Introduction to Distributed Generation

Eugeniusz Rosołowski

Protection and Control of Distributed Energy Resources

Chapter 1

Choose yourself and new technologies

HUMAN CAPITAL
HUMAN – BEST INVESTMENT!

Wrocław University of Technology

EUROPEAN SOCIAL FUND

Project co-financed from the EU European Social Fund

General Information

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The course consists of:

- **lecture (15 h/semester),**
- **lab (15 h/semester),**
- **seminar (15 h/semester).**

Conditions of the course acceptance:

- **exam,**
- **laboratory pass,**
- **seminar pass.**

1. **Distributed energy resources**
   - **characterisation ,**
   - **fault protection issues.**
2. **Relay protection of distribution networks**
   - **general introduction,**
   - **line protection,**
   - **transformer protection,**
   - **generator protection,**
   - **network earthing issues.**
3. **Impact of distributed generation on network protection**
   - **islanding,**
   - **auto-reclosure,**
   - **protection devices coordination.**

4. **Distributed generation interconnection**
   - **requirements,**
   - **methods of islanding detection.**
5. **Wind turbine with Doubly-Fed Induction Generator**
   - **configuration,**
   - **aim of control,**
   - **active and reactive power control,**
   - **rotor flux control during transients (crowbar control).**
6. **DC generators connected via electronic devices.**

1. ***Network Protection & Automation Guide*. Alstom 2011. Available in (~25MB): http://electrical-engineering-portal.com/download-center/books-and-guides/electrical-engineering/automation-guide**
2. **ELMORE W.A., *Protective Relaying Theory and Applications.* MARCEL DEKKER, INC. 2004.**
3. **ALTUVE FERRER H.,J., SCHWEITZER, III, E.O. (Ed.), *Modern Solutions for Protection, Control, and Monitoring of Electric Power Systems*. Schweitzer Engineering Laboratories, Inc. 2010.**
4. **GE Publication Library: http://www.geindustrial.com/publibrary**
5. **SEL Technical Papers: https://selinc.com/literature/technical-papers/**

What are Renewable Energy Resources?

- **Renewable energy is defined as energy that is produced by natural resources - such as:**
  - **sunlight,**
  - **wind,**
  - **rain,**
  - **waves,**
  - **tides,**
  - **and geothermal heat**

that are naturally replenished within a time span of a few years.

What are Renewable Energy Resources?

Renewable energy includes the technologies that convert natural resources into useful energy services:

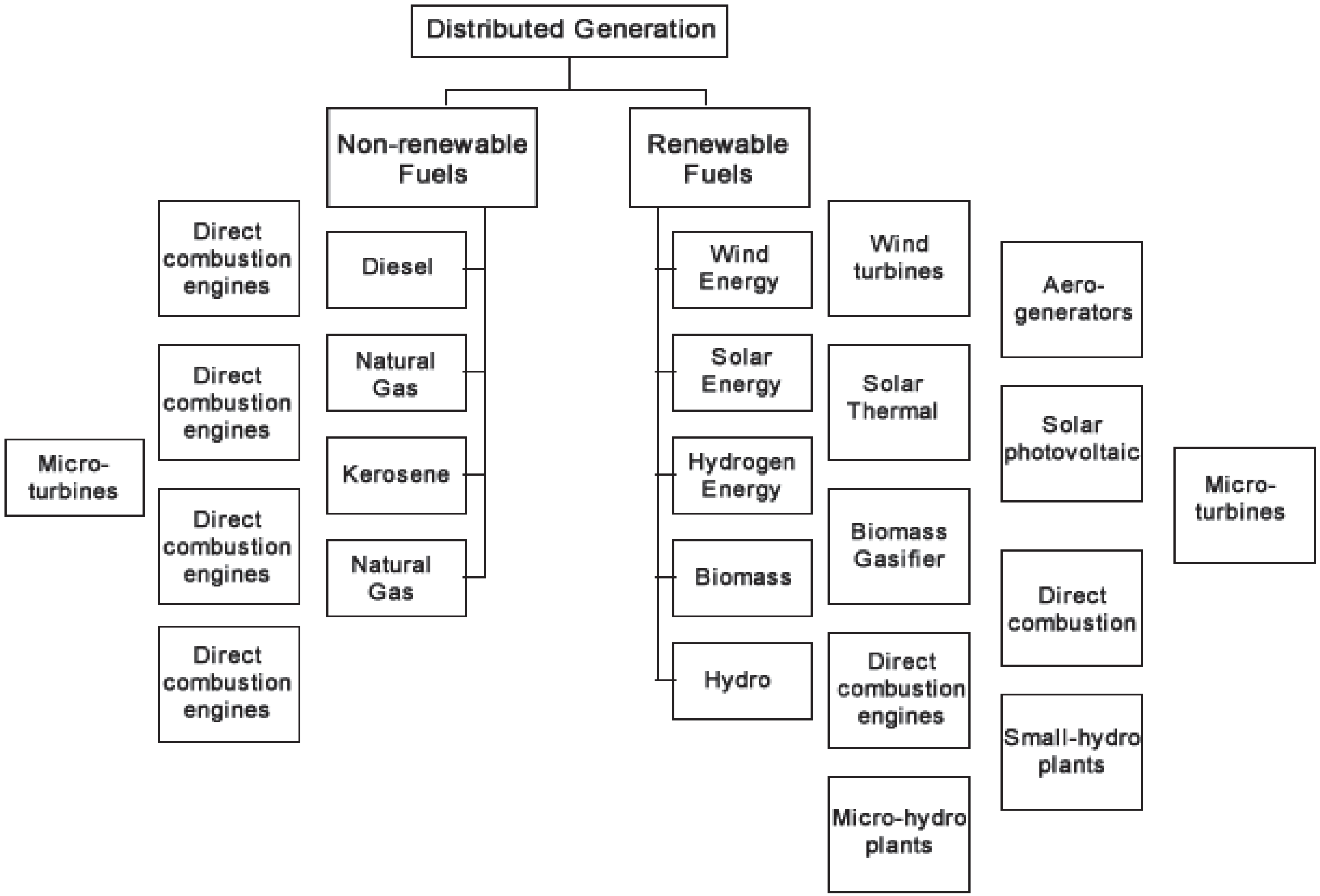
- **wind, wave, tidal, and hydropower (including micro- and river-off hydropower);**
- **solar power (including photovoltaic), solar thermal, and geothermal;**
- **biomass and biofuel technologies (including biogas);**
- **renewable fraction of waste (household and industrial waste) .**

What is Renewable Energy?

Renewable energy is energy obtained from natural and persistent flows of energy occuring in the immediate environment. Examples is solar energy, with a period (persistance) of 24 hours. Note that such energy fluxes exist whether or not they are harnessed. Also called green energy or sustainable energy.

Non-renewwable energy is energy obtained from static stores of energy that remain underground unless released by human intervention. Examples include nuclear fuels and the fossil fuels of coal, oil and natural gas. Also called finite supplies or brown energy.

Renewable and non-conventional Generation



What are Distributed Energy Resources?

Technologies installed by:

- **customers,**
- **energy service providers (ESP) or**
- **utility distribution company (UDC)**

at or near a load for an economic advantage over the distribution grid-based option.

What are Distributed Energy Resources?

- **Generates or stores electricity,**
- **Located at or near a load center,**
- **May be grid connected or isolated,**
- **Greater value than grid power:**
  - **Customer value,**
  - **Distribution system benefits,**
  - **Back-up or emergency power,**
  - **Social or environmental value.**

Sources of Renewable Energy

Primary source	Medium	Natural conversion	Technical conversion
Sun	Water	Evaporation, precipitation, melting.	Water power plants.
	Wind	Atmospheric airflow, wave movement	Wind energy conversion, wave power plant, ocean power plant .
	Solar energy	Ocean current, heating earth and atmosphere, solar radiation.	Thermal power, heat pomps, heliothermal conversion, photovoltaic conversion.
Earth	Biomas	Biomas production.	Co-generation plants.
	Isotop decay	Geothermal heat.	Co-generation plants.
Moon	Gravitation	Tides.	Tide power plants.

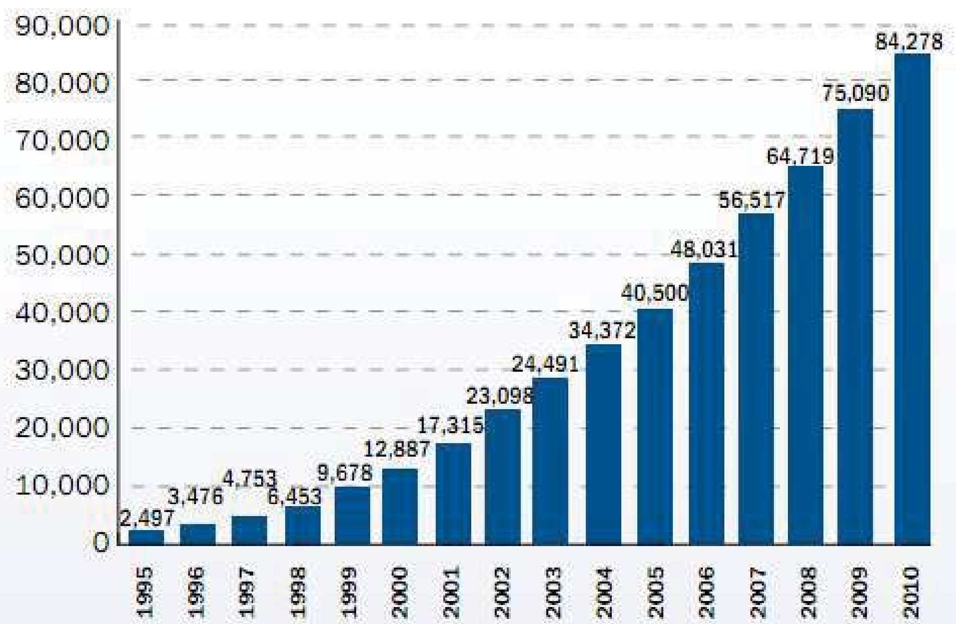
Renewable energy includes the technologies that convert natural resources into useful energy services:

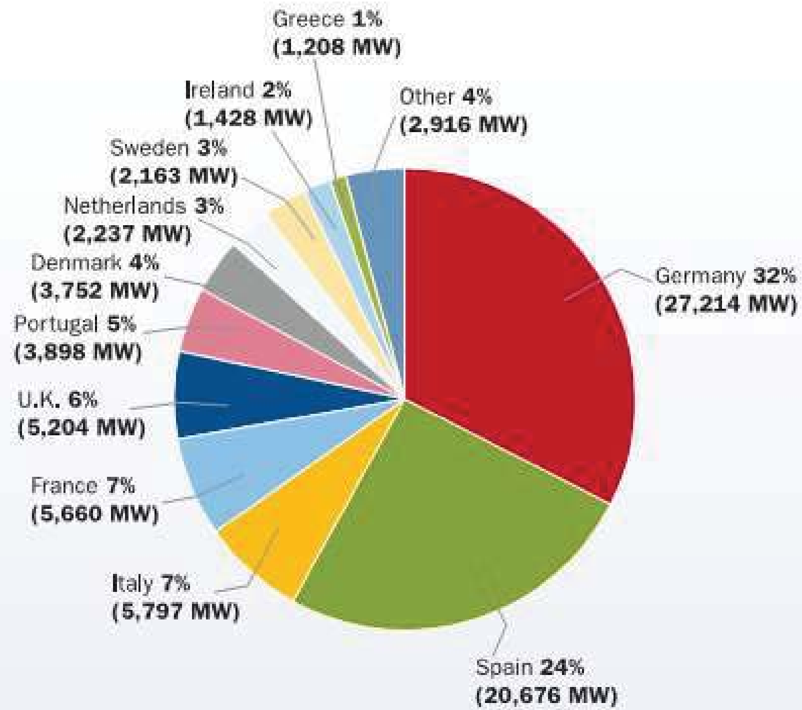
- Wind turbines and wind farms,
- Solar photovoltaic (PV) cells,
- Solar-thermal energy,
- Fuel Cells
- Geothermal,
- Wave and tidal energy,
- Biomass,
- Micro or mini hydro.

Characteristics of PES with Wind

- Review of Wind Generation Penetration in The World
- Review of Wind generation technologies used in Electric Power Systems (EPS)
- Wind Generation Effects on the Power System Operation
    - Frequency control performance
    - Voltage control performance
    - Other issues related to wind generation connection
- Effects of Wind intermittency

The amount of wind generation is constantly growing





World: 194 GW

Wind Power

- **A wind turbine consists of two or three propeller-like blades.**
- **The rotor is attached to the top of a tall tower.**
- **As the wind blows it spins the rotor.**
- **As the rotor spins, it produces energy in generator.**
- **Wind farms are places where many wind turbines are clustered together.**

Wind farms are places where many wind turbines are clustered together.

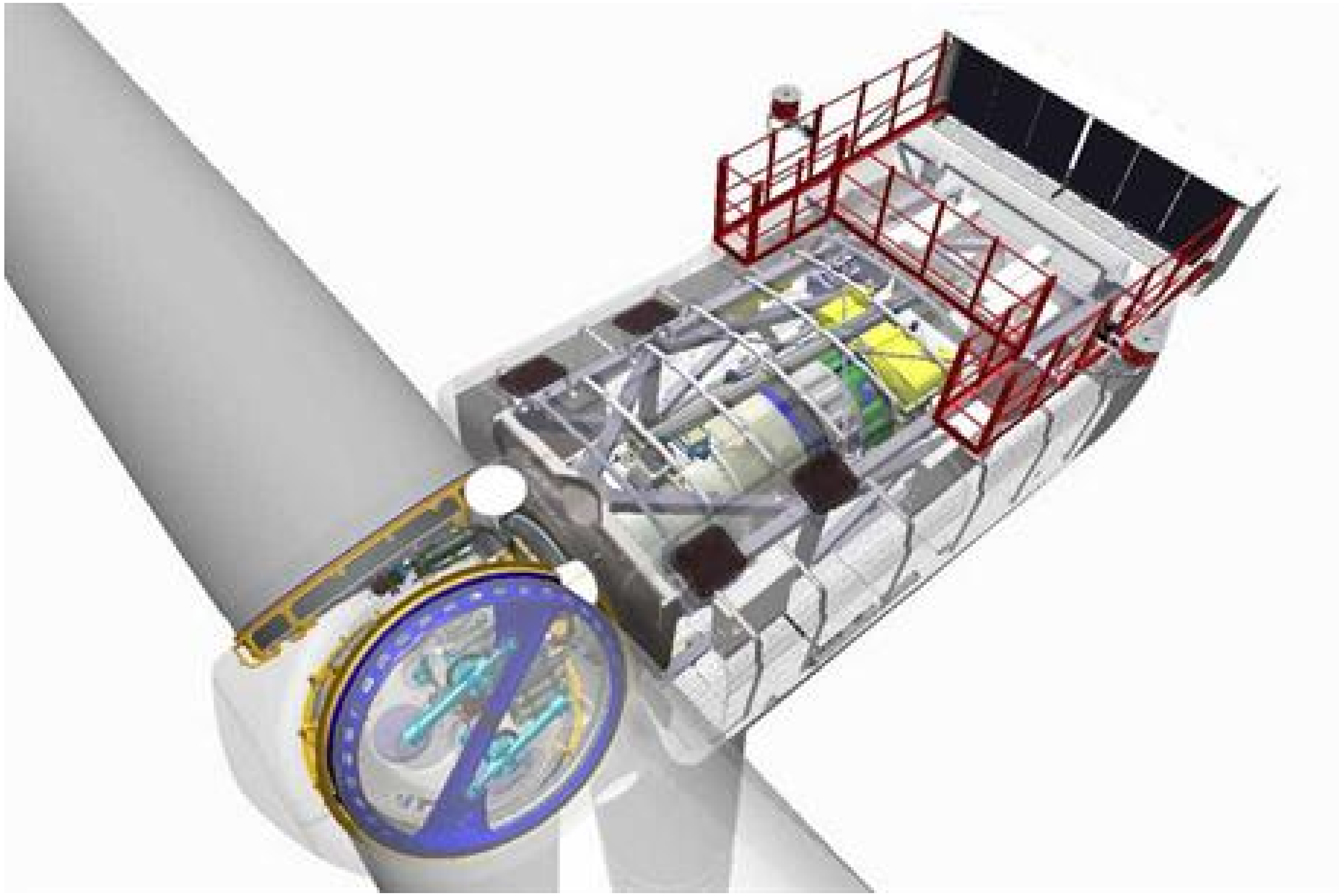
Wind Power Potential

- **Wind power could provide for the entire world's current and future energy needs.**
- **They also included the possibility of offshore wind turbines, but restricted them to 50 nautical miles off the coast and to oceans depths less than 200 meters.**
- **wind energy could not only supply all of the world's energy requirements, but it could provide over forty times the world's current electrical consumption and over five times the global use of total energy needs.**

Enercon E126, World's Largest Wind Turbine at 6 MW
The hub height is 135m while the rotor diameter is 126m.

Aurich, Germany, 2009

http://upload.wikimedia.org/wikipedia/commons/5/56/E_126_Georgsfeld.JPG



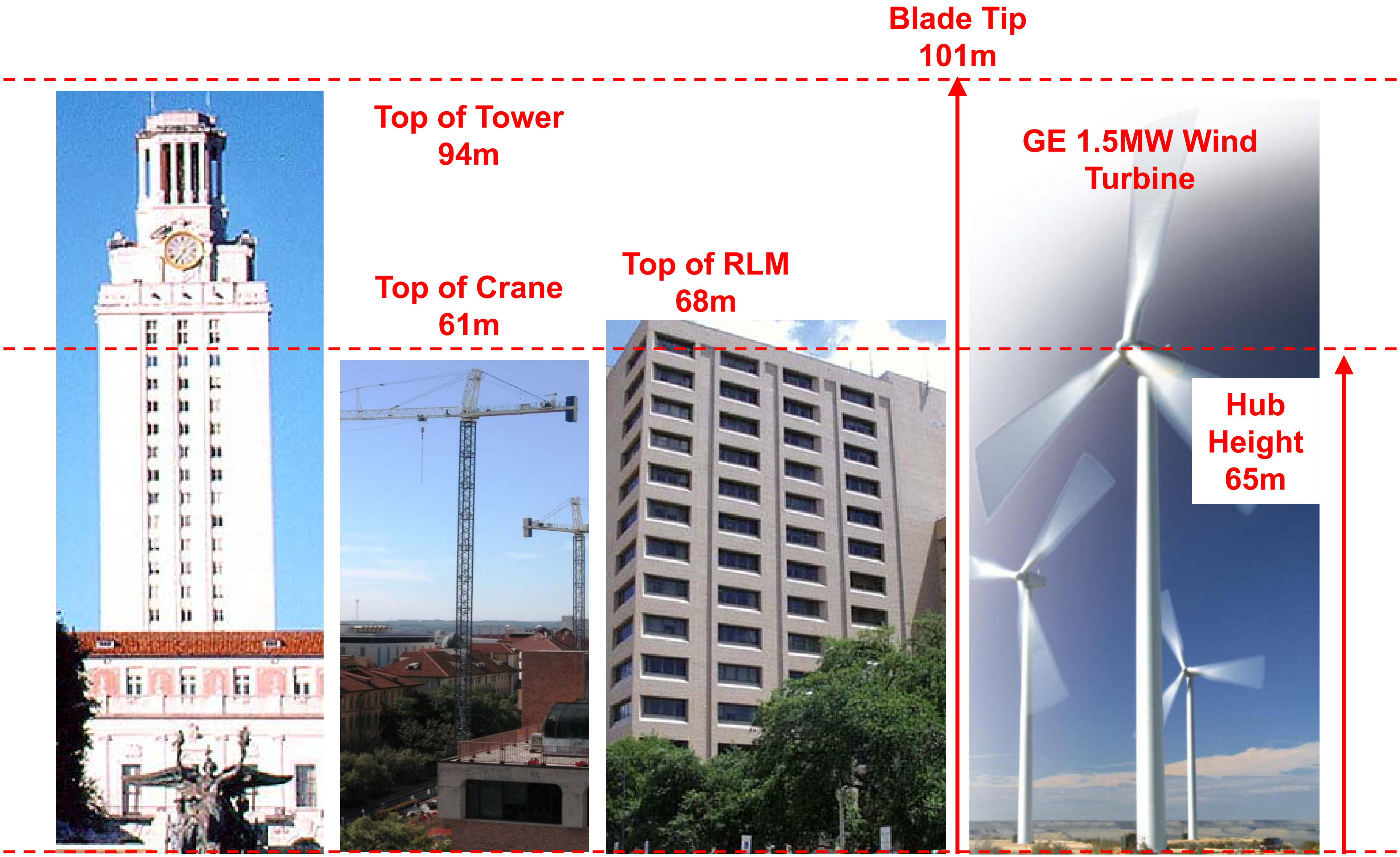
Vestas V164-8.0 nacelle and hub.

World's Largest Wind Turbine at 8 MW
The rotor diameter is 164m.
710V generator.

Odense Fjord, Jutland, Denmark 2016

http://www.windpowermonthly.com/article/1211056/close-vestas-v164-80-nacelle-hub

How Tall Are Wind Turbines?

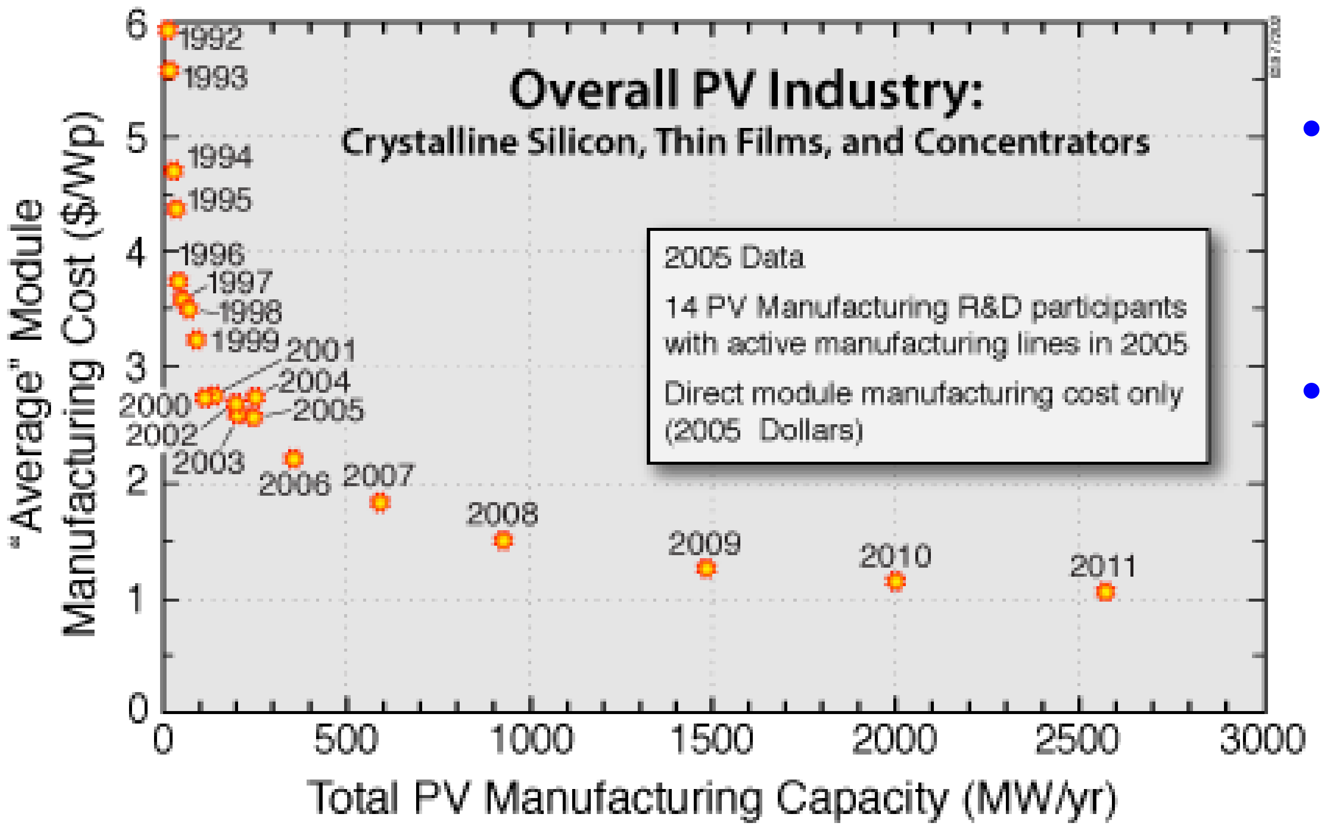


http://www.ece.utexas.edu/~grady/

PhotoVoltaic (PV)

- **Solar PVs are arrays of cells containing a material that converts solar radiation into direct current electricity.**
- **Materials presently used for PVs include amorphous silicon, polycrystalline silicon, microcrystalline silicon, cadmium telluride, and copper indium selenide/sulfide.**
- **Photovoltaic production has been doubling every 2 years, increasing by an average of 48 percent each year since 2002.**
- **This makes it the world's fastest-growing energy technology.**
- **At the end of 2008, the cumulative global PV installations reached 15,200 megawatts.**

PV



- **Cost/Capacity Analysis.**
- **Wp = peak Watt**

http://courses.engr.illinois.edu/ece333/fall2010/notes/

http://www.nrel.gov/pv/pv_manufacturing/cost_capacity.html

PV

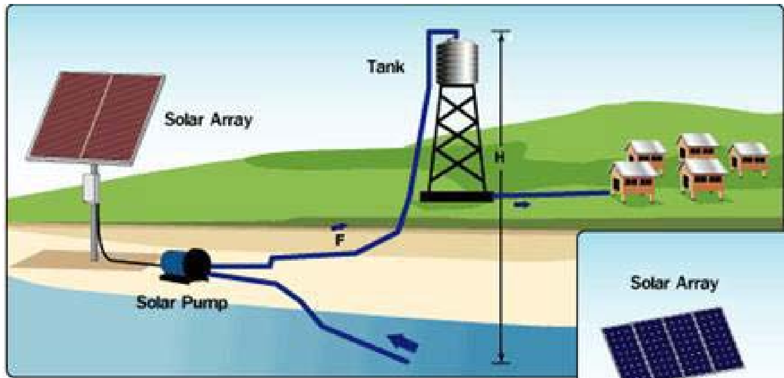
- **Roughly 90% of this generating capacity consists of grid-connected electrical systems.**
- **Solar PV power stations today have capacities ranging from 10-60 MW although proposed solar PV power stations will have a capacity of 150 MW or more.**

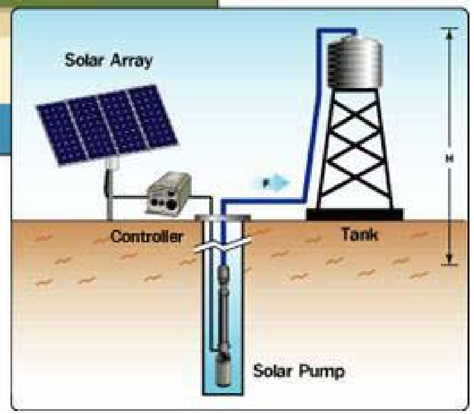
PV

- **Mojave Desert, California**
- **Aerial view of the five 30MW parabolic trough plants**
- **Solar Electric Generation System (SEGS)**
- **Largest solar energy facility in the world – 354 MW**

PV application

- Around the world nowadays **there are more than 15,000 solar powered bore and surface water pumps in use.** These are extensively used at farms and outback stations to supply surface and bore sourced water to livestock's and irrigation.





http://solar-investment.us/solar-pv-surface-and-bore-water-pumping/

SOLER R., *Solar Energy*, PSCC Conference, 22 August 2005

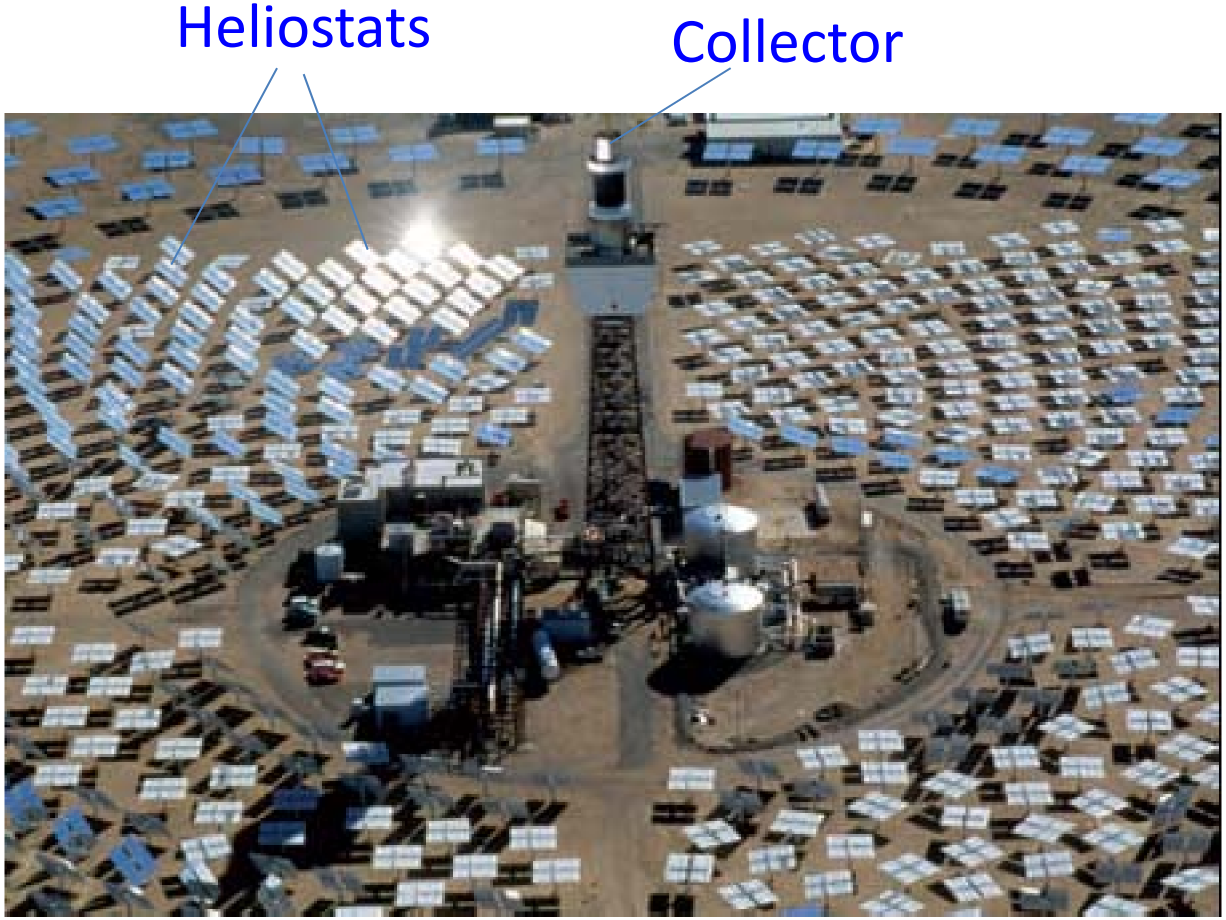
SOLER R., *Solar Energy*, PSCC Conference, 22 August 2005

Solar-Thermal

- **Example from a Spanish company: world's first solar thermal plant named PS-10 near Seville.**

- **Giant mirrors are placed on the ground that tracks the sun all day long and reflects its light on a white tower. PS-10 is in operation since March 2006 and generates 11 MW of power.**

Solar-Thermal



Large-scale, central receiver, solar thermal installation:
10 MW Solar Two installation in the Mojave Desert, California.

Solar Thermal Power Plants

Location: 10 km east of Guadix in the municipal area of Aldeire and La Calahorra in the Marquesado del Zenete region, Granada Province
Turbine capacity: 49,9 MW
Estimated lifespan at least 40 years

available: http://www.flagsol-gmbh.com/flagsol/technology/solar-thermal-power-plants/index.html

Solar Thermal Power Plants

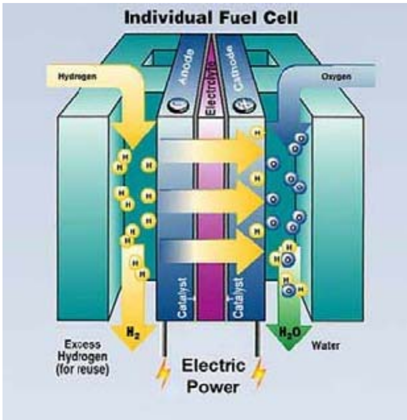
- **Solar-thermal power plants generate electricity by converting solar radiation into heat energy. The adoption and economics of each Concentrating Solar Power technology (CSP) depends on a series of factors, including geographic location, transmission, land constraints, materials and Operations & Maintenance (O&M).**
- **Several technologies are already established as viable. Parabolic trough installations have proven themselves the most efficient and economical solar thermal power plant technology available for producing electricity on a large scale.**

available: http://www.flagsol-gmbh.com/flagsol/technology/solar-thermal-power-plants/index.html

Other Forms of Generation

Geothermal

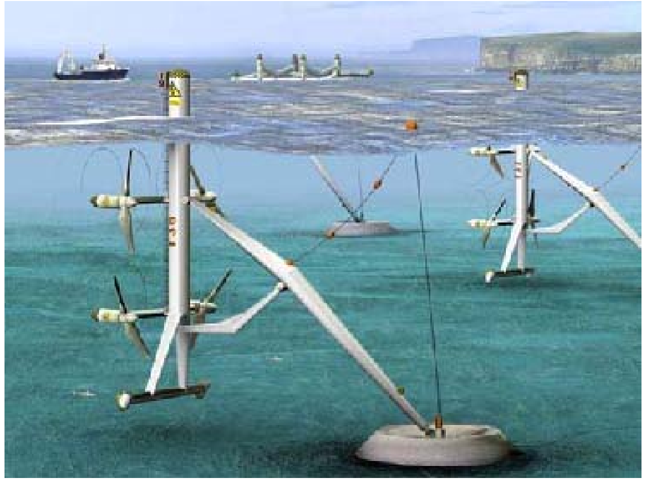
Hydro



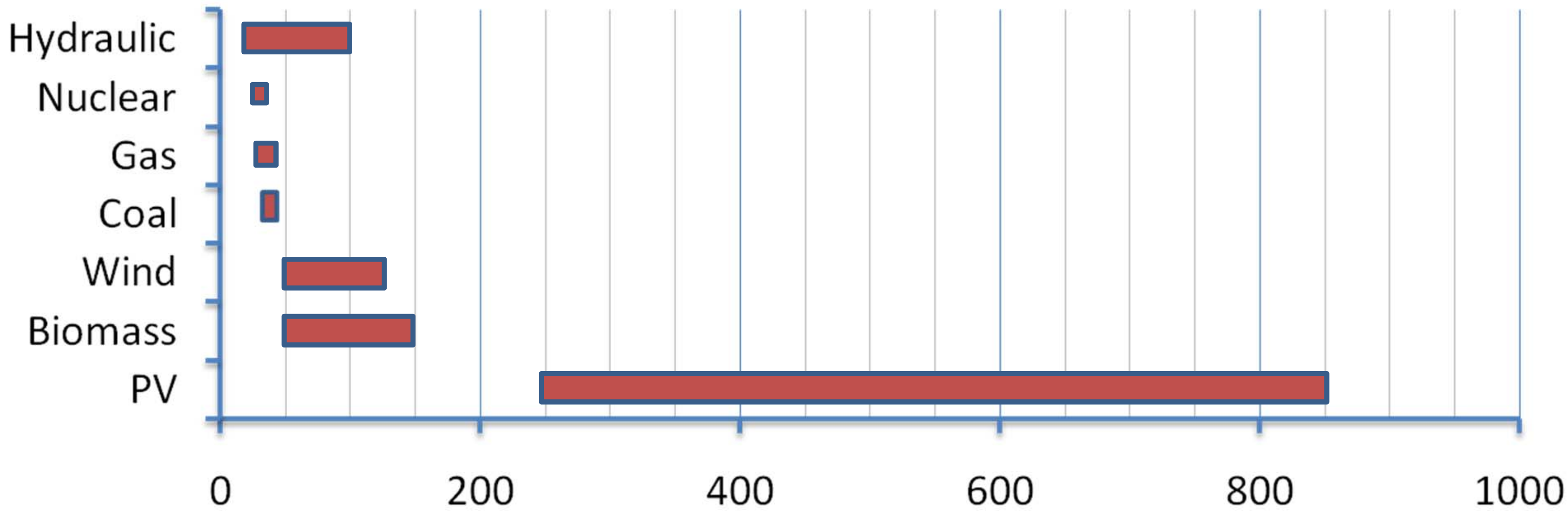
Fuell Cell

Microturbine

Tidal



Cost of Generation *in €/MWh)*



	PV	Biomass	Wind	Coal	Gas	Nuclear	Hydraulic
From	250	50	50	37	33	32	20
To	850	150	130	40	43	35	100

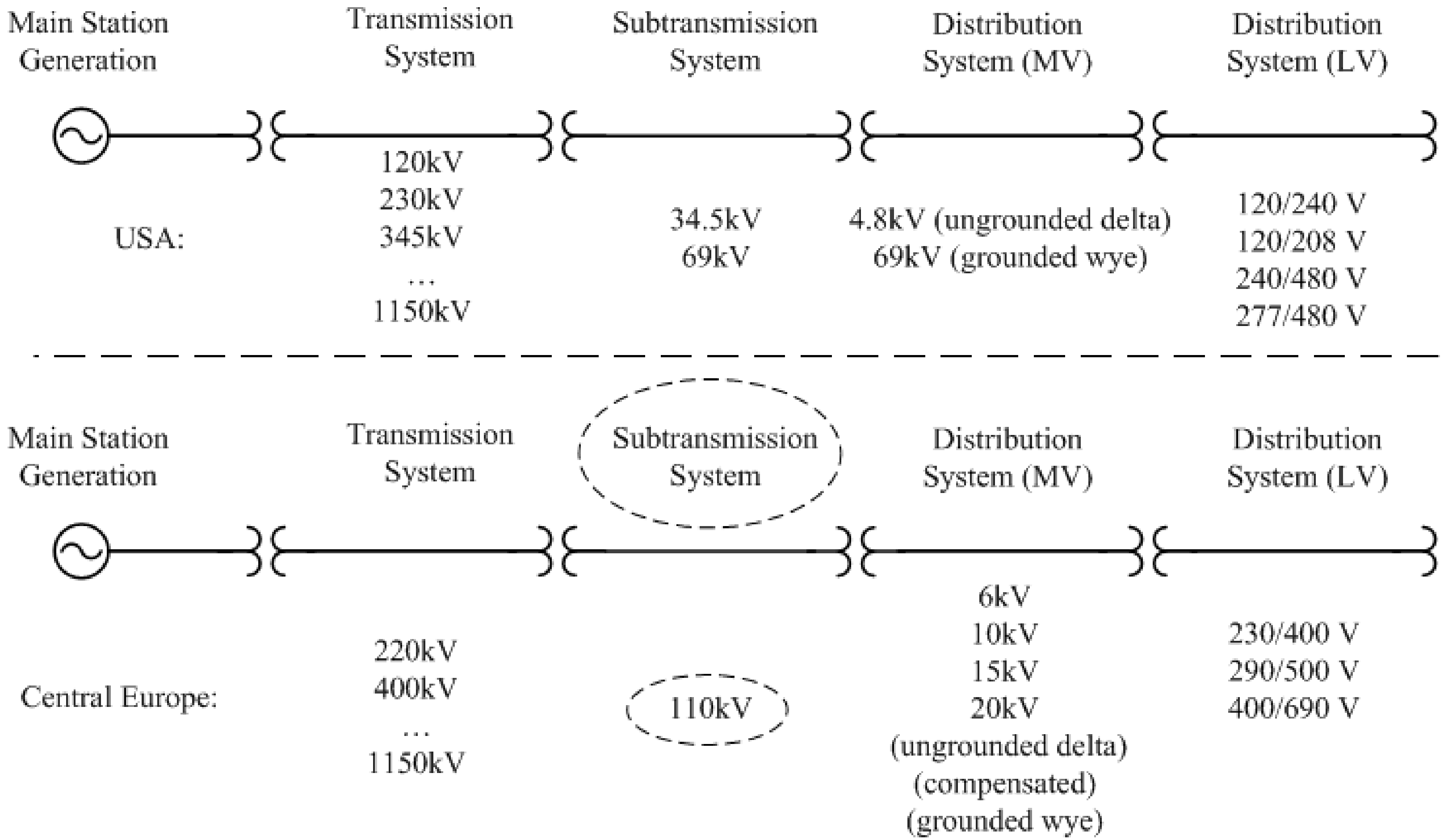
SOLER R., *Solar Energy*, PSCC Conference, 22 August 2005

Transmission and Distribution System Characteristics

The *transmission system* connects the generating stations and loads together through nodes called substations. The substations contain switches and circuit breakers, transformers to connected different voltage levels, and substation equipment (voltage control capacitor banks, reactors, metering and control equipment, etc.).

The *distribution system* provides the infrastructure to deliver power from the substations to the loads. Typically radial in nature, the distribution system includes feeders and laterals.

Transmission and Distribution System Characteristics



Distributed Generation (DG)

Distributed generation is any small-scale electrical power generation technology that provides electric power at or near the load site; it is either interconnected to the distribution system, directly to the customer's facilities, or both.

Distributed Generation (DG), Distributed Resources (DR), Distributed Energy Resources (DER) or Dispersed Power (DP) is the use of small-scale power generation technologies located close to the load being served.

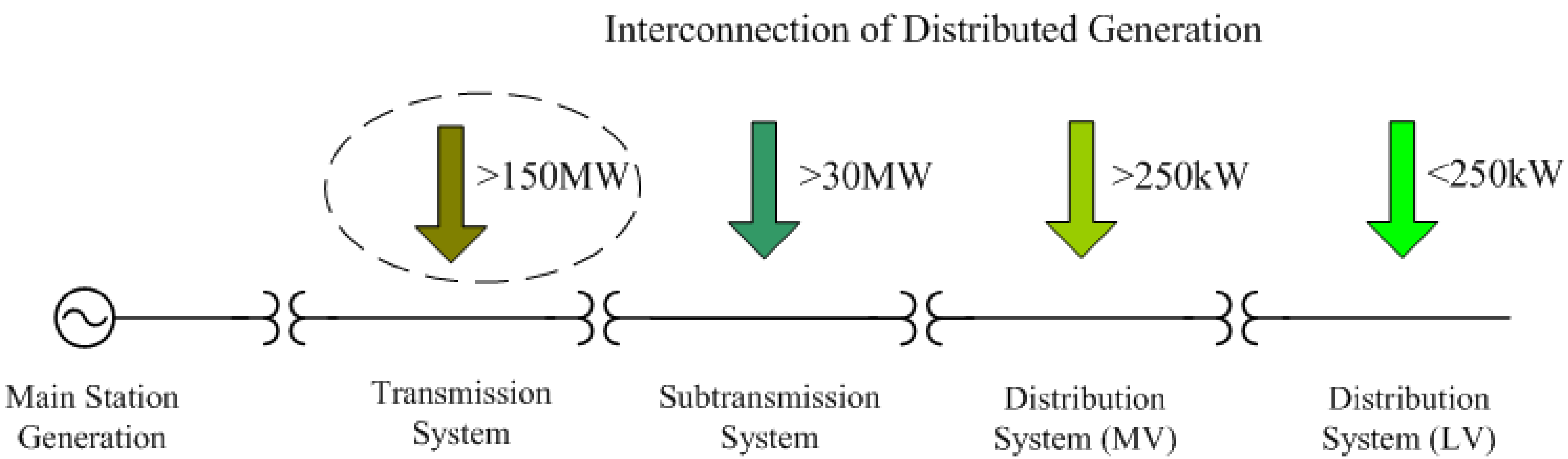
http://www.distributed-generation.com/library.htm

The Interconnection System

The interconnection system performs the functions necessary to maintain the safety, power quality, and reliability of connected EPSs and DRs.

System complexity depends on the level of interaction required between the DR and the EPS technologies located close to the load being served.

The Interconnection System



Characteristics of Distributed Generation

Connection of different energy resourses with different characters of loads needs special solution for control system.
Contemporary concepts aim at developing technology for integration and control of Renewable Energy Sources in Smart Grid Distributed Generation (SGDG).
SGDG system would provide the platform for the use of renewable sources and adequate emergency power for major load center (as metropolitan) and would safeguard in preventing the complete blackout of the interconnected power systems.

Characteristics of Distributed Generation

The Smart Grid can be operated in two modes of operations:

- **synchronized operation with the local utility system;**
- **island mode of operation upon loss of the utility system.**

If a Smart Grid DG system is connected to the local utility system the DG system can not change either the bus voltage or the system frequency.

Upon separation from a utility system, Smart Grid system regulates its frequency and voltage.

Characteristics of Distributed Generation

The Smart Grid realizes its tasks through the following measures:

- on-line control of the process parameters (voltage, frequency, quality indices, etc.);
- applying energy storage devices (SMES - superconducting magnetic energy storage, super capacitor energy storage (SCES), flywheel, etc.);
- implementing adequate fault protection system and other maintenance solutions – e.g. isolation and overload control;
- introducing un interraptible power supply (UPS) technology;

what needs special Smart Grid solutions, techology and communication.

Characteristics of Distributed Generation

To connect a DG-unit to the system certain minimum requirements have to be fulfilled. These requirements are usually specified by the transmission system operator and is called GRID CODE.

Two important areas of the requirements are:

- **how to ride-through a voltage disturbance, at for instance short-circuits,**
- **and how the power plant shall contribute to the power balance at frequency excursion situations.**

There are also standards and other regulations that state how the distributed generator shall behave at different disturbances.

Fault Protection Purposes

Fault protection detects abnormal power system conditions resulting from faults and intiates corrective action as quickly as possible in order to switch-off the faulty circuit and return the power system to its normal state.
The response must be automatic, quick and should cause a minimum amount of disruption of the power system. Response times of the order of a few *ms* are often required. Consequently, personnel intervention in the protection system operation is not possible.

WHY THE PROTECTIVE RELAYING IS NEEDED?

- **A primary objective of all power systems is to maintain a very high level of continuity of service, and when intolerable conditions occur, to minimize the extent and time of the outage.**
- **Loss of power, voltage dips, and overvoltages will occur, however, because it is impossible, as well as impractical, to avoid the consequences of natural events, physical accidents, equipment failure, or misoperation owing to human error. Many of these result in faults:**
  - **inadvertent, accidental connections, and flashovers between the phase wires or**
  - **from the phase wires to ground.**

The most important consequences of a fault:

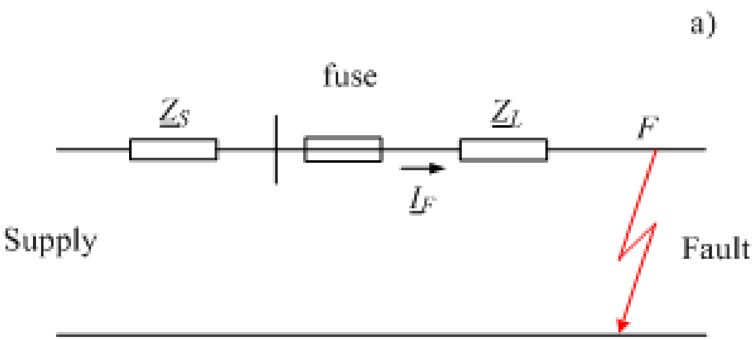
- **damage to plant due to the dynamic effects of the fault current**
- **damage to plant due to thermal effects of the current**
- **loss of system stability**
- **loss of supply to loads, also during downtime for repairs**
- **danger to life**

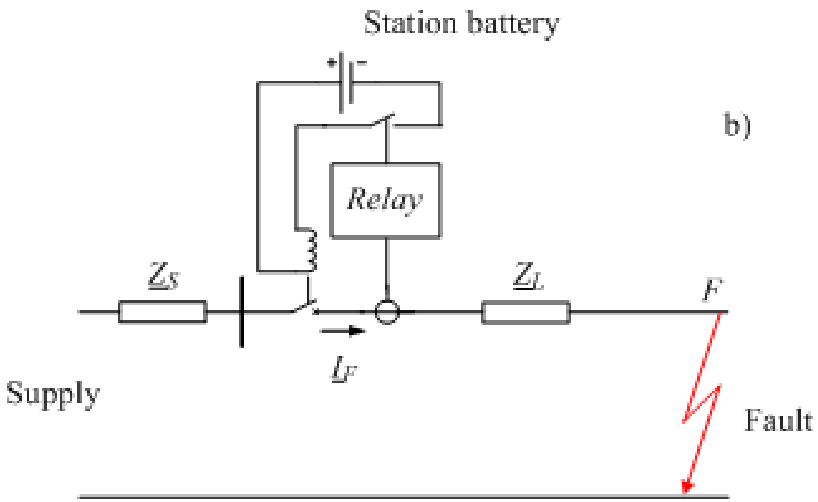
The damage a fault can bring about can be serious so the protection devices must operate:

- **as quickly as possible**
- **selectively - in order to isolate the faulty item of the plant**
- **reliably - no overfunction or underfunction**

Meeting of these requirements is the basic task of protection engineers

Principle of fault protection





Protection by a fuse

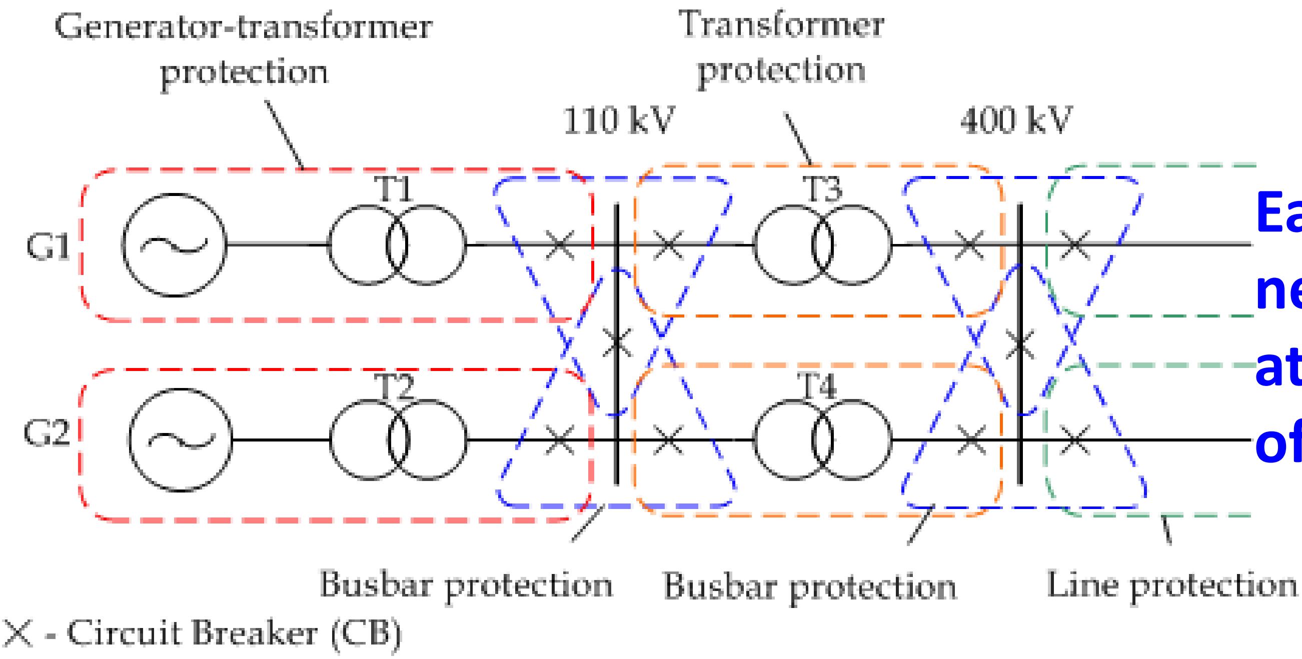
Protection by a relay

THE FUNCTION OF PROTECTIVE RELAYING

- **The function of protective relaying is to cause the prompt removal from service of any element of a power system when it suffers a short circuit, or when it starts to operate in any abnormal manner that might cause damage or otherwise interfere with the effective operation of the rest of the system.**
- **The relaying equipment is aided in this task by circuit breakers that are capable of disconnecting the faulty element when they are called upon to do so by the relaying equipment.**

ZONE OF PROTECTION

- **A zone of protection is the area where a protective relaying scheme is expected to detect faults and initiate isolation of failed components in order to minimize damage, to prevent consequential damage, and to prevent system collapse.**



Each circuit element needs to be included in at least one zone of protection.

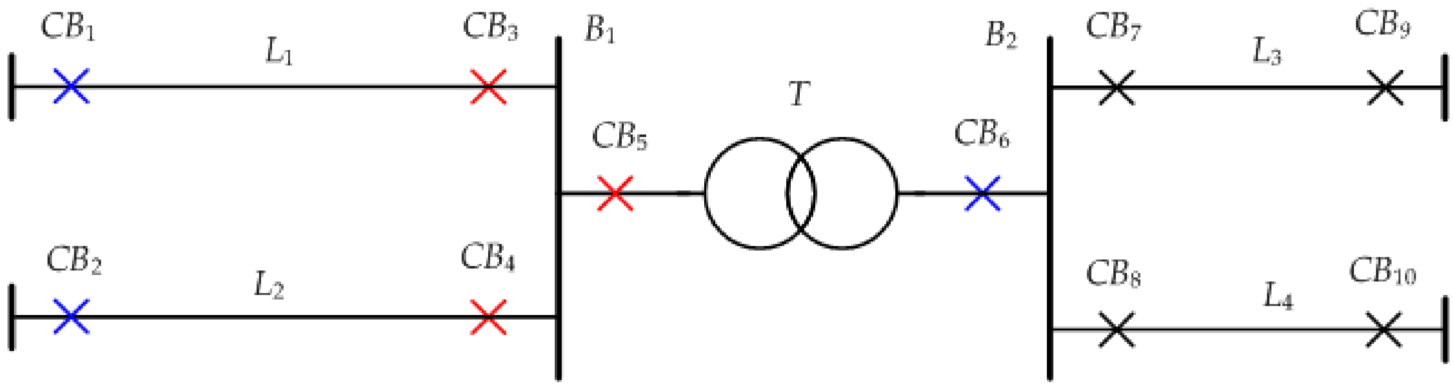
PROTECTIVE RELAYING PHILOSOPHY

- **Each line, bus, transformer, generator, motor, reactor, capacitor or other network element needs to be included in at least one zone of protection.**
- **Circuit breakers and circuit reclosers need to be included in two overlapping zones of protection.**
- **Circuit breakers are generally located so that each generator, transformer, bus, transmission line, etc., can be completely disconnected from the rest of the system. These circuit breakers must have sufficient capacity so that they can carry momentarily the maximum short-circuit current that can flow through them, and then interrupt this current.**

PROTECTIVE RELAYING PHILOSOPHY

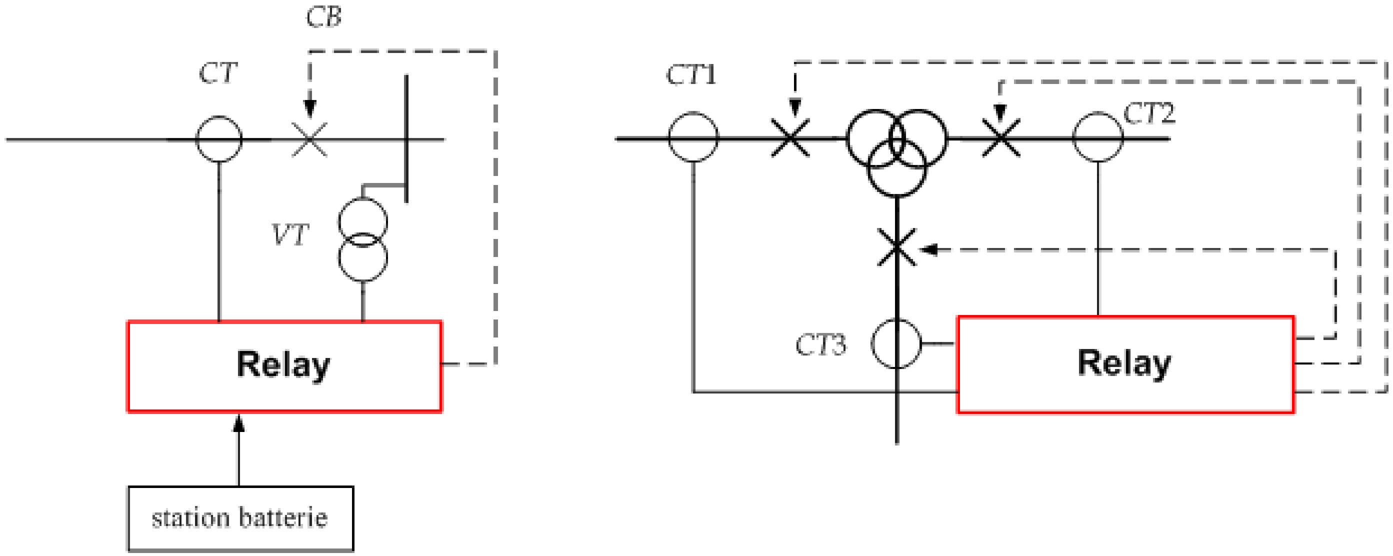
- Fusing is employed where protective relays and circuit breakers are not economically justifiable.
- There are two groups of relaying: -one which we shall call ‘primary’ relaying, and the other -‘back-up’ relaying. Primary relaying is the first line of defense, whereas back-up relaying functions only when primary relaying fails.
- Back-up relaying is employed only for protection against short circuits.
- Back-up relays should be connected to a separate set of instrument transformers (measurement devices).

PRINCIPLE OF BACK-UP PROTECTION



- **Primary busbar B_1 protection controls: CB_3, CB_4 and CB_5. Back-up protection relays of the same busbar control: CB_1, CB_2 and CB_6.**
- **Primary transformer T protection controls: CB_5 and CB_6. Back-up protection relays of the transformer control: CB_1, CB_2, CB_9 and CB_{10}.**

PROTECTIVE RELAYING SCHEME



Relaying scheme consists of:

relay itself,

CT – current transformer, VT – voltage transformer,

CB – circuit breaker.

RELAY CHARACTERISTICS

- Selectivity (discrimination) - **the quality where a relay or protective system is enabled to pick out and cause to be disconnected only the faulty element.**
- Stability **describes the quality of a protective system by virtue of which it remains inoperative under specified conditions usually associated with high values of fault current: requirement to remain inoperative under all conditions associated with faults outside their own zone.**
- Sensitivity - **refers to the level of fault current at which operation occurs; in other words, it is the fault setting and is usually expressed either in amperes referred to the primary circuit, or as a percentage of the rated current of the current transformers.**

RELAY CHARACTERISTICS: Selectivity

The ability to isolate only the defective plant from the rest of the system which can be achieved by:

- **Time grading , i.e. the protection device nearest the fault trips the fastest and all the others between it and the power source relatively slower**

  Application: overcurrent and distance protection
- **Amplitude and/or phase comparison of the currents at both sides of the protected unit**

  Application: pilot wire and differential protection
- **Determination of fault power flow direction at both sides of the protected unit**

  Application:

  directional comparison protection
  distance protection with communication channel

RELAY CHARACTERISTICS: Reliability

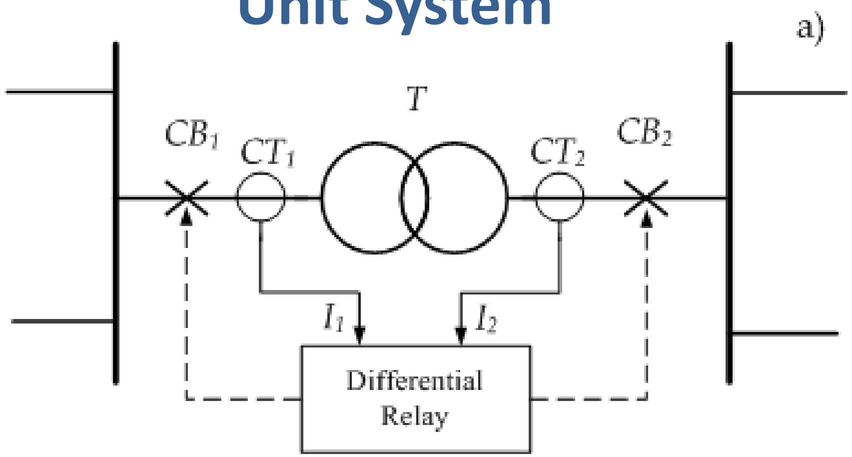
The ability of a protective device to fulfill its purpose throughout its operational life

- **depedability: the assurance that the protection device will perform its function and selectively trip the protected item of a primary plant in the event of a fault**
- **security: the assurance that the protection device will not trip unless there is a fault on the protected item of a primary plant**
- **availability: the ratio of the time that a protection device is actually serviceable to the total time it is in operation**

TYPES OF PROTECTIVE RELAYING SCHEME

- **Unit system protection – it is able to detect and respond to an abnormal condition occurring only with the zone or the element which is specifically intended to protect. It is said to have *absolute discrimination*.**
- **Nonunit system protection - has dependent (or relative) discrimination.**

Unit System



Nonunit System