System Models

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System Models : Fundamentals of electrical, mechanical, fluid and thermal systems, electromechanical systems.

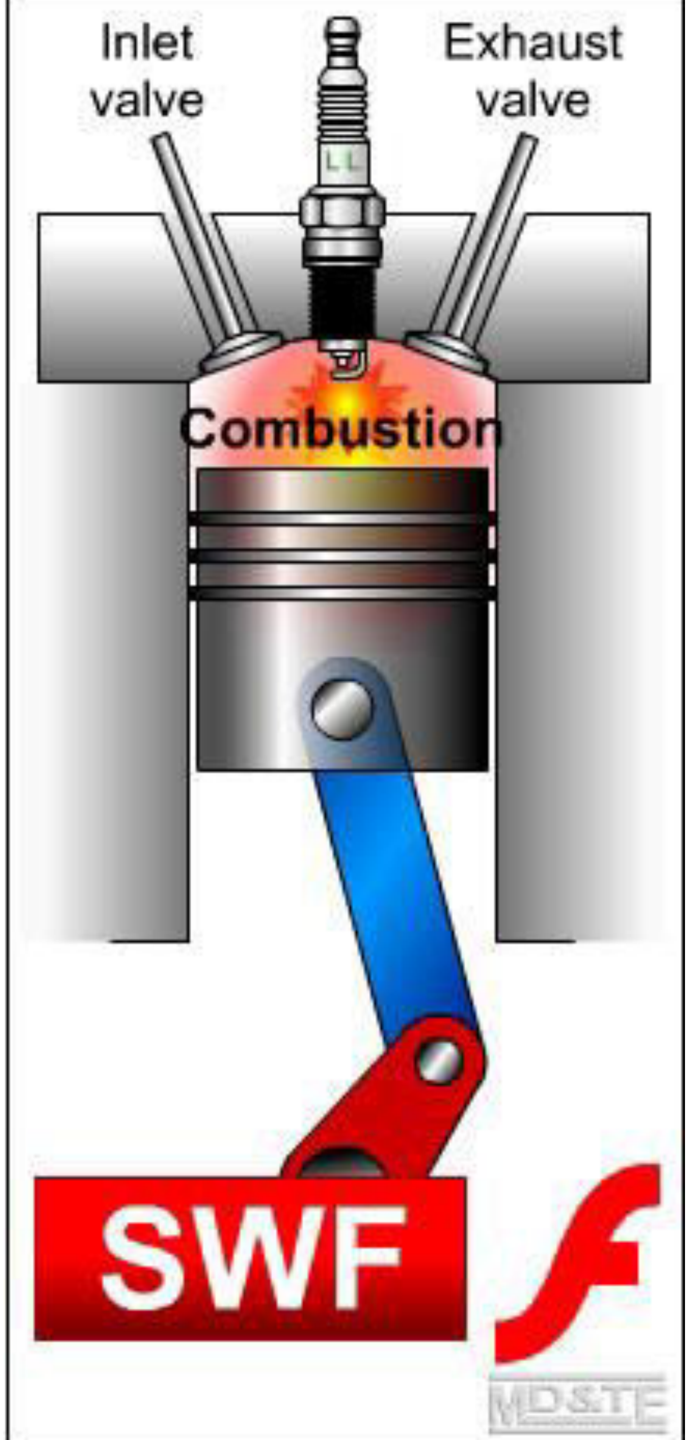
Mechanical System

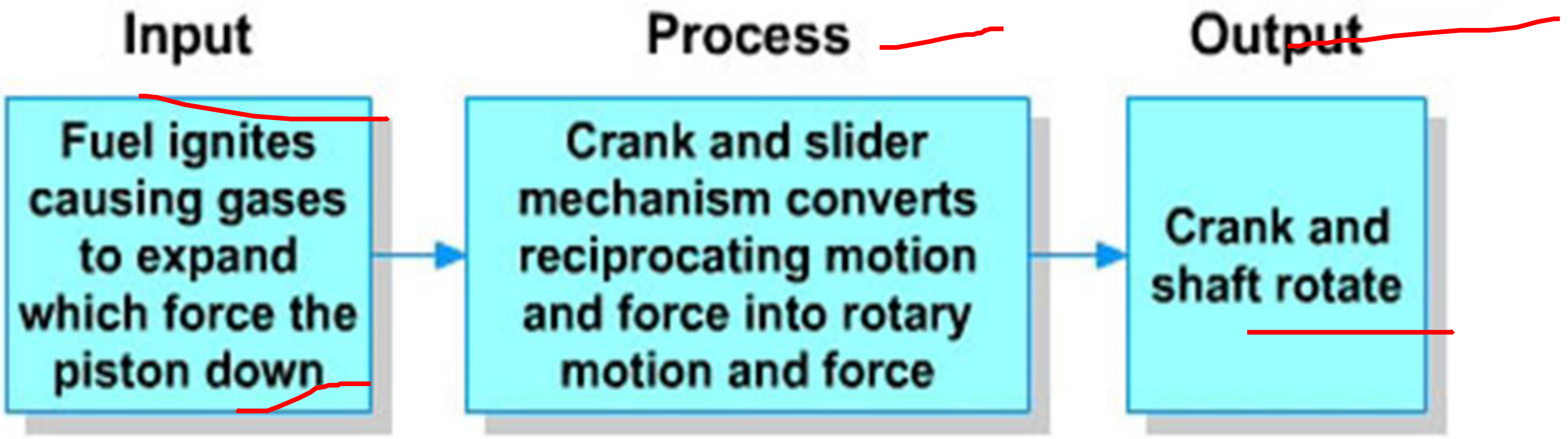
- A mechanical system is a set of physical components that convert an input motion and force into a desired output motion and force.
- Mechanical systems have at least three elements: **input, process** and **output**.
- The input part of the system is any type of motion and force that drives the mechanical system.
- The input motion and force may be from any power source including human effort, e wind energy , water, heat etc., from a chemical reaction or from an electrical, pneumatic or hydraulic device.
- The process part of the system is where mechanisms are used to convert the input motion and force into an output motion and force.
- The output is the change created in the input motion and force by the mechanism.

Example of Mechanical System

- A simplified diagram of a single cylinder internal combustion engine is shown.
- An internal combustion engine is a system that gives a motor vehicle the power to move.

- Combustion is a chemical process in which a substance reacts rapidly with oxygen and gives off heat.
- The original substance is called the fuel, and the source of oxygen is called the oxidizer.
- The fuel can be a solid, liquid, or gas.

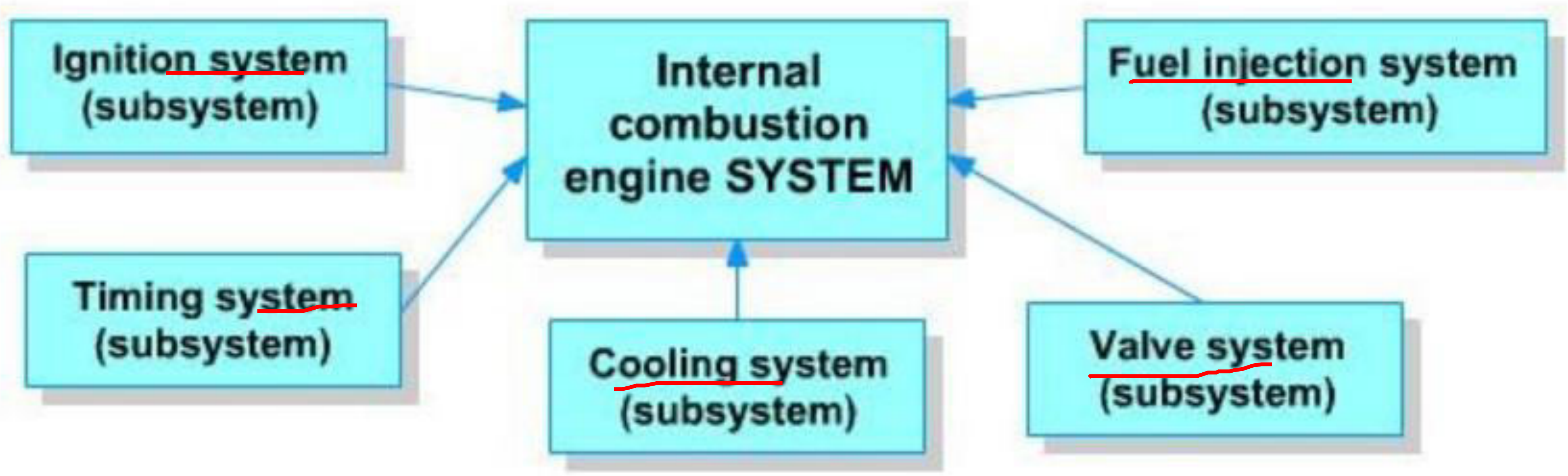




The system shown above is a small part of a larger and more complex system, e.g.

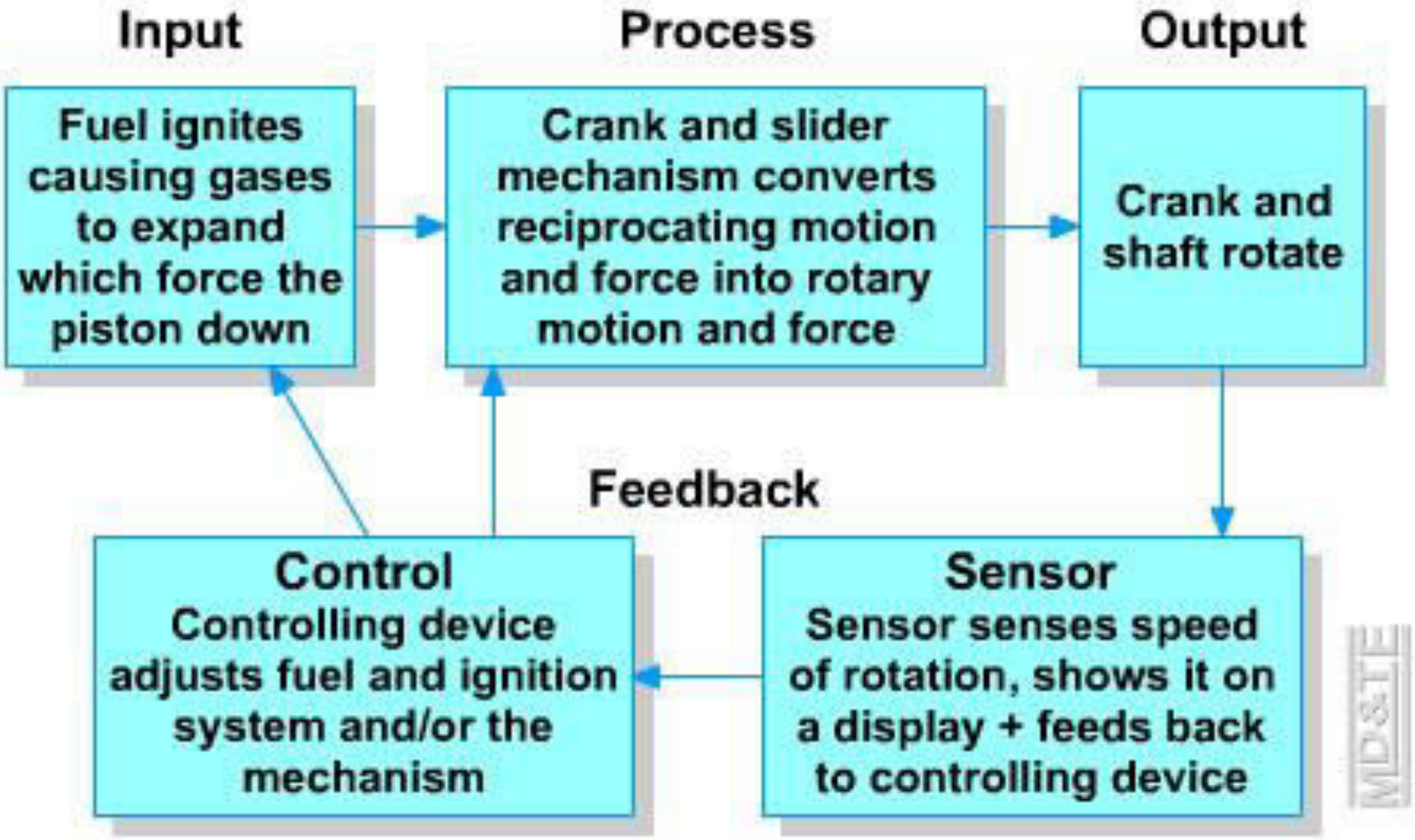
- In order for the fuel to ignite, an ignition system must be in place.
- The fuel must ignite at precisely the correct time so a timing system must also be in place.
- A measured amount of fuel must be injected into the combustion chamber at precisely the correct time so a fuel injection system must be place.
- Exhaust gases must be evacuated from the combustion chamber so a valve system must be in place.

- The ignition system, the timing system, the fuel injection system and the valve system are subsystems of the internal combustion engine system.
- Subsystems are systems that are part of a larger system. Mechanical systems usually comprise of a number of subsystems.



Feedback and Control

- The system consists of input, process and output elements that result in a crankshaft rotating.
- The system does not allow for control over the speed of rotation of the crankshaft.
- In order to control the speed of rotation, there must be a monitoring and control subsystem built into the system. This can be achieved by:
- **Using sensors to monitor the input part of the system**
- **Using sensors to monitor the mechanisms in the process part of the system**
- **Using sensors to monitor output part of the system**
- **Feeding the information to a controlling device that makes changes to input and/or the process part of the system.**


Input
Process
Output
Fuel ignites causing gases to expand which force the piston down
Crank and slider mechanism converts reciprocating motion and force into rotary motion and force
Crank and shaft rotate
Feedback
Control
Controlling device adjusts fuel and ignition system and/or the mechanism
Sensor
Sensor senses speed of rotation, shows it on a display + feeds back to controlling device
MD&TE

Examples of sensors used on a motor vehicle

Example 1

- A sensor senses the speed of a vehicle and feeds information back to the driver through a speedometer.
- The driver has control of the vehicle and decides whether to increase, decrease or maintain current speed.

Example 2

- A sensor senses the temperature of the internal combustion engine and displays the information on a meter (thermometer).
- The information is also fed to a controlling device.
- When the temperature reaches a predetermined point the controlling device switches on an electric fan that cools the engine.

- The fan continues cooling the engine until the engine temperature is back within normal working limits and is then switched off by the controlling device.

Example 3

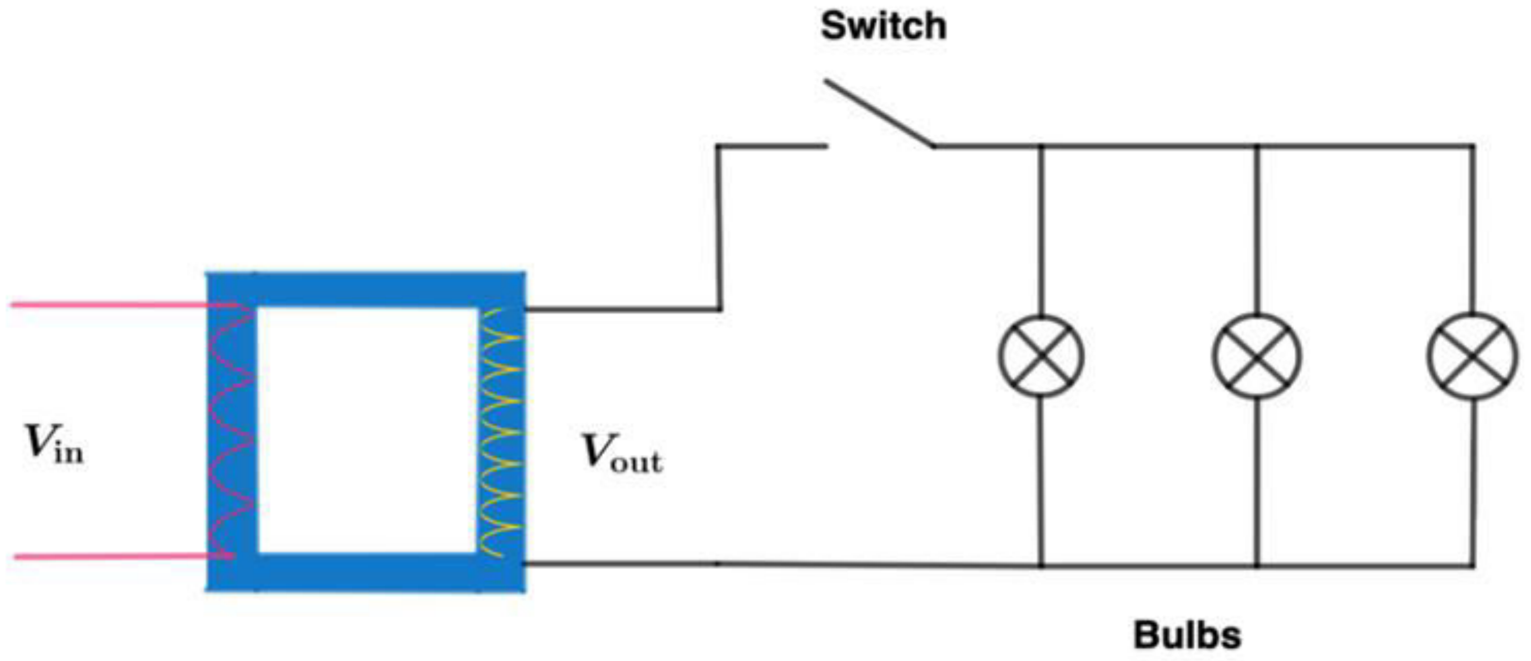
- An **engine control unit (ECU)** uses information from sensors together with settings programmed by the driver to control the fuel and ignition systems and so control the speed of the vehicle.
- Other uses of the control unit can be to:
    - maintain a constant speed by the use of a cruise control
    - maintain optimum revolutions of the crankshaft for any given driving condition
    - control brake pressure to prevent the vehicle from skidding
    - disengage vital systems in order to prevent theft of the vehicle.

Electrical System

- Electrical systems are groups of electrical components connected to carry out some operation.
- They might be subsystems of larger systems and have subsystems of their own.
- The basic components of an electrical system are resistors, capacitors, and inductors.
- The primary objective is to drive the electrical circuit with two electrical parameters, voltage and current, which can be measured for understanding and control of the electrical systems, so that desirable system outcomes can be achieved.
- An electrical power system takes energy generated from various types of energy sources and converts it into electrical energy.
- Solar panels are an example of electrical systems that transport energy from natural sunlight to domestic homes.

Examples of Electrical Systems

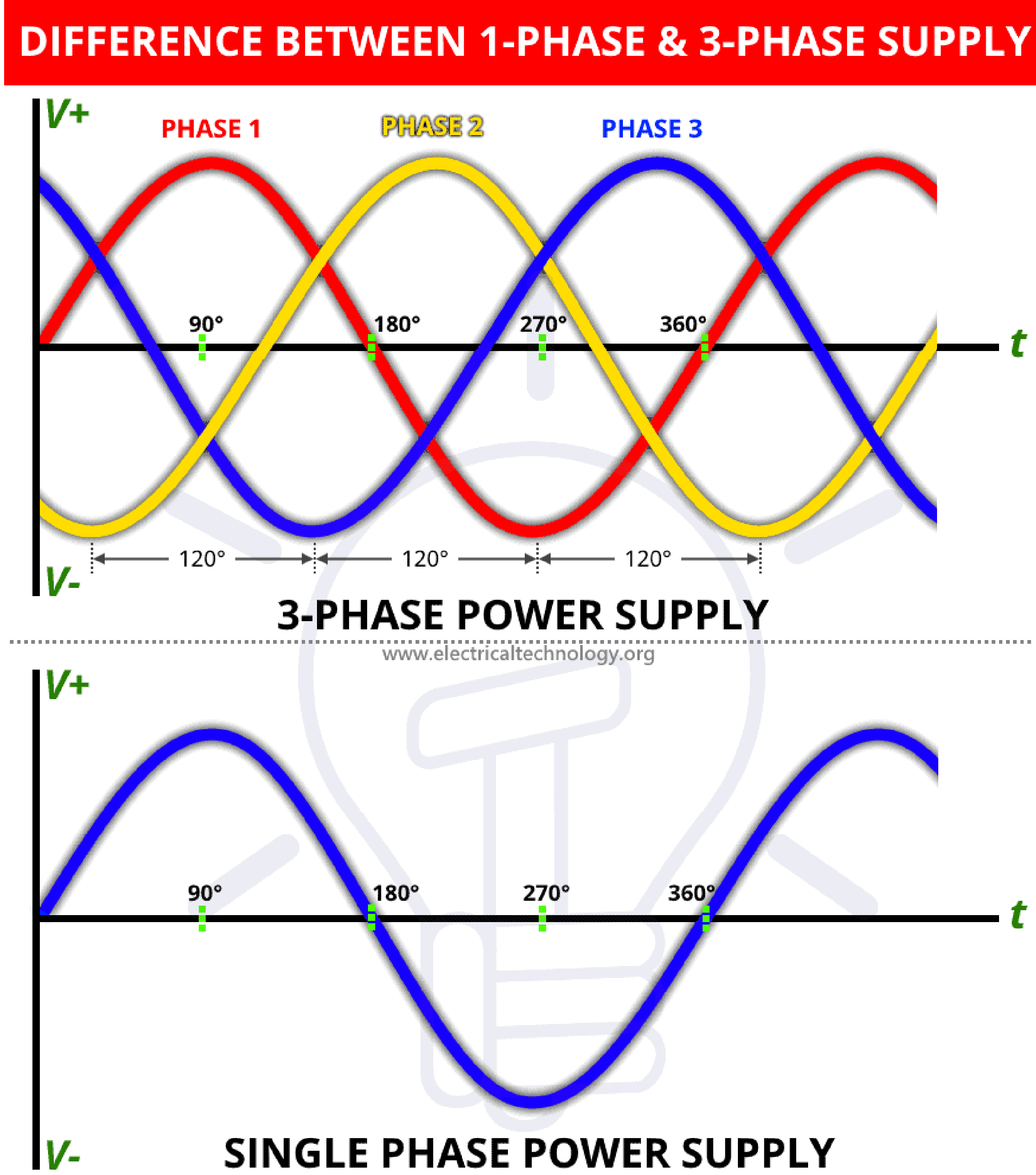
- Let's consider an example of an electrical system, a circuit in your house used to take power from the main power lines and turn on the lights in your house.
- We represent this in the figure as a circuit diagram.
- Here we have a step-down transformer converting energy from the power grid into voltages safe for domestic use.
- This then acts as a power source for three bulbs connected in parallel orientation.
- The bulbs are turned on or off is dependent on the switch connected to the circuit:
- When closed, all the bulbs will have energy supplying them, and when open, the bulbs will be turned off.
- This is an example of an electric system that may be found in domestic households.



- There are only **two main types** of electric systems used around the world, with varying physical connections:
- 100–127 volts, at 60 Hz frequency (North America including Central America, Japan)
- 220–240 volts, at 50 Hz frequency (The rest of the world, with some exceptions)
- Electrical systems are also classified as Single phase and Three phase systems.

Phase of Electrical systems

- In electricity, the phase refers to the distribution of a load.
- Residential homes are usually served by a single-phase power supply, while commercial and industrial facilities usually use a three-phase supply.
- Single-phase systems can be derived from three-phase systems.



Single-phase vs three-phase connection.

- In a single-phase connection, the flow of electricity is through a single conductor. A three-phase connection consists of three separate conductors that are needed for transmitting electricity.
- In a single-phase power supply system, the voltage may reach up to 230 Volts. But on a three-phase connection, it can carry a voltage of up to 415 Volts.
- For smooth flow of electricity on a single-phase connection, it requires two separate wires. One represents the neutral wire and another one represents a single phase. In a three-phase connection, the system requires one neutral wire and three phase (each phase ac signal 120 electrical degrees apart) wires to complete the circuit.

Single-phase vs three-phase connection.

- A single-phase connection consists a simple network. But the network is complicated on a three-phase connection because there are four different wires.
- Single-phase power supplies are most commonly used when typical loads are lighting or heating, rather than large electric motors but a three-phase power supply better accommodates higher loads.
- Because a single-phase connection has one phase wire, if anything happens to the network, the complete power supply gets interrupted.

  However, in a three-phase power supply, if anything happens to a single phase the other phases still work. As such, there is no power interruption.

Thermal System

- Thermal systems are those that involve the storage and transfer of heat.
- Heat stored in a material object is manifested as a higher temperature.
- For example, a hot block of metal has more heat stored in it than an equivalent cool block.
- Heat flows between objects by one of three mechanisms: conduction, convection (or mass transfer), and radiation.
- Conductive heat transfer occurs when a temperature difference exists across an object.
- An example is the flow of heat that occurs through the wall of a building if the temperature inside is higher (or lower) than the temperatures outside.

Thermal System

- Convective heat transfer involves the flow of heat in a liquid or gas, as when a fan blows cool air across a hot object; the air carries away some heat of the object.
- Radiative heat transfer, like conductive transfer, is caused by a temperature difference between objects, does not require a physical medium for heat flow.
- It is exemplified by the heat transfer from sun to earth.
- There are two fundamental physical elements that make up thermal systems,

  Thermal resistances and Thermal capacitance.
- There are also three sources of heat,

  A power source, a temperature source, and fluid flow.

Thermal Resistance:

- Thermal resistance is a heat property and a measurement of a temperature difference by which an object or material resists a heat flow.
- Thermal resistance is the reciprocal of thermal conductance. (Absolute) thermal resistance R in kelvins per watt (K/W) is a property of a particular component.

$$R_\theta = \frac{\Delta x}{A \times k}$$

- Rθ = Absolute thermal resistance (K/W) across the thickness of the sample
- Δx = Thickness (m) of the sample (measured on a path parallel to the heat flow)
- K = Thermal conductivity (W/(K·m)) of the sample
- A = Cross-sectional area (m^2) perpendicular to the path of heat flow

Heat Transfer via Conduction

- Heat flow through an object is determined by several quantities including

  the thickness of the object (in the direction of heat flow),

  the area through which heat can flow and

  the thermal conductivity (SI unit is watts per meter-kelvin of W/(m-°K)).
- **Thermal conductivity** can be defined as the rate at which heat is transferred by conduction through a unit cross-section area of a material, when a temperature gradient exits perpendicular to the area.
- The thermal conductivity of a material is a measure of its ability to conduct heat.

Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity.

$$K = \frac{Qd}{A\Delta T}$$

K	=	Thermal conductivity
Q	=	Amount of heat transferred
d	=	Distance between the two isothermal planes
A	=	Area of the surface
ΔT	=	Difference in temperature

- We will consider only objects of uniform cross section, with heat flow in one direction (perpendicular to the cross section).
- Consider the circular cylinder shown below.

- A is the area of the cylinder face, L is the length of the cylinder, and σ is the thermal conductivity of the cylinder.

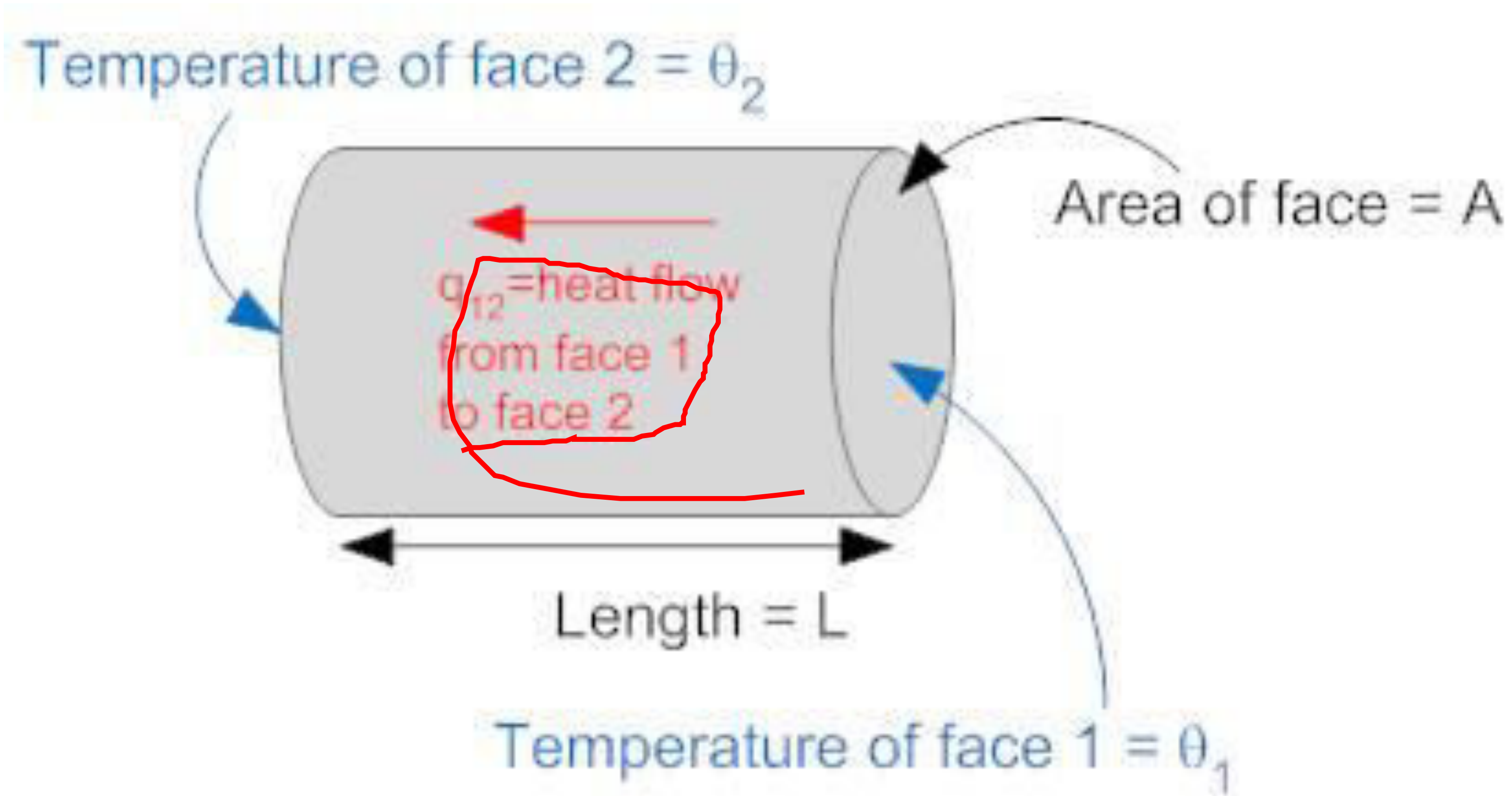
$\sigma \rightarrow \mathfrak{D}$

- One end of the cylinder is at temperature θ_1 and the other is at θ_2, The heat flow from face 1 to face 2 is given by

$$q_{12} = \frac{\theta_1 - \theta_2}{R_{12}}$$

Thermal Resistance

$$R_{12} = \frac{L}{A \cdot \sigma}$$



Heat Transfer through Convection

- When a fluid impinges on a solid surface that is at a different temperature, heat will flow between them (from hot to cold).
- If we have a fluid at temperature θ_1 impinging on an object at temperature θ_2, then we model the heat flow from the fluid to the object as

$$q_{12} = \frac{\theta_1 - \theta_2}{R_{12}} \qquad R_{12} = \frac{1}{h \cdot A}$$

- A = area of the object, and h = coefficient of convective heat transfer ($W/(m^2 \cdot °K)$).
- The coefficient of convective heat transfer is a function of the fluid used (e.g., air and water have very different coefficients) as well as the velocity of the fluid (the coefficient generally increases with the velocity of the fluid).

Thermal Capacitance

- Thermal capacitance is the amount of heat energy required to increase the temperature of the given subunit by one degree.
- The thermal capacitance of any quantity of material is $C = m \cdot c_p$
- Where "C" is the thermal capacitance, "m" is the mass in kilograms, and "c_p" is the specific heat in J/(kg-°K).
- **Specific heat**, the quantity of heat required to raise the temperature of one gram of a substance by one celsius degree.
- The units of specific heat are usually calories or joules per gram per Celsius degree.
- For example, the specific heat of water is 1 calorie (or 4.186 joules) per gram per celsius degree.
- The thermal capacitance of an object is a measure of how much heat it can store.

Sources of heat

Power Source (or heat source)

- A common part of a thermal model is a controlled power source that generates a predetermined amount of power, or heat, in a system.
- This power can either be constant or a function of time.
- In the electrical analog, the power source is represented by a current source.

Temperature Source

- Another common source used in thermal systems is a controlled temperature source that maintains a constant temperature.
- An ideal temperature source maintains a given temperature independent of the amount of power required.
- A refrigerator is an example of such a source.

Sources of Heat

Mass Transfer (fluid flow)

- Mass transfer is the net movement of mass from one location to another.
- Fluid Flow involves the motion of a fluid subjected to unbalanced forces.
- This motion continues as long as unbalanced forces are applied.
- The mass flow formula:

  Mass Flow Rate = (density) × (velocity) × (area of the cross-section)

  Mathematically, $m = \rho \times V \times A$
- Thermal fluid systems are heating systems in which the thermal fluid, such as glycol or thermal oil, is heated and then recirculated supplying indirect heat to process equipment, materials, and systems

Electromechanical systems

- Electromechanics focuses on the interaction of electrical and mechanical systems as a whole and how the two systems interact with each other.
- A electro-mechanical system converts electrical energy into mechanical energy or vice versa.
- Almost every moving device is powered by an electro mechanical system.
- Some of the most common devices are used in:
  - Household appliances such as dishwashers, refrigerators or vacuum cleaners
  - Transportation, such as trains and trams
  - The automobile industry, with alternators and electric motors
  - CD and DVD players, printers
  - Motors and other hydraulic presses

Electric Motor

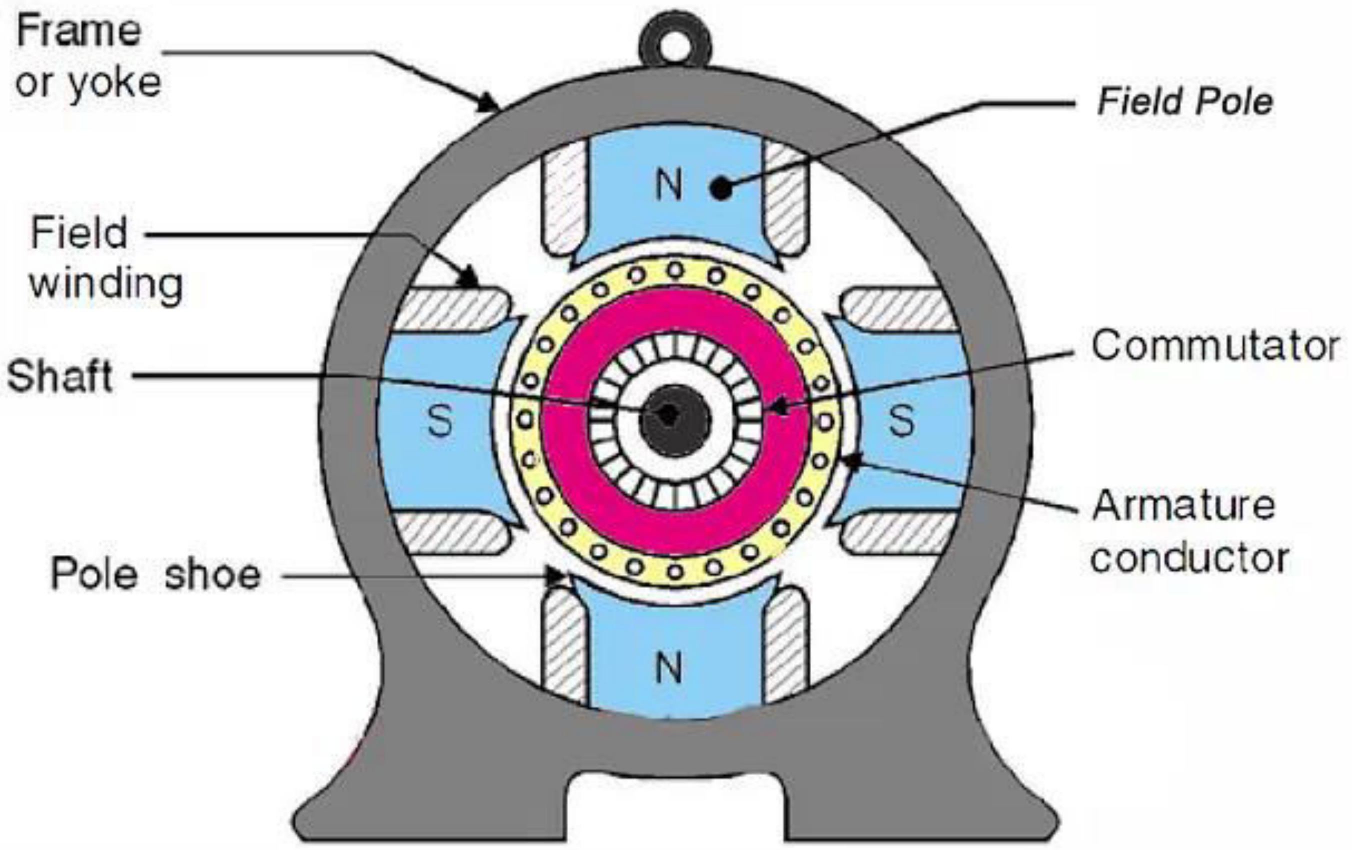
- Electric motors are essentially electrical machines that convert electrical energy (electricity) into mechanical energy (torque) using a system of gears and magnetic fields, powered by an electrical system.
- An electric generator is mechanically identical to an electric motor, but operates with a reversed flow of power, converting mechanical energy into electrical energy.
- The types of Electric motors are available in three main segments:
  - DC motor
  - AC motor
  - Special purpose motors.

Terminologies of Motor

- The **stator** is the stationary part of a rotary system.
- The **rotor** is the rotating part of the motor's electromagnetic circuit. Magnetic field from the stator induces an opposing magnetic field onto the rotor
- A **shaft** is a rotating machine element, usually circular in cross section, which is used to transmit power from one part to another
- **Armature** is the winding of an electric machine which carries alternating current.
- A **commutator** is a rotary electrical switch in that periodically reverses the current direction between the rotor and the external circuit.
- A **brush** or carbon brush is an electrical contact which conducts current between stationary wires and moving parts, most commonly in a rotating shaft.

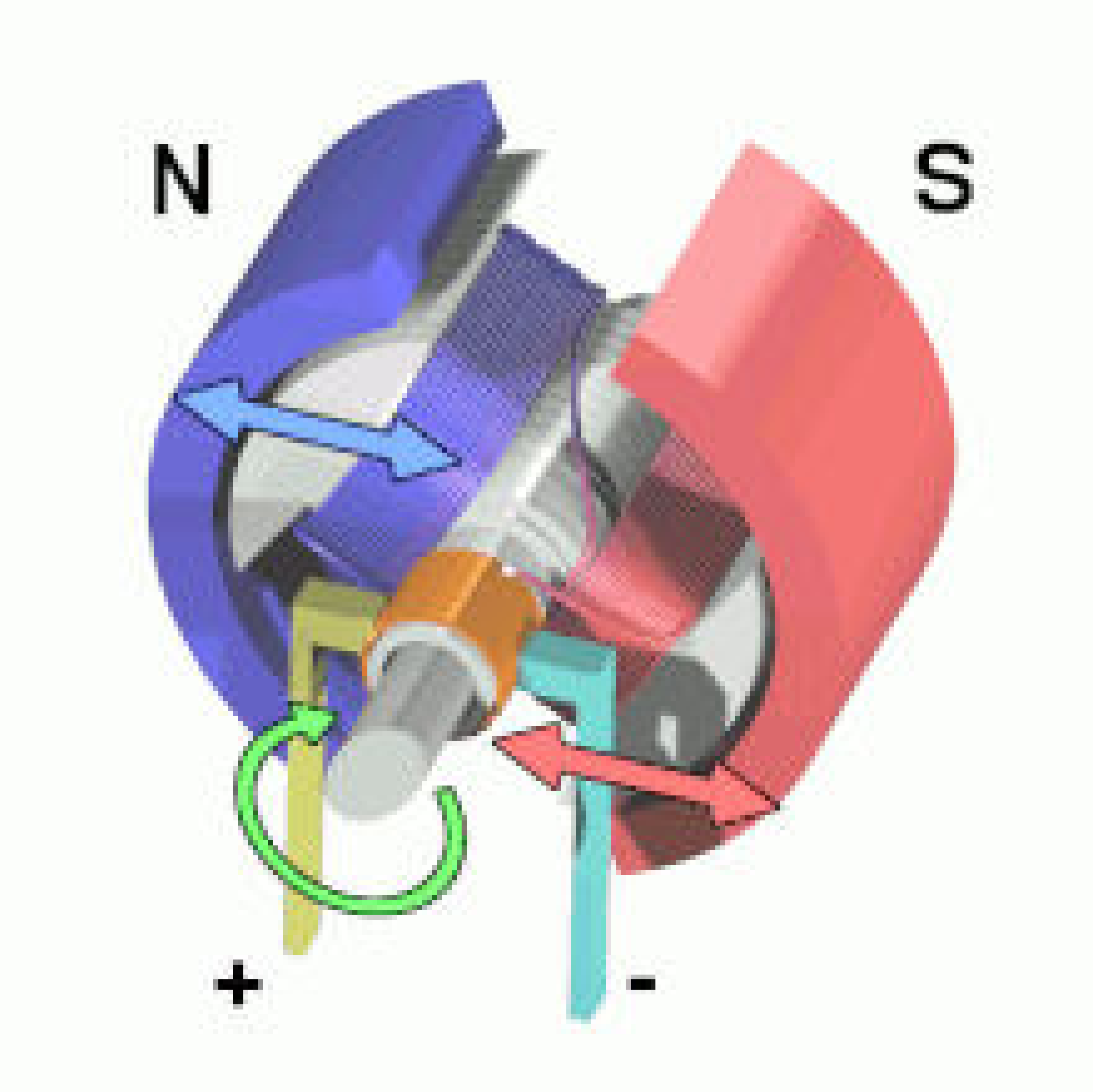
DC Motor

- It is an electrical motor that uses direct current to produce mechanical force.
- The most common types rely on magnetic forces produced by currents in the coils.
- A coil of wire with a current running through it generates an electromagnetic field aligned with the center of the coil.
- The direction and magnitude of the magnetic field produced by the coil can be changed with the direction and magnitude of the current flowing through it.



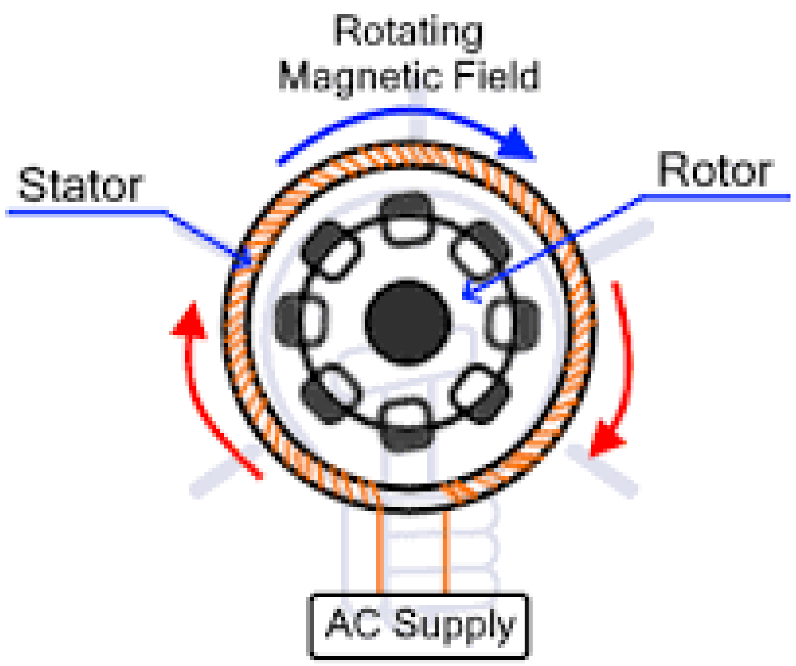
DC Motor

- A simple DC motor has a stationary set of magnets in the stator and an armature with one or more windings of insulated wire wrapped around a soft iron core that concentrates the magnetic field.
- The commutator allows each armature coil to be energized in turn and connects the rotating coils with the external power supply through brushes.
- Brushless DC motors have electronics that switch the DC current to each coil on and off and have no brushes.



AC Motor

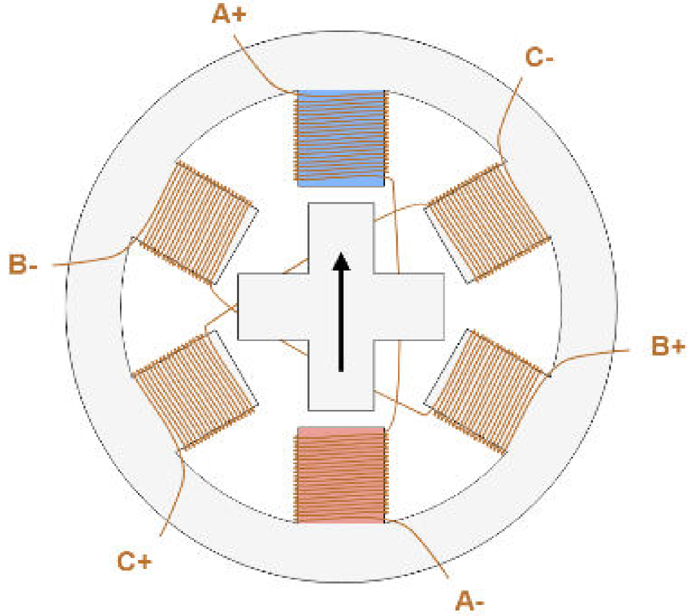
- An AC motor is an electric motor driven by an alternating current (AC).
- The AC motor commonly consists of two basic parts.
- An outside stator having coils supplied with alternating current to produce a rotating magnetic field.
- An inside rotor attached to the output shaft producing a second rotating magnetic field.
- The rotor magnetic field may be produced by permanent magnets.
- A **Universal motor** is a design that can operate on either AC or DC power.

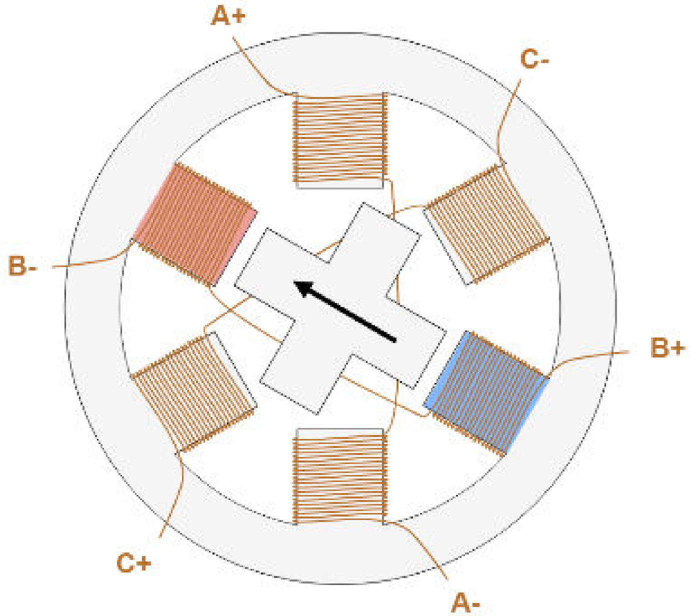


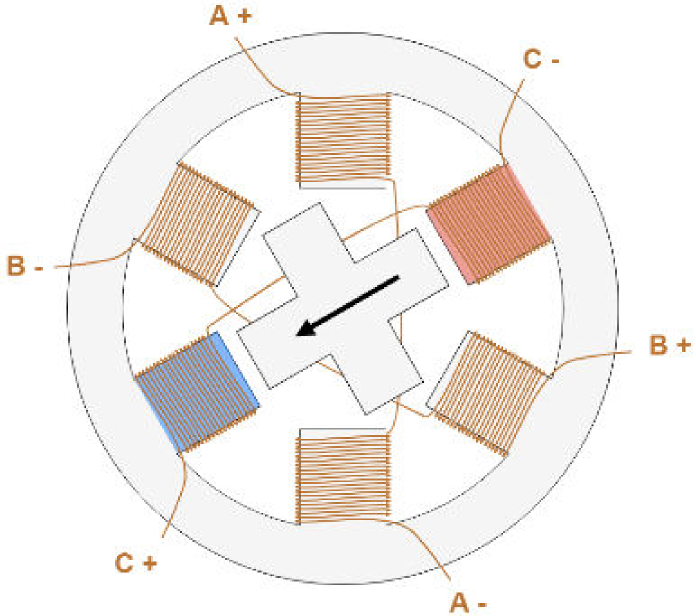
AC Motor

Stepper Motor

- Stepper motor is a brushless DC motor that divides a full rotation into a number of equal steps.
- Figure shows a representation of the working principle.
- At the beginning, coil A is energized and the rotor is aligned with the magnetic field it produces.
- When coil B is energized, the rotor rotates clockwise by 60° to align with new magnetic field.
- The same happens when coil C is energized. In the pictures, the colors of the stator teeth indicate the direction of the magnetic field generated by the stator winding.







Efficiency

To calculate a motor's efficiency, the mechanical output power is divided by the electrical input power: $\eta = \frac{P_m}{P_e}$

where η is the conversion efficiency,

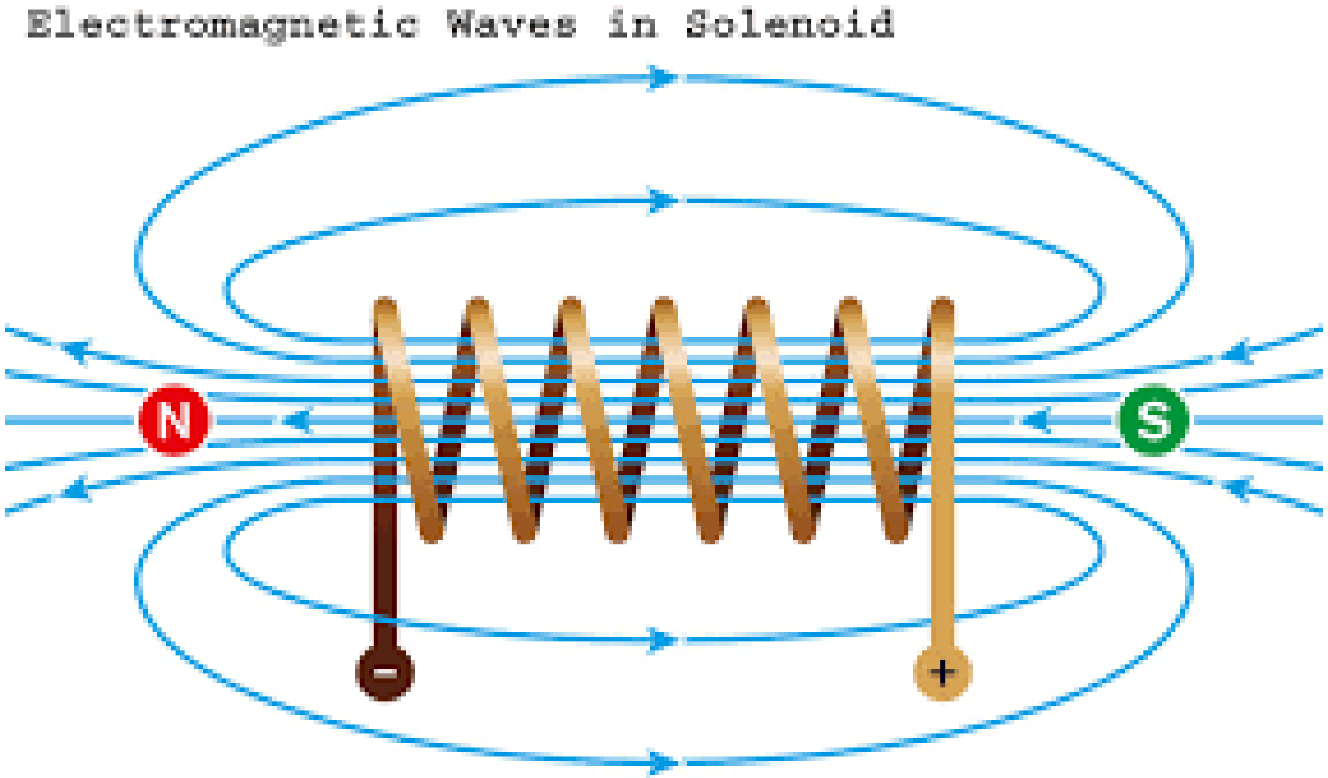
P_e is electrical input power: $P_e = IV$

P_m is mechanical output power: $P_m = T\omega$

Where, **V** is input voltage, **I** is input current, **T** is output torque, and ω is output angular velocity.

Solenoid

- A solenoid is a type of electromagnet formed by a helical coil of wire whose length is substantially greater than its diameter, which generates a controlled magnetic field.
- The coil can produce a uniform magnetic field in a volume of space when an electric current is passed through it.
- Solenoids are extremely useful and incredibly versatile.
- We can find them almost everywhere from doorbells to paintball guns and in automated factory equipment.
- In doorbell, the audible sound generates because the metal piston strikes at a tone bar.



Fluid systems

- A fluid system is a transmission system where liquids and gases are used to transmit power.
- Fluid systems use pressurized fluid to transmit energy.
- Hydraulic systems use liquids and pneumatic systems use gases.
- All fluid systems rely on the same basic components for power transmission, but the specific kinds each type of system uses varies.
- Fluid systems are used in many industrial applications. Examples of closed fluid systems are a hydraulic brake system, body's circulatory (blood) system etc..
- Fluid flows through an open fluid system only one time—it is not retained and recirculated.
- Open fluid systems include city water systems, an irrigation system etc..

Fluid

- Fluids are substances with no distinct shape and change easily relative to the presence of external pressure.
- Force is related to the pressure exerted on a fluid by the equation, F = PA

  where F is force, P is pressure, and A is area.

Let's try a quick example to reinforce our understanding.

- Wind, with a pressure of 310 Pascal, is blowing on a 15 m^2 wall. Calculate the force acting on the wall.
  - Answer: F = PA

    = (310 Pa) (15 m^2)

    = 4650 N

Fluid Power

- Use of fluids under pressure to generate, control, and transmit power.
- Fluid power is subdivided into hydraulics and pneumatics.
- Steam is also a fluid, but steam power is classified separately from fluid power.
- Compressed-air and water-pressure systems were once used to transmit power from a central source to industrial users over extended geographic areas; fluid power systems today are usually within a single building or mobile machine.
- Fluid power systems perform work by a pressurized fluid bearing directly on a piston in a cylinder or in a fluid motor.
- A fluid cylinder produces a force resulting in linear motion, whereas a fluid motor produces torque resulting in rotary motion.
- Within a fluid power system, actuators do the desired work.

Fluid System Types:

- Fluids are classified into four categories depending on certain properties.
- Ideal fluids are incompressible and have zero viscosity.
- **Incompressible** refers to fluids whose volume and density do not change due to pressure.
- **Viscosity** refers to friction because viscosity causes resistance to motion by causing shear or frictional forces to be present in between particles.
- No viscosity indicates that no friction is present in an ideal fluid.
- It is important to note that this type of fluid does not exist in reality.

Fluid System Types

- **Real fluids** can be compressible, and viscosity is present.
- Compressible refers to fluids whose volume and density change due to pressure.
- Examples of real fluids include castor oil, petrol, and kerosene.
- **Newtonian fluids** have constant viscosity where viscosity is not affected by shear stress.
- Common examples of Newtonian fluids include water and air.
- **Non-Newtonian fluids** have variable viscosity meaning viscosity changes with respect to shear stress.
- Common examples of these fluids include salts, blood, toothpaste, and corn starch.

Shearing stress

- Shearing stress is a force acting parallel to the surface, which causes a breakdown of structure.
- Shearing stress is one of two types of stress fluids undergo.
- In physics, stress refers to a force per unit area acting on an infinitesimal surface.
- Stress is a vector quantity and is divided into normal stress and tangential stress.
- Normal stress includes pressures that act inward and perpendicular to the surface.
- Tangential stress includes shear stress.
- The main reason shear stress is present in fluids is friction due to viscosity.
- Fluids cannot resist shear stress.
- This means that when shear stress is applied to a fluid at rest, the fluid moves as it is unable to remain at rest.

Fluid System Components

- The components that define fluids, as well as solids, are microscopic molecules.
- The movement of these molecules determines a substance's state of matter.
- In solids, the arrangement of particles is fixed as a result of not enough thermal energy present to overcome intermolecular interactions between particles.
- Hence, solids have a more compact structure because molecules can vibrate but cannot move or switch positions with neighboring molecules.
- Consequently, solids have definite shape and volume.

Fluid System Components

- In contrast, liquids, and gases have a more loosely packed structure.
- Liquids have partial energy that enables them to overcome intermolecular interactions.
- This fact allows the particles to move about freely while still being in close proximity to each other.
- Liquids have definite volume but no shape.
- Gases have enough energy to completely overcome intermolecular interactions.
- Meaning that the particles completely separate from one another and move freely.
- Hence, gases have no definite shape or volume.

Characteristics of Fluid System

- Fluid power systems can produce high power and high forces in small volumes, compared with electrically-driven systems.
- The forces that are exerted can be easily monitored within a system by gauges and meters.
- fluid power systems are known to have long service lives if maintained properly.
- The working fluid passing through a fluid motor inherently provides cooling of the motor, which must be separately arranged for an electric motor.
- Fluid motors normally produce no sparks, which are a source of ignition or explosions in hazardous areas containing flammable gases or vapors.

Characteristics of Fluid System

- Fluid power systems are susceptible to pressure and flow losses within pipes and control devices.
- Fluid power systems are equipped with filters and other measures to preserve the cleanliness of the working fluid.
- Any dirt in the system can cause wear of seals and leakage, or can obstruct control valves and cause erratic operation.
- The hydraulic fluid itself is sensitive to temperature and pressure along with being somewhat compressible.

Applicatons

Mobile applications of fluid power are widespread.

Below is a more detailed list of applications that fluid power is used for:

- in many vehicles, which includes a hydraulic torque converter.
- Industrial : Automated systems
- Metalworking

  Injection molding

  Controllers

  Material handling
- Aerospace: Landing gears

  Brakes

Importance of Fluid Systems

- To understand the importance of fluid systems, let's look at hydraulics.
- Hydraulics is the practical application, fluid mechanics is its theoretical foundation.
- Fluid mechanics focus on the forces that arise due to the behavior of fluids.
- Fluid mechanics is divided into two parts: fluid dynamics and fluid statics.
- Fluid statics is the study of fluids at rest.
- Fluid dynamics is the study of fluids in motion.
- Hydraulic engineers apply fluid mechanics to flowing water within pipes, pumps, or open channels, i.e., lakes or rivers, as well as the containment of water in dams or tanks.
- Understanding fluid mechanics allows hydraulic engineers to design structures, and hydraulic systems powered by the pressure of a fluid, to withstand intense pressure.

Fluid Systems Examples

- Fluid systems use the force of flowing liquids or gases to transport power.
- An easy way to understand this is to think about the act of breathing.
- For a fluid to move, a pressure difference is necessary.
- We create high-pressure and low-pressure areas every time we breathe that enable air to move in and out of our lungs.
- When we inhale, we do work as we expand our chest cavities to create an area of low pressure inside our lungs.
- An area of higher pressure exists outside our lungs, which then forces air into lungs.
- When we exhale, we work to shrink our lung volume, which in turn increases the air pressure inside our lungs and forces air out.
- Thus, the act of breathing is an example of a fluid system.