EEE270
Introduction to Electrical Energy Systems

Lecture 1

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Content of the Course

- Introduction to power systems.
- Sinusoidal steady-state analysis.
- Sinusoidal steady-state power calculations.
- Balanced three-phase systems.
- Transformers and per-unit calculations.
- Single line diagrams.
- Voltage drop and power loss calculations.
- Reactive power compensation.
- Power and wiring cables.

Course Objectives

- Give brief information on low voltage power systems.
- Perform steady-state analysis on single and balanced three-phase systems.
- Understand the operating principle and steady-state equations of single- and three-phase transformers.
- Understand per-unit, change of base concept, and load concept.
- Perform voltage drop and power loss analysis in single and three-phase systems.
- Apply reactive power compensation technique to the single and three-phase systems.
- Understand how to select suitable conductor size in single and three-phase systems and which factors effect ampacity.

Learning Outcomes

After successful completion of the course, the students are able to

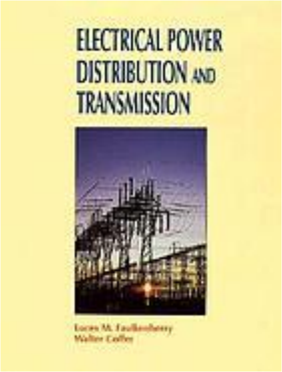
- Analyze simple single- and three-phase systems by means of current, voltage, power, loss, and efficiency.
- Analyze single- and three-phase systems including transformers.
- Perform per-unit calculations and change of base operation on single- and three-phase systems including transformers.
- Calculate exact and approximate voltage drop in single and three-phase systems.
- Apply reactive power compensation technique to the single- and three-phase systems.
- Perform selection of suitable conductor size in single and three-phase systems using voltage drop and ampacity criterion.

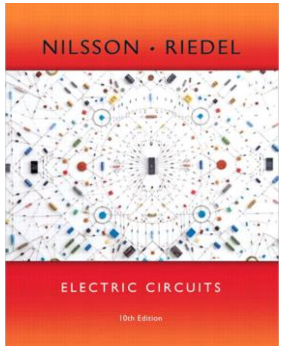
References

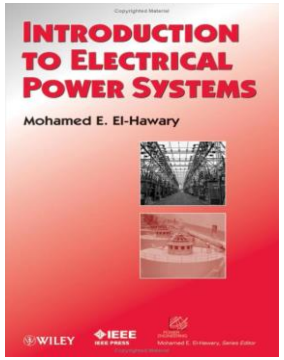
- Electrical Power Distribution and Transmission (Luces M. Faulkenberry and Walter Coffer, *Prentice Hall*

- Electric Circuits (10th Edition) (James W. Nilsson and Susan A. Riedel, *Pearson*

- Introduction to Electrical Power Systems, Muhammed E. El Hawary, *Wiley*







References (*Continue*)

- *Analysis and Design of Low Voltage Power Systems: An Engineer's Field Guide*, İsmail Kaşıkçı, Wiley-VCH, ISBN: 3-527-30483-5.
- *Engineering Circuit Analysis*, William H. Hayt, Jack E. Kemmerly, Steven M. Durbin, 7th Edition, Mc-Graw Hill, ISBN: 0.07-286611-X.
- *Electric Power Distribution System Engineering*, Turan Gören, 2nd Edition, CRC Press, 2008.
- *Electric Power Distribution Handbook*, 2nd Edition, Thomas Allen Short, CRC Press, 2004.
- Lecture Notes on *Energy Distribution* Course of Dr. Fahri Okan PEKİNER from Yıldız Technical University.

Grading Policy

- Midterm-1 : **30%**
- Midterm-2 : **30%**
- Final : **40%**
- TOTAL : **100%**

✓Exams are closed-book

✓Homework(s)/Project can be assigned during the semester

(The performances of the students will be included into the grading policy)

✓Attendance is minimum 70% to class

Students who has registered to EEE 270 ***MUST follow*** *the web pages of both Prof. Dr. A. Mete VURAL and/or Assist. Prof. Dr. Ali Osman ARSLAN for all announcements and getting other course related materials.*

Some Advices !

- Keep attendance as much as poosible ! (70% or more)
- Take your own notes
- Practice is good. Do it as much as possible
- Do not try to summarize, try to learn the fundamental idea
- Solve examples, problems as many as possible
- Make your study plan by yourself
- Know yourself ! Study alone or within a group
- Do not postpone anything ! Do it now

The Prefixes Used with SI Units

Prefix	Symbol	Meaning	Scientific Notation
exa-	E	1,000,000,000,000,000,000	10^{18}
peta-	P	1,000,000,000,000,000	10^{15}
tera-	T	1,000,000,000,000	10^{12}
giga-	G	1,000,000,000	10^{9}
mega-	M	1,000,000	10^{6}
kilo-	k	1,000	10^{3}
hecto-	h	100	10^{2}
deka-	da	10	10^{1}
—	—	1	10^{0}
deci-	d	0.1	10^{-1}
centi-	c	0.01	10^{-2}
milli-	m	0.001	10^{-3}
micro-	μ	0.000 001	10^{-6}
nano-	n	0.000 000 001	10^{-9}
pico-	p	0.000 000 000 001	10^{-12}
femto-	f	0.000 000 000 000 001	10^{-15}
atto-	a	0.000 000 000 000 000 001	10^{-18}

Greek alphabet letters used as symbols in electrical engineering

UPPER CASE

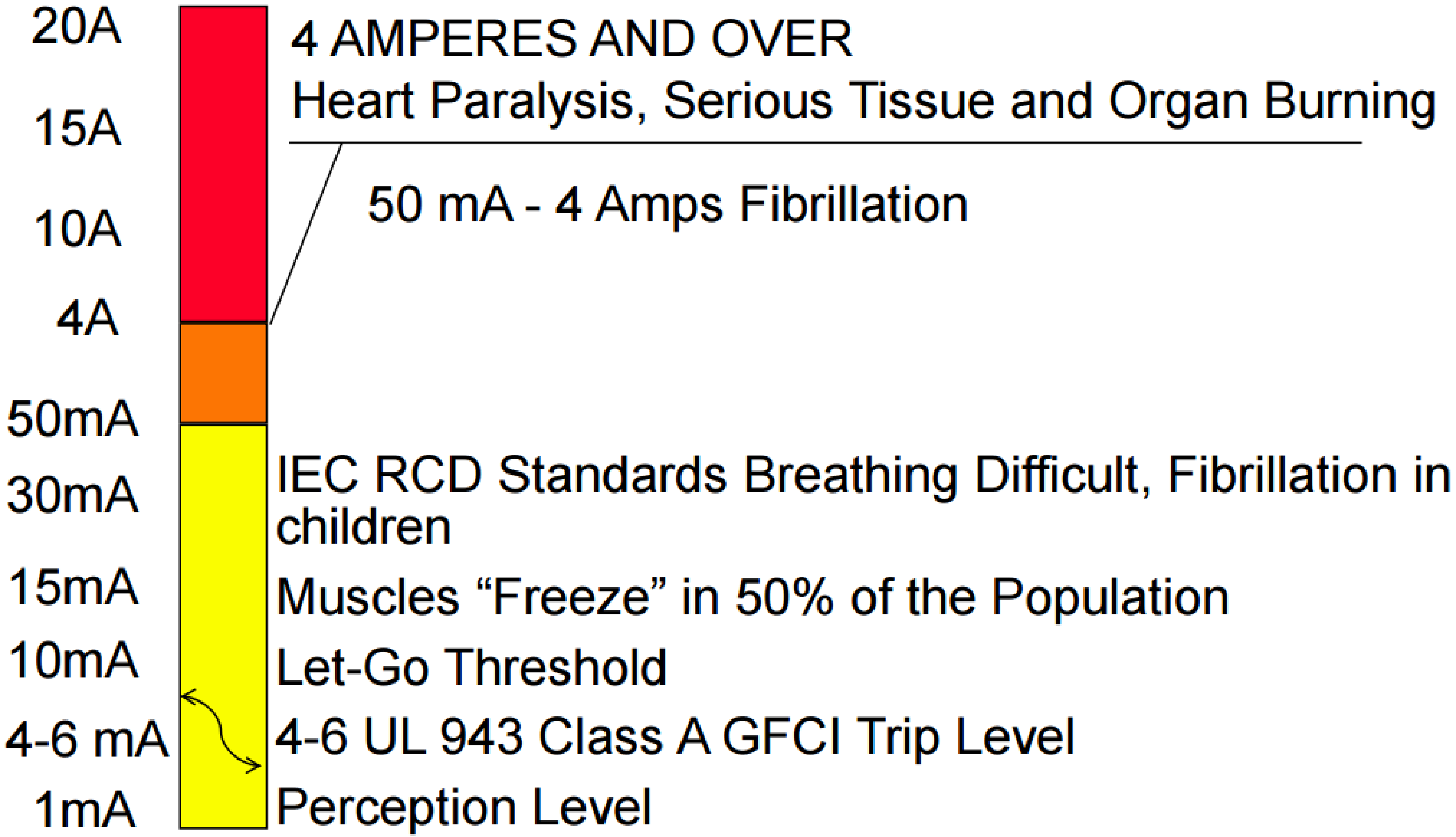
Α	α	alpha	Ν	ν	nu
Β	β	beta	Ξ	ξ	ksi
Γ	γ	gamma	Ο	ο	omicron
Δ	δ	delta	Π	π	pi
Ε	ε	epsilon	Ρ	ρ	rho
Ζ	ζ	zeta	Σ	σς	sigma
Η	η	eta	Τ	τ	tau
Θ	θ	theta	Υ	υ	upsilon
Ι	ι	iota	Φ	φ	phi
Κ	κ	kappa	Χ	χ	chi
Λ	λ	lambda	Ψ	ψ	psi
Μ	μ	mu	Ω	ω	omega

lower case

English unit vs SI unit

English Unit	SI Unit	Conversion
Mile	Kilometer	1 mile = 1.609 Km
Foot	Meter	1 ft = .305 M
Inch	Centimeter	1 inch = 2.54 Cm
Pound	Grams	1 lb = 453.59 G
Ounce	Grams	1 oz = 28.35 G
Gallon	Liter	1 gallon = 3.79 L
Celsius	Kelvin	0 Degree C = 273.15 K

Effects of Electrical Shock



Source: http://www.nema.org

LECTURE 1

INTRODUCTION TO POWER SYSTEMS

Electrical Power System Consideration

- Societies must use energy resources in the form in which they appear, wheather as water, wind, oil, or uranium, to accomplish the task the societies consider desirable.
- The desirable tasks may be heating, cooling, lighting, manufacturing or transportation of people and materials.
- Finding and converting the raw energy resources to usable energy is a vital function, as the design, production and use of efficient equipment to convert energy to useful work (motor, heaters, air conditioners, etc)
- Recall that electricity is an efficient and convenient transportation system for energy that allow the raw energy resources ad equipment that converts energy to work to be seperated by great distances.

Electrical Power System Consideration

- Electricity does exist in nature as lightning and static electricity, but it cannot be controlled well enough to be put to practical use.
- Thus electricity must be generated by converting another raw energy resource.
- Electricity can be stored in batteries, but only in relatively small quantities.
- Therefore, at least for the present time, electricity must be produced at the same time it is used.

Electrical Power System Consideration

- Electrical power is the prime source of energy that supports almost all of other technologies.
- Electricity is the most convenient and energy type available today. (*Imagine your life without it.*)
- Electric power systems are real-time energy delivery systems.
- Real time means that power is generated, transported, and supplied at the same time.(*It is a process that begins from the moment you turn on the light.*)
- Electric power systems are not storage systems like water systems and gas systems. Instead, generators produce the energy as the demand calls for it.
- It is safe, convenient and efficient way to transport large amount of electrical power long distances.

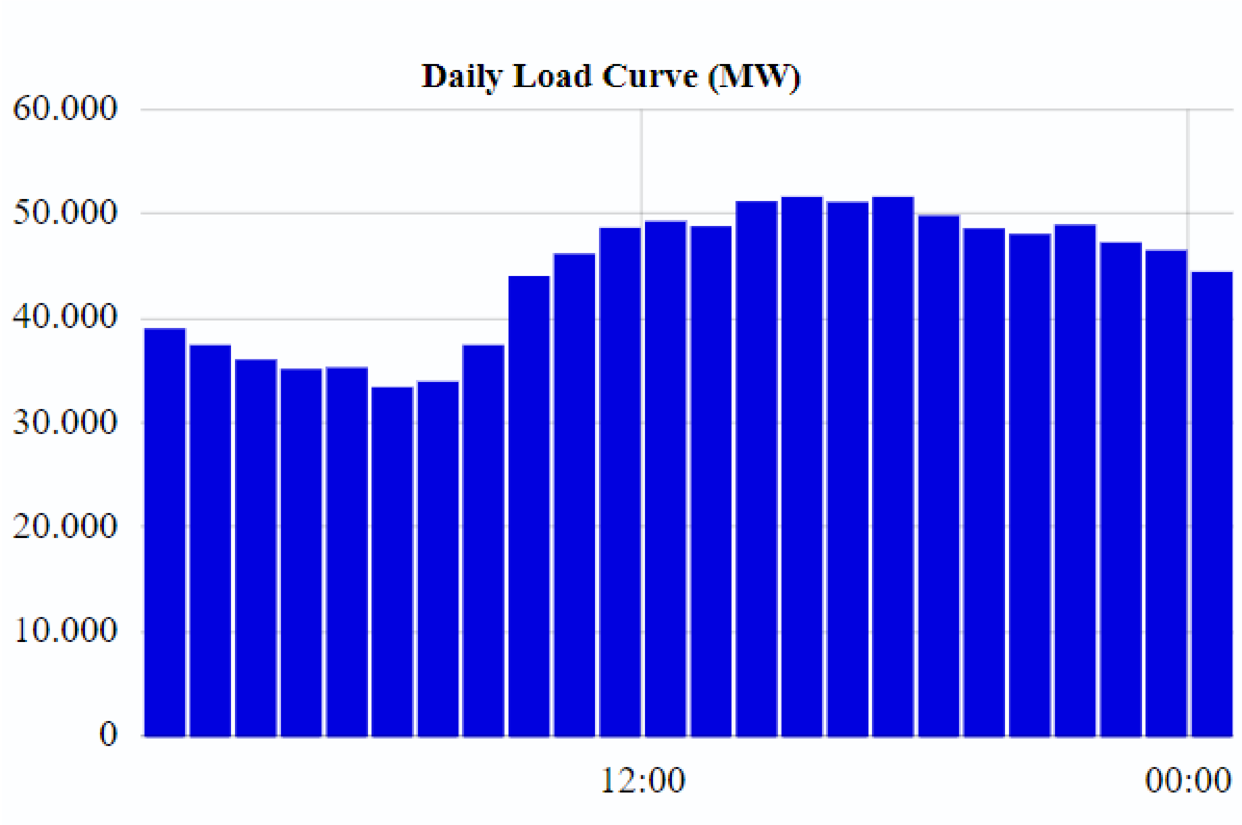
Reserve

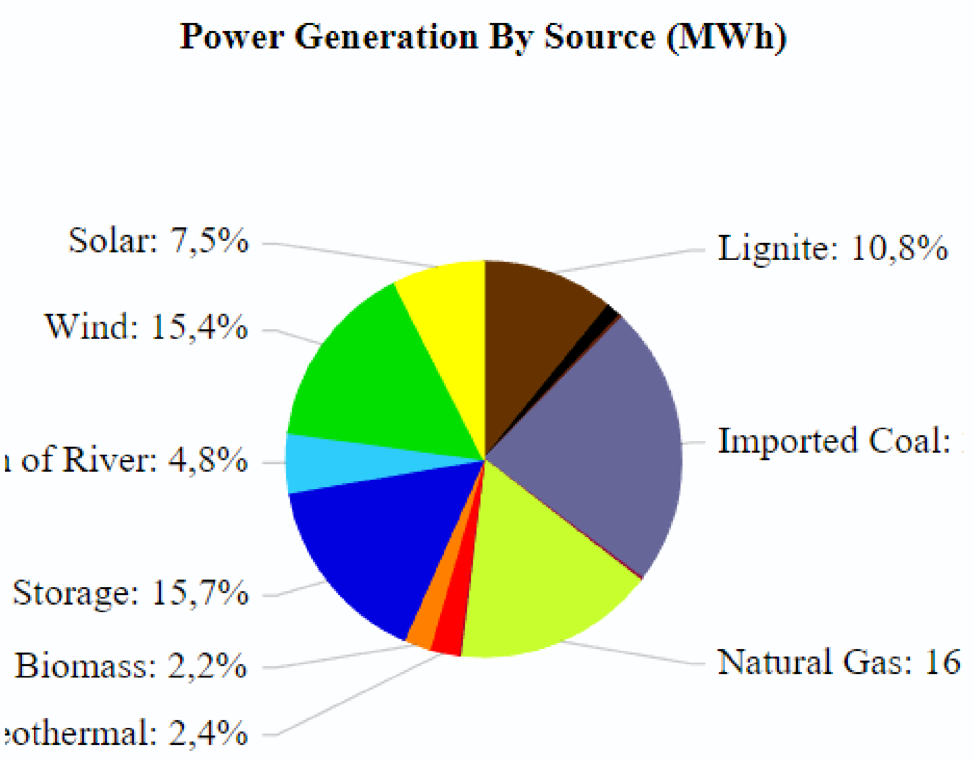
- Reserve is that portion of an electric utility's available generating capacity that is not producing electricity at a given time.
- Spinning reserve is the generating capacity that is being driven at the proper speed to provide proper voltage, but is not producing power.
- Spinning reserve can provide power to the system almost instantaneously if the system load is increased or a generator must be taken out of service.
- The Federal Energy Regulatory Commission (FERC) established a requirement that each electric power company construct sufficient excess capacity that it can supply its largest normal load with its largest generating plant off line. This rule has been modified for some circumstances, as will be discussed later. Spinning reserve shold be sufficient to meet any sudden load changes anticipated by the utility

Diversity

- Diversity is the term used to refer to load changes during a period of time. Load varies during the day because people get up, go to work, and return in the evening using different amounts of electricity to support their various activities.
- Similarly, industrial and commercial power use will vary during the day. There are also weekly and seasonal variations in electricity usage.
- Summers that peaks daily in the late afternoon. The result of diversity is that the electric utility must supply varying amounts of power depending on the time of day, day of the week, and season.

Diversity in Türkiye - 17/07/2023



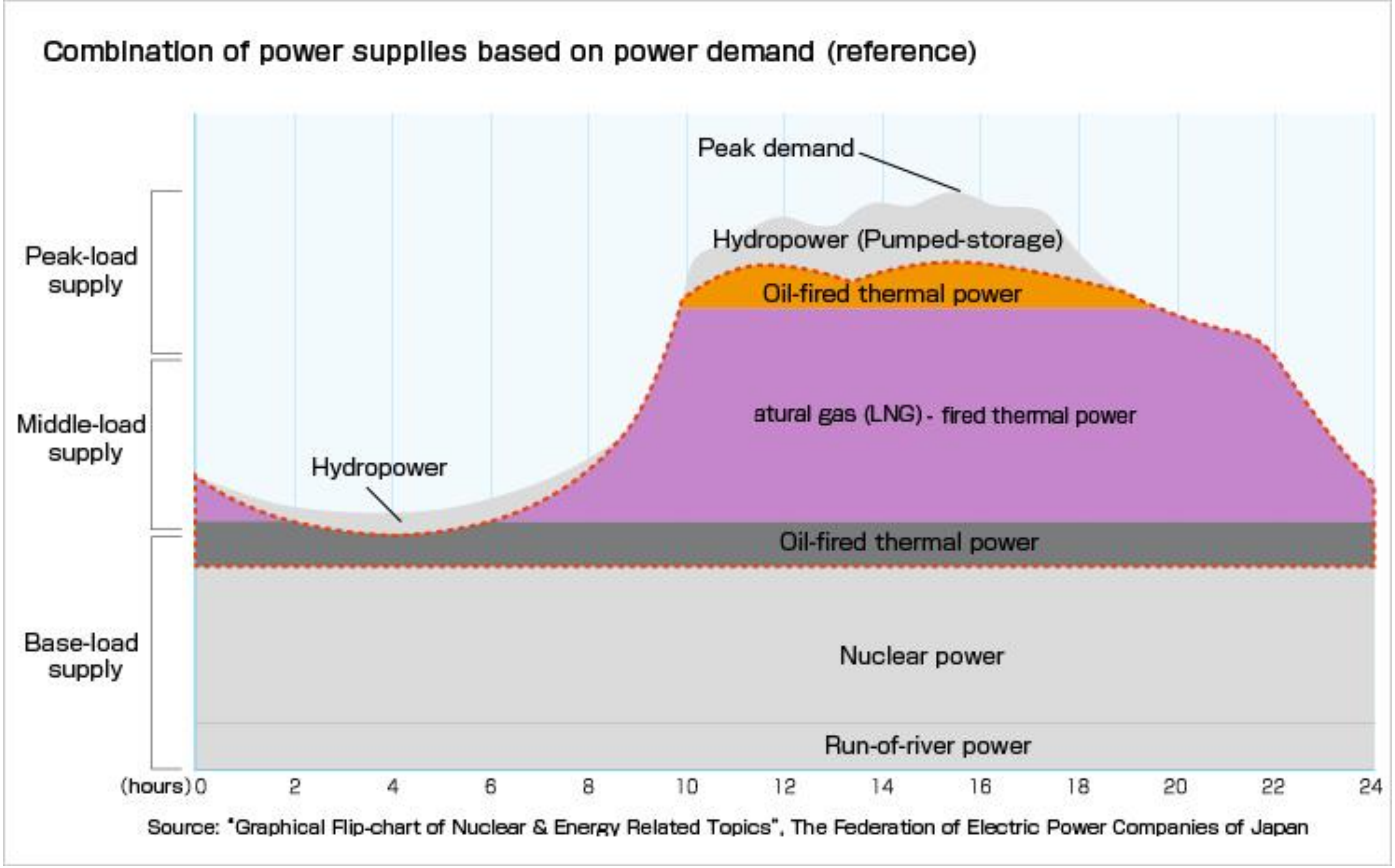


[İstatistikler (teias.gov.tr)](teias.gov.tr)

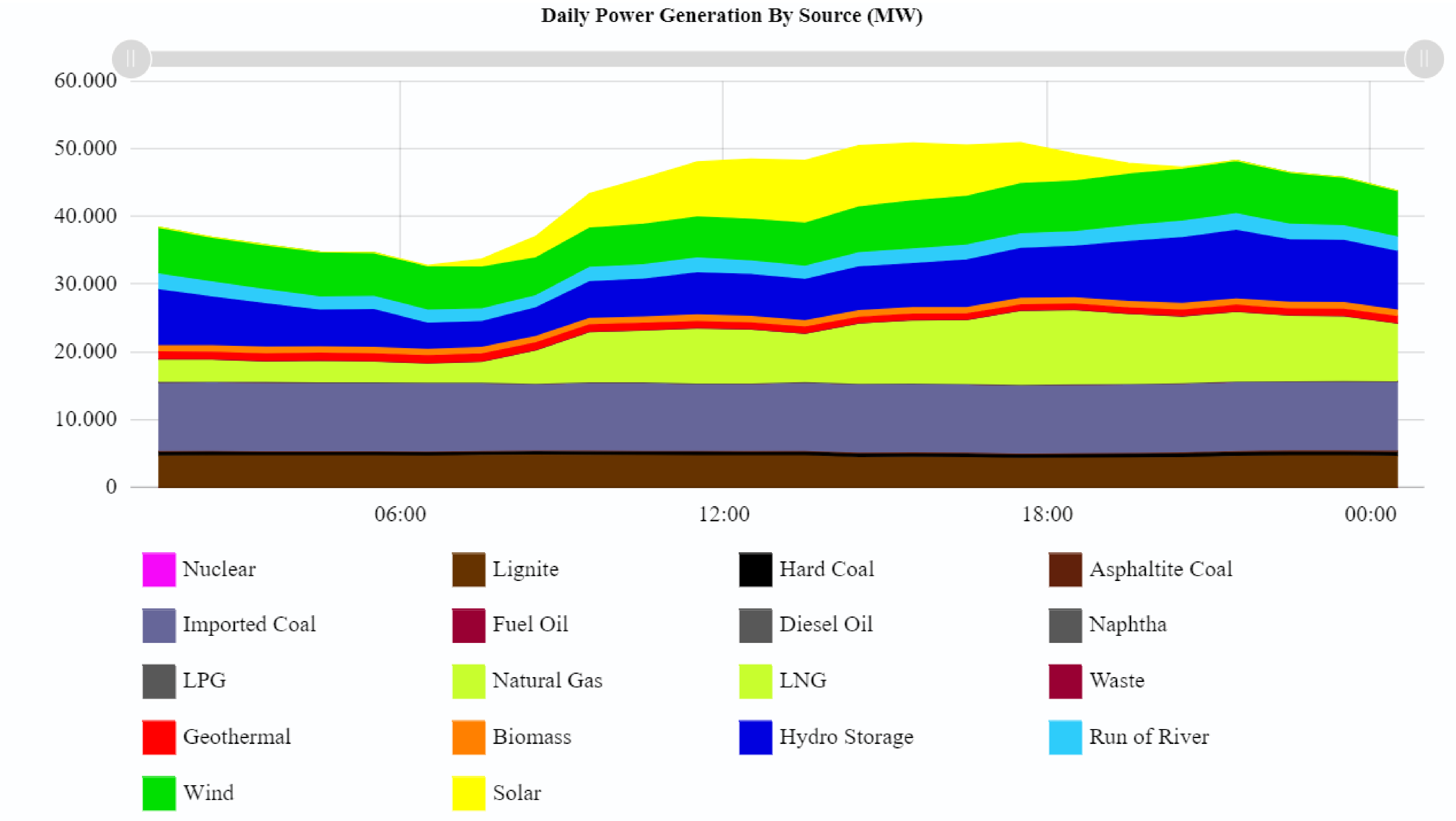
Figure shows a 24-hour diversity curve for electric power consumption in Türkiye
Date: 17/07/2023

Economic Dispatch

- Economic dispatch refers to serving the load at all times with as little excess capacity as possible using the most efficient generating units possible.
- Properly sequencing the timing and size of generating units put into service can result in very large cost savings while adequately serving the load.
- The more efficient units are used to serve the base load and the less efficient units are used to serve the peak loads.
- Many factors must be considered other than just generator efficiency for economic dispatch in a large system.
- Line losses for various lines, fuel cost, availability and cost of interconnected capacity, and many other factors must be considered also, so economic dispatch alternatives are calculated on complicated computer programs.



Source: Power Generation [KEPCO]



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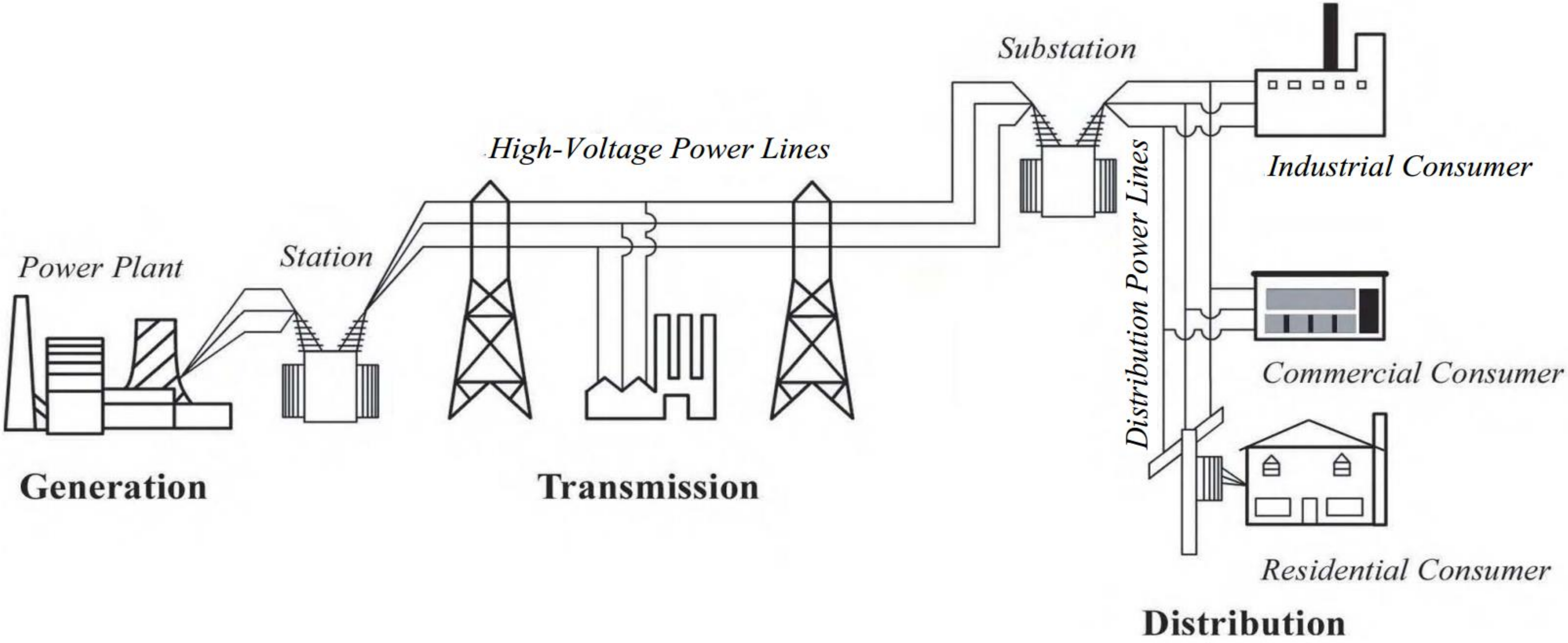
Electrical Power System



System Components

Electrical power system can be composed of following major parts:

1. Generation: production of the electricity, source of the power, ideally with a specified voltage and frequency

2. Transmission: the system of lines that transport the electricity from generating plant to the area in which it will be used. ideally as a perfect conductor

3. Distrubution: the system of lines that connect the individual costumer to the electrical power systems

Electrical Power System

- The system starts with generation, by which electrical energy is produced in the power plant and then transformed in the power station to high-voltage electrical energy that is more suitable for efficient long-distance transportation.

- The power plants transform other sources of energy in the process of producing electrical energy. For example, heat, mechanical, hydraulic, chemical, solar, wind, geothermal, nuclear, and other energy sources are used in the production of electrical energy. High-voltage (HV) power lines in the transmission portion of the electric power system efficiently transport electrical energy over long distances to the consumption locations.

- Finally, substations transform this HV electrical energy into lower-voltage energy that is transmitted over distribution power lines that are more suitable for the distribution of electrical energy to its destination, where it is again transformed for residential, commercial, and industrial consumption.

Voltage Levels

- The major losses in transporting electricity are proportional to the current squared, thus doubling the current quadruples the loss.
- Power is the product of current times voltage so as voltage is increased, current is decreased, and losses are decreased for a given amount of power transfer.
- Thus the highest economically feasible voltage is favoured for generating, transmitting, and distributing electrical power.

Voltage Levels

- Rotary machines (generators and motors) have practical voltage limits set by limitations in insulation and cooling technology. Voltages allowable on rotary machines are increasing, but slowly now.
- Maximum generator voltages are currently about 24 kV and about 12 kV for motors.
- The voltage limits for transmission voltages are set by protective devices (mainly circuit breakers) rather than transformers and insulators.
- Bundled conductors and shielding have removed the past limit of the breakdown of the air around the conductors.

General Voltage Levels of System Components

Different electric utilities have set different standard voltages, but the following voltages are common

- Generators: 11kV to 24kV
- Extra High Voltage Transmission: 345kV, 500kV and 765kV for AC
  500kV (±250kV) , 800kV (±400 kV) and 1000kV (±500kV) for DC

- Transmission: 138kV to 230kV
- Sub-Transmission: 34.5kV to 69kV
- Distribution: 12.5kV to 34.5kV

Voltage Levels according to ANSI

Standard nominal three-phase system voltages per **ANSI** C84.1-1989 (*American National Standards Institute*)

Voltage Class	Three-wire	Four-wire
Low Voltage		208 Y/120
	240	240/120
	480	480 Y/277
	600	
Medium Voltage	2,400	
	4,160	4,160 Y/2400
	4,800	
	6,900	
		8,320 Y/4800
		12,000 Y/6,930
		12,470 Y/7,200
		13,200 Y/7,620
	13,800	13,800 Y/7,970
		20,780 Y/12,000
		22,860 Y/13,200
	23,000	
		24,940 Y/14,400
	34,500	34,500 Y/19,920
	46,000	
	69,000	
High Voltage	115,000	
	138,000	
	161,000	
	230,000	
Extra-High Voltage	345,000	
	500,000	
	765,000	
Ultra-High Voltage	1,100,000	

Voltage Levels according to IEC

The International Electrotechnical Commission (**IEC**) has classified the voltages into the following levels (**IEC 60038**). This classification system is gaining fast acceptance:

Low Voltage - upto 1000V

Medium Voltage - 1000V to 35kV

High Voltage - 35kV to 230 kV

Extra High Voltage - above 230 kV

P.S: In some Turkish sources, **154 kV** is given instead of **230 kV**

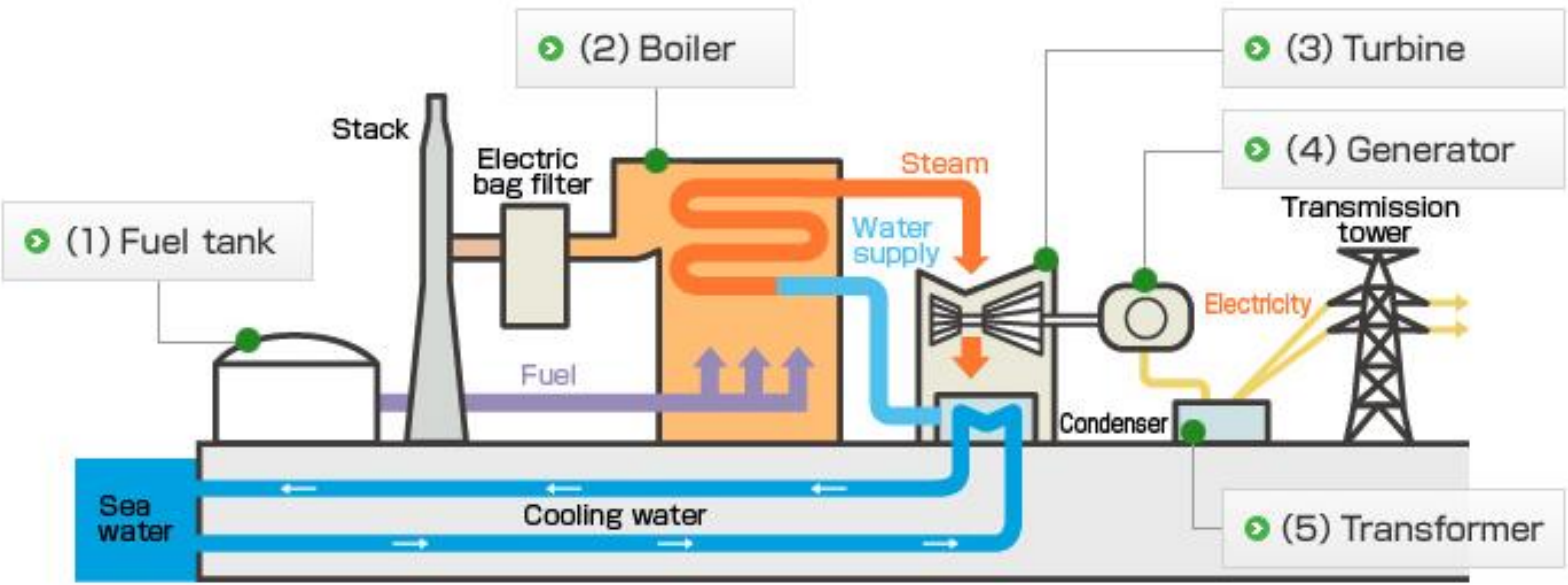
Frequency

- Many different frequencies were tried for electrical power systems in early days of ac power.
- 60 Hz was chosen in the United Stated because of convenient fit with the 60-second minute and absence of other problems. Lowest possible frequency is desirable for electricity transmission to lower the reactive voltage drop on the line and reduce radiative loss (like antenna radiation) . The lower practical limit on the frequency was set by the flickering of the incandescent lamp.
- Europe settled on 50 Hz. Most of Africa and some of Asia followed suit because of European colonization.

Generation

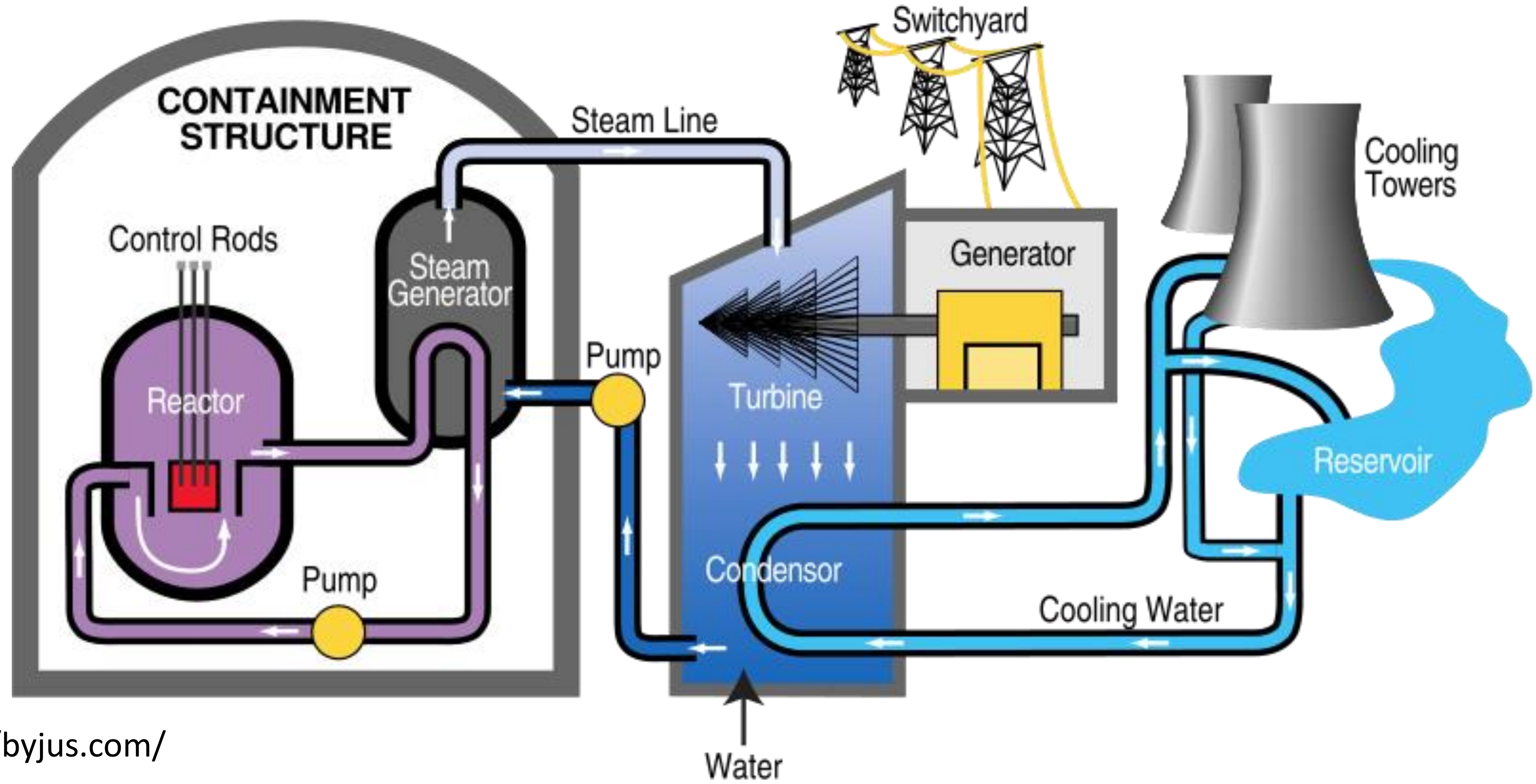
- Classification by the “mechanical means” used to turn the generator.
- Thermal (water steam by burning Coal, Oil, CNG)
- Nuclear (water steam by Uranium or Plutonium fission)
- Geothermal
- Hydroelectric (falling water)
- Wind
- Solar

Thermal



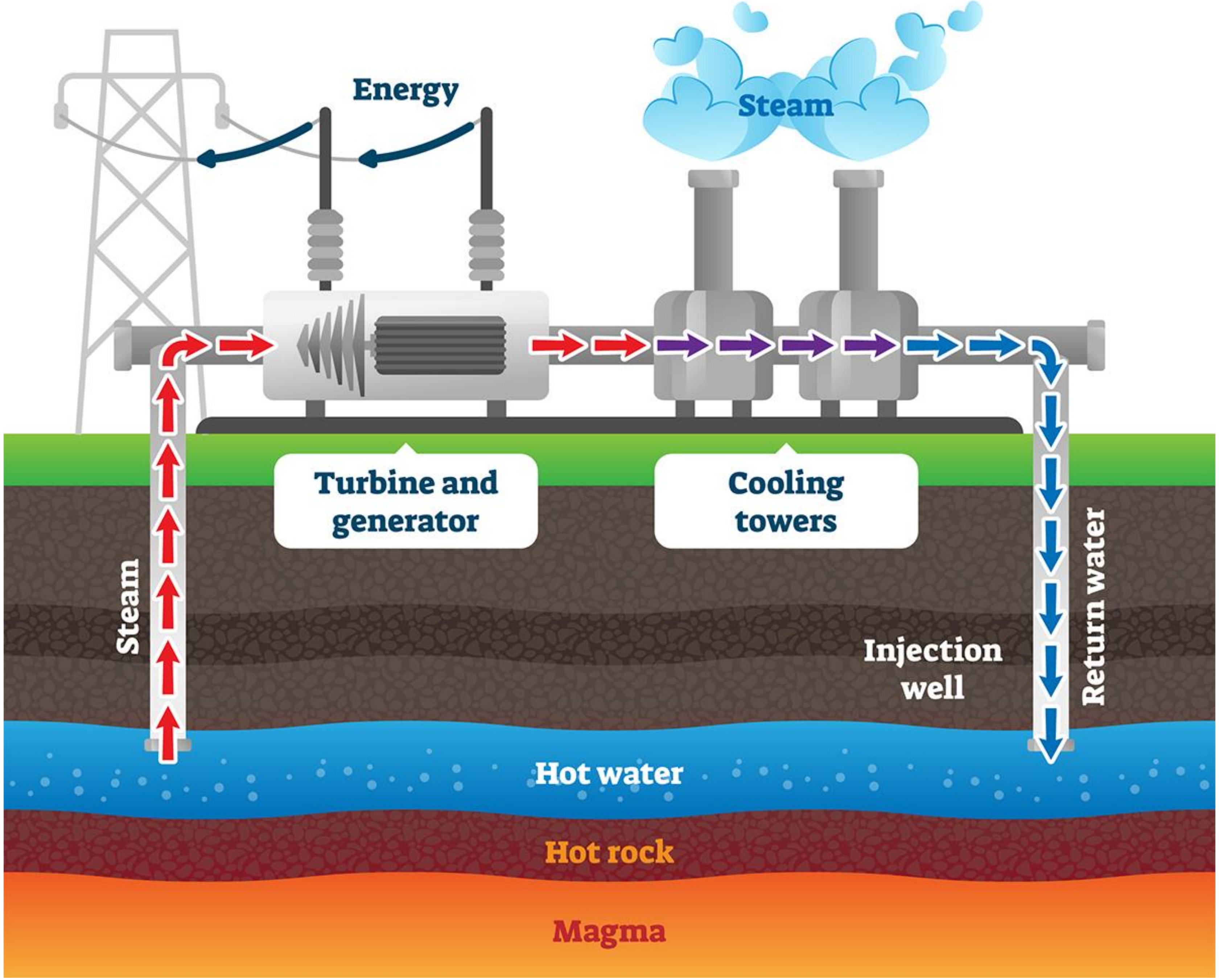
[Types of fuel [KEPCO]]

Nuclear



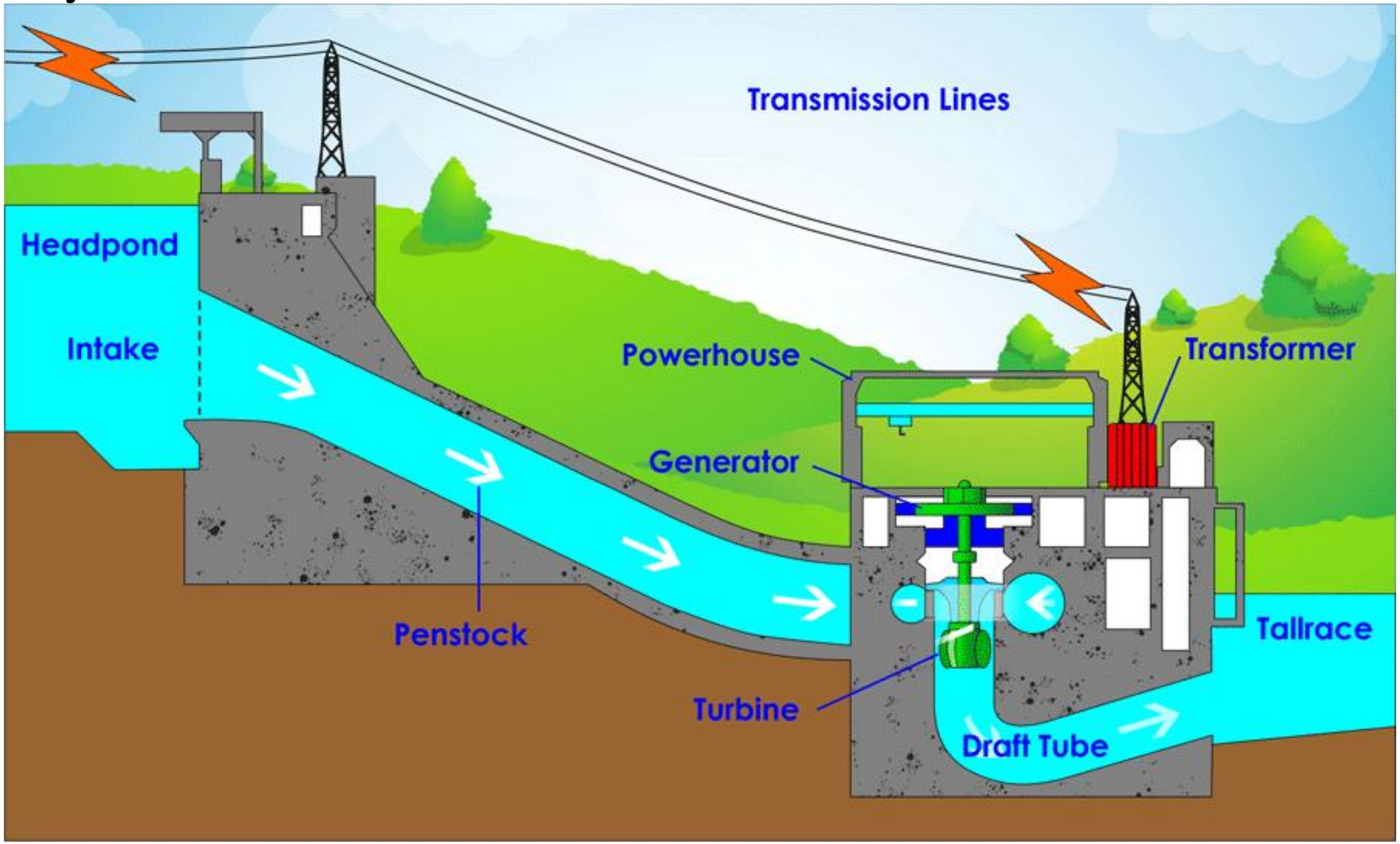
https://byjus.com/

Geothermal



Energy
Steam
Turbine and generator
Cooling towers
Steam
Injection well
Return water
Hot water
Hot rock
Magma

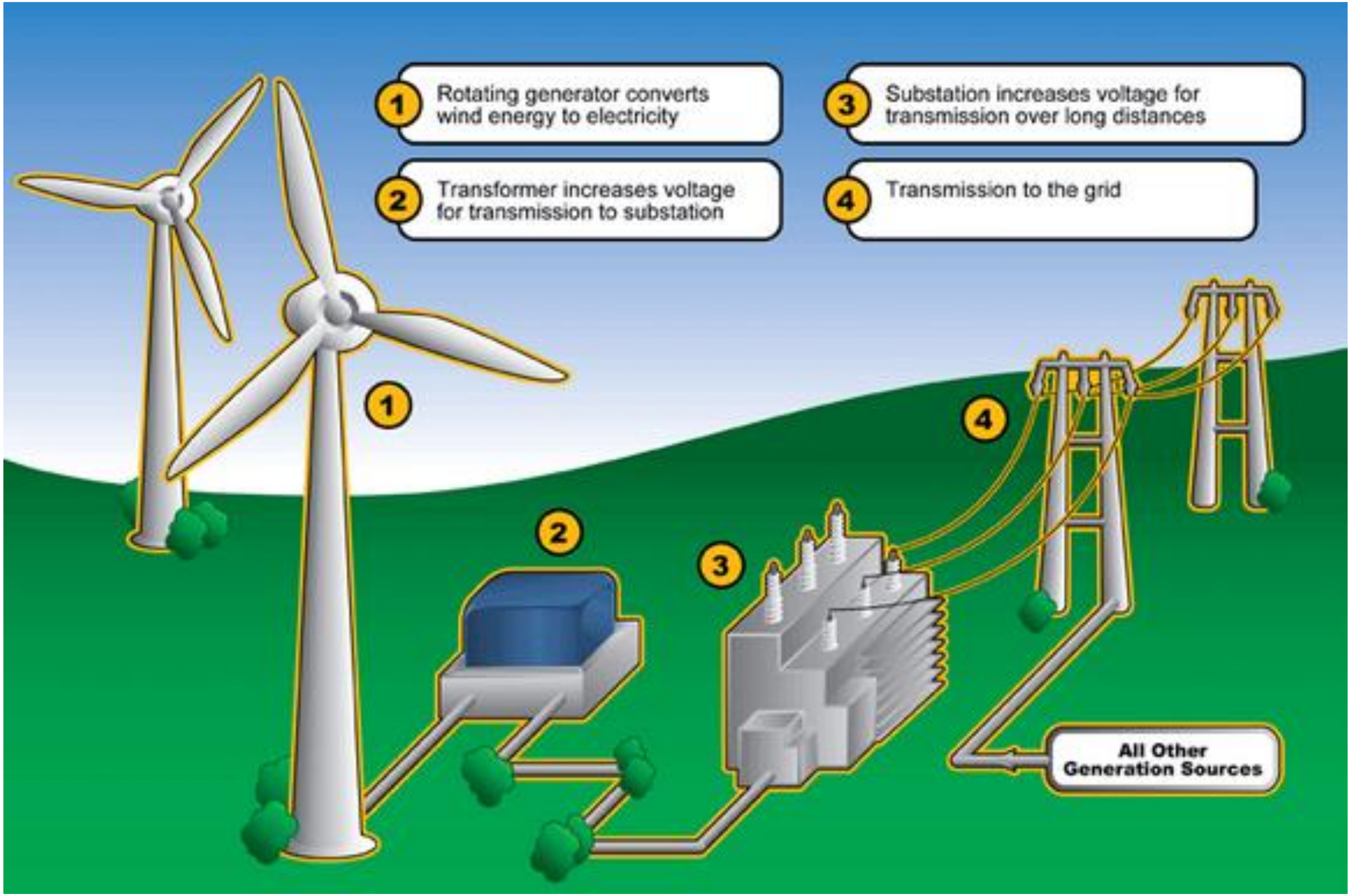
Hydroelectric



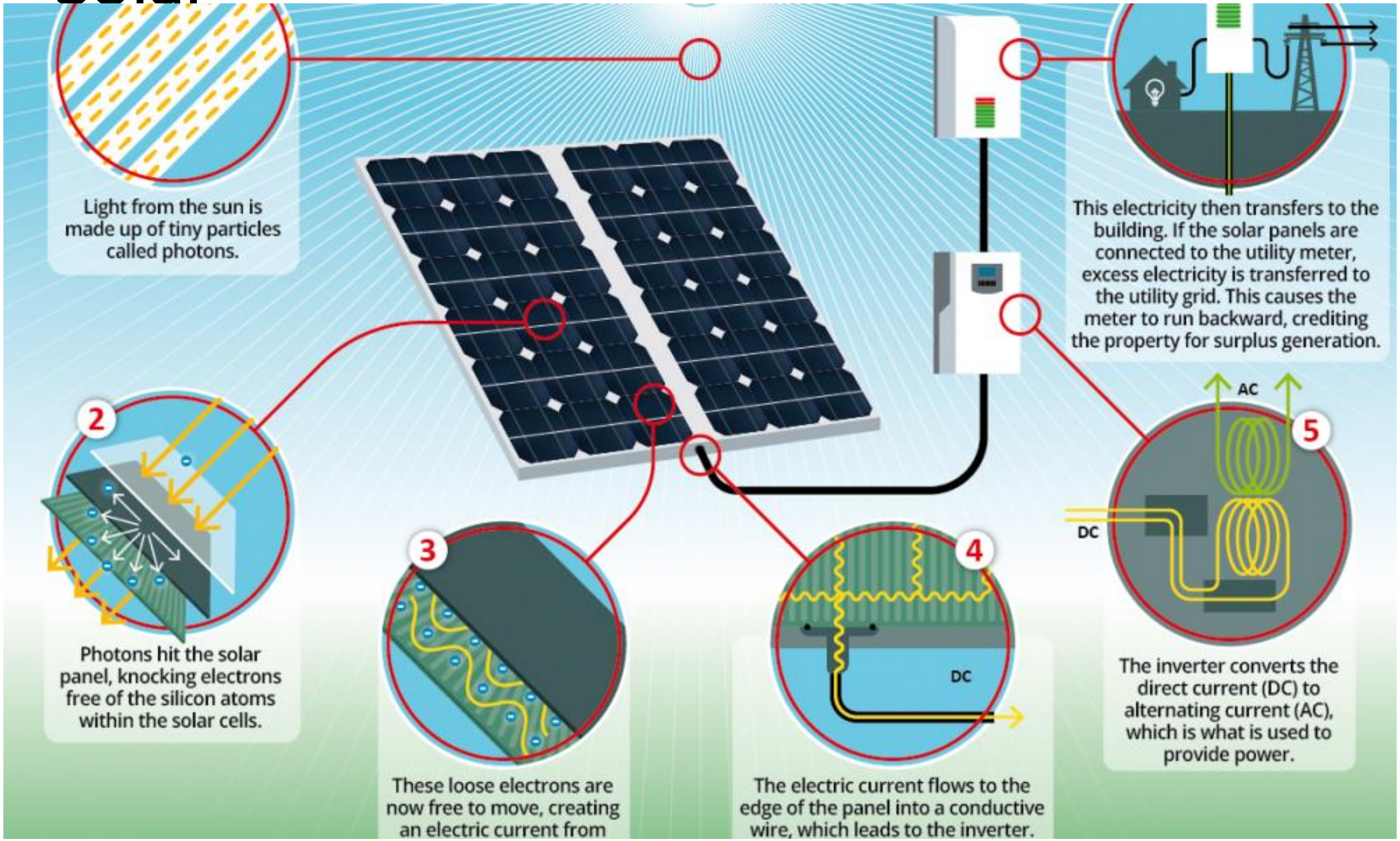
Falling water was one of the first sources of energy man exploited for work and also one of the first forms of energy used to produce electricity

Hydroelectric Power: (electronicslovers.com)

Wind


1 Rotating generator converts wind energy to electricity
2 Transformer increases voltage for transmission to substation
3 Substation increases voltage for transmission over long distances
4 Transmission to the grid
1
2
3
4
All Other Generation Sources

Solar



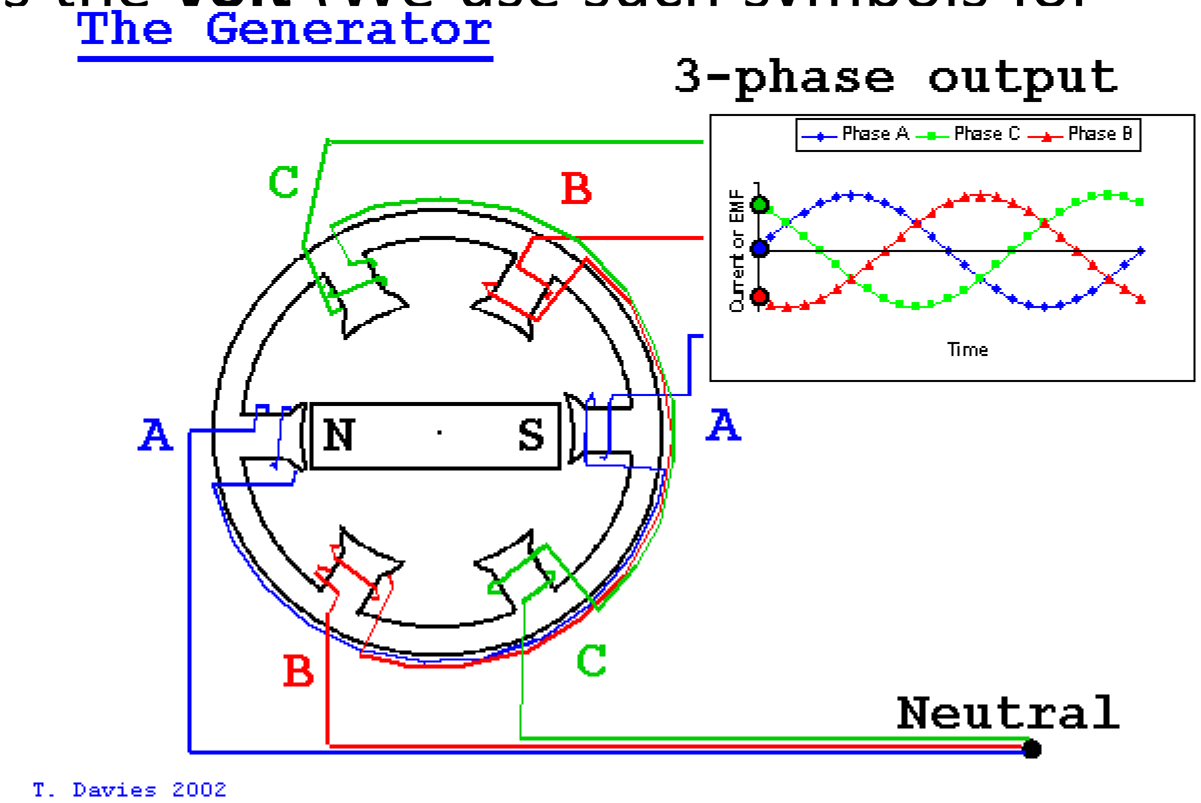
[How Do Solar Panels Work (best-infographics.com)](#)

Basic Concepts

- **Voltage** is the potential energy source that moves a charge in an electrical circuit. Voltage is also called "***Electromotive Force***" or "***EMF***". The basic unit of voltage is the **volt** (We use such symbols for voltage: "**V**", "**E**", "**U**"
- The voltage of a generator is
- $E_{G\ RMS} = 4.44\boldsymbol{\Phi} N f$

where

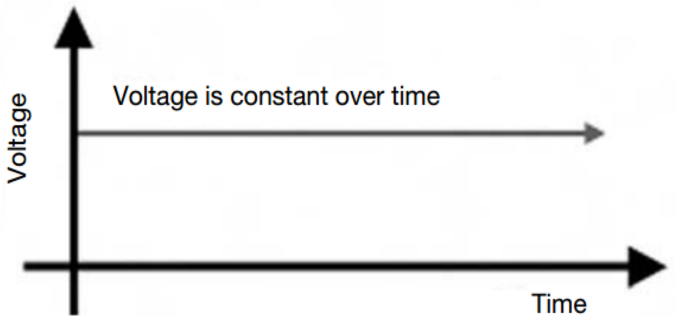
  - $\boldsymbol{\Phi}$: Flux per pole (Wb/pole)
  - N : Number of turns per phase
  - f : Frequency (Hz)



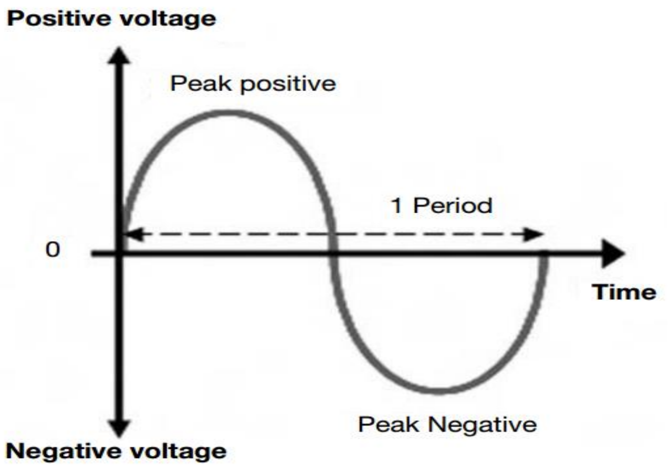
Basic Concepts

- **DC Voltage and Current**
- Direct current (dc) is the flow of electrons in a circuit that is always in the same direction. Direct current (i.e., one-direction current) occurs when the voltage is kept constant.

- **AC Voltage and Current**
- When the terminals of the potential energy source (i.e., voltage) alternate between positive and negative, the current flowing in the electrical circuit likewise alternates between positive and negative. Thus, alternating current (ac) occurs when the voltage source alternates. The length of time it takes to complete one cycle in a second is called the period of the cycle. Frequency is the term used to describe the number of cycles in a second. The number of cycles per second is also called hertz.



Direct current (dc voltage).



Alternating current (ac voltage).

Basic Concepts

- **Current** is the flow of electrons in a conductor (wire). Electrons are pushed and pulled by voltage through an electrical circuit or closed-loop path. The electrons flowing in a conductor always return to their voltage source. Current is measured in amperes, usually called amps. Electrical current is identified by the symbol “i”or “I.”
- The basic unit of **power** is the watt (W). Voltage by itself does not do any real work. Current also by itself does not do any real work. However, voltage and current together can produce real work.
- **Electrical energy** is the product of electrical power and time. The unit for electrical energy is **Watt-hours (Wh)**. These common units of energy are also used in todays life, such as **kWh** and **MWh**.

Why Alternating Current

- Starting in the late 1880s, Thomas Edison and Nikola Tesla were embroiled in a battle now known as the War of the Currents.
- Edison developed direct current -- current that runs continually in a single direction, like in a battery or a fuel cell. During the early years of electricity, direct current (shorthanded as DC) was the standard in the U.S.
- But there was one problem. Direct current is not easily converted to higher or lower voltages.
- Tesla believed that alternating current (or AC) was the solution to this problem. Alternating current reverses direction a certain number of times per second -- 60 in the U.S. -- and can be converted to different voltages relatively easily using a transformer.

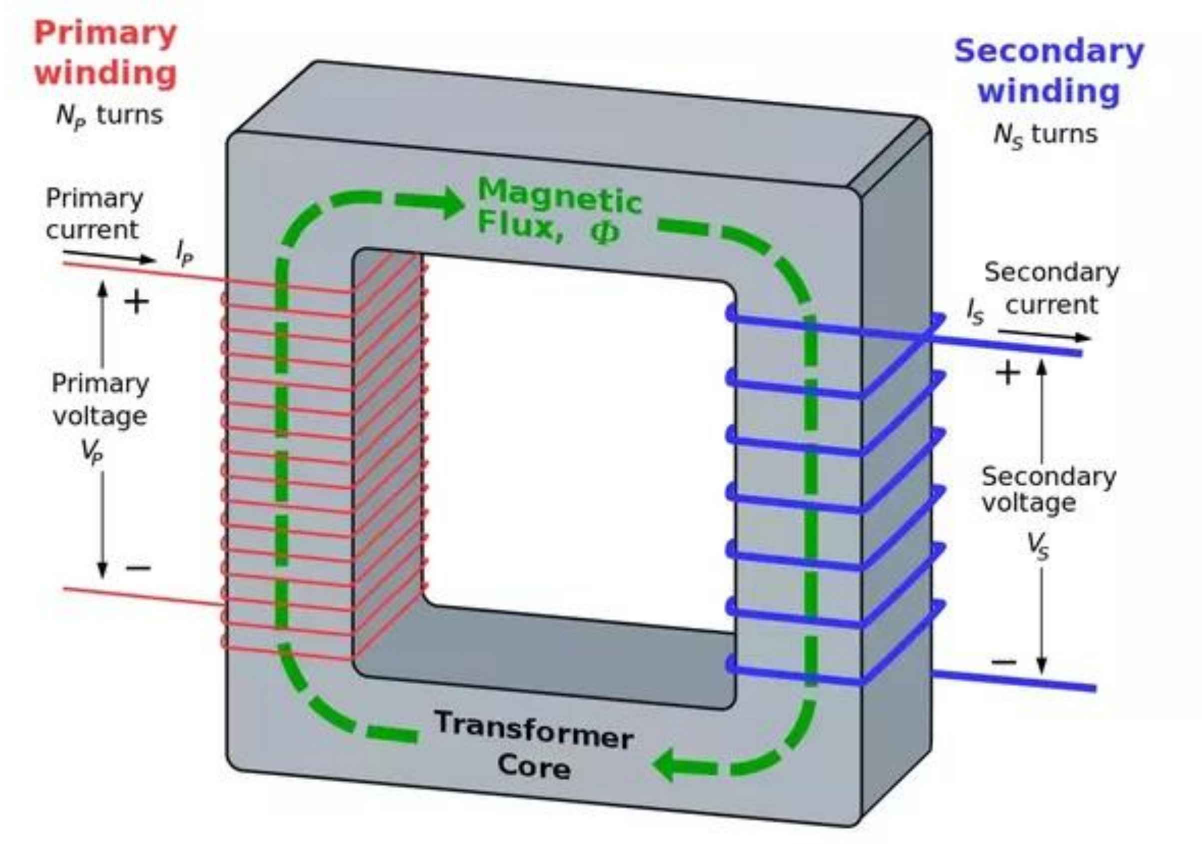
Advantages of AC

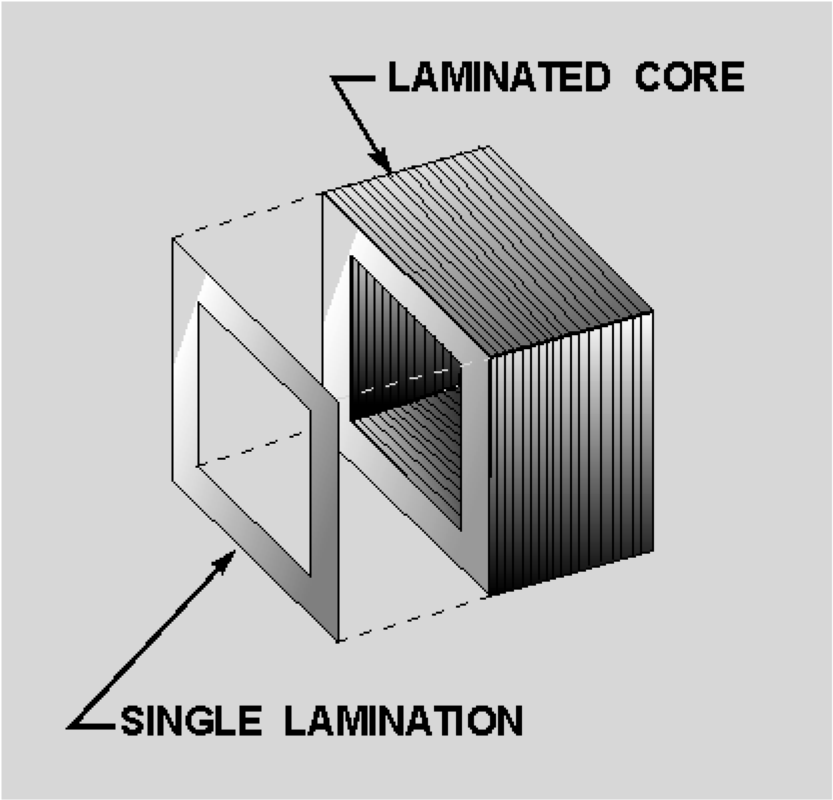
- The use of AC makes the transmission of electrical power to great distances much more economical.
- There are distinct advantages of AC over DC electricity. The ability to readily transform voltages is the main reason we use AC instead of DC in our homes.
- The major advantage that AC electricity has over DC electricity is that AC voltages can be readily transformed to higher or lower voltage levels, while it is difficult to do that with DC voltages.
- Since high voltages are more efficient for sending electricity great distances, AC electricity has an advantage over DC. This is because the high voltages from the power station can be easily reduced to a safer voltage for use in the house.
- Changing voltages is done by the use of a transformer. This device uses properties of AC electromagnets to change the voltages.

Transformers

- Transformers are essential components in electric power systems. They come in all shapes and sizes.
- Power transformers are used to convert high voltage power to low-voltage power and vice versa. Power can flow in both directions: from the high-voltage side to the low-voltage side or from the low-voltage side to the high-voltage side.
- Generation plants use large step up transformers to raise the voltage of the generated power for efficient transport of power over long distances. Then step-down transformers convert the power for further transport or consumption.
- Distribution transformers are used on distribution lines to further convert distribution voltages down to voltages suitable for residential, commercial, and industrial consumption

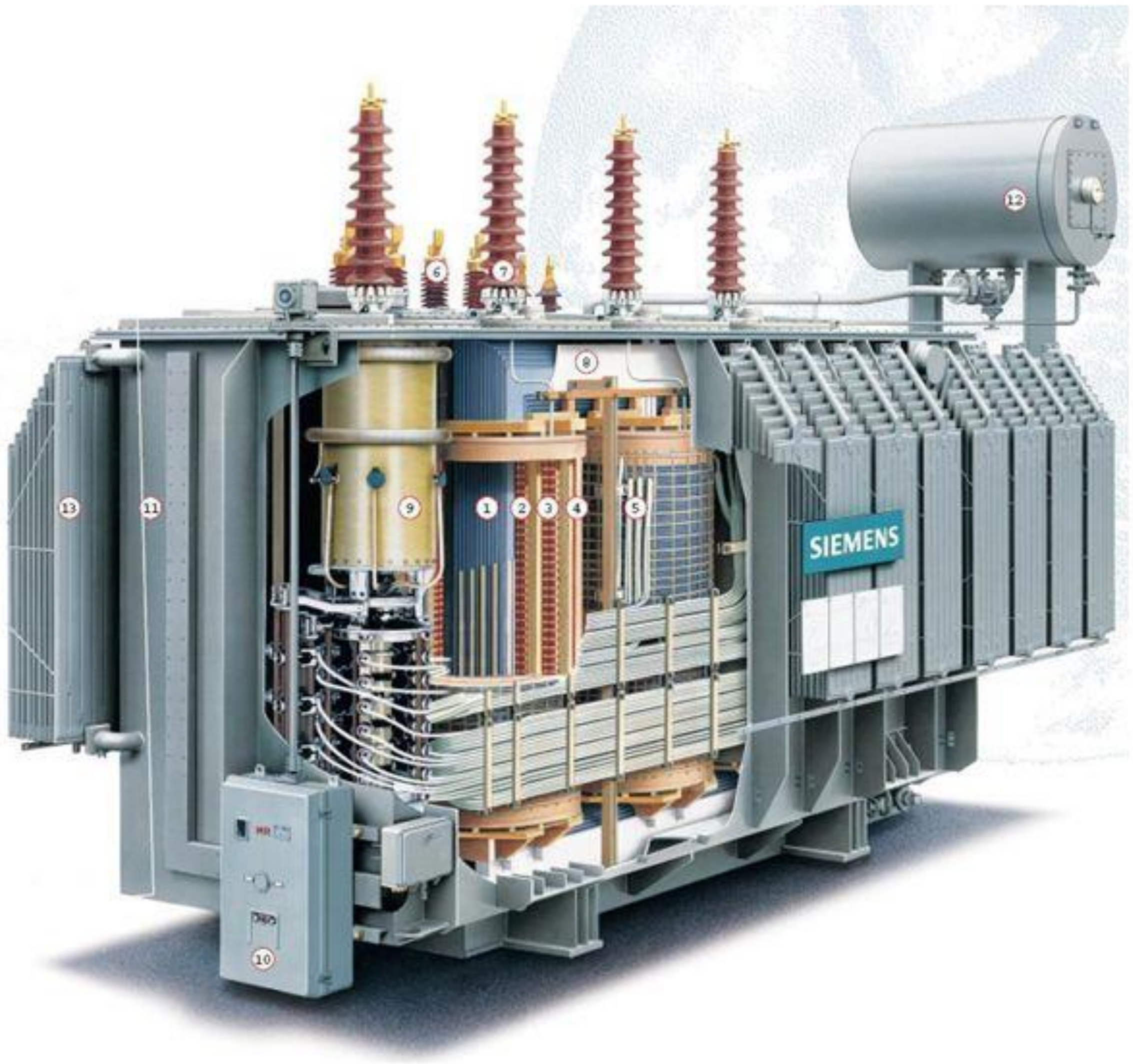
Transformers





Transformer Main Parts

1. Three-limb core
2. LV Winding
3. HV Winding
4. Tapped Winding
5. Tap Leads
6. LV Bushings
7. HV Bushings
8. Clamping Frame
9. On-Load Tap Changer
10. Motor Drive
11. Tank
12. Conservator
13. Radiators



Transmission Lines

- The **electrical power** (*in principle*) is the multiplication of voltage and current;

$$POWER = VOLTAGE \times CURRENT$$

- Therefore, increasing the voltage decreases the current for constant power.

- Since transmission losses are a function of the square of the current flowing in the conductors, increasing the voltage to lower the current drastically reduces transportation losses. Plus, reducing the current allows one to use smaller conductor sizes.

$$POWER\ LOSS = I^2 R_{transmission\ line}$$

Load

- Electrical energy consumption is the electrical energy use by all the various loads in the power system. Consumption also includes the energy used to transport and deliver the energy. For example, the losses due to heating conductors in power lines, transformers, and so on is considered consumption.
- In residential electrical consumption, the larger users of electrical energy are items such as air conditioning units, refrigerators, stoves, space heating, electric water heaters, clothes dryers, and, to a lesser degree, lighting, radios, and TVs. Typically, all other home appliances and home office equipment use less energy and, therefore, account for a small percentage of total residential consumption.

END OF THE LECTURE

Any questions ?