THE HONG KONG POLYTECHNIC UNIVERSITY
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Department of Aeronautical and Aviation Engineering
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Introduction to Aircraft Systems

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Aircraft electrical system/電氣系統

- Introduction
- Characteristics of the civil aircraft electrical system
- Electrical load
- Power generation & supply
- Power generation control
- Primary power distribution
- Summary
- Appendix

Even the old piston-type aircraft need to produce electricity for engine's ignition

Introduction

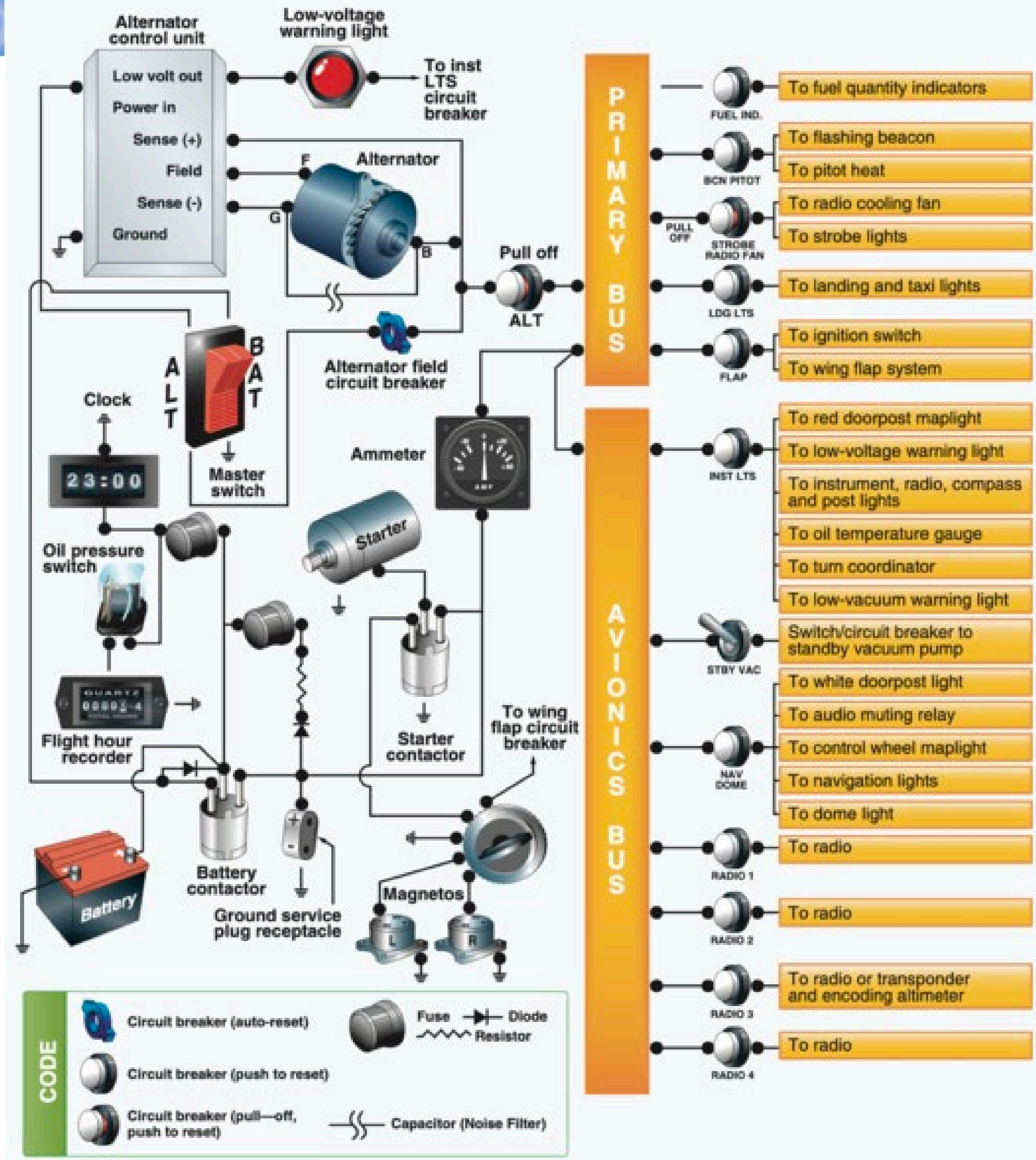
Introduction

- What is an aircraft electrical system?
  - A self-contained network of components that generate, transmit, distribute, utilize, and store electrical energy.
- Nearly all aircraft contains some form of electrical systems. The complexity of the electrical power system varies with the size and functionality and operational requirements.
- Even in the early aircraft, the piston type engine used to the electricity to ignite and start the engine

Introduction

- For an aircraft, electrical system can be used for:
  - Engine ignition
  - Lighting system
  - Heating system
  - Signal processing
  - Radar and electronic warfare jamming equipment
  - Electrical actuator, e.g., for landing gear, etc.
  - Other onboard electrical needs

Electrical load



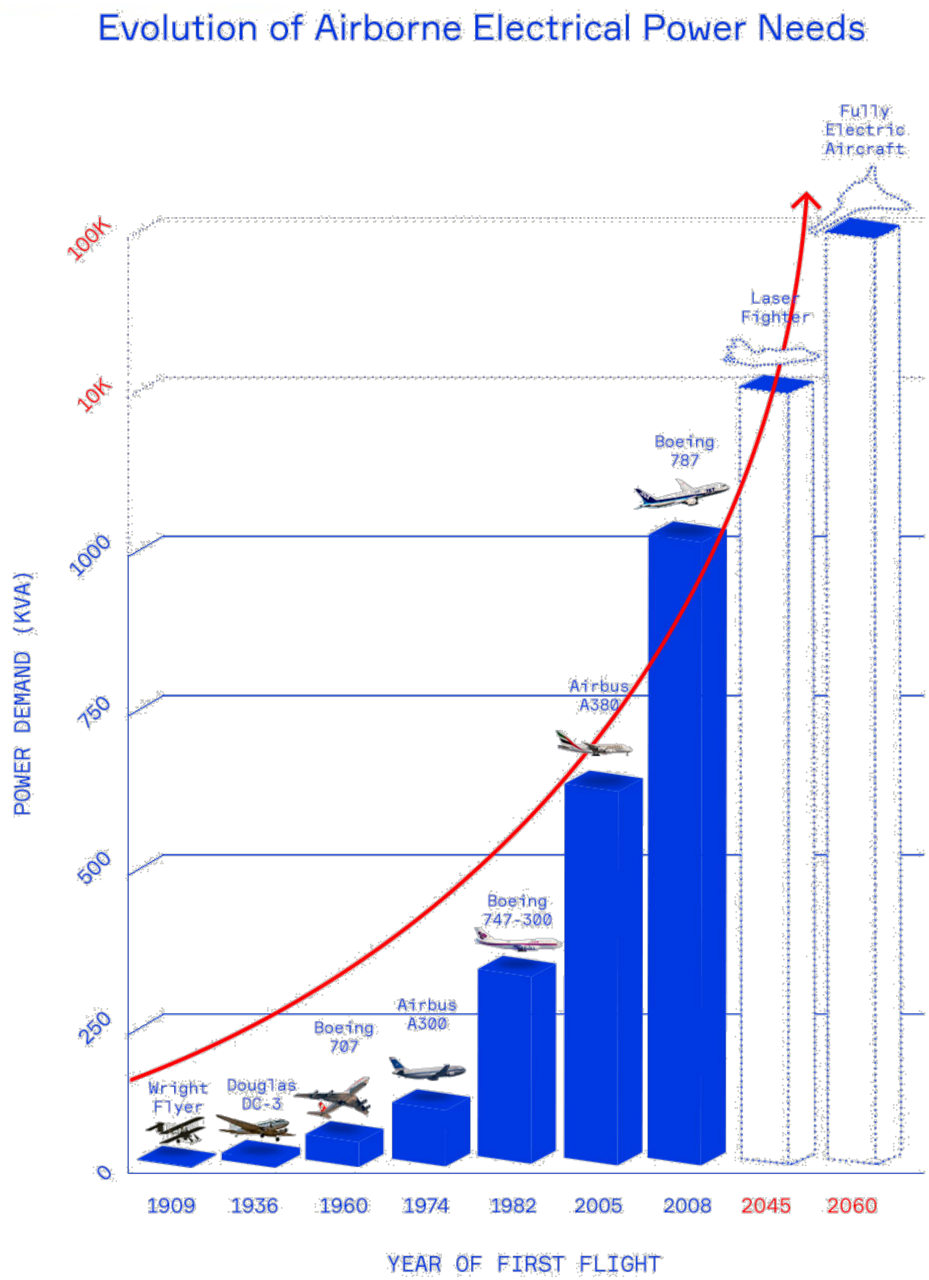
Alternator control unit
Low-voltage warning light
Low volt out
Power in
Sense (+)
Field
Sense (-)
Ground
To inst LTS circuit breaker
F
G
B
Alternator
Pull off
ALT
ALT
BAT
Master switch
Alternator field circuit breaker
Clock
23:00
Ammeter
Oil pressure switch
Starter
Flight hour recorder
Starter contactor
To wing flap circuit breaker
Battery contactor
Battery
Ground service plug receptacle
Magnetos
L
R
PRIMARY BUS
AVIONICS BUS
FUEL IND.
To fuel quantity indicators
BCN PITOT
To flashing beacon
To pitot heat
PULL OFF
STROBE RADIO FAN
To radio cooling fan
To strobe lights
LDG LTS
To landing and taxi lights
FLAP
To ignition switch
To wing flap system
INST LTS
To red doorpost maplight
To low-voltage warning light
To instrument, radio, compass and post lights
To oil temperature gauge
To turn coordinator
To low-vacuum warning light
STBY VAC
Switch/circuit breaker to standby vacuum pump
NAV DOME
To white doorpost light
To audio muting relay
To control wheel maplight
To navigation lights
To dome light
RADIO 1
To radio
RADIO 2
To radio
RADIO 3
To radio or transponder and encoding altimeter
RADIO 4
To radio
CODE
Circuit breaker (auto-reset)
Circuit breaker (push to reset)
Circuit breaker (pull—off, push to reset)
Fuse
Diode
Resistor
Capacitor (Noise Filter)

Introduction: redundancy and reliability

- For large aircraft, one way to increase reliability is to allow more than one power sources for any given load, i.e., **redundancy**.
  - Battery is used as an ultimate backup source of power.
- To ensure the reliability of electrical power, the power distribution systems could also contain:
  - several distribution points (called bus bar)
  - a variety of control and protection components, e.g., circuit breakers.

Introduction: tendency

- More-electric Aircraft (MEA): to use electrical power to drive non-propulsive aircraft systems:
  - Increase performance
  - Reduce maintenance cost
  - Environmental protection
- The civil aircraft, e.g., Airbus A380 and Boeing B787, has substantial increase in on-board electric power demand.



Introduction: electric power evolution

For DC:
$P = U \cdot I$

- Tendency: using higher AC voltage
  - Driven by the increasing needs in power & electrical channels
- For DC systems:
  - A sensible limit around 400 amps: due to the limitations of feeder size and high-power protection switchgears
  - As a result, the provided power is not sufficient.

- Example:
  - for the voltage is 28V, i.e., 28VDC, even at 400 amps, the power is about 12 kVA (or 12 kW), which is far below of the requirements of most aircraft.
  - This level might be sufficient for the General Aviation (GA) aircraft

AC: alternating current
DC: direct current

Introduction: electric power evolution

- For larger aircraft, 20-90 kVA per channel is needed.
  - A380 utilizing 150kVA per channel
  - Boeing B787 uses 500 kVA per channel.
- Therefore, the alternating current is often needed.

Characteristics of the aircraft electrical system

Electrical system characteristics

- Electrical system:
  - Details of the electrical system can significantly vary from one type of aircraft to another.
  - But the basic principles and requirements of all electrical power system are essentially the same.
- An electrical system contains the following major elements:
  - Electrical loads
  - Power sources
  - Components in the system:
    - Control devices
    - Conversion devices
    - Protection devices
  - Power distribution

What is the electrical power used for?

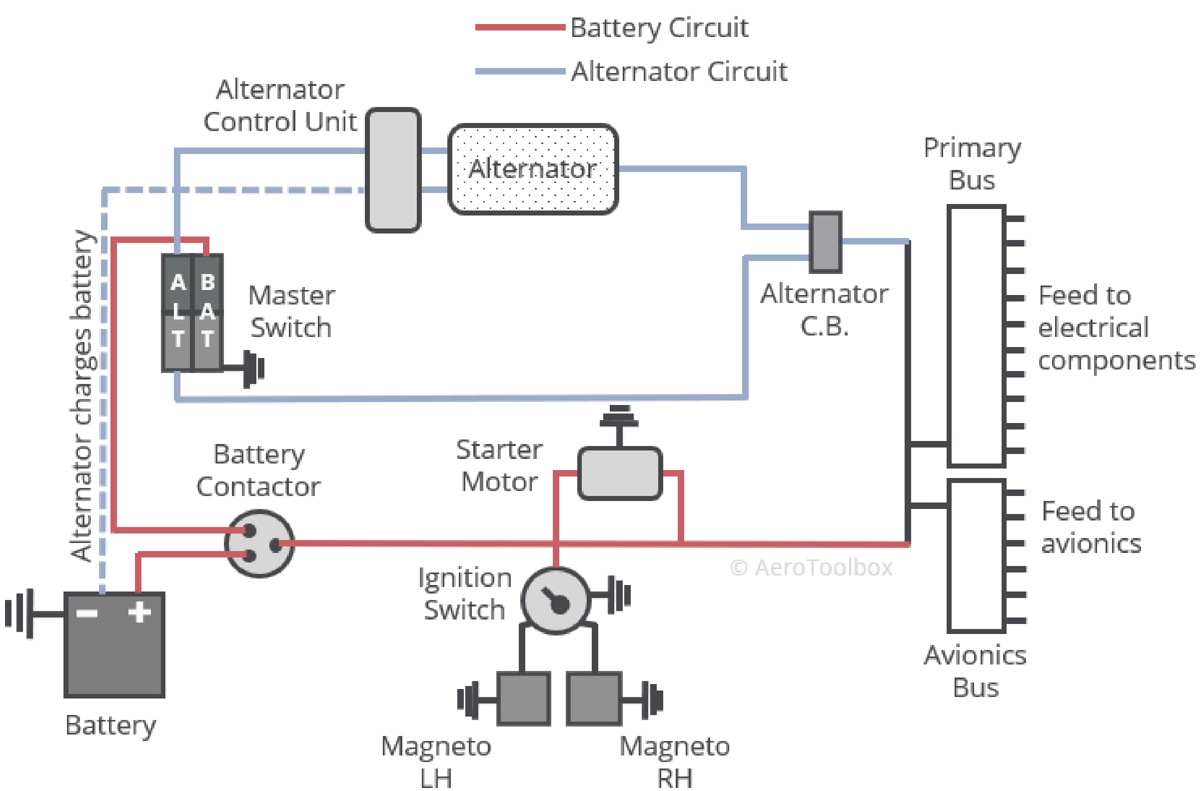
Where is the electrical power from?

How is the function realized?

How to account for the complexity of the aircraft application

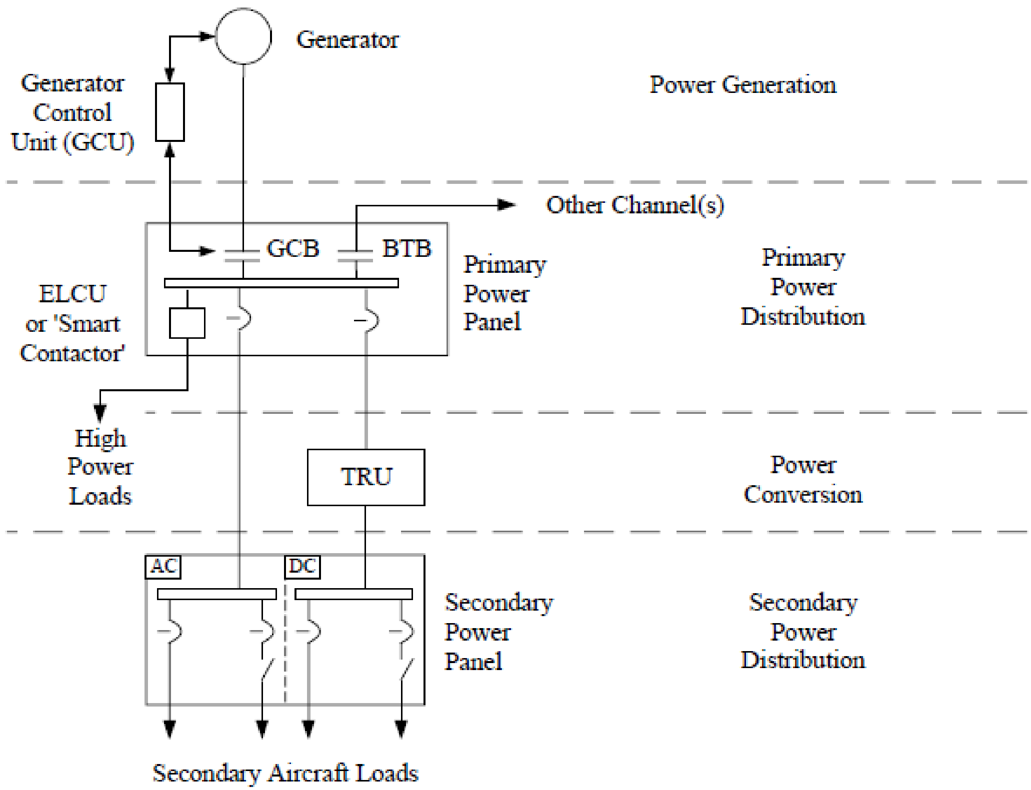
Simplified electrical system layout

Note: in many applications, battery is charged by DC (direct current) . In this case, AC/DC convertor is needed.



- The alternator, i.e., power source, is used when the engine is running.
- The battery is used when the system is not running
- Battery can also be used to start the engine

Simplified electrical system using AC generator



It contains:

- Power generation
- Primary power distribution and protection
- Power conversion and energy storage
- Secondary power distribution and protection

Electrical system requirement

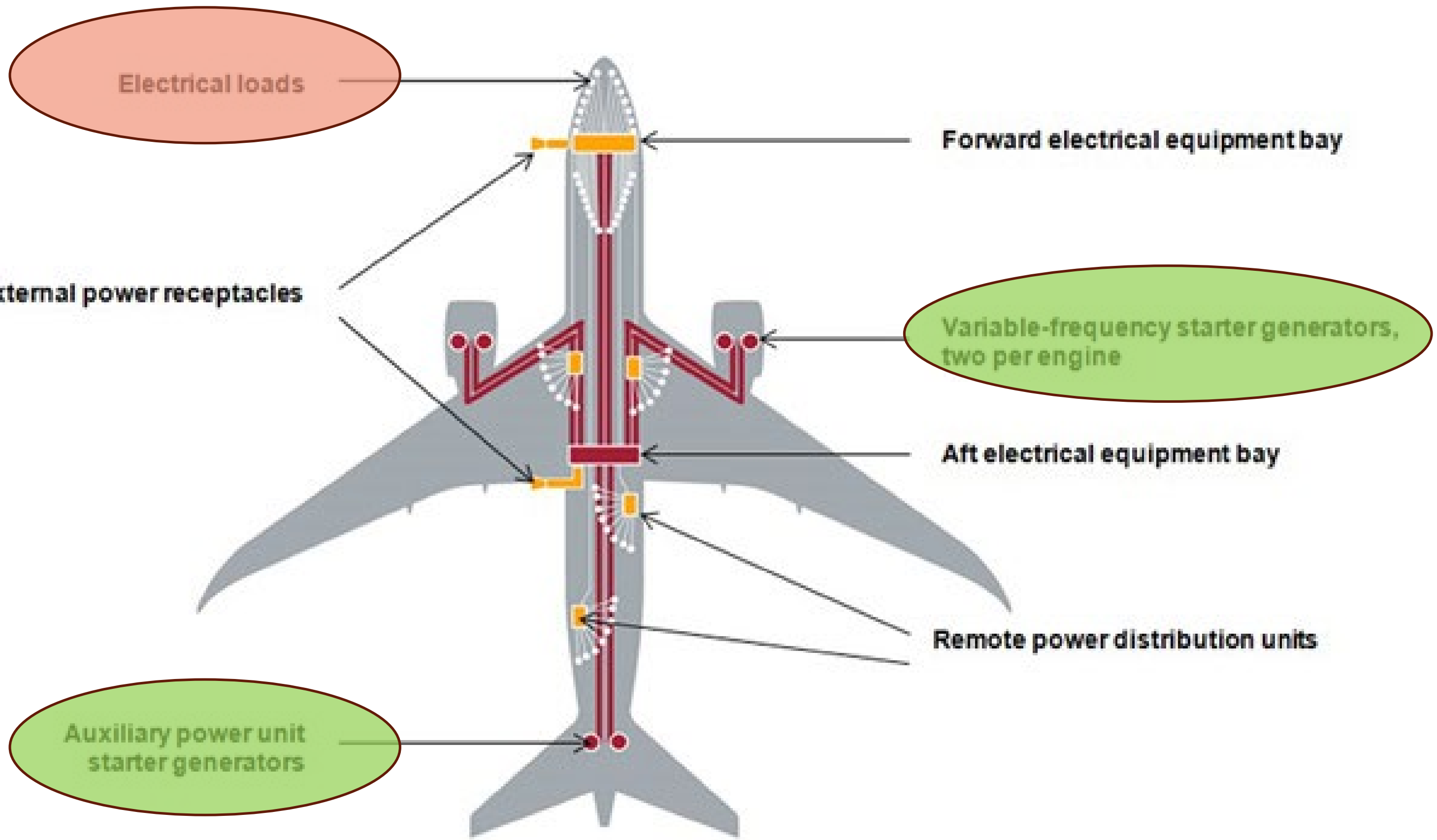
- The electrical system should:
  - Be able to supply all electricity requirements for all modes of operation
  - Be able to supply additional capacity to provide for growth loads.
  - Provide protection to prevent unsuitable external power from being applied to the airplane.
- In case of failure:
  - non-flight critical and/or pre-selected loads should be automatically disconnected to save the electrical power.
  - In recently certified airplanes, there must be enough battery power available to power the critical items for IFR flight for 30 minutes.

IFR (Instrument Flight Rules): flight depends upon flying by reference to instruments in the flight deck, and navigation is accomplished by reference to electronic signals.

Electrical load

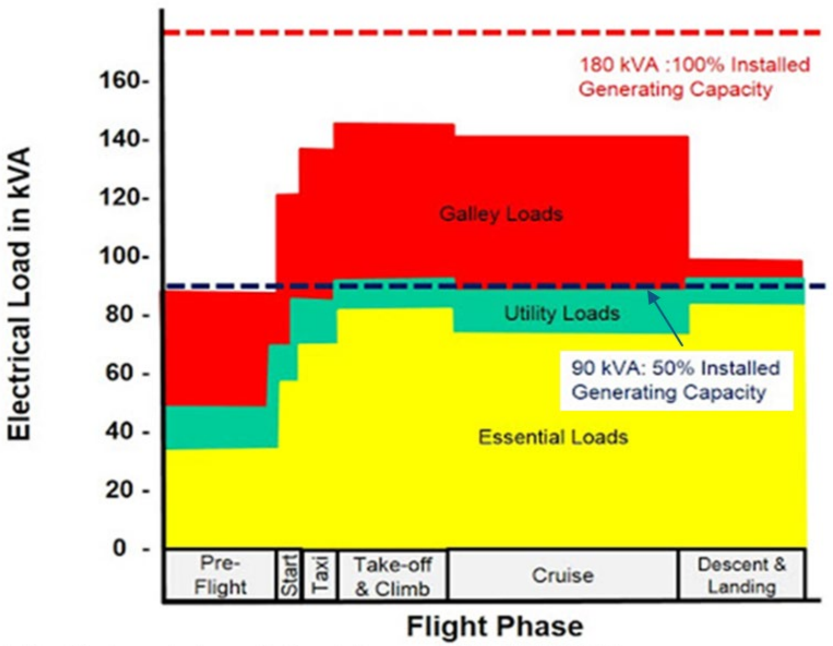
Electrical loads

- Electrical load refers to any device or equipment that demands electricity to function requires power from the aircraft's electrical power system.



Electrical loads: classification based on the distribution

- These loads are distributed throughout the aircraft and may be broadly subdivided into 3 categories.
  - Galley loads: ovens, toilets, hot water machines, etc.
  - Utility loads: cabin lights, air conditioners, etc.
  - Essential loads: motors, external lights, etc.



http://alverstokeaviation.blogspot.hk/2016/03/

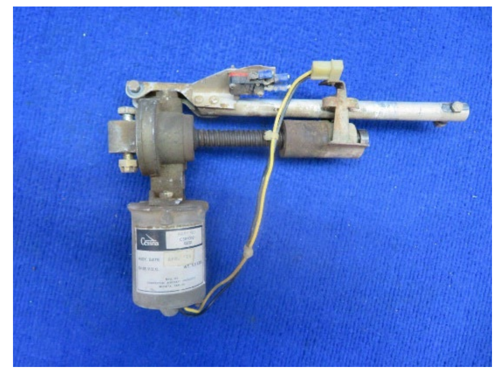
Electrical loads: classification based on services

- Another classification of the electrical load is based on the services provided in the aircraft:
  - Motors and actuation
  - Lighting services
  - Heating services
  - Subsystem controllers and avionics systems

- DC motors
- AC motors

Electrical loads: motors and actuation

- Motors are used to drive the valves and other actuators. Typical examples of using motors in aircraft include:
  - Position actuators for engine control
  - Trim actuators
  - Flap/slap operation
  - Hydraulic control valves
  - Air control valves
  - Engine starting
  - APU operation
  - Pumps in fuel system, hydraulic systems, etc.
  - Fans to return cool air to passengers or equipment

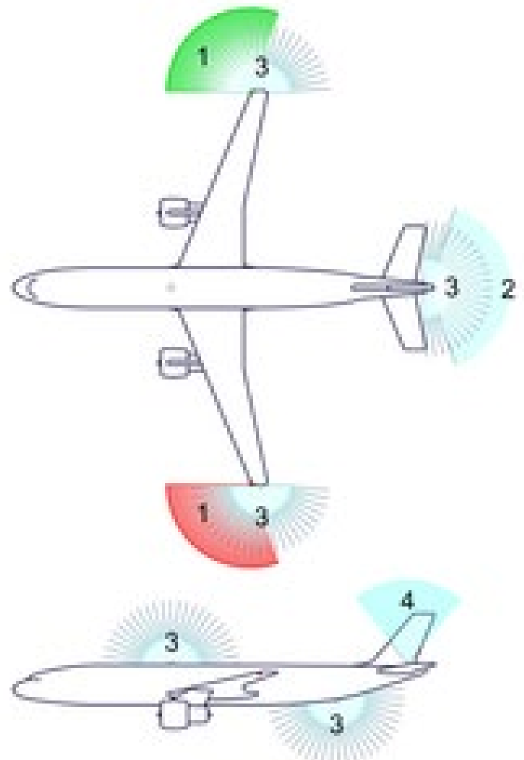


Example of the flap actuator

Electrical loads: lighting

Lighting is important since a large proportion of the aircraft operation time is in the low-visibility conditions

- External lighting systems:
  - 1. Navigation lights
  - 2. Aft lights
  - 3. Strobe lights
  - 4. Logo lights
  - Landing/taxi lights
  - Inspection lights
  - Emergence evacuation lights
  - Searchlights



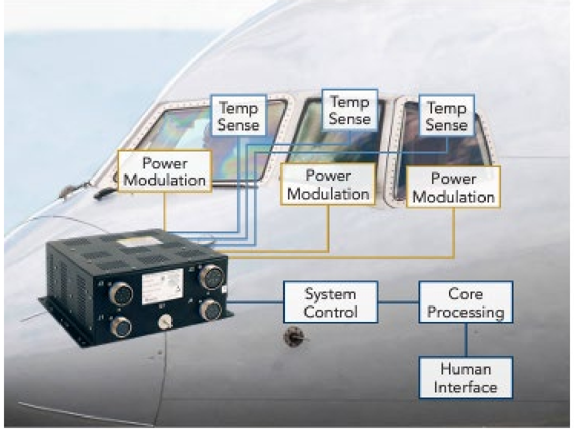
Electrical loads: lighting

Lighting is important since a large proportion of the aircraft operation time is in the low-visibility conditions

- Internal lighting systems:
  - Cockpit light
  - Passenger information light
  - Passenger cabin lights
  - Emergence lights
  - Cargo bay lights

Electrical loads: Heating

- Heating is another extensive load to the electrical system.
- The electrically powered anti-icing systems can consume the electrical power up to tens of kVA
  - Fortunately, these powers do not have strict requirement in frequency stability. They are easy to be generated
  - The anti-icing system uses both electrically-powered heating systems and engine bleed air.
- Windscreen heating is another important source of electric heating service.



Electrical loads: Subsystem controllers & avionics systems

- With the increasing complexity of the aircraft subsystems, many controllers and the advanced avionics systems are involved.
  - The DC or AC powers are used.
- Many of them may use internal power supply units to convert the aircraft power to levels better suited to the electronics requiring a relatively low voltage and low electric load:
  - E.g., 5VDC range
- However, as there are many of these types of systems, a certain proportion of the electric load is needed.
- Besides, adequate source of emergency power is also needed.

Power generation

Power generation

- In the aircraft electrical system, the power can be supplied by
  - Batteries
  - Generators
    - AC generators: to drive AC systems
    - DC generators: to dive DC systems
- We only introduce the fundamental features of them

Battery is used as an ultimate backup source of power

Major source power

Battery

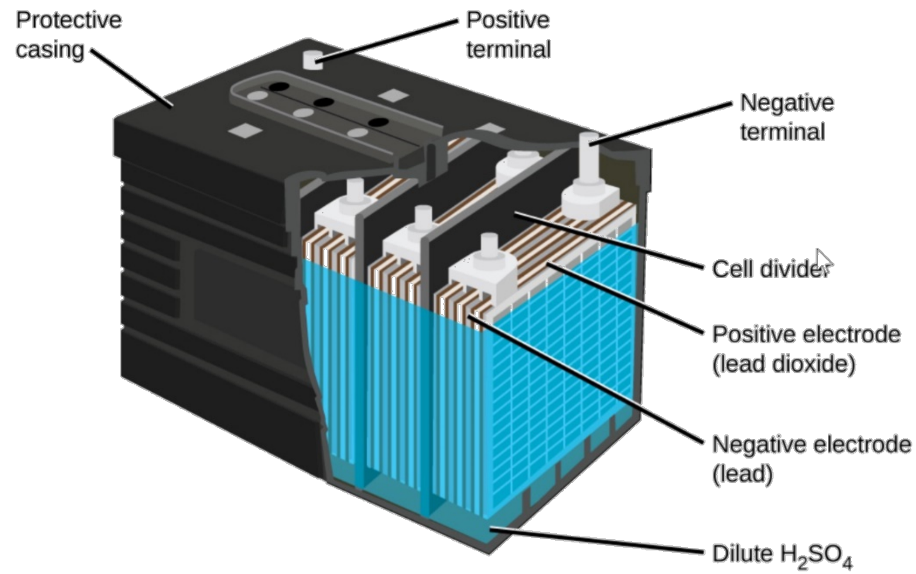
- A battery is a device that converts chemical energy to electricity energy.
- It is a power reservoir that stores energy in the chemical form and it does not produce energy.
- They are used for:
  - Providing power when no other power source is available
  - Providing a short-term source during emergence condition
  - …
- It is automatically recharged when the engine-driven generator is operated.

Battery

- The capacity of battery is measured in ampere-hours
- In an aircraft, two types of batteries are used:
  - Lead-acid batteries/鉛酸電池
  - Nickel cadmium batteries/鎳鎘電池

Battery: Lead-acid battery

- It is made up of cells with positive/negative **plates of lead** and filled with electrolyte of sulfuric acid/硫酸 and water
- It has corrosive effects
- A frequent **total discharge** and **remaining battery** in discharged condition can shorten its life
- It is usually found in piston-engine aircraft



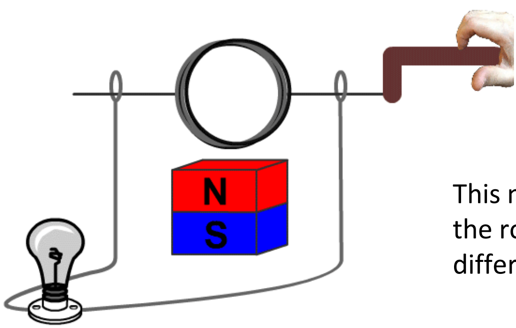
Battery: Nickel-cadmium battery

- Commonly used in turboprop and turbojet aircraft.
  - High charge/discharge rate without voltage drop
  - In the overheating, they may be subjected to the thermal runway condition. It will destructs itself.

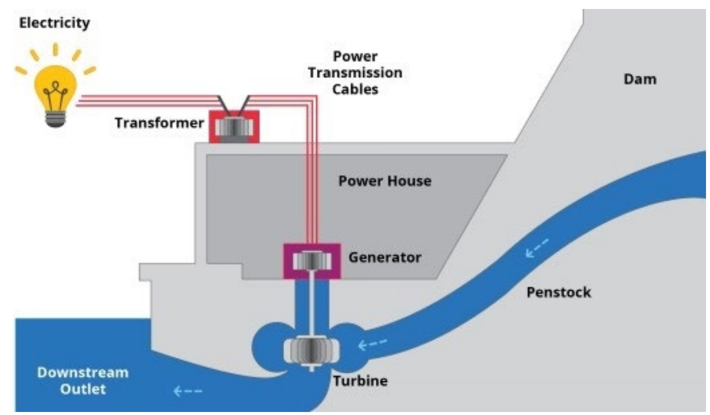
$$Cd + 2NiO(OH) + 2H_2O \rightarrow 2Ni(OH)_2 + 2Cd(OH)_2$$

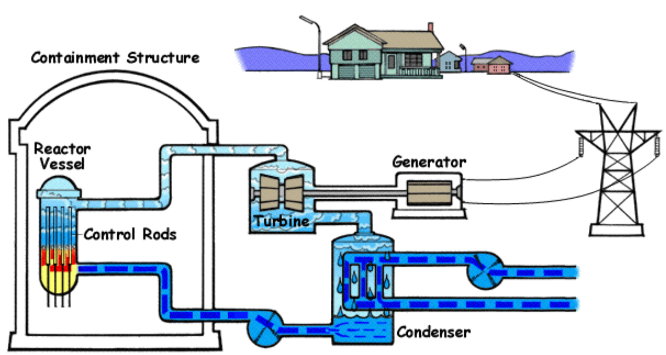
Generator: principle

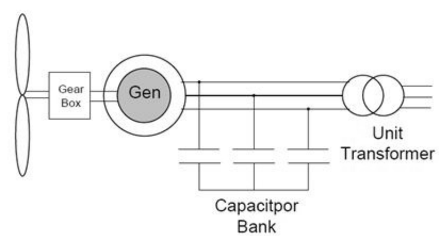
- A generator is a machine that converts **mechanical energy** into electrical energy through the electromagnetic induction
- A generator will produce the electric current, which transmits through a circuit that contains the load and other components.

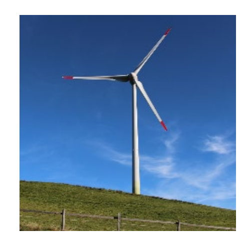


This mechanical energy related to the rotatory motion is provided by different sources









Generator

- In aircraft, the mechanical energy is provided by:
  - Engines (mainly)
  - APU (sometimes)
  - Hydraulic motor (sometimes)
  - Ram Air Turbine (RAT, sometimes)

Generator

- Based on the outcome current, the generator can be classified to:
  - Direct current (DC) generator:
  - Alternating current (AC) generator:
- DC generator: a commutator is used to generate the current
- AC generator: a slip ring is used to generate the current.

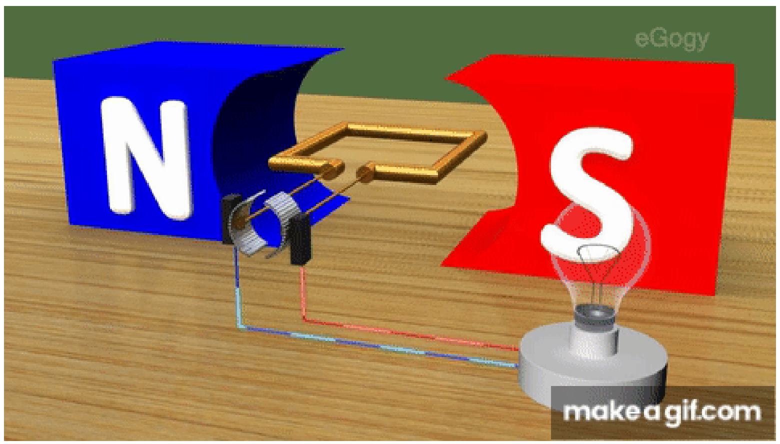
DC generator

- The direct current (DC) generator supplies nearly constant voltage.
  - Usually, the voltage is about 28 VDC
  - In some old aircraft, the voltage can be 14 VDC
  - In military applications, the voltage could be 270 VDC.
- The current can be up to 400 A in the circuit.
- Many aircraft do not have a separate DC generator. Instead, the AC generated by the AC generator is converted to the DC to power the DC systems.

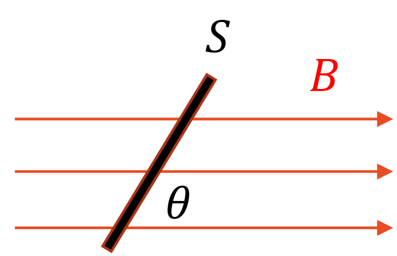
Related to rotation speed

DC power generation

- DC power generators contain rotating electromagnets (field coil) to generate electric power.



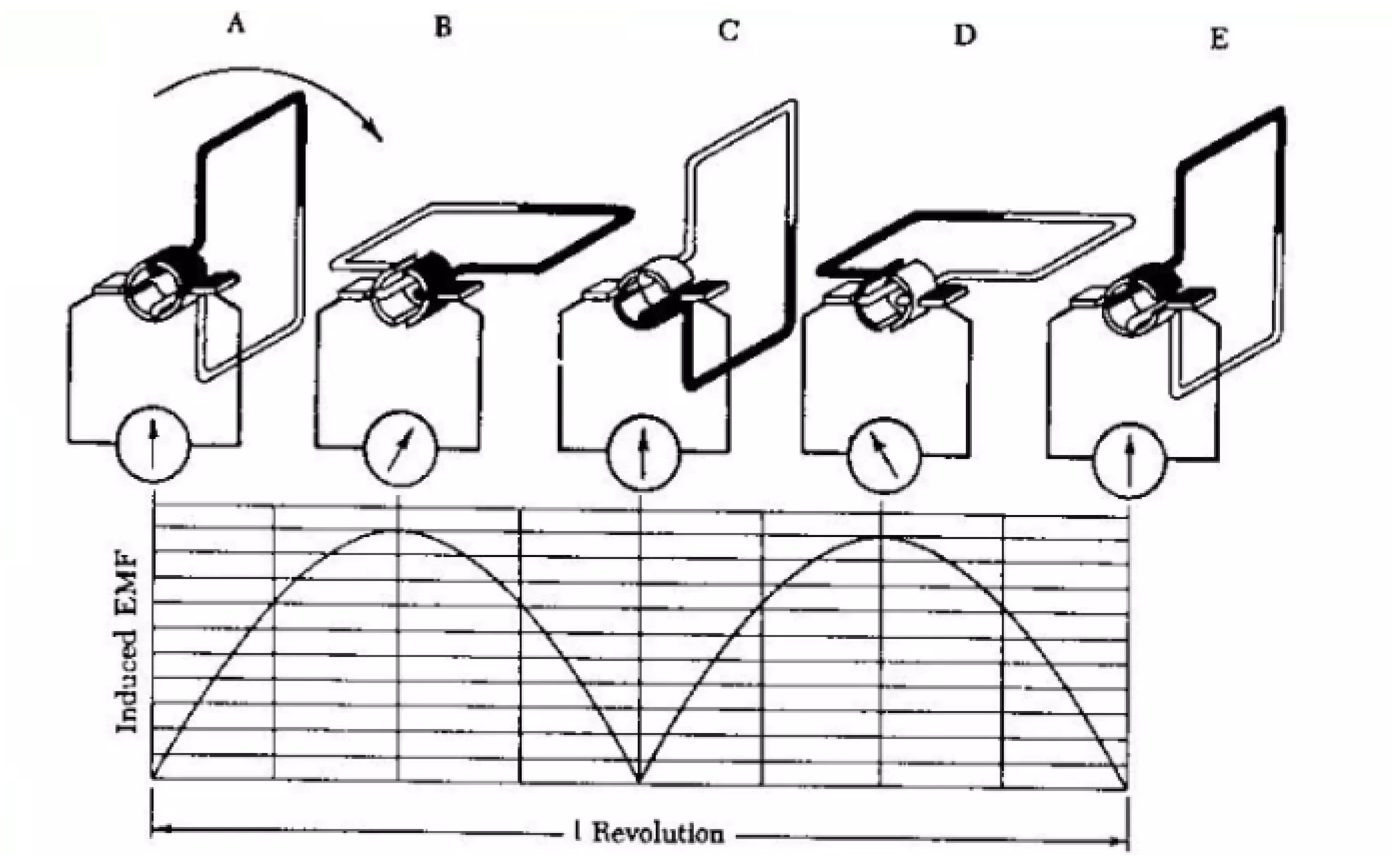
- Faraday‘s law of electromagnetic induction
$$\mathcal{E} = -\frac{\mathrm{d}\Phi_\mathrm{B}}{\mathrm{d}t}$$
    - Φ_B: magnetic flux.
    - $\mathcal{E}$: electromotive force
- Denote B as magnitude of magnetic field, S as area
$$\Phi_B = BS\cos\theta = BS\cos(\omega t)$$



This will lead to an output electromotive force/voltage as a sine function

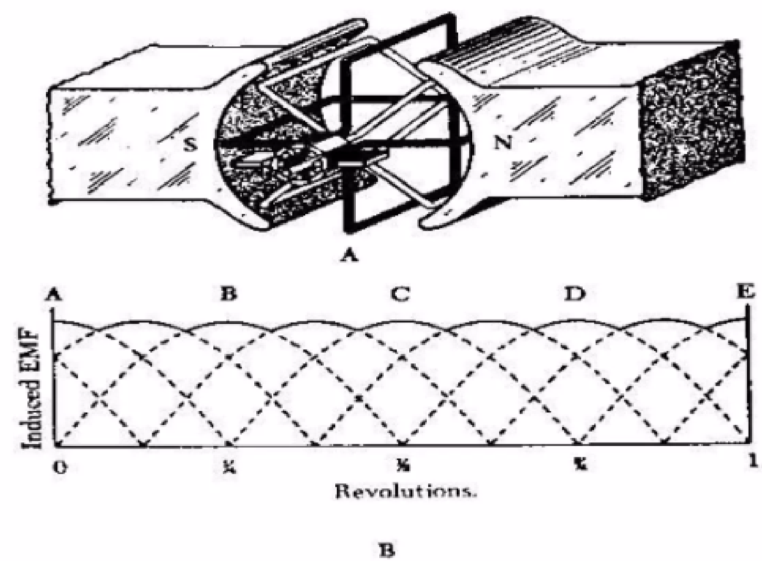
DC power generation

- A device called commutator/换向器 is employed to ensure the output voltage, which would appear as a simple sine wave, to be effectively half-wave rectified.



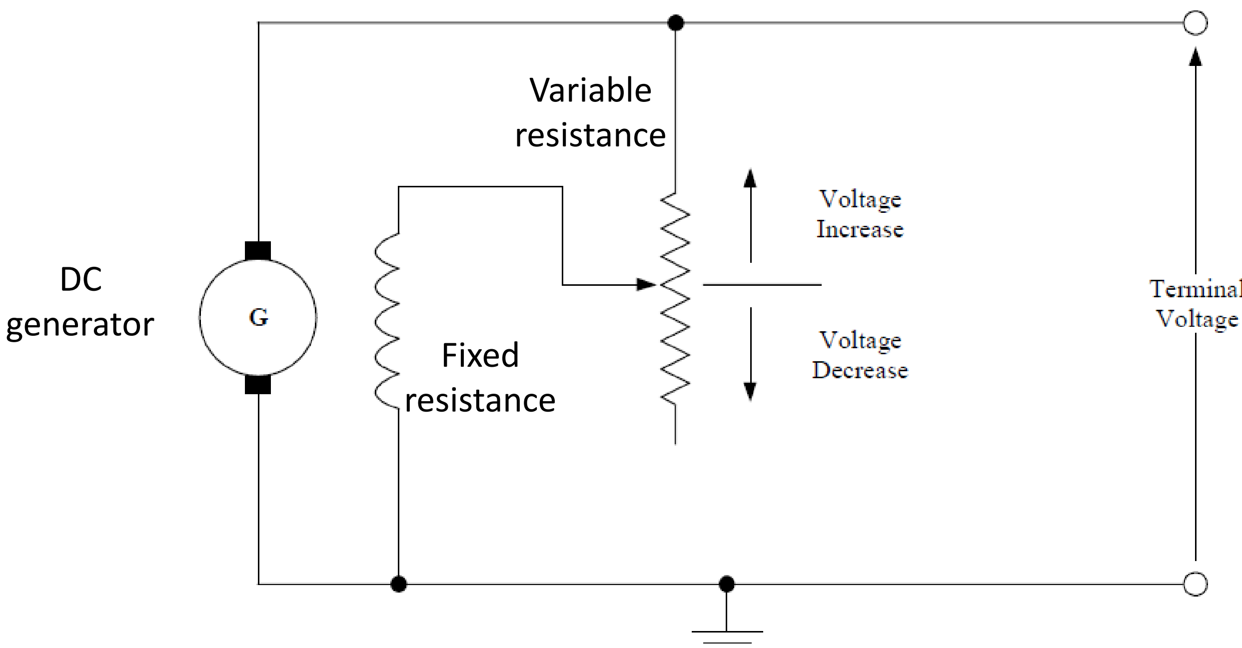
DC power generation

- In practice, several coils will be used simultaneously
  - The output voltages have different phases
  - The signals will be superimposed
  - The overall signal will be smoothed
  - A steady direct current power is generated.

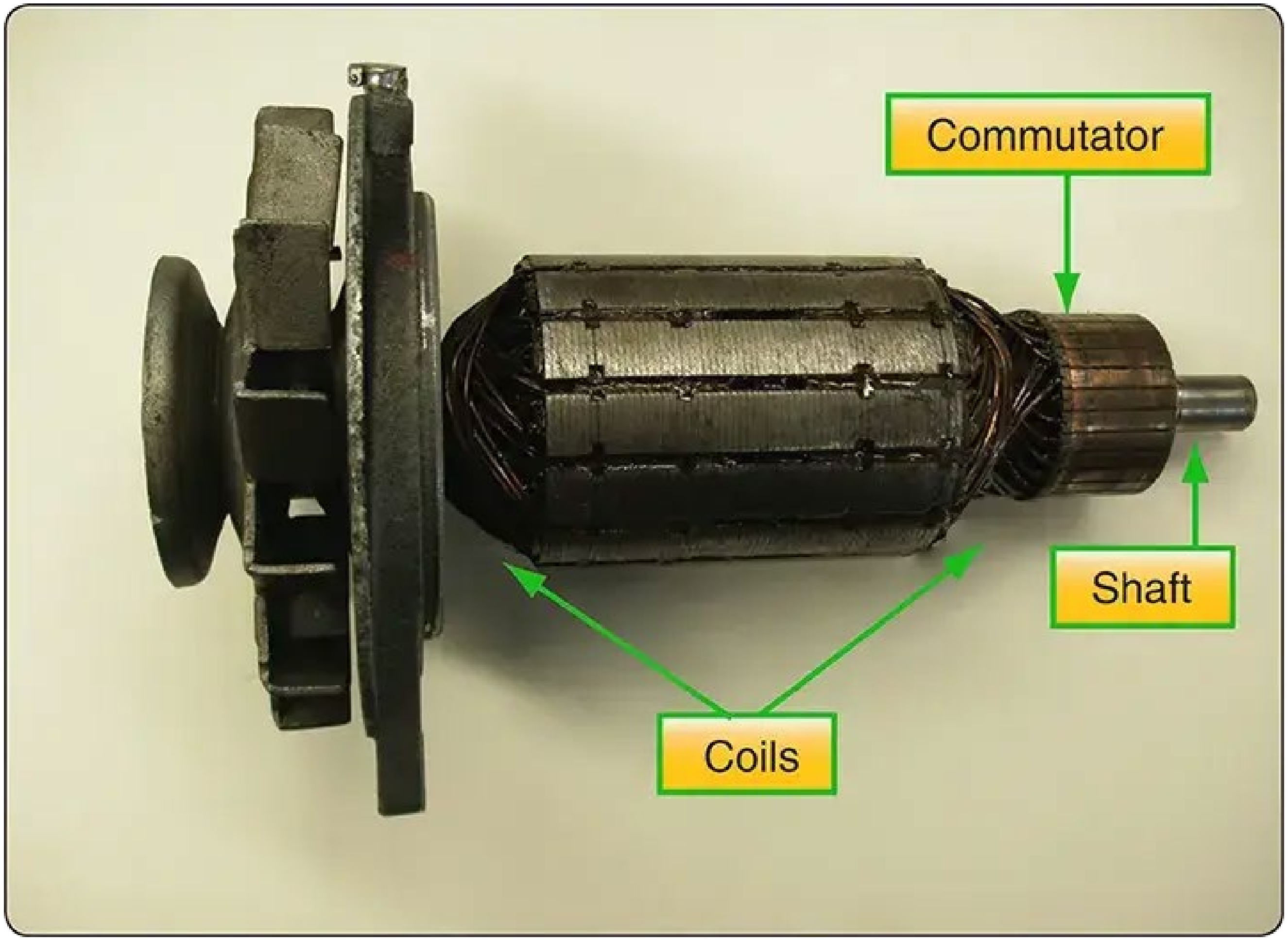


DC power generator

- The rotating of the magneto is driven by engine, but the rotating speed can vary, depending on the working condition
- However, the devices with electric demand are operated at specific voltage, e.g., 28 VDC.
- The DC voltage regulator is designed to modify the field current to ensure the terminal voltage is maintained.



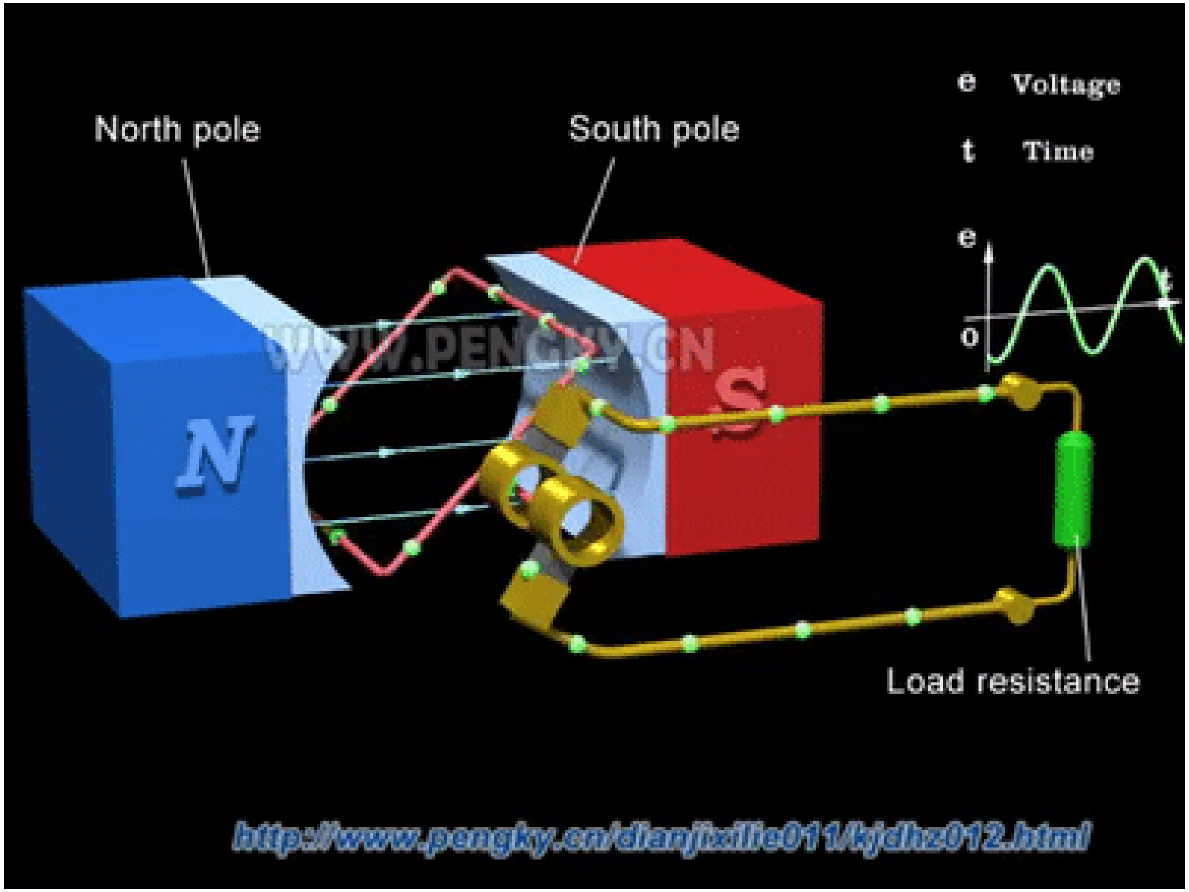
DC power generator



AC power generator (Alternator)

- On most large aircraft, the high-load electrical devices use AC power
- AC is generated by an AC generator, which is also called alternator
- AC generators use slip rings instead of commutators to provide the current to the circuit
- AC generators produces the three-phase current
- The standard aircraft voltage is 115 VAC with 400 Hz

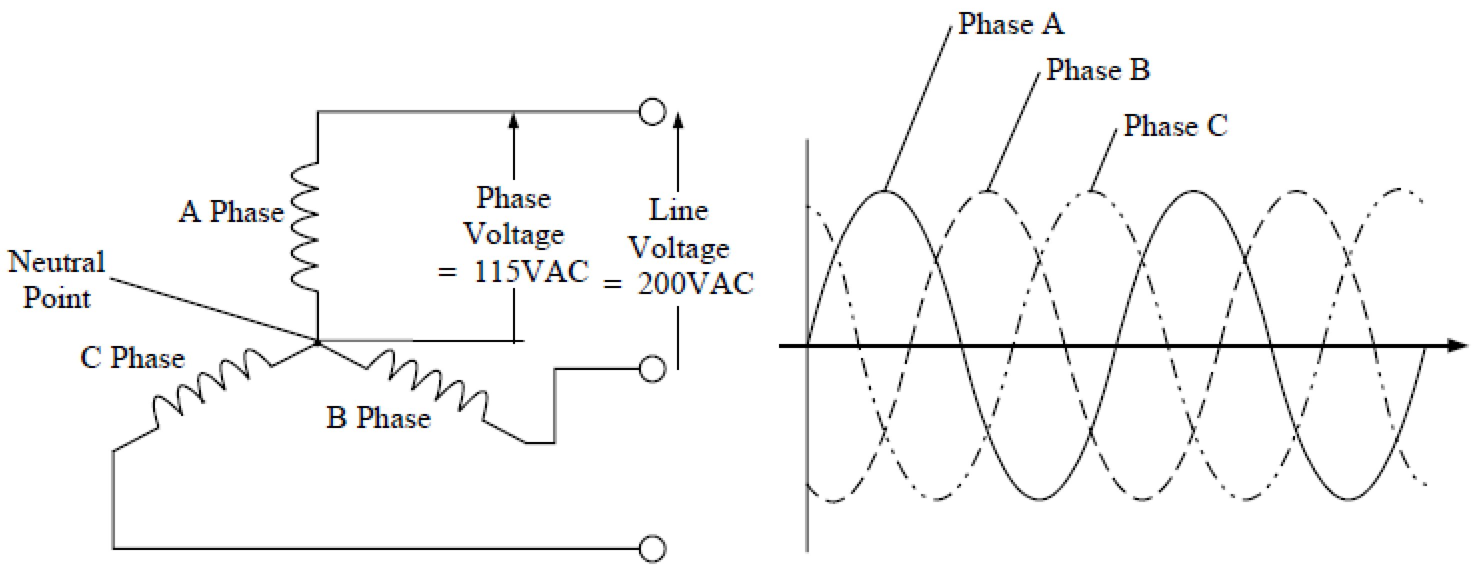
Basic AC generator



It is simple than the DC generator and no commutator is required.

AC generator

- An AC generator generates a sine wave of a given voltage, and in most cases, of a constant frequency.
- Most AC systems used on aircraft use a three-phase system:
  - 3 sine waves are generated with a phase difference of 120 degrees.



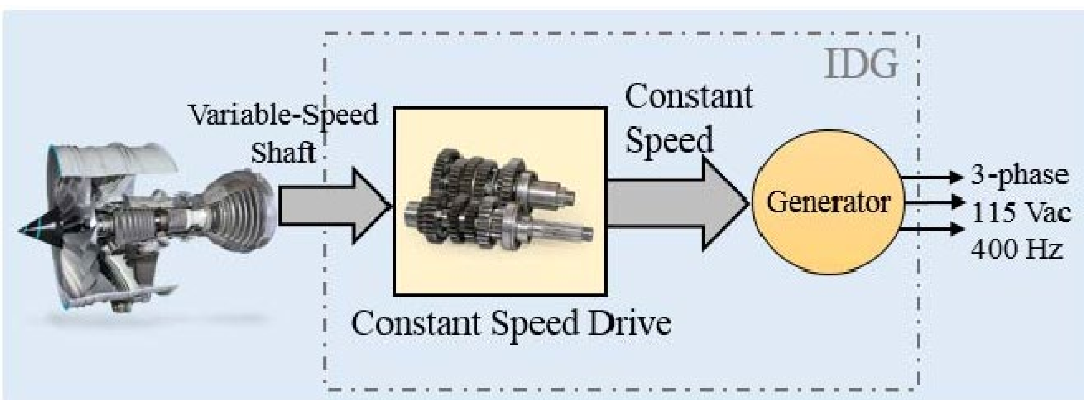
The common output voltage is 115 VAC, much higher than the DC system with 28 VDC.

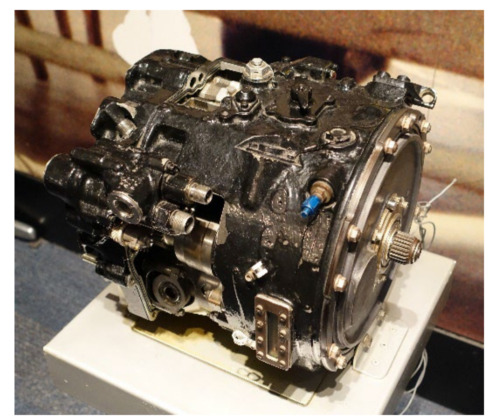
AC generator

- Apart from the constant output voltage, it is essential that the AC generator output have the same frequency of 400Hz with small tolerance.
- However, speed of the engine, which is used to provide the rotational mechanical energy, can vary with time, depending on the rotation speed.
- Solutions:
  - Constant speed drive (CSD)
  - Variable Speed Constant Frequency (VSCF) generator

AC generator: CSD

- Constant speed drive (CSD) unit is a device used between the engine and AC generator.
- CSD is often hydromechanically operated and maintained in terms of oil levels and oil cleanliness





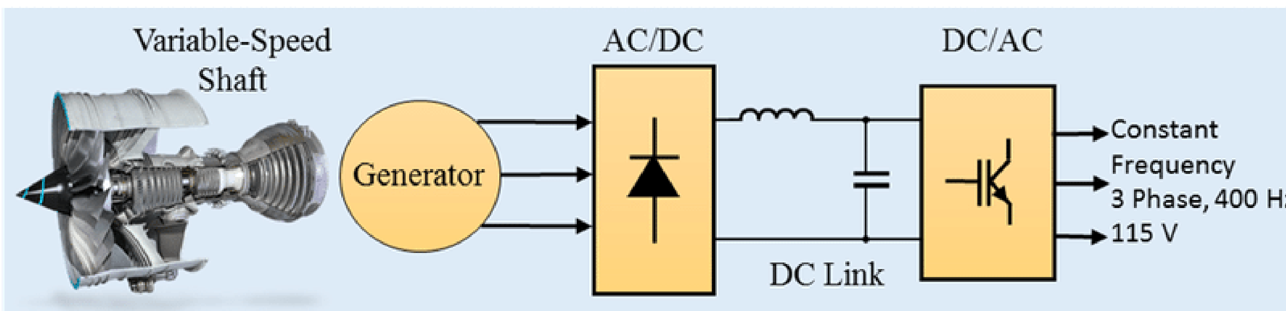
AC generator: CSD and IDG

- An AC generator and a constant speed drive unit is called an integrated drive generator (IDG).

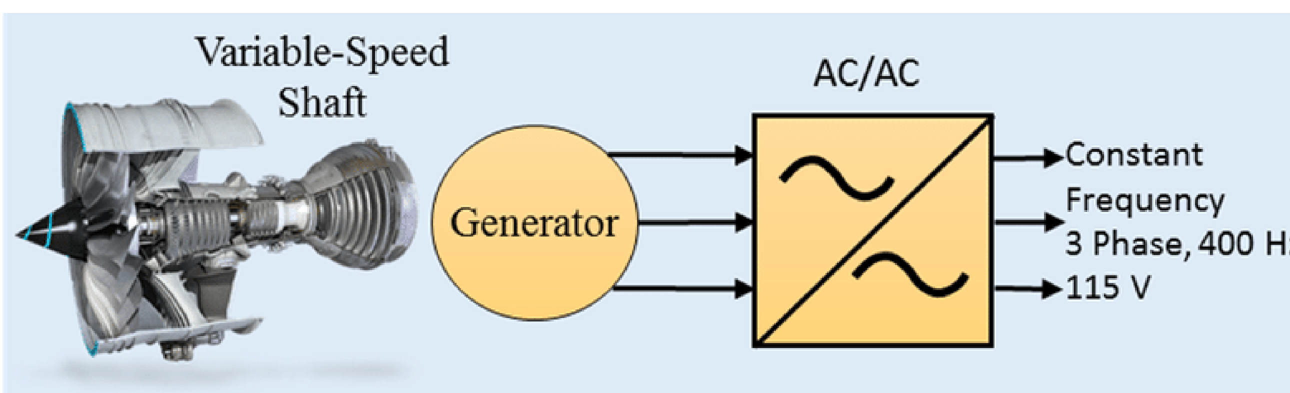
Example of the IDG for aircraft application

AC generator: VSCF

- Variable Speed Constant Frequency (VSCF) generator
  - The variable frequency power produced by the AC generator is converted to a constant frequency of 400 Hz, 115 VAC by solid-state devices electronically.



Using DC link



Using AC/AC converter

Alternators v.s. DC generators

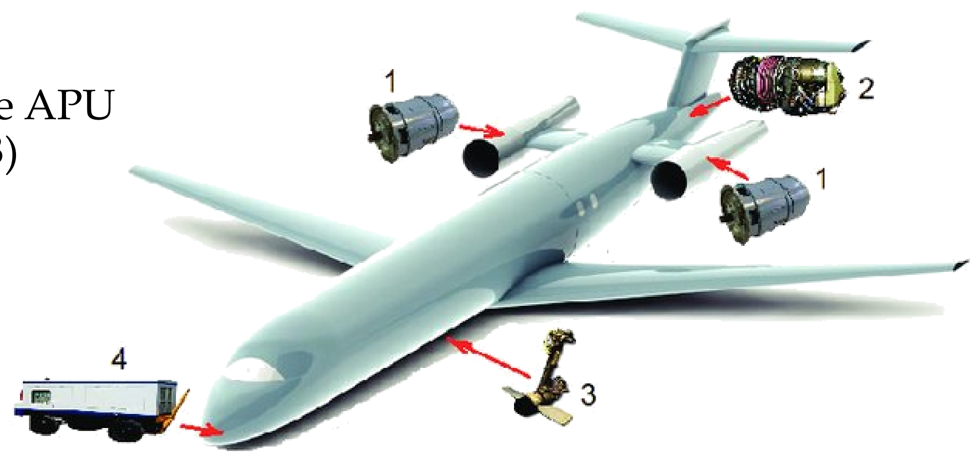
- DC generators produce direct current.
  - Most electronics equipment in an airplane is designed to operate on direct current, so the power from an alternator require to be converted into DC.

- Alternators create alternating current
  - Alternator in general creates more power for its size and weight than a generator
  - Alternator can produce more power at lower rpm.

Electrical power supply

Power sources

- In the case of a typical civil airliner the aircraft may accept power from the following sources:
  - Main aircraft generator
  - Alternate aircraft generator: in case of generator failure
    - APU generator: controlled by the APU Generator Control Breaker (GCB)
    - Backup converter
    - RAT generator



1: main generator
2: APU
3: RAT
4: GPU: ground power unit

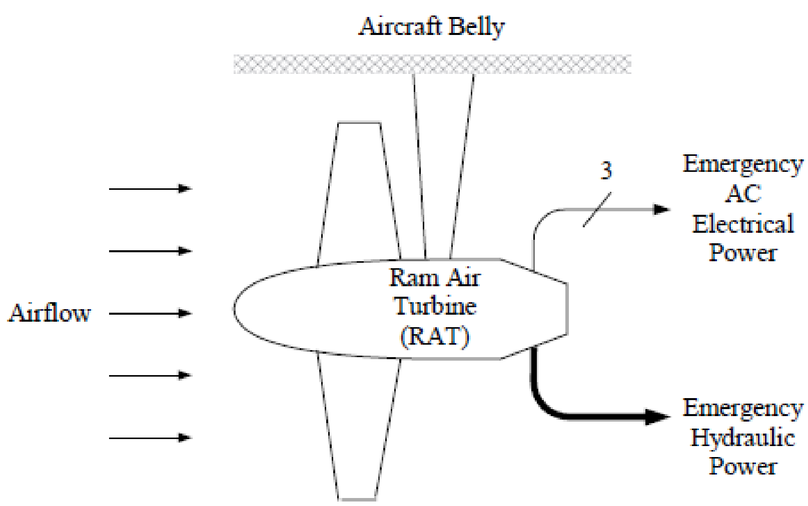
Emergency power generation

Only use engine

- In certain emergency conditions, typical power generation system may not meet the safety requirements, e.g., as regulated by the airworthiness authorities, additional emergency power sources may need to be used.
- Battery might be used for a short duration, typically up to 30 mins. But may not be enough. For example, the twin-engine aircraft may need to fly for 180 mins for alternative airport.
  - It is the ultimate solution.
- Therefore, backup power sources are needed, including:
  - Ram air turbine (RAT)
  - Permanent magnet generators (PMGs)
  - Others: e.g., backup power converters in Boeing B777

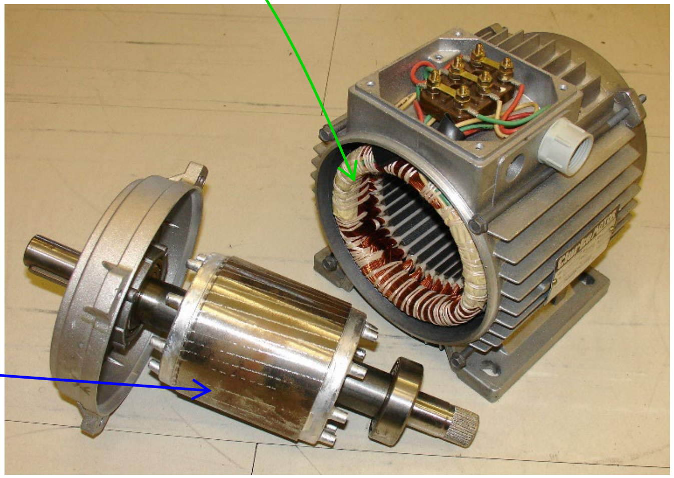
Ram air turbine/衝壓空氣渦輪

- RAT is deployed when most of the conventional power generation system has failed or unavailable for some reason.
- The RAT is an air-driven turbine, normally stowed in the aircraft ventral or nose section that is extended either automatically or manually in emergency condition.
- Typical RAT generator sizing may vary from 5 to 15 kVA



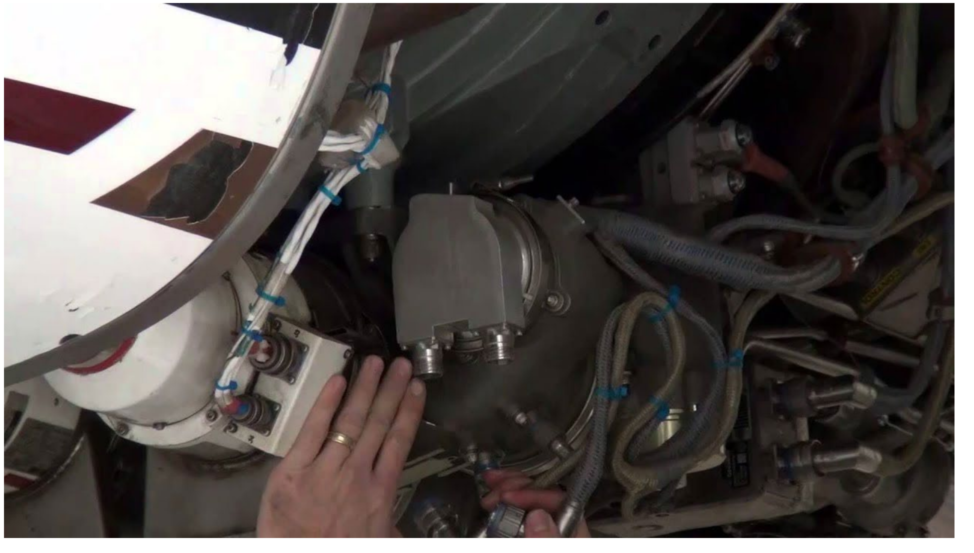
Permanent magnet generators (PMG)

- In generators, the magnetic field is necessary.
  - Variation of the magnetic flux induces the electricity.
- How is the magnetic field provided?
  - In common generators, it is provided by the coils on the stator
  - When additional AC power is supplied to the coils, the magnetic field will be generated.
  - Coils on the rotor, which is driven by external power, can lead to variation in the magnetic flux, generating electricity



Permanent magnet generators (PMG)

- An alternative solution is to use permanent magnet to provide the magnetic field.
- The use of PMGs to provide emergency power has become more popular.
- A backup converter hosts PMGs to supply several hundred watts of independent for flight control. Usually, the voltage should be regulated to 28 VDC.



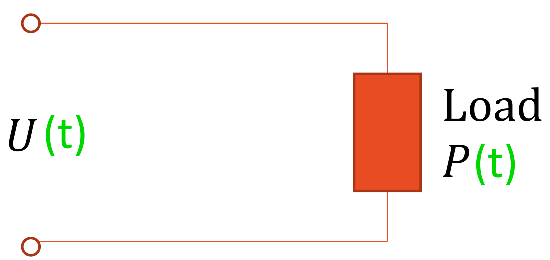
Power generation control

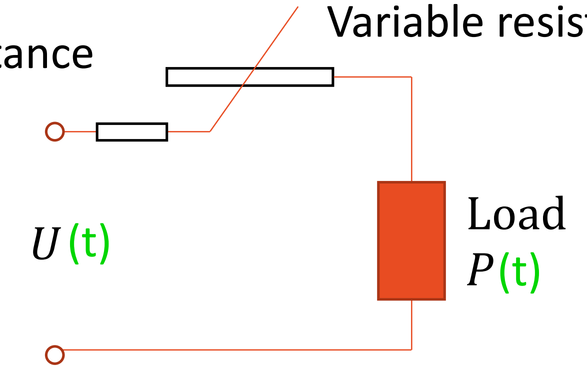
Power generation control

- Power produced by generators is usually controlled by the generator control unit (GCU)
- The primary functions of GCU are:
  - Voltage regulation
  - Parallel operation
  - Use direct current to charge the battery
  - Protect the circuit and generators by disconnecting the generator from the system

Voltage regulation

- The purpose of voltage regulation is to maintain the working voltage in different load and power output.
- In actual application, the voltage regulation is an automatic function accounts for the load and engine speed.
- An approach is to adjust the resistance of the field coils.
- MIL-STD-704D: a standard that is used to specify aircraft power generation systems.





Parallel operation

- In multi-engine aircraft, each engine drives its own generator.
  - It is desired that no-break or uninterrupted power is provided in case of engine/generator failure
  - Otherwise, a number of sensitive aircraft instruments and navigation devices may be disturbed and need restarting
- Therefore, in the DC systems, the generators are paralleled to ensure the load is evenly distributed.
  - The parallel generator operation leads to the need of interlink the voltage regulators.
- In the AC systems, the no-break requirement might be controlled in a similar way for the AC generators with constant frequency.
  - But in general, the parallel operation will be more complex because of the varying voltage phases.

Protection functions

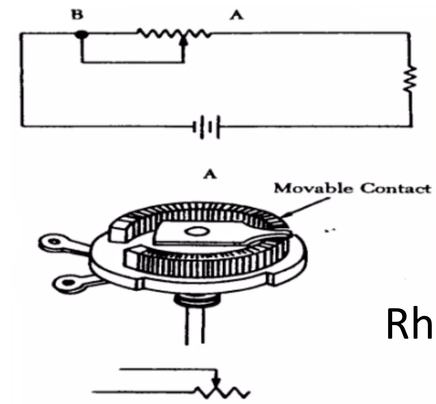
- In a DC system, protections are needed for these conditions include:
  - Reverse current: the current should flow from the generator to busbars and distributions
  - Overvoltage: fault in the field excitation circuit can cause the generator over-cited and may cause permanent damage to the electrical load devices
  - Undervoltage: in the multi-generator configuration, the undervoltage of one path can cause failure of the whole system
- Devices:
  - Circuit breakers: to prevent the circuit in the event of electrical overload
  - Solid state power controllers (SSPC): combines the functionalities of relay or switch and circuit breaker.
  - SSPCs are rapidly developed.

Control devices

- The GCU is realized by using some devices in the circuit, including:
  - Switches/開關: to start, stop or change the current direction
  - Rheostats/變阻器: to control the amount of current through the circuit and used as dimmer devices for instruments and cockpit lights
  - Relays/繼電器: electromagnetic switching device to **remotely** control electric circuit carrying large amount of current
  - Solenoids/電磁閥: Being similar to relays. But they are designed to move a shaft over a **short distance for** mechanical controls, e.g., valves.

Control devices

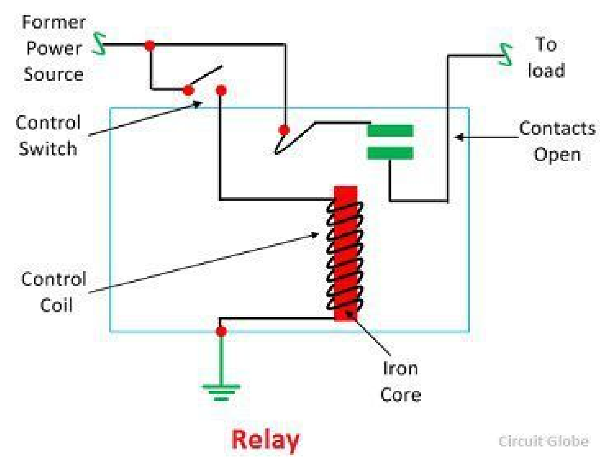
Toggle switch/撥動開關



Rheostats/變阻器

rotary switch/旋轉開關

Relays/繼電器



Conversion devices

- There are also occasions within an aircraft electrical system it is needed to convert power from one to another, e.g.,
  - Conversion from 115 VAC to 28 VDC, e.g., for battery charging
  - Conversion from one AC voltage to another
- The associated devices are:
  - Transformer/變壓器: to change AC voltage levels
  - Rectifiers/整流器: to convert AC to high-amperage, low-voltage DC
  - Transformer-rectifiers units (TRUs): the main units to convert AC to DC
  - Inverters/逆變器: convert 28 VDC to 26 VAC or 115 VAC
  - Transistors: convert AC to DC

Transformer rectifier units (TRU)

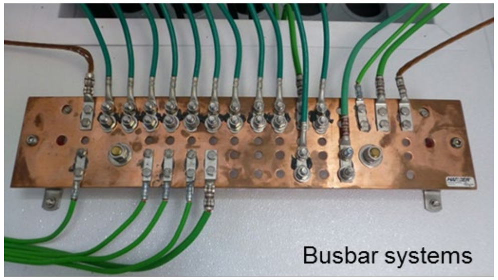
Primary power distribution

Primary power distribution

- In most aircraft, output from those generators is send to one or more conductors before distributing to the whole system.
  - These conductors are called **busbars** and they act as distribution center for the electric power.
  - A busbar system is set up that each power source supplies one or more specific buses.
- The primary power distribution system coordinates the aircraft electrical power input.

Busbar

- Various electrical items are bunched to each bus for power, e.g.,
  - The high-current items are connected to the bus of the engine-driven generator
  - Emergency lights are connected to the powered off battery bus
- The buses are interconnected via circuit protection devices which are called bus ties:
  - The bus ties are made of switches and relays to connect or disconnect buses from each other



Busbar systems

Wires and cables

- Wires and cables conduct electrical power to the equipment
- In aircraft electrical systems:
  - the conductor is made of copper or aluminium.
  - The insulation material may be nylon, PIV, fiberglass, etc.
- When selecting the wire, conditions shall be considered include:
  - Overheating property
  - Voltage drop property
  - The electrical wire chart may be used.

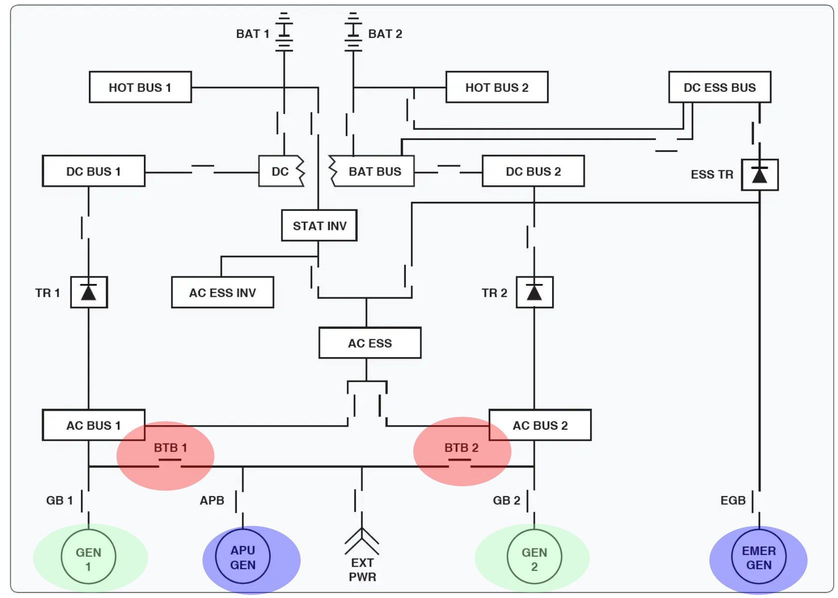
Primary power distribution

- Electrical distribution for large aircraft may be categorized into three types:
  - split-bus system
  - parallel system
  - split-parallel system

BTB: bus tie breaker
GB: generator breaker

Split-bus distribution systems

- Under normal conditions, each engine-driven AC generator powers only one main AC bus
- The buses are kept split from each other, and two generators can never power the same bus simultaneously.
  - This is very important since the generator output current is not phase regulated.
- APU and RAT can work as back-up generators

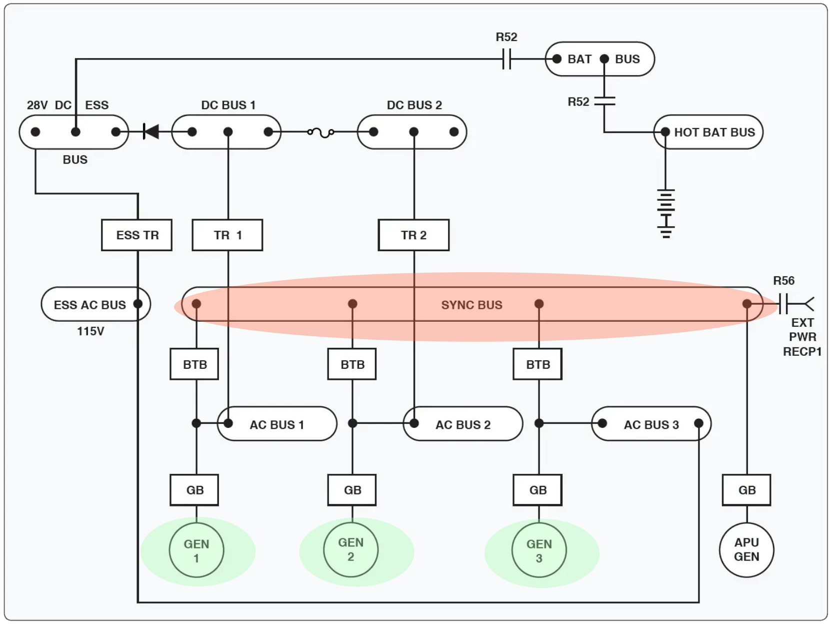


Schematic of split-bus power distribution system

Modern twin-engine aircraft, such as the Boeing 737, 757, 777, Airbus A-300, A-320, and A-310, employ a split-bus power distribution system

Parallel systems

- During normal flight conditions, all engine-driven generators connect together and power the AC loads.
- In this configuration, the generators are operated in parallel:
  - parallel power distribution system.
- In a parallel system, all generator output current must be phase regulated
- Advantage of parallel systems:
  - If a generator failure, the busses are already connected and the defective generator need only be isolated from the system

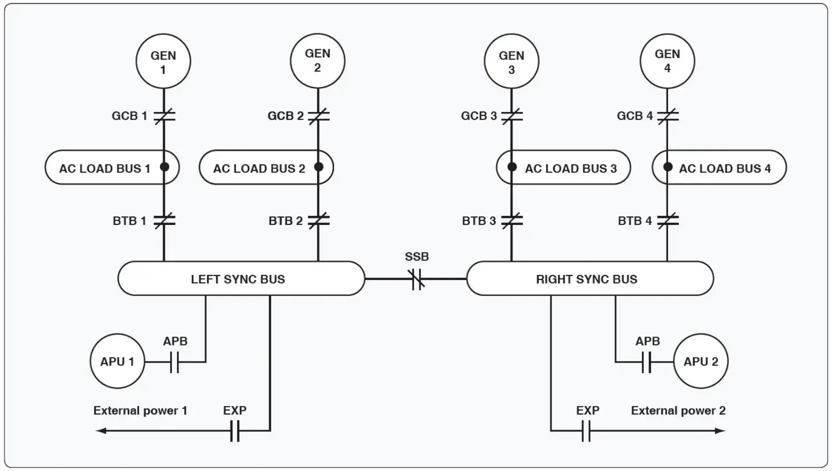


Schematic of parallel power distribution system

Multiengine aircraft, such as the Boeing 727, MD-11, and the early Boeing 747, employ a parallel power distribution system

Split-parallel systems

- A split-parallel bus basically employs both split-bus and the parallel-bus systems.
- The system can operate with all generators in parallel, or the generators can be operated independently as in a split-bus system.
  - During a normal flight, all four engine-driven generators are operated in parallel.
  - In case of failure (or using external power), the system is operated in split-bus mode.



Schematic of split-parallel power distribution system

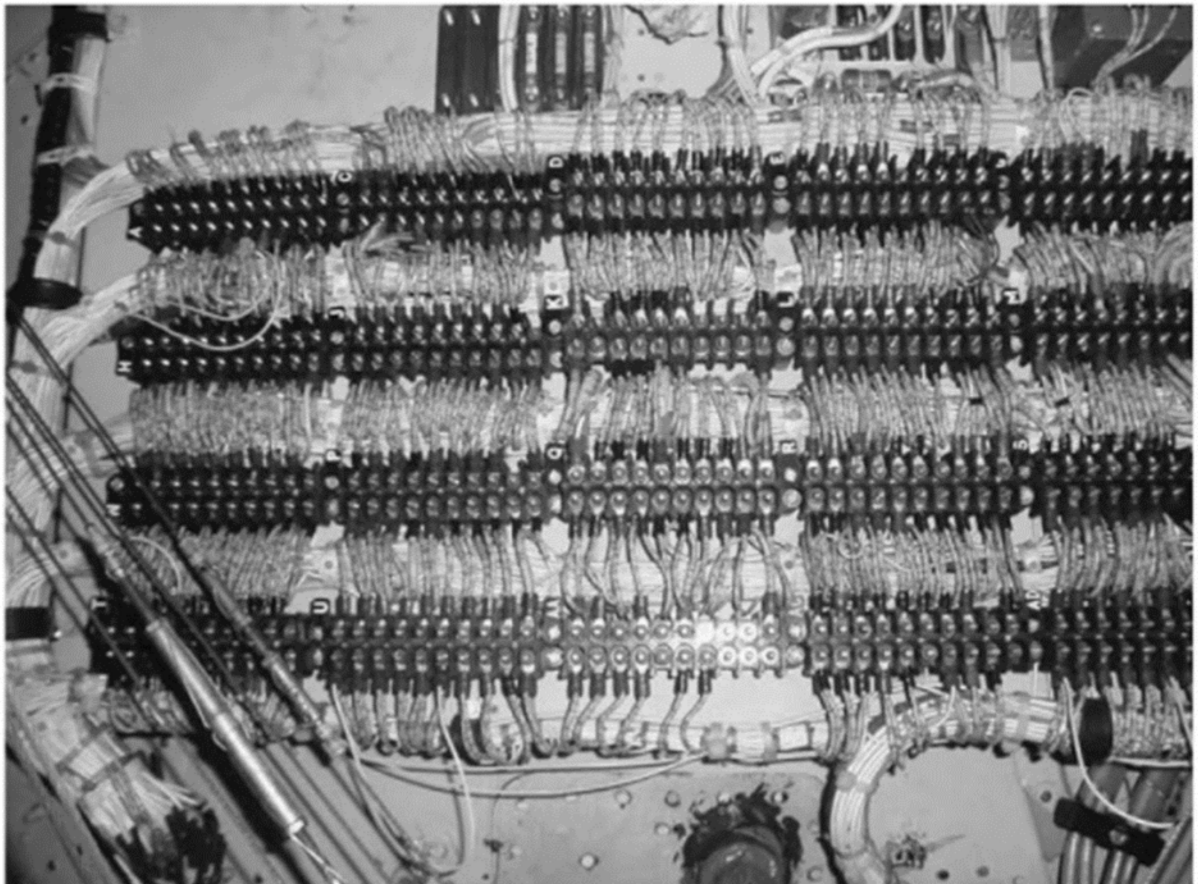
Example of the split-parallel system: Boeing 747-400 contains 4 engine-driven generators driven by two APU-driven generators

Split V.S. parallel bus systems

- Parallel bus systems
  - Provides a continuity of electrical supply.
  - Prolongs the generator life expectancy, since each generator is normally run on part load.
  - Readily absorbs large transient (surges / spikes) loads
  - Expensive protection circuitry is required since any single fault may propagate through the complete system.
  - Parallel operation does not meet the requirements for totally independent supplies.
  - Load shedding is required when more than 2 generating sources failed.

- Split bus systems
  - The generator operates independently. That is, generator output frequencies and phase relationships need not be so closely regulated.
  - Unequal loading is experienced in each Generator.
  - Loss of one generator and APU means a complete loss of power to loads connected to that given bus.

Typical Power Distribution



Aircraft Electrical and Electronic Systems By David Wyatt, Mike Tooley

Summary

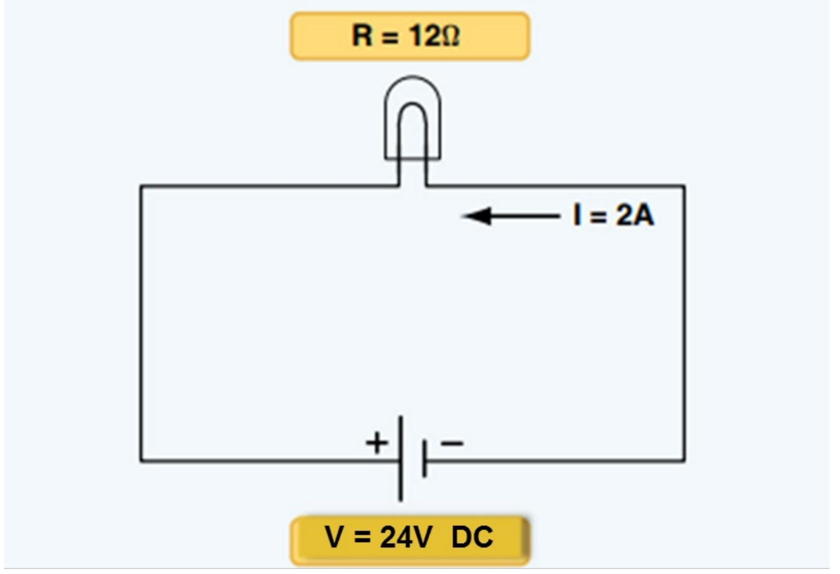
Summary

- The characteristics of the civil aircraft electrical system is introduced
- Brief introduction to the electrical demands in aircraft
- Methods of the electrical power generation and the major power suppliers in aircraft
- Introduction to the elementary devices to control the electrical circuit in aircraft
- Introduction to different layouts of the electrical power system in aircraft
- Some background knowledge regarding electrical circuit is presented in the appendix

Appendix

Simple DC electrical circuit

- Any electrical circuit must have at least three parts.
  - The source of electrical power (V)
  - The electron transportation, distribution and protection system (circuit)
  - The load (Where the work is done, R)



This diagram shows a basic electrical circuit of a Light (12 ohm) connected to a 24V DC source.

Ohm’s law

- Ohm’s Law describes the basic mathematical relationships of DC electrical circuit. Ohm’s Law is:

$$I = \frac{V}{R}$$

  – where V = electromotive force measured in volts, I = current flow measured in amps, and R = resistance measured in ohms.

Georg Simon Ohm (1789-1854)
German Physicist and Mathematician

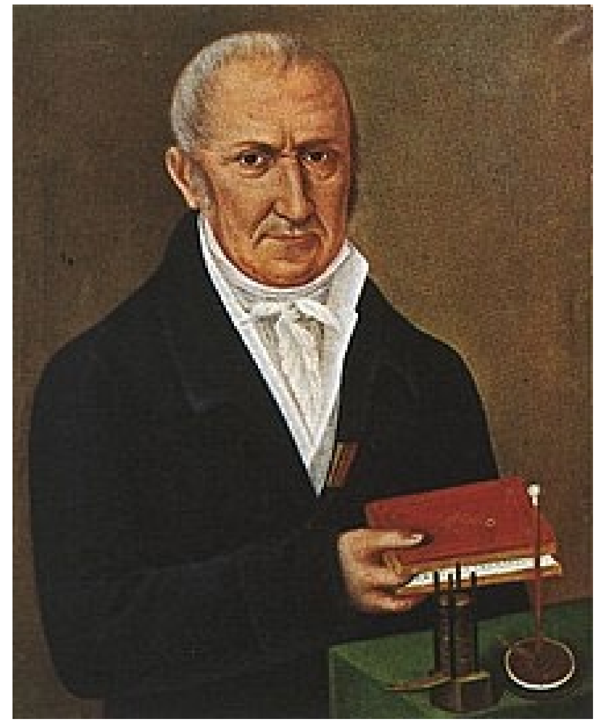
Ohm's law

- Current
  - Electrical current is the movement of electrons. This electron movement is referred to as current, flow, or current flow.
  - In practical terms, this movement of electrons must take place within a conductor (wire).
  - Current is typically measured in amperes. The symbol for current is I and the symbol for amperes is A. The current flow is actually the movement of the free electrons found within conductors.
  - Greater the current, thicker the conductor is needed to transport the electrons to prevent over heating or melting of the conductor.

André-Marie Ampère (1775-1836), French physicist and mathematician

Ohm's law

- Electromotive Force (Voltage)
  - Voltage is most easily described as electrical pressure force. It is the electromotive force (EMF), or the push or pressure from one end of the conductor to the other, that ultimately moves the electrons. The symbol for EMF is the capital letter E.
  - EMF is always measured between two points and voltage is considered a value between two points.



Alessandro Giuseppe Antonio Anastasio Volta (1745-1827)
Intalian physicist and chemist

Ohm's law

- Resistance
  - The two fundamental properties of current and voltage are related by a third property known as resistance.
  - In any electrical circuit, when voltage is applied to it, a current results. The resistance of the conductor determines the amount of current that flows under the given voltage.
  - In general, the greater the circuit resistance, the less the current.

- Factors affecting resistance
  - The resistance of a metallic conductor is dependent on the type of conductor material.
  - Certain metals are commonly used as conductors because of their large number of free electrons in their outer orbits.
  - Copper is usually considered the best available conductor material, since a copper wire of a particular diameter offers a lower resistance to current flow than an aluminum wire of the same diameter.
  - However, aluminum is much lighter than copper and cheap. Therefore, aluminum is often used when the weight factor is important.

DC’s power

- Electrical power is given by:

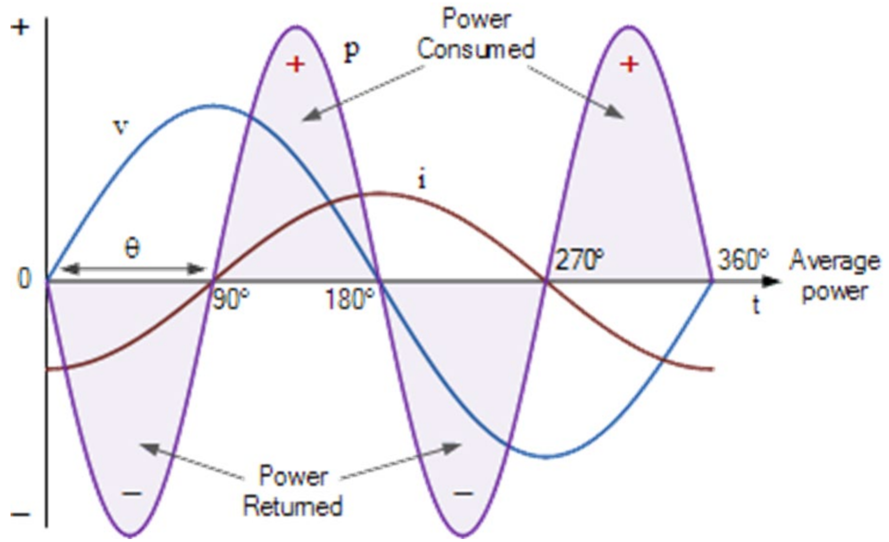
$$P(\text{Watts}) = V \cdot I = I^2 R = \frac{V^2}{I}$$

where:

- V is the DC voltage,
- I is the DC current
- R is the value of the resistance.
- Therefore, power within an electrical circuit is only present when both the voltage and current are present. That is, no open-circuit or short-circuit conditions.

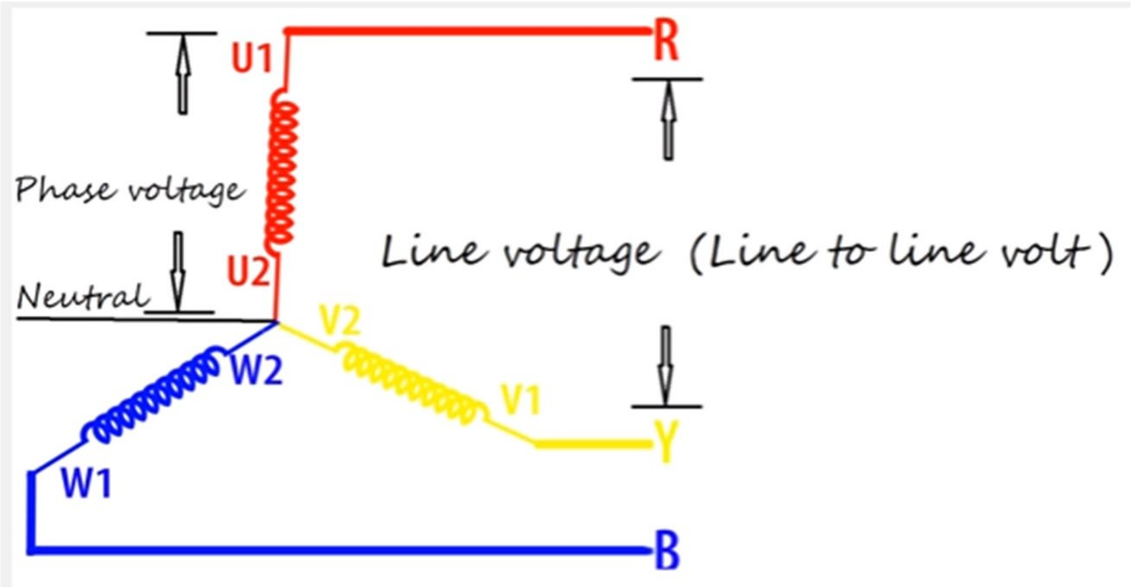
AC's power

- In a DC circuit, the power consumed is simply the product of the voltage times the current (i.e. V x I), and is measured in watts. However, for AC circuit, it is not so straight forward.
  - In an AC circuit, the instantaneous values of the voltage, current and therefore power are constantly changing being influenced by the supply. So the power in AC circuits is complicated.
  - However, instantaneous power (p) is still equal to the instantaneous voltage (V) times the instantaneous amperage (I).



Basic AC electric quality

- In a three-phase wye electric power system, each single phase is measured with respect to the "Neutral". When you measure any phase (ΔU or ΔW or ΔV) with respect to Neutral, it is called "Phase Voltage."



When you measure voltage between any two phases (Δ U - Δ W or ΔW - ΔV or ΔV - ΔU), it is called "Line Voltage."

Basic AC electric quality

- The relationship between phase voltage V_p and line voltage V_L is:

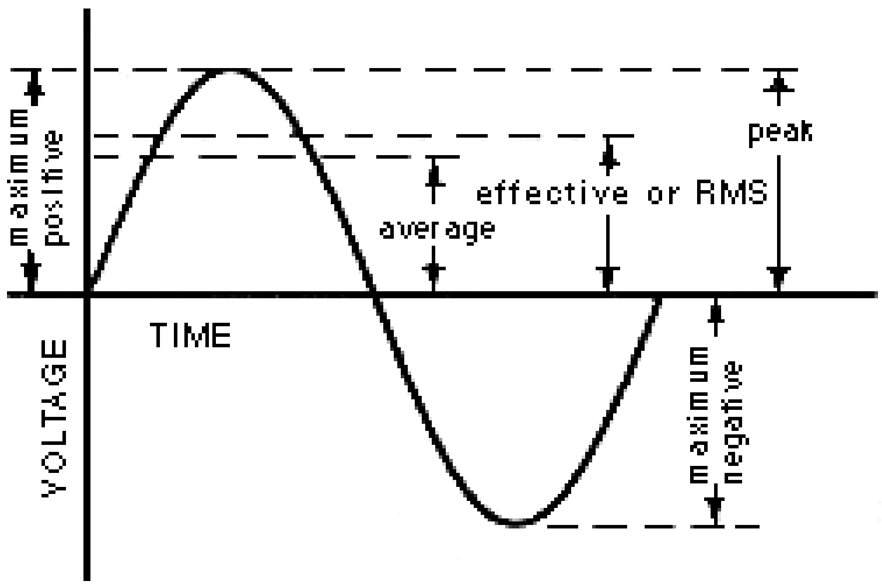
$$V_L = \sqrt{3}V_p$$

- The relationship between peak voltage V_{peak} and rms voltage V_{rms} is:

$$V_{peak} = \sqrt{2}V_{rms}$$

- The relationship between rms voltage V_{rms} and average voltage $V_{average}$ is:

$$V_{rms} = \frac{\pi}{2\sqrt{2}}V_{average}$$



Instantaneous power

- Given the voltage and current alternates at angular frequencies (ω_V *and* ω_I), the instantaneous or active Power P(t) is given by:

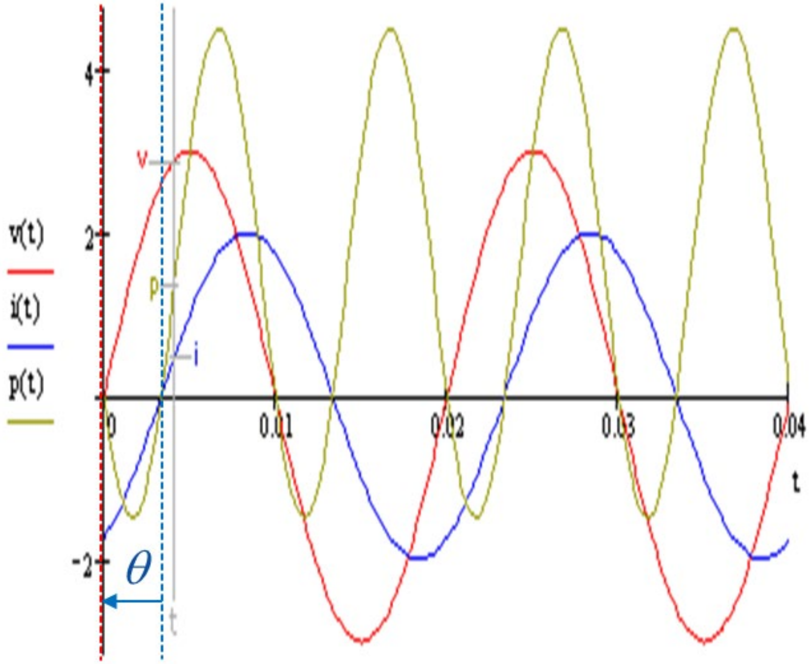
$$P(t) = V(t) \cdot I(t)$$

- where

$$V(t) = V_{peak} \sin(\omega_V t)$$

$$I(t) = I_{peak} \sin(\omega_I t + \theta)$$

  – θ is the phase difference of the voltage waveform from the current waveform.

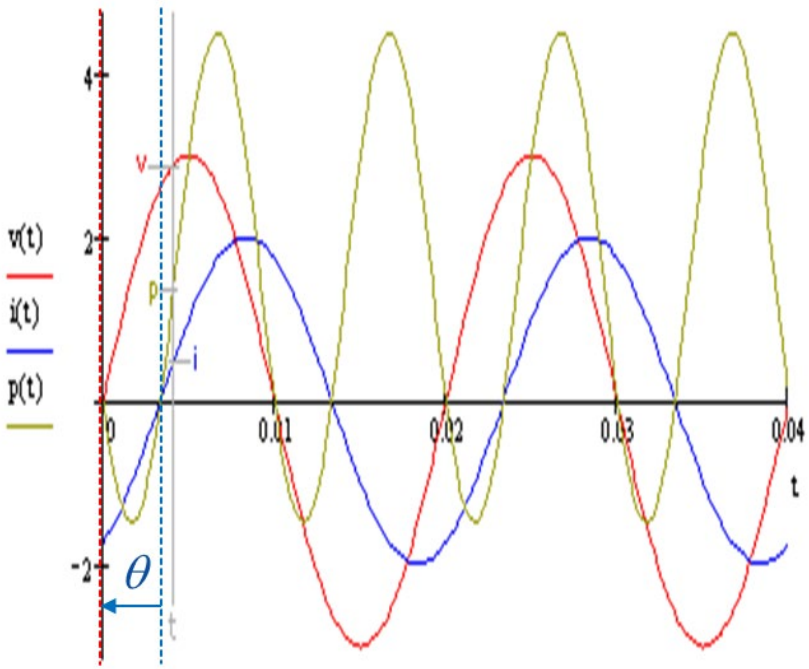


Instantaneous power

- We can write,

$$P(t) = V_{peak} I_{peak} \sin(\omega_V t) \sin(\omega_I t + \theta)$$
$$= \frac{V_{peak}}{\sqrt{2}} \frac{I_{peak}}{\sqrt{2}} \times 2f(t) = V_{RMS} I_{RMS} \times 2f(t)$$

Here 2 $f(t)$ is called the power factor, $V_{RMS}I_{RMS}$ is the apparent power *VA*.



All electric aircraft

- Advantages of more complex electrical power system
  - Decreased total usage of heavy gauge power feeders, which results in reduced weight
  - Decreased total power distribution wiring
  - Better electronic control of load throughout airplane

- Disadvantages of more complex electrical power system
  - More vulnerable to electrical failure
  - Significant increase in the need for power, which can be very dangerous in the case of emergency
  - Increased probability of short circuit and loss of power, due to more electrical circuits