ELECTRICS 1 – BASIC DIRECT CURRENY THEORY

ELECTRIC CHARGES

- Electron = -- ve
- Proton = + ve
- Neutron = No charge

- Usually electrons and protons are equal and the atom is in equilibrium.
- **Ionization** upsets the balance of electrons and atom ends up with a **net charge**.

CONDUCTORS & ISULATORS

- The outer shell = **Valence sheet** and the electrons within are **valence electrons.**
- Few valence electrons = **conductor**
- Lots of valence electrons = **insulator**
- Approx 4 = **semi-conductor**

TYPES OF DRIFT

- **Random drift**
- **Directed drift** (electron flow)
- Electron Flow = -- VE to + VE
- Conventional Flow = + VE to - VE

ELECTRICAL CURRENTS

- $\textbf{Ampere} = \frac{\textbf{Coulombs}}{\textbf{Seconds}}$
- The coulomb = 6.25 x 10^{18} electrons.
- I = Q / t
- **Ammeter** connected **in series.**

ELECTRICAL FORCE

- **EMF / potential difference**
- **Potential is always present** even if circuit is open (eg/ waterfall and dam)
- **Voltmeter** connected in **parallel**
- Voltmeter must have **high resistance.**
- Has symbol V or U. Measured in volts.

RESISTANCE

- **Specific resistance** is the resistance offered by a cube of material at 0^0C. This allows for comparisons of materials.
- **Conductance** is the reciprocal of resistance.

$$\textbf{Resistance} = \frac{\textbf{Length}}{\textbf{Cross Sectional Area}} \textbf{ x Spec R } (\boldsymbol{p})$$

- **Positive temperature coefficient =** resistance increases with temp increase (most conductors).
- **Negative temperature coefficient** found in insulators and semi-conductors.

- Resistors in series: $R_T = R_1 + R_2 + R_3$
- In parallel: $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

- More resistors, when added in parallel, will cause total resistance to decrease and current increase (assuming V is constant).

OHM'S LAW

- V (Voltage) = I (Current) x R (Resistance)

KIRCHOFF'S LAWS

- **1st Law** = Sum of the currents entering a junction must equal sum of currents exiting.

- **2nd Law** = In any closed circuit the sum of the voltage drops equals the supply voltage.

POWER (WATTS)

- $P = V \ x \ I = I^2 R = \frac{V^2}{R}$

WEATSTONE BRIDGE

- When the circuit is balanced the galvanometer (very sensitive ammeter) reads zero.
- R1 x R3 = R2 x RX

FINDING VOLTAGE DROP

$$V_1 = \frac{R_1}{R_T} \times V_T$$

ELECTRICS 2 – AIRCRAFT WIRING AND PROTECTIONS

DIPOLE / TWO – WIRE SYSTEM

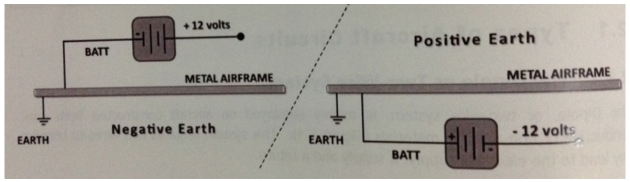
- Mainly used on aircraft constructed from **non-conductive / non-metallic materials.**

UNIPOLE SYSTEM

- **A.K.A: Single Pole / Earth Return System**
- **Metallic airframe** acts as the return path between load and the power source.
- **Reduces wiring** and saves space
- **Low resistance** – Due to big cross section
- **Saves weight**
- **Easier to trace** origin of wiring faults.
- **Short circuits** are more likely however.

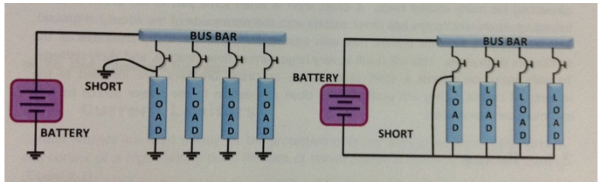
COMMON REFERENCE POINT

- Earth is always 0 V
- If earth is at – ve terminal:
    - **"Negative Earth"**
    - + ve battery terminal is 12 V
- If earth is at + ve terminal:
    - **"Positive Earth"**
    - - ve battery terminal is -12 V
- In either case, the **PD is still 12 V** (not +12 V or – 12V)



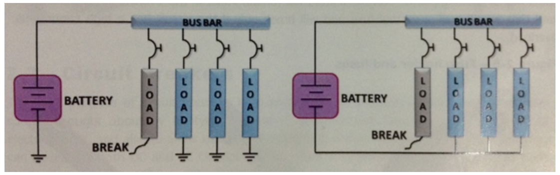
SHORT CIRCUITS

- Occurs when the **load is bypassed**.
- Extremely **high current** will flow due to negligible resistance.
- Can cause damage to circuit / burn cables / cause a fire.



OPEN CIRCUITS

- When there is a **break in a conductor.**
- Load becomes **inoperative** like opening a switch.



FUSES

- **Spare Fuses** - 10% with a minimum of 3 for each rating.
- **Rated in amperes (A)**
    - The amp capacity of device to be protected should be checked before installing.
- Constructed of a low melting point filament in a glass or ceramic envelope.
- Located as **near to the supply** as possible.
- Only ever replace **once** in flight.

CIRCUIT LIMITER

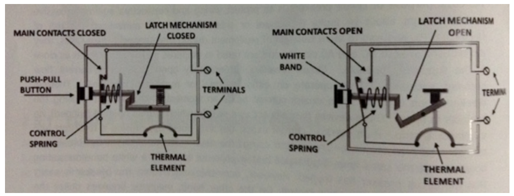
- Will allow for a **high transient load.**
- Only breaks with high **continuous** overload.
- Normally used to protect heavy duty circuits such as the bus bar.
- Constructed of a high melting point filament in a ceramic housing.

CIRCUIT BREAKERS

- Can be **reset** so no spare fuses required.
- Can be used as switches to aid in **diagnosis**
- When popped, a **white band** will show.
- Protects system in event of overload / overheating. Fitted in series.
- Can be used in both AC & DC circuits.
- Can be **thermal (bi-metallic)** or **magnetic**.
    - Magnetic is quicker to respond as it does not rely on heating.
- Thermal CB protects the system in the event of a **prolonged** overcurrent (delayed due to time taken to heat bi-metallic strip)
- CB should **only be re-set if necessary for safe flight and landing and fault has been rectified.**
- Only **one reset** should be attempted.

NON – TRIP FREE CB

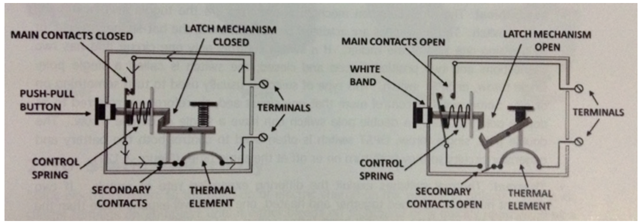
- The CB can be **held in against the fault** however which can cause damage.



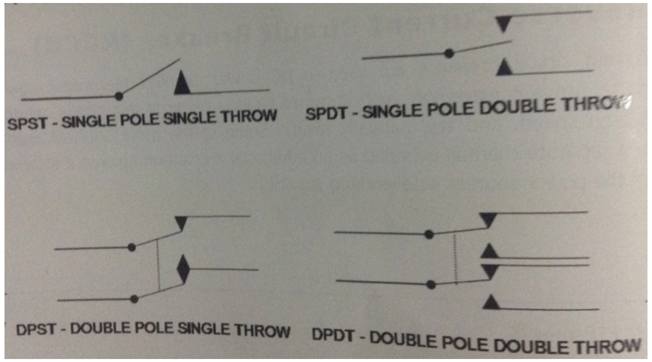
ELECTRICS 2 – AIRCRAFT WIRING AND PROTECTIONS

TRIP FREE CB

- **Secondary contact** prevents early re-set.
- It is not possible to hold the contacts closed while current fault exists.



MECHANICAL SWITCHES



STATIC ELECTRICITY

- **"A build up of electrical charge on the surface objects."**
- Occurs when electrons are transferred between materials. A.K.A **Tribolectric effect.**
- Most likely in **dry / low humidity air** or in **extreme turbulence.**

CAUSES OF STATIC ELECTRICITY

- **Friction** (Skin & Propellers)
- **Lightning**
- **Electrical circuits & equipment**

EFFECTS OF STATIC ELECTRICITY

- Materials **attract / repel** each other.
- **Sparks** and associated fire risk.
- **'Pitting'** of materials leading to corrosion.
- **Interference** with radio equipment.
- **St Elmo's Fire**

BONDING

- Bonding is the **connection of two or more metallic objects by means of a conductor.**
- Achieved using **bonding strips.**
- Creates a **faraday cage**.
- A electrical path of **negligible resistance** is created throughout the structure.

PURPOSE OF BONDING

- **Equalising of static charges / potential**
- **Provide a single earth for unipole system**
- Safe transmission of **lightning discharges**
- Reduce **interference** (sign of poor bonding)
- **Prevention of electric shocks**
- **Prevention of static discharges** (fire haz)
- **Provides safe distribution of electrical charges and currents**

GROUNDING

- **Will equalise the airframe to 0V** and remove the static charge that has built up during flight.

STATIC DISCHARGE WICKS

- If a static charge on the aircraft fails to dissipate, **corona discharge** occurs. (Min radii / causes glow + interference)
- Static discharge wicks on the trailing edges:
  - Safely dissipate static charges
  - Minimise radio interference
  - Limit risk of transfer of electrical charges between aircraft and electrified clouds.

LANDING PROTECTION

- Earthing strips or semi-conductive tyres are used to **eqaulise to earth potential**.

LIGHTNING STRIKES

- Some components may become **magnetised** if struck and compass becomes inaccurate.
- Some **electrical systems** may also fail.

SCREENING

- Enclosing of cables in a **continuous metal sheath** to reduce radio interference.

ELECTRICS 3 – BATTERIES

HOW A CELL WORKS

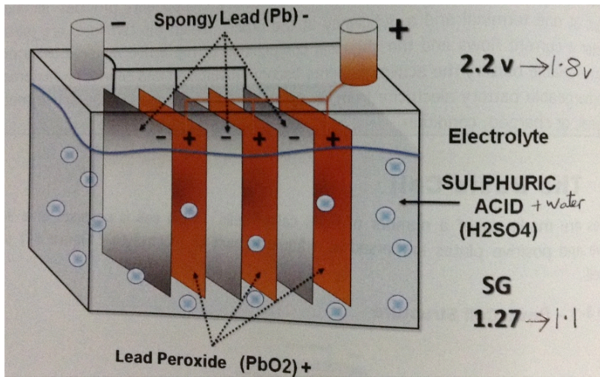
- **Reduction –** Loss of electrons at cathode (+)
- **Oxidation –** Gain of electrons at anode (-)
- Reduction / oxidation caused by **electrolyte**
- PD exists as electrolyte is a conductor
- EMF reduced as deposits build up.
  - Tendency for voltage to decrease under load when almost fully discharged.
- Recharged = **DC of slightly higher voltage**

CELL TYPES

- **Primary Cell –** Not rechargeable (10 mins)
  - Used for emergency lighting
- **Secondary Cell –** Rechargeable (30 mins)
  - Used for aircraft batteries

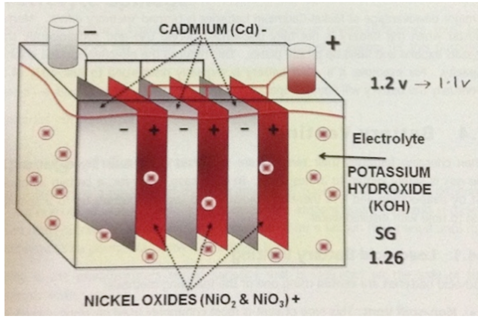
LEAD-ACID

- **Deposits** = Lead Sulphate
- **Spillage =** Bicarbonate of Soda
- **Charging =** Constant Voltage Method



ALKALINE CELL / NiCad

- **Deposits** = Cadmium & Nickel Hydroxide
- **Spillage =** Boric Acid
- **Charging =** Pulse Charging (Faster than LA)
  - Risk of thermal runaway



ALKALINE VS LEAD-ACID

- **Lead-acid have insufficient capacity and are volume and weight inefficient.**
- Alkaline has a **more stable voltage output before a rapid discharge.**
- Alkaline suffer from the **memory effect.**
- Alkaline **weighs less** than lead –acid => most commonly used.
- Wider permissible temperature range
- Good storage capability
- Sturdiness owing to metal casing

BATTERY CAPACITY

- Measure of the **total energy it contains**
- Depends on **size and number of plates**
- Measured in **ampere hours (Ah)**
- **Ah = A x h**
- **Actual capacity** checked every 3 months.
  - Must be 80% + of **rated capacity**
- Typical capacity in aviation 12- 18 Ah

BATTERY VENTING

- Used to remove / contain **volatile hydrogen gas** given off during charging due to temperature increase.
- Water lost by evaporation must be topped up from time to time with **distilled water**.
- **Lead-Acid Venting:**
  - Non-Spill Vent (Prevents electrolyte spillage during maneuvers)
  - Cell Cross-Flow System (passes cabin pressurisation air over top of cells)
  - Sealed Batteries (aerobatic / military)
- **Alkaline Venting:**
  - Semi-Open (uses Cross-Flow System)
  - Sealed Batteries

THERMAL RUNAWAY (DURING CHARGING)

- Temp Inc ---> Internal Resistance Decreases ---> Current Increases ---> Temp Inc
- Indicated by a significant increase in battery temperature.

ELECTRICS 3 – BATTERIES

COLD TEMPERATURES

- **Reduces the capacity** of the battery.
- Constant charge / thermal blanket
- A fully charged lead-acid battery is less likely to freeze in cold temperatures.

SERIES VS PARALLEL

- **In Series -** Add voltages, capacity the same as one.
- **In parallel -** Add capacities, voltage the same as one.

- Charge state is ascertained by comparing on-load and off-load battery voltages.
- In a lead-acid battery, this can also be done by measuring the SG of the electrolyte.

BROKEN CELLS

- If one of the cells within a Lead-acid battery has a broken connection, it is rendered unserviceable.
  - Since cells are connected in series.

BATTERY CONTROL UNIT

- Isolates battery from bus when:
  - Battery charge has been completed
  - Battery overheat condition occurs
  - Internal short circuit occurs

BATTERY PURPOSE

- One of the main functions of the battery in large transport aircraft is to be an emergency source of electrical power.

ELECTRICS 4 – MAGNETISM & ELECTROMAGNETISM

THEORY OF MAGNETISM

- A static electron will be surrounded by an **electrostatic field.**
- A moving electron (spins round its own axis) produces a **magnetic field.**
- The electrostatic field is at **right angles** to the magnetic field.
- This combination forms an **electromagnetic field.**

LOADSTONE

- Other than earth, loadstone is the only **natural magnet.**
- All other magnets are produced artificially.

MAGNETIC FLUX LINES

- **Originate from NP and go to SP.**
  - This property of direction = polarity
- **Within the magnet flux lines run from SP to NP.**
  - This provides for a complete loop.
- Flux lines **never cross** each other.
- **Flux density is greatest inside** the magnet.

CUTTING A MAGNET

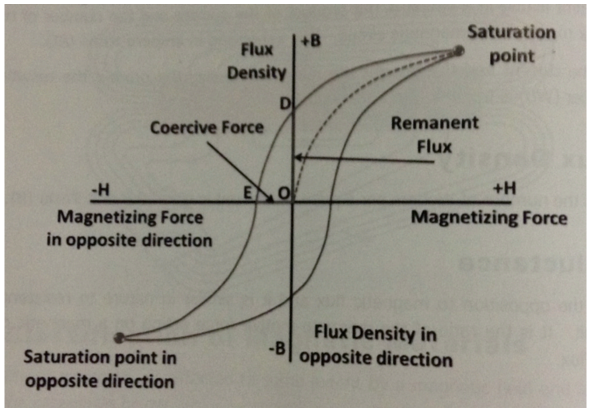
- Each individual piece forms a complete magnet although strength is decreased.

DOMAIN THEORY

- In an **unmagnetise**d metal, domains are **randomly arranged** and the overall field is zero.
- When subjected to a strong magnetic field, the domains **line up** and the metal becomes a magnet.

FERROMAGNETISM

- The property of a material **enabling it to become a magnet** when placed in a magnetic field.
- **EG/ Iron, Cobalt & Nickel**
- **Soft Iron** (Temporary Magnet)
  - Easily magnetized
  - Easily looses magnetism
- **Hard Iron** (Permanent Magnet)
  - Hard to magnetise
  - Retains magnetism very well

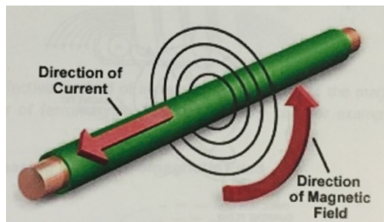


HYSTERISIS (LAG) LOOP

- When a magnet can no longer accept magnetism, it is said to be **saturated**.
- Once a material has been driven to saturation (max flux density), the magnetizing force can be removed but the material will retain most of its flux **(remanent flux).**
- A **coercive force** (reversing the magnetizing force) must be applied to remove the flux.
- Flux density **lags behind** the changing values of magnetizing forces.

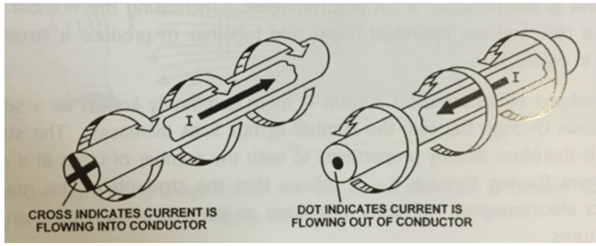
MAGNETISM & CURRENT FLOW

- When current flows through a conductor, a magnetic field is produced around the conductor.
- **Magnitude ∞ Current Flow**
- **Right hand grasp rule:**
  - Thumb = Direction of current flow
  - Fingers = Direction of magnetic field



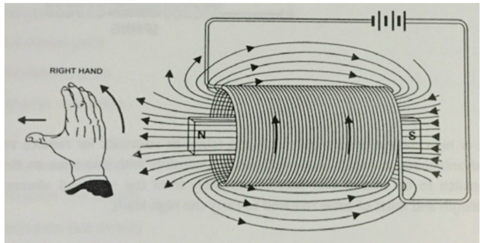
ELECTRICS 4 – MAGNETISM & ELECTROMAGNETISM

DIRECTION OF CURRENT FLOW



COIL

- When a wire loop is created, there is a **greater flux density in the centre of loop.**
- Multiple loops can be used to form a **coil.**
- A coil takes on the same properties as a permanent magnet with **polarity**.
- Unlike a normal magnet, this can be **turned on and off easily.**
- Options for making the **magnet stronger:**
  - More current
  - More loops
  - Soft iron core
- **Determining polarity of coil:**
  - RH Fingers = Direction of current flow
  - RH Thumb = Direction of NP

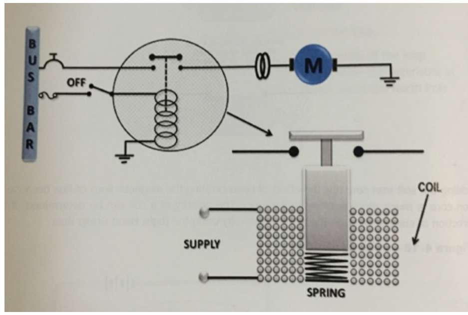


RELAY

- A relay is an **electrically operated switch**
- An electromagnet is used to operate a **hinged switching mechanism.**

SOLENOID

- A relay that can handle **high power**
- Differs from relay by using a **plunger type switch**
  - Contains a moving soft iron bar and mechanical linkage.
- Allows control switches to be **smaller** and situated **remotely** from switched element:



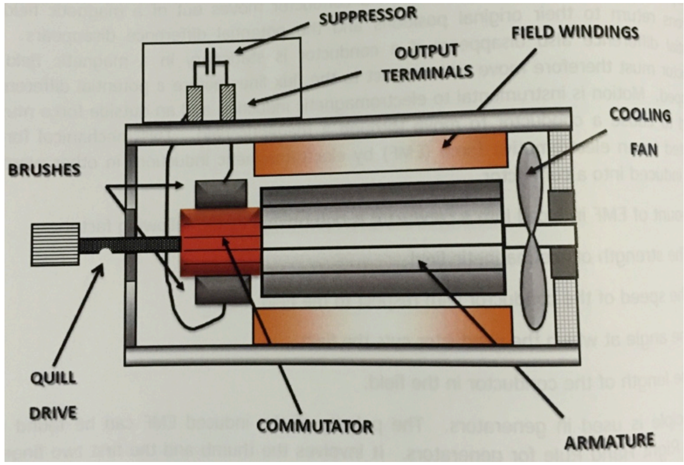
ELECTRICS 5 – DC GENERATORS

FARADAY'S LAW

- The amount of EMF induced depends on:
  - **Strength** of magnetic field.
  - **Angle** at which conductor cuts the field.
  - **Length** on conductor in field.
  - **Speed** of conductor with respect to field
  - A
- Strength is the most important factor.

FLEMING'S RIGHT HAND RULE

- First Finger = Field
- Centre Finger = Current
- Thumb = Motion



EMF / LORENTZ FORCE

- When a conductor cuts the field lines of a magnetic field, an EMF (Lorentz force) is induced in the conductor.

BASIC OPERATION

- **Stator** – Casing that normally remains static and contains field windings.
- **Rotor** – Contains armature and commutator and normally rotates within stator.

- Battery used to pass current through the **field winding,** inducing an magnetic field.
- The rotor is turned by the engine and a current is induced within the armature.
- Part of the induced EMF now provides the current for field windings so battery no longer required.
- The same effect occurs if the stator is rotated and the rotor held constant. It is the **relative movement** that matters.
- Conditions required to start are:
  - Presence of a permanent field
  - Minimum rotation speed

COMMUTATOR

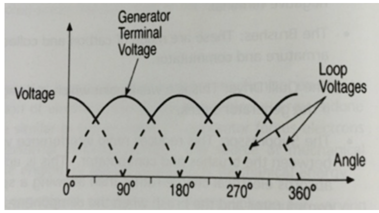
- The generator will output AC naturally.
- **A commutator** is used to **rectify** to DC.
- Contains carbon **brushes.**
- Ensures that only positive current flows to positive terminal and vice versa.

QUILL DRIVE

- Weak point designed to shear and **protect the engine** if the generator seizes.

MULTI SEGMENT ARMATURE

- More armatures can be used to provide a more stable output voltage.



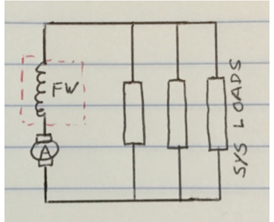
SERIES WOUND GENERATOR

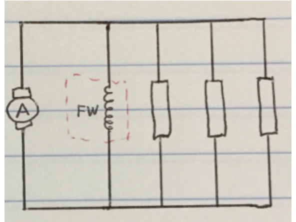
- Different arrangements exist for feeding current back to the field windings.
- In series wound, the field windings are **connected in series** with armature.
- Not normally used as **voltage is difficult to regulate.**
  - As loads connected in parallel, resistance drops when more are added.
  - Current will increase and this will be fed straight back into field wirings.
  - Voltage output increases.

SHUNT WOUND GENERATOR

- Field windings are **connected in parallel** with armature.
- Increased loads will cause a slight fall in voltage output but this is predictable.

ELECTRICS 5 – DC GENERATORS



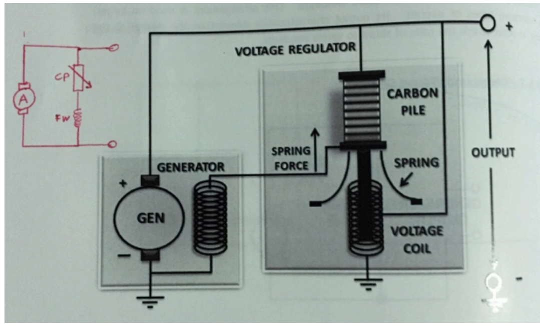


COMPOUND WOUND

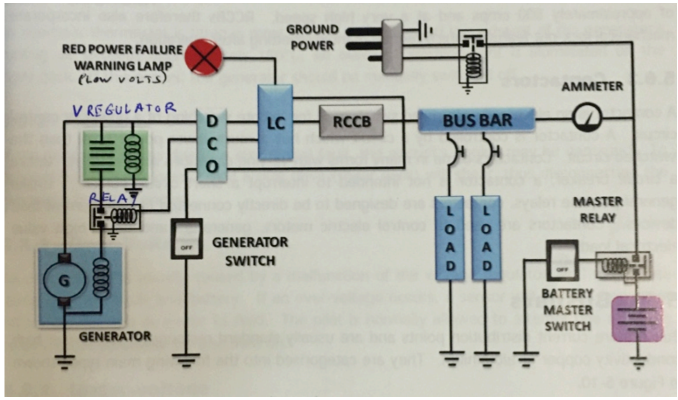
- Some field winding in series and some in parallel.
- Not widely used except on larger aircraft.

VOLTAGE REGULATOR

- As engine RPM increases, the output voltage will vary unless it is corrected for.
- Voltmeter senses circuit (output) voltage and then controls the generator output by varying the field strength.
- Uses **carbon pile** which is a mechanical variable resistor.
    - Resistance decreases when compressed and increases when expanded.
- Engine RPM increased...
    - Higher DC voltage output from gen
    - Solenoid receives more voltage
    - Carbon pile extended
    - Resistance increased and current into field wirings is reduced
    - Generator output reduced
- Carbon pile and field wirings are connected in series with each other but in a shunt wound arrangement.



SINGLE ENGINE DC SYSTEM



DIFFERENTIAL CUT OUT (DCO)

- Commands the **line contactor** (relay type switch) to join generator to bus bar once it's producing enough electricity.
- Protects the generator from battery voltage when the engine is shut down.
- Isolates the generator when a **reverse current of 20 – 30 amps** is sensed. (Will allow 11.5 V at GEN and 12 V at battery)
- A generator warning light will illuminate when GEN V < BATT V and switch is open.

REVERSE CURRENT CIRCUIT BREAKER

- In the event of a **short circuit**, protects the LC + DCO + GEN from reverse current.
- Activates when **reverse current of 300 – 500 amps** is sensed.
- **Electromagnetic** type CB (faster reaction than thermal)
- Can only be **manually reset** once tripped.

GEN OVERHEAT

- **GEN cooling fan exhaust > 160°C**
- Overheat lamp illuminates
- GEN should be manually turned on and off again after allowing it to cool.

OVERVOLTAGE

- **When voltage regulator u/s**
- Can be isolated automatically with DCO or manually with GEN switch.

AMMETER

- **Zero Left** – Reads only when generator is providing current.
- **Centre Zero** – Reads – ve when battery providing and + ve when generator providing.
    - High charge rate after start is to be expected (battery recharging) but should return to normal within a short time.

ELECTRICS 5 – DC GENERATORS

BUSBARS

- Busbars are **low resistance conductors that serve as current distribution points.** They provide a convenient means of connecting positive supplies to the various loads.
- Loads on the busbar are connected in parallel.
- They can be used to group loads according to their importance.
- In the event of generator failure, non-essential loads can be quickly turned off.

- **ESS BUSBAR** (Essential)
  - Flight Instruments
  - Compass
  - Radio
  - Cockpit Lighting
- **NON-ESS BUSBAR** (Non-Essential)
  - Galley services etc
- **HOT BAT BUSBAR**
  - Connected directly to battery
  - There is no switch for this bus bar due to the importance of the loads
  - Emergency Lights
  - Fire Extinguishers
  - Landing Gear
- **BAT BUSBAR**
  - Enough for initial check and start

INSTRUMENTS

- **Ammeter** and **voltmeter** used to monitor electrical power.
- When multiple generators are installed:
  - Ammeter for each channel
  - Single multi-channel voltmeter fitted

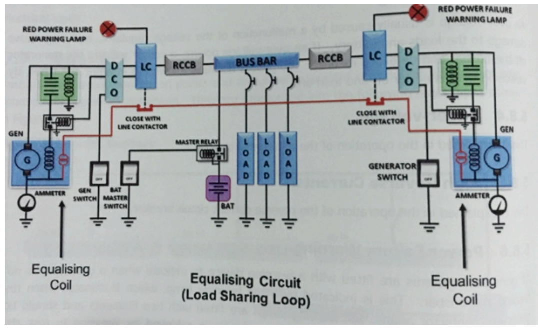
TWIN ENGINE DC SYSTEM

SPLIT VS PARALLEL

- **Split Busbar –** Each engine feeds independent busbars.
- **Parallel Busbar –** Busbars share load from each generator. This is the most common.
  - This provides max power.

LOAD SHARING

- Load sharing is required to ensure the same lifespan of each generator.
- Also provides greater redundancy.
- **Equalising coils** are installed to the voltage regulators in order to adjust their output as required by varying current in field coil.
- **A differential relay** is used to ensure the generator voltages are almost equal before they are paralleled.



GENERATOR COOLING

- Achieved using ram air.

GROUND POWER

- Short **auxiliary pin** in the ground power socket operates a **hold off relay**.
  - Disconnects GEN & BATT when ground power is in use.
  - Prevents thermal runway from overcharging battery.

FEEDER FAULTS

- On a DC circuit, results from a flux unbalance between the voltage coil and the series winding turn.

VOLTAGE REGULATOR CONT.

- If electrical load is increased, the VR will increase the intensity of the excitation current.

GENERATOR BREAKER

- Closes when voltage of generator is greater than the battery voltage.
- Opens when battery voltage is greater than generator voltage.

LOAD SHEDDING

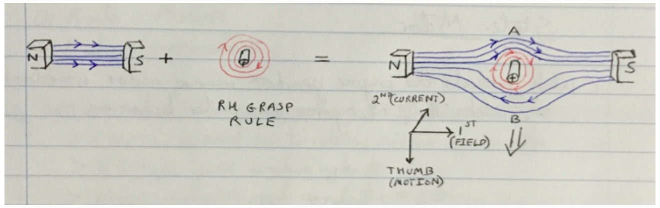
- Results in a current decrease.

ELECTRICS 6 – DC MOTORS

BASIC PRINCIPLE

- When **a current carrying conductor** is placed in a magnetic field, the **field around the conductor reacts with the magnetic field** causing the conductor to move.

- In the example below, flux density is greatest at A (both conductor field and magnetic field in same direction) so the **conductor moves down.**
- **Flemings left hand rule** (motors) used to determine direction of motion.
- **Reversing the current** would cause the conductor to move in the opposite direction.

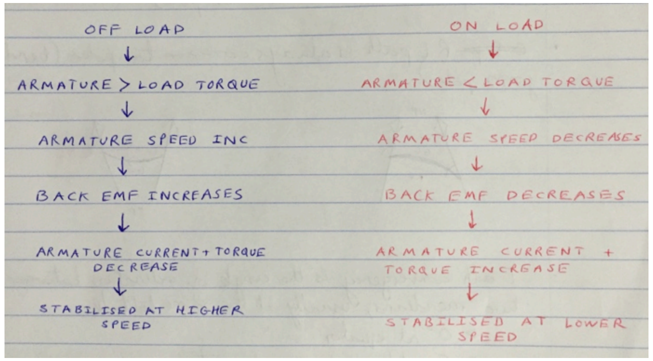


BACK EMF

- **Induced motion causes a back EMF.**
- Direction determined using Flemings Right Hand Rule (Generators)
- More current through conductor results in a stronger back EMF.

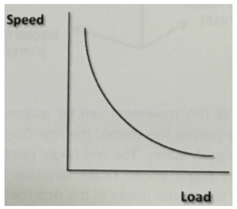
SELF-REGULATION

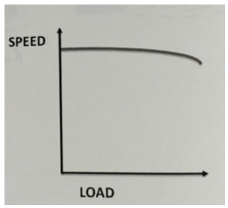
- DC motors are **self-regulating.**
- **On Load = Stabilises at lower speed**
- **Off Load = Stabilises at higher speed**



TYPES OF DC MOTOR

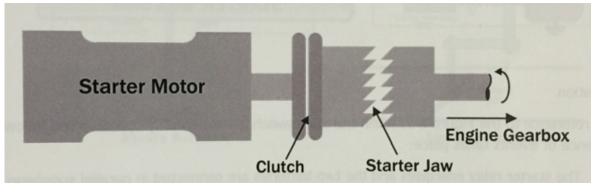
- **Series Motor**
  - When off-loaded, rpm is very high.
  - Must be started on load.
  - Ideal as a starter motor due high torque at low rpm.
- **Shunt Motor**
  - Fairly constant rom across loads
  - Used for fuel pumps, fans etc
- **Compound** (Not normally used due cost)





STARTER MOTOR

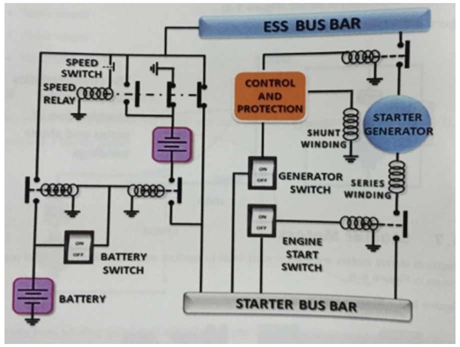
- **Frictional clutch** will slip when force from motor becomes too great.
  - Protects the engine gearbox



COMBINED STARTER / GENERATOR SYS

- Since a motor is **essentially a generator provided with current**, they can be combined into one unit.
- When both batteries are **in parallel**, 24V is delivered to the ESS BUS and 24V to the STARTER BUS.
- When batteries **in series,** 24V is delivered to ESS BUS and 48V to the STARTER BUS.
  - Starter initially starts with 24V to reduce initial torque thereby increasing it's life.
- The switching of series to parallel is done by the **speed switch.**
  - Connects in series when RPM between 10 – 60%.
- The **control and protection unit** is located in **parallel** with the generator.
  - Contains DCO + LC + RCCB + Voltage Regulator

ELECTRICS 6 – DC MOTORS



ACTUATORS

- **High-speed, reversible, series-wound motors.**
- **Convert high motor speed into a high driving torque.**
- They are essentially motors specifically designed for mechanical movement.

- Reversibility is achieved by:
  - Reversing the current through armature or field coil
  - Reversing the polarity of either the stator or the rotor.
  - Cannot do both at same time however.
- Series-wound in order to achieve **high torque initially** to overcome inertia.
- **Friction plates** (single / multi plate) must be installed to prevent damage.

- **Rotary Actuator –** Used to operate valves in air con and fuel system etc.
- **Linear Actuator –** Used to operate flaps etc

- **Limit switches** stop the motor when they read the desired setting.
  - They are normally closed to allow current flow to power the motor in the correct sense.
  - They open when the actuator reaches it's limit of travel in order to stop the motor.
- **Electromagnetic brakes** prevent over travel / undesired movement when motor is switches off.

ELECTRICS 7 – SINGLE ENGINE AIRCRAFT ELECTRICAL SYSTEM

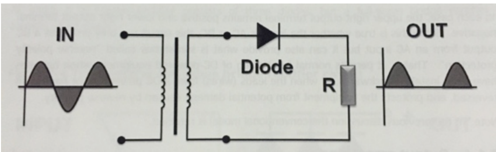
RECTIFIER

PURPOSE

- **Converts AC to DC**

HALF WAVE RECTIFIER

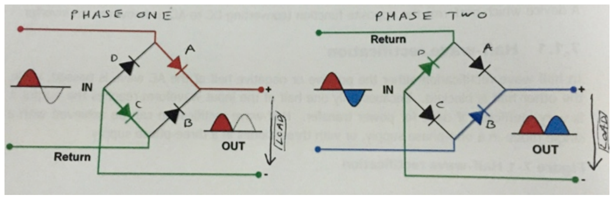
- **A diode** is used which only allows current flow in one direction.
- A **pulse DC** current is produced however which is inefficient.



FULL WAVE RECTIFIER

- **4 diodes** are used in a **diode bridge** configuration.

- In the first phase, current can only travel through diode A then through the load.
- The return path can only travel through diode C.
  - It will avoid D and B since there is already current flowing the other side of it (path of least resistance).



- In the second phase, current now enters from the lower supply terminal since AC has changed direction.
- Current can only travel through diode B and **will flow through the load in the same direction as before.**
- It can only exit through D.

OUTPUT SMOOTHING

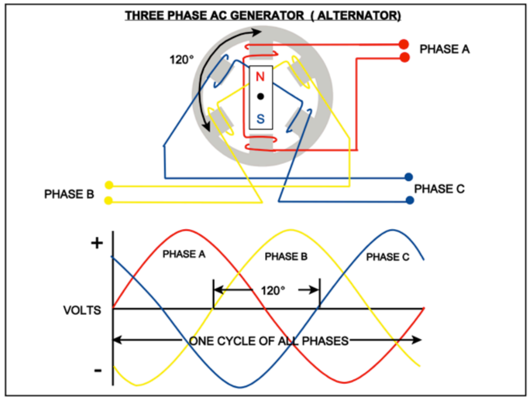
- The DC output using a full wave rectifier varies between max voltage a 0 V however.
- **A capacitor** is used to fill the voltage gaps and give a constant DC output.

ALTERNATOR

3 PHASE AC GENERATOR (ALTERNATOR)

- A more efficient way of generating electricity compared with a DC generator, is by using a 3 phase AC generator.
- Here, the **roles of the rotor and stator are reversed.**
  - Magnetic field rotates on rotor
  - Conductors (armuature) are on stator
- **3 phase rectifier** is required
  - Consists of 6 diodes
  - Only 4 diodes in use at any one time
- Capacitor is used for **output smoothing**

3 PHASE AC GENERATOR (RECTIFIER)

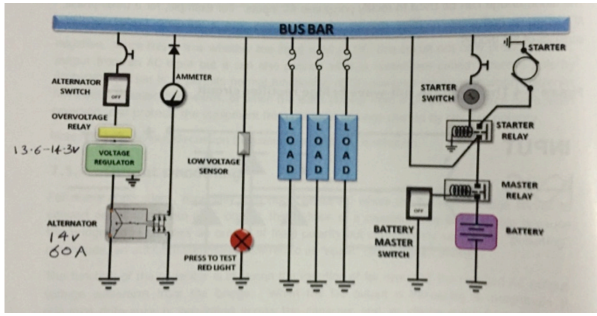


LIGHT AIRCRAFT DC SYSTEM

- Known as a **frequency wild DC system**
  - Alternator speed is dictated by engine RPM so the frequency is not regulated at a constant value.
- **Voltage regulator** will maintain an output of 13.6 V – 14.3 V by altering the current into the rotor field windings.
- **Overvoltage relay** protects loads from overcurrents.
- **A diode** is used instead of an RCCB
- **Low Voltage Lamp** – Flashes when the output voltage drops below 13.6 V
- **ALT Light** – Illuminates when alternator is offline.
- The rotor is driven by a **drive belt** so in the event of alternator seizure the engine is protected.

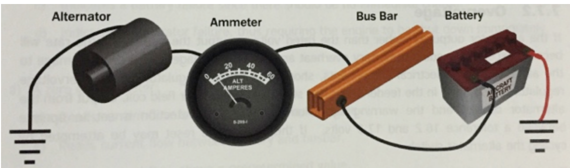
ELECTRICS 7 – SINGLE ENGINE AIRCRAFT ELECTRICAL SYSTEM

LIGHT AIRCRAFT DC SYSTEM

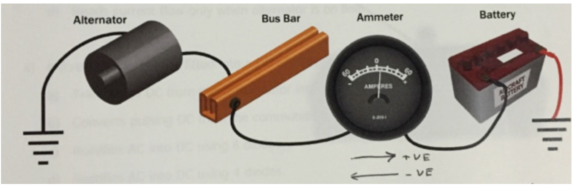


AMMETER

- **Zero-Left / Loadmeter**
  - Measures the output current from the alternator.



- **Centre Reading Ammeter**
  - Measures the flow of current to / from a battery.
  - Shows the battery charge / discharge rate



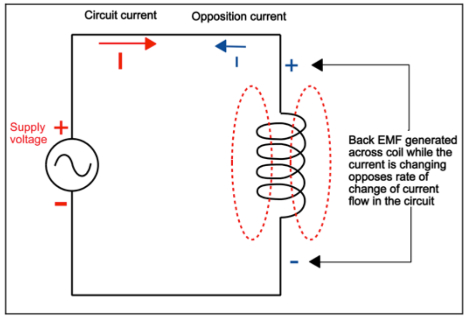
- Both types are sometimes fitted to provide a full picture of system behavior.

ELECTRICS 8 – INDUCTANCE AND CAPACITANCE

INDUCTANCE

DEFINITION

- Considering the current flow being reversed through a conductor (as with AC current), the flux lines will change when the current is reversed.
- The effect of this is that a **back EMF is induced with opposes the change in current flow.**



- **Inductance** is a measure of the ability for a device / circuit to produce a back EMF.
  - High Inductance = Greater back EMF
- The unit of measurement for inductance is the **Henry (H)**

INDUCTORS

- A device designed to have a specific value of inductance is known as an **inductor.**
- The inductance of an inductor can be increased by:
  - Increasing the number of coil turns
  - Inserting a soft iron coil

INDUCTORS IN SERIES & PARALLEL

- **In series**: Inductances are directly added.
- **In parallel:** Reciprocals are added.

CAPACITANCE

DEFINITION

- **The property of an electrical component which enables it to store energy in an electrostatic field.**
- Unit of measurement is the **Farad (C)**
  - C = Capacitance in Farads
  - Q = Charge in coulombs
  - V = Voltage in volts

$$C = \frac{Q}{V}$$

CONSTRUCTION

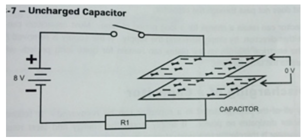
- Two metal plates separated by a non-conductive material called a **dielectric**.
- Capacitance depends on:
  - Area of the plates used (A)
  - Type of dielectric (k)
  - Distance between plates (d)

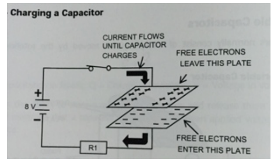
$$C \infty \frac{kA}{d}$$

- Can be **fixed or variable**

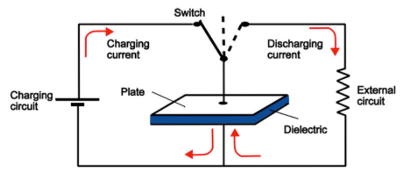
CHARGING / DISCHARGING

- Initially, both plates have the same number of free electrons.
- When the supply is connected, a **surplus** of electrons occurs on one plate and a **deficiency** on the other.
- A **potential difference equal but opposite** to the supply is now created across the plates.





- When it is removed from the supply and connected across a resistor, the capacitor will discharge.



CAPACITORS IN SERIES & PARALLEL

- **In series**: Add reciprocals
  - Thickness decreased => Capacitance Decr.
- **In series**: Add directly
  - Area increased => Capacitance Incr.

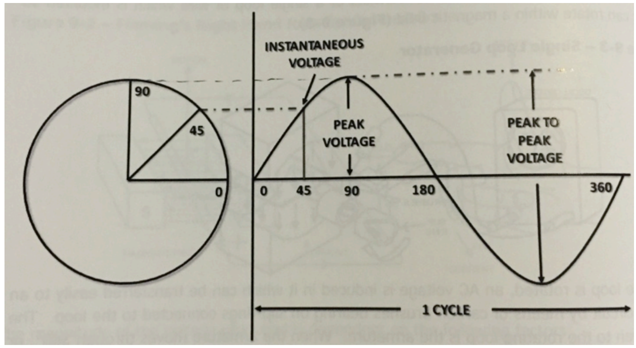
ELECTRICS 9 – BASIC AC THEORY

WHY AC

- Easy to **transform** from one voltage to another
- **Easier to construct AC generators**
- Easy to **rectify** to DC
- **Information can be sent on AC**

TERMINOLOGY

- **Instantaneous Voltage** – Voltage at a specific instant in time.
- **Peak Value** – One positive peak value and one negative peak value occurs during each cycle.
- **Peak To Peak Value** = Peak Value x 2



AVERAGE VALUE

- The average value of either voltage / current is the average of the instantaneous values in a cycle:

Average Value = 0.637 x Peak Value

ROOT MEAN SQUARED (RMS) VALUE

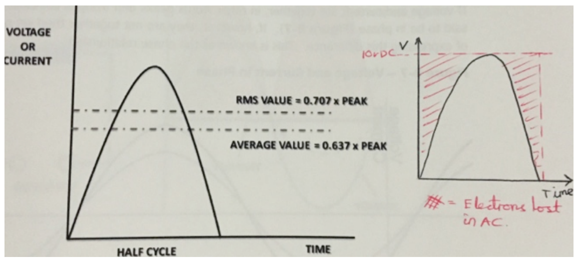
- In reality, it is useful to compare the efficiency of an AC supply with that of a DC supply.

- Since AC follows a sine pattern, electrons are effectively 'lost' in comparison to DC.
- If a bulb is connected to firstly a 10V AC supply then a 10V DC supply, it will shine less brightly in the AC circuit.
- If it is connected to a 10V AC supply then a 7V DC supply, the brightness will be the same in both cases.

- The DC voltage / current that produces an equivalent heating effect is calculated by:

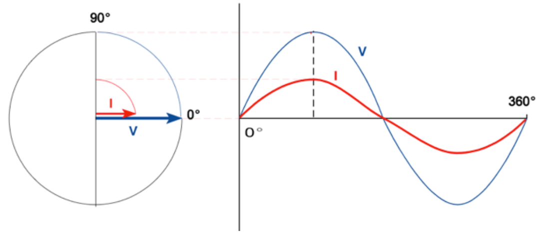
RMS Value = 0.707 x Peak Value

- The RMS measure is used when stating voltages and current of AC systems.
- So, a 240V AC supply from the mains has a peak value of 339V and provides the same heating effect as a 240V DC supply.



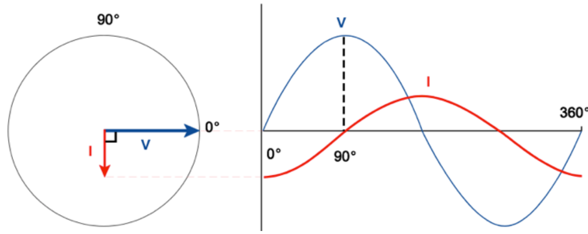
IN PHASE

- If the **peaks and troughs of two waves at the same frequency coincide**, they are said to be in phase.



IN PHASE

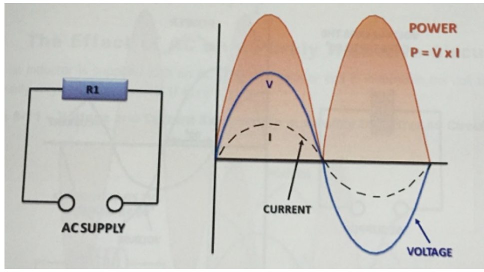
- In the example below, the peaks and troughs do not coincide.
- The peak voltage occurs 90^0 before the peak current.
- It can be said that **voltage leads current by 90^0** OR **current lags voltage by 90^0**



ELECTRICS 9 – BASIC AC THEORY

PURELY RESISTIVE AC CIRCUIT

- Voltage and current will be **in phase**.
- The power is always positive and all of it can be used to do useful work.
- **True power** is produced that does useful work.



PURELY CAPACITIVE AC CIRCUIT

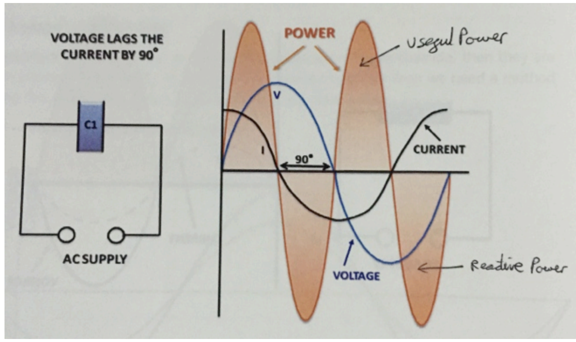
- **Current leads voltage by 90 degrees.**
- The voltage across the capacitor is always in constant opposition to the supply voltage.
- The voltage is essentially pushed back.

- The useful power is cancelled out by the reactive power required to overcome the opposition.
- There is no true power available.

- The opposition to the current which is generated is called the **capacitive reactance**.

$$X_C = \frac{1}{2\pi f C}$$

X_C = Capacitive resistance in ohms
f = Frequency in hertz



PURELY INDUCTIVE AC CIRCUIT

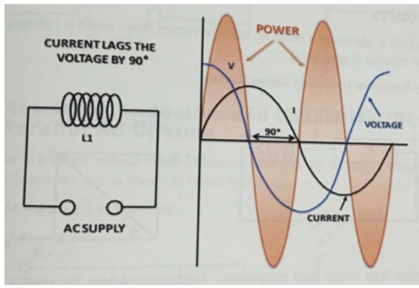
- **Voltage leads current by 90 degrees.**
- The current is essentially pushed back due.

- The useful power is cancelled out by the reactive power required to overcome the opposition.
- There is no true power available.

- The opposition to the current which is generated is called the **inductive reactance**.

$$X_L = 2\pi f L$$

X_C = Inductive resistance in ohms
f = Frequency in hertz
L = Inductance in Henry's



NET EFFECT (CIVIL)

- In reality, circuits will contain all 3 types of resistance.
- The CIVIL rule helps to determine the net effect.

- **If $X_C > X_L$ the circuit is said to be mainly capacitive and current leads voltage (CIV…)**

- **If $X_L > X_C$ the circuit is said to be mainly inductive and voltage leads current (… VIL)**

- The resultant phase difference will be somewhere between 0 and 90 degrees.
- Ideally, we would like to achieve zero phase different to all power is true power that can do useful work.

IMPEDENCE (Z)

- Impedance is the **total opposition** present in a circuit. It is the resultant vector of R, X_C & X_L

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

RESONATE FREQUENCY

- The frequency at which $\mathbf{X_C = X_L}$
- At the resonate frequency, the total impedance will just be the resistance.
- Since a purely resistive circuit is in phase, the current flow is maximum and all power is true power.
- This is the ideal situation.

ELECTRICS 9 – BASIC AC THEORY

TYPES OF POWER

- **True / Effective / Real Power (W)**
    - Power consumed by resistive components within the circuit.
    - Measured in Watts

- **Reactive Power (VAR)**
    - Power consumed by reactive components (capacitors + inductors).
    - Measured in Volt-Ampere Reactive

- **Apparent Power (VA)**
    - Total power required meet circuit demand (true power) and overcome reactance (reactive power)
    - Measured in Volt-Ampere

POWER FACTOR

$$\mathit{Power\ Factor} = \frac{\mathit{True\ Power}}{\mathit{Apparent\ Power}}$$

- Typically 70 – 90%

ELECTRICS 10 - TRANSFORMERS

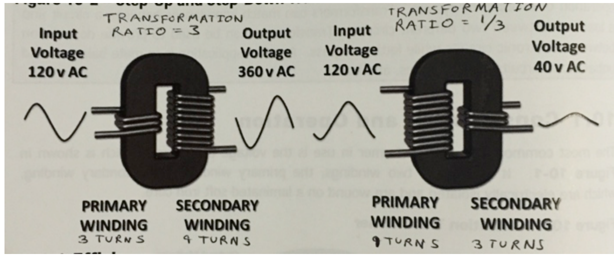
TRANSFORMER USES

- **Convert** one voltage to another voltage
- **Isolate** sections of circuits (primary from secondary)
- **Allow passage of AC whilst blocking DC**

ISOLATION TRANSFORMER

- AC voltage applied to primary winding
- Flux changes produced which induce an EMF within the secondary winding

- Voltage increased if there are more turns of the secondary coil than primary coil.
- Voltage decreases if there are less turns of the secondary coil than the primary coil



TURNS RATIO

$$Turns\ Ratio = \frac{V_S}{V_P} = \frac{N_S}{N_P}$$

CONSTANT POWER

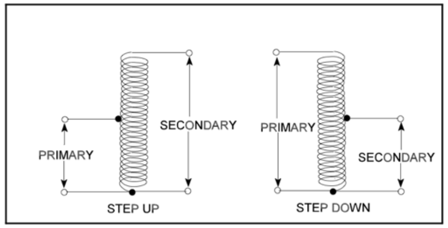
- Assuming a 100% efficient transformed, power remains constant.
- Given P = I x V
- Step-up = Voltage Increases => Current Decr.
- Step-Down = Voltage Decr => Current Incr.

EFFICIENCY

- Transformers are **very efficient**
- Typically 80 – 95% efficient

AUTO TRANSFORMER

- **No isolation** between primary and secondary
- A continuous winding is used
- **Lighter and cheaper** than the isolation type but do not isolate.

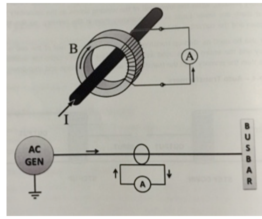


VARIAC TRANSFORMER

- **Variable Autotransformer**
- Can be used to control **lighting intensity**

CURRENT TRANSFORMER

- Feeder cable is passed through a soft iron ring with windings wrapped around it.
- Alternating magnetic field produced by feeder induces an EMF in the windings.
- **Ammeter** connected to the windings will measure the current.
- This set-up is usually used to measure output of an AC generator for example.



TRANFORMER RECTIFIER UNIT

- Contains a transformer and a rectifier for use when a DC output is required.
- The secondary winding is connected to a **3 phase full wave bridge diode rectifier.**

INVERTERS

ROTARY INVERTER

- DC is used to power **a motor which drives an AC motor on a common shaft.**
- Around **50% efficient** as energy is lost to mechanical energy.

STATIC / TRANSISTORISED INVERTER

- More reliable and requires less servicing.
- **Much more efficient (75%)** as there is no mechanical loss but it is **power limited** compared to the rotary inverter.

ELECTRICS 11 – 3 PHASE MACHINES

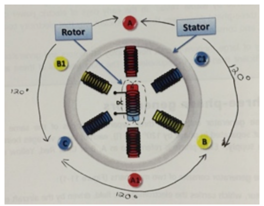
ADVANTAGES OF AC GENERATION

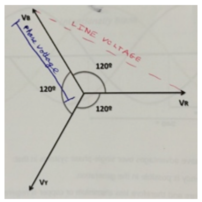
- **Higher efficiency possible** in AC generation
- **Fewer conductors** required
- **Same source** can be used for single / three phase AC supplies
- 3 phase motors have **better characteristics** than single-phase ones.

PHASOR DIAGRAM

- As the rotor rotates, it can be seen the peak voltages are induced 120^0 apart.
- **Line voltage** is the PD between a line and the neutral point.
- **Phase Voltage** is the PD between two phases.

$$Line\ Voltage = \sqrt{3} \times Phase\ Voltage$$





ARRANGEMENT METHODS

- The outputs of an AC generator can be connected in either a **star or delta configuration.**

STAR CONFIGURATION

- Here, the line voltage between Red and Blue phases is the vector sum of the phase voltages.

$$Line\ Voltage = \sqrt{3} \times Phase\ Voltage$$

- There is only one path however for current to flow through between phases so:

$$Line\ Current = Phase\ Current$$

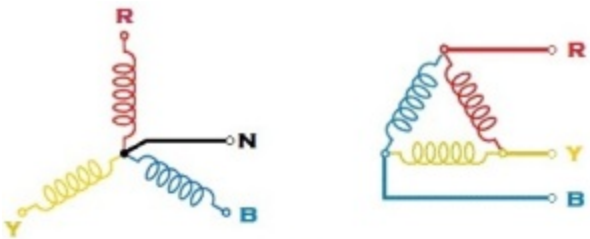
DELTA CONFIGURATION

- Here, the line voltage between Red and Blue phases is the same as the phase voltage.

$$Line\ Voltage = Phase\ Voltage$$

- There are two paths for current to flow in however so:

$$Line\ Current = \sqrt{3} \times Phase\ Current$$



Comparison b/w Star (Y) & Delta (Δ) Connections
© www.electricaltechnology.org

DELTA VS STAR

- **Star method uses 4 conductors:**
  - 1 conductor for each phase
  - 1 conductor used as the neutral point
- **Delta method uses 3 conductors:**
  - There is no neutral point
- **Efficiency**
  - Both produce the same power although the delta connection is lighter with only 3 conductors.
- **Aviation**
  - Star method required since there is no earth connection available. The neutral is needed to absorb excessive current.

TYPICAL AIRCRAFT AC FIGURES

- **Frequency** = 400 Hz
- **Phase Voltage** = 115 V
- **Line Voltage** = 200 V

VOLTAGE AND FREQUENCY CONTROL

- Voltage controlled by adjusting field excitation via a **voltage regulator**.
- Frequency adjusted via **rotational speed of rotor and number of magnetic field poles.**

$$f = \frac{N \times P}{60}$$

- Therefore, increasing the number of poles allows same frequency to be generated at a lower rpm.

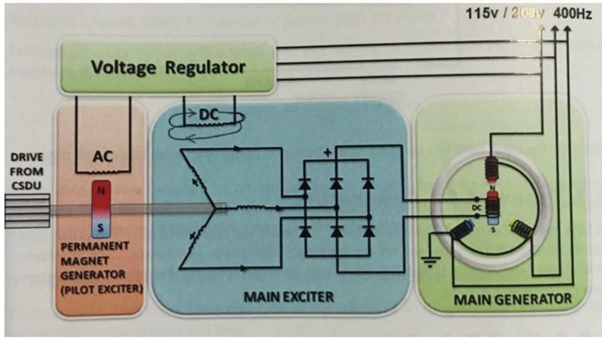
ELECTRICS 11 – 3 PHASE MACHINES

BRUSH TYPE GENERATORS

- An example of a brush type connector is the **salient pole generator**.
- Electromagnets on rotor are excited with DC current via **carbon brushes** and **slip rings**.
- The intermittent contacts produce sparks however which increase in intensity with increasing altitude (lower insulation from air which is less dense)

BRUSHLESS TYPE GENERATOR

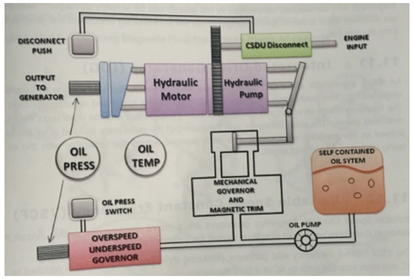
- Constant Speed Drive Unit (CSDU) rotates shaft giving a constant output frequency.
- Permanent magnet generator (PMG) is turned which induces an AC voltage in the pilot exciter.
- This is rectified to DC via the voltage regulator and fed to the main exciter.
- In the main exciter, a 3 phase AC voltage is induced which is rectified to DC and passed to the main generator.
- Main generator produces a bigger 3 phase AC which is fed back to the voltage regulator as required in order to increase the magnetic field within the main exciter, thus achieving the required output voltage of 115V/200V.



CONSTANT SPEED DRIVE UNIT (CSDU)

- Constant speed and hence constant frequency is important in order to achieve the **correct and constant resonant frequency** within a circuit.

- Governor senses the CSDU output RPM and if required, adjusts the pressure within the **hydraulic pump.**
- This alters the RPM of the **motor**, thus ensuring a constant rpm is obtained (usually 8,000 rpm)



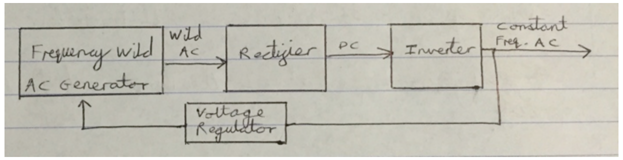
- **Hydraulic fluid sight glass** is to be checked on the pre-flight.
- **CSDU can be disconnected** in the event of abnormal functioning.
  - Once disconnected, can only be reset on the ground.

IDG (INTEGRATED DRIVE GENERATOR)

- CSDU + Generator in the same unit

VSCF GENERATOR

- Variable Speed Constant Frequency
- Recent development
- No mechanical gears / hydraulics
- Cannot match power output of IDG however

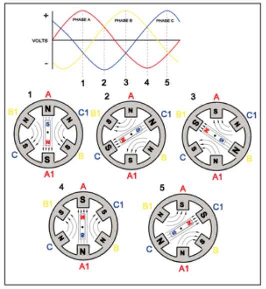


AC MOTOR

- A rotating magnetic field is set-up within the stator field coils.
- A soft iron bar mounted on the rotor shaft will follow this magnetic field and cause the shaft to rotate.

- A slight lag will exist due to **mechanical loading** which results in the shafting lagging the magnetic field (synchronous speed).
- **Increasing voltage** will strengthen the magnetic field and **reduce the slip speed.**

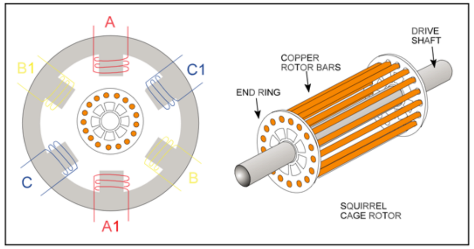
Slip Speed = Synchronous Speed – Rotor Speed



ELECTRICS 11 – 3 PHASE MACHINES

SQUIRELL CAGE MOTOR

- AKA **Induction Motor / Asynchronous Motor**
- By mounting conductors on a cage, an EMF is induced within the conductors as the magnetic field from the stators rotates.
- This creates a magnetic field within the conductors on the cage.
- The interaction of the fields (like with a DC motor) causes the cage to rotate.



LOSS OF PHASE

- Motor will continue to run at a reduced torque but it may overheat as remaining phases carry a greater current.

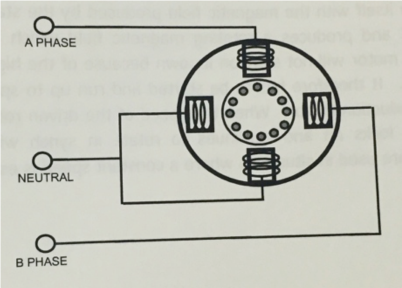
- If not already running, motor cannot be started since fuses / CBs will blow in the other two phases.
    - Greater current required in order to start motor.

TWO PHASE INDUCTION MOTOR

- One phase is the **reference phase**
- Other phase is the **control phase**

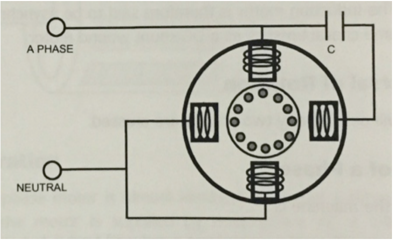
- Changing the phase will change the direction of the magnetic field.
- Rotor will then re-align itself with the field.

- Used on auto-pilot servo motors



SPLIT PHASE INDUCTION MOTOR

- Behaves like a two phase induction motor
- One of the windings is capacitive and the other resistive.
- Used to drive actuators



SINGLE PHASE INDUCTION MOTOR

- Will rotate continuously in one direction and change direction when the field is reversed.
- Generally not used on aircraft

SYNCHRONOUS MOTOR

- Used when a constant speed is required to be output at high RPMs
- Ideal for gyro's

- **Rotor carries field windings** as well which create a magnetic field that will try and align itself with the one created by the stators.
- On start-up, there is an initial period where they are asynchronous as **inertia** is overcome

ELECTRICS 12 – AC SUPPLY AND DISTRIBUTION

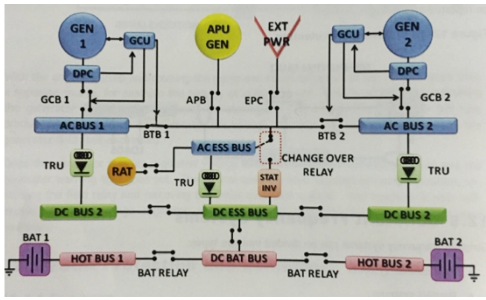
SYSTEM TYPES

- **Frequency Wild**
  - Used in light aircraft for heaters etc
- **Constant Frequency**
  - Split Busbar
  - Parallel Busbar

SPLIT BUSBAR

- Parallel loads are only allowed with DC and must be kept separate in AC.
- When both GENs are running, only one BTB (**Bus Tie Breaker)** will be open to allow powering of the AC ESS BUS.
- In the event a GEN fails, both BTBs are closed to allow one GEN to feed AC BUS 1, AC ESS BUS & AC BUS 2.

- **GCU (Generator Control Unit)**
  - Controls the opening / closing of GCB
- **GCB (Generator Circuit Breaker)**
  - Switch rather than CB which connects generator to the system.
- **DPC (Differential Protection Circuit)**
  - Monitors generator output vs return current to detect a current leaks.
  - Opens the GCB via the GCU if a fault is detected



AC EXTERNAL POWER

- **Before connecting** external power, the following conditions must be met:
  - Correct Voltage
  - Correct Frequency
  - Correct Phase Order
  - Dead AC Busbar (no other sources providing power to it)

PARALLEL BUSBAR

- AC generator must have the following **conditions in common** before they can be paralleled:
  - Voltage
  - Frequency
  - Phase Difference
  - Phase Order

- **Advantages** of the parallel busbar design:
  - Redundancy
  - Load Sharing
  - Prolonged Generator Life

- **Disadvantages** of the parallel busbar design:
  - Fault Propogation
  - Does not meet independent system requirements

LOAD SHARING

- **Real Load Sharing** – Adjusting magnetic trim in the CSDUs

- **Reactive Load Sharing** – Adjusting excitation of the generator fields.

TROUBLESHOOTING

- Separate the generators by opening the BTBs
- They may settle down once this is done.
- If one of the generators is a persistent problem then trip the GB and GFR.

EASA TROUBLESHOOTING ANSWERS

- Trip Exciter Breaker & Generator Breaker for:
  - Persistent Under-Excitation
  - Persistent Over-Excitation
  - Persistent Over-Voltage
  - "AC Generator Fault"

- For an underspeed fault:
  - Open GB only to allow stabilisation

- For a persistent phase imbalance:
  - Open the BTB to allow independent operation

- Pulling of the fire handle opens:
  - Exciter Control Relay & Generator Breaker
  - BTB operation depends on the system