Electrical Theory

"The Basics"

Lecture#5

Introduction

- Basic Terminology
- Ohm’s Law
- Kirchhoff’s Laws & Applications
- Basic Circuit Analysis
- AC/DC Machines
- Transformers

Basic Terminology

- Electromotive Force (E or V)
  - Force which causes electrons to move from one location to another
  - Known as emf, potential difference, or voltage
  - Unit is volt (V)
  - Source:
    - Generator
    - Battery
  - Like pump that moves water through “pressure”

Basic Terminology

- Current (I)
  - Flow of electric charges - electrons (or holes) - through a conductor or circuit per increment of time
  - Unit is ampere (number of charged particles passing a point each second)
  - 1 amp = 1 coulomb/sec = 6.02×10^{23} electrons/sec
  - Like rate of flow of water through a pipe

Basic Terminology

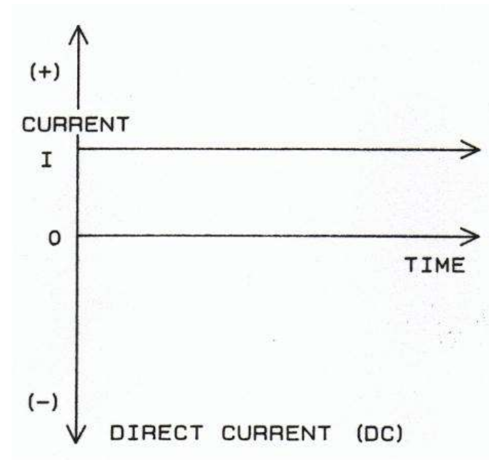
- Resistance (R)
  - An electrical circuit's opposition to the flow of current through it
  - Measured in ohms (Ω)
- Conductor
  - All materials will conduct electricity, but at varying resistances
  - Good conductors have little resistance (ie: silver, copper, aluminum, iron)

Basic Terminology

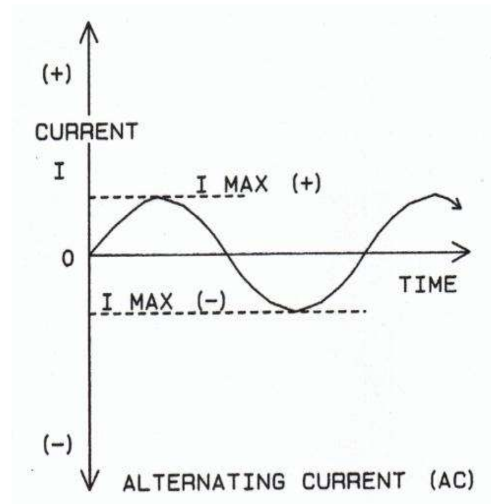
- Insulator
  - Substances which offer high resistance to current flow (ie: wood, rubber, plastics)
  - Circuits made of wires covered with insulator
- Power (P)
  - Rate at which work is performed
  - Measured in watts (W)

Basic Terminology

- Direct Current (DC)
  - Current flow is unidirectional and of constant magnitude (battery)

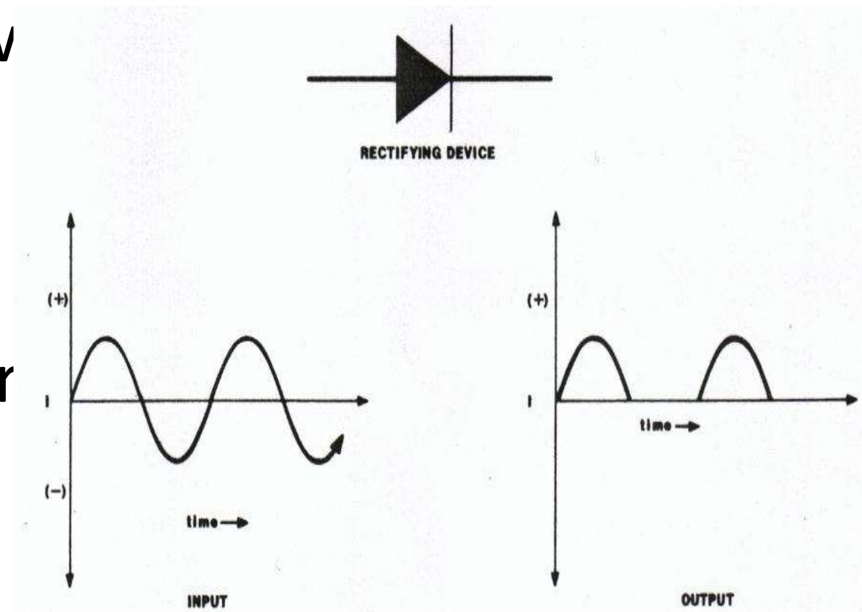


- Alternating Current (AC)
  - Magnitude & direction of current flow periodically change
  - Each sequence called a cycle
  - Frequency is cycles per second (Hz)



Electrical Devices

- Rectifier
  - Converts AC to DC
  - Designed to have small resistance to current flow in one direction & large resistance in opposite direction
  - Typically called a diode or rectifier



Ohm's Law & Applications

- Law: current of a circuit is directly proportional to the applied voltage and inversely proportional to circuit resistance;

$I \propto V, I \propto 1/R \quad V = IR$

- Power →

$P = VI \qquad P = (IR)I = I^2R$

Applications

- Resistors in Series

  $R_T = R_1 + R_2 + R_3 + \ldots$

- Resistors in Parallel

  $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$

- Examples: should be able to find total current flow in circuit, current flow through each resistor, voltages, power dissipated, etc.

Kirchhoff's Laws

- **Kirchhoff's Current Law (KCL)**
  - A node is any junction in a circuit where two or more elements meet
  - Currents into a node sum to zero OR
  - Current entering a junction is equivalent to the current leaving a junction
  - For any given voltage rise, there must be an equal voltage drop somewhere in the circuit

Kirchhoff’s Laws

- **Kirchhoff’s Voltage Law (KVL)**

  – A loop is any path in a circuit that current can take so that it meets back up to where it starts

  – Voltages around a CLOSED loop sum to zero

Electrical Theory II – The Applications

Harnessing the Power…

… *of*

AC/DC

Introduction

- **Electromagnetic Induction**
- **DC**
  - **Generators: mechanical energy→elecrical energy**
  - **Motors: electrical energy→mechanical energy**
- **AC**
  - **Generators**
  - **Motors**
  - **Three-phase AC**

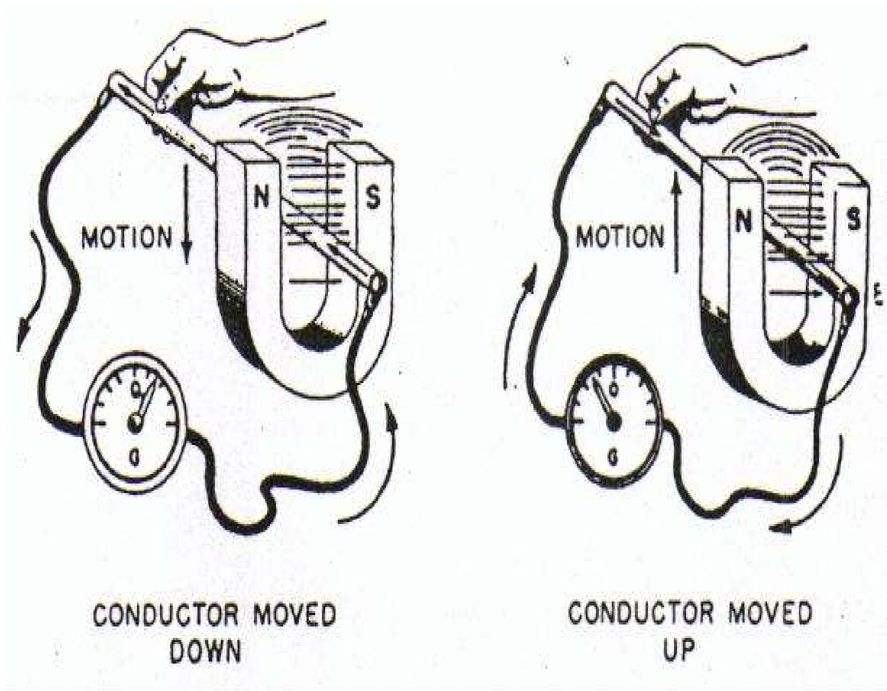
How is Electricity Produced?

- Friction: “static electricity” from rubbing (walking across a carpet)
- Pressure: piezoelectricity from squeezing crystals together (quartz watch)
- Heat: voltage produced at junction of dissimilar metals (thermocouple)
- Light: voltage produced from light striking photocell (solar power)
- Chemical: voltage produced from chemical reaction (wet or dry cell battery)
- Magnetism: voltage produced using electromotive induction (AC or DC generator).

Electromagnetic Induction

- Faraday (1831):
  - Showed that an emf is induced in a conductor if a magnet passes by a conductor

- When pole of magnet entered coil, current flowed in one direction
- When direction of magnet reversed, current flowed in opposite direction

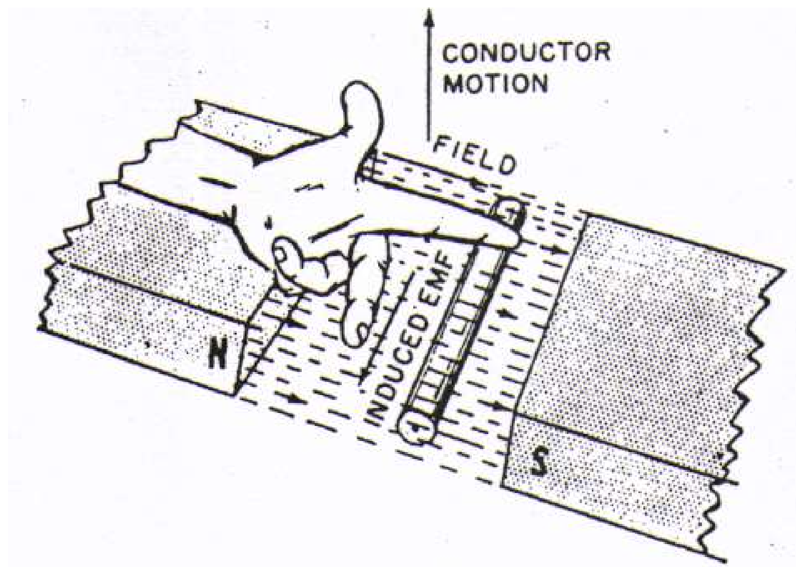


Electromagnetic Induction

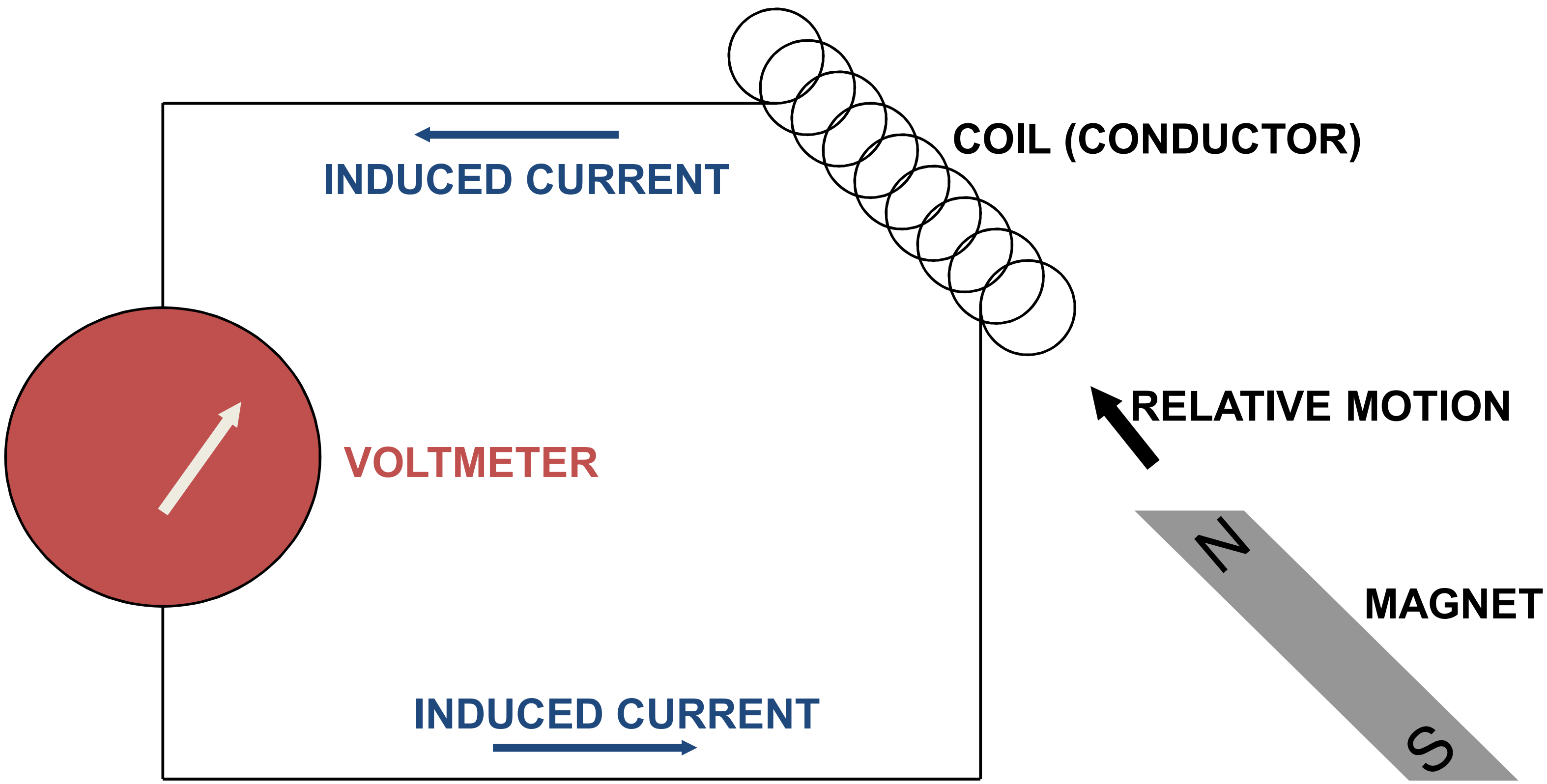
- Results in:
  - Generator action: generator converts mechanical to electrical energy
  - Motor action: motor converts electrical to mechanical energy

Generator Action

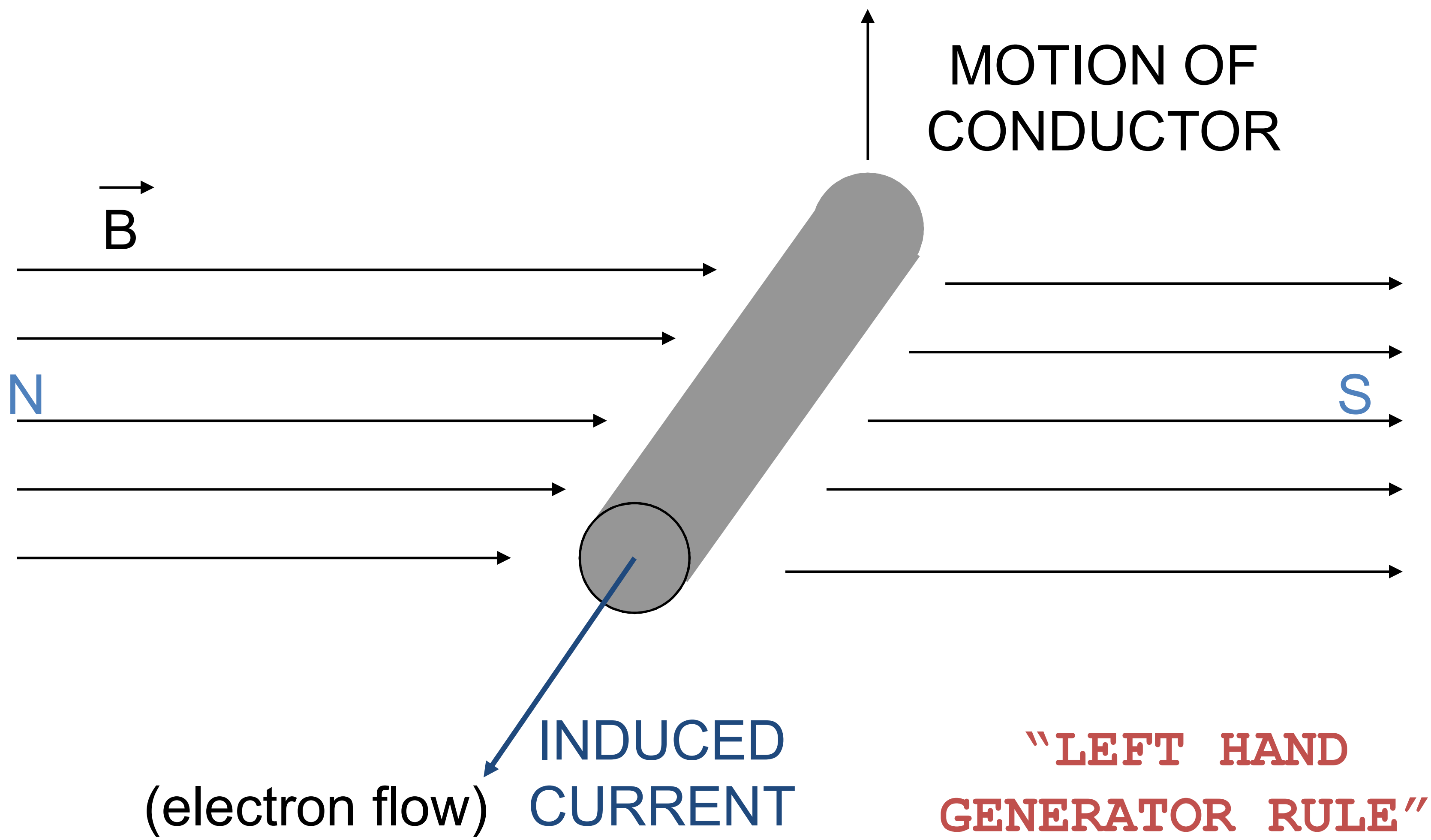
- For emf/current (electricity):
  - Magnetic Field
  - Conductor
  - Relative Motion b/t the two
- Voltage produced: “induced emf/voltage”
- Current produced: “induced current”
- Left-hand rule for generator action



Electromagnetic Induction



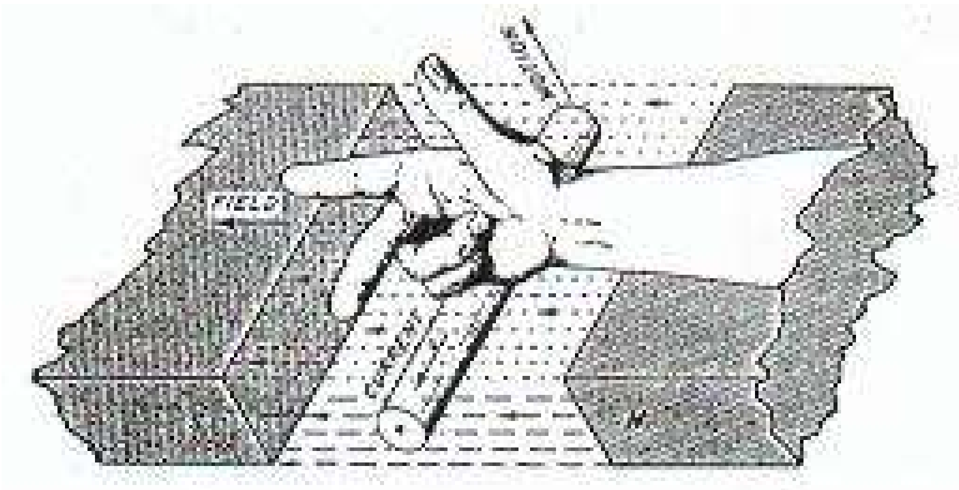
Direction of Induced emf



Motor Action

- For motor action (torque/motion):
  - Magnetic Field
  - Conductor
  - Current flow in conductor

- Torque produced: “induced torque”
- Right-hand rule for motor action



Electromagnetic Induction

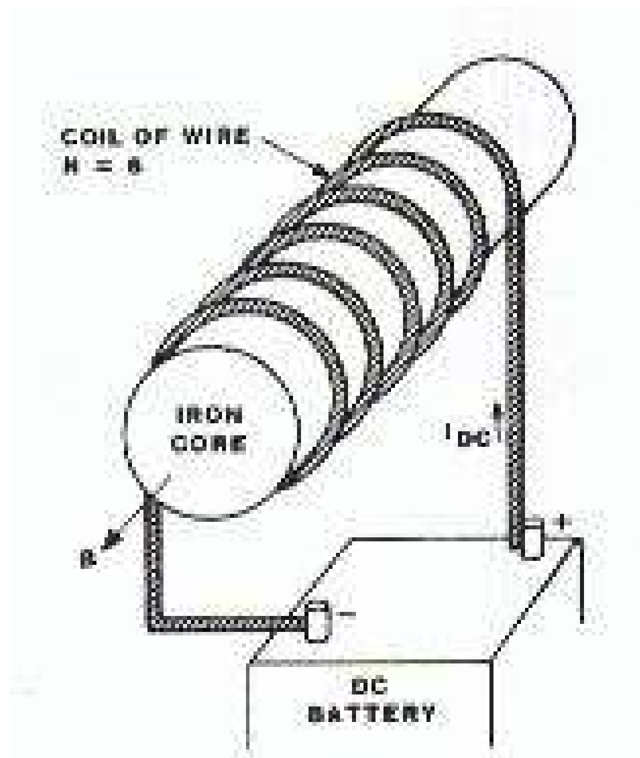
- **Magnitude of induced current can be increased by:**
  - Increasing strength of magnetic field
  - Increasing speed of relative motion
  - Positioning of field & conductor to increase number of magnetic lines of flux cut

- **Magnetic field usually produced by electromagnet**

Electromagnet

- Soft iron core wound with coils of wire
- When current present (excitation current), core becomes magnetized
- Field strength determined by number of turns and magnitude of current:

$$B \propto NI_{DC}$$

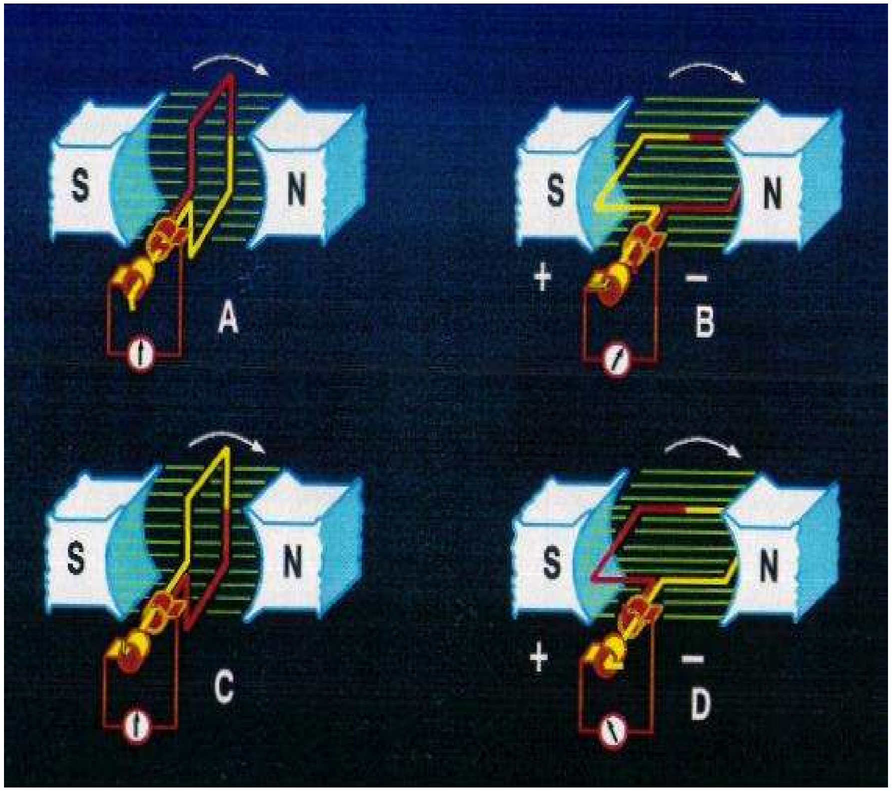


Generator Parts

- Prime mover: mechanical work which turns the rotor, may be a steam turbine, gas turbine, diesel engine...
- Armature windings: the conductor in which the output voltage is induced
- Field windings: the conductors used to produce the electromagnetic field (needs a DC power supply), the magnet
- Stator: stationary housing of the generator, contains the magnet (field windings)
- Rotor: rotates inside the stator, moved by a prime mover (steam turbine, gas turbine, diesel…), contains the conductor (armature windings)
- Poles: one set of armature windings is called a pole in the generator

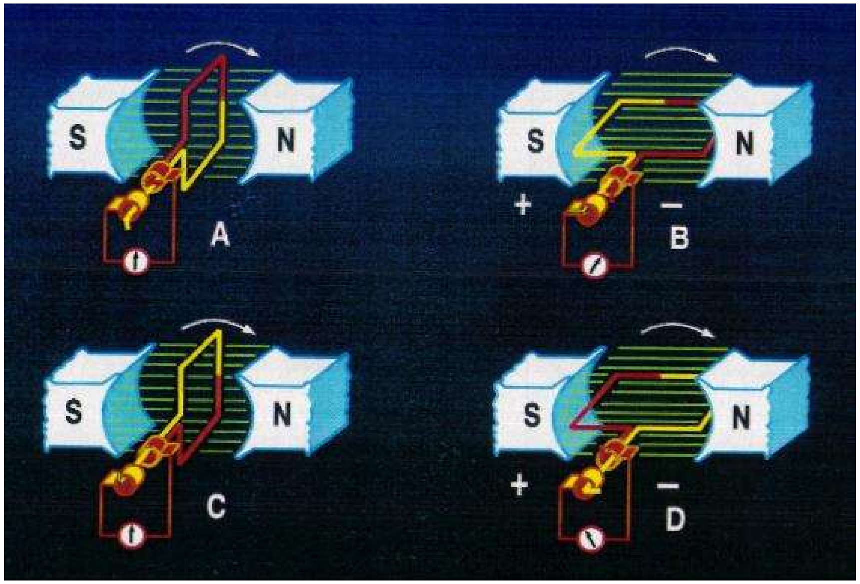
DC Generators

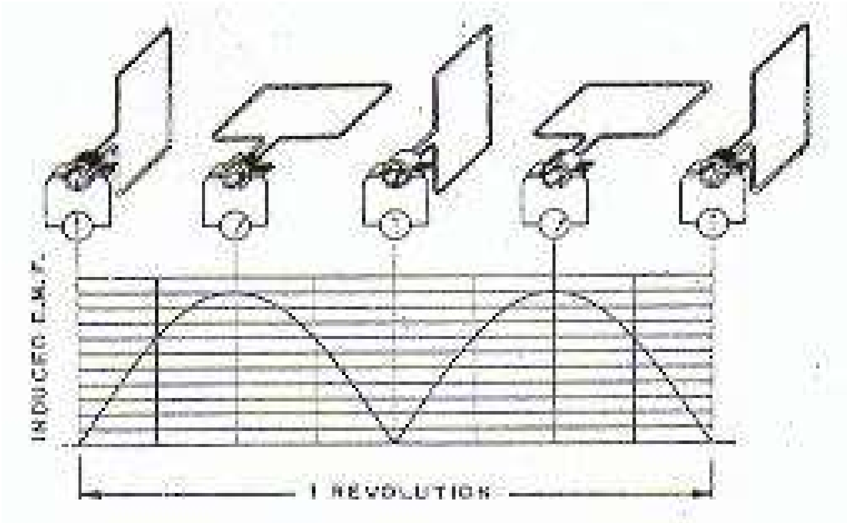
- Basic Principle: rotate a conductor within a magnetic field to induce an EMF
- Field windings located on stator & receive current from outside source



DC Generators

- Armature windings on rotor
  - Commutator rings used to mechanically reverse the armature coil connection to the external circuit
  - EMF developed across the brushes becomes a DC voltage/current (pulsating and unidirectional)





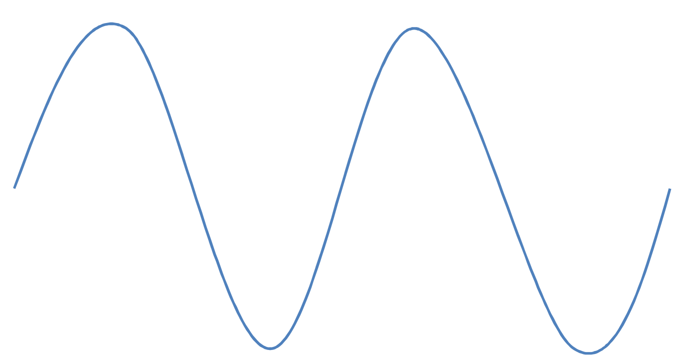
AC Power

Alternating Current (AC) Theory

- AC- The magnitude and direction of current flow in an AC circuit will change periodically (called a cycle).
- The frequency (Hz) of an AC circuit is the number of cycles per second.

Alternating Current (AC)

- Current is constantly changing in magnitude and direction at regular intervals
- Current is a function of time and usually varies as a sine function

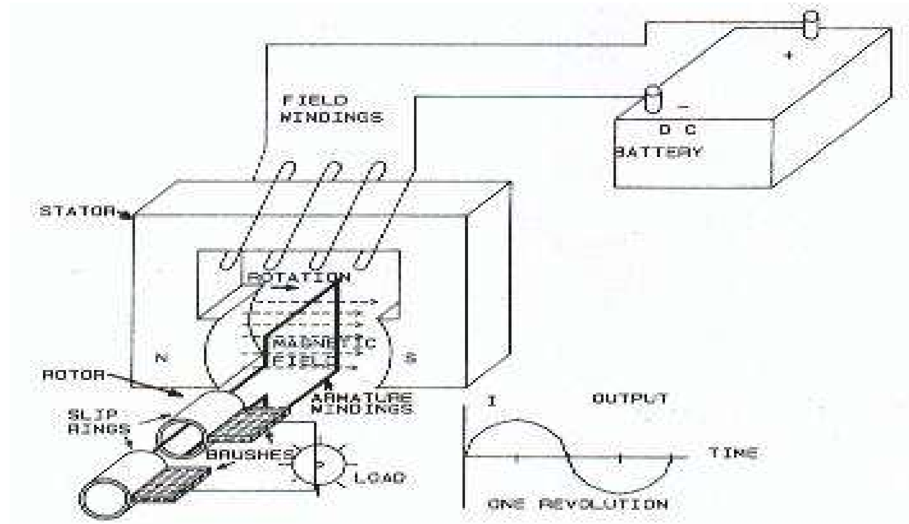


AC Generators

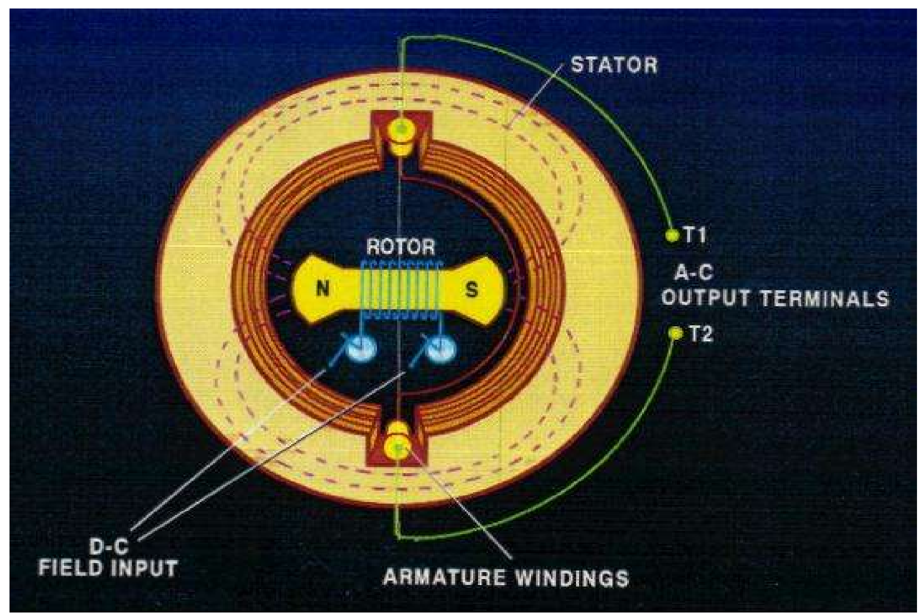
- Most electrical power used is AC made by AC generators
- Basic principle: rotating magnetic field "cutting through" a conductor
  - Regardless of size, all AC generators work on same principle
- Two types:
  - Revolving armature (Not used normally)
  - Revolving field

AC Generators

- Two types:
  - Revolving armature (NOT commonly used)

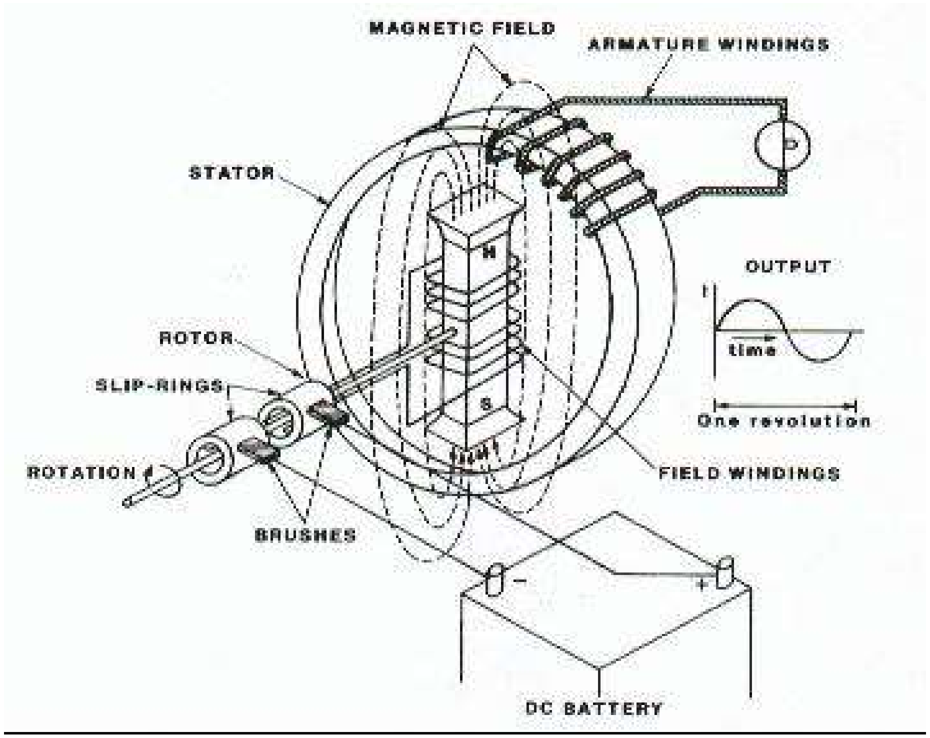


  - Revolving field



AC Generators

- Field windings on rotor
  - DC current provided for field via slip rings and brushes (vice commutator rings)
  - Rotor turned by prime mover → creates rotating magnetic field
- Armature windings on stator
  - As field rotates, AC current produced in armature
  - Since stationary contacts, no arc-over



Relationship Between Generator Speed and Frequency

- Most electrical equipment in the United States operates on 60 Hz AC electrical power (many foreign countries use 50 Hz)
- How fast must a 2-pole generator be rotating to produce a 50/60 Hz output?

$$N \times P = 120 \times f$$

N - rpm P - poles f - frequency (Hz)

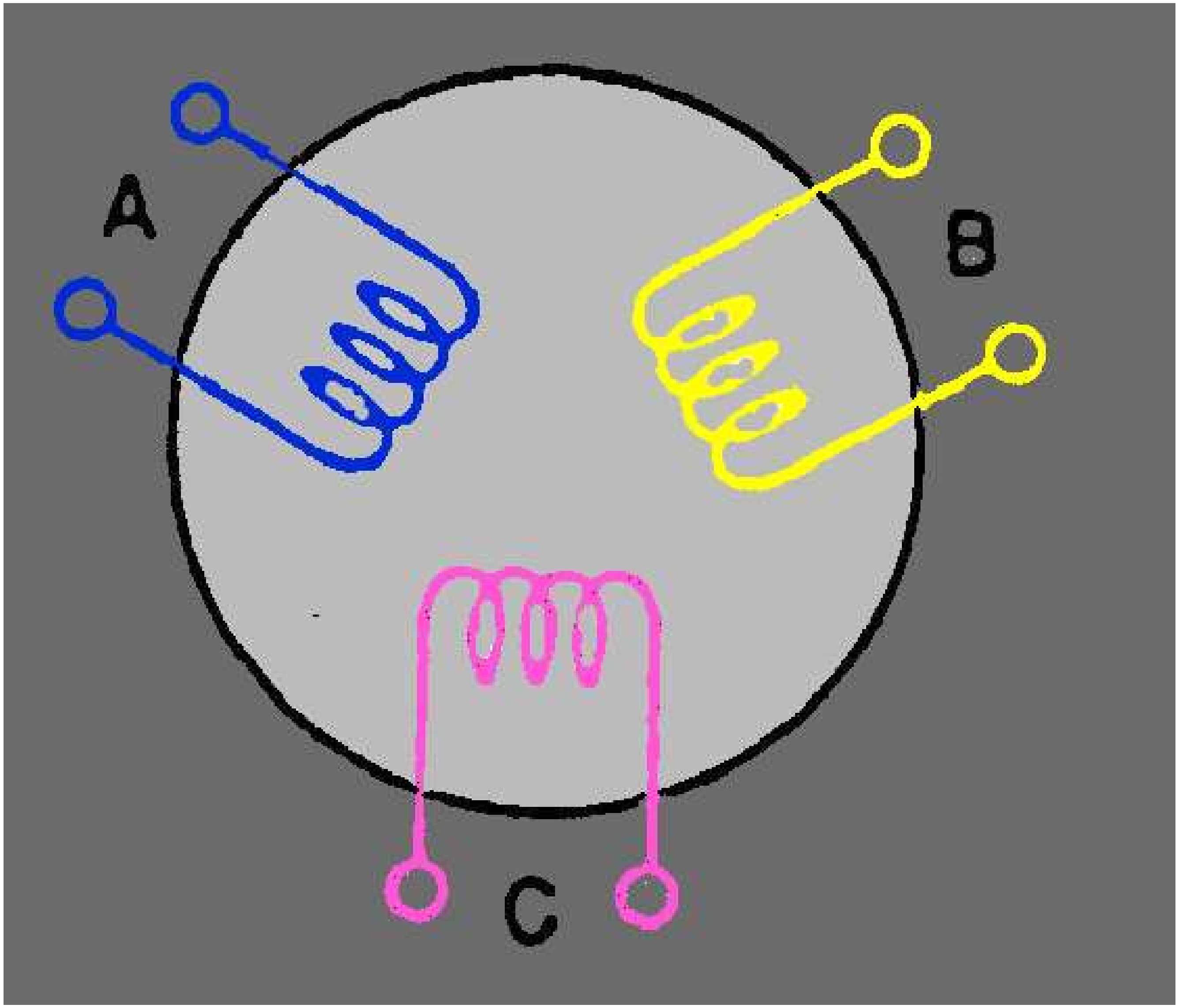
Classifying AC Generators

- Number of phases: most shipboard electrical power is 3 phase, this is more reliable plus loss of one phase will not cause a loss of equipment operability
- Frequency: most shipboard electrical power is 60 Hz, some electronic equipment operate at 400 Hz or higher
- Voltage: usually 450 V, smaller appliances use 120 V
- Power rating: measured in kW, most shipboard generators are 2,000 - 3,000 kW

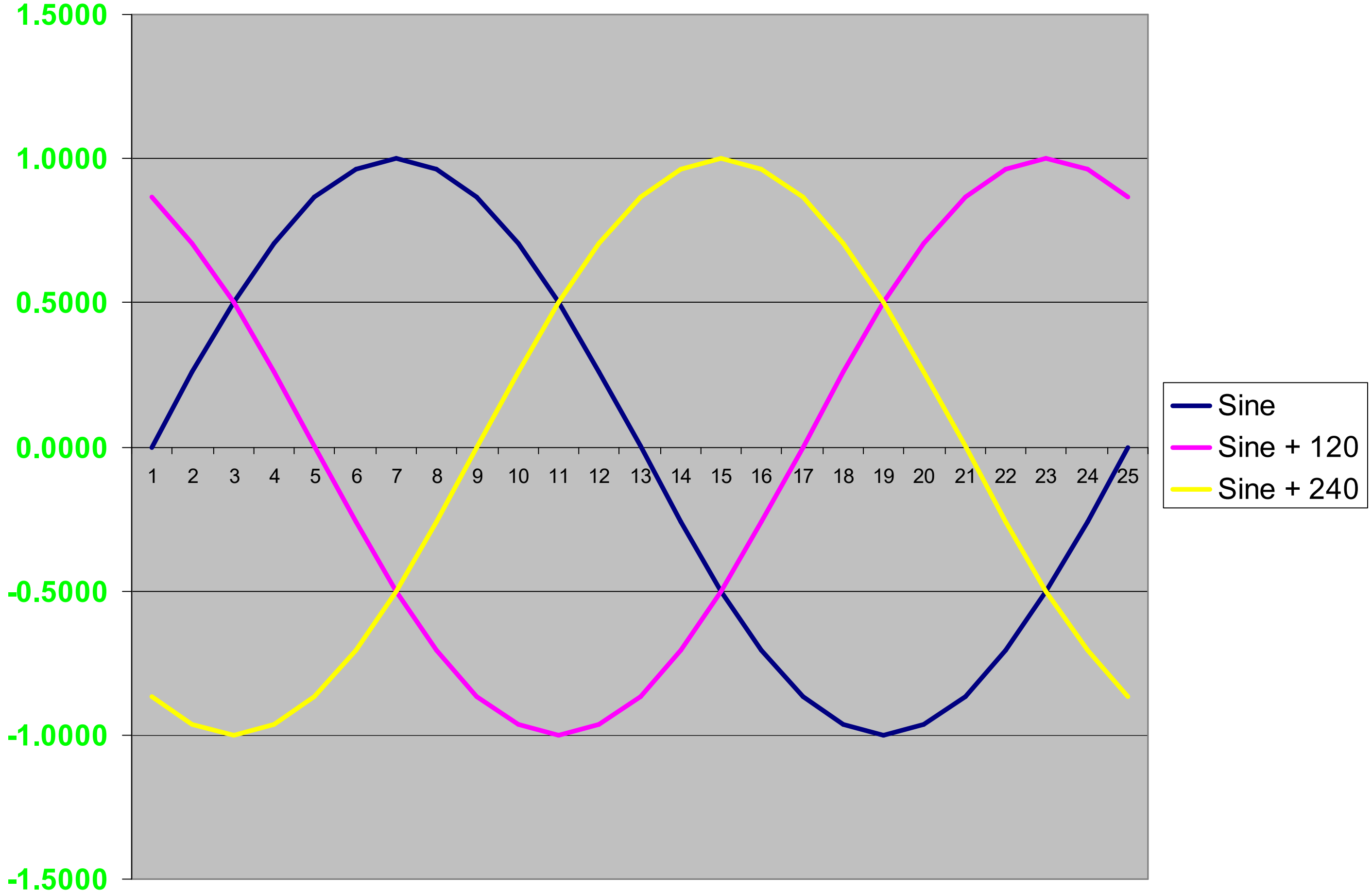
Three-Phase Electrical Power

- Uses three sets of armature windings to produce three separate outputs
- Armature windings are physically separated 120^o from each other, and therefore, each phase is 120^o apart from another
- More power may be generated by a generator of a given size and weight
- Provides continuous power to electrical equipment even if one phase is damaged

3 Phase



Three Phase


1.5000
1.0000
0.5000
0.0000
-0.5000
-1.0000
-1.5000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Sine
Sine + 120
Sine + 240

AC vs DC

- AC power is easier to generate and requires less complex equipment (smaller machines)
- AC energy can be used in transformers to step up or step down voltages where DC energy cannot
- DC can be “stored” for reserve use, i.e. the ship’s battery!!!

Batteries

- Dry-cell batteries: cylindrical zinc container, carbon electrode, and ammonium chloride/water electrolyte
- Wet-cell batteries: lead-acid battery is the most common, can be charged by forcibly changing the direction of electrical current

Transformers

- A device that transfers energy by electromagnetic induction
- Primary windings (receive energy from AC source) and secondary windings (delivers energy to the load) (insulated from each other electrically) are mounted on opposite sides of a ferromagnetic core
- Used to raise voltage (“step-up transformer”) or lower voltage (“step-down transformer”)
- Voltage is raised when the primary winding has fewer turns than the secondary winding, and voltage is lowered when the primary winding has more turns than the secondary winding

A Simple Transformer