POWER PLANTS

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Lecture # 1 and 2 (Introduction)

COURSE OUTLINE

1. Introduction to power sector
2. Conventional power plants
3. Steam Power Plants:
4. Gas Turbine Power Plant:
5. Jet propulsion Plant:
6. Introduction to Hydel Power Plants:
7. Nuclear Power Plants:
8. Non-Conventional power plants:
9. Financial aspects

REFERENCES/SOURCES/TEXTBOOKS

1. Power Plant Engineering, Farshid Zabihian, 1st Edition, CPC Press, 2021
2. Power Plant Technology, By M. M. El Wakil, McGraw-Hill

GRADING

2 Quizzes	6
2 Homeworks/Assignments	6
Presentation	3
Complex Engineering Problem	10
Mid Term Exam	25
Final Exam	50
Total Points	**100**

Note: There might be a chance to earn 5 points as extra credit ☺

INTRODUCTION

- A Power Plant, known also as a Power Station, is an industrial facility used to generate electricity.
- To generate power, an electrical power plant needs to have an energy source.
- One source of energy is from the burning of fossil fuels, such as coal, oil and natural gas.
- Then we also have nuclear power, and finally renewable energy sources such as wind, solar, wave and hydroelectric.
- Originally, the only source of power for industrial power plants was Direct Current, or DC systems, but it wasn't until Alternating Current, or AC systems were introduced that the power could be carried the distances necessary to be suitable for distribution to the masses.

INTRODUCTION

Categorization by energy resource

•Fossil fuels (oil, coal, or natural gas)

•Nuclear energy

•Renewable energies (originated from solar energy)

- –Hydropower
- –Solar energy
- –Wind energy
- –Wave energy
- –Ocean thermal energy
- –Biomass

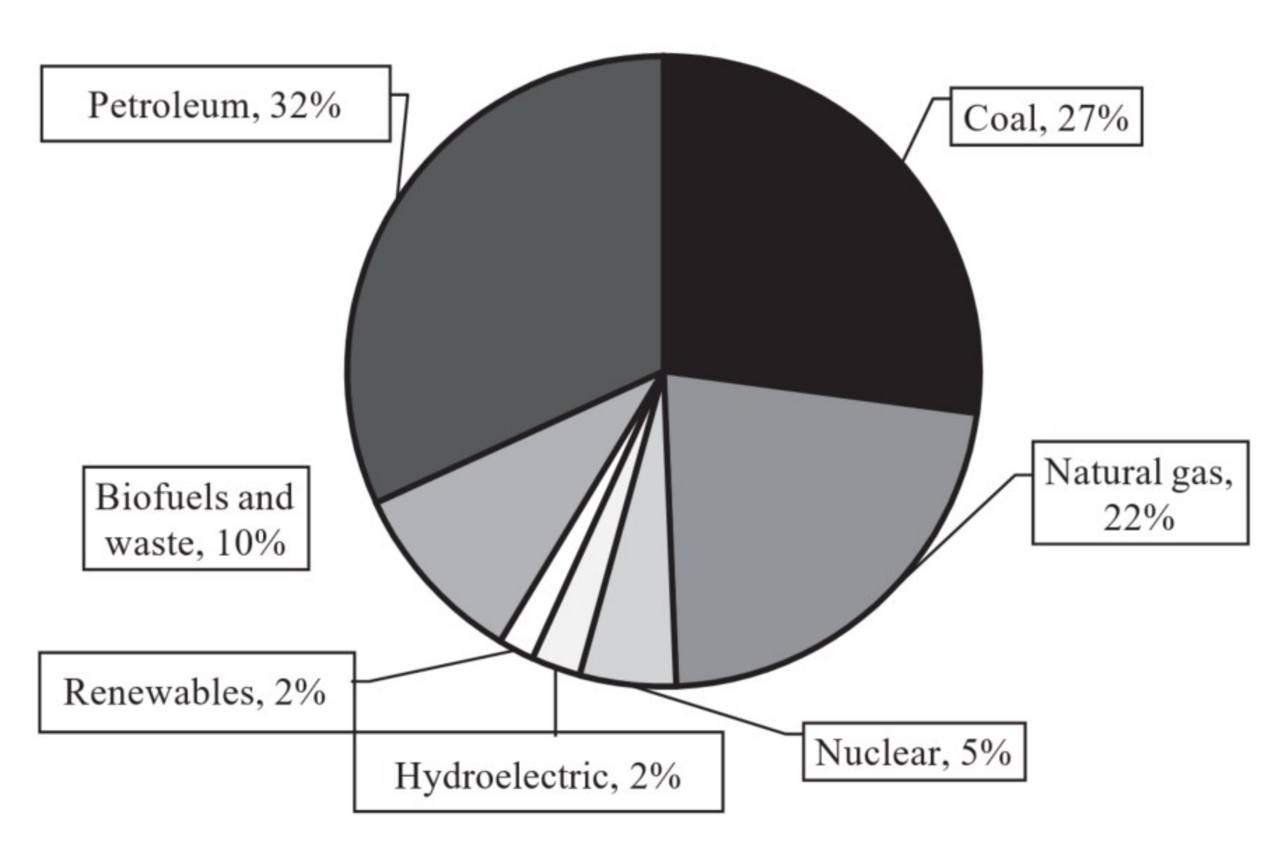
•Renewable energies (non-solar energy)

- –Tidal energy
- –Geothermal
- –Osmotic energy (energy available from the difference in the salt concentration between seawater and river water.)

•Other resources

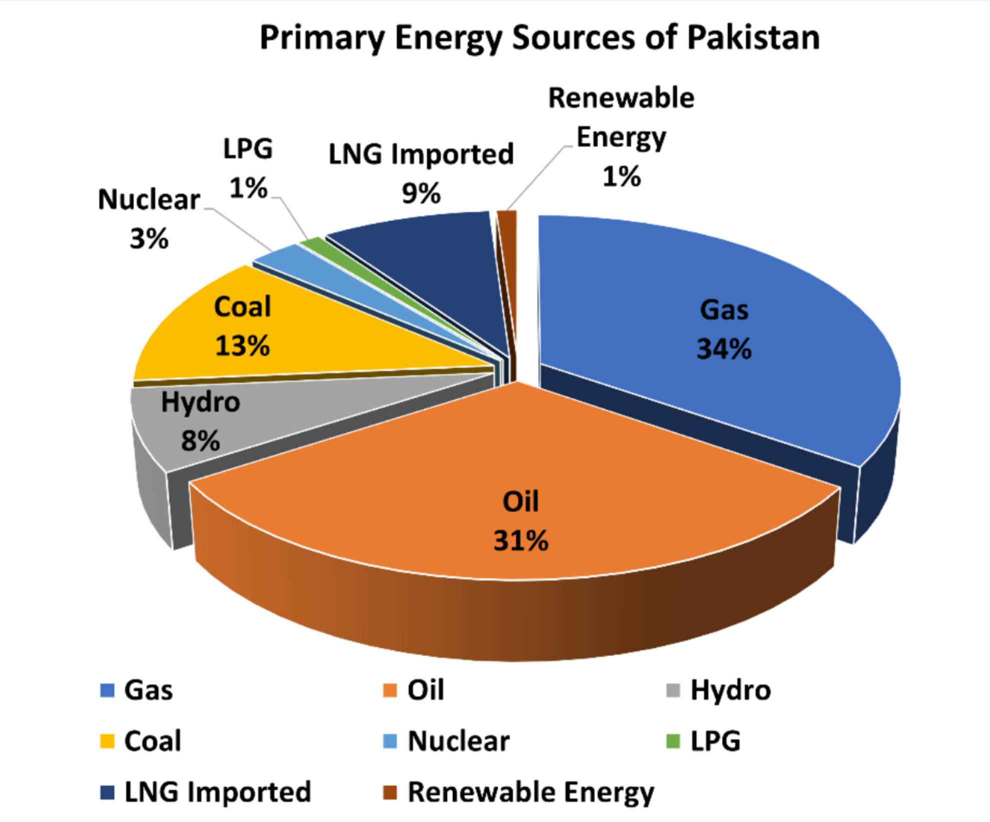
- –Solid waste
- –Heat recovery

INTRODUCTION



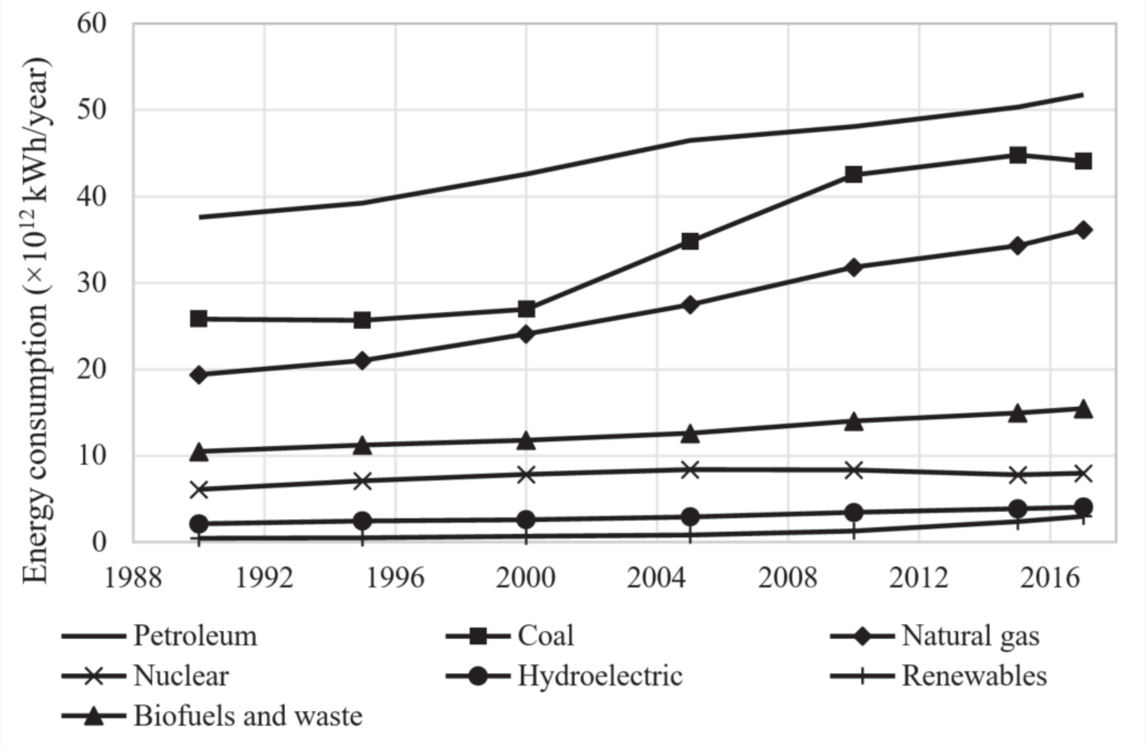
Global primary energy production sources in 2017.
(Based on the data provided by IEA.)

INTRODUCTION



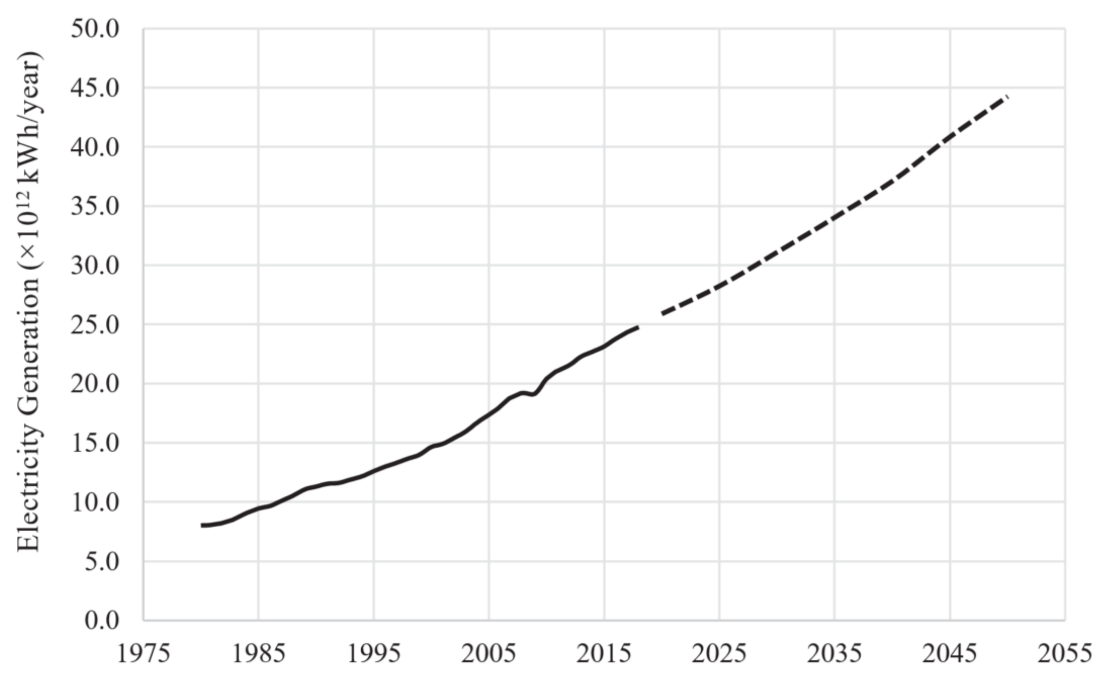
Pakistan primary energy production sources - NEPRA | State of Industry Reports 2020

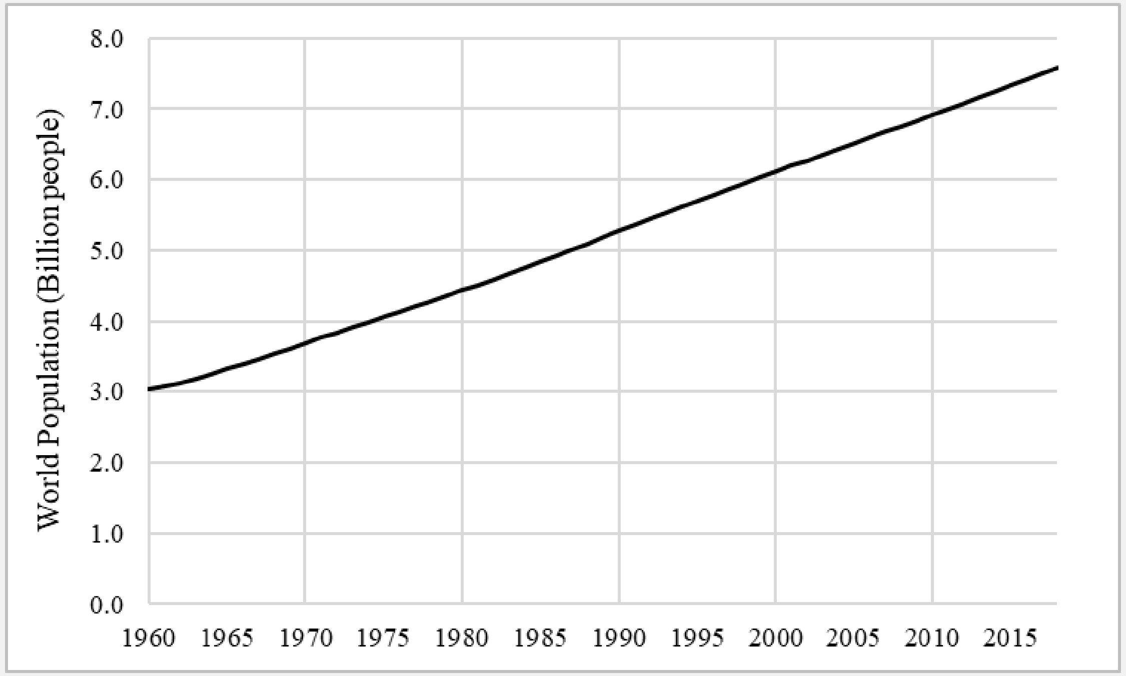
INTRODUCTION



Global annual primary energy production sources between 1990 and 2017. (Based on the data provided by IEA.)

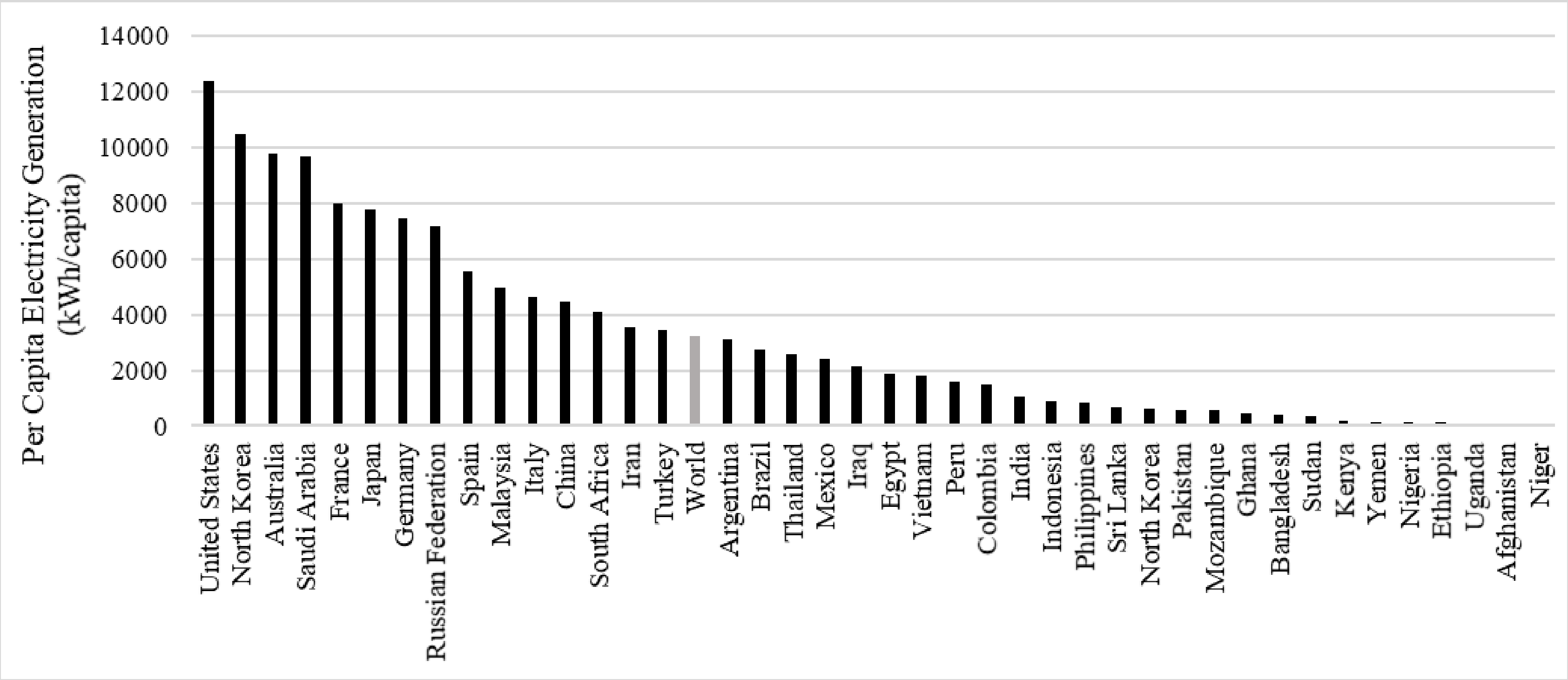
INTRODUCTION





Global annual electricity generation between 1980 and 2050. (Based on the data provided by EIA, data before 2018 are from actual generation and beyond that are projection.)

INTRODUCTION

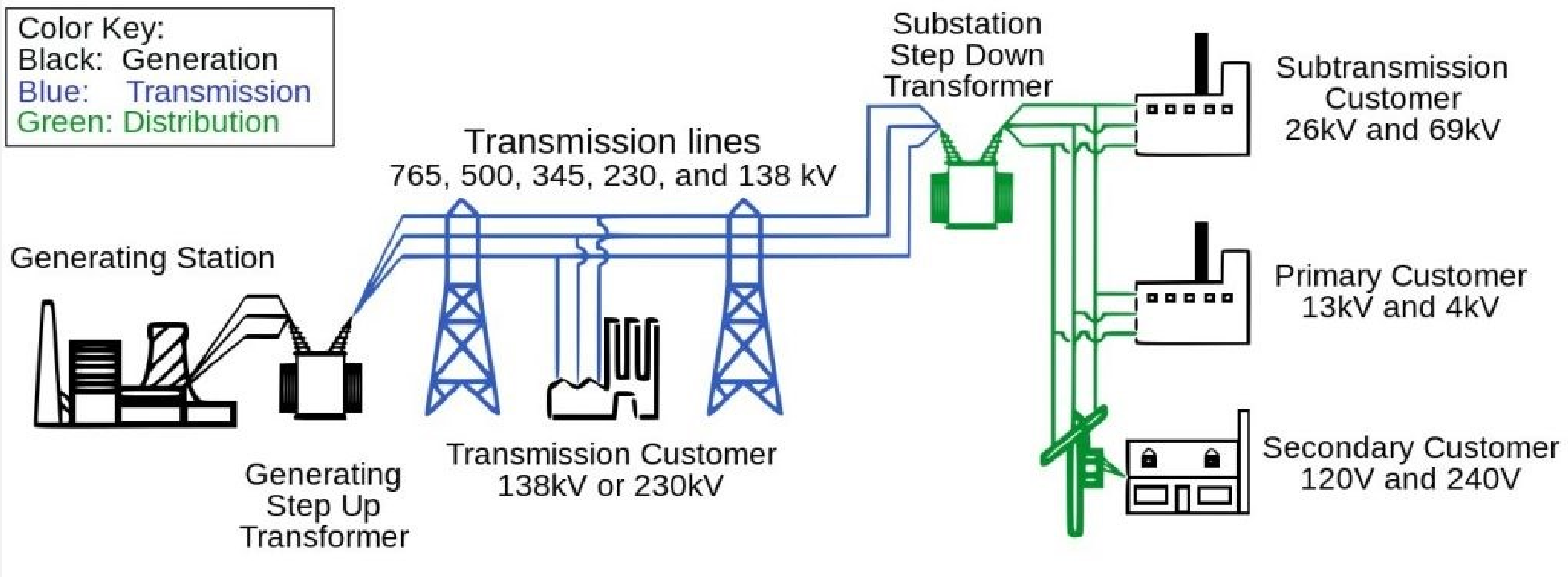


Annual per capita electricity generation for some countries in 2018. (Based on the data provided by The World Bank.)

INTRODUCTION

Structure of electric infrastructure

- Power generation
- Transmission
- Distribution



INTRODUCTION

- Power generation units are facilities that convert various forms of energy, such as coal, natural gas, nuclear energy, solar energy, and wind energy, to electrical energy.

- A transmission system is a network of electricity transmission lines, either overhead or underground, which transmit high-voltage electricity produced in power plants to substations near consumption centers.

- A distribution system is mainly composed of power lines and transformers to safely and reliably deliver the required quantities of electricity at a specified voltage to consumers.

WORK IN MOVING BOUNDARY SYSTEMS (CLOSED SYSTEM)

$\delta W = Fdx$

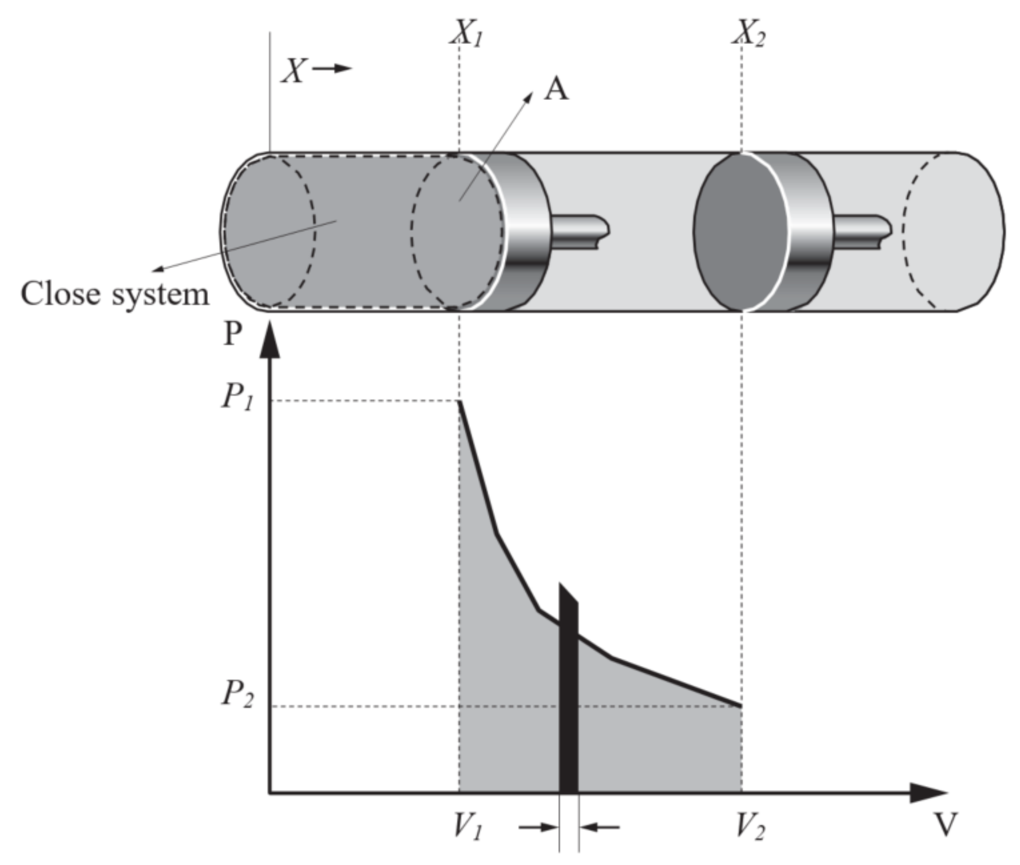
$F = PA$

$\delta W = PAdx$

$\delta W = PdV$

$$W_{1-2} = \int_1^2 \delta W = \int_{V_1}^{V_2} P\,dV$$

$$w_{1-2} = \int_1^2 P\,dv$$



Work in a piston and cylinder assembly and graphical representation of the relationship between P, V, and work in a close system

WORK IN CONTROL VOLUMES

$w_{1-2} = q_{1-2} + (h_1 - h_2)$ (the 1st law of thermodynamics)

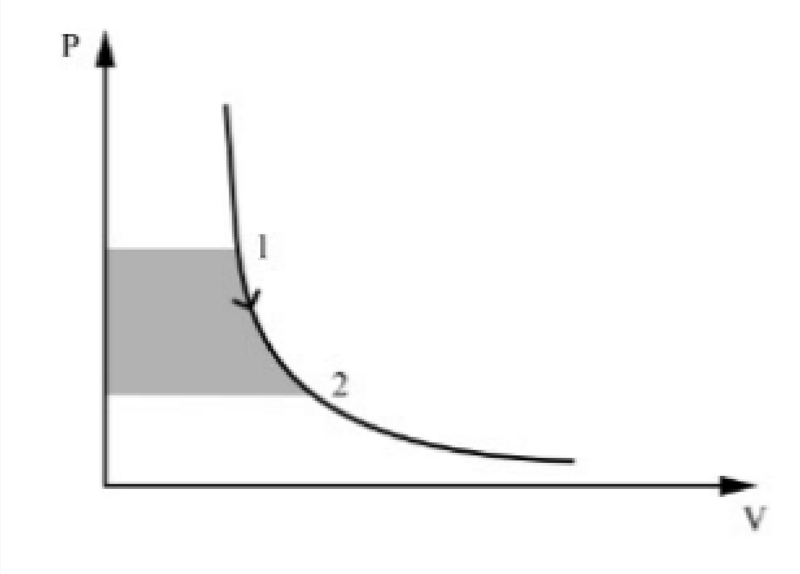
$q_{1-2} = \int_1^2 Tds$ (the 2nd law of thermodynamics)

$$w_{1-2} = \int_1^2 Tds + (h_1 - h_2)$$

$Tds = dh - vdP$ (the Gibbs equation)

$$w_{1-2} = \int_1^2 (dh - vdP) + (h_1 - h_2)$$

$$w_{1-2} = -\int_1^2 vdP$$



Graphical representation of the relationship between *p*, *v*, and specific work in a control volume.

PERFORMANCE EVALUATION PARAMETERS

Thermal efficiency $$\eta_{\mathrm{Th}} = \frac{w_{\mathrm{Net}}}{q_{\mathrm{Input}}} = \frac{\dot{W}_{\mathrm{Net}}}{\dot{Q}_{\mathrm{Input}}}$$

ENERGY AND POWER

- Although the terms energy and power are commonly used interchangeably in everyday discussions, they are different.
- Broadly speaking energy is the capacity of a system to do work. It can be in the form of heat, work, kinetic, potential, electrical, chemical, nuclear, light, or sound energy among others.
- Power is the time rate of energy conversion or transmission.
- Power is associated with the size or capacity of the system whereas energy is related to both the size of the system and the duration of system operation.
- While power can be defined for a point in time, energy is only meaningful when expressed for a period of time.
- When you are buying an electric system, its power consumption is important. But when you are paying for your utility bill, it is for energy usage.

ENERGY AND POWER

Energy: N m=J (joule), ft.lbf, and Btu[18] (British thermal unit)[19]

Power: Nm/s=J/s=W, ft.lbf/s, Btu/h, and hp[20] (horse power)

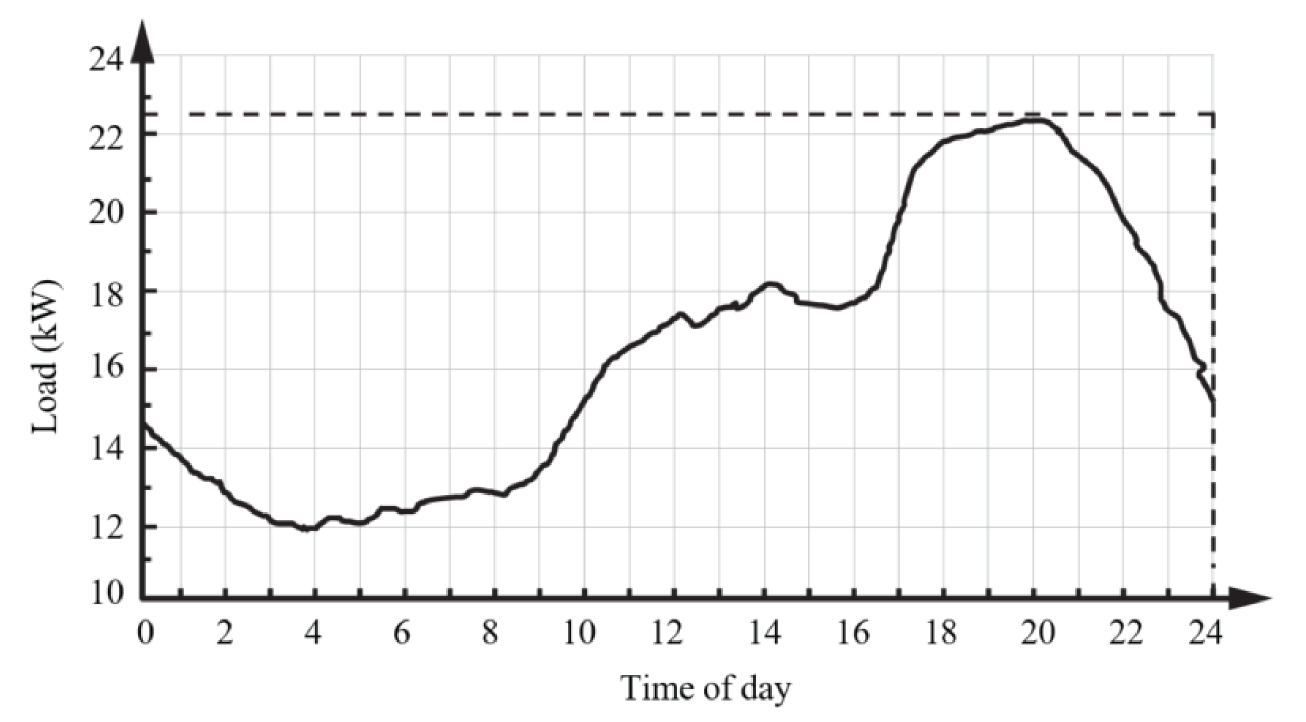
Based on these definitions, the power consumption or generation of a system multiplied by the duration of system operation will give energy consumption or production in the system for that period. In some applications, especially related to electrical energy, the unit of Wh or kWh is used for energy.

$$\text{Power (demand)} = \frac{\text{Energy use or production}}{\text{Duration of energy use or production}} \qquad (1.1)$$

CHARACTERISTICS OF LOAD DEMAND FOR ELECTRICITY

Storing energy is not economical in many cases

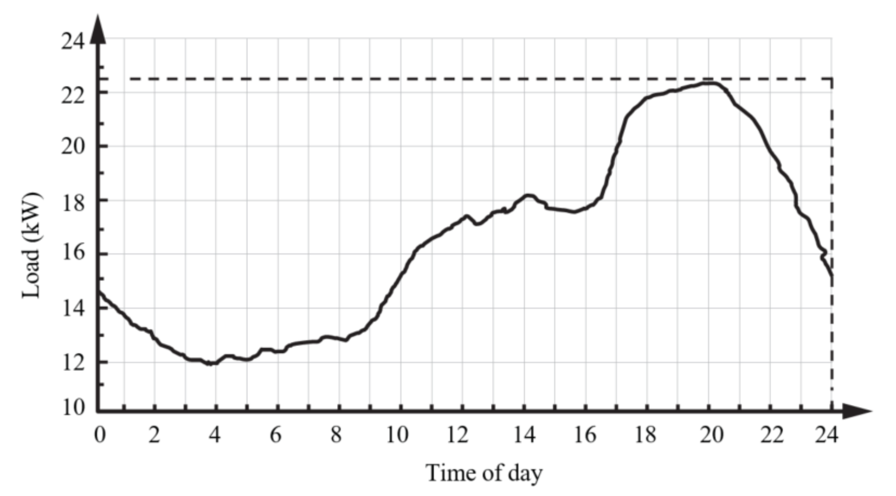
- Maximum load demand
- Baseload demand
- Total electrical energy generation and consumption
- Average load
- Load factor (LF)
- Demand Factor
- Coincidence factor



An example of a load profile of a typical day.

CHARACTERISTICS OF LOAD DEMAND FOR ELECTRICITY

- A load curve can provide valuable information about the nature of electricity consumption in a specific region.
- The **highest point** of the curve is called the maximum load demand.
    - The power generation systems under investigation should be able to provide this maximum load albeit for a short period of time to avoid power shortage and outage.
- The **minimum load** in the curve is called the baseload demand.
    - This is the load that should be provided during the entire given period.
- The area under the load curve is equal to the **total electrical energy** consumed in the given period (with the unit of 'power ×time').



An example of a load profile of a typical day.

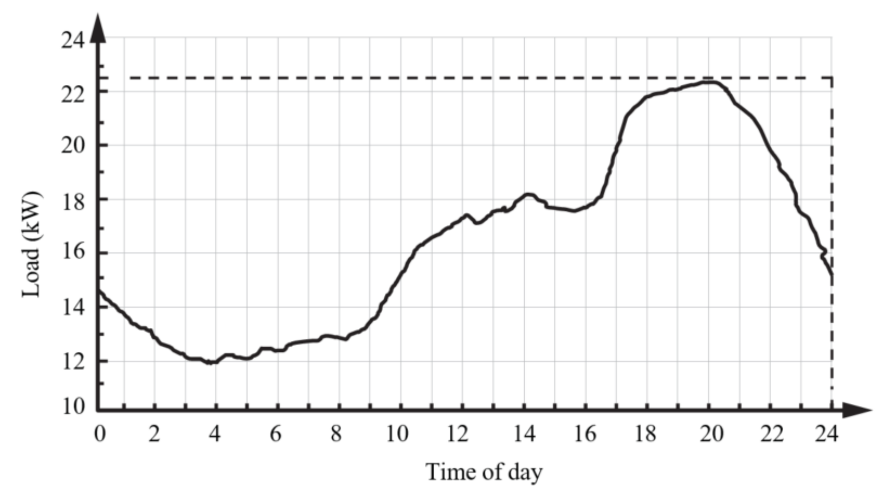
CHARACTERISTICS OF LOAD DEMAND FOR ELECTRICITY

- The total electrical energy usage, the area under the load curve, divided by the total time of the use is the **average load**

$$\text{Average load} = \frac{\text{Total electrical energy usage}}{\text{Total time of the use}} \tag{1.2}$$

A **load factor** is the average load divided by the maximum load and is always ≤1.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum load}} \tag{1.3}$$



An example of a load profile of a typical day.

- The load factor indicates how effective a power generation system is being utilized.

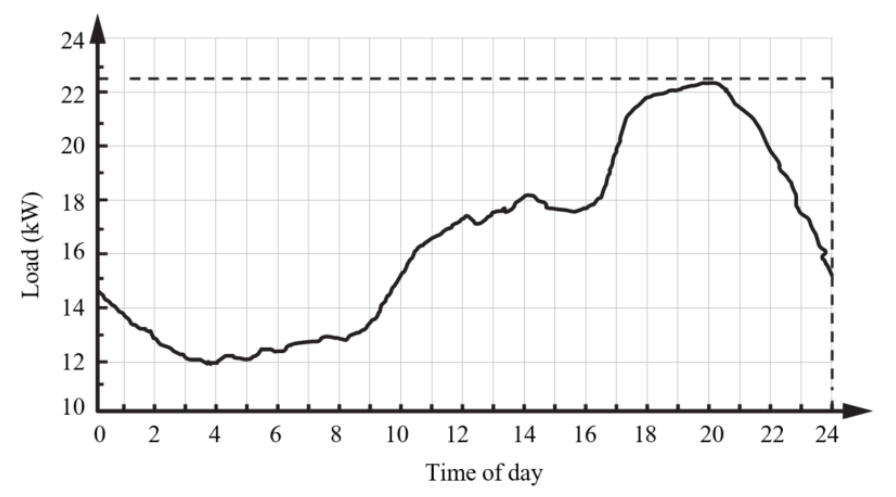
- A high load factor is desirable because it indicates that the power generation system operates close to its maximum capacity, which means more electricity to sell.

CHARACTERISTICS OF LOAD DEMAND FOR ELECTRICITY

The next two terms cannot be determined using solely the load curve. A **demand factor** is the ratio of the maximum load to the maximum possible load.

$$\text{Demand factor} = \frac{\text{Maximum load}}{\text{Maximum possible load}} \tag{1.4}$$

The maximum possible load, also known as the total connected load, is the load when all electrical devices (electricity consumers) are operating at the maximum capacity at the same time for a single consumer. For example, assume that in your house all electrical appliances operate at the same time. The power consumption in this case is the maximum possible load, say 1000 W. However, you generally do not operate all equipment at once, so the maximum load is usually lower than the maximum possible load, e.g., 500 W. In this case, the demand factor for your house is 0.5. The value of the demand factor is always less than or equal to unity.



An example of a load profile of a typical day.

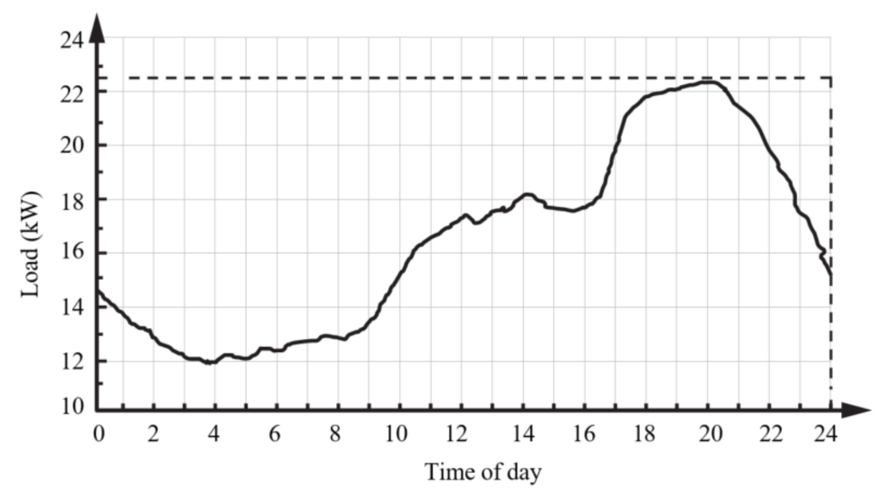
CHARACTERISTICS OF LOAD DEMAND FOR ELECTRICITY

A **coincidence factor** is the ratio of the maximum load to the sum of all maximum demands of individual customers in the region of interest.

$$\text{Coincidence factor} = \frac{\text{Maximum load}}{\text{Sum of all maximum demands of individual customers}} \tag{1.5}$$

Since typically the maximum demands of all consumers do not coincide (this is called diversity), the maximum demand will be less than the sum of individual demands. Therefore, the value of the coincidence factor is always ≤1. Note that the demand factor and coincidence factor are different. The former is based on all consumers connected, while the latter is based on the observed maximum demand of individual consumers, e.g., each home.

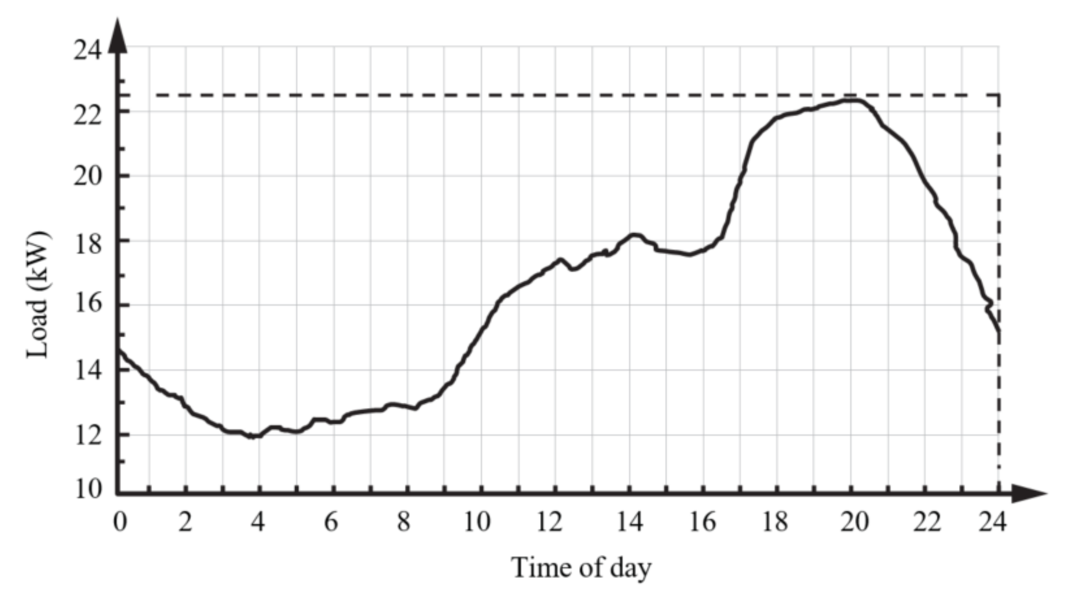
The demand and coincidence factors are the indication of the possibility of having a load greater than the maximum load. The greater demand factor suggests that a greater spare power generation capacity in the network is needed.



An example of a load profile of a typical day.

EXAMPLE 1

In the load curve presented below, determine the maximum and base demands, total electrical energy consumed, daily average load, load factor, and demand factor if the unit of the electrical load in the diagram is kW. Assume that the maximum possible demand is 30 kW.



EXAMPLE 2

A neighborhood has ten identical houses. The maximum possible power consumption in each house is 7 kW (if all electrical appliances operate at the same time). However, in practice, the maximum power consumption in each house is 3 kW. If the maximum power consumption of the neighborhood is 20 kW, determine the demand factor for each house and the coincidence factor for the neighborhood.

CHARACTERISTIC OF POWER GENERATION SYSTEMS

- Previous terms were defined for the demand (consumer) side of the system. The following terms are defined for the electricity generation side.
- Plant capacity factor
- Availability factor
- Utilization factor or use factor

CHARACTERISTIC OF POWER GENERATION SYSTEMS

capacity factor is the ratio of the actual electrical energy produced by a single power generation unit or a system of power generation units to the maximum possible electrical energy that could have been produced, i.e., if the system was operated at the full installed capacity at all time, during a certain period.

$$\text{Capacity factor} = \frac{\text{Actual electrical energy produced}}{\text{Maximum possible electrical energy that could have been produced}} \tag{1.6}$$

CHARACTERISTIC OF POWER GENERATION SYSTEMS

The following three factors contribute to the less than a unity capacity factor:

(1) if the system operates at a reduced load or is out of service due to a failure in equipment, routine maintenance, or unplanned maintenance

(2) if the system operates at a reduced load or is shut down because electrical energy is not needed or it is not economical to produce electricity due to a low price of sale

(3) if the system does not generate electricity due to unavailability of energy sources, for example in a gas turbine when natural gas from the pipeline is not available

- Steam power stations such as coal, geothermal, and nuclear power plants: between 50% and 95%.
- Gas turbines: from 80% to 99%.
- Wind farms: 25%–40%.
- Photovoltaic solar units: <25%.
- Hydroelectricity: 20%–99%

CHARACTERISTIC OF POWER GENERATION SYSTEMS

The **availability factor** is the ratio of the time that the plant or system is able to generate electricity, regardless of if it is actually operating or not, to the total time in a given period.

$$\text{Availability factor} = \frac{\text{Time that the plant or system is able to generate electricity}}{\text{Total time in a given period}} \tag{1.7}$$

The duration in which the system operates at part loads due to maintenance may or may not be considered in this definition and should be clarified for each case.

CHARACTERISTIC OF POWER GENERATION SYSTEMS

In contrast to the availability factor, a **utilization factor** or **use factor** is the ratio of the time that a power generation plant or system is in use to the total time that it is available to be used.

$$\text{Utilization factor or use factor} = \frac{\text{Time that a power generation unit or plant is in use}}{\text{Total time that it is available to be used}} \tag{1.8}$$

A low utilization factor and capacity factor along with a high availability factor for a plant indicates that the plant is maintained and operated properly, and the reason for the low utilization factor and capacity factor is the lack of demand or the shortage of primary energy.

EXAMPLES

Example 3: Determine the capacity factor for a power plant with the installed capacity of 2000 MW that produces 15,000 GWh per year.

Example 4: A power plant operates four hours a day, 40 weeks a year. If on average the plant is not available for five hours a week for scheduled and unscheduled maintenance, determine the plant's availability and utilization factors.

SELECTING CAPACITY AND TYPE OF ELECTRICITY GENERATING UNITS

- Number and size of units to approximately fit the annual load curve.
- Minimal partial load operation.
- Units to be of different capacities to meet load requirements.
- Extra capacity for future expansion.
- Spare generating capacity.
- Avoid selecting smaller units to closely fit load curve.

SELECTING CAPACITY AND TYPE OF ELECTRICITY GENERATING UNITS

Baseload power plant: plant devoted to the production of baseload supply (continuous energy demand) and produce energy at a constant rate.

- Low cost generation
- High efficiency
- High plant capacity factor
- High capital costs
- Low marginal costs

SELECTING CAPACITY AND TYPE OF ELECTRICITY GENERATING UNITS

Peaking power plants (Peaker plants): generally, run only when there is a high demand.

- Many days to as little as a few hours per year operation
- Usually not very efficient
- Low capital costs
- High marginal costs
- Gas turbines, reciprocating engines, pumped hydro storage and other storage technologies, and hydroelectric plants

IDEALIZATION OF POWER GENERATION SYSTEMS

Ideal cycles for common power generation systems

Type of Power Plant	Ideal Thermodynamics Cycle	Working Fluid Phase	Energy Source	Renewable (R) or Non-renewable (N)
Steam power plant	Rankine	Vapor and liquid	Coal	N
			Natural gas	N
			Petroleum products	N
			Biomass	R
			Nuclear reaction	N
			Geothermal	R
			Solar thermal	R
			Ocean thermal	R
Gas turbine	Brayton	Gas	Natural gas	N
			Petroleum products	N

(*Continued*)

IDEALIZATION OF POWER GENERATION SYSTEMS

Type of Power Plant	Ideal Thermodynamics Cycle	Working Fluid Phase	Energy Source	Renewable (R) or Non-renewable (N)
Combined cycle	Rankine + Brayton	Vapor and liquid + gas	Natural gas	N
			Petroleum products	N
Integrated gasification combined cycle	Rankine + Brayton	Vapor and liquid + gas	Coal	N
			Biomass	R
Fuel cell	None	None	All gaseous and liquid fuels	N
Hydroelectric	None	None	Kinetic energy of water	R
Wind turbine	None	None	Kinetic energy of wind	R
Solar-photovoltaic	None	None	Solar radiation	R
Ocean energies (waves, tides, currents)	None	None	Ocean waves and tides	R
Spark-ignition piston and cylinder engine	Otto	Gas	Gasoline	N
Compression-ignition piston and cylinder engine	Diesel	Gas	Diesel	N

ELECTRICITY TRANSMISSION LINES

Note that the power transmitted through a line can be determined by

$$P_T = IV \tag{1.9}$$

where P_T is transmitted electric power (W), I is current (A), and V is the voltage (V) of the transmission line. Also, the power loss in the transmission and distribution lines is directly proportional to the square of the current.

$$P_L = I^2R \tag{1.10}$$

where P_L is the loss of power during the transmission of electric power (W), I is the current (A), and R is the resistance (Ω) of the transmission line. The low-voltage and high-current electricity transmission meant a significant loss of power in long-distance transmissions (Example 1.5).

ELECTRICITY TRANSMISSION LINES

In the late 19th century, when commercial electricity was in its infancy, power generation units were located near consumption centers. This was mainly because generated power was direct current (DC), and it was difficult to change the voltage of DC power. This meant that the voltage of generated electricity and that of the consumed electricity must be equal. There were even different classes of electricity at different voltages with dedicated power generation and distribution systems. The low-voltage electricity meant that to transmit a significant amount of electric power, high current was required.

EXAMPLE 5

A power plant produces 100 MW electric power, which is transmitted through a high voltage line at 115 kV to a consumption center. If the resistance of the line is 10 Ω, determine the power loss in the transmission line. Determine the loss if the power was transmitted through a 34 kV line.

END OF THE LECTURE