Introduction to Smart Grids*

*SMART GRID
Fundamentals of Design and Analysis
by James Momoh, 2012

CHAPTER 7:

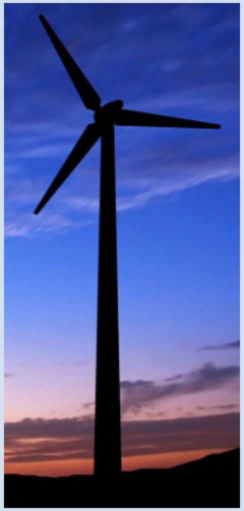
Renewable Energy and Storage

Introduction

Renewable Energy Resources

Desing & Development of the smart grid requires modeling;

- Wind
- PV
- Solar
- Biomass
- Fuel Cells



Trend is deployment of Distributed Energy Resources (DERs)

Sustaniable Energy Options For The Smart Grid

Sustainable energy is derived from natural sources that replenish themselves over of time. (They can be called «green power», since they are sun, wind, hydro etc.)

Renewable energy options are meant to provide the smart grid with;

- Remote utilization and storage of RER output,
- Enhanced Functionality of grid-connected RE Systems (RES)
  - Facilitating give and take of energy from the system
  - Redistribution of unused power from grid connected RES
  - Facilitating energy storage
  - Tracking interactions for billing and further studies
- Enhanced functionality for electric vehicles
- Utilization of e-car's battery packs as storage devices

The Common RER in Smart Grid Networks

1. Solar Energy
2. Wind Turbine Systems
3. Biomass-Bioenergy
4. Small and Micro Hydropower
5. Fuel Cell
6. Geothermal Heat Pumps

The Common RER in Smart Grid Networks

1. Solar Energy

It has no emission, it is reliable and it requires minimum maintenance

Harnessed by the use of PV cells discovered in 1839 by French physicist Edmund Becquerel.

It can be;

Single Panel

String of Panels

Paralel Strings of Panels

The PV system considers;

-Insolation: The availability of solar energy conversion to electricity. (temp, light intensity, position of panels etc)

-Emission: PV emission levels are e-friendly.

Several materials used for manufacturing;

-amorphoues silicon

-polycrystalline silicon

-cadmium telluride

-microcrystalline silicon

-copper indium selenide

The Common RER in Smart Grid Networks

1. Solar Energy

Cost of installation reduces day by day.

For modelling PV systems, there are some simulation programs such as «PV-DesignPro», which takes one year's worth of hourly global direct radiance, temp and wind speed data as input, computes the power output for different kinds of PV cells.

The I-V char. of power cell is modeled by belove;

$$I = I_{sc} - I_{os}\left(e^{\frac{q(V+IR_s)}{nkT}} - 1\right) - \frac{V+IR_s}{R_{sh}}$$

$$I_{os} = AT^{\gamma} e^{\left(\frac{-E_g}{nkT}\right)}$$

$$I_d = I_{sc} - I_{os}\left(e^{\left(\frac{q}{nkT}E_d\right)} - 1\right)$$

where for an array of $N_s \times N_{sh}$ solar cells:

$$I_d = \frac{I_{d\_mod}}{N_{sh}}$$

$$E_{d\_mod} = E_d \times N_s$$

$$R_{s\_mod} = R_s\left(\frac{N_s}{N_{sh}}\right)$$

I: current flowing into load of a solar cell (A)
I_{sc}: short circuit current (A)
I_{os}: saturation current (A)
s: insolation (kW/m^2)
q: electron charge (1.6 x 10^{-19} (C))
k: Boltzmann constant (1.38 x 10^{-23} (JK^{-1}))
T: p-n junction temperature (K), t (ºC)
N: junction constant
A: temperature constant
γ: temperature dependency exponent
E_g: energy gap (eV)
V: voltage across solar cell (V)
V_{oc}: open circuit voltage of a solar cell (V)
R_s, R_{s_mod}: series parasitic resistance for cell and entire module (Ω)
R_{sh}, R_{sh_mod}: shunt parasitic resistance for cell and entire module (Ω)
E_d, E_{d_mod}: across voltage of an ideal solar cell and entire module (V)
I_d, I_{d_mod}: current of an ideal solar cell and entire module (A)
N_s: number of series cell junctions of a PV module
N_{sh}: number of parallel cell junctions of a PV module
V_{out}: across voltage of a PV module (V)
I_{out}: current of a PV module (A)
R: connected load (Ω)

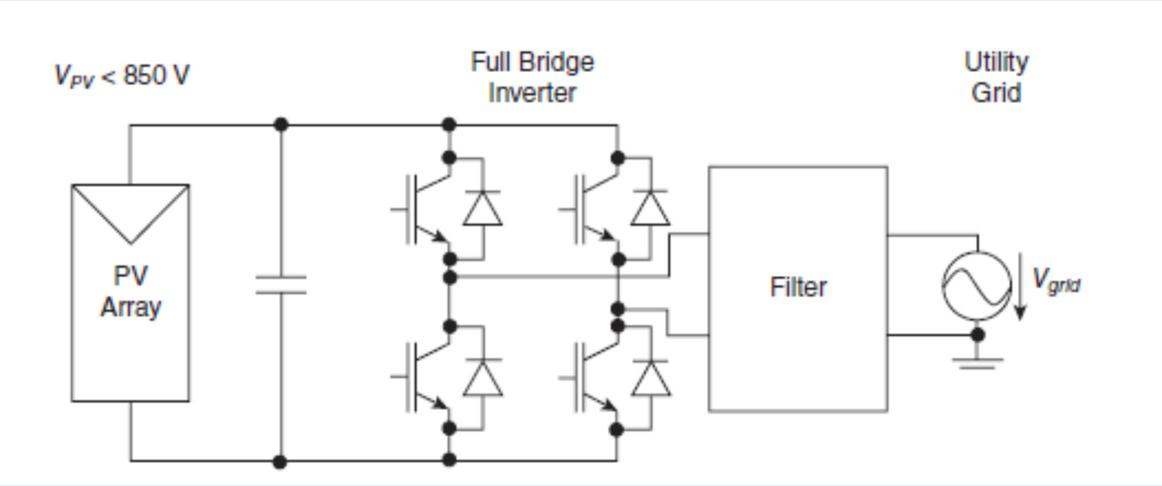
The Common RER in Smart Grid Networks

1. Solar Energy

Conversion & Power Electronic Tech:

Several Inverter systems convert or transfrom DC into AC for grid.

Mathematical models and probability density used to model PV behaviour include Beta and Rayleigh density functions.



PV inverter system for DC-AC conversion.

The Common RER in Smart Grid Networks

2.Wind Turbine System

It is the fastest growing RER in World right now.

It is cheaper than Solar since it can be connected to grid much more easily.

A wind türbine consists of;

- a rotor,
- a generator,
- blades
- driver or coupling device.

Although turbines produces no $C0_2$ and very very e-friendly, there is a big drawback;

- No consistency, power is produced only when there is sufficient wind.
- Output power cannot be controlled.
- Noise pollution

The Common RER in Smart Grid Networks

2. Wind Turbine System

For modelling wind turbines;

$$P_m = \frac{1}{2}\rho \cdot \pi R^2 \cdot V^3 \cdot C_p$$

where

ρ is the air density (kg/m^3)

R is the turbine radius (m)

C_p is the turbine power coefficient power conversion efficiency of a wind turbine

V is the wind speed (m/s)

The electrical power output is given by:

$$P_e = n_o P_m$$

where

$n_o = \eta_m \eta_g$

η_m, and η_g are the efficiency of the turbine and the generator, respectively

The Common RER in Smart Grid Networks

2. Wind Turbine System

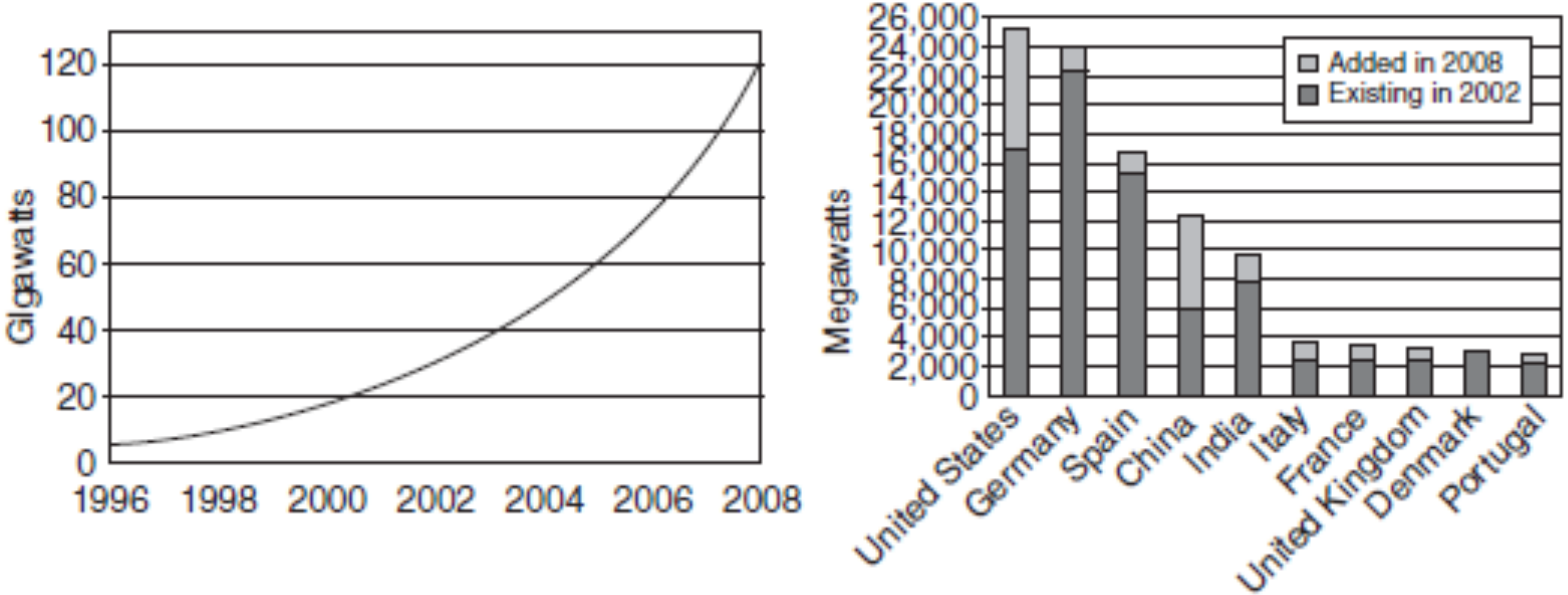


Figure 7.2. (a) Wind power, existing world capacity, 1996–2008; (b) wind power capacity, top ten countries, 2008.

The Common RER in Smart Grid Networks

3. Biomass-Bioenergy

Energy derived from organic matters such as;

- Corn
- Wheat
- Soybeans
- Wood

Biomass plants’ power ranges between 0.5GW to 3.0GW.

In developing countires biomass, it is used domesticliy for cooking and heating.

Biomass is not so green, produces $C0_2$ like thermal plants.

The Common RER in Smart Grid Networks

4. Small & Micro Hydropower

Most common RER in the World.

Small ones vary from 100kW to 30MW

Micro ones smaller than 100kW

Induction motors provide a generator for a türbine system,

hydraulic türbine converts the water energy to mechanical rotational energy.

The Common RER in Smart Grid Networks

5. Fuel Cell

Used for enchancing power delivery in the smart grid

Fuels from Hydrogen, Natural Gas, Methanol, Gasoline.

Fuel Cells are e-friendly, **nearly** no C-emission but more expensive than the other RER

The topology of a fuel cell holds the electrodes and electrolytic material.

Good for enviroment but bad for high power demand situations since it has high capital cost.

Most common used ones are;

- Phosphoric acid fuel cells (PAFC)
- Proton membrance fuel cells. (operates at lower temp, no chemicals)

The Common RER in Smart Grid Networks

6. Geothermal Heat Pumps

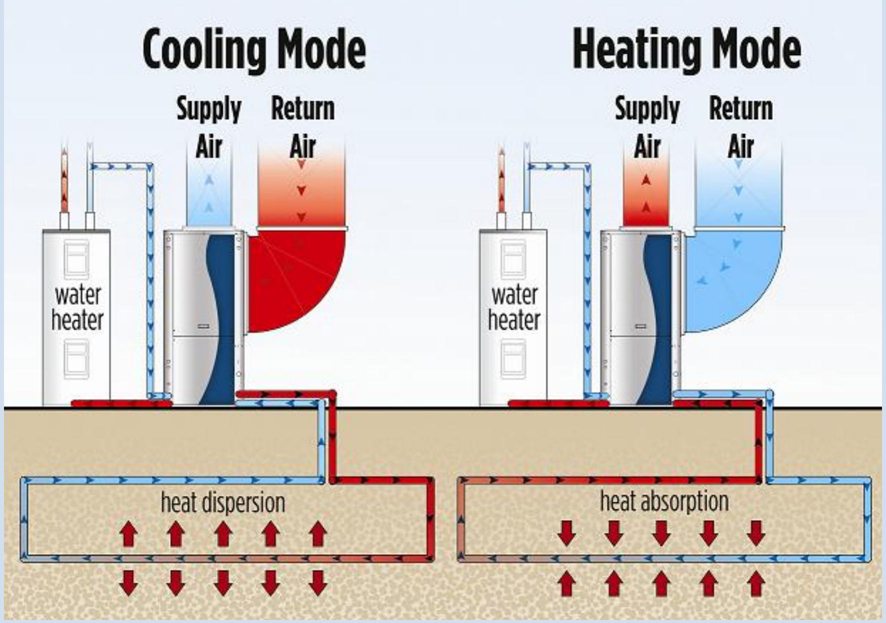
This form of power is based on accesing the underground steam or hot water from wells drilled several miles into earth.

Conventional steam turbines drive the electrical generator that produces power.

There are several types of it, namely;

- Dry Stream,
- Flash Stream,
- Binary Cycle.

Needs significant amount of investment and exploration risk must be calculated while planing geo-power plants.



Demand & Response Issues

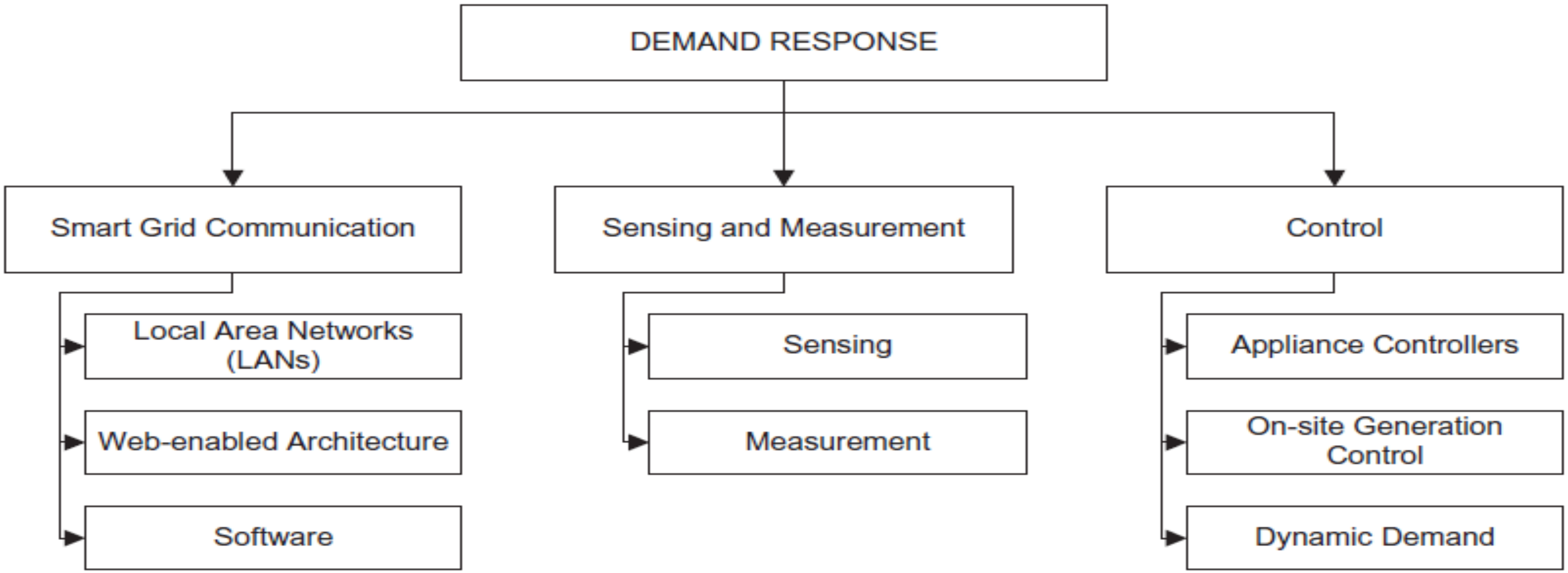


Figure 7.3. Demand Response technology tree.

Demand & Response Issues

Monitoring operating parameters such as voltage, angle, and frequency of system by real-time sensors is very important for answering the changing conditions of electric-prices. Demand and Response (DR) is the key feature of the smart grid.

DR can be categorized into 4 components as;

A. Energy Efficiency
B. Price-based DR
   a. Time-of-use (TOU)
   b. Day-ahead hourly pricing
C. Incentive-based DR
   a. Capacity/ancilliary services
   b. Demand bidding buy-back
   c. Direct load control
D. Time scale commitments and dispatch
   a. Years of system planning
   b. Months of operational planning
   c. Day-ahead economic scheduling
   d. Day-of economic dispatch
   e. Minutes dispatch

Electric Vehicles & Plug-in Hybrids

Integration of e-cars is another component of smart grid system.

Vehichle-to-gird (V2G) power uses e-cars to provide electirc to the system at certain time of the day.

When the car is at park state, and there is demand of power with high costs, owner of the e-car can set his/her car as generator make profit from it.

But regulations are not clear and the tech. behind this is not finished yet.

Very e-friendly as no CO2 emission as legacy cars.

Impact of Plug-in Hybrid E-Vehichle Technology (PHEV)

- PHEV will 50% of the market end of 2025 in USA
- Chargin battery will increase the load by 18% in USA
- This means voltage collapse up to 96% of the nominal voltage level in some areas of USA
- Charging time should be planned according to the peak-demand times in order to prevent voltage collapses.

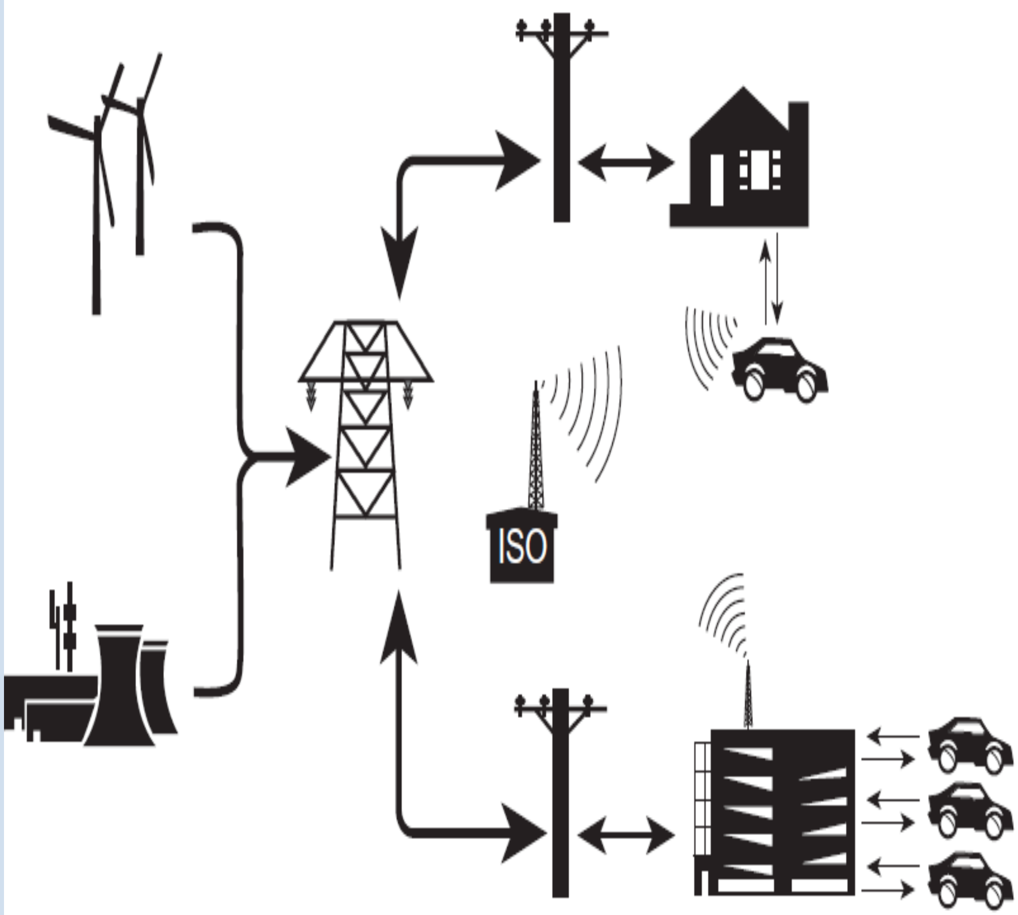


Figure 7.4. Schematic of proposed power line and wireless control connections between electric vehicles and the grid.

Enviromental Implications

Climate change is the term which is commonly linked to global warming & cooling (ice age)

Changes in long period of;

- in temperature
- in rainfall,
- in snow,
- wind patterns

Main causes of theese changes are;

- natural factors (such as changes in the sun's & earth's orbit, ocean circulation, acceptable)
- human factors (Co2 emission with burning C-bases fuels.)

Storage Technologies

Energy storage is important for utility load leveling, e-vehichles, solar energy systems.

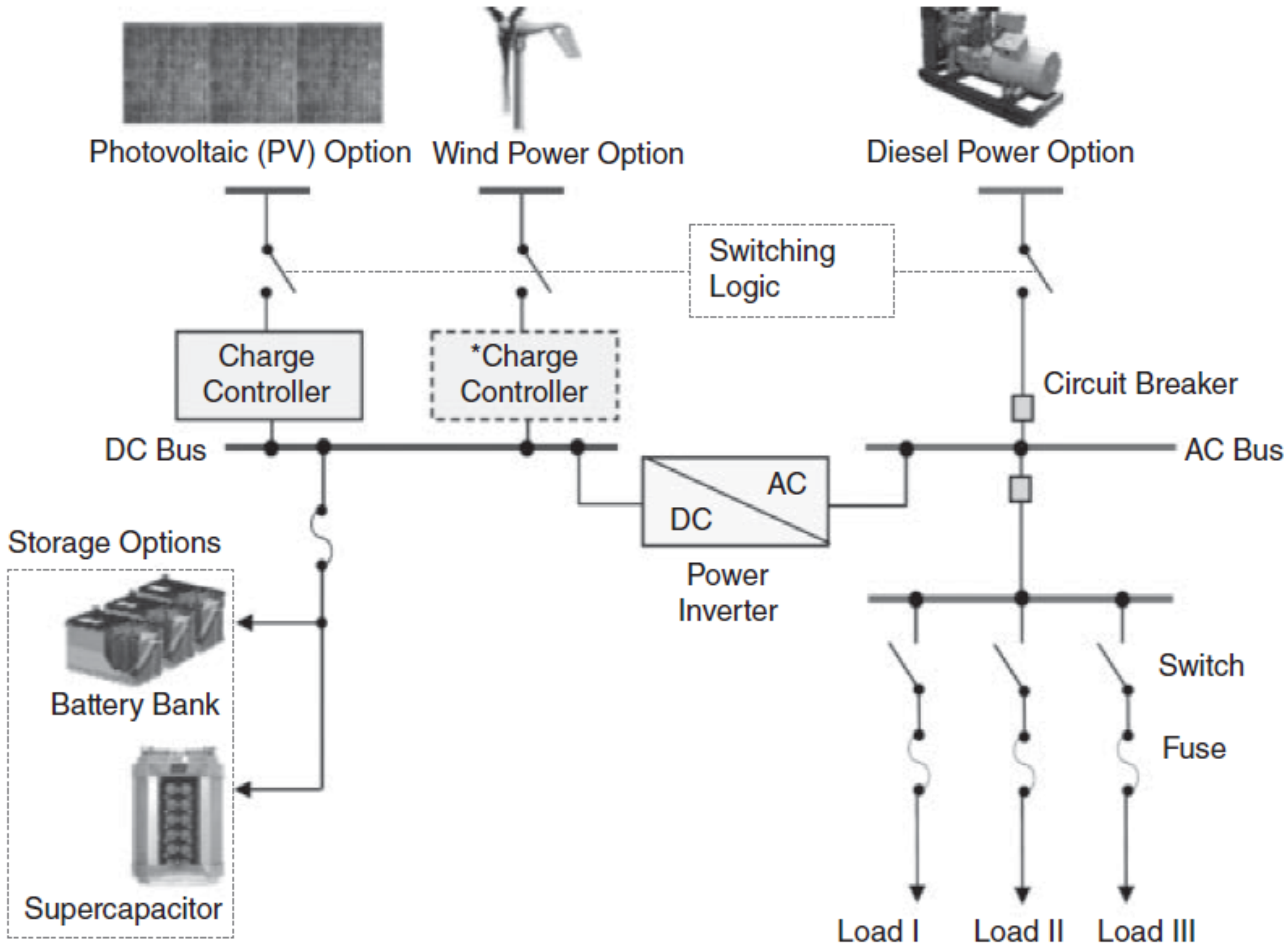


Figure 7.5. Microgrid topology with storage technologies.

Storage Technologies

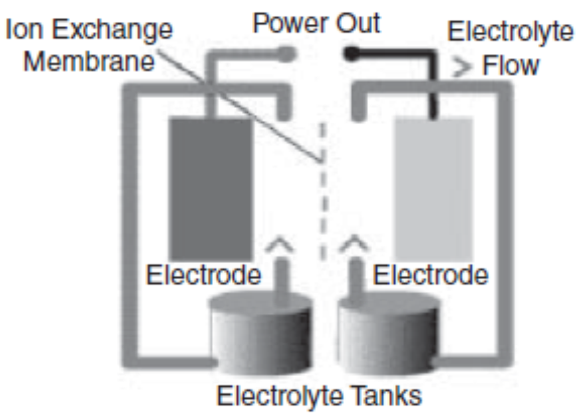
- **Unit Size**: Scale of technology. Storage technologies have an associated range for application, for example, large units support grid-connected RER technologies.
- **Storage Capacity**: Total store of available energy after charging.
- **Available Capacity**: Average value of power output based on the state of charge/ depth of discharge.
- **Self-discharge Time**: Time required for a fully charged, non-interconnected storage device to reach a certain depth of discharge (DOD), this is contingent on the operational condition of the system.
- **Efficiency**: Ratio of energy output from the device to the energy input issue of conversion technology and design of RER and storage and conversion needed.
- **Durability or Life-cycle**: Number of consecutive charge-discharge cycles a storage installation can undergo while maintaining the installations and other specifications within limited ranges. Life-cycle specifications are made against a chosen DOD depending on the applications of the storage device.

Storage Technologies

- **Autonomy:** Ratio between energy capacity and maximum discharge power; indicates the maximum amount of time the system can continuously release energy.
- **Mass and Volume Densities:** Amount of energy accumulated per unit mass or volume of the storage unit.
- **Cost:** Cost of installation, operation, and maintenance of storage technology; cost should be analyzed throughout system lifespan.
- **Feasibility:** Degree of adaptability to the storage applications.
- **Reliability:** Guarantee of service.

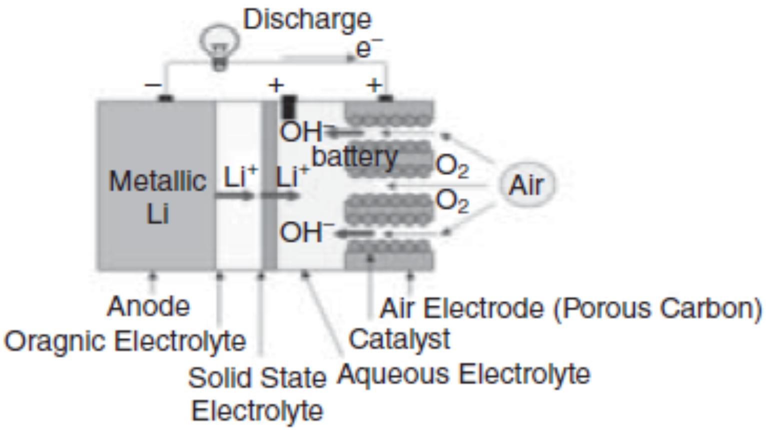
Storage options can be evaluated based on the characteristic of the application, for example, whether the application requires portable or fixed storage methods, the duration when storage will be operational, and the maximum power needed for the application. The selection of the proper storage technology is based on the following parameters:

Comparison Between Storage Technologies

Storage Technology	Characteristics/Particulars	Advantages	Disadvantages
Flow Batteries	Similar to lead-acid batteries, but the electrolyte is stored in a external container and it circulates through the battery cell stack 	• Unlimited electrical storage capacity, the only limitation is the size of the electrolyte storage reservoir	• Limited number of cycles of usage, after three (3) to five (5) years the system has to be changed

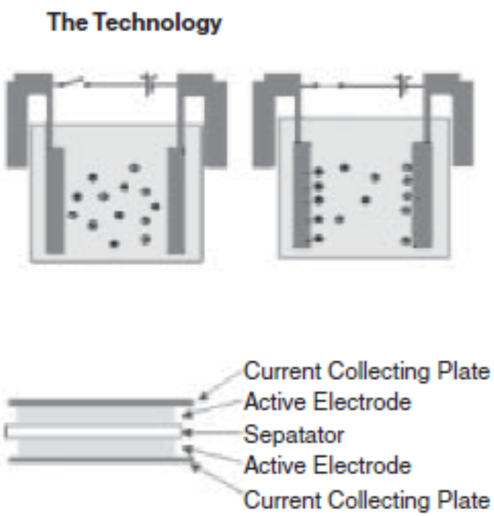
Comparison Between Storage Technologies

Advanced Batteries	Advanced batteries include lithium-ion, polymerion, nickel metal hybrid and sodium sulfur type	• Use less space than lead acid batteries	• Too expensive for large scale applications

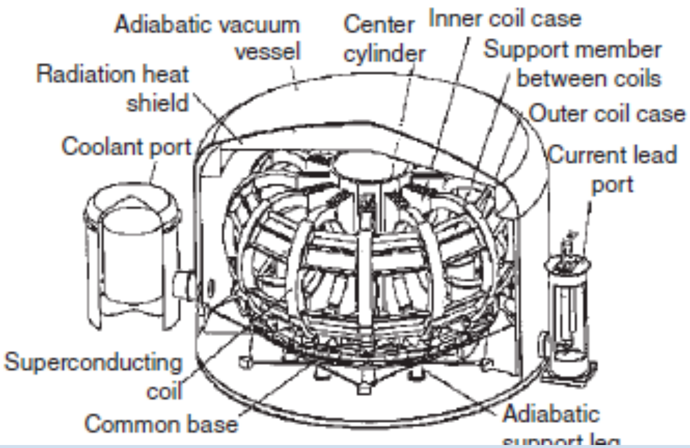


Comparison Between Storage Technologies

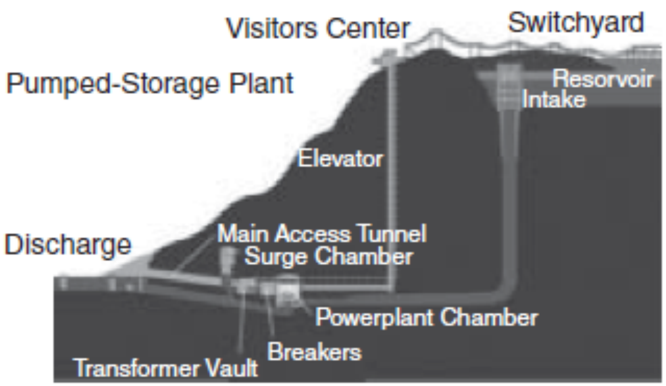
Super capacitors	Electronic device with the capacity to provide high power and energy which have the characteristics of capacitors and electrochemical batteries except there is no chemical reaction.	• Virtually unlimited cycle life • Low impedance • Rapid charging • Simple charge methods	• Linear discharge voltage prevents use of the full energy spectrum • Low energy density • Cells have low voltages • High self-discharge



Comparison Between Storage Technologies

Super Conducting Magnetic Energy Storage	Energy stored in the magnetic field created by the flow of direct current in a coil of superconducting material that has been cryogenically cooled. 	• Power is available almost instantaneously • High power output for a brief period • No loss of power • No moving parts	• Energy content is small and short-lived • Cryogenics, cold temperature technology, can be challenging

Comparison Between Storage Technologies

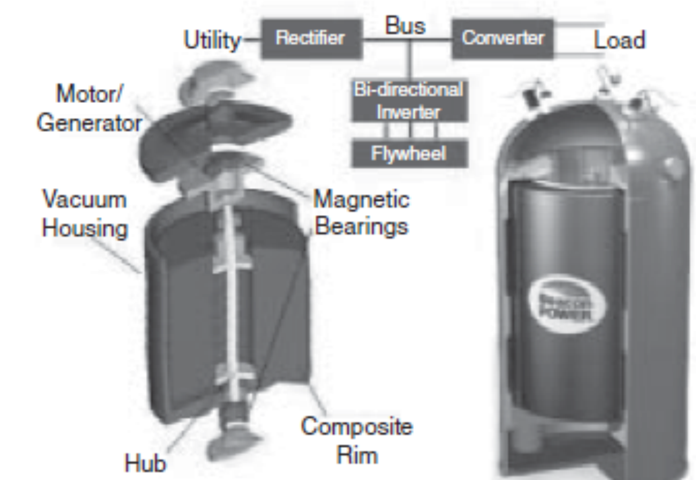
Pumped Hydro	The process of water being pumped from a lower reservoir uphill then allowing it to flow downhill to through turbines to produce electricity 	• Readily available and widely used in high power applications • Lower cost of power, frequency regulation on the grid, and reserve capability	Spends years in regulatory and environmental review • Can only be implemented in areas with hills

Comparison Between Storage Technologies

Compressed Air	Compressed Air Energy Storage (CAES) utilities use electricity generated during off-peak hours (i.e., storage hours) to compress air and store it in airtight underground caverns. When the air is released from storage, it expands through a combustion turbine to create electricity.	• Conserves some natural gas by using low-cost, heated compressed air to power turbines and create off-peak electricity	• Low efficiency due to the extra reheating energy needed to turn on the turbines • For every kilowatt-hour of energy going in, only.5 kilowatt-hour of energy can be taken out

Comparison Between Storage Technologies

Storage Technology	Characteristics/Particulars	Advantages	Disadvantages
Flywheels	A cylinder that spins at a very high speed, storing kinetic energy.	• Charge and discharge rapidly • Affected little by temperature fluctuations • Take up relatively little space • Long life span • Tolerant of abuse • Lower maintenance requirements than batteries	Power loss faster than for batteries



Courtesy of Beacon Power

Thank you for Listening