Distributed Generation

Lecture #13

DG vs. CG

- An overview of DG and CG
- Location and sizing of alternative sources of energy
- Review of energy sources for DG
- DG under the point of view of power systems – interconnection issues;
- Heat management as a useful sub-product of power generation – cogeneration/CHP

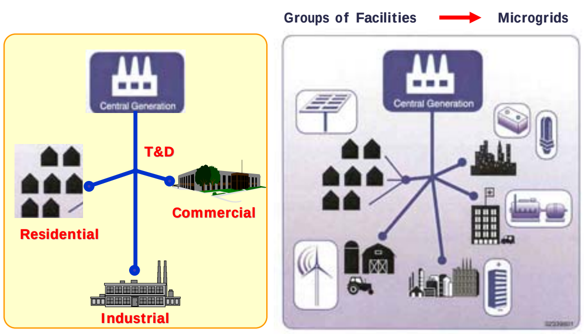
What is Distributed Generation?

- Small generators distributed along transmission and distribution system
- Power generation capacity normally lower than 10MW
- Location close to load
- Types of generation:
- Reciprocating engines
  - Microturbines and industrial turbines
  - Low-head hydro generation
  - Fuel cells
  - Renewables (wind, solar, biomass, geothermal, tidal)

What is Concentrated Generation?

- Large central station power plants
- Common output power: 150 to 800 MW
- Site selection is a challenge
- High environmental impact
- Types of generation:
  - Fossil-fuels
  - Nuclear
  - Large hydro

CG x DG



Concentrated Power Generation

Distributed Power Generation

DG Advantages x Disadvantages

Advantages

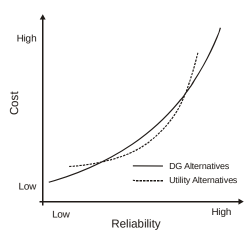
- Reduces T&D costs
- Good efficiency
- Modularity
- Environmental friendly
- Possibility of cogeneration

Disadvantages

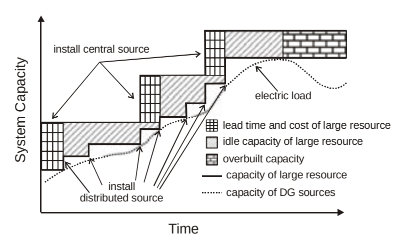
- Ownership and operation
- Fuel Delivery
- Unproven technology

DG vs. CG

- DG wins at either end of cost-reliability spectrum



Addition of Central or Distributed Sources to Match Demand

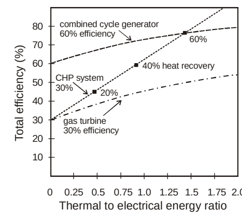


DG Efficiency

- Industrial, commercial, and residential DG systems can be tailored for efficiency improvement by using, for example, heat exchangers, absorption chillers, or dehumidification to reach overall fuel-to-useful energy efficiencies of more than 80%
- Three thermal recovery efficiencies are shown on the plot. Two systems assume separate generation of electricity and heat; the third is a CHP system. The assumed thermal generation efficiency for the non-CHP examples is 85%; the electrical efficiencies are 60% and 30%, respectively. If a loading ratio of 1 is assumed, the overall efficiencies of the separate systems are 70% and 44%. For the case in which the waste heat is near the heat load, it can be used instead of fuel to provide the required heat.

DG Efficiency

- Typical thermal recovery efficiencies range from 20% to 80%. The maximum ratio of heat to electricity is limited. For example, if the electrical efficiency is 30%, 70% of the fuel will result in waste heat. If this waste heat can be converted to useful heat, assuming a thermal recovery efficiency of 40%, the total energy efficiency is 58%, and the ratio of thermal energy to electrical energy is 1. This is the maximum loading and maximum total efficiency for this system. If the system is not loaded to this level, the total efficiency drops linearly.



Benefits of DG

- Modularity
- Efficiency
- Low or No Emissions
- Security
- Load Management

Types of Alternative Energy

- Hydrogeneration
- Wind Turbines
- Photovoltaic Systems
- Fuel Cells
- Biomass
- Gas turbines and microturbines
- Storage schemes: electrical + heat + “ac battery”
- Others

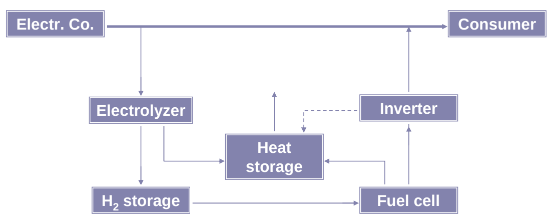
DG Perspectives

- Peak shaving of power and energy;
- Power generation close to consumption point: heating schemes;
- Remote loads;
- Probable substitute of urban heat and power;
- High quality energy: phase balance, THD, voltage tolerance, high PF;
- Energy reliability: uninterruptibility, UPS, backup, emergency systems;
- Increased power reliability
- System optimization and decision making;

DG Perspectives – Cont.

- DG systems such as photovoltaic and solar-thermal power supplies can play a role in clipping peak demand if it coincides with their output.
- In valley-filling strategies, the goal is to build up off-peak loads to smooth out the load and improve the economic efficiency of the utility.
- An example of valley filling is charging electric vehicles or electrolyzing water to produce hydrogen and oxygen at night, when the utility is not required to generate as much power as during the day. Large battery storage can also be operated at night, and the energy stored can be used for peak clipping during the day. Economic assessment, including charging/discharging losses, must be accounted for to validate the viability of this option

Example: Peak Shaving with Fuel Cell



Concepts in Energy Conservation

- distributed generation;
- static generation: batteries, FC, PV;
- power plants of alternative energy;
- HFAC link integration.

Main Drivers for DG

- Energy Efficiency
- Increased Reliability / Power Quality
- System Voltage Support
- Environmental Emissions Reduction
- New Technology Development
- Reduced Transmission and Distribution Costs
- Marketing advantage for Landlords
- Market Liberalization / Deregulation / Customer Choice

Efficiency x Size

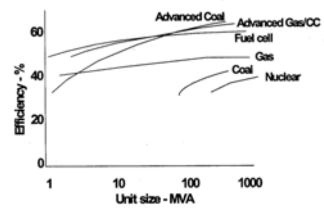


Figure 1.1 Best estimates of the realizable average lifetime maximum fuel efficiency for various technologies of generation as a function of unit size show a definite economy of scale in all cases. This data was developed by the authors from technical and marketing literature about generating units available to the power industry.

H. L. Willis, W. G. Scott, "Distributed Power Generation – Planning and Evaluation," Marcel Dekker, Inc., 2000.

Economy of Scale

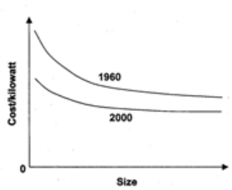


Figure 1.2 Although there is still a considerable economy of scale in cost, the advantage that a large generator had over a small one constantly shrank during the last half of the 20th century, as technological advance tended to improve small-generator performance more than that of larger units. Coupled with the increasing proportion of costs that must be devoted to T&D (see text) this trend was more than enough to make DG competitive against larger generators in many situations.

Economy of scale favorable to small generators along the years due to:

- Technological advance in fuel conversion
- Technological advance in insulation and thermal engineering
- Shifts in fuel price
- Automation and control

H. L. Willis, W. G. Scott, "Distributed Power Generation – Planning and Evaluation," Marcel Dekker, Inc., 2000.

Energy Source Mixture Availability

- Assessment of wind vs. solar uses a small representative turbine and a PV module
- The energy ratio plotted throughout a year indicates the relative energies available, which can then be compared with system cost
- The actual energies available can then be compared with longer-term climate data to estimate annual variations
- Life-cycle costs of the two systems must be included to get a comprehensive determination of an optimal system design
- One of the systems might be omitted if the energy contribution is less than ~5% of the total

Types of Distributed Generation

Small Plants

Capacity:	**5-10 kW**
Generation voltage:	**110-480 V**
Interconnection voltage:	**110-480 V**
Prime mover:	**Microturbine, Fuel Cell, Wind, Solar, Recips, Microhydro**
Fuel:	**Natural Gas, Propane, Bio Gas, Hydrogen, Alcohol, Gasoline, Water, Renewable**

Types of Distributed Generation

Medium Plants

Capacity:	**10-50000 kW**
Generation voltage:	**480-4160 V**
Interconnection voltage:	**13 kV**
Prime mover:	**Gas Turbine, Fuel Cell, Wind, Solar, Recips**
Fuel:	**Diesel, Natural Gas, Bio Gas, Hydrogen, Alcohol, Gasoline, Renewable**

Types of Distributed Generation

Large Plants

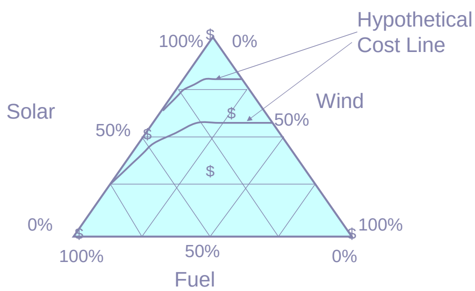
Capacity:	**>5 MW**
Generation voltage:	**13.8 kV**
Interconnection voltage:	**69-138 kV**
Prime mover:	**Gas Turbine, Wind, Reciprocates**
Fuel:	**Natural Gas, Renewable**

Reciprocating Engines

- Known technology - low risk
- Existing service infrastructure
- What's new is packaging and controls

Home

Energy Source Cost Choices



- Assess cost of various mixes of energy, enter total costs, sketch contours to seek lowest cost region

Balance of Systems (Diesel)

- Fueled systems will require tanks, lines, and possibly pumps
- In cold weather, diesel oil thickens, and insulation or heating may be required
- Small car engines may use 3 liters per 100 km (78 mpg)
- If at 78 mph, that would be 3 l/hr, or to avoid mixed units systems, about one gallon/hour
- A typical 500 gallon tank would hold 500 hours of fuel, so replacement fuel must be obtained faster than that to keep the tank filled

Balance of Systems (BOS)

- The balance of system must include the necessary fuel tanks, piping, transportation support, etc.
- Mechanical shops may be needed to perform engine overhaul, since the distance to civilization may be great
- BOS must include means of transporting fuel to the engine
  - If a truck is normally used to travel to a location that has fuel, there might not be an extra trip or expense
  - The labor (driver) cost is increased slightly for getting fuel, but greatly if the trip would not have been otherwise made

Fuel Consumption

- The rate of diesel fuel consumption is critical to the analysis
- Diesel fuel costs more than gasoline
- Fuel transportation raises the cost and must be included in the price
- The engine speed must be matched to the generator/alternator to optimize efficiency
- When the generator runs, it should do so at full load, charging batteries if necessary

Economics of Plant Combination

- The location is a prime driver of the cost-analysis
- When the remoteness and lack of roads makes fuel-hauling or helicopter transport too costly, the wind or solar components must be increased to ensure reliable power
- Mountain-top radio repeaters exemplify the inaccessible site, and access may be limited to hiking or horseback
- Matching of the load times to the energy times determines the need for storage

Power Control

- System monitoring by computer allows programming of automated supervisory monitoring and determines actions to take in response
  - The system functions might include
  - Start an engine
  - Control battery charging
  - Control energy load dumping for wind turbine
  - Change loads to match available power
  - Engage engine clutch
  - Report alarms to a distant operator

Power Control for Backup Engine-Generator

- The engine-generator starting sequence automatically begins when the line voltage sags (drops) below perhaps 105 volts
- A transfer switch changes the load from the wind/solar inverter output to the engine-generator output
- The battery is connected to the starter motor and the engine is cranked to start under a solenoid-controlled choke fuel enrichment
- As the starter turns over the engine-generator, the speed is sufficient to provide voltage to the load
- Once the engine is running, the choke is opened to provide a normal fuel mixture
- The entire sequence is so fast that lights on the load side don't noticeably flicker
- When inverter power returns, the load is switched to the inverter (after a delay) and the engine is stopped

Power Control for Continuous Hybrid System

- In a full hybrid system, the engine runs continuously and the wind/solar sources subsidize (add to) the available energy, saving fuel
- The inverter is synchronously matched to the power frequency and voltage, providing more or less power as is available

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Why Renewable Energy Sources?

- hydro + windpower
- hydro + photovoltaics
- windpower + photovoltaics + batteries
- windpower + fuel cells
- photovoltaics + fuel cells
- windpower + photovoltaics + fuel cells
- windpower + photovoltaics + biomass
- gas turbines
- storage schemes: electrical + heat + “ac battery”

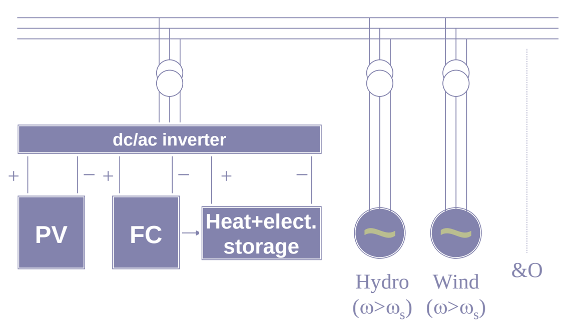
Wind/Solar Hybrid Systems

- Erratic energy sources like wind and solar are not dispatchable, that is, available on command of utility dispatchers
- Sometimes or often, the wind blows when it is cloudy, or the sun shines when the wind is calm
- A system that combines various energy sources is called “hybrid”
- Diesel generators are often used for “reliable” power, and wind or solar are used to decrease the fuel costs
- Studies of a site can indicate the optimal combination of wind, solar, and diesel (or gasoline) to provide power at the lowest overall cost

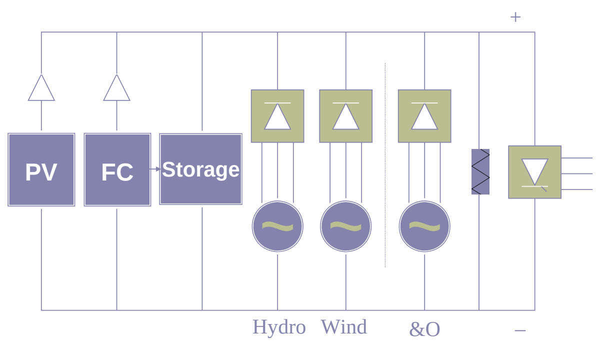
Electrical Integrating Buses

- DC bus
- AC bus (50/60 Hz)
- HFAC bus (500 Hz)

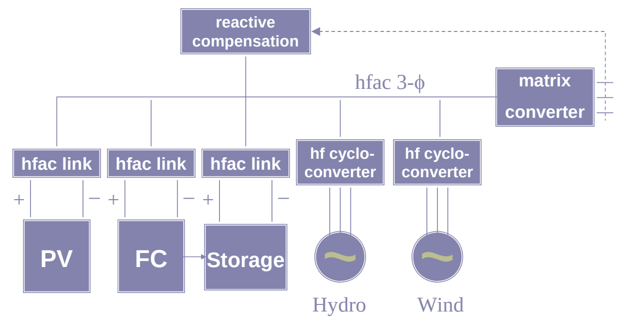
AC Bus (50/60Hz)



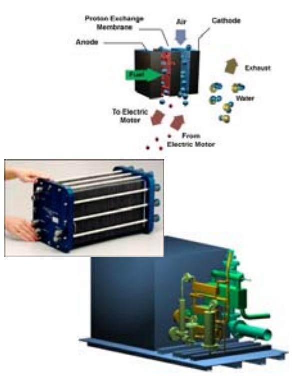
DC Bus



HFAC Link



Fuel Cells



- Extremely low emissions
- High efficiency
- Fueled by Hydrogen
- High cost
- Current applications are for premium power and residential
- May include heat recovery
- Higher risk

Microturbine Generators

- Run on most liquid or gaseous fuels
- Self-contained, compact
- Ultra-quiet
- Ultra-low emissions

Other Technologies

- Niche market applications
- Variable energy supply

Utility Concerns Regarding DG

- Electric power distribution systems designed for one-way operation
- Personnel safety and grid stability are dominant concerns
- Utilities reluctant to rely on unfamiliar, customer-supplied protective relaying schemes
- Integrated interconnection packages not generally accepted and known

Utility Approach to Interconnection

- Maintain grid stability and reliability
- Minimize problems from uncontrolled customer generation
- Obtain protective relaying to protect the grid
- Discourage customer generation

Customer Interconnection Concerns

- Utility interconnection costs can be a “Deal breaker” for smaller-sized projects
- Some requirements not understood by customer and may appear unreasonable
- Manufacturer, customer and utility DG activities are frequently not coordinated
- Interconnection requirements are far from standard

Related IEEE Standards

- **IEEE Std C37.95-1989:** IEEE guide for protecting relaying of utility-consumer interconnections
- **ANSI/IEEE Std 1021-1988:** IEEE recommended practice for utility interconnection of small wind energy conversion systems
- **IEEE Std 1109-1990:** IEEE guide for the interconnection of user-owned substations to electric utilities
- **IEEE P1547/D08 -** Draft Standard for Interconnecting Distributed Resources with Electric Power Systems
- **P1589** - Draft Standard for Conformance Test Procedures For Equipment Interconnecting Distributed Resources With Electric
- Power Systems
- **Proposed IEEE SCC21 P1614** - Draft Guide for Monitoring, Information Exchange and Control of Distributed Resources

DG Interconnection Goals

- **Reduce technical barriers:**
  - Adopt uniform technical standard for interconnecting
  - Develop testing and pre-certification procedures for DG equipment
  - Develop distributed power control technology
- **Reduce business practice barriers:**
  - Establish standard commercial practices for utility review
  - Establish standard business terms for interconnection agreements
  - Develop tools for utilities to assess the value and impact of distributed power at any point on the grid
- **Reduce regulatory barriers:**
  - Develop new regulatory principles for distributed power choices in both competitive and utility markets
  - Adopt regulatory tariffs and utility incentives for distributed power
  - Establish expedited dispute resolution processes
  - Define the conditions necessary for a right to interconnect

Cogeneration - CHP

- **Combined Heat and Power is the generation of electricity and heat sequentially from the same energy source.**
- **Electricity primarily used on-site, but some can be sold back to grid. Grid can serve as back-up or swing provider.**
- **Thermal energy used for heating/cooling or process applications.**

Cogeneration - CHP

Traditional approach
- Electric Power
  - 100% remotely generated
- Comfort Heating
  - Boiler or Furnace
  - Gas or other fuel
- Domestic hot water
  - Hot water tank
  - Gas or other fuel

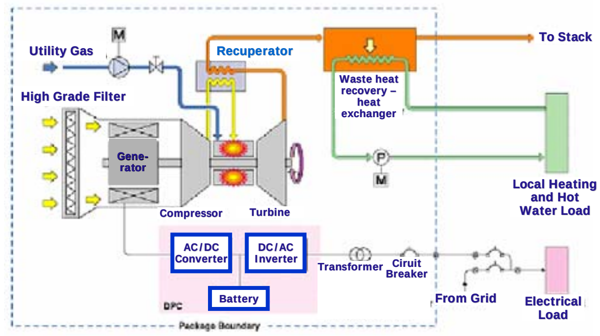
CHP Approach
- Electric Power
  - Local cogenerator
  - Utility supplemented
- Comfort Heating
  - Cogenerated heat
  - Back up Furnace
- Domestic Hot water
  - Heated by cogenerator hot water stream

Cogeneration - CHP

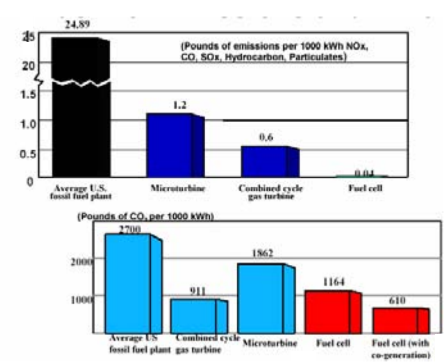
- CHP is more efficient than separate generation of electricity and heat.
- Higher efficiency translates to lower cost.
- Use of waste or byproduct fuel, where available, further reduces cost.
- On-site electric generation avoids distribution costs, a significant component of grid electricity price.
- Increased reliability and power quality can also add significant value.

Cogeneration - CHP

Microturbine Heat Recovery System



Efficiency and Emissions



Conclusions

- DG offers a valuable alternative to traditional sources of electric power for residential, commercial and industrial applications
- Modern technology means that small generators can compete with electric power systems (they can be more efficient, more reliable and simpler)
- The combination of grid and DG can provide higher performance than either could alone
- Usually in isolated and remote cases DG is the only reasonable alternative
- It offers an alternative that diligent business and utility planners should explore in the search for the best solution to electric supply problems


Questions ?