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ELEC3310:
Electrical Energy Conversion and Utilisation

Topic 1: Introduction

Professor Mithulan Nadarajah.

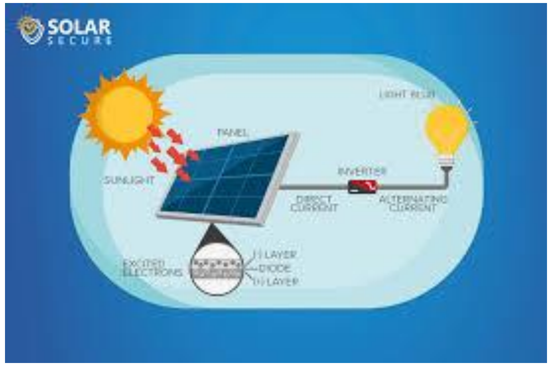
Office 47-405A

Energy Sources

Energy may be classified as either

- Primary sources
  - Directly obtainable from nature
    - Nuclear
    - Fossil fuels (Coal, Oil, Gas)
    - Renewable (Solar, Wind, Hydro, Biomass, Tidal, Geothermal etc.)

- Secondary sources
  - Derived from primary
    - Electricity is a secondary source of energy



Electrical Energy Production - Conventional Methods

Basic process is conversion of mechanical energy into electrical energy

Different sources of mechanical energy exist

- Water under hydraulic pressure used to rotate turbine coupled to generator shaft
  - Efficiency of 80 – 90 %
- Energy of fuel converted to heat which is used to create high temperature steam. Steam pressure used to rotate turbine
  - Efficiency of 30 – 40%
- Electrical Energy from natural sources
  - Low efficiency 15-40 %
  - Intermittency

Hydroelectric Plants

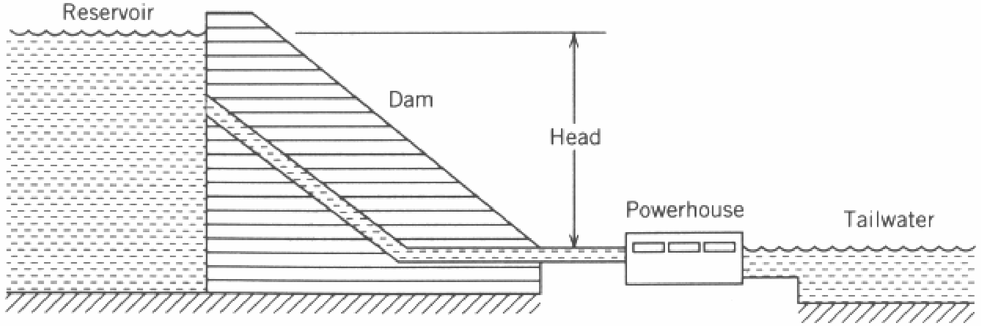
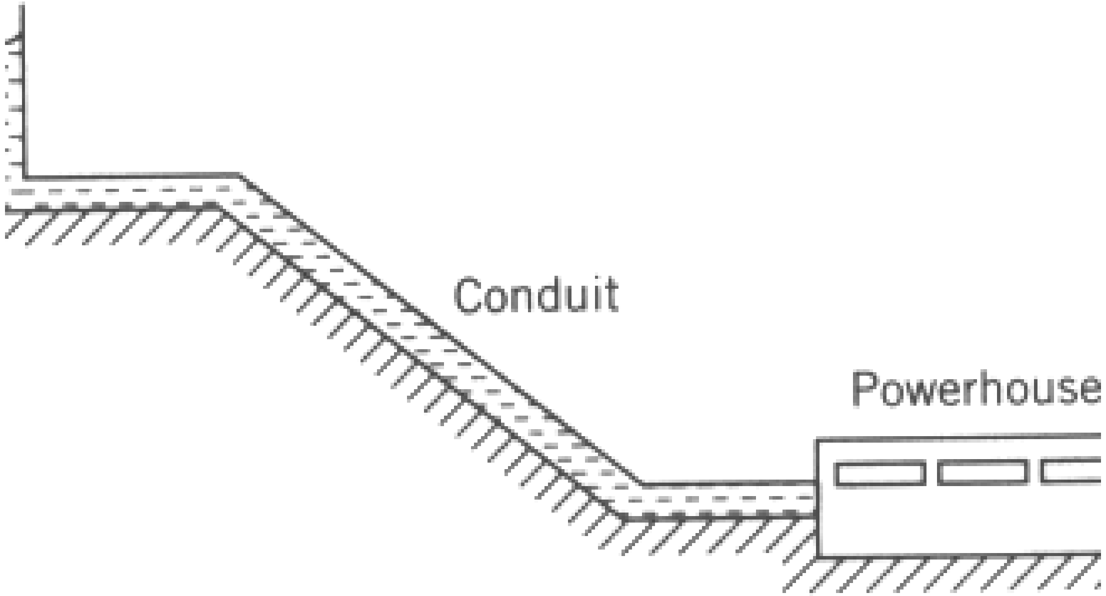


FIGURE 1.1 Schematic diagram of a hydroelectric power plant.

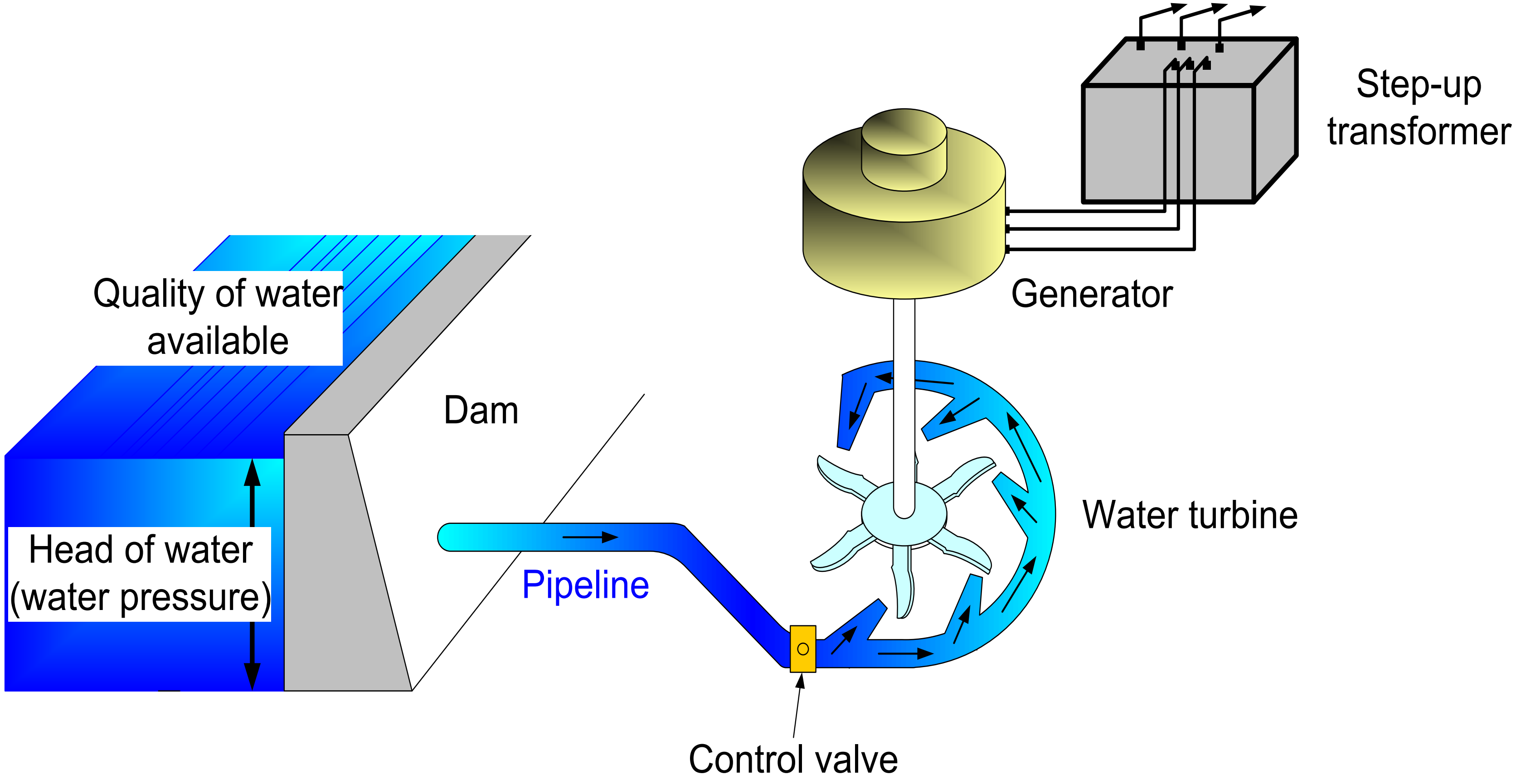
Hydroelectric Plants



Schematic diagram of a pumped-storage pow

https://youtu.be/Lx6UfiEU3Q0?t=17

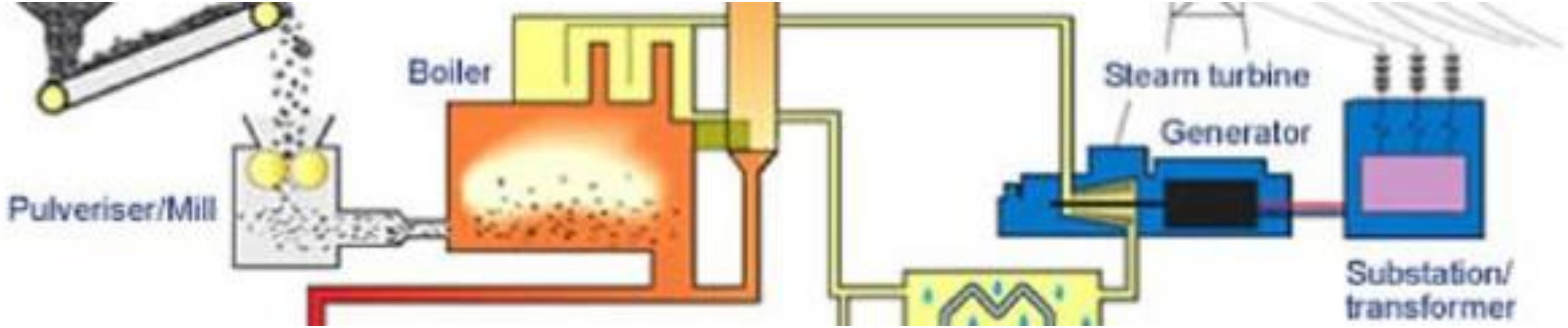
Schematic Diagram of Hydroelectric Plants



Energy Conversion

Potential Energy
to
Kinetic Energy
to
Mechanical Energy
to
Electrical Energy

Thermal Power Plants - Steam Turbine



https://www.youtube.com/watch?v=IdPTuwKEfmA

Thermal Power Plants - Gas Turbine

Gas Turbine

- Convert heat energy of combustion into mechanical energy
- Efficiency like internal combustion engine
- Fuelled by: natural gas, liquid fuels or gasified solid fuel (such as coal)
- "Peaking" power plants – able to follow load variations
  - Fast start-up & shut-down times
    (2 -3 minutes, compared with 20 minutes for steam turbines)

https://www.youtube.com/watch?v=KVjtFXWe9Eo

Thermal Power Plants - Nuclear Fission Plant

Heat energy released by fission of Uranium (^{235}U) or Plutonium used to produce steam which drives generator prime mover

Potential limitations

- Cost
- Safety
- Waste

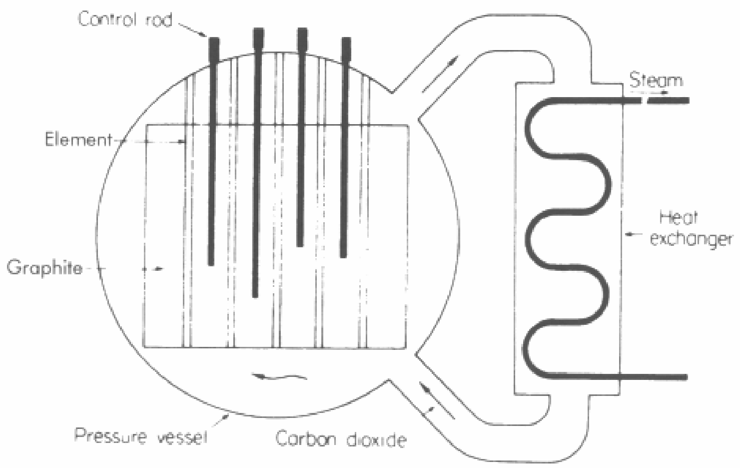


Figure 1.10 Schematic view, nuclear reactor—British Magnox type

B. M. Weedy and B. J. Cory, *Electric power systems*, 4th ed. Chichester ; New York: John Wiley Sons, 1998.

In thermal power plants, hundreds of Induction Motors are also employed in addition to Synchronous Generator

https://www.youtube.com/watch?v=R7WPEYGr1Vs

Electrical Energy Production- Alternative Methods

Solar power

Wind power

Biomass

Geothermal energy

Tidal power

Electrochemical devices

- i.e. Hydrogen fuel cells

Solar Energy

Thermal conversion

Solar energy used for heating purpose

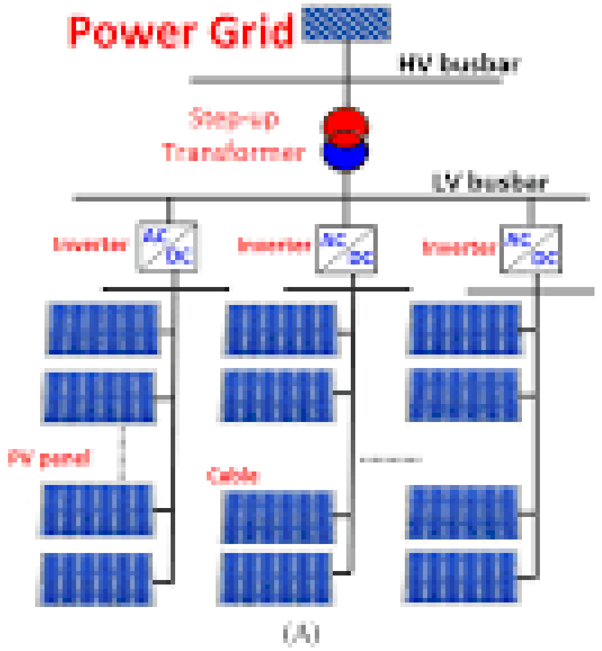
- Space and water heater for domestic applications
- Large scale heat collection for steam production for electricity generation

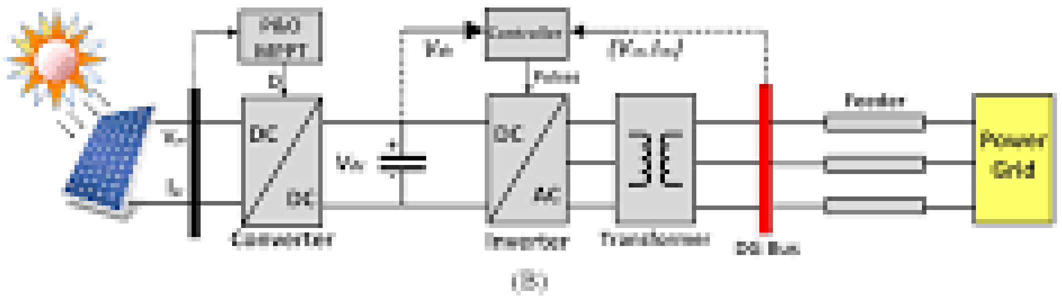
Direct conversion to electricity

Photovoltaic conversion

- Electrons liberated by incidence of light on body Theoretical efficiency ~ 25%
- Practical efficiencies ~ 16% achieved

Solar PV Plants – Direct Conversion to Electricity





Solar Energy is converted into Direct current (DC).

- Depends upon Solar Irradiance
- Ambient Temperature
- Panel conditions

DC should be converted into Alternating Current (AC) to be able to integrate into power grids.

DC/DC can also be used in the process in the intermediate process before converting into AC.

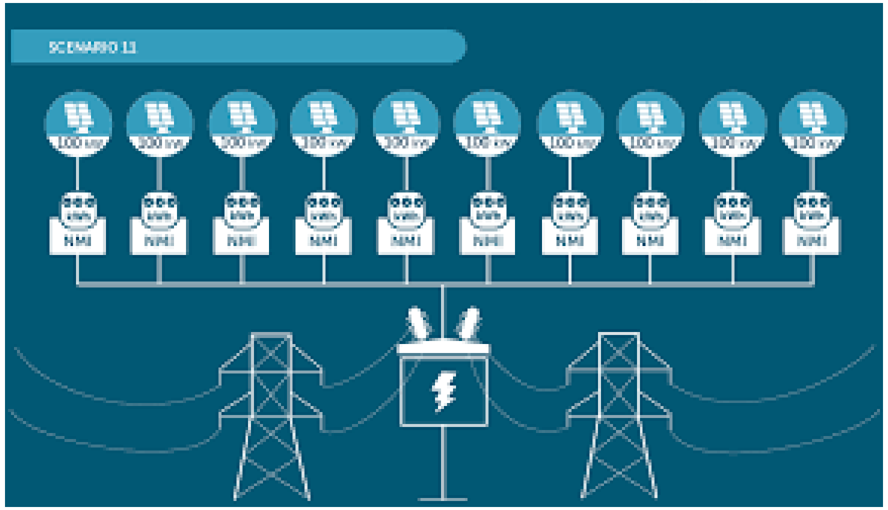
Solar PV Plants – Direct Conversion to Electricity

PV Applications

- Stand-alone off-grid systems: applied for remote areas, remote telecommunication systems and in developing countries with out access to basic energy resources.

- Grid-connected systems are used when an electricity grid is accessible, and the energy produced by the PV system is not enough to meet the demand.

- Large-scale photovoltaic power plants: Consist of many PV arrays installed together and can provide bulk power. Utilities can build PV plants faster than conventional power plants and can expand the size of the plant as the demand increases.



Wind Energy

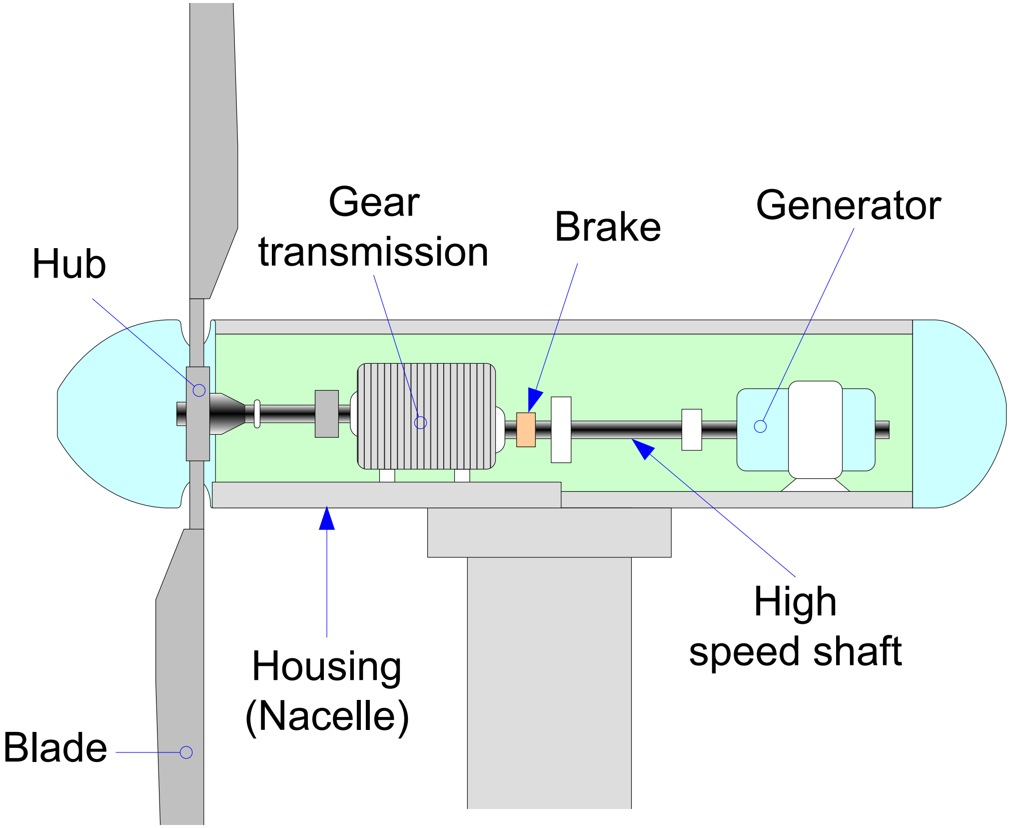
Indirect use of solar energy

- Turbine type wind energy generators transform kinetic energy of wind into rotary shaft motion to electrical energy

Limitations

- Wind is a low-density fluid, requiring large blade dimensions
- Large (daily) fluctuations in magnitude and direction of wind
- Size and location of plant critical
  - Power output α (wind velocity)^3
  - Wind velocity α tower height

Wind Energy



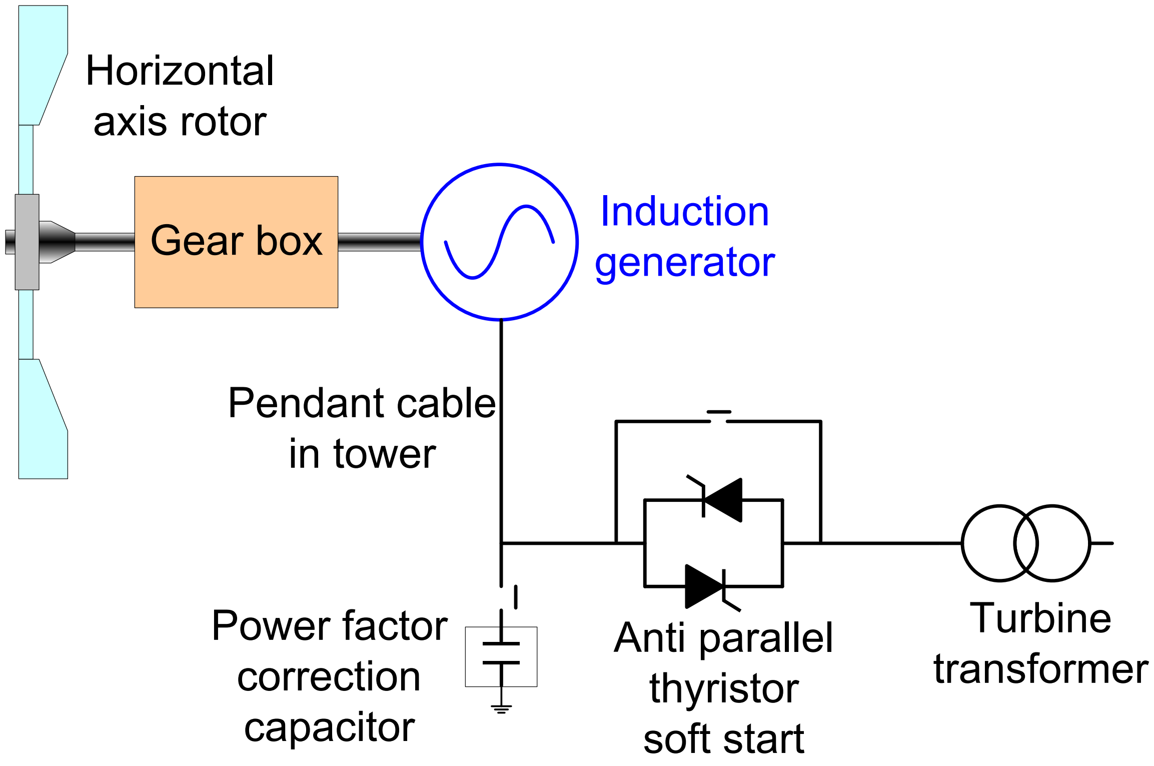
There are two options for wind electrical conversion as follows:

With varying wind speed, the turbine is operated at constant speed by blade pitch control. In this case a conventional AC Machine (Induction Machine) is used to generate a constant frequency output.

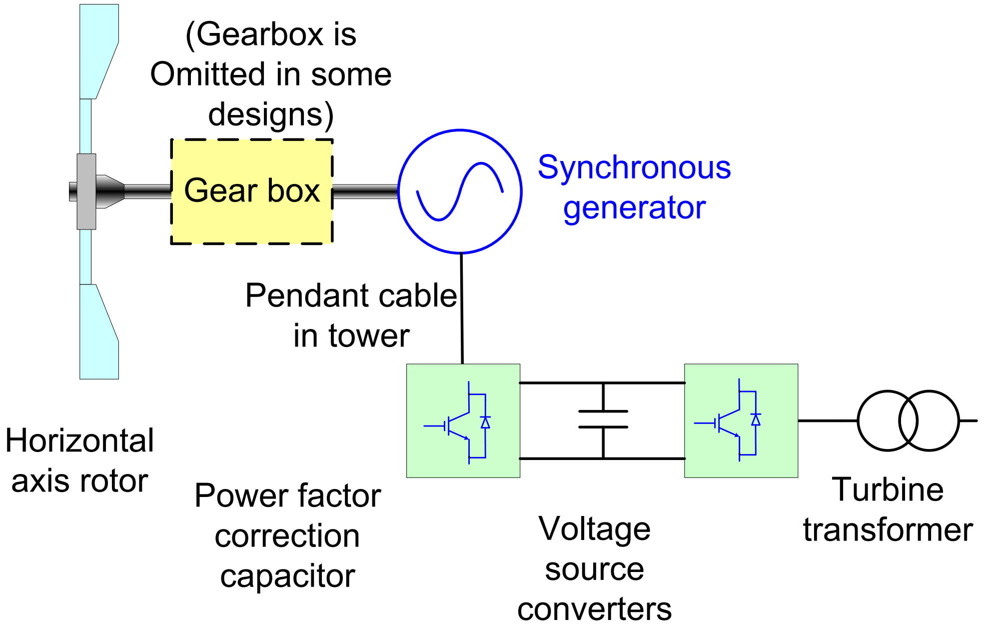
By using an induction generator with or without an adjustable Var supply. In this case, the turbine operates at a nearly constant speed. Or the rotational speed can be allowed to vary with wind to maintain a constant and optimum tip speed ratio. Then special power electronics converter technology is employed to obtain a high-quality AC power with minimum harmonic distortion.

Wind Energy

Fixed Speed Wind Turbine System

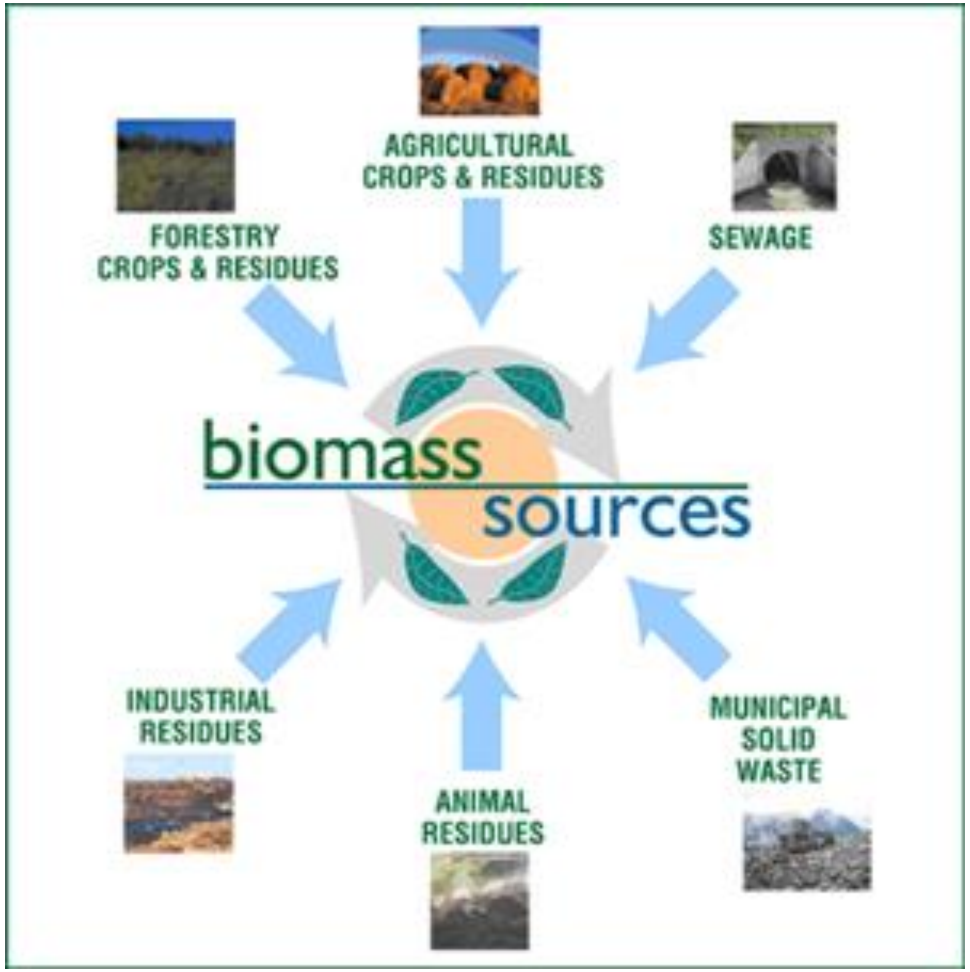


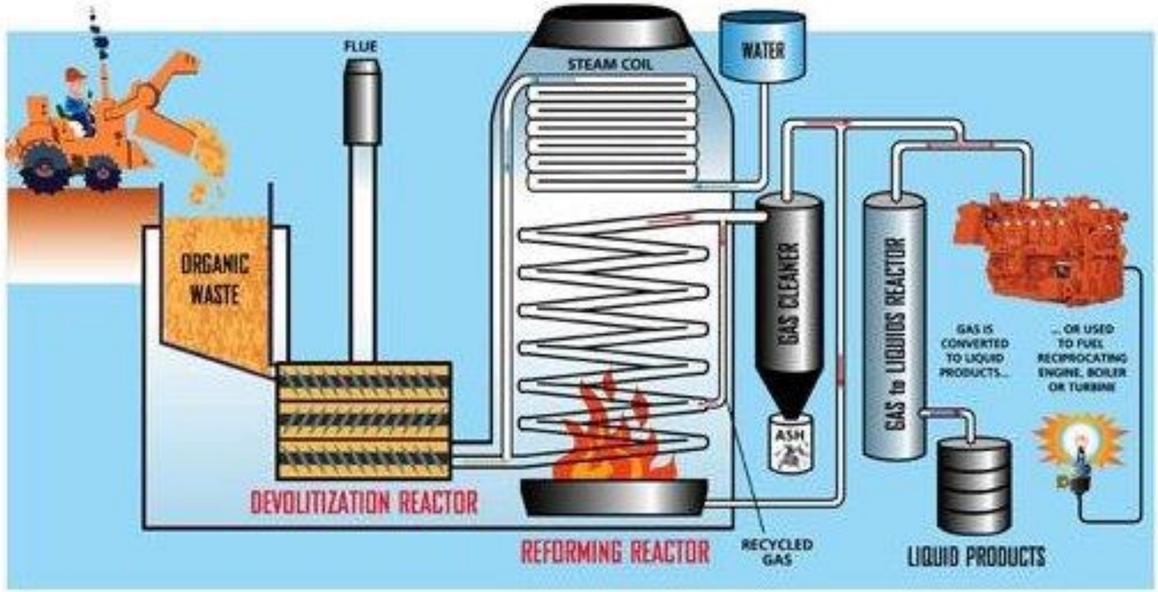
Variable Speed Wind Turbine System



The variable speed option offers optimum performance as far as efficiency is concerned for a large range of wind speeds. This results in a system that produces higher output with lower structural loads and stresses.

Biomass


AGRICULTURAL CROPS & RESIDUES
FORESTRY CROPS & RESIDUES
SEWAGE
biomass sources
INDUSTRIAL RESIDUES
ANIMAL RESIDUES
MUNICIPAL SOLID WASTE


FLUE
STEAM COIL
WATER
ORGANIC WASTE
GAS CLEANER
GAS to LIQUIDS REACTOR
GAS IS CONVERTED TO LIQUID PRODUCTS...
... OR USED TO FUEL RECIPROCATING ENGINE, BOILER OR TURBINE
ASH
DEVOLITIZATION REACTOR
REFORMING REACTOR
RECYCLED GAS
LIQUID PRODUCTS

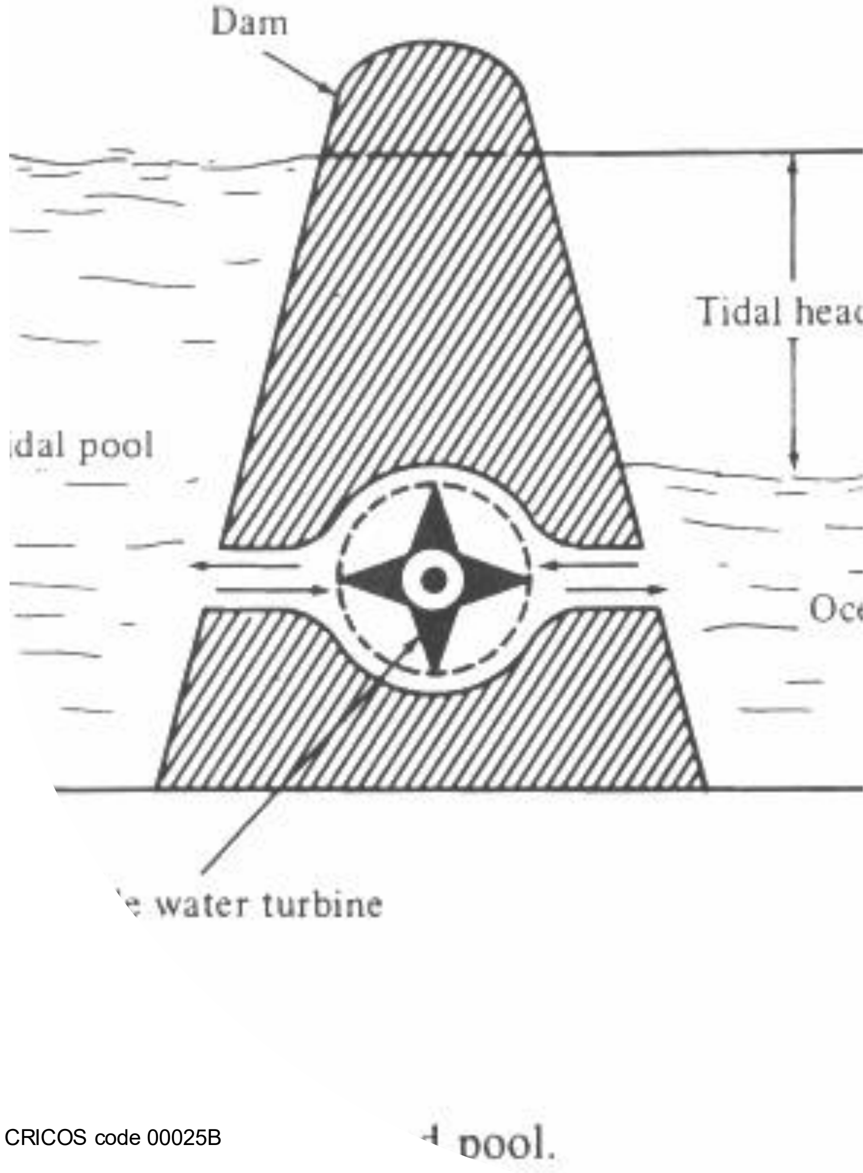
Tidal Power / Wave Power

Tidal Power

- Large potential
  - 64 billion watts worldwide
- Requires large plants for peak flows every 12 hrs
- Difficult to match supply to load

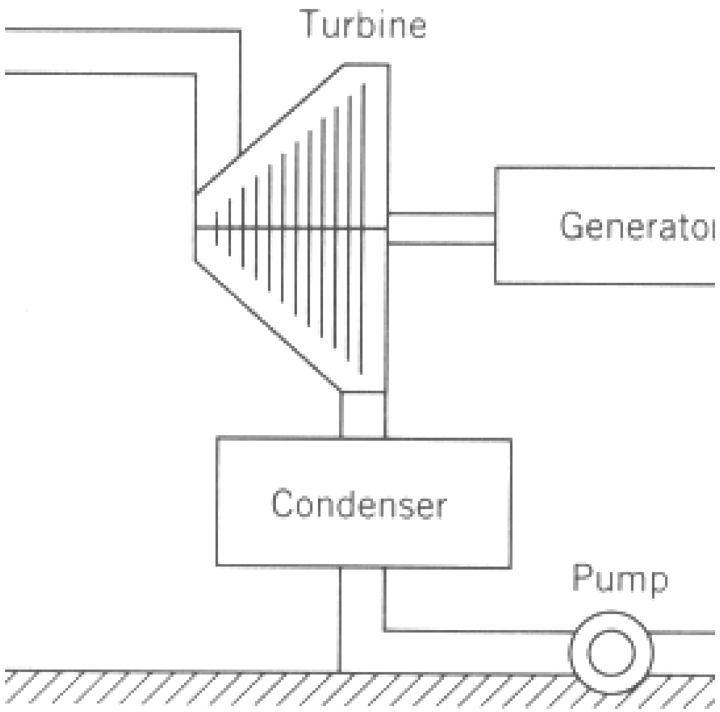
Wave Power

- Large potential
  - Waves off NW Britain average 80 kW/m wave crest length
- Large variability in power production
  - Plant must be rated for maximum power of 1 MW/m



S. A. Nasar, *Electric energy systems*. Upper Saddle River, N.J.: Prentice Hall, 1996.

Geothermal Plants



5 Schematic diagram of a geotherm

Utilize almost limitless reserve of heat within Earth's crust

Wells can produce of steam directly

- Steam can be corrosive and poisonous (sulphur, mercury, arsenic etc.)

Only limited use,

but technology still developing

Hydrogen

Hydrogen is the simplest, lightest and nonmetallic highly flammable diatomic gas they are colorless and odorless.

The following technologies can be used to produce Hydrogen

Steam Methane Reforming (SMR)

Auto Thermal Reforming (ATR)

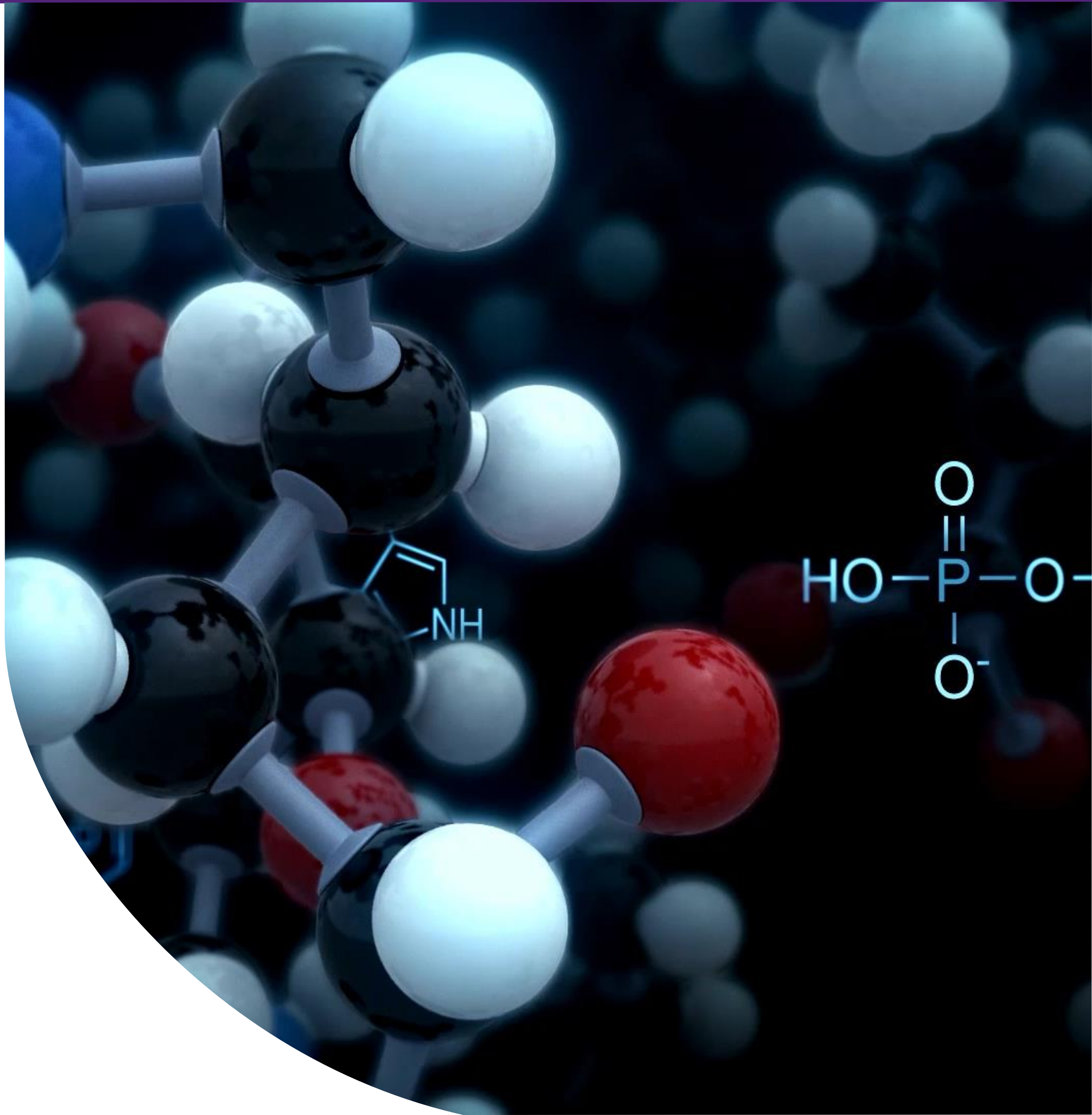
Solid Oxide Electrolysis

Alkaline Electrolysis

Photo Fermentation

Dark Fermentation

PEM Electrolysis



Hydrogen

Steam Methane Reforming (SMR)

- SMR is a technology for hydrogen production from natural gas.
- Reaction of methane with steam to produce hydrogen and CO2.

Chemical equation:

-$CH_4 + H_2O(g) \rightarrow CO + 3H_2$

$-CO + H_2O(g) \rightarrow CO_2 + H_2$

Advantages:

- High hydrogen yield.
- Cost-effective at large scale.

Disadvantages:

- Produces greenhouse gases.
- Requires natural gas as a feedstock.

Hydrogen

Auto Thermal Reforming (ATR)

- ATR combines partial oxidation and steam reforming.
- Can use various hydrocarbon feedstocks.

Chemical equation:

-$CH_4 + H_2O(g) \rightarrow CO + 3H_2$

-$CO + H_2O(g) \rightarrow CO_2 + H_2$

Advantages:

- High efficiency.
- Reduced greenhouse gas emissions compared to SMR.

Disadvantages:

- Requires control of oxygen and steam ratios.
- Complex process engineering.

Hydrogen

Solid Oxide Electrolysis

- Operates at high temperatures using a ceramic electrolyte.
- Utilizes high-temperature heat sources.

Chemical equation:

- $Anode: 2H_2O + \ +4e^- \rightarrow \ 2O^{2-} + 2H_2$
- $Cathode: \ 2O^{2-} \rightarrow \frac{1}{2}O_2 + 2e^-$
- $Overall: 2H_2O \rightarrow \ 2H_2 + O_2$

Advantages:

- High efficiency due to high-temperature operation.
- Integration with high-temperature fuel cells.

Disadvantages:

- Material and thermal management challenges.
- Limited to specific industrial applications.

Hydrogen

Alkaline Electrolysis

- Uses an alkaline electrolyte solution.
- Known for its reliability.

Chemical equation:

- $Cathode: 2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
- $Anode: 2OH^- \rightarrow \frac{1}{2}O_2 + H_2O + 2e^-$
- $Overall: H_2O \rightarrow H_2 + \frac{1}{2}O_2$

Advantages:

- Mature technology.
- High efficiency.

Disadvantages:

- Limited current density.
- Extreme operational condition.

Hydrogen

Photo Fermentation

- Uses photosynthetic microorganisms.
- Converts organic compounds into hydrogen using light.

Chemical equation:

- $Organic\ substrate + H_2O \rightarrow H_2 + CO_2 + Biomass$

Advantages:

- High hydrogen yield in light presence.
- Potential for wastewater or organic waste as feedstock.

Hydrogen

Dark Fermentation

- Occurs in the absence of light.
- Anaerobic breakdown of organic substrates to produce hydrogen.

Chemical equation:

-$C_6H_{12}O_6 \rightarrow 2H_2 + 2CO_2$

Advantages:

- Operates without light, suitable for continuous production.
- Flexibility in feedstock selection.

Disadvantages:

- Lower yield compared to photo-fermentation.
- Production of organic acids.

Hydrogen

PEM Electrolysis

- Uses a solid polymer electrolyte membrane.
- Operates at lower temperatures and pressures.

Chemical equation:

- $Anode: 2H_2O \rightarrow O_2 + 4H^+ + 4e^-$
- $Cathode: 4H^+ + 4e^- \rightarrow 2H_2$
- $Overall: 2H_2O \rightarrow O_2 + 2H_2$

Advantages:

- Fast response time.
- Suitable for various applications.

Disadvantages:

- Requires high-purity water.
- High initial capital costs.

Hydrogen – Projects in Australia

https://www.csiro.au/hydrogen-map

Hydrogen to Electricity

Hydrogen Fuel Cells can be used to produce electricity from hydrogen using a reverse electrolysis process.

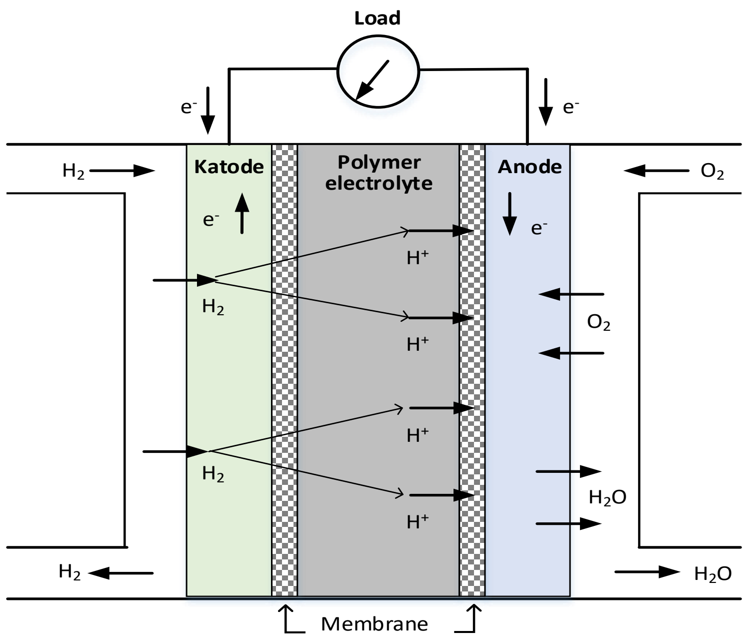
Applications:

Power Grid Support.

Power sources for uninterruptable power supplies.

Power sources for vehicles, e.g. Cars, Trucks, Buses, Boats and Submarines.

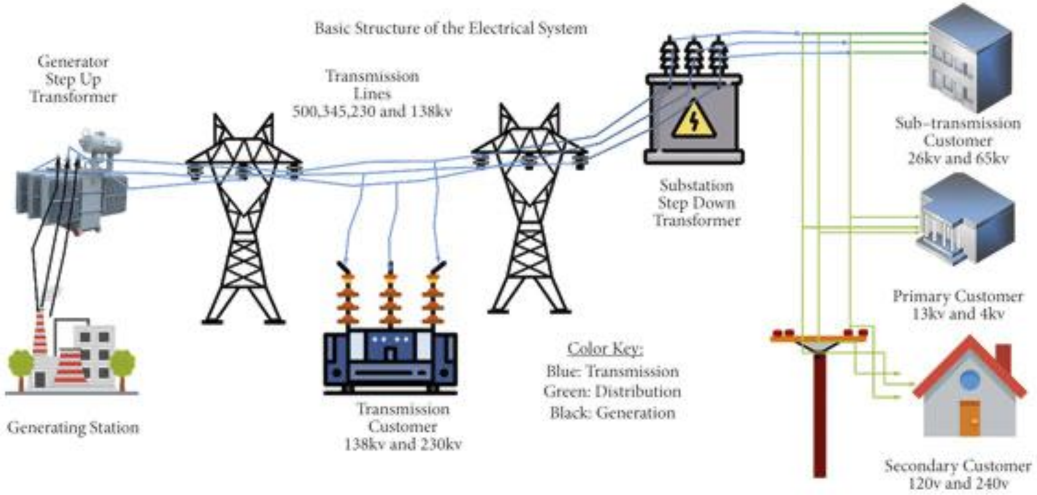
Power sources for Spacecraft, Weather stations and Military technologies.



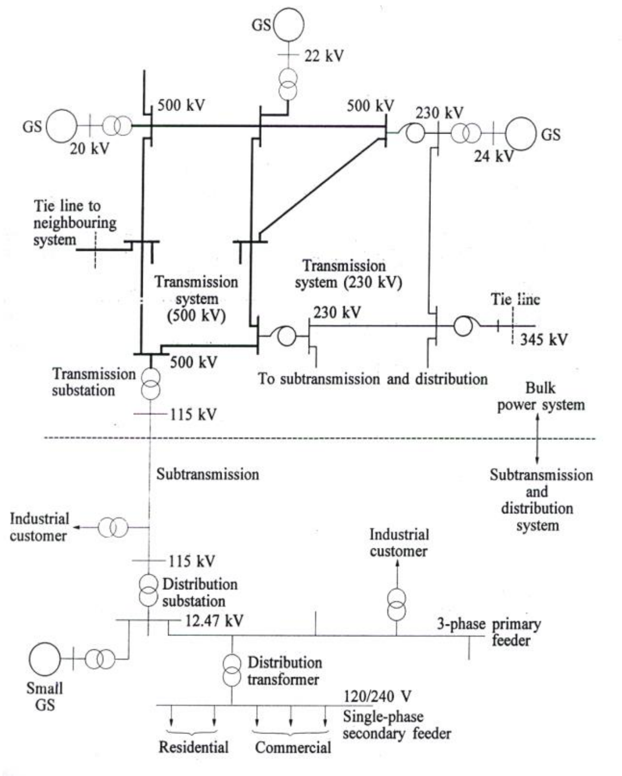
PEM Fuel Cell

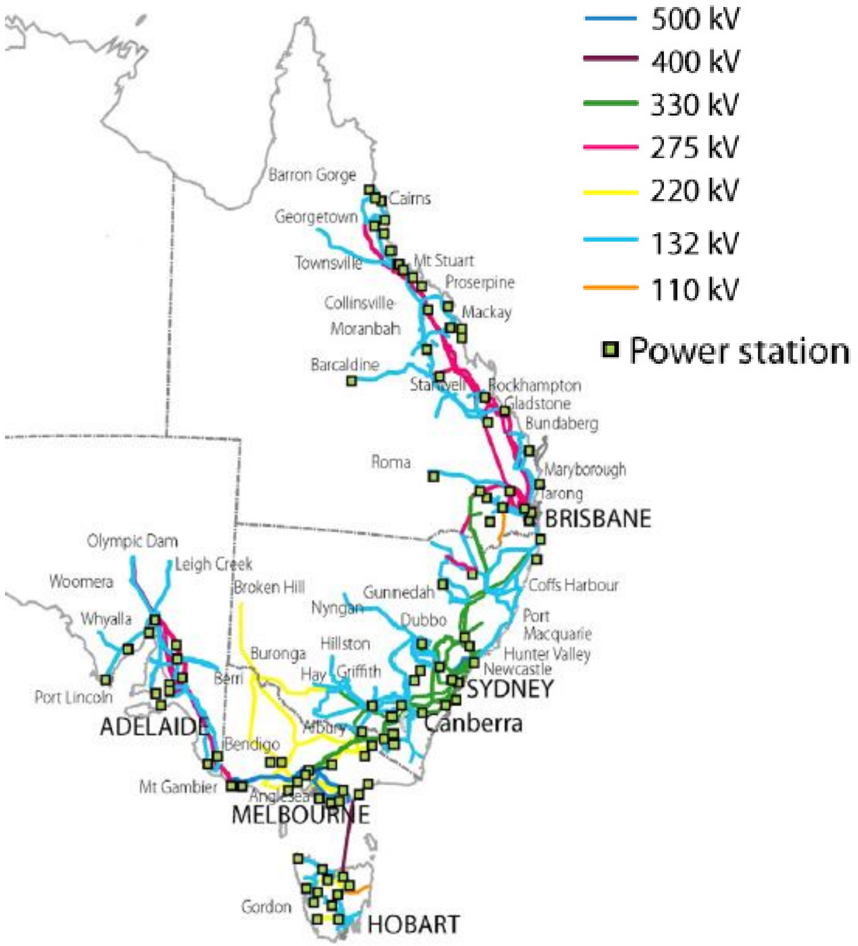
Power System Components

- Prime movers and generators generate electricity
- Unit transformers raise voltage to transmission levels
- Circuit breakers/switchgear sectionalise and protect grids
- Transmission lines transmit power from source to load centres
- Step down transformers reduce voltage for distribution
- Cables distribute power to the consumers
- Instrumentation systems monitor, control & protect
- Loads
  - passive eg. lighting and heating or
  - dynamic eg. motors and/or generators

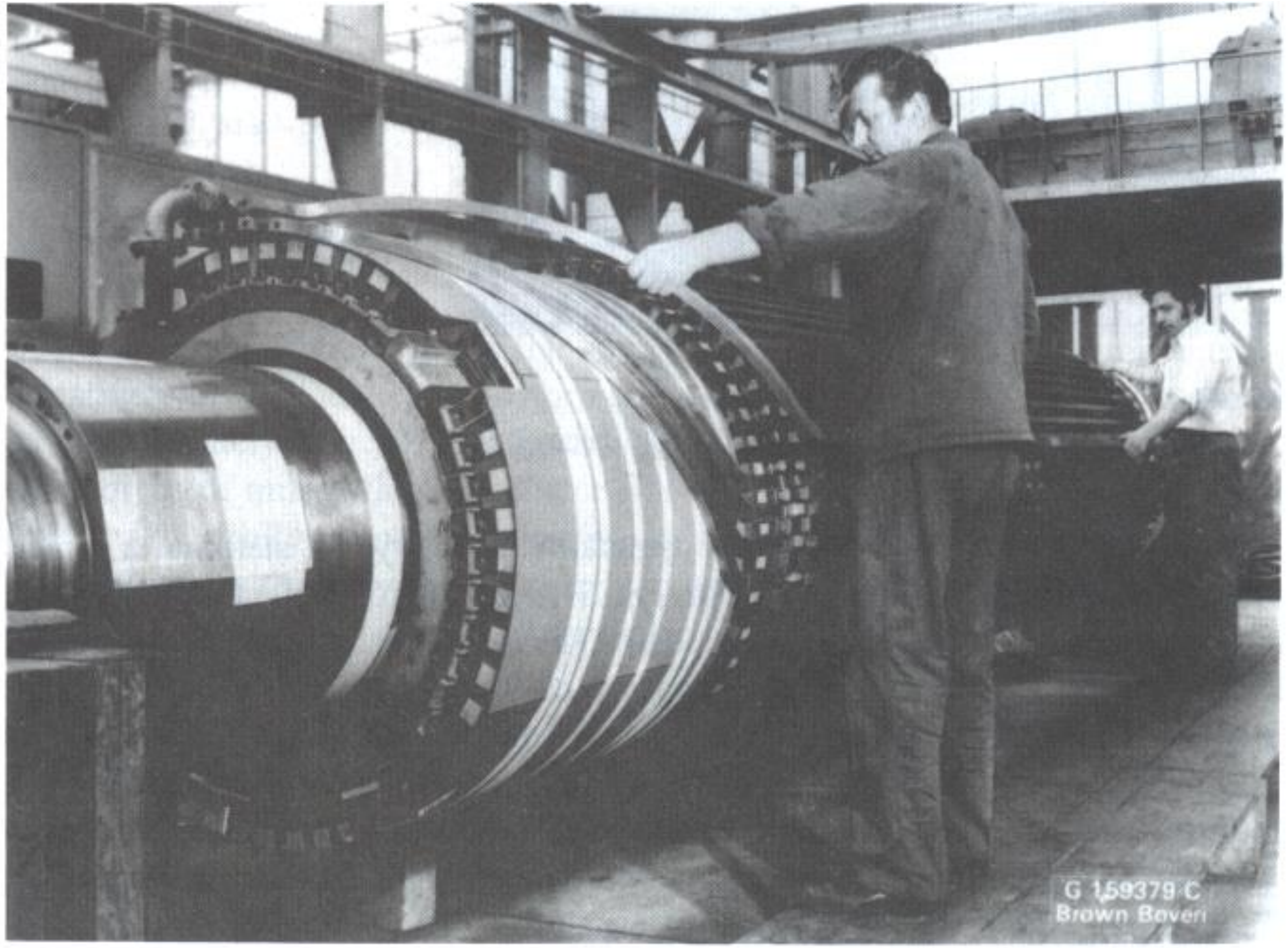


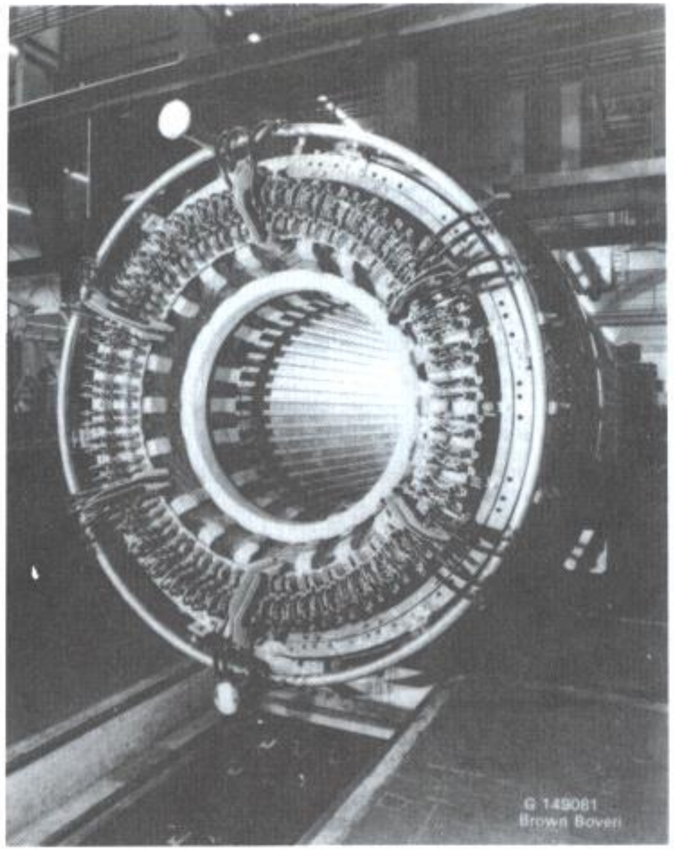
Power Systems- Example





Synchronous Generators





(a)

S. A. Nasar, *Electric energy systems*. Upper Saddle River, N.J.: Prentice Hall, 1996.

Generators- Stator and Rotor

Google Search

Generators

Synchronous machines driven at constant speed by a prime mover

The rotor has a single winding (the field winding) carrying dc current to establish magnetic flux

The stator can have any number of coils

- Normally either single/three phase

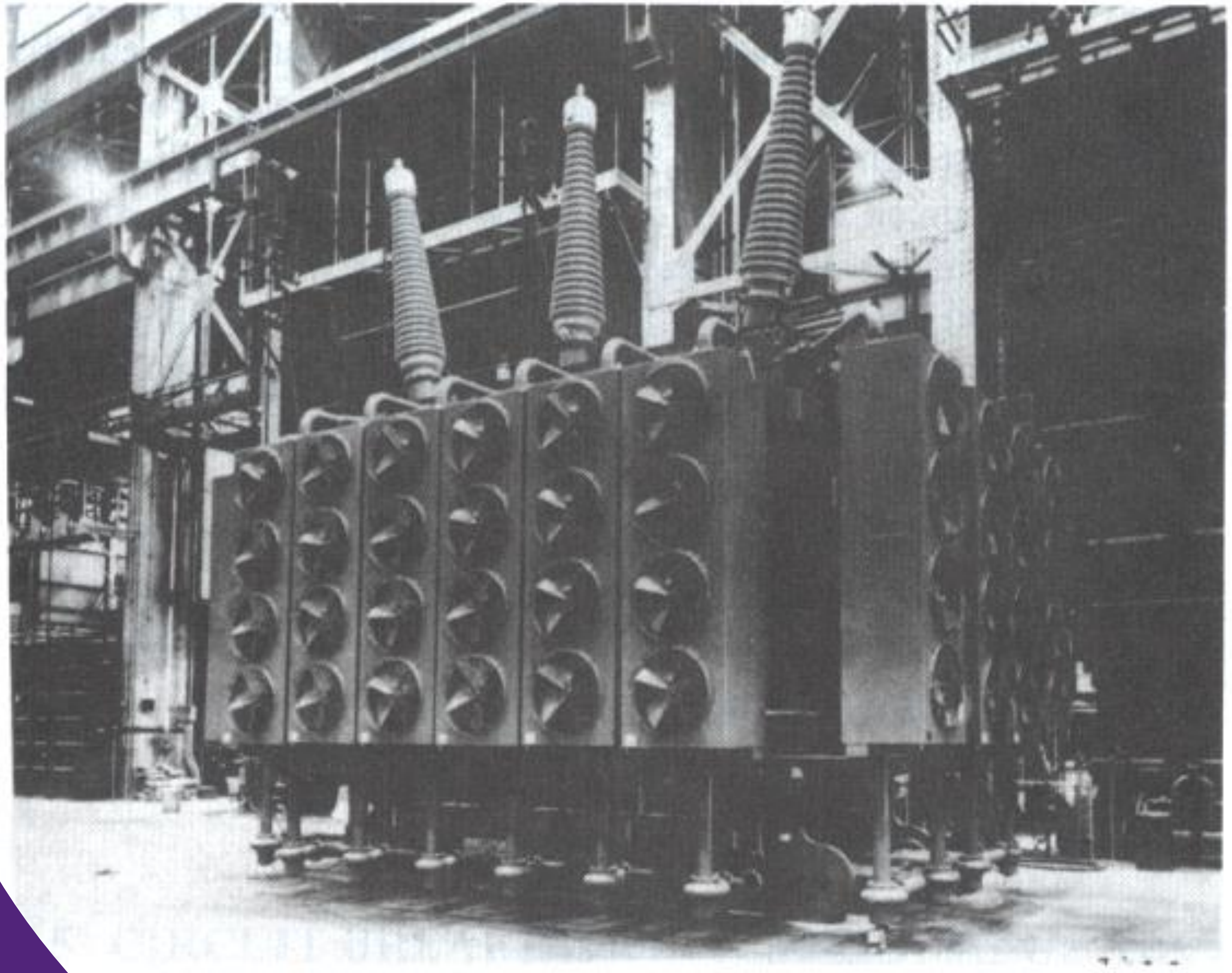
Machines range in size from

- single phase units of few kVA, driven by diesel engines
- 1,300 MW three phase machines driven by steam turbines

Large generators always 3 phase

- Rating normally
  - maximum real power output (eg 120 MW @ 0.8 pf)
  - equivalent VA rating (150 MVA)

Transformers



00 MVA 345/24 kV power transformer. (Courtesy of Westinghouse Electric Corp

Transformers

Transformers

Static devices used to raise and lower the voltage and current on the system

- Enable efficient transmission of large amounts of electric power over long distances.
- Higher voltage reduces the current, size of conductor needed and resistive losses.
- Enables the power stations to be built near the fuel source, some distance away from the city centres.

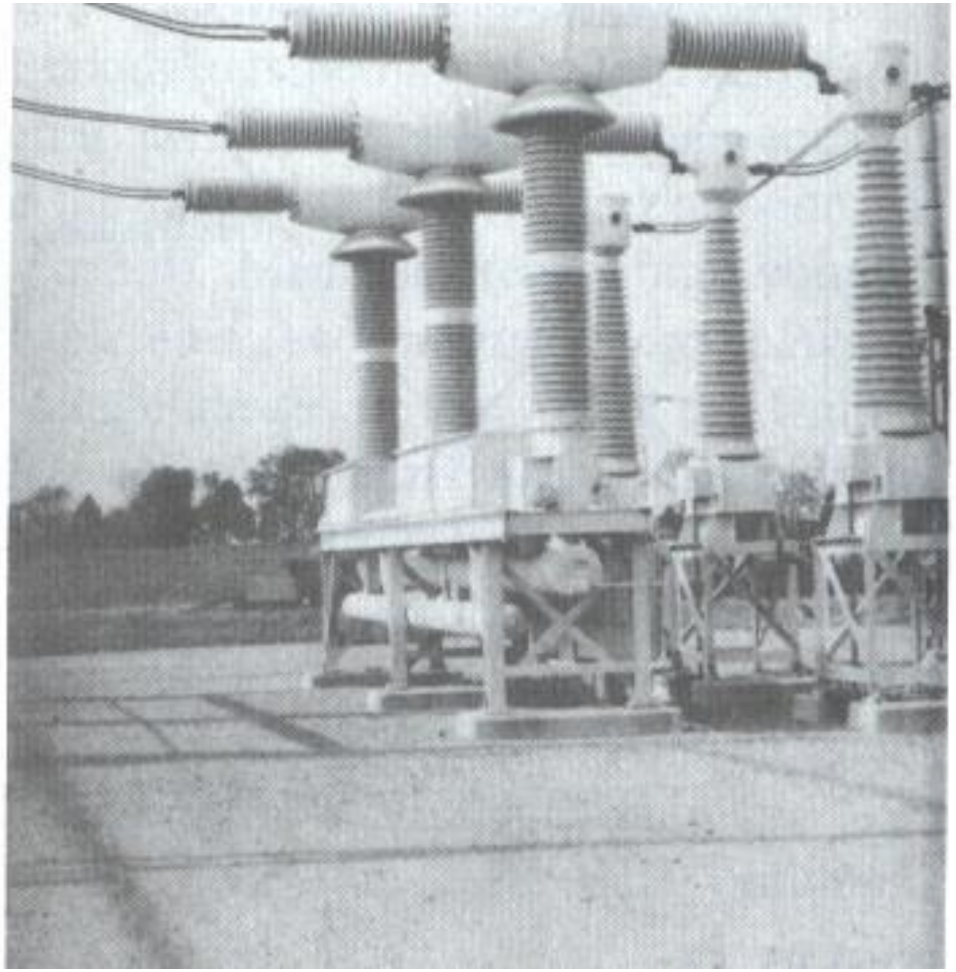
Unit transformer raise generator voltage ~20 kV to transmission levels

- Ratings of up to 1,300 MVA required.

Voltage level reduced for the local system

- Power ratings of transformers are chosen for local load level.
  - Transformers rated at 500 kVA are common.
  - Distribution transformer supply 40-60 homes
    (Typical peak household load of 6 to 10 kVA)

Circuit Breakers



Circuit Breakers

Powerful spring - operated switches

Used to make the connections to the system at all voltage levels.

Breaker must be capable of withstanding

- Normal system voltage
- Continuous rated current
- Much higher current levels which arise when faults occur on the system.

Transmission and Distribution

Transmission Tower: Single Tower with Single Circuit

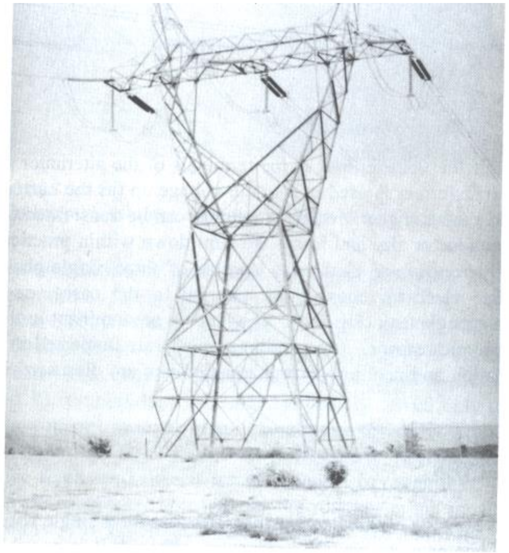
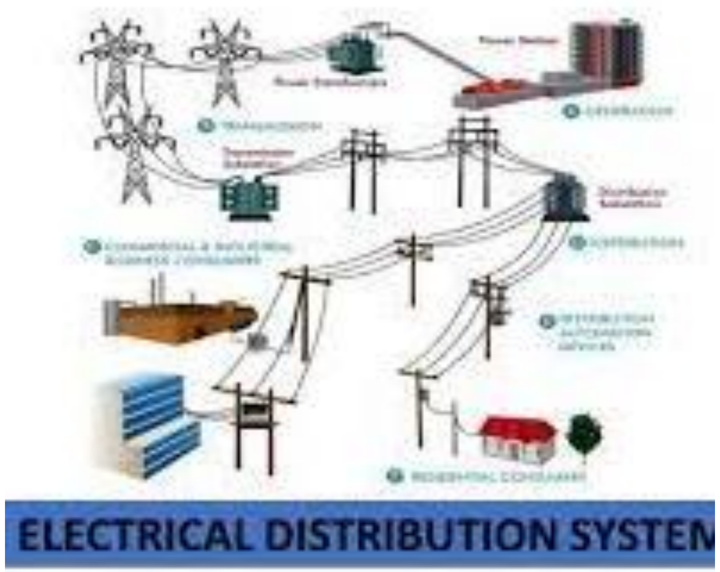


FIGURE 3.4

A 345-kV transmission line, insulators, and

Transmission Corridors with Multiple Circuit



Transmission and Distribution

Standard transmission and distribution voltages

- 1100, 750, 400, 275, 132, 66, 33, 11, 6.6 and 3.3kV

The HV transmission either by overhead lines or underground cables.

- Underground cables in order of five times more expensive than overhead lines
  - Transmission over long distances is by overhead lines
  - Underground cables are used only near cities.

Standard line voltage for local distribution for <u>three phase systems</u>

- 415 volts line voltage
- 240 volts phase voltage

Power System Loads

Four Main Categories

- Residential
  - Passive
    - Lighting, cooking, heating/cooling
  - Dynamic
    - refrigeration, washing machines
- Commercial – office buildings, shops
  - Similar load to residential - larger
- Industrial – factories, manufacturing, mining
  - Passive
    - Similar to commercial, along with furnaces
  - Dynamic
    - Motors, fans, presses, pumps, etc
- Other

Power System Loads

Signification portion (70-80%) of all power generated is used in electric machines (motors).

Most of the electricity used passively goes to provide either lighting or heating

- Includes all aspects of entertainment such as TV, radio, Hi Fi systems etc

Power System Components

- Motors
- Generators
- Transformers
- Transmission Lines
- Distribution systems
- Electricity Consuming Loads

- **Power systems consist of three phase**, all three phases reaching up to the residential customers, though most of the residential customers are single phase.

Recap

Have looked at energy and how it is utilised

- Different types of sources
- Different types of generation
- Power system components
- Load types

Will now move onto three-phase fundamentals

- How this electrical energy is received by various consumers

Questions?

Mithulan Nadarajah,
School of Information Technology and Electrical Engineering,
The University of Queensland, Brisbane,
Australia, mithulan@eecs.uq.edu.au, mithulan@ieee.org

http://researchers.uq.edu.au/researcher/2221

https://twitter.com/mithulann

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