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Subject Name: Energy Efficient Practices

Course Offered To: B.Tech 6th Semester Students

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Unit-2

Electrical Supply Systems

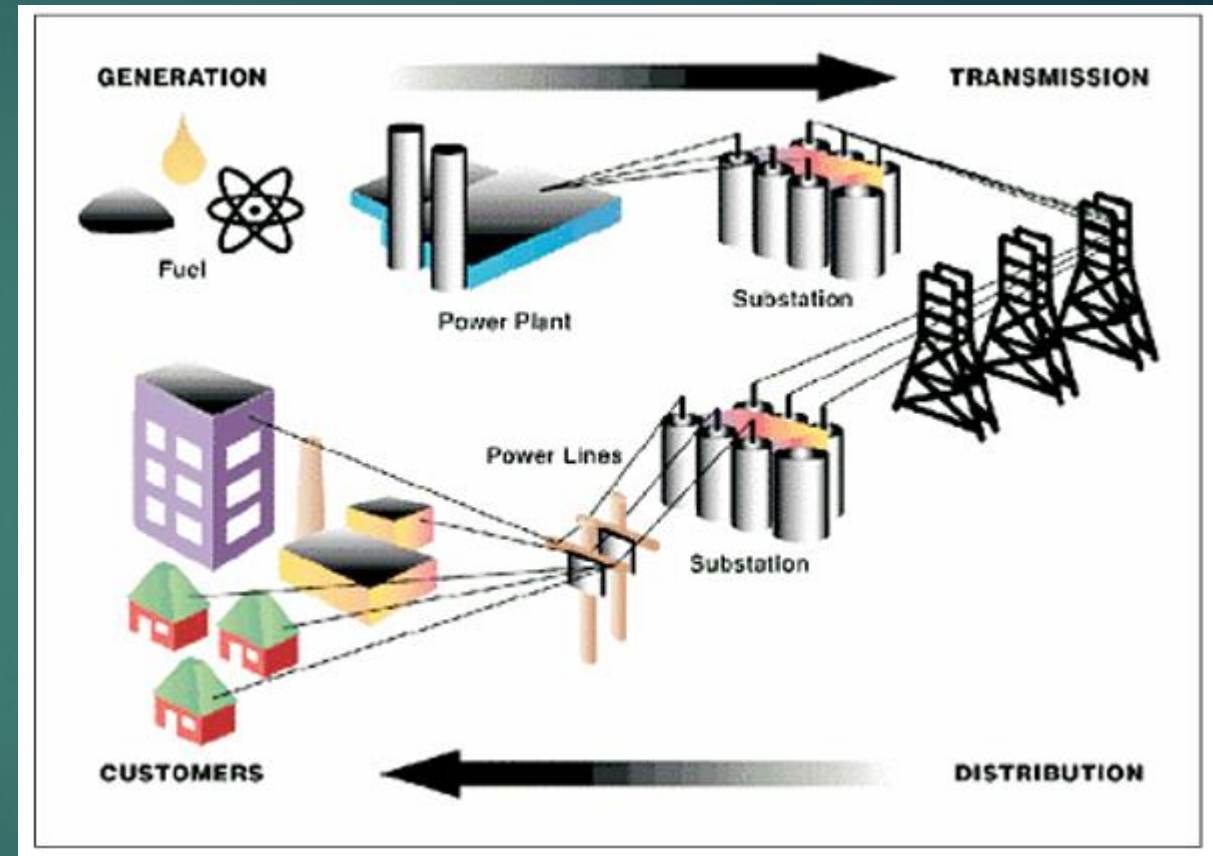
- ❑ Electrical supply system
- ❑ Components of AC Power
- ❑ Concept of sanctioned load
- ❑ Maximum demand
- ❑ Contract demand
- ❑ AC Machines

Electrical Supply System

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Supply Systems Definition: Electric power supply system in a country comprises of **generating units** that **produce electricity**; **high voltage transmission lines** that **transport electricity** over long distances; **distribution lines** that **deliver the electricity** to consumers; **substations** that connect the pieces to each other; and **energy control centers** to coordinate the operation of the components.

A system responsible for the generation, transmission, and distribution of electricity.



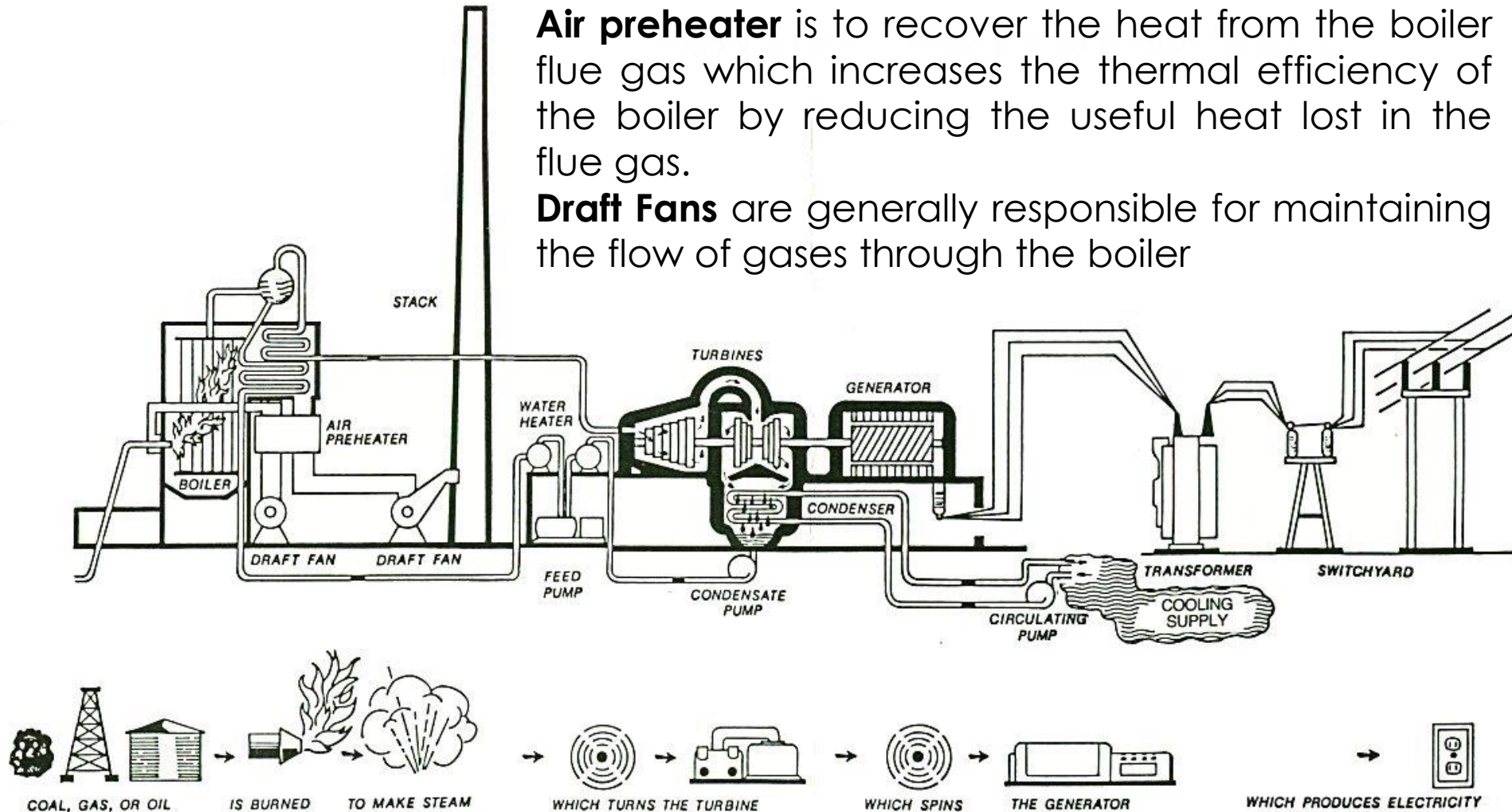
Typical Electric Power Supply System

Power Generation Plant

- The fossil fuels such as coal, oil and natural gas, nuclear energy, and falling water (hydel) are commonly used energy sources in the power generating plant.
- About 70 % of power generating capacity in India is from coal based thermal power plants.
- Coal is pulverized to the consistency of talcum powder. Then powdered coal is blown into the water wall boiler where it is burned at temperature higher than 1300°C . The heat in the combustion gas is transferred into steam. This high-pressure steam is used to run the steam turbine to spin. Finally turbine rotates the generator to produce electricity.
- In India, for the coal based power plants, the overall efficiency ranges from 28% to 35% depending upon the size, operational practices and capacity utilization.
- Where fuels are the source of generation, a common term used is the “HEAT RATE” which reflects the efficiency of generation. “HEAT RATE” is the heat input in kilo Calories or kilo Joules, for generating ‘one’ kilo Watt-hour of electrical output.

Air preheater is to recover the heat from the boiler flue gas which increases the thermal efficiency of the boiler by reducing the useful heat lost in the flue gas.

Draft Fans are generally responsible for maintaining the flow of gases through the boiler



Block diagram of thermal power plant

Transmission and Distribution Lines

The power plants typically produce 50 cycle/second (Hertz), alternating-current (AC) electricity with voltages between 11kV and 33 kV. At the power plant site, the 3-phase voltage is stepped up to a higher voltage for transmission on cables strung on cross-country towers.

High voltage (HV) and extra high voltage (EHV) transmission is the next stage from power plant to transport A.C. power over long distances at voltages like; 220 kV & 400 kV. Where transmission is over 1000 km.

Sub-transmission network at 132 kV, 110 kV, 66 kV or 33 kV constitutes the next link towards the end user. Distribution at 11 kV / 6.6 kV / 3.3 kV constitutes the last link to the consumer, who is connected directly or through transformers depending upon the drawl level .

- There is no difference between a transmission line and a distribution line except for the voltage level and power handling capability. Transmission lines are usually capable of transmitting large quantities of electric energy over great distances. They operate at high voltages. Distribution lines carry limited quantities of power over shorter distances.
- The power loss in line is proportional to resistance and square of current. (i.e. $P_{\text{LOSS}} = I^2 R$).

Let's say we need to transmit 10 MW of power over a long distance. We compare two scenarios:

- Scenario 1:** Transmitting at 10 kV.
- Scenario 2:** Transmitting at 100 kV.

Scenario 1:

- Power, $P = 10 \text{ MW} = 10^7 \text{ W}$.
- Voltage, $V = 10 \text{ kV} = 10^4 \text{ V}$.
- Current, $I = \frac{P}{V} = \frac{10^7}{10^4} = 10^3 \text{ A}$.
- Power loss, $P_{\text{LOSS}} = I^2 R = (10^3)^2 R = 10^6 R$.

Scenario 2:

- Power, $P = 10 \text{ MW} = 10^7 \text{ W}$.
- Voltage, $V = 100 \text{ kV} = 10^5 \text{ V}$.
- Current, $I = \frac{P}{V} = \frac{10^7}{10^5} = 10^2 \text{ A}$.
- Power loss, $P_{\text{LOSS}} = I^2 R = (10^2)^2 R = 10^4 R$.

Comparing the power losses:

- Scenario 1: $P_{\text{LOSS}} = 10^6 R$.
- Scenario 2: $P_{\text{LOSS}} = 10^4 R$.



The primary function of transmission and distribution equipment is to transfer power economically and reliably from one location to another.

- Conductors in the form of wires and cables strung on towers and poles carry the high-voltage, AC electric current. A large number of copper or aluminum conductors are used to form the transmission path. The resistance of the long-distance transmission conductors is to be minimized. Energy loss in transmission lines is wasted in the form of I^2R losses.
- **Capacitors** are used to correct the power factor (real power/apparent power) by providing reactive power, which helps to balance the inductive effects of the loads like motors, transformers etc.
- Circuit-interrupting devices are switches, relays, circuit breakers, and fuses. Each of these devices are designed to carry and interrupt certain levels of current. Making and breaking the current carrying conductors in the transmission path with a minimum of arcing is one of the most important characteristics of this device.
- Relays sense abnormal voltages, currents, and frequency and operate to protect the system.
- Transformers are placed at strategic locations throughout the system to minimize power losses in the T&D system. They are used to change the voltage level from low-to-high in step up transformers and from high-to-low in step-down units.



Transformer

PURPOSE: to change the voltage

- ▶ increase = "step-up"
- ▶ decrease = "step-down"

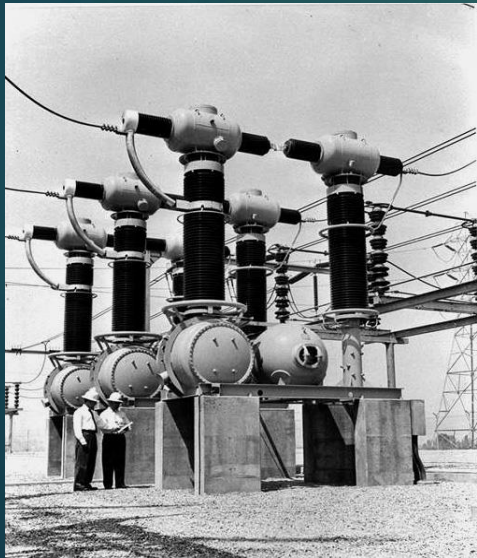
Often run hot, must be cooled,
prone to explode.

- ▶ oil inside
- ▶ cooling fins and fans
- ▶ blast walls



Transformer sub-station

Purpose: To reduce the very high voltages from the transmission lines (>100kV) to intermediate voltages used to serve an individual town or section of a city (typically 66 kV or 33 kV)



Circuit breaker

PURPOSE: stop the flow of current if too much flows (due to short circuit or excess demand)



To our house

Purpose: Smaller transformers (on power line poles or green boxes on the ground) reduce the voltage further to the 240V delivered to individual home.

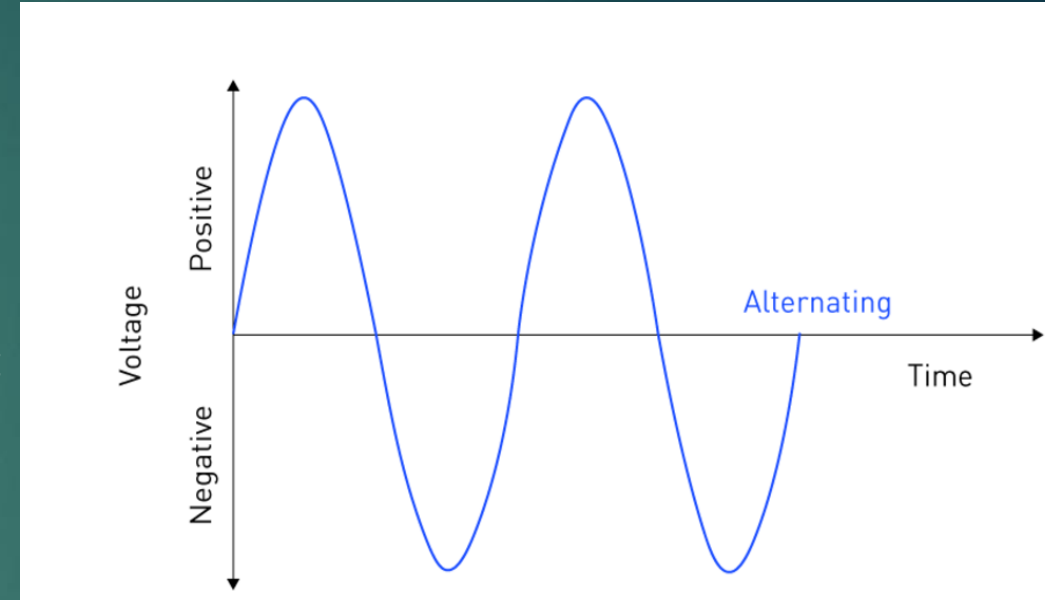
AC Power Definition

Modern electrical systems are built on **alternating current (AC) power**, which powers **homes, companies, and infrastructure worldwide**. **AC electricity oscillates back and forth** in contrast to its counterpart, **Direct Current (DC)**, which flows in a consistent direction.

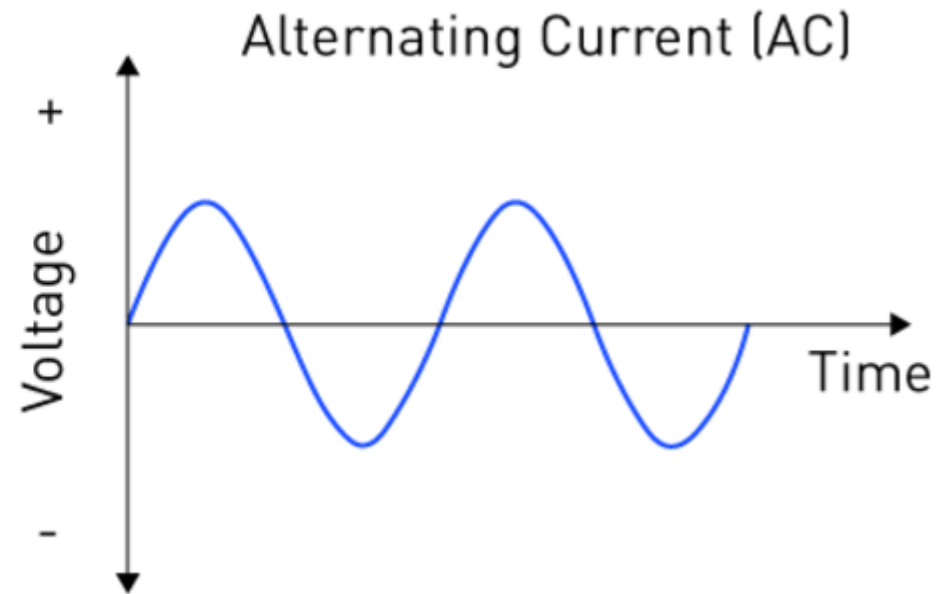
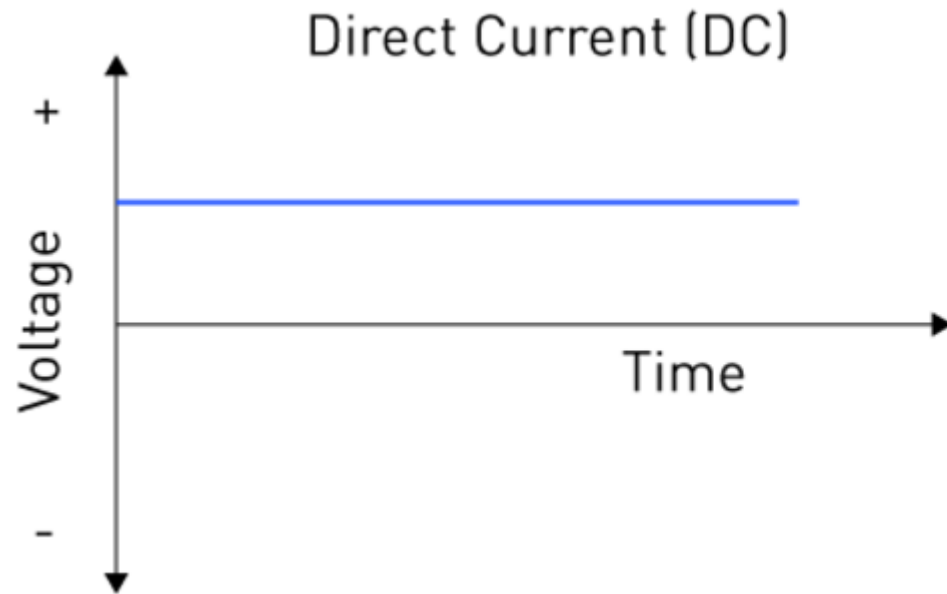
The **resistance and current** in a circuit **determine its power loss**, not the **circuit's AC or DC voltage**. Since the resistance is constant, less current must be used in order to minimize losses.

Transformers **step up (boost) the voltage for AC power transmission** and **step down (lower) it for local distribution**. **Transmission losses are decreased by stepping up the voltage** since it **lowers current**.

The crucial function that AC power plays in the electrical grid is highlighted by its ability to **efficiently distribute over large networks** and **convert between high and low voltages** with ease through the use of transformers.



- The **direction of the electron flow** is the main technical distinction between **AC and DC power**.
- **Electrons in DC systems only move in one direction**, which **maintains a steady voltage**. Because of its **constancy**, DC is perfect for applications like **electronic gadgets** that need **steady and dependable power**.
- On the other hand, the **direction of electron flow periodically changes** in AC systems. Because of its **alternating nature**, power distribution is optimized and **losses are minimized** through the easy use of transformers to step up or step down voltage levels.



AC vs DC Power

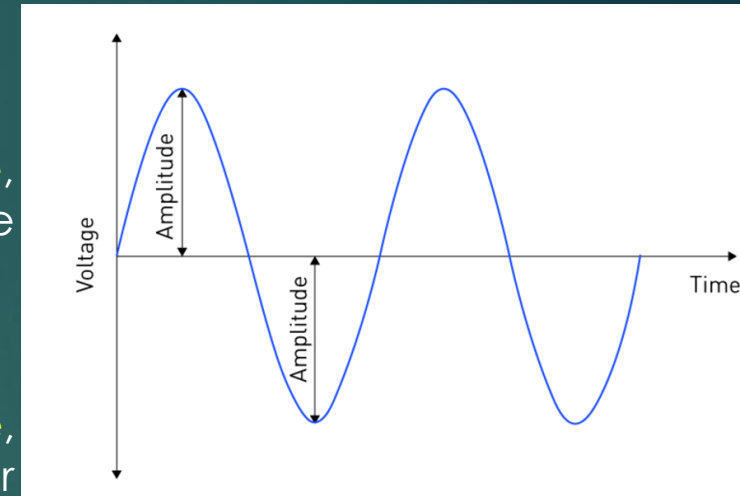
AC Power Applications	DC Power Applications
Residential lighting	LED lighting
Industrial motors	Mobile phones
HVAC systems	Battery backup systems
Household appliances	Electric vehicles (EVs)

Key Properties of AC Power

Three fundamental properties of Alternating Current (AC) power are **amplitude**, **frequency**, and **phase**. In addition to defining the features of AC power, these attributes also support its adaptability and effectiveness in a variety of applications.

Amplitude

- The **amplitude** of an **alternating current** waveform is defined as its **peak value**, which **reflects the maximum strength of the electric field** or the **highest voltage or current in a cycle**. Practically speaking, amplitude is equivalent to the "height" of the **waveform** in a graphic representation.
- **Higher amplitudes indicate** that **more power** can be **applied to a load**; this is directly correlated with the system's power capacity.
- In order to **guarantee that every device** receives the **proper amount of power** for its operation, engineers use **amplitude control** to regulate the **power levels** supplied to multiple devices.

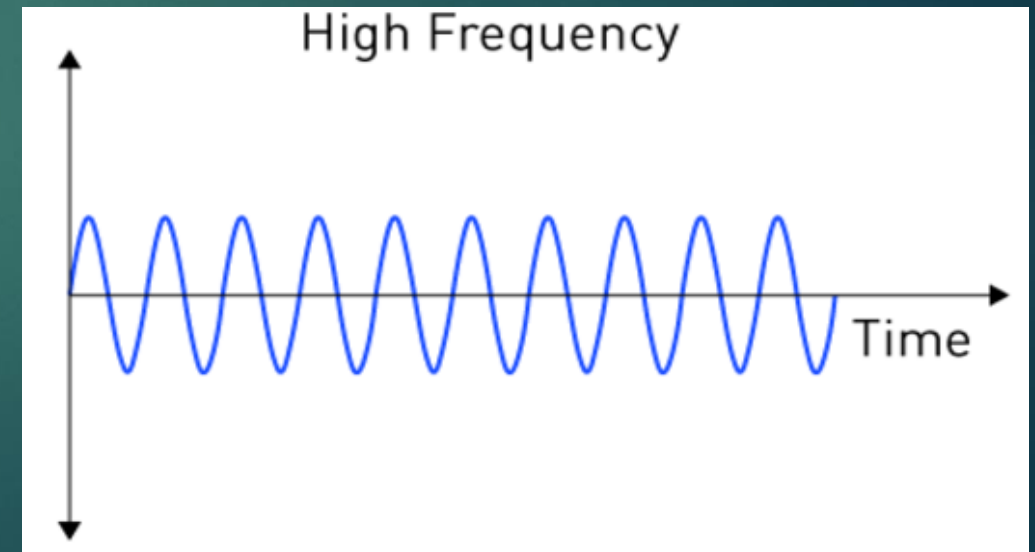
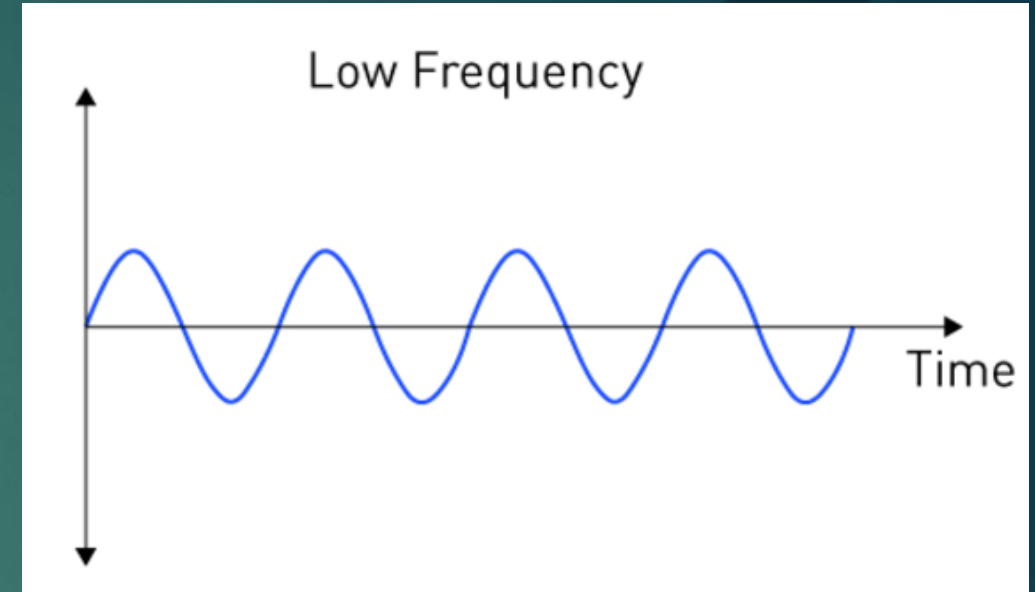


Amplitude

Frequency

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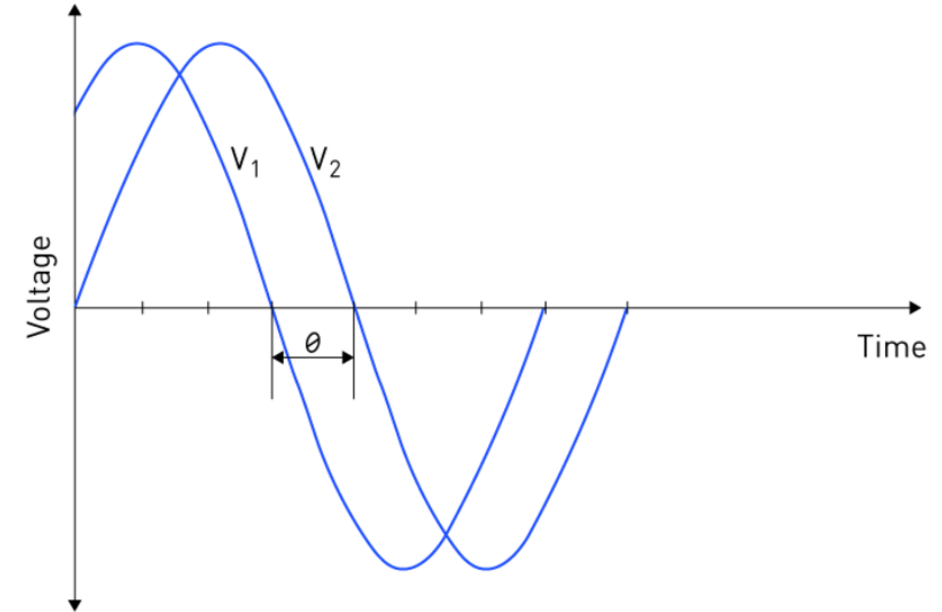
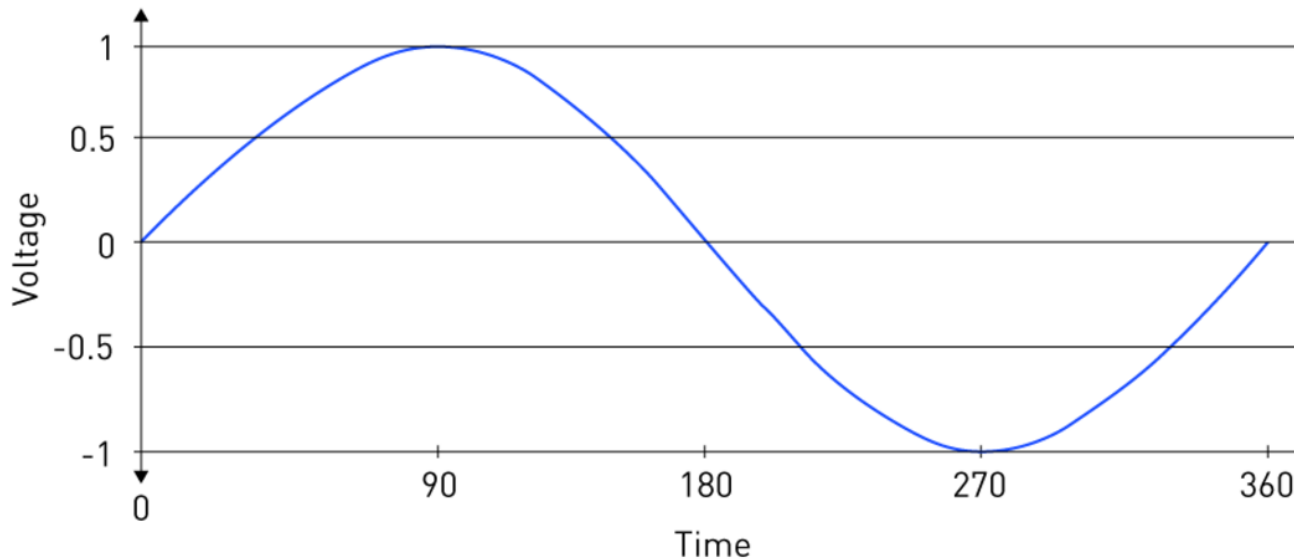
- The frequency, expressed in **Hertz (Hz)**, tells us how many waveform cycles there are in a second.
- It is a vital property of AC power that has an **impact on everything** from the **grid's stability** to the way electric motors operate.
- In most of **Europe, Asia, Africa, and Australia**, the standard **frequency is 50 Hz**; in **North America** and some regions of South America, it is 60 Hz.
- In electricity networks, **frequency needs** to be carefully controlled to provide **grid synchronization** and **facilitating effective distribution** and **transmission**.



Phase

A waveform's phase indicates where it is in relation to other waveforms in time. For effective power transmission and motor functioning in AC power systems, particularly those that use polyphase (e.g., three-phase) systems, the phase difference between the individual waveforms is necessary.

The waveforms in a three-phase system are normally 120 degrees out of phase with one another, which results in a more steady power flow and more smoothly and effectively operating electric motors.



Phase difference between voltages V_1 and V_2

Waveform

A **waveform** is a visual representation of how an electrical quantity varies over time. It graphically represents the change in **voltage or current inside an electrical circuit**. Waveforms can take many **different shapes**, the most popular being **sinusoidal, square, triangular, and sawtooth**. A waveform's shape is defined by the source and the circuit components with which it interacts. Understanding waveforms is critical for studying the behavior of various electrical signals and systems.

Sinusoidal Wave

A **sinusoidal wave** is a **periodic, smooth oscillation that has a pattern** resembling a sine. Because it provides the best representation of how **AC voltage** and **current fluctuate over time**, it is the most fundamental waveform in AC power systems.

The three core features of a sinusoidal wave are its **amplitude (the wave's peak value)**, **frequency** (the wave's repetition frequency per second), and **phase** (the wave's change with respect to a reference point). It is very effective for the generation and transmission of electrical power because of its consistency and predictability.

The sinusoidal wave's general equation is

$$y(t) = A \sin(\omega t + \phi)$$

In this case, the wave's value at any given time t is denoted by $y(t)$, the amplitude by A , the angular frequency by ω , and the phase by ϕ . The relationship between angular frequency and wave frequency is expressed as

$\omega = 2\pi f$ where frequency is denoted by f .

Power

The pace at which electrical energy is delivered to an electric load or transformed into another kind of energy (heat, light, mechanical energy, etc.) is referred to as power in the context of electrical systems. Watts (W) are used to measure it.

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Real Power (P): The actual power used by equipment to perform work (e.g., lighting, heating, running motors).

Reactive Power (Q): Power stored in capacitors. This power is required to create and maintain electric and magnetic fields in certain types of equipment, such as motors, and transformers,.

Apparent Power (S): The total power supplied by the utility, which includes both real power and reactive power.

$$\text{Apparent Power}^2 = \text{Real Power}^2 + \text{Reactive Power}^2$$

Power Factor: The power factor (PF) is a measure of how effectively electrical power is being used in a system. It is the ratio of real power (measured in kilowatts, kW) to apparent power (measured in kilovolt-amperes, kVA):

$$\text{Power Factor (PF)} = \frac{\text{Real Power (kW)}}{\text{Apparent Power (kVA)}}$$

When the voltage and current are in phase and all of the available power is efficiently put to use for work, the power factor equals 1. A smaller power factor, on the other hand, indicates that some power is reactive and not being used, which causes inefficiencies in the power system.

Capacitance

Capacitance is a component's or circuit's ability to store and discharge electrical energy in the form of an electric charge. Capacitance is a fundamental property of devices that store energy in an electric field. It is measured in farads (F). Capacitors are essential components in filtering, tuning, and energy storage applications because they block low-frequency signals in AC circuits while allowing higher-frequency signals to go through.

Inductance

The ability of an inductor to store energy in a magnetic field while an electrical current passes through it is known as inductance, and it is measured in henry (H). Changes in current flow are opposed by inductance, which modifies the amplitude and phase of AC waveforms. It is essential to the operation of filters, chokes, and tuning circuits and is used in the design of transformers, motors, and other AC power transmission components.

Power Factor

The power factor in an AC circuit is a dimensionless number that ranges from 0 to 1 and indicates the phase difference between the voltage and current waveforms. When the voltage and current are in phase and all of the available power is efficiently put to use for work, the power factor equals 1. A smaller power factor, on the other hand, indicates that some power is reactive and not being used, which causes inefficiencies in the power system. For AC power systems to operate more efficiently and at a lower cost, improving the power factor is essential.

Sanctioned load

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Sanctioned Load refers to the **maximum electrical load** (in kilowatts or kilovolt-amperes) that a **utility company agrees to supply** to a **consumer**. This value is determined when a consumer applies for an **electricity connection**, based on the expected power requirements of their premises.

Key Features of Sanctioned Load

Agreement-Based: It is specified in the **agreement between the electricity distribution company** (DISCOM) and the **consumer** at the time of connection approval.

Billing Implications:

- The **electricity tariff structure** often depends on the **sanctioned load**. For example, **consumers may incur penalties** if their **actual load exceeds the sanctioned load** (known as "overloading").
- Fixed charges on **electricity bills** are usually calculated **based on the sanctioned load**.

Categories of Consumers:

- **Residential Consumers:** **Load** depends on **household appliances** like air conditioners, heaters, etc.
- **Commercial Consumers:** **Load** is based on equipment like **computers, lights, and HVAC systems**.
- **Industrial Consumers:** **Load** is much higher and determined by the machinery used.

Key Components:

Connected Load: Sum of the rated power of all electrical equipment/appliances installed at the premises.

Diversity Factor: Accounts for the fact that not all equipment operates simultaneously.

Sanctioned Load Calculation Example

Suppose a residential building has the following connected appliances:

Appliance	Quantity	Power Rating (kW)	Diversity Factor
LED Lights	10	0.01	1.0
Ceiling Fans	5	0.07	0.8
Air Conditioners	2	1.5	0.6

Step 1: Connected Load

$$\text{Connected Load (kW)} = (10 \times 0.01) + (5 \times 0.07) + (2 \times 1.5) = 3.85 \text{ kW}$$

Step 2: Sanctioned Load

If the **average diversity factor** is 0.8, the formula becomes:

$$\text{Sanctioned Load (kW)} = \frac{\text{Connected Load (kW)}}{\text{Diversity Factor Average}}$$

Substitute the values:

$$\text{Sanctioned Load (kW)} = \frac{3.85}{0.8} = 4.8125 \text{ kW}$$

Chart showing consumer categories and their corresponding sanctioned loads

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Consumer Category	Sanctioned Load Range	Examples	Remarks
Residential (Domestic)	1 kW - 15 kW	Apartments, houses with appliances (TV, AC, geyser).	Load varies with household size and equipment.
Small Commercial	5 kW - 25 kW	Small shops, clinics, small offices.	Load depends on lighting, computers, and small equipment.
Medium Commercial	25 kW - 75 kW	Restaurants, showrooms, medium-sized offices.	Requires additional load for HVAC and lighting.
Industrial (Small Scale)	50 kW - 150 kW	Workshops, small-scale manufacturing units.	Includes load for motors and small machinery.
Industrial (Large Scale)	150 kW and above	Steel plants, chemical industries, textile mills.	High demand for continuous operation machinery.
Agricultural	3 kW - 20 kW	Water pumps for irrigation, farming operations.	Load varies by pump capacity and farm size.

Maximum demand

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Maximum demand refers to the highest level of electrical power or load that a system, building, or equipment consumes over a specified period, usually in kilowatts (kW) or kilovolt-amperes (kVA).

It helps utility providers and facility managers assess peak energy usage, design systems for optimal capacity, and implement cost-effective energy management.

The general formula to calculate maximum demand is:

$$\text{Maximum Demand (kW)} = \text{Energy Consumed (kWh)} / \text{Time Interval (hours)}$$

Key Points to Note:

- **Time Interval:** The measurement is usually taken over a specific period, such as 15, 30, or 60 minutes, depending on utility practices.
- **Units:** Maximum demand is typically expressed in kilowatts (kW) or kilovolt-amperes (kVA) if power factor is considered.

Example

A factory consumes 300 kWh of energy over a 30-minute period. Calculate its maximum demand.

Calculation:

- Energy Consumed = 300 kWh
- Time Interval = 30 minutes = 0.5 hours

$$\text{Maximum Demand (kW)} = \frac{300 \text{ kWh}}{0.5 \text{ hours}} = 600 \text{ kW}$$

Applications of Maximum Demand

1. Energy Management:

- Identifying peak load times to optimize energy consumption and reduce costs.
- Helps organizations avoid penalties imposed by utility providers for exceeding contracted demand limits.

2. Infrastructure Design:

- Used to design electrical systems, including transformers, generators, and substations, ensuring they can handle peak loads.

3. Cost Allocation:

- Utilities use it to calculate demand charges, which can form a significant part of electricity bills.

Measurement Tools for Maximum Demand

1. Maximum Demand Indicators (MDI):

- Mechanical or digital devices installed on electrical panels to measure peak load over a period.

2. Energy Meters with Demand Measurement:

- Modern digital energy meters (smart meters) come with built-in features to record maximum demand.

3. Power Analyzers:

- **Portable devices** for **real-time measurement** and analysis of **electrical load**, including maximum demand.

4. Supervisory Control and Data Acquisition (SCADA):

- **SCADA systems monitor and record maximum demand** as part of broader energy management systems



MDI



Energy Meters



SCADA



Power Analyzers

Contract demand

Contract demand refers to the maximum level of electrical power that a consumer agrees to draw from the utility provider, as specified in a formal agreement.

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It is a predetermined value, typically expressed in kilowatts (kW), and forms the basis for infrastructure planning, energy supply, and billing.

Contract Demand Charge = Contract Demand (kW) × Rate per kW

Aspect	Contract Demand	Maximum Demand
Definition	The pre-agreed maximum power (kW) a consumer commits to drawing from the utility provider.	The actual highest power consumed by the consumer during a specific period.
Determination	Based on a formal agreement between the consumer and utility provider, considering the consumer's estimated needs.	Measured dynamically and represents the peak load during a billing cycle or observation period.
Nature	Fixed value as specified in the contract.	Variable and depends on real-time power consumption patterns.
Control	Controlled and chosen by the consumer in agreement with the utility.	Determined by the consumer's operational usage and load patterns.
Purpose	Helps utilities allocate resources, plan infrastructure, and ensure grid reliability.	Helps track and analyze peak energy usage for operational efficiency.
Revision	Consumers can request to revise the contract demand, usually with advance notice and utility approval.	Cannot be revised but can be managed by controlling load patterns.
Examples	A factory signs a contract to draw a maximum of 1,000 kW from the grid.	The factory's peak usage during a specific month reaches 900 kW.

Billing Statement

Customer Name: XYZ Industries
Account Number: 123456789
Billing Period: 1st January 2025 to 31st January 2025
Tariff Plan: HT Industrial Tariff

Energy Consumption Details

Parameter	Value	Units
Energy Consumed	50,000	kWh
Maximum Demand Recorded	1,100	kVA
Contract Demand	1,000	kVA
Power Factor	0.95	-
Billing Demand (95% of CD or MD, whichever is higher)	1,100	kVA

Charges Summary

Description	Rate	Quantity	Amount (₹)
Energy Charges	₹5.50 per kWh	50,000 kWh	₹2,75,000.00
Demand Charges (on Billing Demand)	₹300 per kVA	1,100 kVA	₹3,30,000.00
Penalty for Exceeding Contract Demand	₹500 per kVA above CD	100 kVA	₹50,000.00
Power Factor Incentive/Disincentive	Incentive @ 2%	-	₹5,000.00

Total Bill Amount (₹)

₹6,60,000.00

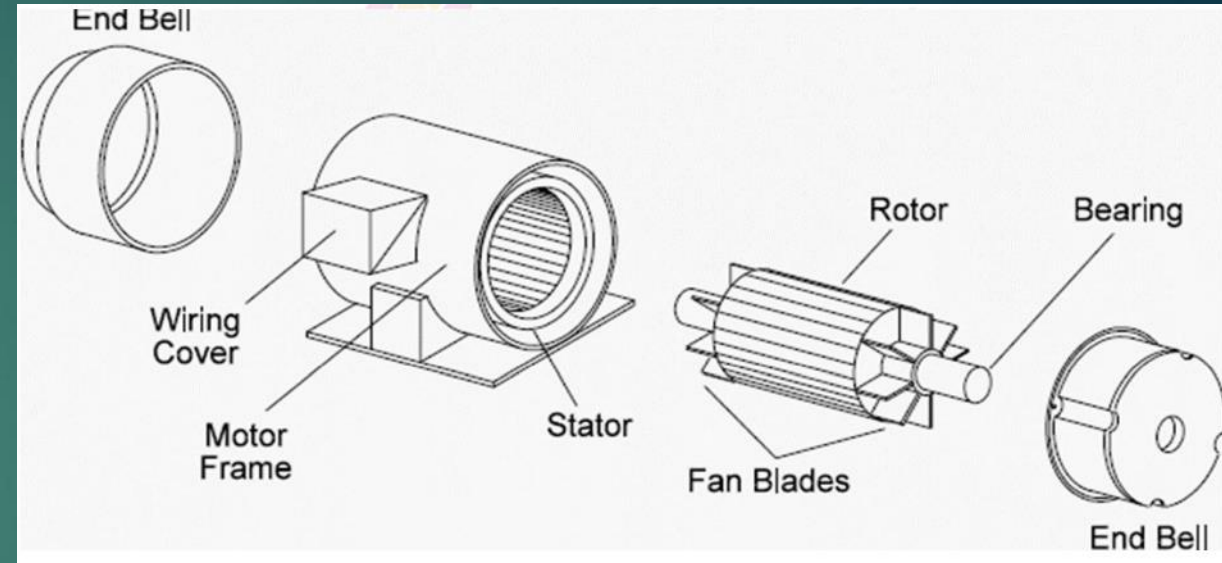
Electric Motor

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- Motors convert **electrical energy** into **mechanical energy** by the interaction between the **magnetic fields set up** in the **stator** and **rotor windings**.
- Industrial electric motors can be broadly classified as **induction motors**, direct current motors or **synchronous motors**.
- All motor types have the same four operating components: stator (stationary windings), rotor (rotating windings), bearings, and frame (enclosure).

Induction Motor

- Induction motors are the **most commonly used prime mover** for various equipments in industrial applications.
- In induction motors, the induced magnetic field of the stator winding induces a current in the rotor. This induced rotor current produces a second magnetic field, which tries to oppose the stator magnetic field, and this causes the rotor to rotate.



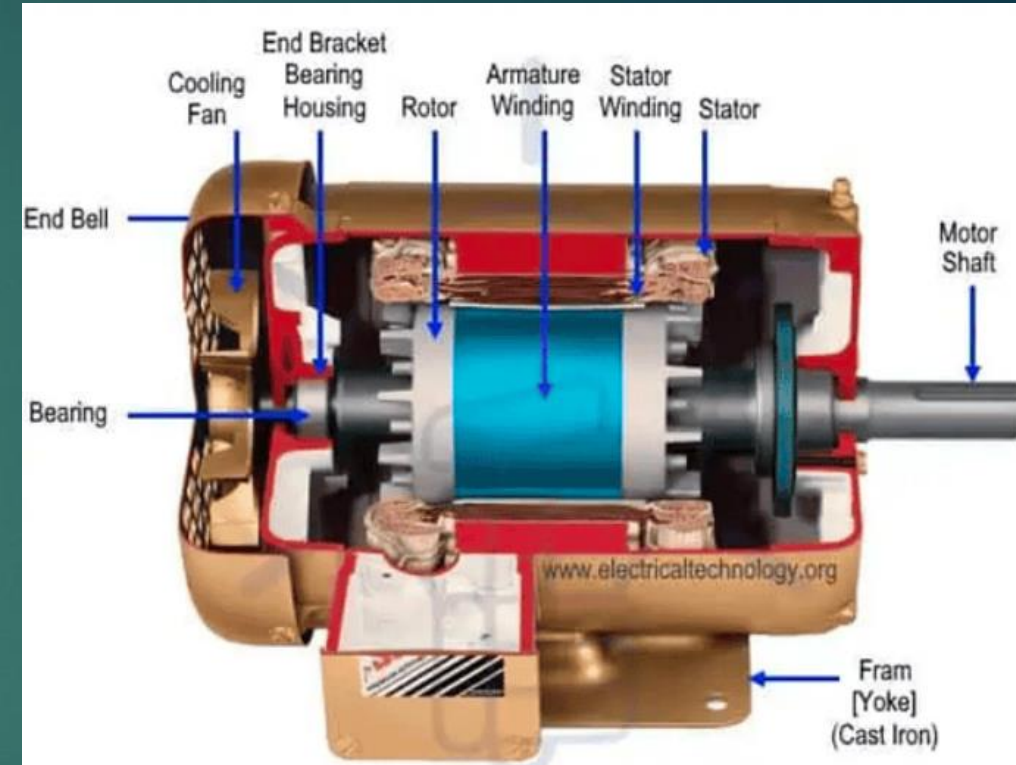
Components of Induction Motor

Types of Induction Motor

1. Single phase Induction motor
2. Three phase induction motor

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- 1. Single Phase induction motor:** A single-phase induction motor works by converting electrical energy into mechanical energy using electromagnetic induction.
- It has a **stator**, which is the stationary part, and a **rotor**, which rotates. When a single-phase AC supply is given to the **stator winding**, it creates a **pulsating magnetic field**.
 - This field alone cannot produce **enough torque** to start the motor, so an **auxiliary winding** or **capacitor** is used to create a **phase difference**, producing a rotating magnetic field.
 - This **rotating field induces** a **current in the rotor**, which generates its own magnetic field. The **interaction between the rotor's magnetic field** and the **stator's field** causes the rotor to turn, resulting in motor rotation.

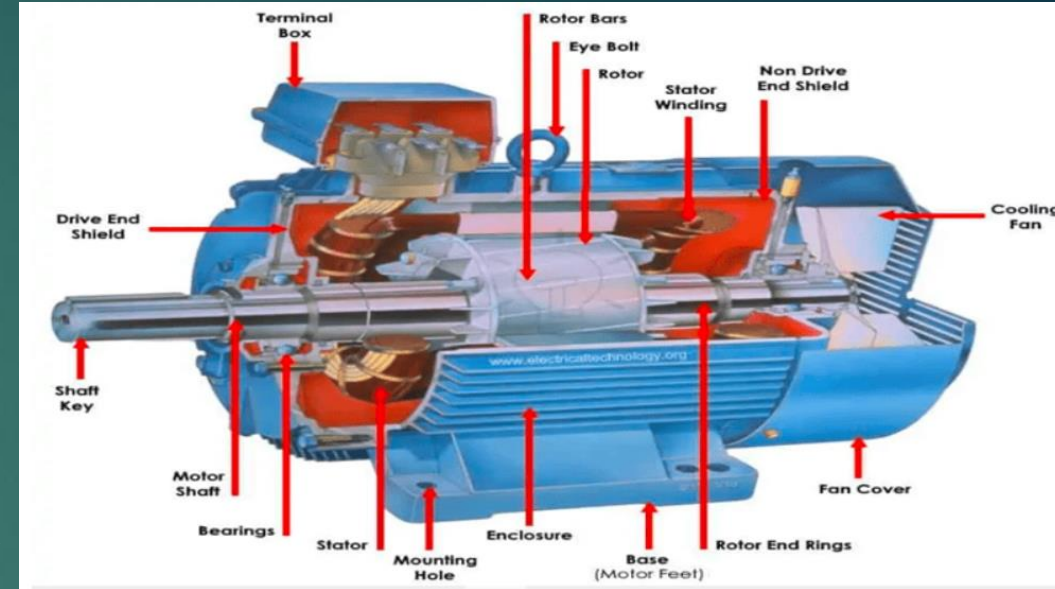


Single phase Induction motor components

Three phase induction motor: A three-phase induction motor works by using **three-phase alternating current (AC)** to produce a **rotating magnetic field**, which causes the **rotor to spin** and **generate mechanical energy**. The **stator**, the stationary part of the motor, has **three sets of windings** spaced **120 degrees apart**. When a three-phase AC supply is applied, it **creates a rotating magnetic field** around the stator. This **rotating field** moves at a **certain speed**, called **synchronous speed**.

The rotor, typically a **squirrel cage** design made of copper or **aluminum bars**, is placed inside this rotating field. As the **magnetic field rotates**, it induces an **electric current** in the **rotor bars**, which generates its own magnetic field.

The **interaction** between the **stator's rotating magnetic field** and the **rotor's magnetic field** creates a **torque**, causing the **rotor to turn**. The **rotor always lags** slightly behind the **stator's rotating field**, which is why it operates at a **slightly lower speed** than **synchronous speed**.



Three phase Induction motor components

Motor Characteristics

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Motor speed: The speed of a motor is the number of revolutions in a given time frame, typically revolutions per minute (RPM). The **speed** of an AC motor depends on the **frequency of the input power** and the **number of poles** for which the motor is wound. The synchronous speed in RPM is given by the following equation, where the frequency is in hertz or cycles per second:

$$\text{Synchronous Speed (RPM)} = \frac{120 \times \text{Frequency}}{\text{No. of Poles}}$$

Indian motors have synchronous speeds like 3000 / 1500 / 1000 / 750 / 600 / 500 / 375 RPM corresponding to no. of poles being 2, 4, 6, 8, 10, 12, 16 (always even) and given the mains frequency of 50 cycles / sec.

The **actual speed**, with which the **motor operates**, will be **less than the synchronous speed**. The **difference between synchronous and full load speed** is called **slip** and is measured in percent. It is calculated using this equation:

$$\text{Slip (\%)} = \frac{\text{Synchronous Speed} - \text{Full Load Rated Speed}}{\text{Synchronous Speed}} \times 100$$

Power factor

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The power factor of the motor is given as:

$$\text{Power Factor} = \cos \phi = \frac{\text{kW}}{\text{kVA}}$$

As the load on the motor comes down, the magnitude of the active current reduces. However, there is no corresponding reduction in the magnetizing current, which is proportional to supply voltage with the result that the motor power factor reduces, with a reduction in applied load. Induction motors, especially those operating below their rated capacity, are the main reason for low power factor in electric systems.

Motor efficiency

It is defined as the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals, and power factor (PF).

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types: fixed losses - independent of motor load, and variable losses- dependent on load.

Motor load

- Motor load is indicator of efficiency
- Equation to determine load:

$$P_i = \frac{V \times I \times PF \times \sqrt{3}}{1000}$$

Where:

P_i = Three-phase power in kW

V = RMS voltage, mean line-to-line of 3 phases

I = RMS current, mean of 3 phases

PF = Power factor as a decimal

Determination of Motor Load

Three methods for individual motors

- **Input power measurement**
 - Ratio input power and rated power at 100% loading
- **Line current measurement**
 - Compare measured amperage with rated amperage
- **Slip method**
 - Compare slip at operation with slip at full load

- Input power measurement
- Three steps for three-phase motors

Step 1. Determine the input power:

$$P_i = \frac{V \times I \times PF \times \sqrt{3}}{1000}$$

P_i = Three Phase power in kW
V = RMS Voltage, mean line to line of 3 Phases
I = RMS Current, mean of 3 phases
PF = Power factor as Decimal

Step 2. Determine the rated power:

$$P_r = hp \times \frac{0.7457}{\eta_r}$$

P_r = Input Power at Full Rated load in kW
hp = Name plate Rated Horse Power
η_r = Efficiency at Full Rated Load

Step 3. Determine the percentage load:

$$Load = \frac{P_i}{P_r} \times 100\%$$

Load = Output Power as a % of Rated Power
P_i = Measured Three Phase power in kW
P_r = Input Power at Full Rated load in kW

The efficiency of a motor is determined by **intrinsic losses** that can be **reduced only by changes in motor design**. Intrinsic losses are of two types: **fixed losses** - independent of motor load, and **variable losses**- dependent on load.

Fixed losses consist of **magnetic core losses** and **friction and windage losses**.

Magnetic core losses (sometimes called iron losses) consist of **eddy current** and **hysteresis losses in the stator**. They vary with the **core material** and geometry and with input voltage.

Friction and windage losses are caused by **friction in the bearings of the motor** and aerodynamic losses associated with the **ventilation fan** and other rotating parts.

Variable losses consist of **resistance losses** in the **stator** and in the **rotor** and miscellaneous stray losses.

Resistance to current flow in the **stator** and **rotor** result in **heat generation** that is proportional to the resistance of the material and the square of the current (I^2R).

Stray losses arise from a **variety of sources** and are difficult to either measure directly or to calculate, but are **generally proportional to the square of the rotor current**.

The **Figures 2.1** shows the effect of load on power factor and efficiency. It can be seen that **power factor** drops sharply at **part loads**.

EFFICIENCY/POWER FACTOR vs LOAD
(Typical 3-Phase Induction Motor)

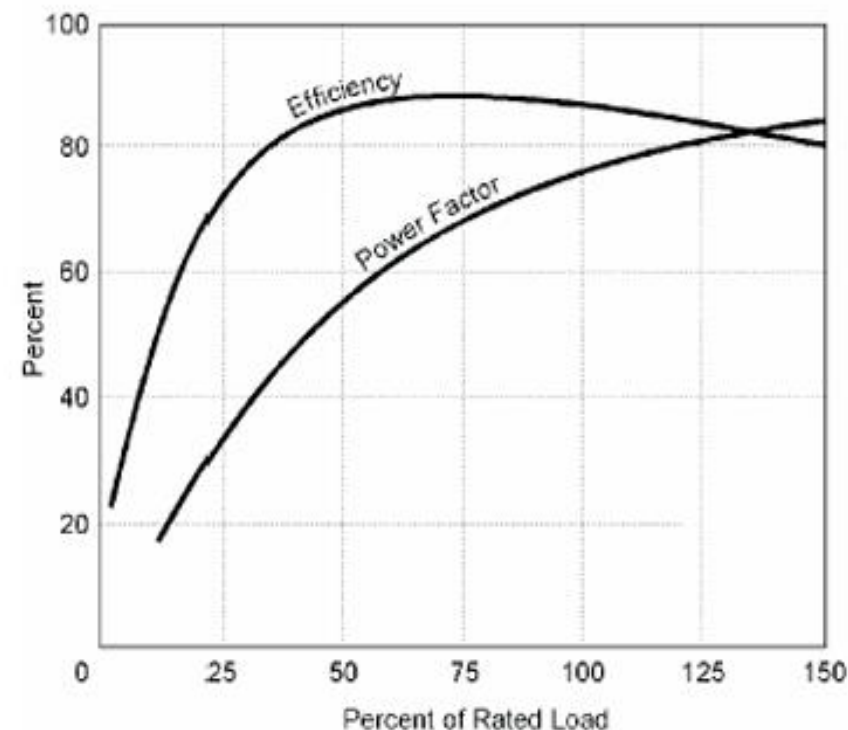


Figure 2.1 % Load vs. Power factor, Efficiency

Selecting a motor for any application requires careful consideration of multiple factors to ensure optimal performance, efficiency, and reliability. The choice depends on the specific requirements of the application and operational conditions.

1. Load Requirements:

Type of Load: Identify whether the load is constant, variable, or cyclic. Some applications may require smooth operation (e.g., conveyors), while others may need frequent start-stop cycles (e.g., robotic arms).

Torque Requirements:

Starting Torque: High starting torque may be required for loads like compressors or crushers.

Running Torque: Ensure the motor can sustain the torque required during steady-state operation.

Speed Range: Consider whether the motor needs a constant speed, variable speed, or multiple speeds.

2. Power requirements:

Operating Power: Ensure the motor provides sufficient power (measured in watts or horsepower) for the load.

Efficiency: Motors with higher efficiency ratings reduce energy consumption and operating costs.

Overload Capacity: The motor should be capable of handling temporary overload conditions without damage.

3. Operating Conditions

Environment:

Temperature: Select a motor designed to operate effectively within the ambient temperature range of the application.

Humidity: For humid or wet environments, choose motors with proper insulation or enclosures.

Hazardous Conditions: In areas with flammable gases or dust, use explosion-proof motors or those certified for hazardous locations.

Ingress Protection (IP Rating): An appropriate IP rating ensures protection against dust and water ingress, such as IP55 or IP66.

4. Control Requirements

Speed Control: For applications requiring variable speeds, use motors compatible with variable frequency drives (VFDs) or electronic controllers.

Positioning: Motors in robotics or precision tools often need accurate positioning capabilities, such as stepper motors or servo motors.

5. Electrical Supply

Voltage and Frequency: Match the motor's voltage and frequency rating with the available power supply (e.g., 230V/50Hz or 460V/60Hz).

Phase: Determine whether single-phase or three-phase power is available.

Current Requirements: Ensure the electrical system can provide the required starting and running currents without overloading.

Transformer

Transformer is an static electromagnetic device that transfers electrical energy from one circuit to another circuit with change in voltage, keeping frequency constant.

Key points:

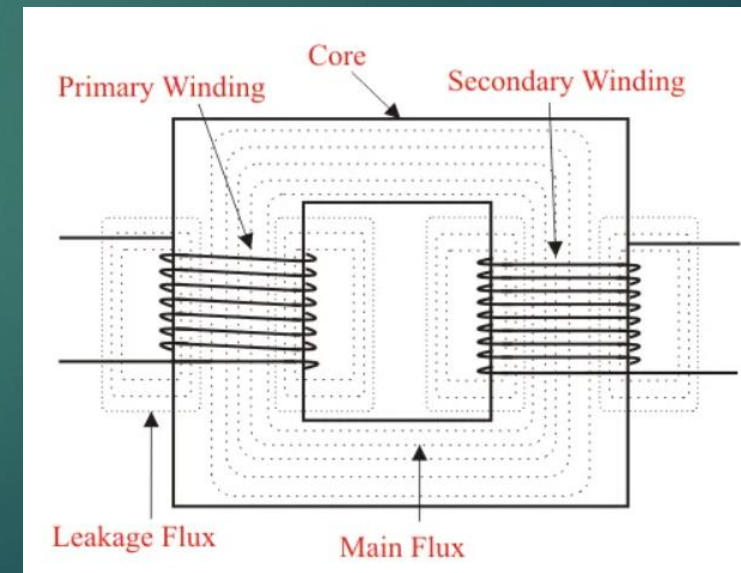
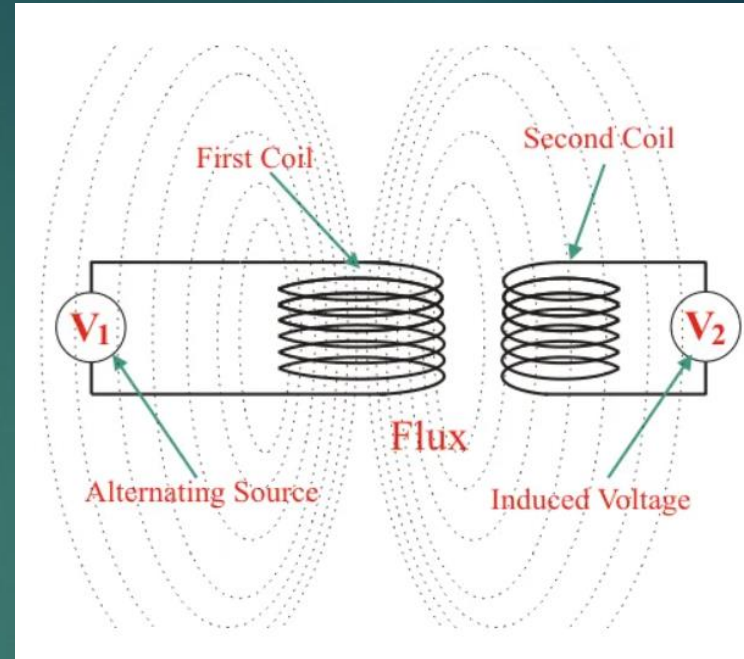
- Transfers electric energy from one circuit to another.
- Frequency is constant.
- Based on electromagnetic induction, where two electric circuits are in mutual inductive influence of each other.



Transformer

Working of Transformer

- Alternating voltage V_1 is applied to the primary winding, a current is established in the primary winding which produces a alternating magnetic flux in the core.
- In the secondary winding the magnetic field generated due to magnetic flux is cut by the conductors in the secondary windings.
- As per Faraday law of electromagnetic Induction, a mutually induced EMF will be generated in the in secondary winding.
- When a load is connected to the secondary side, current will start flowing in the secondary winding.
- The voltage induced in the secondary winding is responsible to deliver power to the load connected to it.
- Thus power is transferred from one circuit to another.

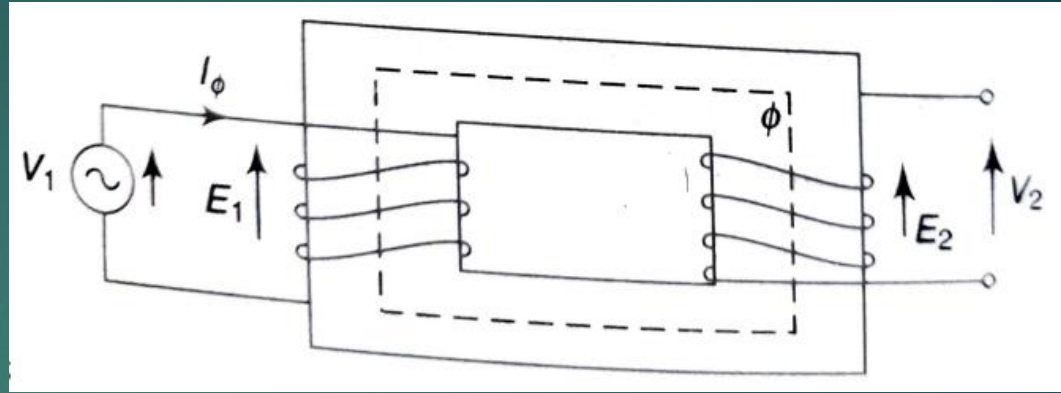


EMF EQUATION OF TRANSFORMER

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The applied voltage is sinusoidal at the primary, the flux (Φ) produced by the primary current is also sinusoidal.

$$\phi = \phi_{\max} \sin \omega t$$



$$e = -N \frac{d\phi}{dt}$$

$$e = -N \frac{d(\phi_{\max} \sin \omega t)}{dt}$$

$$e = -2\pi f \phi_{\max} N \cos \omega t$$

$$E_{\max} = 2\pi f \phi_{\max} N \text{ ----- max value of above eqn}$$

$$\text{Therefore, } E_{\text{rms}} = \frac{E_{\max}}{\sqrt{2}} = \frac{2\pi f \phi_{\max} N}{\sqrt{2}} = 4.44 \phi_{\max} f N$$

$$\text{Thus, } E_1 = 4.44 \phi_{\max} f N_1 \text{ ----- RMS value of induced EMF at Primary with } N_1 \text{ Turns}$$

$$E_2 = 4.44 \phi_{\max} f N_2 \text{ ----- RMS value of induced EMF at Secondary with } N_2 \text{ Turns}$$

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = K = \text{TransformationRatio}$$

For an ideal tranformer, if we neglect the losses

$$E_1 I_1 = E_2 I_2$$

$$\frac{E_1}{E_2} = \frac{I_2}{I_1}$$

$$\text{Therefore, } K = \frac{I_2}{I_1} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{V_1}{V_2}$$

Way to remember above relationship - Current is transformed in reverse ratio of the voltage and turn's ratio.

With the selection of K: Two cases are possible-

1. If $N_1 > N_2$ or, $E_1 > E_2$ **Step down Transformer**
2. If $N_2 > N_1$ or, $E_2 > E_1$ **Step up Transformer**

Losses in transformer

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- Consist of Primary and Secondary Windings placed in a magnetic Core
- Magnetic Core is a stack of thin silicon steel laminations.
- Lamination reduces Eddy current loss and Steel reduces hysteresis loss
- **Eddy current Loss (P_e)**- The eddy currents are the circulating currents set up in the core. These are produced due to the magnetic flux being cut by the core resulting in eddy current generation in core leading to heat generation. The loss occurred due to this is called eddy current loss (Watt).

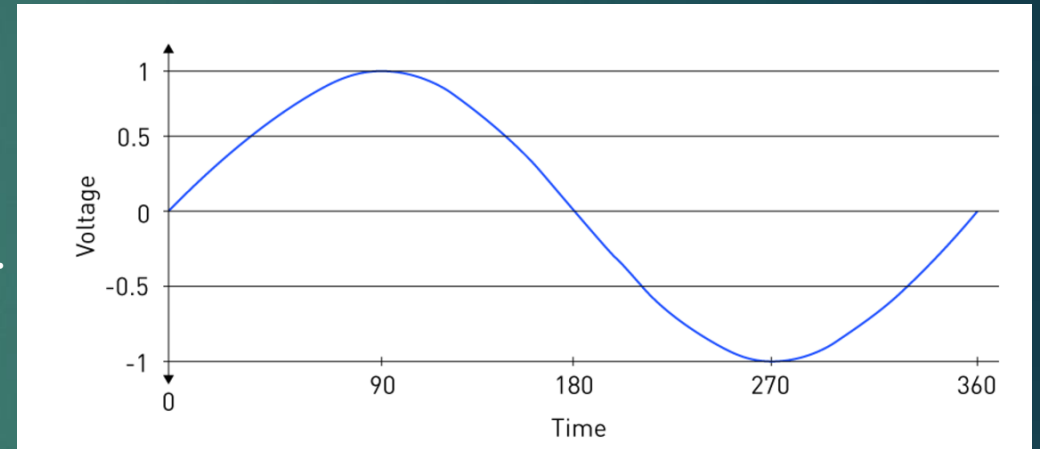
$$P_e = K_e B_{\max}^2 f^2 t^2 v$$

Where, K_e is the constant depends on the conductor.

B_{\max} is the maximum flux density in (Wb/m²)

f is frequency, t is thickness of the lamination (metre)

v is the volume of the core (m³)



- **Hysteresis loss (P_h)**- When alternating current flows through the winding, the core of the material undergoes cyclic processes of magnetisation and demagnetisation. The occurred loss due to this process is called hysteresis loss (Watt).

$$P_h = K_h B_{\max}^n f v$$

K_h is the hysteresis coefficient and n is also another constant which depends on material ($1.5 < n < 2.5$)

Copper losses: Copper losses are the heat produced in a transformer's windings when an electric current passes through them. It's also known as winding loss.

Ideal Transformer	Practical Transformer
It has 100% efficiency	It has below 100% efficiency
It has no losses	It has losses
It has no leakage drop	It has leakage drop
It is not utilized in practical conditions	It is utilized in practical conditions

Thank You