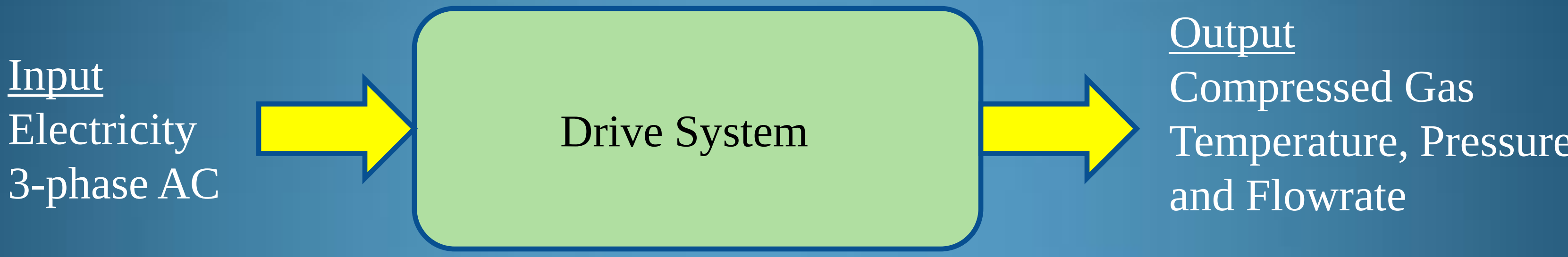
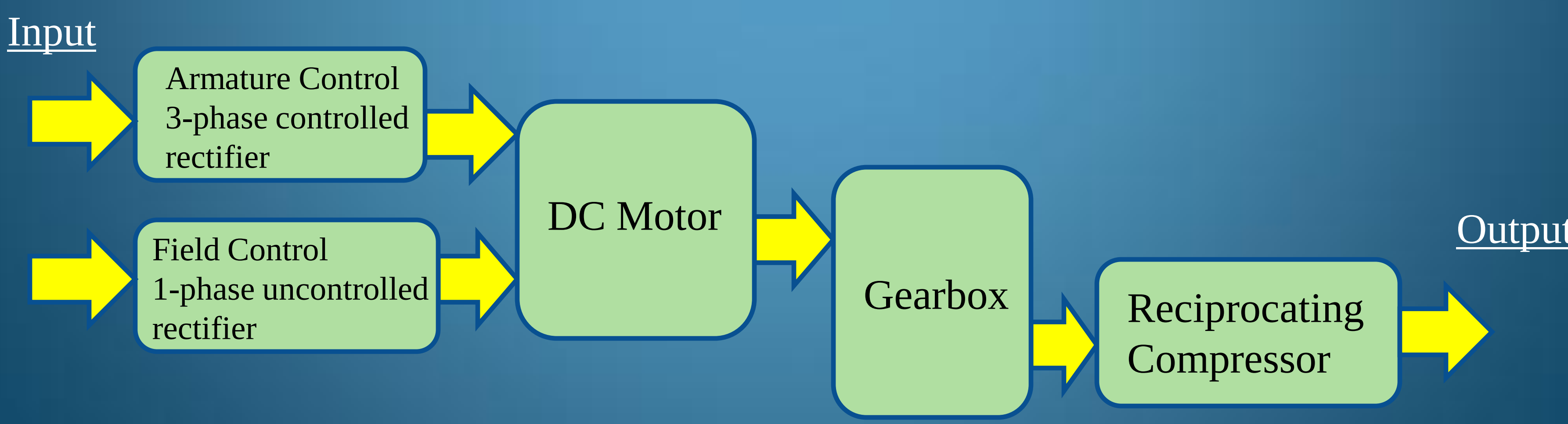
Mathcad – Assignment System Calculation

Dr Malcolm W. Renton

Compressor Drive System

- Block Diagrams:



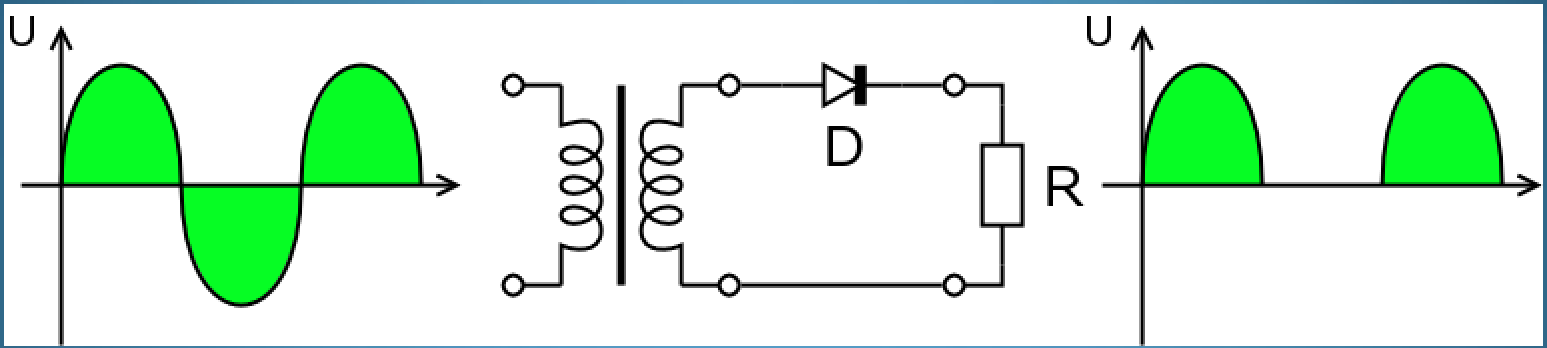


AC-DC Rectifier

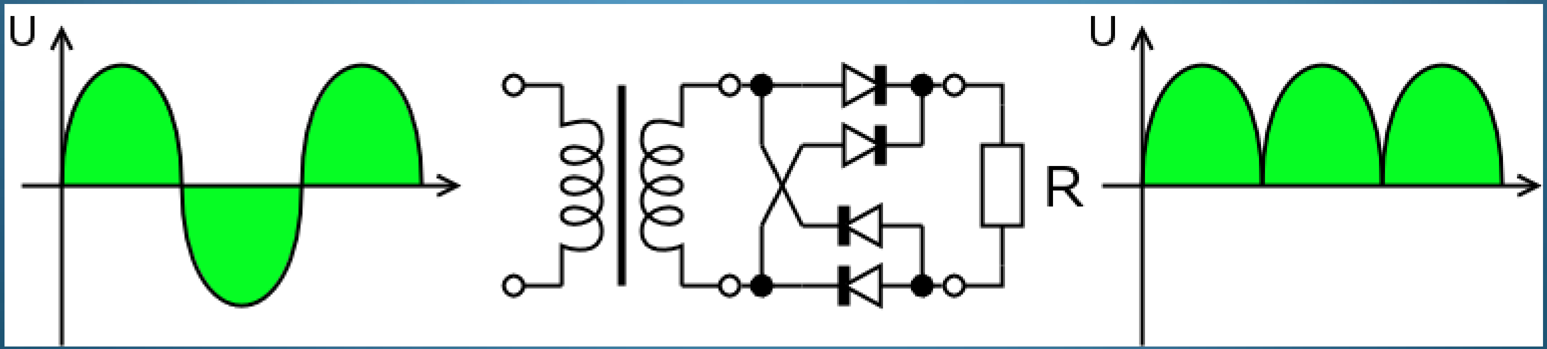
- Converts Alternating Current to Direct Current
- Two basic types:
  - Half-Wave
  - Full-Wave
- Two modes of operation:
  - Uncontrolled
  - Controlled
- Used throughout industry, commerce and domestic installations

Half Wave and Full Wave

- Half-Wave:

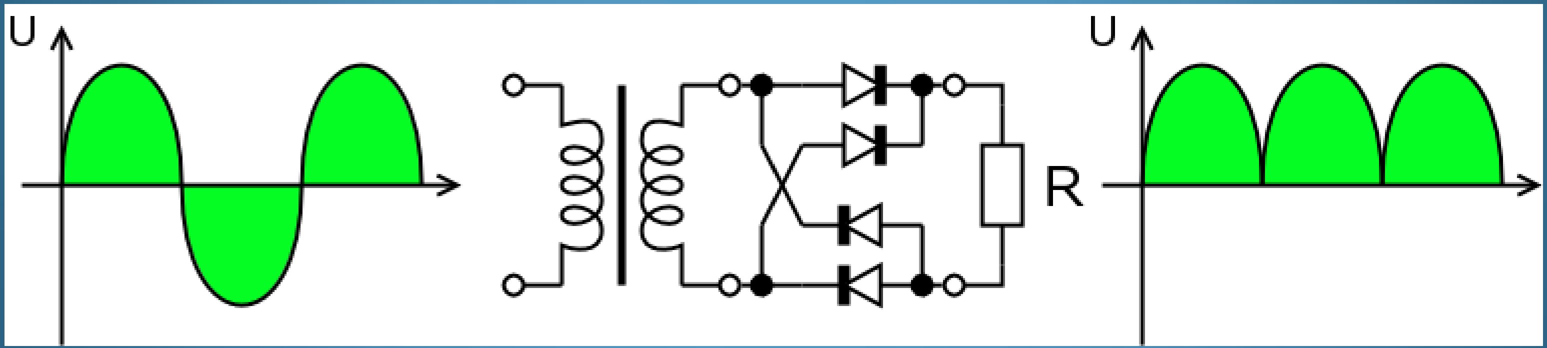


- Full-Wave:



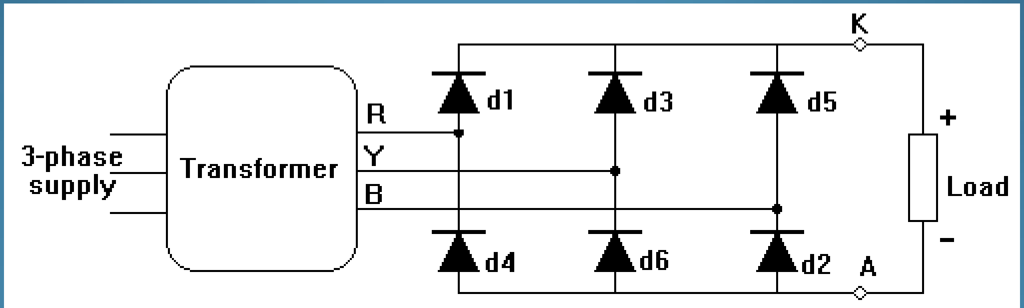
Uncontrolled Rectifier

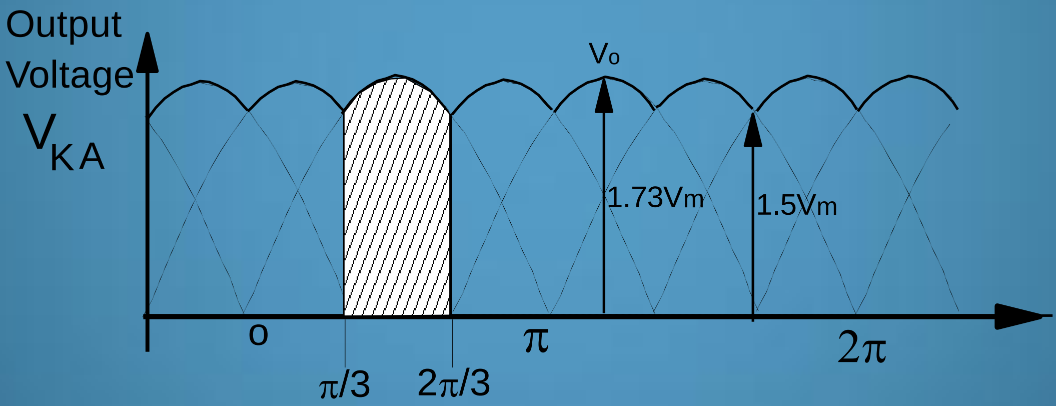
- Diodes conduct when cathode (K) voltage is greater than the anode (A).



- Governing Equation:
- Single-Phase supply $E_{DC} = 0.9E_{AC}$

Three-Phase Uncontrolled rectifier

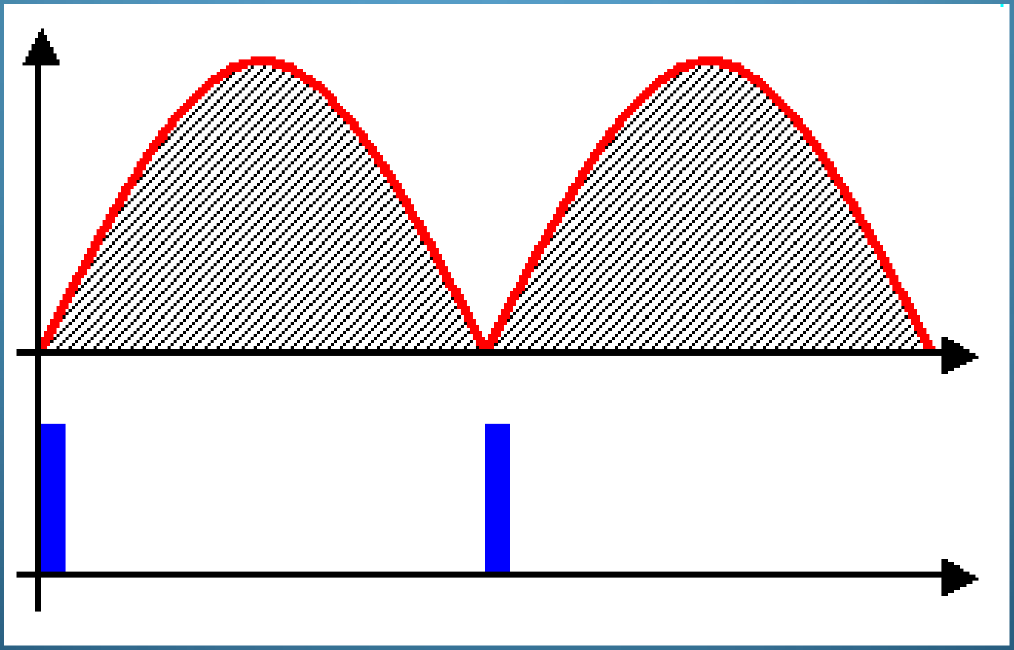




- Governing Equation:
- Three-Phase Supply: $V_{KA} = 1.35E_{AC}$
- or $E_{DC} = 1.35E_{AC}$

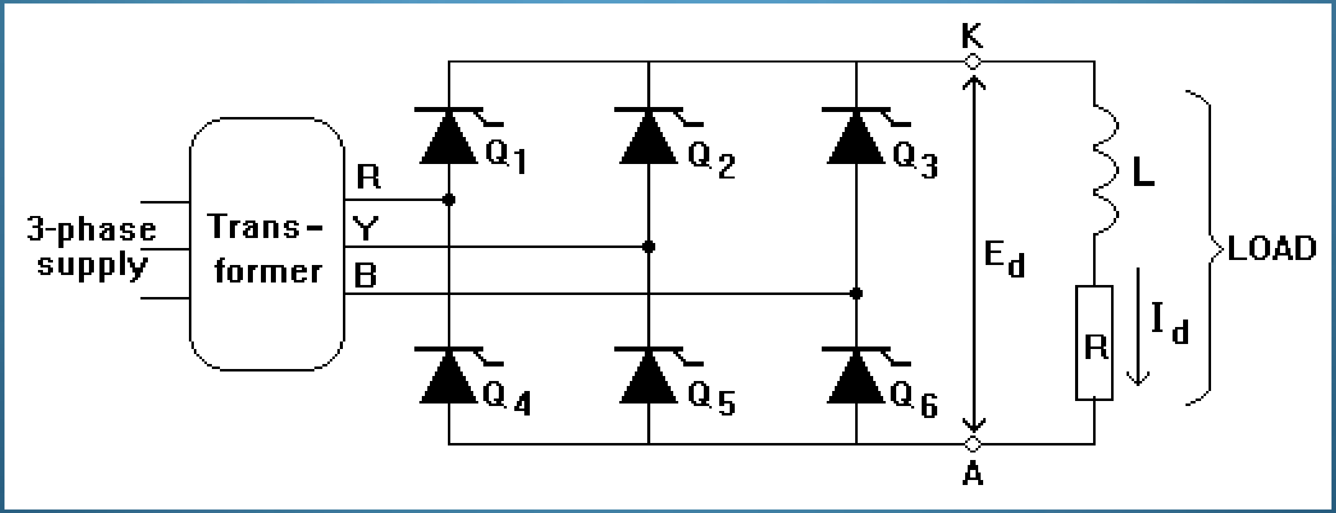
Controlled Rectifier

- Transistors or Thyristors instead of Diodes
- Timed switching, controls output D.C. Level
- Single-phase supply $E_{DC} = 0.87 E_{maxAC} \cos(\alpha)$
  - where α is the firing angle of the thyristor



3-phase Controlled Rectifier

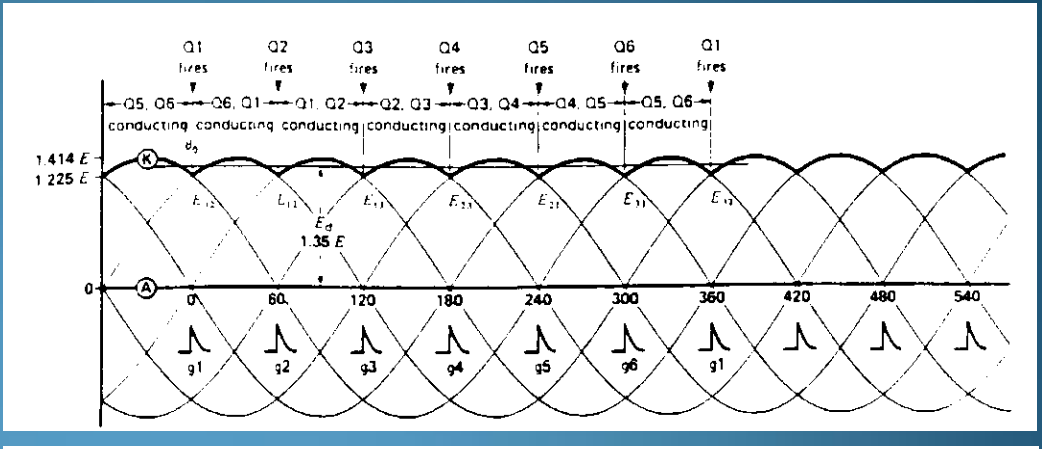
- Three or Six Thyristors instead of Diodes
- Governing Equation
- $E_{DC} = 1.35\ E_{AC} \cos(\alpha)$



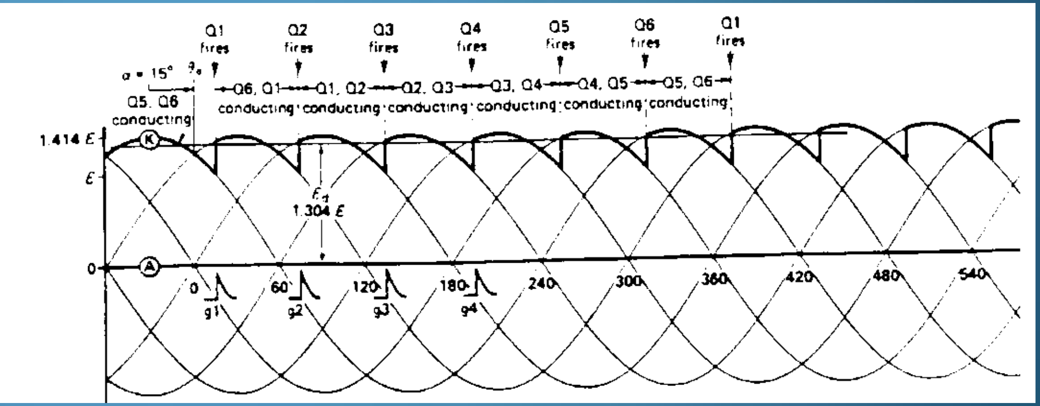
Firing Angle Control

- Increasing firing angle:

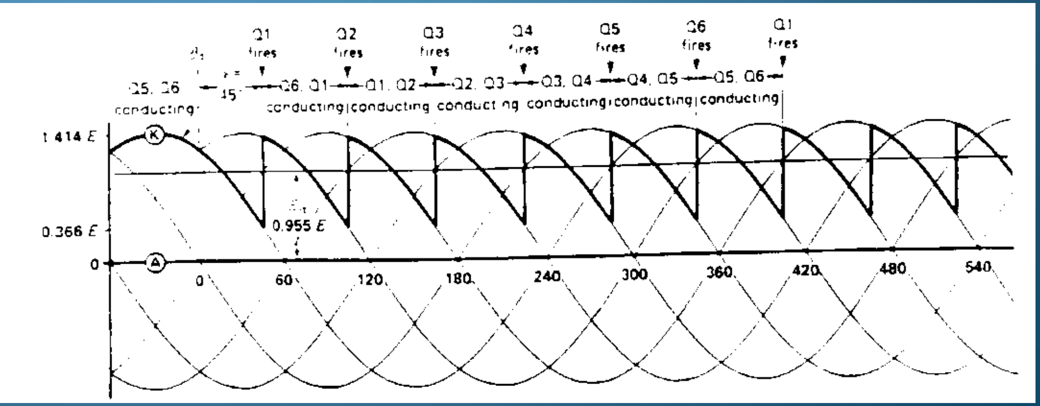
0°



15°



45°



Rectifier Arrangements

- Simple Uncontrolled Bridge >

- Power Rectifier >

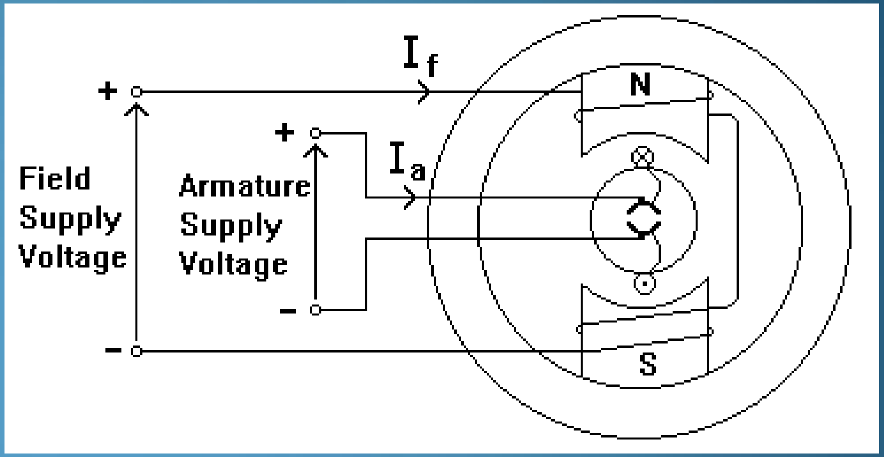
DC Motors

DC Machine (Motor)

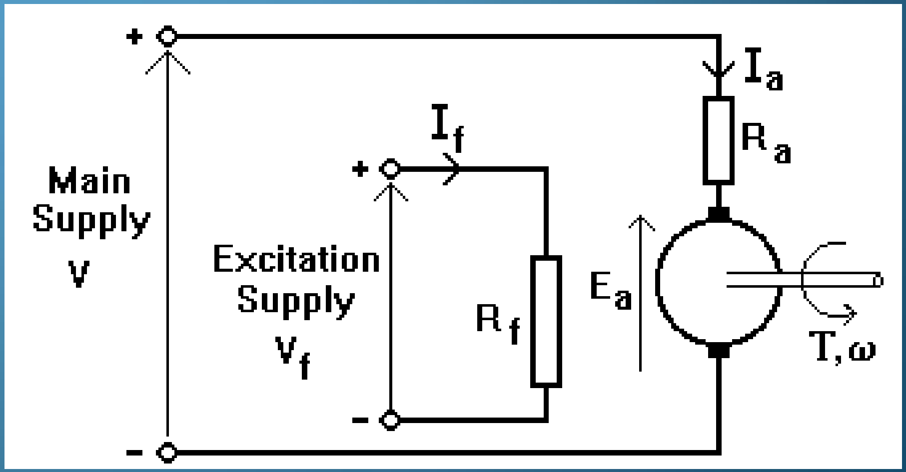
- Comprises two windings (coils) through which current flows:
  - Armature (has resistance R_a and current I_a)
  - Field (has resistance R_f and current I_f)
- Different characteristics of motor due to the connection arrangement of the two windings:
  - Shunt
  - Series
  - Separate
  - Compound (cumulative or differential)

Separately Excited

- Schematic Diagram:



- Equivalent circuit:



Governing Equations

- Basic Eq^n : $E_a = V - I_a.R_a$ and $V_f = I_f.R_f$
- Proportionality :
  - $T \alpha \phi.I_a$ and $E_a \alpha \phi.N$
- Also flux $\phi \alpha I_f$ thus
  - $T \alpha I_f.I_a$ and $E_o \alpha I_f.N$
- Vary voltage (field or armature) to vary speed
- Reverse voltage – reverse speed

DC Motor Constants

- Constant **k** associated with the machine internal arrangement:
  - – Number of coils (z)
  - – Number of pole pairs (p) – (no. of poles/2)
  - – Coil arrangement (c)
    - 2p for lap wound
    - 2 for wave wound
- k = (z.2.p)/(60c)
- Hence: $T = k.\phi.I_a$ and $E_a = k.\phi.N$
- Also flux $\phi = k_{mag}I_f$ where k_{mag} is the flux/amp.

DC Motor Power

- A motor converts electrical energy to mechanical energy
- Equating the previous proportional relationships:
- Electrical $E_a.I_a = T.\omega$ Mechanical

- Note: This is the developed power of the motor
- The output power is less,
  - due to mechanical efficiency
  - i.e. Friction and windage losses

Gearboxes

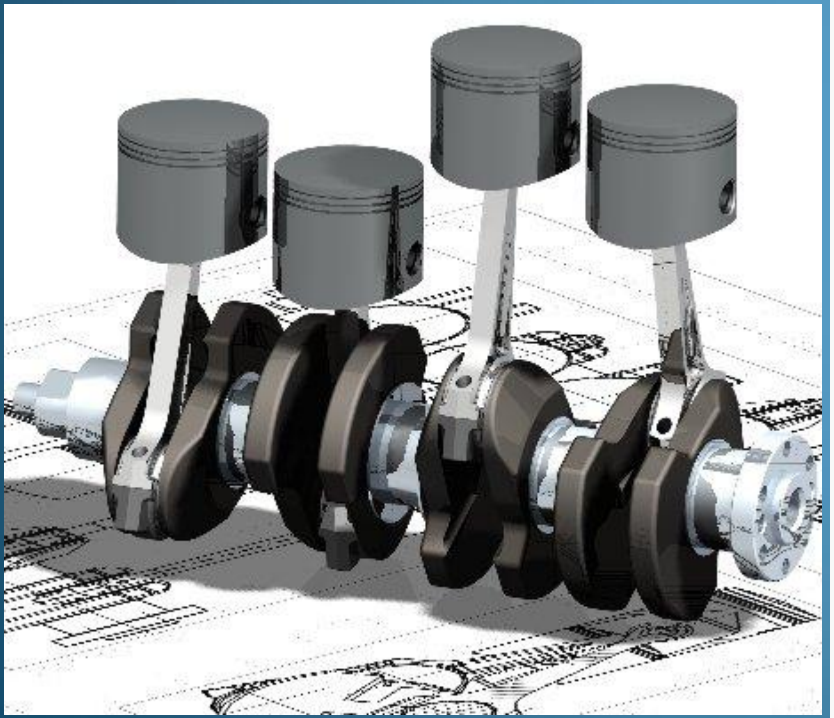
- Devices to change speed, direction and or alignment.

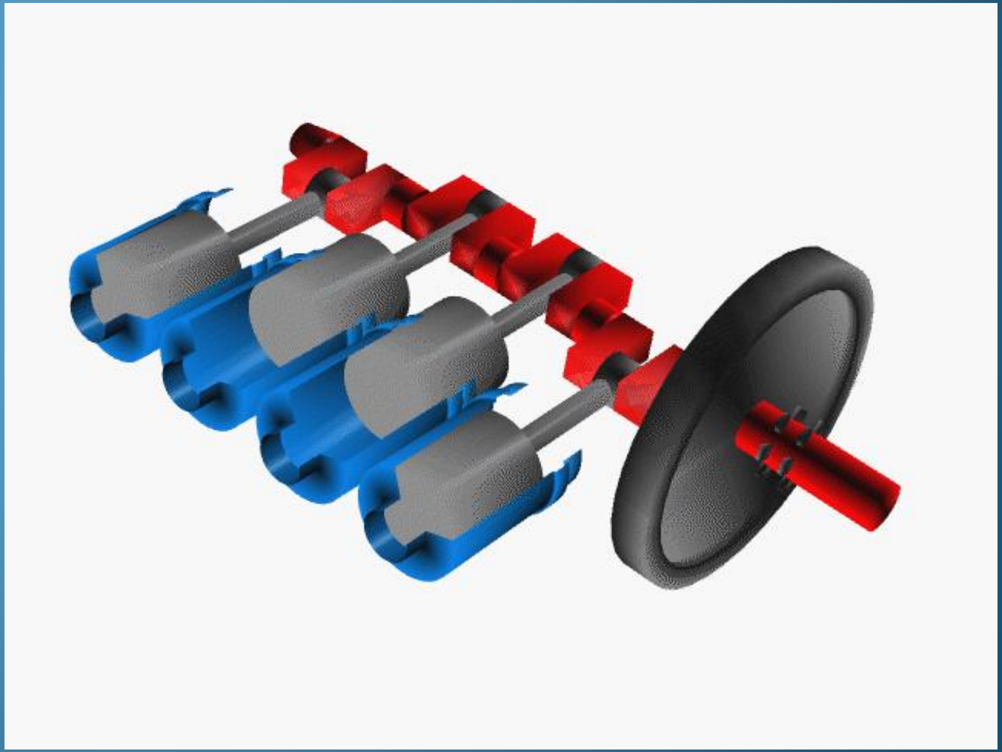
Gearbox Equation

- The gear ratio (e.g. 3:1) is the ratio of input/output speed
  - also the inverse ratio of gear teeth on the gearwheels
  - and the inverse ratio of input/output torque
- In an ideal gearbox Power in = Power out
- When efficiency is less than 100%, power out and output torque are reduced
  - but speed remains the same!

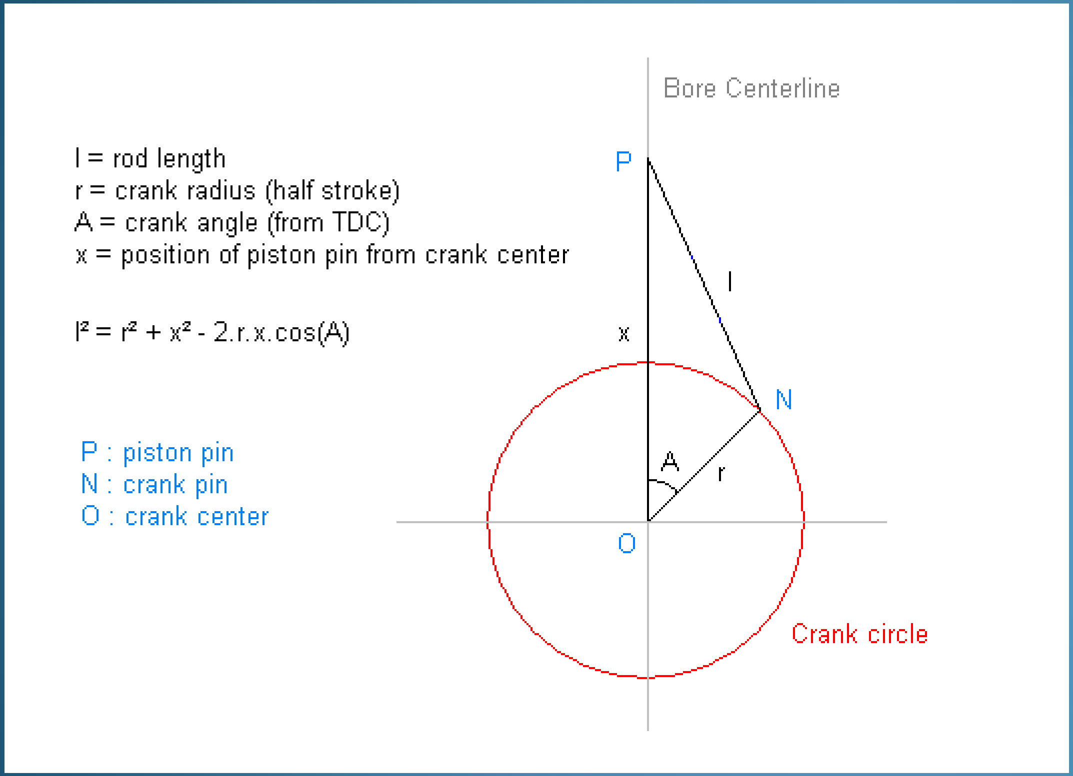
Crank Shaft

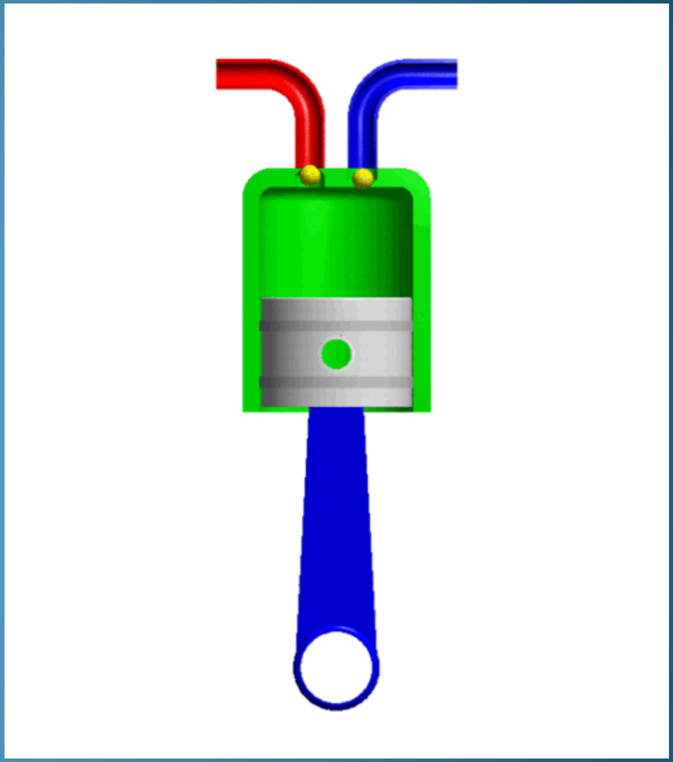
- Physical connection between a rotating shaft and a reciprocating piston





Camshaft Geometry

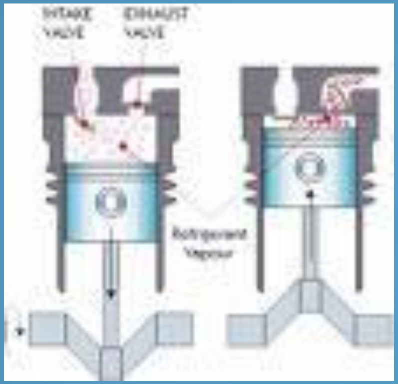




- Relationships associated with displacement, velocity and acceleration can be developed from this diagram

Reciprocating Compressor

- Device that uses pistons to compress fluid



- Operation depends on camshaft speed, physical dimensions of the pistons, fluid intake conditions and Gas Laws

Properties

- Pressure (p) in bar or Pa
- Temperature (T) in degrees Kelvin (K)
- Gas Constant R in (Nm/kgK)
- Polytropic index (n) – characteristic of fluid
- Mass flow rate (m) in kg/min
- Volume flow rate (V) in m^3/min
- Stroke (l) - length of piston in metres
- Bore (d) – diameter of piston in metres

Governing Equations

$$Piston\ Volume = \frac{\pi}{4} d^2 l$$

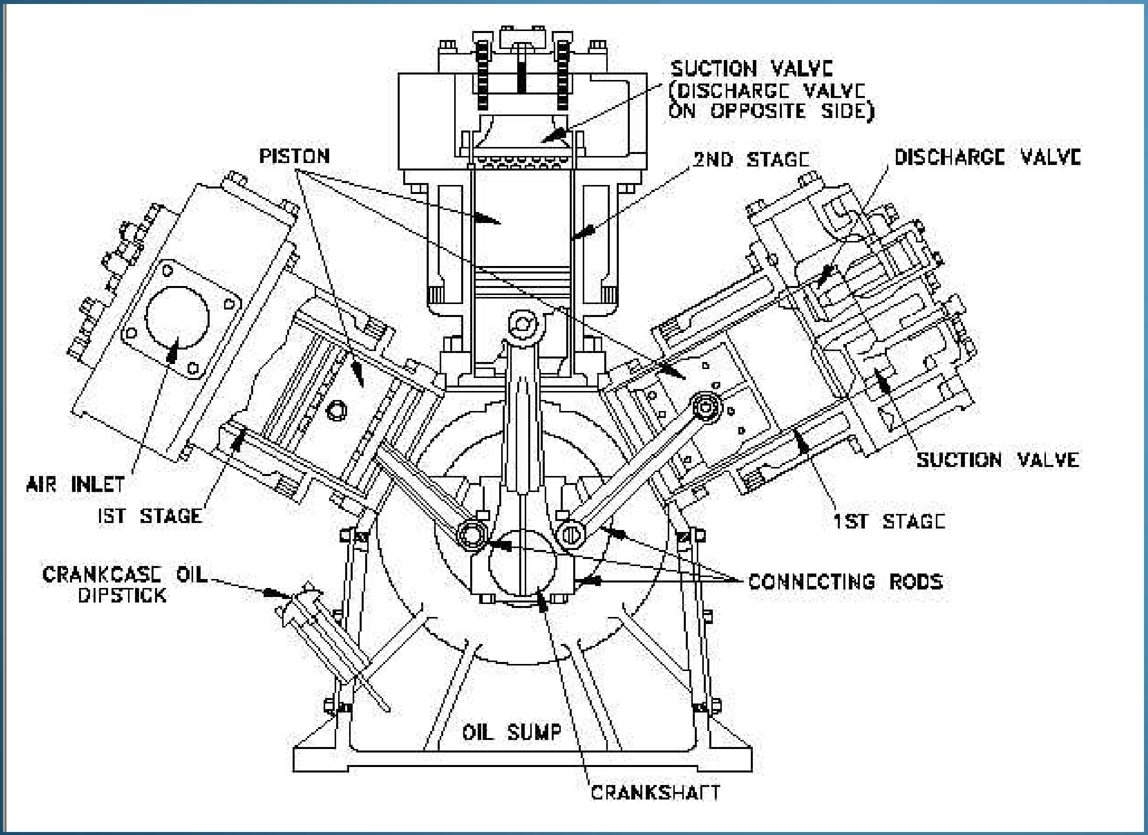
$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{(n-1)}{n}}$$

$$PV = \dot{m}RT$$

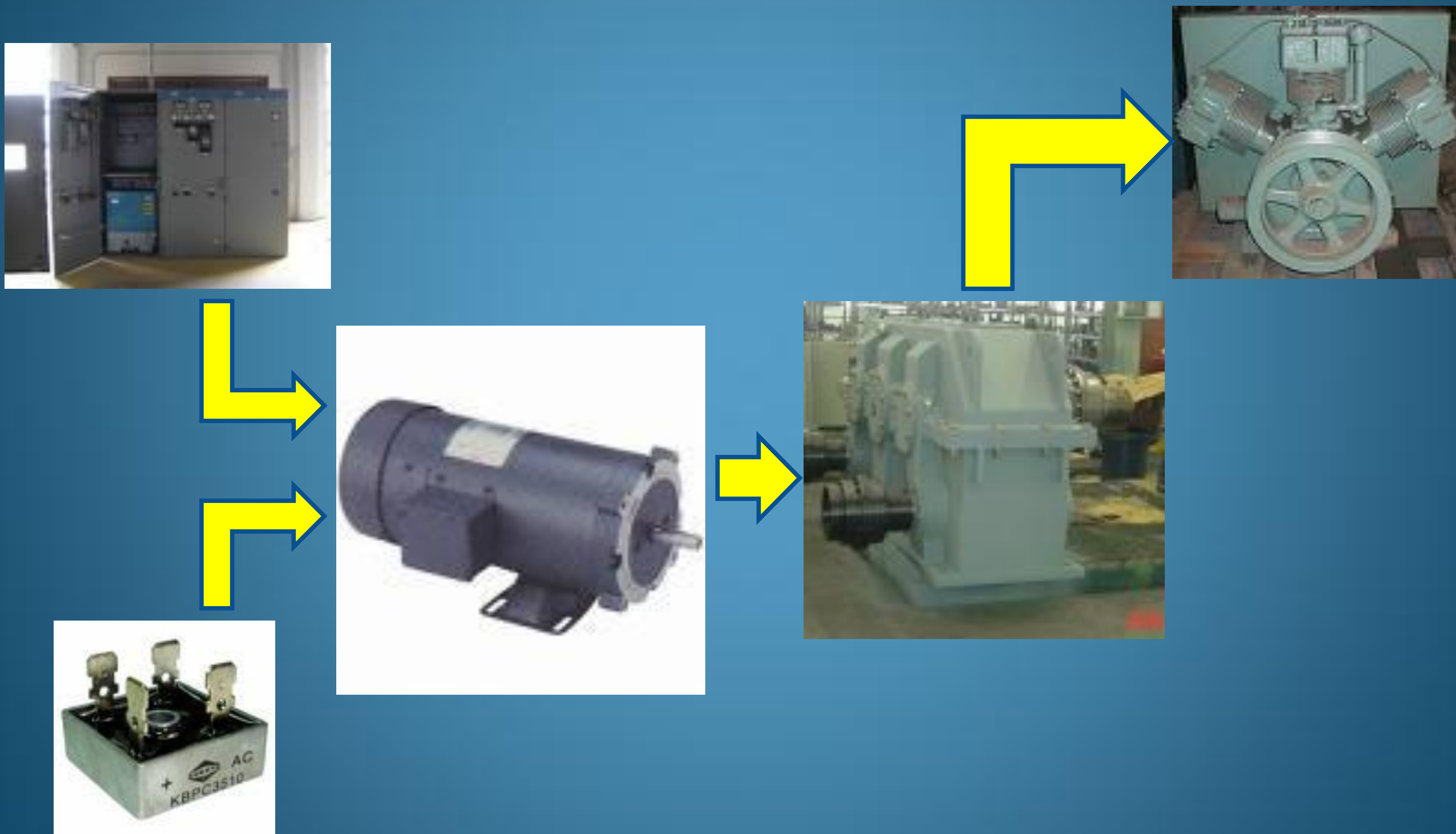
$$indicated\ work = \frac{n}{n-1} \dot{m}R(T_2 - T_1) \quad kJ/\mathrm{min}$$

Reciprocating Compressor

- V arrangement



Complete System



Assignment

- For rectifier firing angles from 0° to 60° determine:
  - Motor speed and output torque
  - Compressor mass flow rate
  - Compressor output temperature and pressure
- Use plot(s) to show the variation of these with firing angle of the rectifier.

Equipment Details

- AC Supply
  - 415V, 3-phase, 50 Hz

$$Note \quad V_{1-phase} = \frac{V_{3-phase}}{\sqrt{3}}$$

- Motor
  - 6-pole, lap-wound separately-excited
  - R_a= 0.2 Ω, R_f =200 Ω
  - Mechanical efficiency = 95%
  - k_{mag} = 0.2 Wb/A
  - I_a = 80 A at full volts (0° firing angle)
    - assume I_a varies in proportion with E
  - Number of conductors = 720

Equipment Details

- Gearbox
  - Gear ratio 3:1
  - Efficiency = 92%
- Compressor
  - Efficiency = 90%
  - 2 cylinder each with a bore of 200 mm
  - Stroke/bore ratio = 1.9:1
  - Intake at atmospheric conditions 1.013 bar, 15°C
  - R= 287 (Nm/kgK) and n = 1.35