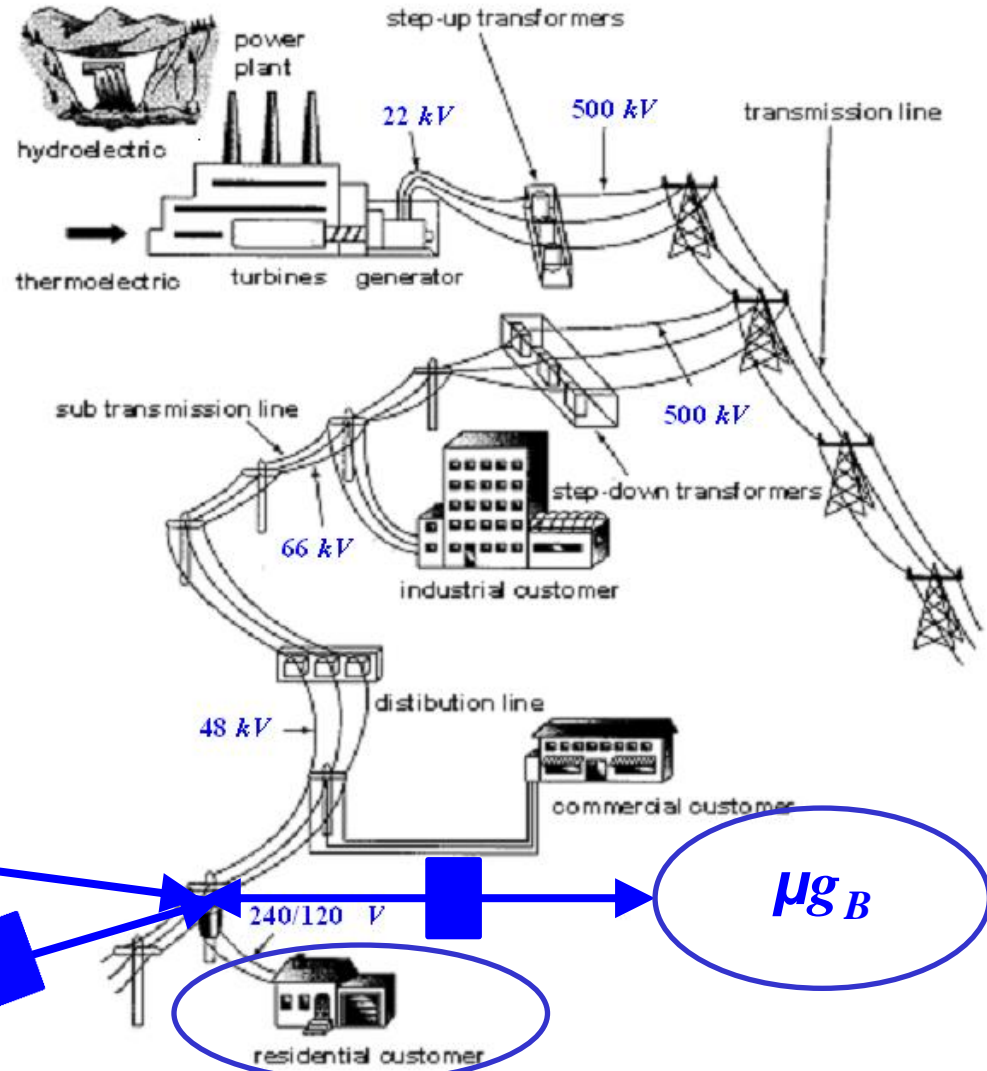
- ❑ A possible solution to the migration towards the distribution level interconnection of generation sources is the deployment of the microgrid – μg – networks that interconnect the supply and the demand resources
- ❑ μg s generate and distribute electricity to loads but do so on a purely local scale
- ❑ μg s may be seen simply as an alternative reconfiguration of power systems than the transmission – level interconnections that are so widely used

THE MICROGRID CONCEPT

- ❑ The key difference between the μg s and the early 20th century isolated power system designs is the ability of μg s to operate in both a connected mode to, as well as an islanded mode from, the grid
- ❑ When connected to the grid, the μg s make full use of the advantages of an interconnected grid
- ❑ Under normal and contingency cases, the μg can disconnect to form an island and to make use of the local generation to maintain continuous supply to its loads

THE MICROGRID CONCEPT

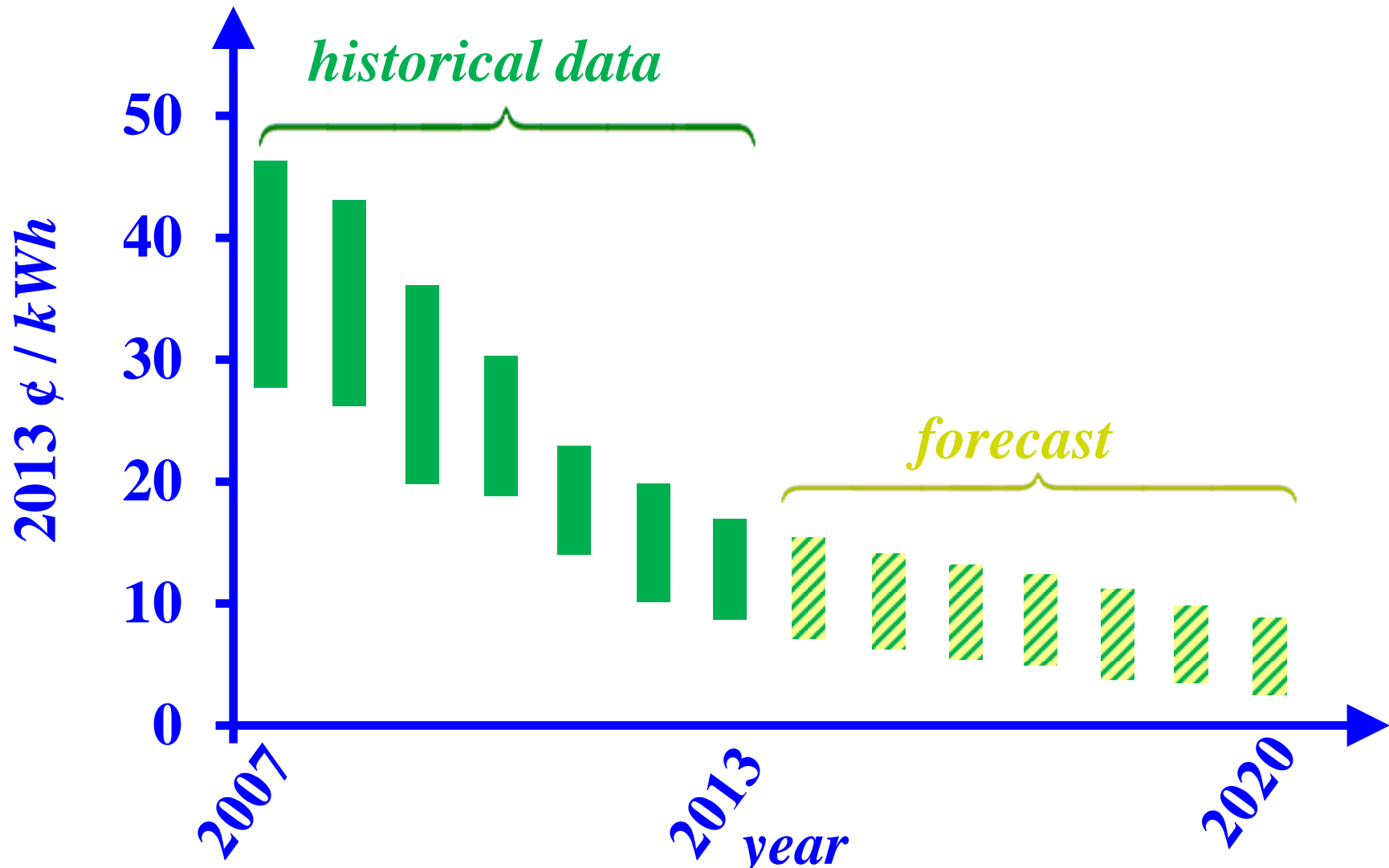
switch or point of common connection (PCC)



THE MICROGRID CONCEPT

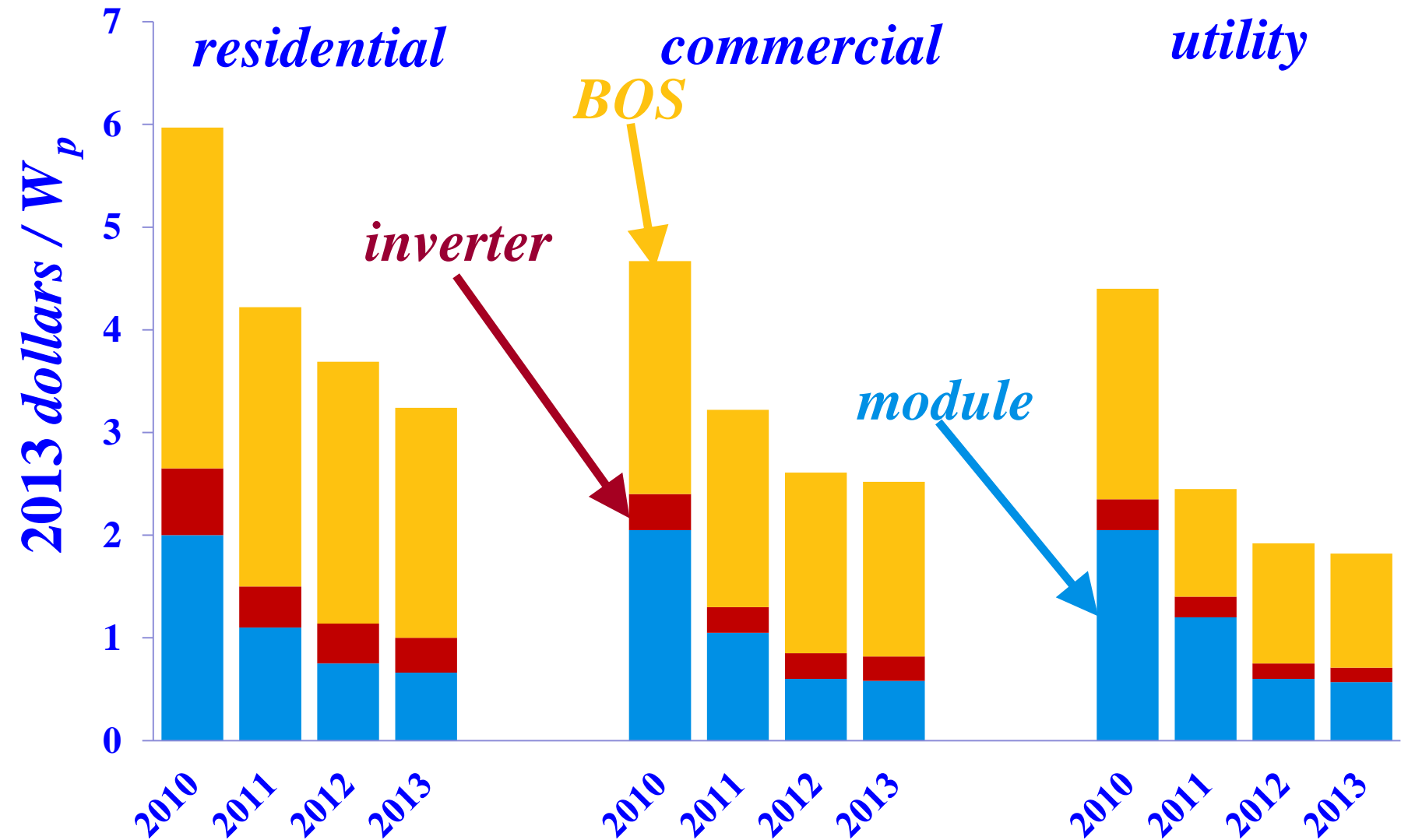
- ❑ μg implementation is generally carried out at the lower voltage levels of the distribution system with the integrated generation resources
- ❑ The rapid pace of μg implementation has resulted in a broad range of projects that vary from a few kW to several MW depending on the application
- ❑ The rapid growth and the technical advancements help the implementation of the μg concept

GLOBAL PV LCOE TRENDS



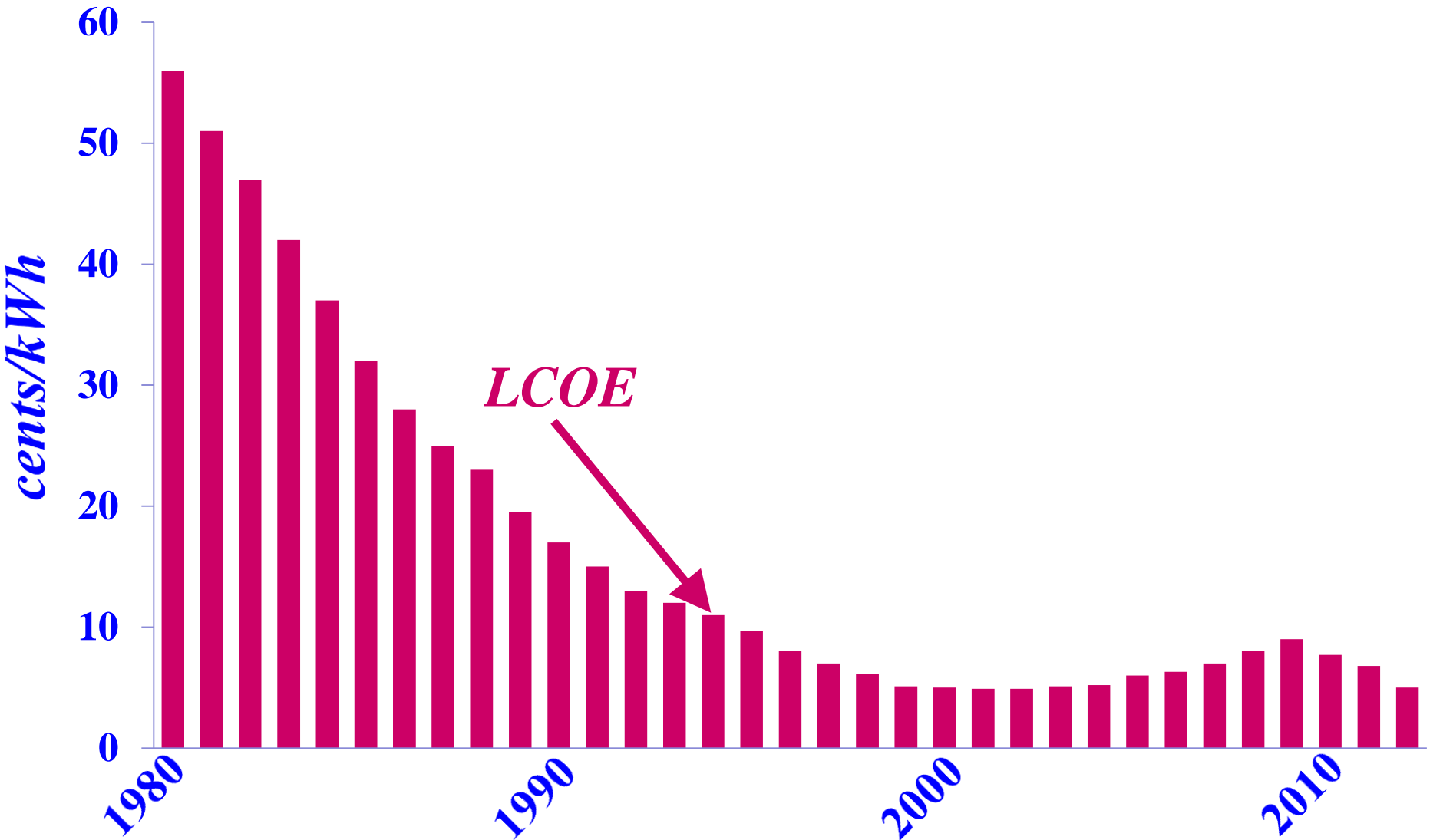
source: <http://climatecommercial.wordpress.com/page/2/>

INSTALLATION COSTS BY SECTORS



source: <http://www.nrel.gov/docs/fy14osti/62558.pdf>

US WIND *LCOE* TREND

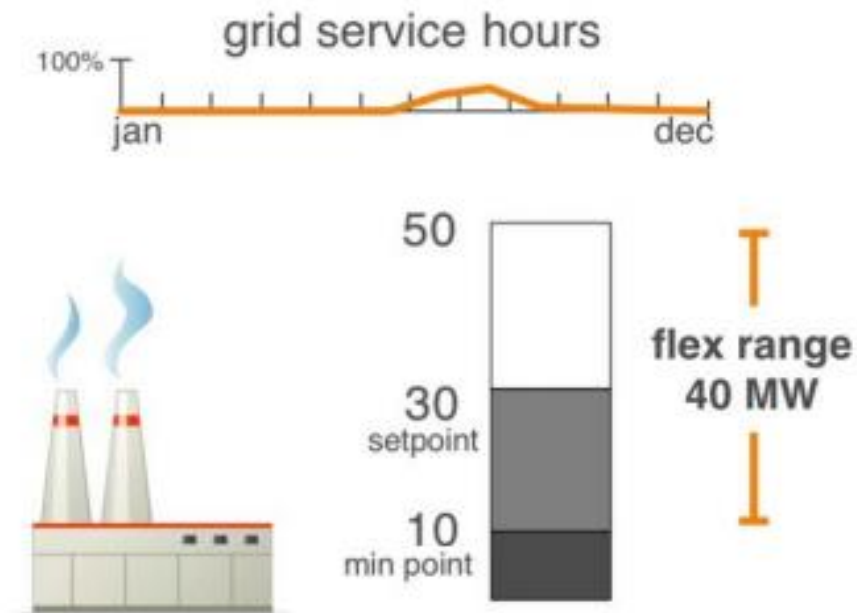


<http://www.awea.org/Resources/Content.aspx?ItemNumber=5547#CostofWindEnergy>

EVOLUTION OF DEVICES USED FOR POWER CONVERSION

<i>year</i>	<i>device</i>	<i>application</i>
1880-1900	<i>MG sets</i>	<i>dc-ac conversion, not an efficient method</i>
1920-1950	<i>mercury arc tubes, selenium rectifier grid control</i>	<i>dc-ac conversion, handle high power levels but with no control</i>
1960	<i>SCR</i>	<i>ac-dc rectification easier but no turn off control</i>
1970-1980	<i>power BJT, FET</i>	<i>can work under high power and frequency, but higher losses, hence used only in amplifiers</i>
1990	<i>insulated gate bipolar transistor</i>	<i>reached even higher power handling levels of 500 kW, grid scale dc-ac conversion possible</i>

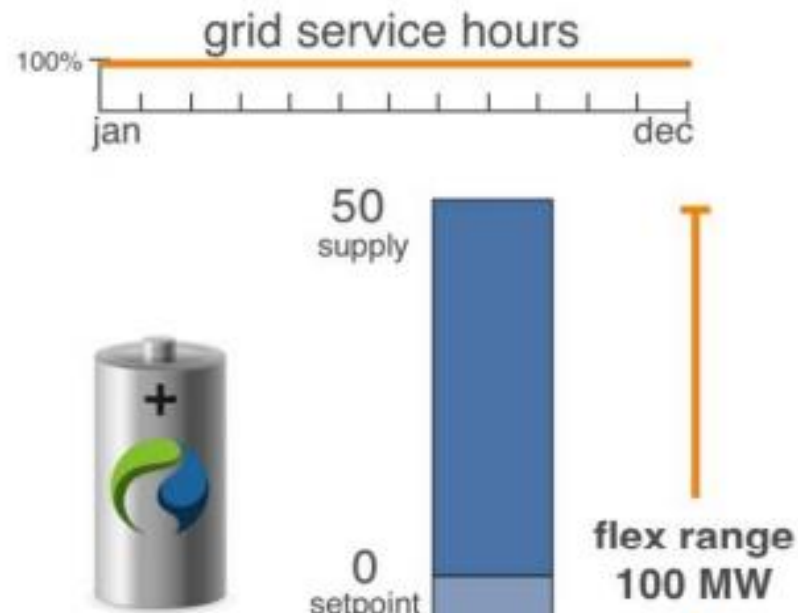
IMPACTS OF TECHNOLOGICAL ADVANCEMENTS OVER TIME



**50 MW
Gas Peaker**

- out of merit generation
- significant standby costs
- standby emissions

minutes to dispatch



**50 MW
Storage Unit**

- 0 direct emissions
- low standby costs

seconds to dispatch

IMPACTS OF TECHNOLOGICAL ADVANCEMENTS OVER TIME

- ❑ The cost of electricity generation from renewable resources has dropped significantly and the performance is much better with improved designs of turbines and *PV* cells
- ❑ Improvements in the area of power electronic conversion has made the integration of renewable energy with the distribution grid possible

IMPACTS OF TECHNOLOGICAL ADVANCEMENTS OVER TIME

- ❑ Renewable resources generally produce *dc* power which needs to be converted to *ac* power at grid level *ac* voltage before integration into the grid
- ❑ The application of switches such as *IGBT* and power *MOSFET* in the *dc-ac* converter circuits was key to the large *dc-ac* power conversion from various sources for grid integration
- ❑ These switches were different from their earlier counterparts as they could attain higher power conversion levels with reduced losses

IMPACTS OF TECHNOLOGICAL ADVANCEMENTS OVER TIME

- These switches can also work under a very high switching frequency of the order of hundreds *kHz* and reduce the size of the converter circuit
- Improved converter designs, better control techniques and reduced switching losses have made the integration of renewable resources more effective

IMPACTS OF TECHNOLOGICAL ADVANCEMENTS OVER TIME

- There is widespread interest in the area of energy storage technology due to its numerous benefits
- Energy storage can play a key role in maintaining the supply – demand balance under various system operating conditions and provides added flexibility in system operations
- Energy storage acts both as a load and as a resource and so is a key grid asset

SALIENT μg FEATURES

- ❑ The two μg operation modes are sometimes referred to as parallel or grid tied mode and islanded or isolated mode
- ❑ The μg load comprises both commercial and residential consumers
- ❑ The μg supply resources are distributed generation units of renewable and non-renewable resources and include energy storage devices, all sited within the clearly defined μg boundaries

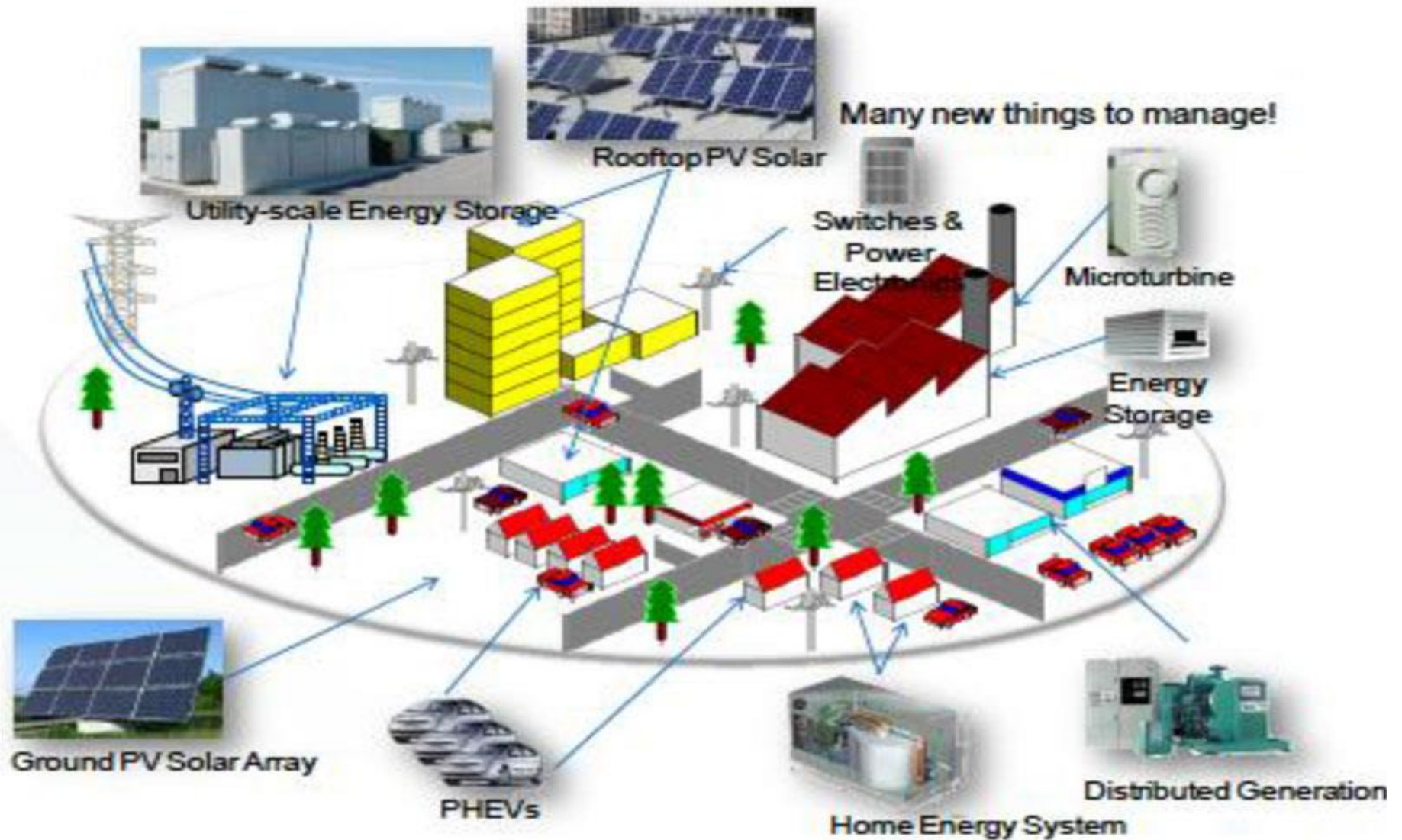
SALIENT μg FEATURES

- ❑ The energy storage devices mainly consist of rechargeable batteries
- ❑ Their operations are coordinated with the other generation and load resources to help in the supply – demand balance maintenance
- ❑ Power electronic converters are generally used to provide grid interface of the various distributed energy resources in a μg

SALIENT μg FEATURES

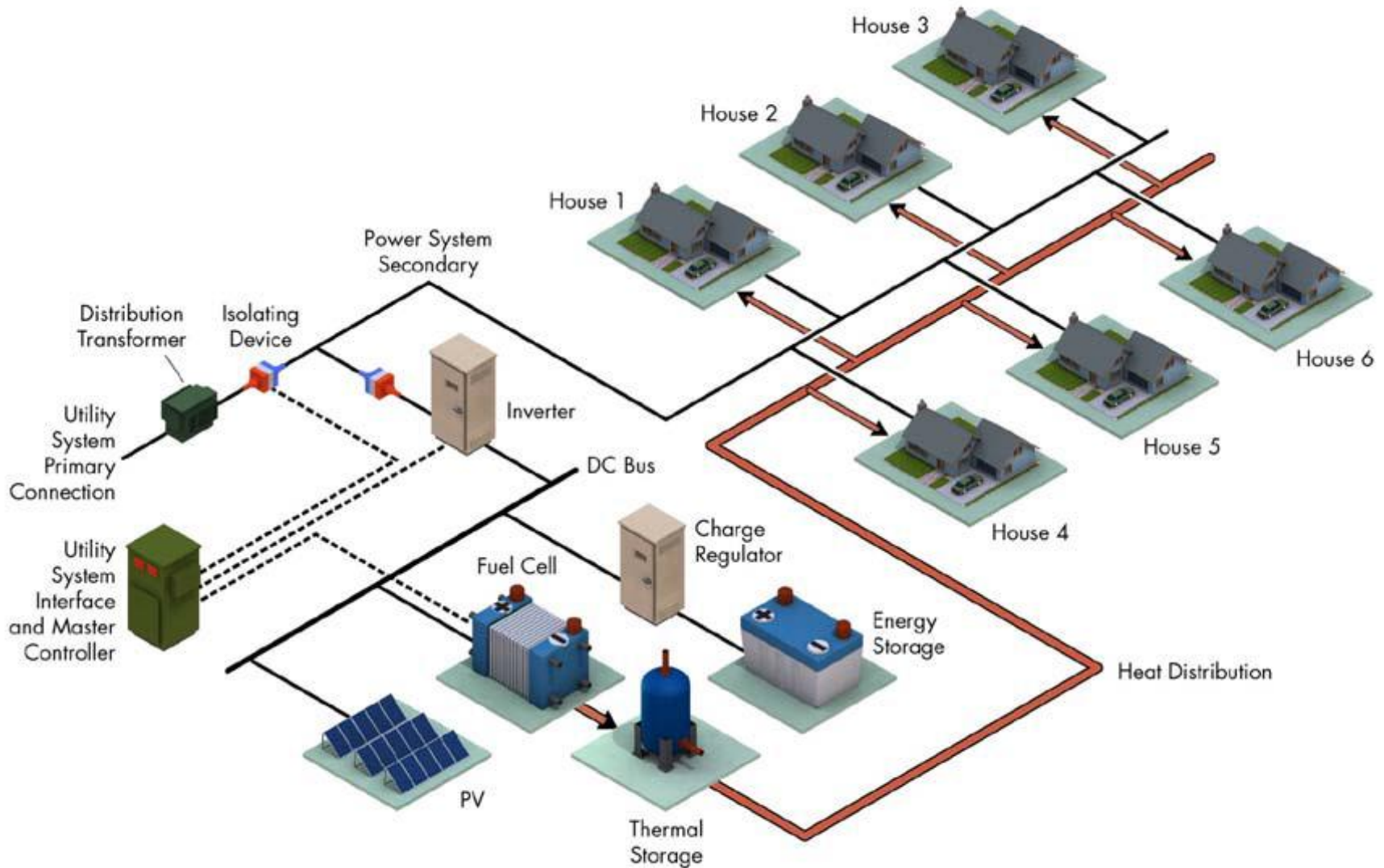
- ❑ The μg consumers also get an opportunity to contribute to electricity generation by the deployment of rooftop solar on their own homes
- ❑ The connection of loads to the local generation may use the utility distribution network or deploy the newly implemented μg wires

A TYPICAL μg DESIGN



source: <http://testtec.us/about-us/about-us/technology/>

A RESIDENTIAL μ g DESIGN



source: EPRI report, Microgrids: A Primer

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CRITICAL LOAD : SANTA RITA JAIL

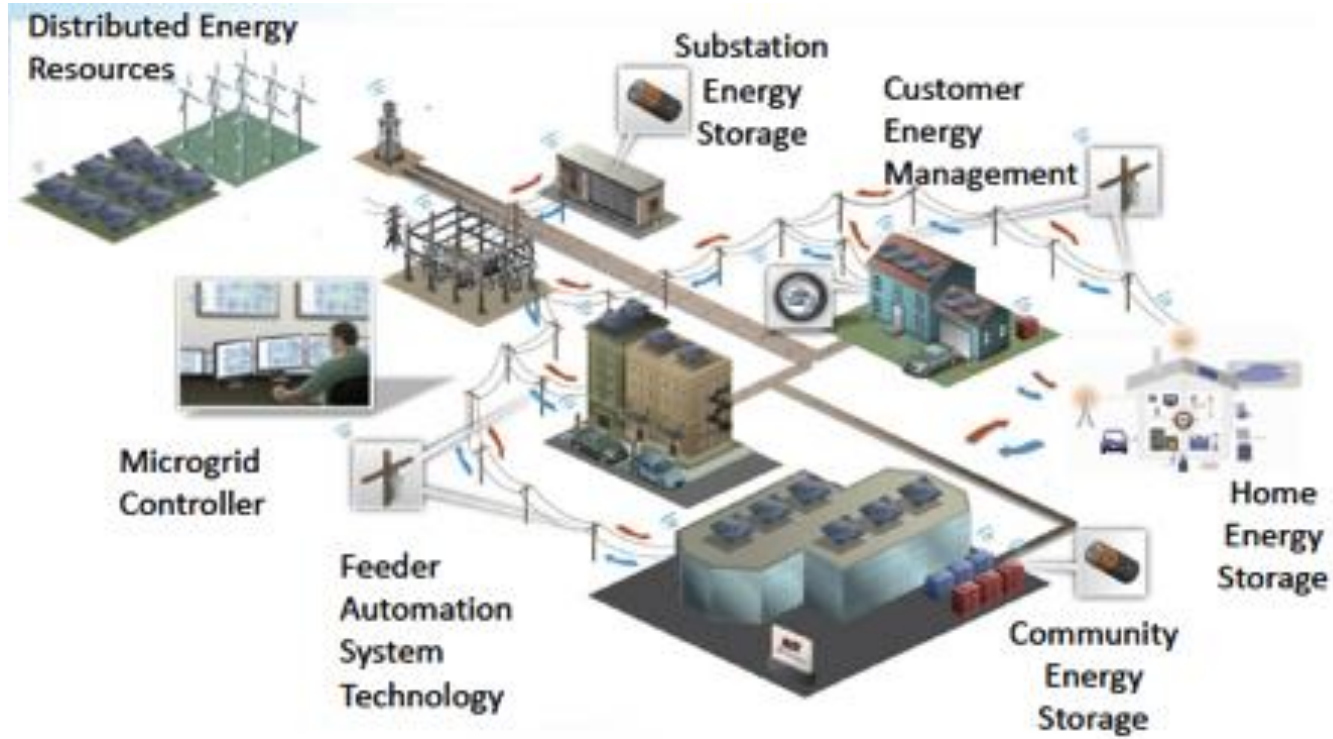


http://upload.wikimedia.org/wikipedia/commons/d/d7/Earth%27s_Axis.gif

SANTA RITA JAIL: μg FEATURES

- ❑ Jail is considered to be a critical load and the continuity of electricity supply is a must which is ensured by a μg implementation
- ❑ Project has a 1.2-MW rooftop solar PV array, 1-MW fuel cell and a 2-MW energy storage system
- ❑ The μg operations alternate between
 - grid-connected mode with power purchases during non peak hours
 - islanded mode with ability to operate autonomously for up to 8 hours

ISOLATED COMMUNITY : BORRREGO SPRINGS μg



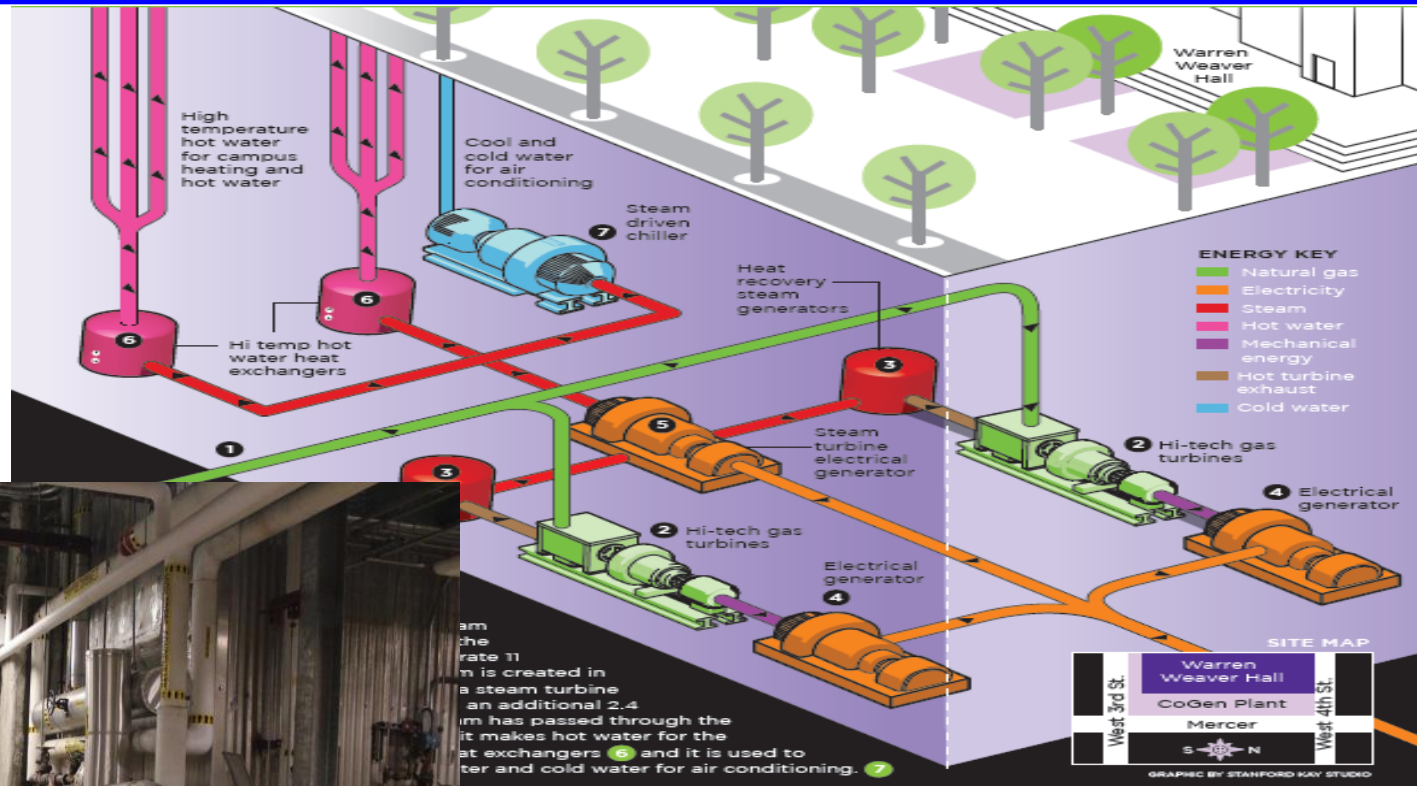
ISOLATED COMMUNITY : BORREGO SPRINGS μg

- ❑ Borrego Springs is an isolated community fed by a single transmission line
- ❑ Any damage to that transmission line may leave a lot of consumers without power, a situation that is avoided by a μg implementation by *SDG&E*
- ❑ In September 2013, a thunderstorm damaged the only transmission line but within a few hours, 1,060 customers had their power restored automatically due to its μg operation

ISOLATED COMMUNITY : BORREGO SPRINGS μg

- ❑ The μg remained islanded during the emergency situation as the utility company repaired the damaged poles
- ❑ Borrego Springs μg consists of two 1.8 *MW* diesel generator, about 700 *MW* of rooftop solar *PV* and batteries for additional storage
- ❑ It is able to serve a peak load of around 4.5 *MW*

NEW YORK UNIVERSITY μg UNDER HURRICANE SANDY



http://upload.wikimedia.org/wikipedia/commons/d/d7/Earth%27s_Axis.gif

NEW YORK UNIVERSITY μg UNDER HURRICANE *SANDY*

- During hurricane *Sandy*, 1.9 million people lost power in *NY* city as *Con Ed* had shut down power to prevent any further damage to the generating system and equipment due to facility flooding
- The *NYU* μg demonstrated the resilient nature of the μg s by generating electricity during the storm by the help of its newly installed cogeneration plant which didn't flood as it was located in a chamber beneath the ground

NEW YORK UNIVERSITY μg UNDER HURRICANE *SANDY*

- ❑ *NYU* μg depended upon the underground natural gas grid lines which supplied the fuel to its local gas powered generators to produce electricity
- ❑ Electricity was then supplied to the buildings which were in close proximity of the generation by its underground distribution network
- ❑ Built with the purpose to reduce energy costs, *NYU*'s cogeneration plant showcased the most important advantage of a μg in maintaining the continuity of supply under an unexpected event

NEW YORK UNIVERSITY μg : OTHER BENEFITS

- ❑ The total savings on the annual energy costs due to the *NYU μg* turned out to be a huge \$ 5 to \$ 8 million per year
- ❑ The *NYU μg* also makes use of the waste heat from gas generators for heating purposes
- ❑ The *NYU μg* generating resources that replaced the old oil fired generators have drastically reduced *NYU's NO_x , SO_2 , and CO_2* emissions

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BENEFITS

- ❑ The most important benefit of the μg is its lesser dependence on the huge and currently stressed grid and hence it shows increased resiliency during unexpected events
- ❑ One of the primary feature of the μg as seen in the examples is the ability to disconnect from the area utility and continue to provide electricity to its customer during unexpected events

BENEFITS

- **μ gs have a smaller demand to manage and hence the control of intermittency of renewable energy generation is easier at a local level through coordination of storage and demand with generation output**
- **μ gs can help in reducing the line losses to a certain extent with the generators and loads existing within a defined boundary**

BENEFITS

□ From the system operator standpoint, a μg can

serve as:

- a reliable, dispatchable energy resource
- an ancillary service resource
- a load shed resource
- A consumption resource (to handle over

generation)

BENEFITS

- ❑ μg s can recapture the waste heat from the local generation to use for heating purposes
- ❑ As μg implementation expands, there will be a reduced need for the existing fossil fuel based central station generations
- ❑ Thus μg s can help in reducing the NO_x , SO_2 , and CO_2 emissions

μg ROLES

- **Grid connected mode of operation**
 - μg can sell the surplus real power, if any, back to the grid and provide reliability to the grid
 - reduce transmission line losses
 - μg can help in demand response strategies by controlling local generation and load

μg ROLES

- can inject reactive power and hence provide voltage support

□ Islanded Mode

- μg ensures continuity of electricity supply to its customers during unexpected events
- μg can play a key role in case of remote area electrification

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μg S ISSUES

- ❑ The unexpected weather events, increased electricity needs and potential threat to the cyber security of the grid have raised several questions over the reliability of the current grid
- ❑ Hence, a pragmatic solution is seen in the widespread implementation of the μg concept
- ❑ The performance of *NYU μg* during the hurricane *Sandy* is an example of the resilient nature of a μg under an extreme event

μ gS ISSUES

- In addition to the resiliency that a μ g can provide, it can also provide several other benefits to its customers
- μ g technologies are getting better and more cost effective with better control algorithms, efficient energy management systems, reduced costs of renewable and natural gas electricity generation

μ gs ISSUES

- There are currently 405 microgrid projects that are under development or fully operating as of April 2013, with 219 projects in the *US*
- **But**, at the same time, μ gs might possess several potential threats to the businesses of the current utility companies in the near future according to the notion that every *kW* produced under a μ g is not sold by the utilities

μ gs ISSUES

- ❑ The threats to the utility companies arise from the fact that the utilities and μ gs are not pitted in a level playing field
- ❑ With the tax incentives, net metering, falling costs of distributed generation, enhanced focus on *DERs* etc. the balance is certainly in favor of the μ gs

μ gs ISSUES

- ❑ μ gs are considered to be the building blocks of a smart, reliable and a resilient grid which is required in today's scenario
- ❑ μ gs are here to stay, but it would be interesting to see how they are received by the other bodies involved in the current electricity grid
- ❑ The need right now is to come up with a well defined economic and a technical footprint of a μ g which does not harm the interests of the existing players in the system