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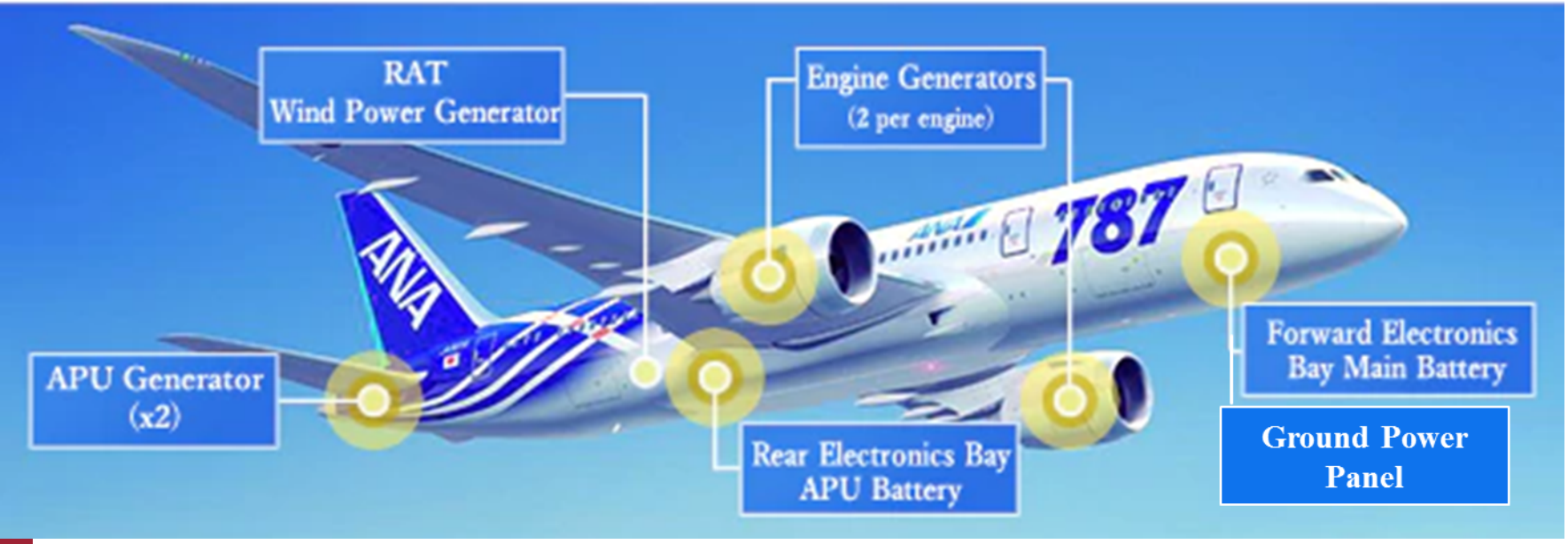
AAE2001 – Introduction to Aircraft Design and Aviation Systems

Electrical System

Dr. Yiping Jiang

Mid-term Test next week

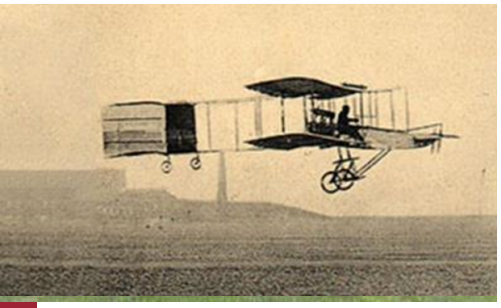
- Open book
- Based on lecture content, assess your understanding and application of certain knowledge point.
- 2h, time restriction, no submission afterwards
- Online test in blackboard, submit online in blackboard



Electrical System

https://www.youtube.com/watch?v=d5sXmNplQHw

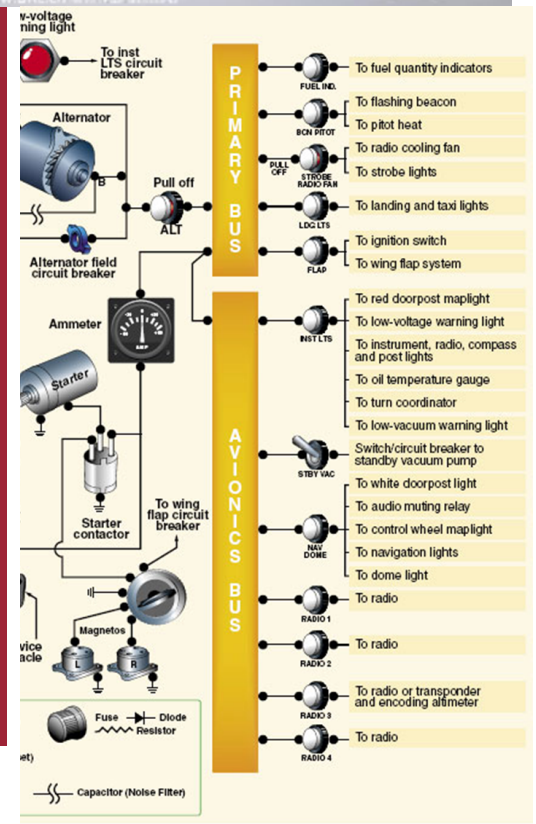
Aircraft Electrical System



Virtually all aircraft contain some form of an electrical system. The complexity of an aircraft's electrical power system varies with its size and operational requirement.

- Even the earliest, most basic piston powered type aircraft must produce electricity for operation of the engine's ignition system.
- Small single-engine aircraft has relatively simple electrical system due to less demand and less redundancy is required
- Large passenger aircraft electrical system becomes highly complicated due to the high load demand and high reliability requirement.

Redundancy and Reliability



For large passenger aircraft, one way to increase reliability is to allow more than one (i.e. **redundancy**) power source can be used to power any given load. Furthermore, battery is used as an ultimate backup source of power.

The power distribution systems could also contain several distribution points (called bus bar) and a variety of control and protection components (circuit breakers and fuses) to ensure the reliability of electrical power.

The electrical power systems becomes more reliable and complex at the same time.

What is Electrical System?

An Aircraft Electrical System is a self contained network of components that **generate**, **regulate**, **transmit**, **distribute**, **utilize** and **store** electrical energy.

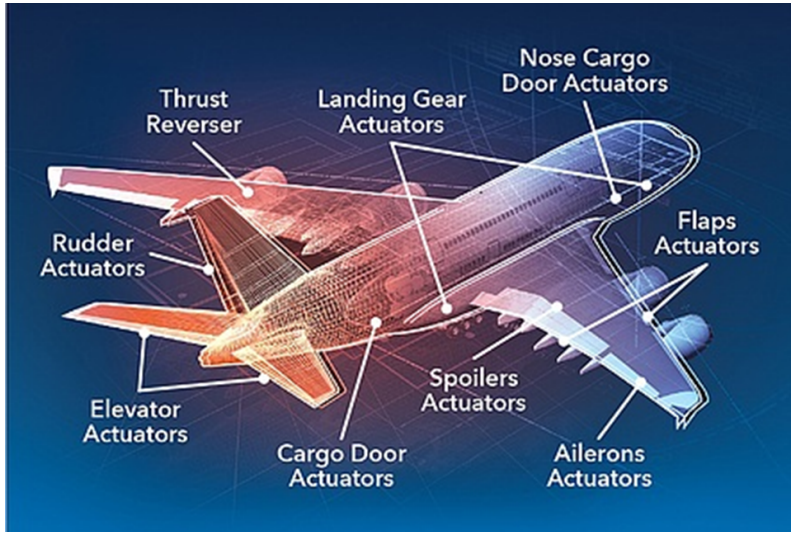
The electrical systems used in the aircraft has been improved progressively over several decades with the advancement of power electronics.

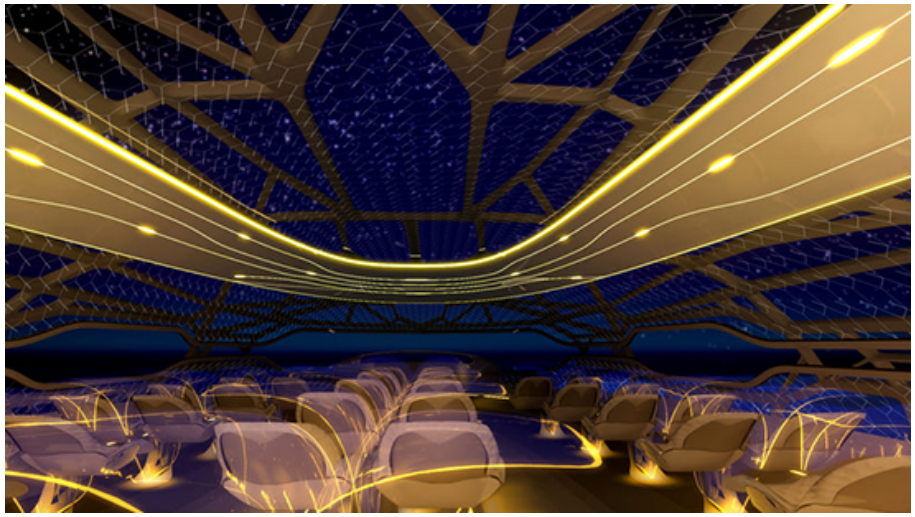
In modern day aircraft, uninterrupted steady electrical power is essential to safe flight in a modern airplane. Aircraft performance and safety are directly connected with the reliability of electrical systems and subsystems.

Aircraft Electrical System

The trend in modern aircraft design is away from mechanical systems (hydraulics, pneumatics, etc.) and toward electrical components. There is an great appetite for more and more electrical power.

In general, aircraft electrical systems today delivers **both AC and DC power**. There are also high voltage and low voltage in an aircraft for powering high voltage and low voltage equipment.





AC or DC?

Some advantages of AC and DC

- AC is much easier to step up and down in voltage using a transformer than DC, and can be done more efficiently (at present at least) than the much more expensive and complex DC step-up/step-down systems.
- Alternators are cheaper
- Alternators generate more power for a given size than DC generators.
- AC is inherently better for long-distance power transmission
- AC is particularly useful for industries, where you can simply take the power of the 3-phase AC supply.
- AC has the downside of inductive and capacitive losses.

AC or DC? Electrical engineers have debated over this question for centuries. For applications, other factors come into play – not just AC or DC alone. And why limit ourselves to just one source?

Electrical Load Analysis

Load: Any device or equipment that demands electricity to function requires power from the aircraft's electrical power system. Each such demand is called a "load" from the EPS's perspective. These loads are distributed throughout the aircraft and may be broadly subdivided into following 3 categories.

- **Galley loads**

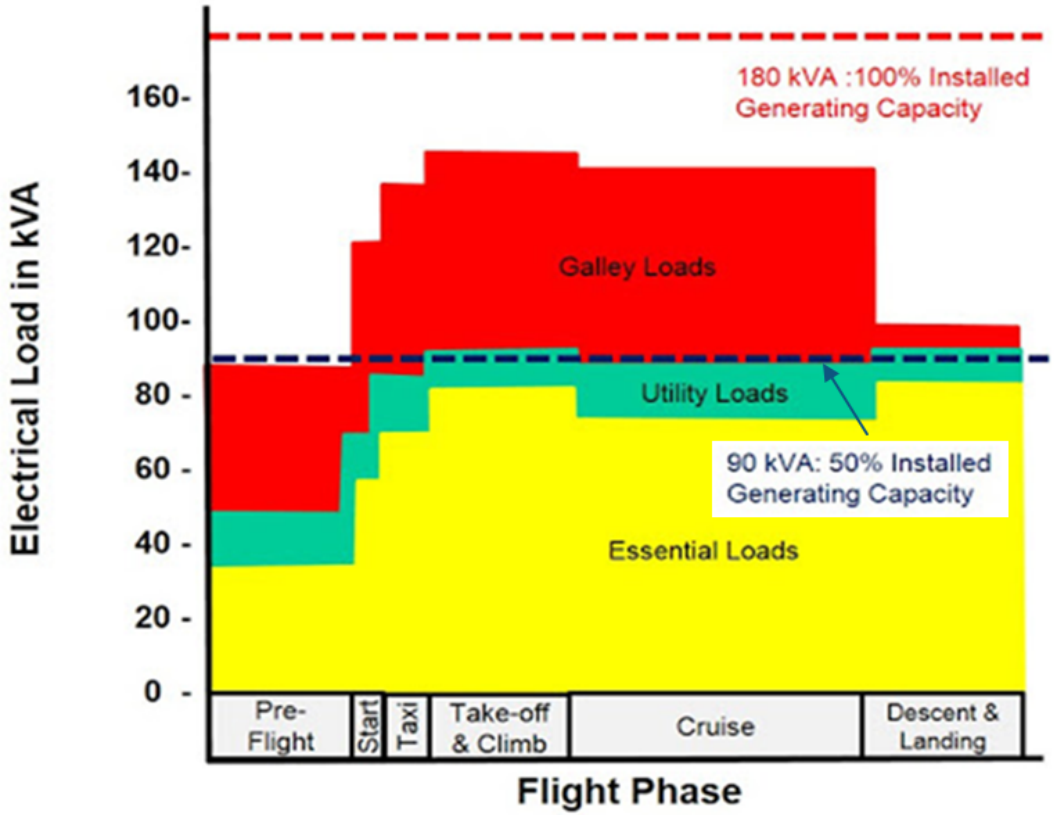
(ovens, coffee and hot water machines, fridges, toilets)

- **Utility loads**

(cabin lights, IFE)

- **Essential loads**

(motors, cockpit lighting, exterior lights, avionics, climate control)



Electrical load analysis (ELA) ▶

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

Electrical Power System Requirement

1. The Electrical Power systems (EPS) should be capable of supplying **all electricity requirements** for all modes of vehicle operation plus additional capacity to provide for growth loads.
2. The EPS shall provide **protection** to prevent unsuitable external power from being applied to the airplane.
3. The buses and distribution circuits shall be configured so normal EPS operation loads receive power from the aircraft primary power source(s), ground power, or an auxiliary power source as applicable. The buses, conductors, and circuit breakers should be capable of handling the load growth provisions.

Electrical Power System Requirement

5. In the event of an EPS failure that reduces the amount of available power below total aircraft requirements, non-flight critical and/or pre-selected loads should be automatically disconnected as required.
6. In recently certified airplanes, there must be enough battery power available to power the critical items for IFR flight for 30 minutes.

In this chapter, we will look over the fundamentals of:

- Electrical Power Generation
- Electrical Power Distribution
- Electrical Power Conversion and Storage

as applied to aircraft, and take the electrical system diagrams of several existing aircraft for case studies.

Power Generation

Aircraft Electrical Supply

Despite the details of the electrical system can significantly vary from one type of aircraft to another, the basic principles and requirements of all electrical power system are essentially the same.

Aircraft electrical and electronics systems utilize both AC and DC power. The industry standard outputs are:

- **115-120V/400HZ AC**
- **28V DC (or 14V DC in older systems)**
- 270V DC (popular in military applications, but also finding increasing interest in civil applications.)

However, don't be surprise if you come across values other than the standards. The B787 generates 230V AC.

For example:

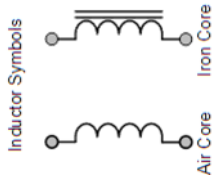
- 115 V AC are used directly as secondary source of power for AC motors and pumps, kitchen galley power supply for kitchen appliances such as oven, rice cooker, kettle, coffee maker, refrigerator, etc.
- 28V DC are used to power avionics, DC electric motors and DC pumps, battery charger, lighting, and flight control computers.

Electrical Frequency in Aircraft

- The frequency of the electrical system used in aircraft is 400Hz. Just for comparison, the frequency used in home, office in most cities is 50Hz or 60Hz.
- The AC phase voltage of the electrical system used in aircraft is 115V. Just for comparison, the AC phase voltage used in home, office in most cities is 240V or 110V.

Why do aircraft use such a higher frequency as compared to our household mains?

Inductor Energy Stored



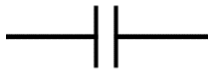
The energy E_L stored in an inductor L is:

$$E_L = \frac{1}{2} L\, I^2$$

The Power P_L processed by the inductor is:

$$P_L = E_L\, f = \frac{1}{2} L\, I^2 f$$

Capacitor Energy Stored



The energy E_C stored in a Capacitor C is:

$$E_C = \frac{1}{2} C\, V^2$$

The Power P_C processed by the capacitor is:

$$P_C = E_C\, f = \frac{1}{2} C\, V^2\, f$$

Electrical Frequency in Aircraft

These equations show: for a given amount of power being processed, higher operating frequency f requires smaller Inductor L and Capacitor C.

Inductor, Capacitor and Transformers are relatively weighty and bulky. Since at a higher operating frequency, smaller and lighter electrical components can be employed, the use of a higher frequency is preferred.

As an approximation, at an operating frequency of 400Hz instead of 50Hz (8 times higher), the electrical components can be reduced to 1/8 in size. However, higher frequency will accompany with high losses due to inductor loss and capacitor loss.

Aircraft Electrical System

The generic parts of a typical AC aircraft electrical system comprises the following.

1. **Power generation**
2. **Primary power distribution and protection**
3. **Power conversion and energy storage**
4. Secondary power distribution and protection

Power Generation

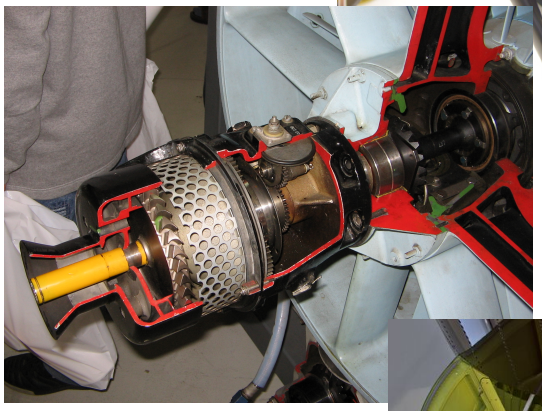
All aircraft electrical systems have generators to generate electricity or provide electricity. Depending upon the aircraft,

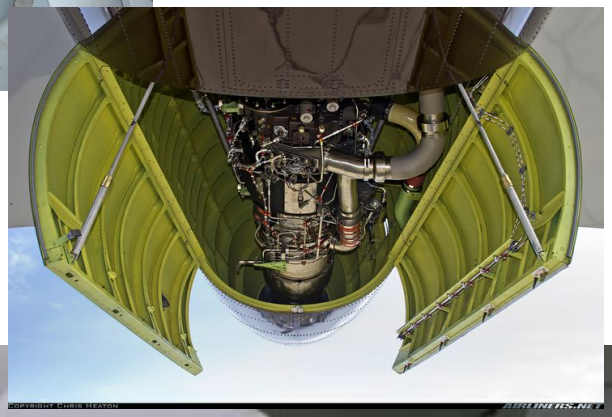
- generators (DC) and/or alternators (AC) are used to generate electricity. Alternators and generators convert rotational energy of engines into electrical power.
- batteries (DC) are used to store and provide electricity when needed. Battery convert chemical energy into electrical energy.

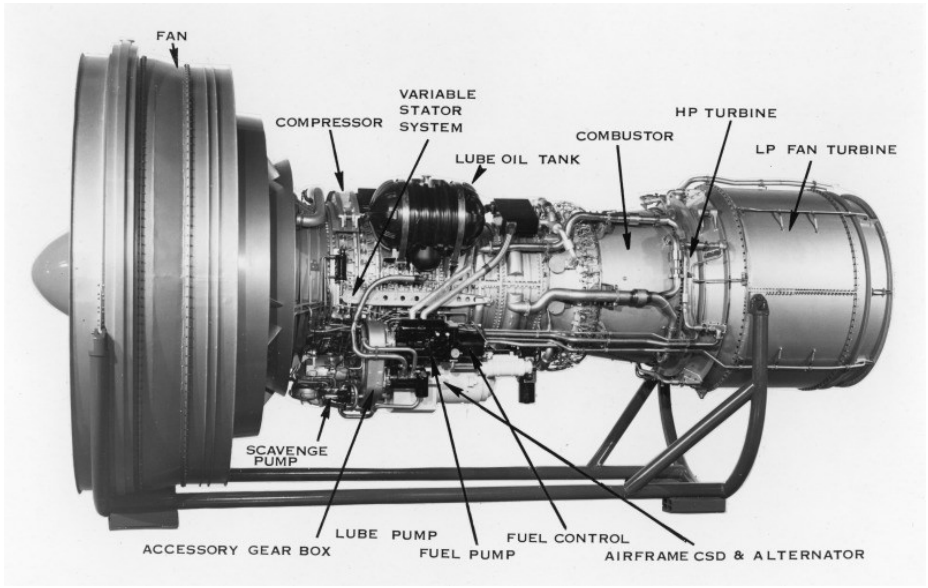
Power Generation

Generators or alternators may be powered by:

- Engines
- APU
- hydraulic motor
- Ram Air Turbine (RAT)

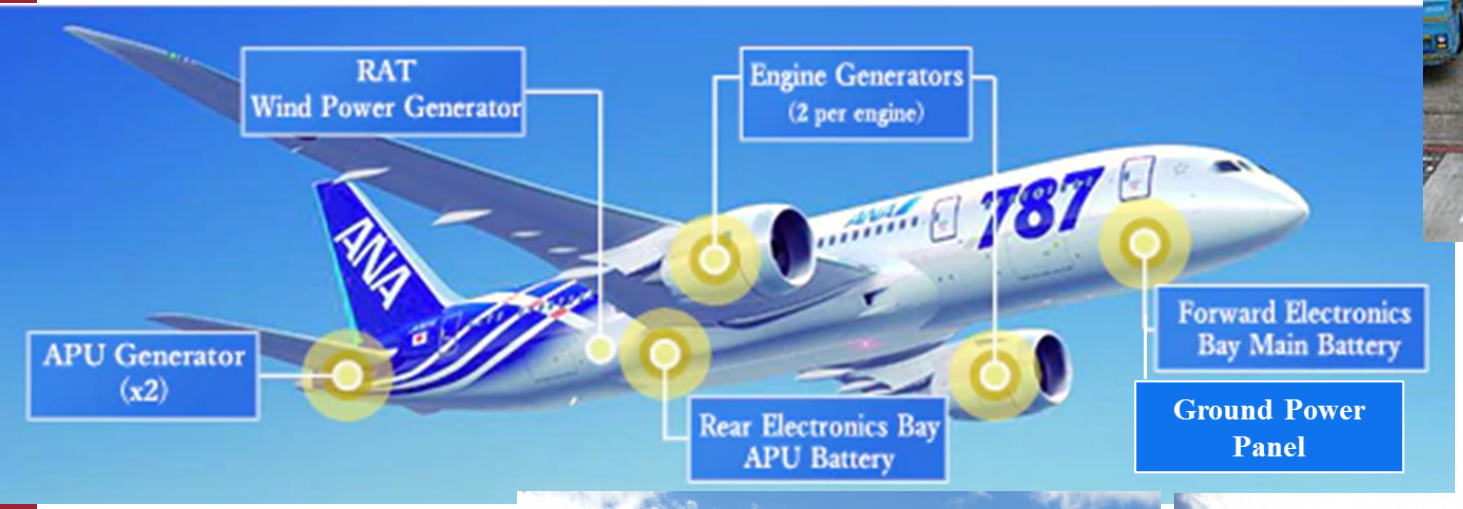




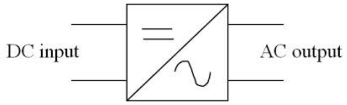


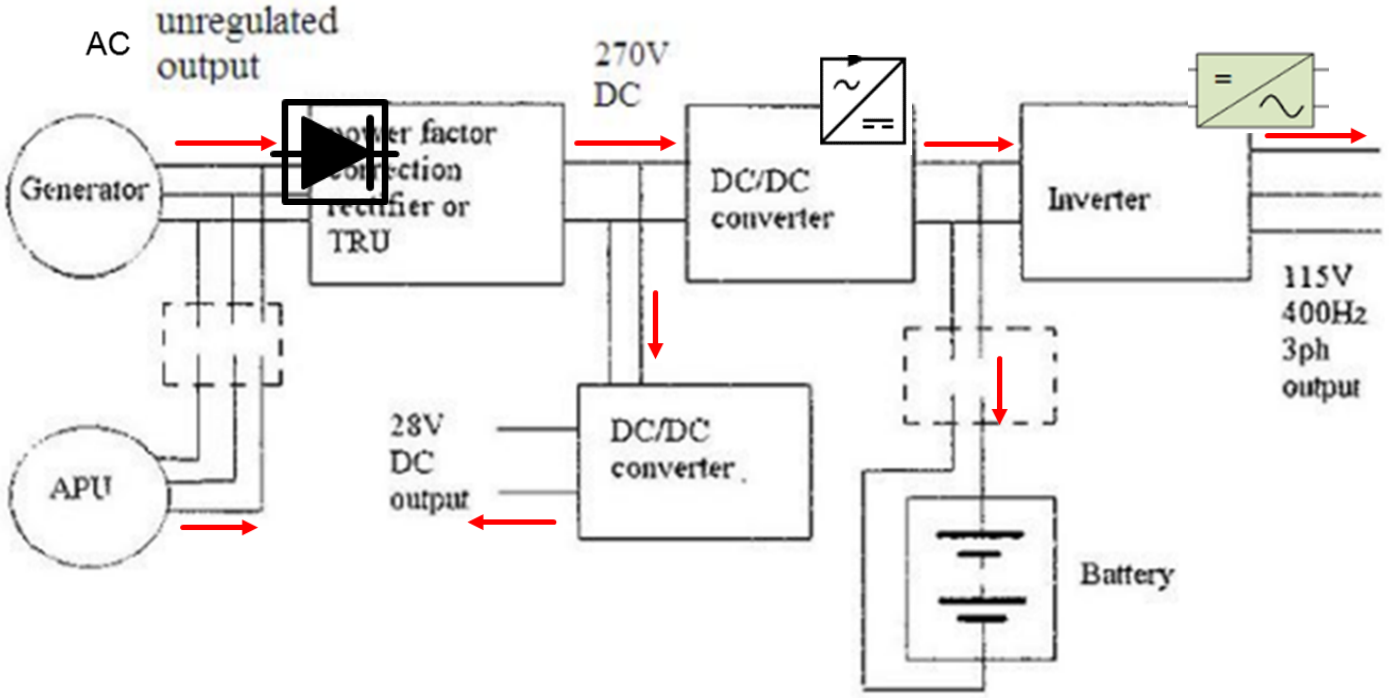
B787 Electrical Power Generation

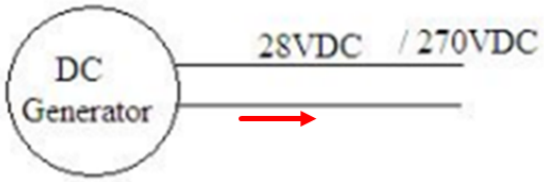
Large commercial aircraft may also accept external power via ground power unit.

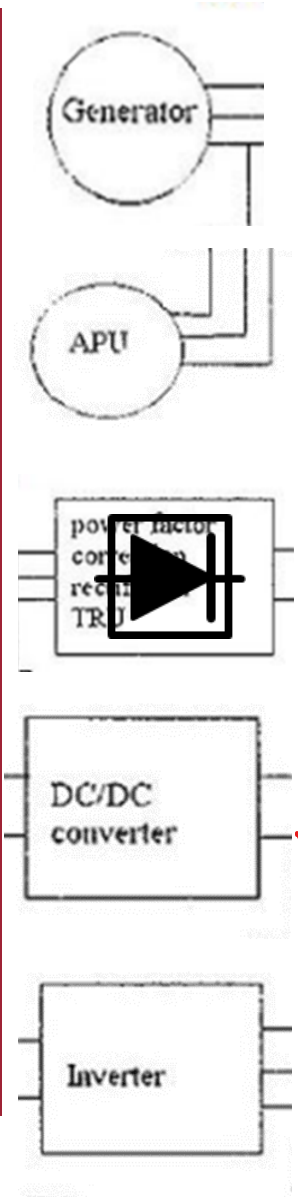


Basic Aircraft Electrical System – AC Generator





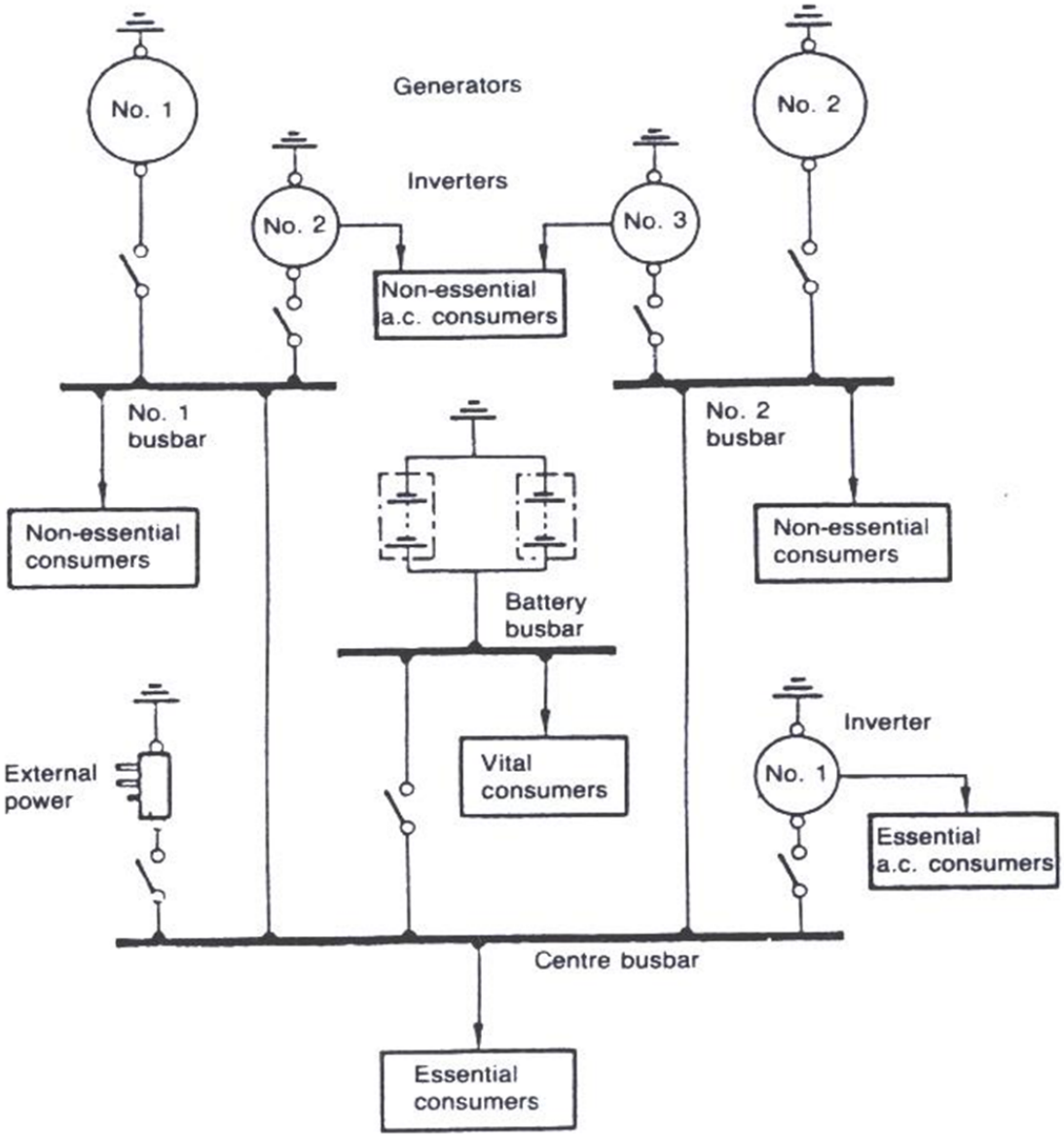




In the diagram:

- **Generator** (alternator) is the main power generating source in an aircraft. It generates AC electrical power that will supply all electrical power utilities (loads).
- **APU** is the auxiliary power unit that generates secondary electrical power also in AC.
- **Power factor correction and TR** is the transformer rectifier unit that converts and regulates AC voltage into 270V DC voltage
- **DC/DC converter** is an electrical component that converts 270V DC power to 28V DC power
- **Inverter** is an electrical component that converts DC power into AC power

Basic Aircraft Electrical System – DC Generator



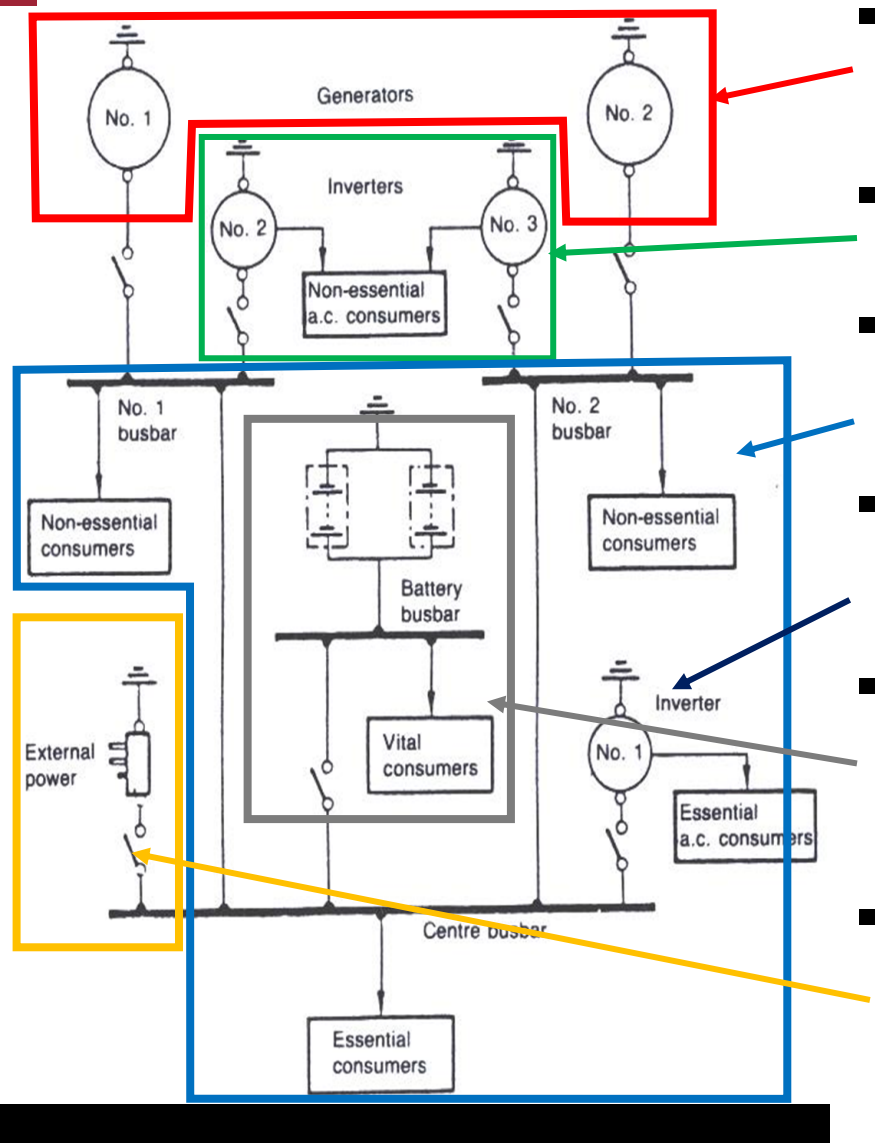
This diagram shows a basic Parallel 28 VDC System.

In this system, there are:

- 2 DC generators
- 3 inverters
- 1 battery
- External power receptacle
- 4 main bus bars
- Numerous switches

In this system, there is no APU or RAT. This may be a typical system of a small twin engine commuter aircraft.

Basic DC Power Generation System



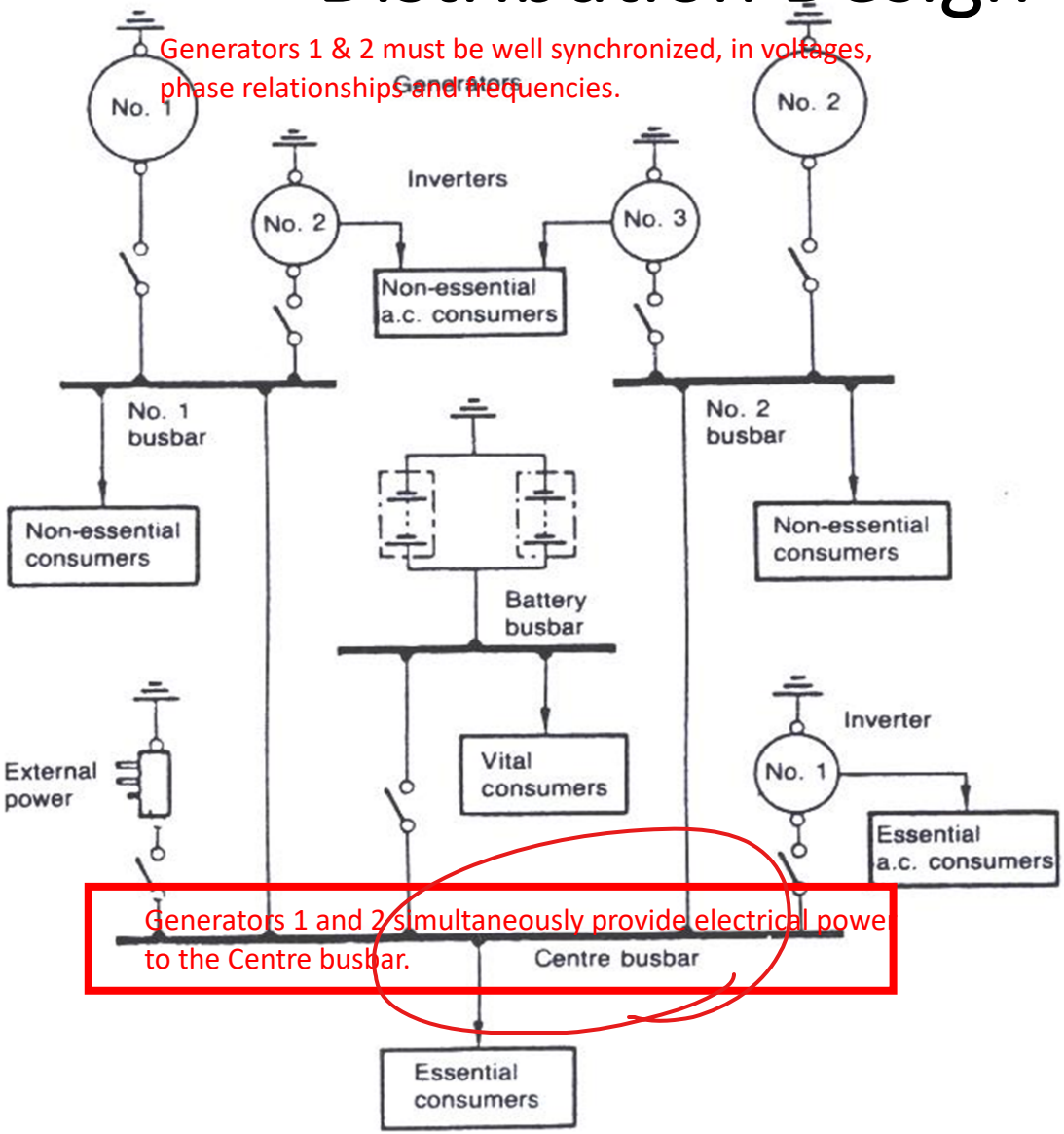
- Two 28 VDC generators in parallel to supply No. 1 and No. 2 main DC busbars. These busbars feed the non-essential DC services.
- 2 Inverters (No. 2 and 3) provide 115 VAC 400 Hz to non-essential AC service.
- No. 1 and No. 2 busbars feed power to the center busbar, which provide DC power to the essential DC services.
- Inverter No. 1 powered off the center busbar provides 115 VAC 400 Hz power to the essential AC services.
- The aircraft battery provides power to the battery busbar and vise versa. It recharges the battery but also feeds the vital DC services – design for emergency situations.
- 28 VDC external power may be feed to this busbar during ground service without generators No. 1 and No. 2 operating.

Primary Power Distribution

Electrical distribution for large aircraft may be categorised into three types:

- **split-bus system**
- **parallel system**
- Split-parallel system

Basic Aircraft Electrical System – Parallel Distribution Design



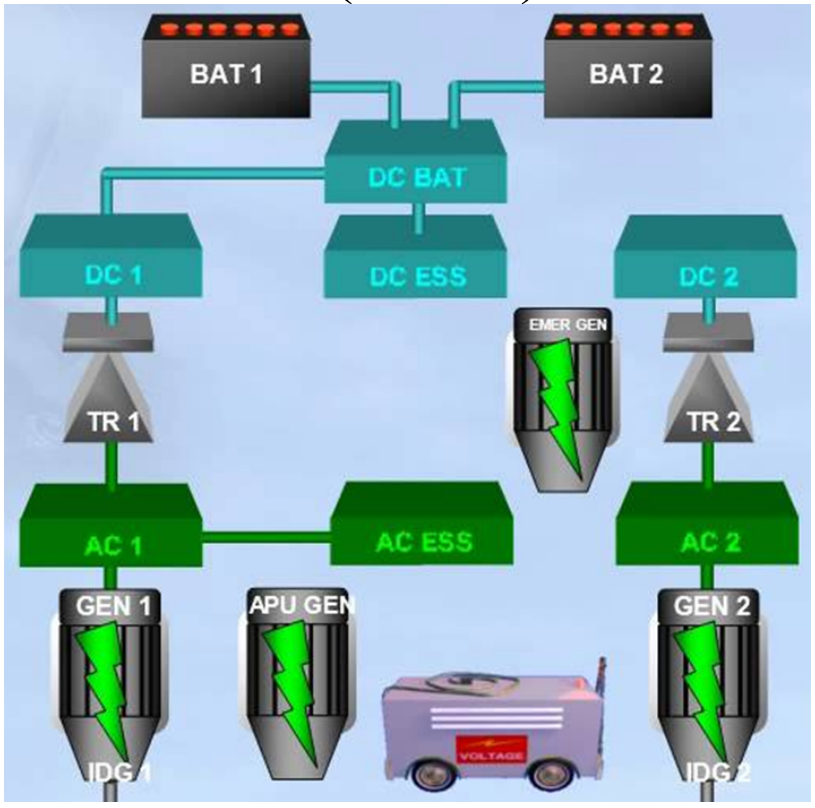
This diagram shows a basic Parallel 28 VDC System.

- Permits multiple generators to supply electrical power to the same bus-bar.
- Parallel system therefore permits equal load sharing amongst the connected generators.
- All generator voltage, frequencies and phase relationship must be controlled to very close tolerances.
- If the above conditions are not met, it could result in loss of generator power.

Basic Aircraft Electrical System – Split-Bus Distribution Systems

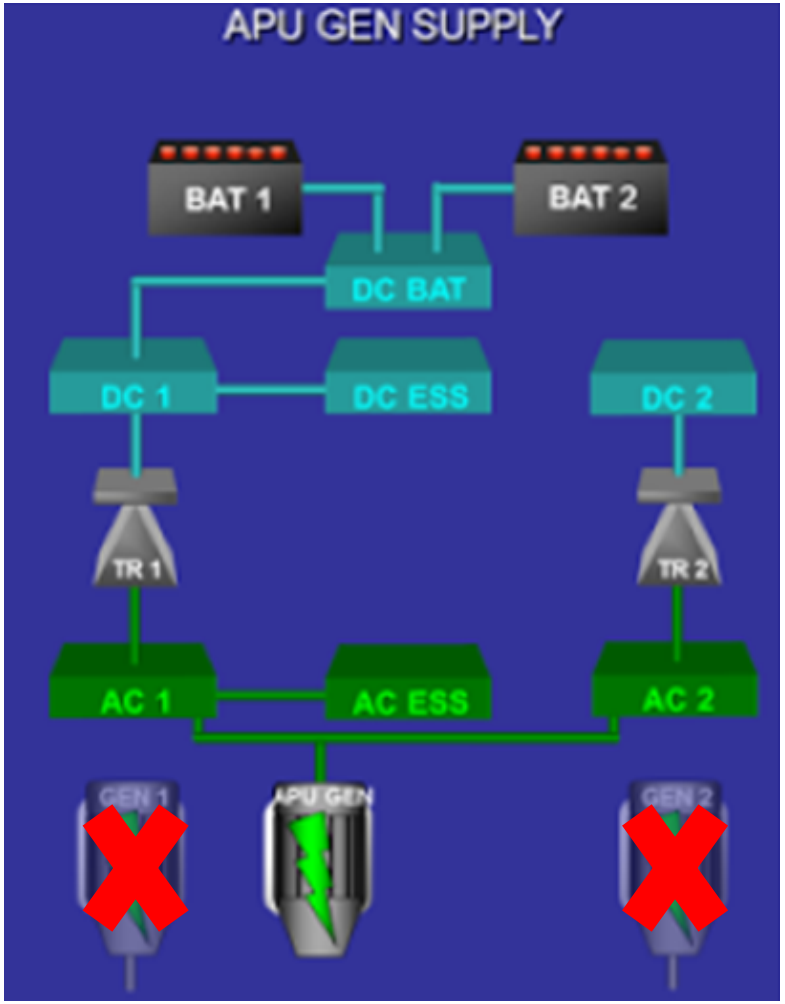
In the Split Bus Distribution system, under normal conditions, each engine-driven AC generator powers only one main AC bus. The busses are kept split such that no two generators can power the same bus simultaneously. This is ensured by the generator control units (GCUs) and bus power control unit (BPCU).

- The main advantage generators not need to operating at exactly the same frequency, voltage or phase.
- The APU generator provide back-up power in the event of a main generator failure.
- An emergency generator (such as RAT) is also available if all generators fail in flight.



Basic Aircraft Electrical System – Split-Bus Distribution Systems

- In the event of more than one generator failing, load shedding activates to direct power to the vital and essential loads.
- During load shedding, not only power supply to non-essential loads such as galleys and utilities (IFE) will be prevented, power to non-essential avionics, flight control system, equipment may also be prevented.

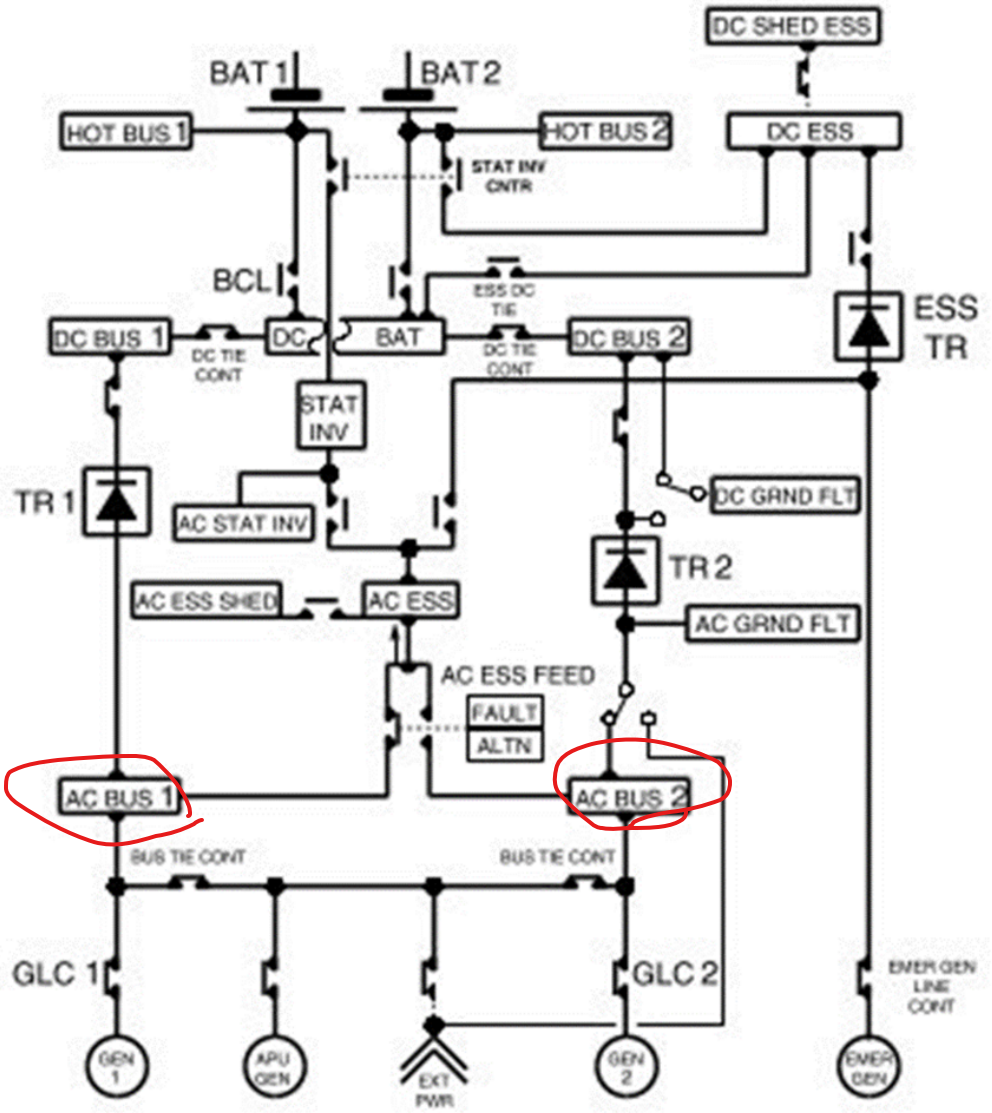


Modern twin-engine aircraft, such as the Boeing 737 and 777, Airbus A320 and A380, employ a split-bus power distribution system.

A320 Electrical System

- Two 90 kVA engine driven alternators supplying continuous power to AC essentials via AC bus bars.
- The electrical power also charge the 2 batteries (23 Ah each) of the aircraft. The AC is converted to DC via Transformer Rectifier Units (TRs).
- The power for DC essentials also comes through a TRU, just the same way as the batteries. In a scenario, where all generators failed, the battery can supply power to both DC essentials and the AC essentials. The DC is converted to AC via a Static inverter.
- The Airbus A320 has standby generators (APU 90 kVA and RAT 5 kVA) that comes online when the main generators cease to function.
- One ground power connector 90 kVA.

A320 Electrical System Architecture



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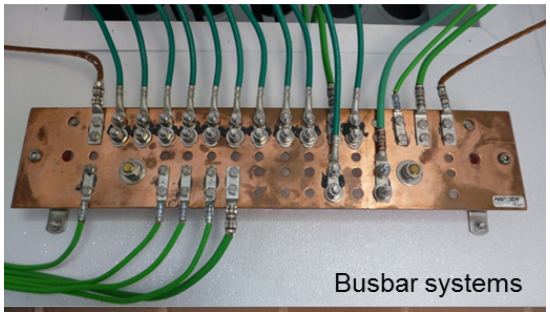
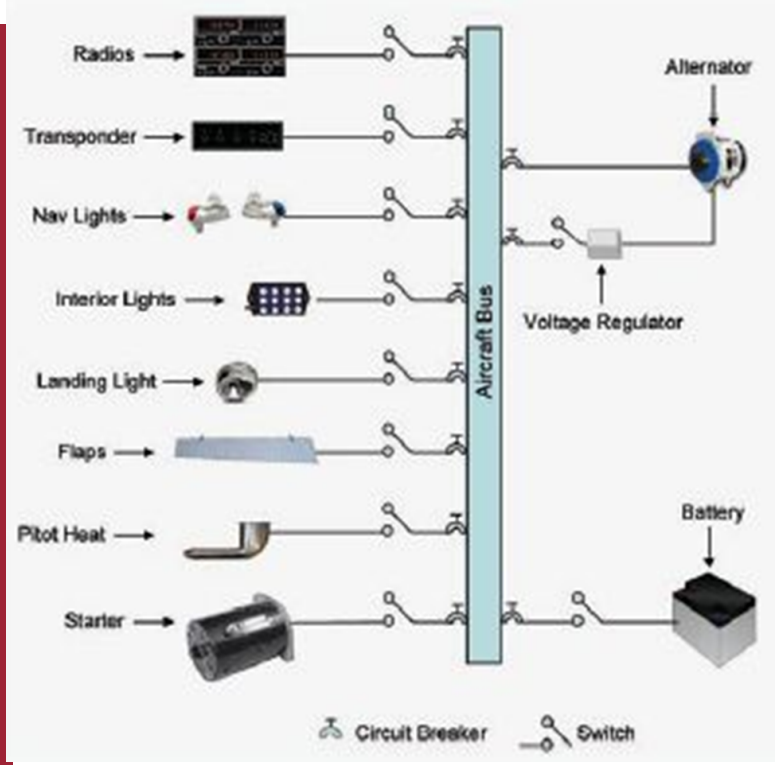
Power Distribution

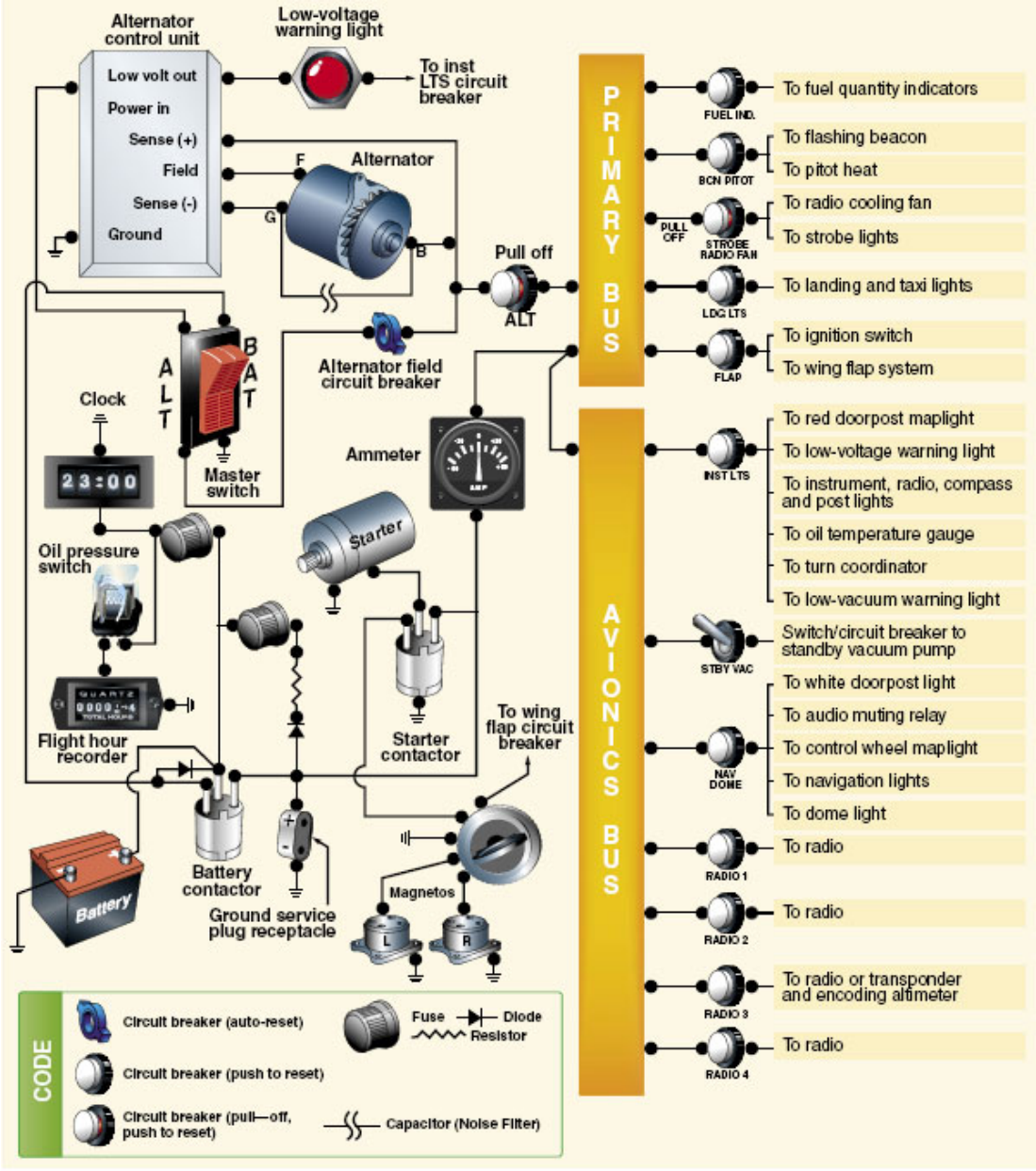
A typical electrical distribution and protection system will consist of most, if not all of the following components.

- Busbar - is a common conductor location, of high capacity, to which numerous electrical power loads are connected to, and acts as distribution centers for electric power. A busbar system is a system of multiple busbars, connected in series, so that each power source may supplies one or more specific buses.
- Circuit breakers –disconnects (and connects) the power source from the circuit when overload is detected. Reset is possible when using a circuit breaker – whereas a fuse is not.
- Bus tie breakers – a circuit breaker that is used to connect two electrical bus bars. It is normally open, so that if one power source fails, the tie can be closed and the remaining power source supplies the required load.
- Switches
- Electrical wire and cables
- Voltage regulator
- Ammeter / load meter

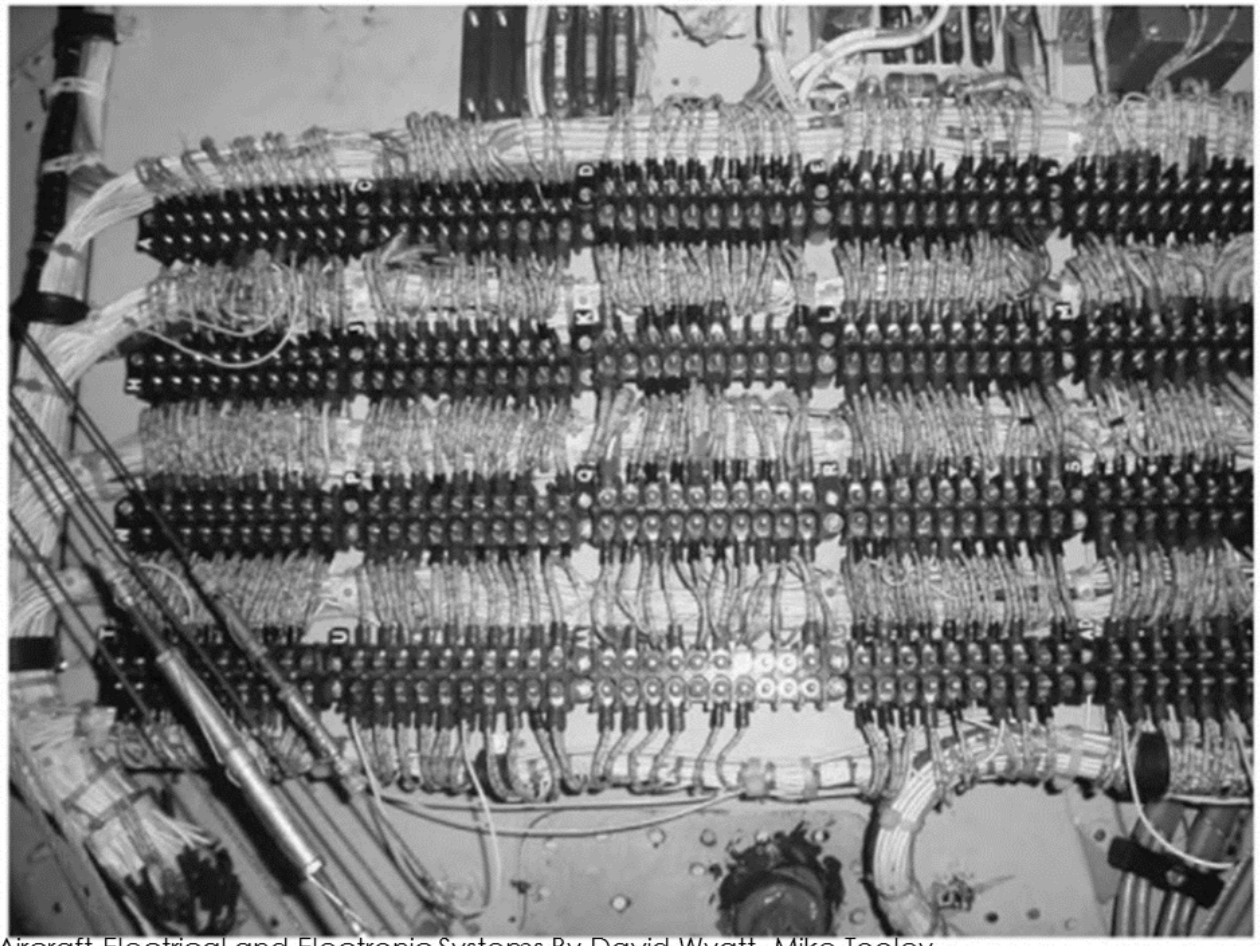


Simplified Power Distribution System



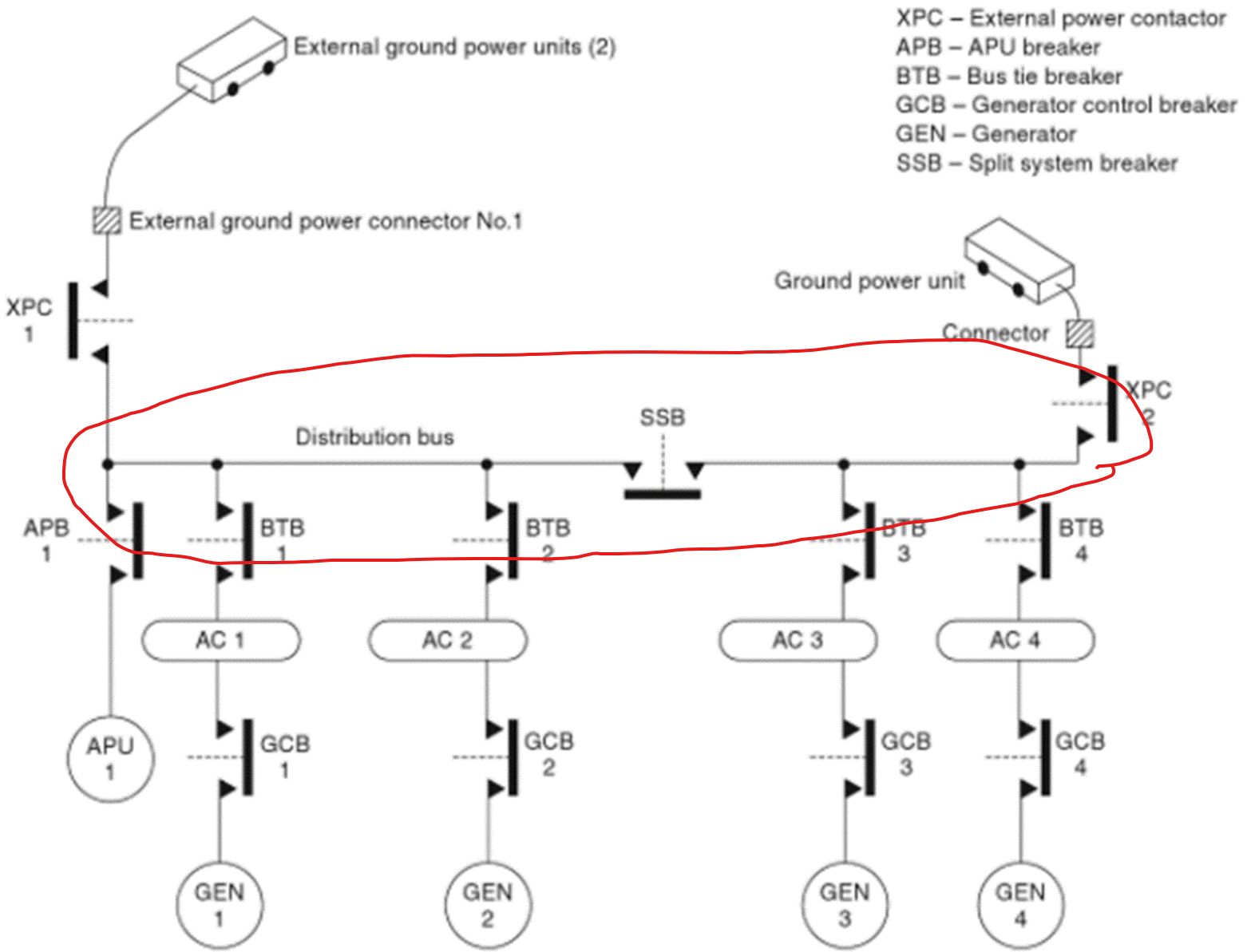


Typical Power Distribution



Aircraft Electrical and Electronic Systems By David Wyatt, Mike Tooley

- Is this a Parallel, Split or Parallel/Split system?
- Can you describe how this distribution system work?



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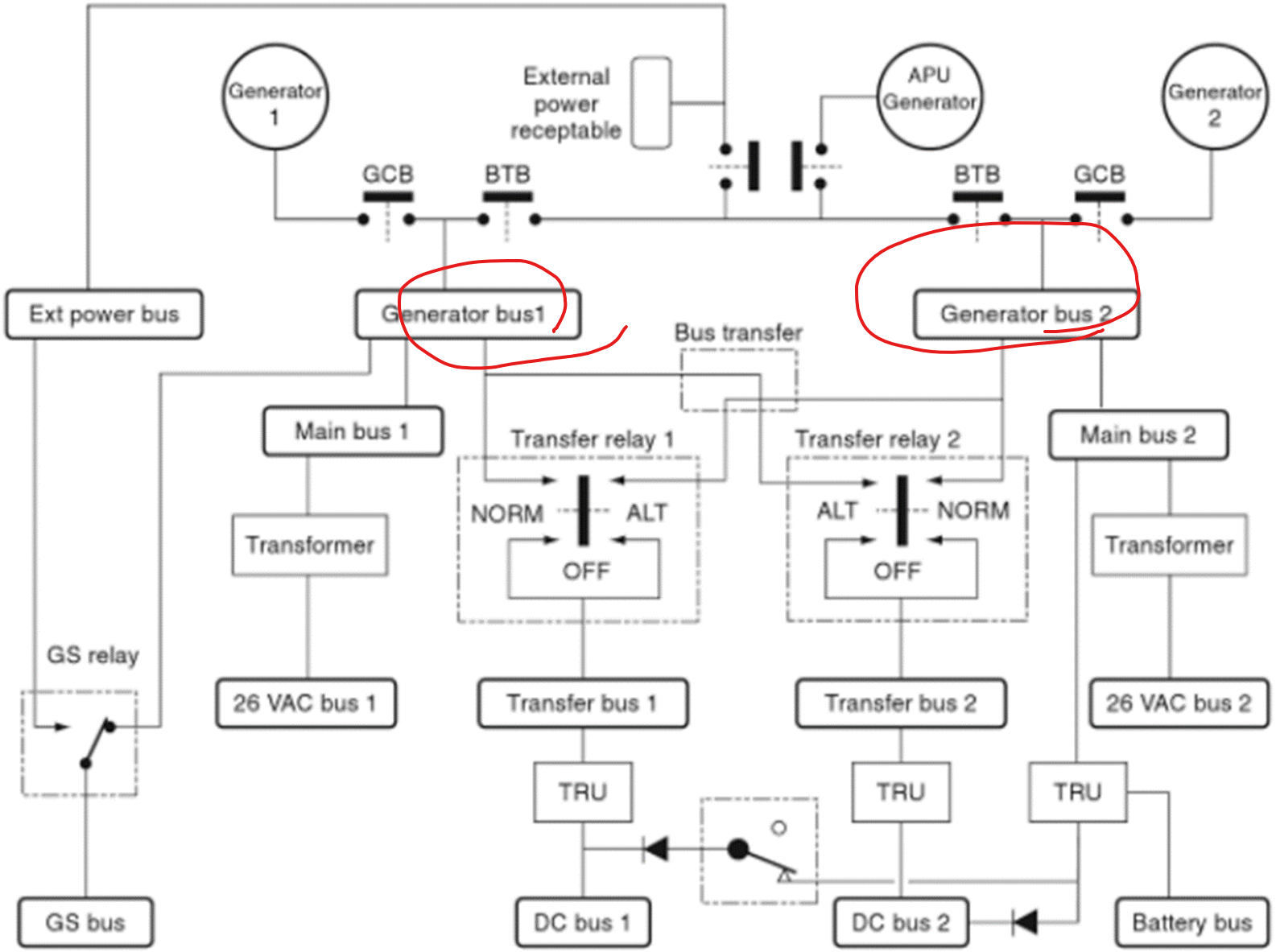

Parallel Bus System

Advantages:

- 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

Disadvantages:

- 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 System

Advantages:

- The generator operates independently. That is, generator output frequencies and phase relationships need not be so closely regulated.

Disadvantages:

- 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.