3 Electrical Power (ATA 24)

3.1 Definition

> *Those electrical units and components which generate, control and supply AC and/or DC electrical power for other systems, including generators and relays, inverters, batteries, etc., through the secondary busses. Also includes common electrical items such as wiring, switches, connectors, etc.* (**ATA 100**)

3.2 System Classification

Electrical power comprises (**ATA 100**):

- power generation:
  - generator drive systems: constant speed drives (CSD)
  - alternating current (ac) generation
  - direct current (dc) generation
  - external power
- power distribution:
  - alternating current (ac) electrical load distribution
  - direct current (dc) electrical load distribution.

3.3 Power Generation

Power is generated with different electrical components. Light aircraft use 14 V or 28 V direct current (dc) generators or alternators. Large aircraft employ generators that produce an alternating current (ac) of 115 V at 400 Hz. Compared to a 28 V dc system, a higher-voltage ac system will develop several times as much power for the same weight, and hence provide a great advantage where heavy electrical loads are imposed.

Aircraft *dc generators* have for the most part been replaced by *dc alternators* on modern aircraft. Although generators and alternators are technically different, the terms alternator and generator are used interchangeably.

A *starter-generator* is a combination of a dc generator and a dc motor in one housing. Starter-generators are typically employed on small turboprop and turbine-powered aircraft.

There are two major types of alternators currently used on aircraft: the *dc alternator* and the *ac alternator*. DC alternators are most often found on light aircraft where the electric load is relatively small. AC alternators are found on large commercial airliners and many military aircraft.

Both ac and dc *alternators* for aircraft show a *construction* with a rotating field (supplied with current from the outside via slip rings) and a stationary armature. The aircraft alternator is a three-phase unit having three separate windings 120° apart.

Light airplanes use an alternator with a three-phase full-wave rectifier to produce dc power. The rectifier is built into the alternator, so that dc current leaves the alternator with a nominal voltage of either 14 V for a 12 V battery system or with 28 V for a 24 V battery system.

Transport category aircraft use three-phase ac alternators with Y-connected stator windings. (Note: high output ac alternators are mostly called ac generators. If they are of a design without slip rings, they are called *brushless generators*.) The output frequency depends on the drive speed of the generator. The required constant frequency of 400 Hz requires the use of a constant speed drive (CSD). The integrated drive generator (IDG) contains both, the CSD and the generator in one unit. Details of this state-of-the-art system are explained using the Airbus example below.

Advantage of ac high-voltage systems include:

- weight savings
- voltage transformation possibilities
- low current, low power losses in the wiring.

Electrical power generation systems on large aircraft show a range of typical **components**:

- A *generator control unit* (GCU) is a solid-state device that carries out voltage regulation, current limiting, and frequency control.
- An *inverter* is a device for converting direct current into alternating current at a demanded frequency (400 Hz). A *static inverter* achieves this with standard electric and electronic components.
- A *transformer rectifier* (TR) unit is a device for converting alternating current into direct current.
- A *variable-speed constant-frequency* (VSCF) system employs a generator driven directly from the engine without a constant-speed drive (CSD). The generator is driven at variable engine speeds, thus producing a variable-frequency output. A generator converter control unit converts the variable frequency into a constant frequency of 400 Hz. A VSCF system is found on the Boeing 737.

3.4 Power Distribution

The design of the power distribution system depends on
1. the size of the aircraft and hence upon its system complexity
2. on the type of primary power generation applied (ac or dc).

A **simple power distribution system** consists of a *bus bar* or *bus*. The bus is a conductor designed to carry the entire electrical load and distribute that load to the individual power users. Each electric power user is connected to the bus through a circuit breaker. Simple distribution systems like this are found on small single-engine aircraft.

More complex power distribution systems consist of *bus bars*, *bus tie breakers*, and various solid-state controllers such as *generator control units* (GCU).

Electrical power distribution systems of large aircraft shows a range of typical **components**:
- *Bus tie contactors* (BTC) (also known as bus ties breaker) are electric solenoids used to connect two bus bars.
- *Generator line contactors* (GLC) (also known as generator breaker) are similar to BTC but connect the generators to the buses.
- *Bus power control units* (BPCU) are supplied with information from all parts of the distribution system. Taking this information into account, the BPCUs will ensure the appropriate distribution system configuration. In some architectures, the GCUs include the BPCU functions. The BPCUs enable *reconfiguration* of the power distribution between individual busses. For example, if a generator fails or a bus shorts to ground, the appropriate BTCs and GLCs must be set to the correct position. In the event of a system overload, the controller must reduce the electrical load to an acceptable level. This is called *load shedding*. The aircraft's galley power is usually the first nonessential load to be disconnected.

Figure 3.1 shows the two principle distribution systems with
1. *primary ac generation* and dc generation through transformer-rectifiers
2. *primary dc generation* and ac generation through inverters.

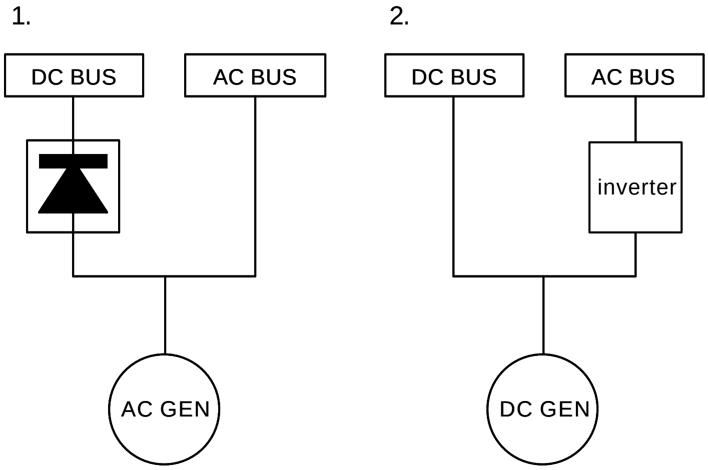

Figure 3.1 Distribution systems with
1. primary ac power generation
2. primary dc power generation

Three different power distributions systems exist for large aircraft, all of which apply primary ac generation:

1. the *split-bus system*
2. the *parallel system*
3. the *split parallel system*.

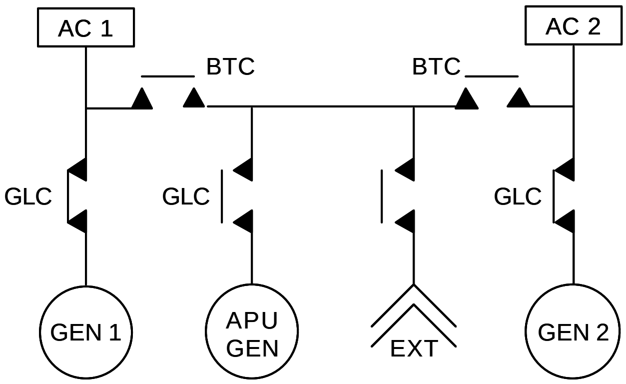

Figure 3.2 General layout of a split-bus system

The **split-bus system** (Figure 3.2) contains two completely isolated power-generating systems. Each system contains its own ac generator. The generator 1 (GEN 1) and generator 2 (GEN 2) power their respective loads independently of other system operations. In the event of a generator failure, the remaining operating generator is connected to both buses AC 1 and AC 2, or the APU generator (APU GEN) may be employed to carry the electrical load of the inoperative generator. The major advantage of a split-bus system is that the generators operate independently, so that generator output frequencies and phase relationships need not be so closely regulated. A split-bus system is used on the Airbus A321 and most other modern twin-engine transport category aircraft. The A321's electrical system diagram is shown below in more detail.

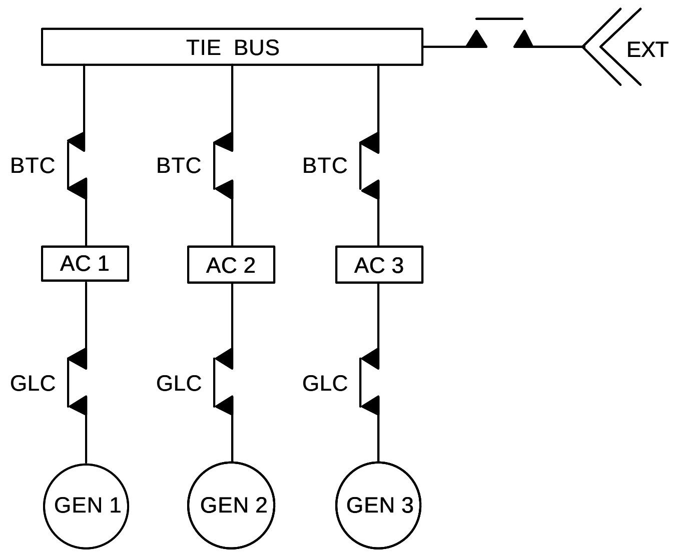

Figure 3.3 General layout of a parallel system

In a **parallel system** (Figure 3.3), all ac generators are connected to one tie bus. This type of system maintains equal load sharing for three or more ac generators. Since the generators are connected in parallel to a common bus, all generator voltages, frequencies, and their phase sequence must be within very strict limits to ensure proper system operation. If one generator fails, the generator is isolated from its load bus. Nevertheless, that load bus still continues to receive power while connected to the tie bus. A parallel system is used on, for example, the Boeing 727.

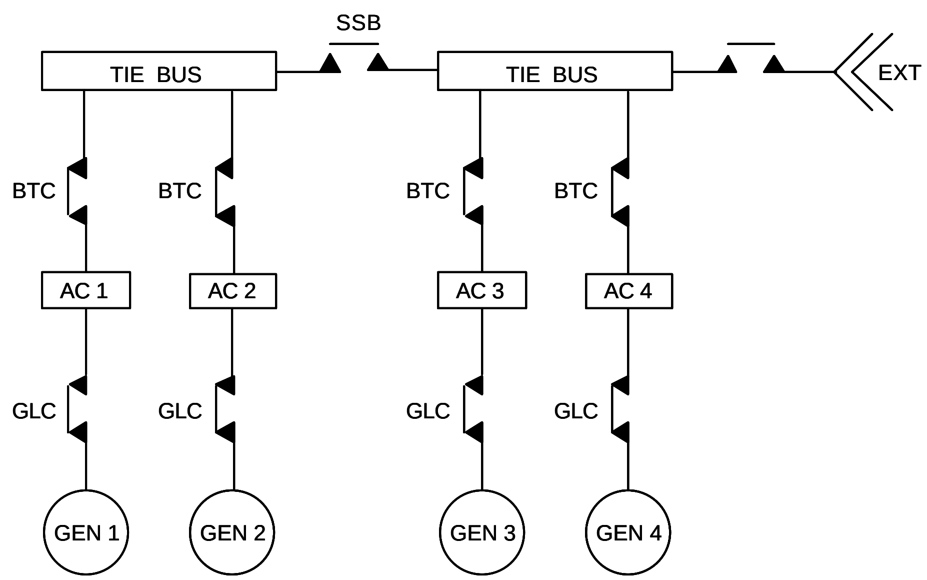

Figure 3.4 General layout of a split parallel system

A **split parallel system** (Figure 3.4) allows for flexibility in load distribution and yet maintains isolation between systems when needed. The ac buses are paralleled through the bus tie breakers (BTB) and the split system breaker (SSB). When the SSB is open, the right system operates independently of the left. With this system any generator can supply power to any load bus (AC 1 AC 2...), and any combination of the generators (GEN 1, GEN 2...) can operate in parallel. A split parallel system is used on the Boeing 747-400.

Let's look at the **dc distribution systems** on aircraft with primary ac power generation. Transformer rectifiers (TR) powered by an ac bus, feed their main dc bus bars. In the event of a complete generator system failure, the aircraft's batteries would supply the essential dc power. An inverter would also be powered from the batteries in an emergency situation to operator all essential ac loads.

The aircraft electrical system is designed with a **power distribution hierarchy**. The system is designed so that the most critical components are the least likely to fail. The generators feed their respective bus AC 1, AC 2... The least critical ac loads are powered by these busses. The critical ac loads are powered by the essential ac bus (AC ESS). The same is true for the dc busses: The least critical dc loads are powered by the DC 1, DC 2... buses, which are fed by their respective transformer rectifier TR 1, TR 2... The next-most critical systems are powered by the essential dc bus (DC ESS), which can be powered by any transformer rectifier. The most critical loads are powered by the battery bus (BAT BUS).

3.5 Example: Airbus A321

In the A321, *primary ac power generation* is applied. In addition, ac is converted to dc by means of transformer rectifiers (TR). The distribution system is a *split-bus system* and consists of two separated distribution networks. Normally, one main generator supplies each network. The two distribution networks may be connected when the aircraft is on external power, APU power, or if one main generator fails. Under no circumstances may two generators be connected.

A321 power generation encompasses primary ac power generation in flight and on the ground, dc power generation, and ac power generation from dc. The location of related components in the aircraft is shown in Figure 3.5.

In flight, two engine-driven generators (GEN 1 and GEN 2), also known as *integrated drive generators* (IDG), supply the aircraft electrical power system. A third *APU-driven generator* (APU GEN) can replace one engine-driven generator. In the event of a major failure, a unit consisting of a constant-speed hydraulic motor coupled to a generator (*Constant-Speed Motor/Generator*, CSM/G) is able to supply the most essential parts of the electrical systems. The CSM/G is powered by the ram air turbine (RAT) via the Blue hydraulic system.

On the ground, an external electrical *ground power unit* (GPU) can supply the aircraft. Alternatively, the APU generator can serve as an independent source for electrical power supply on the ground.

All the power sources named above supply the distribution network with ac power. **DC power** is supplied by *transformer rectifiers* (TR). Two *batteries* are used as dc emergency power source and for APU start in flight and on the ground.

Essential ac power can be obtained in an emergency situation from the batteries through a *static inverter*.

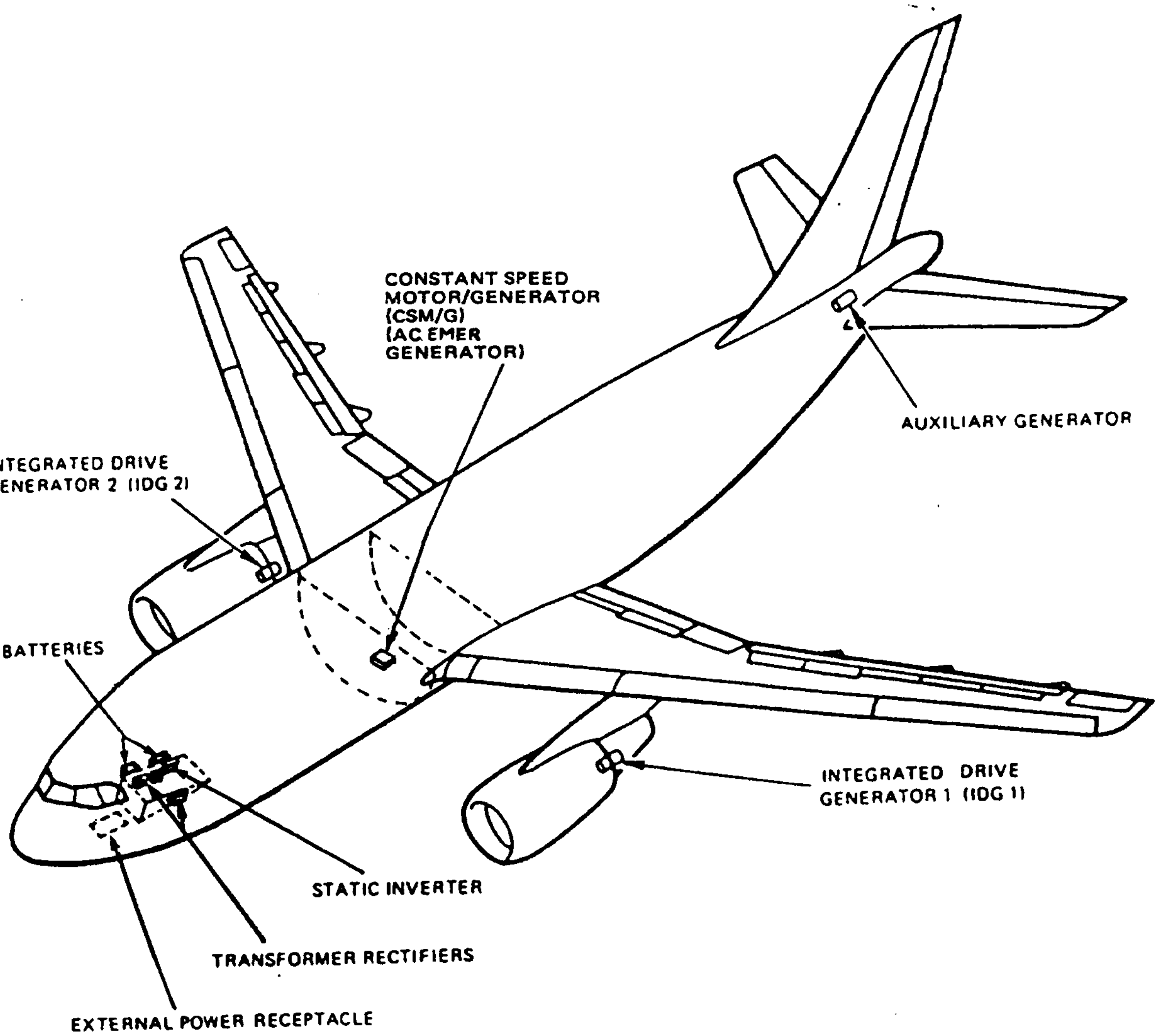

Figure 3.5 A321 electrical power sources and their location in the aircraft

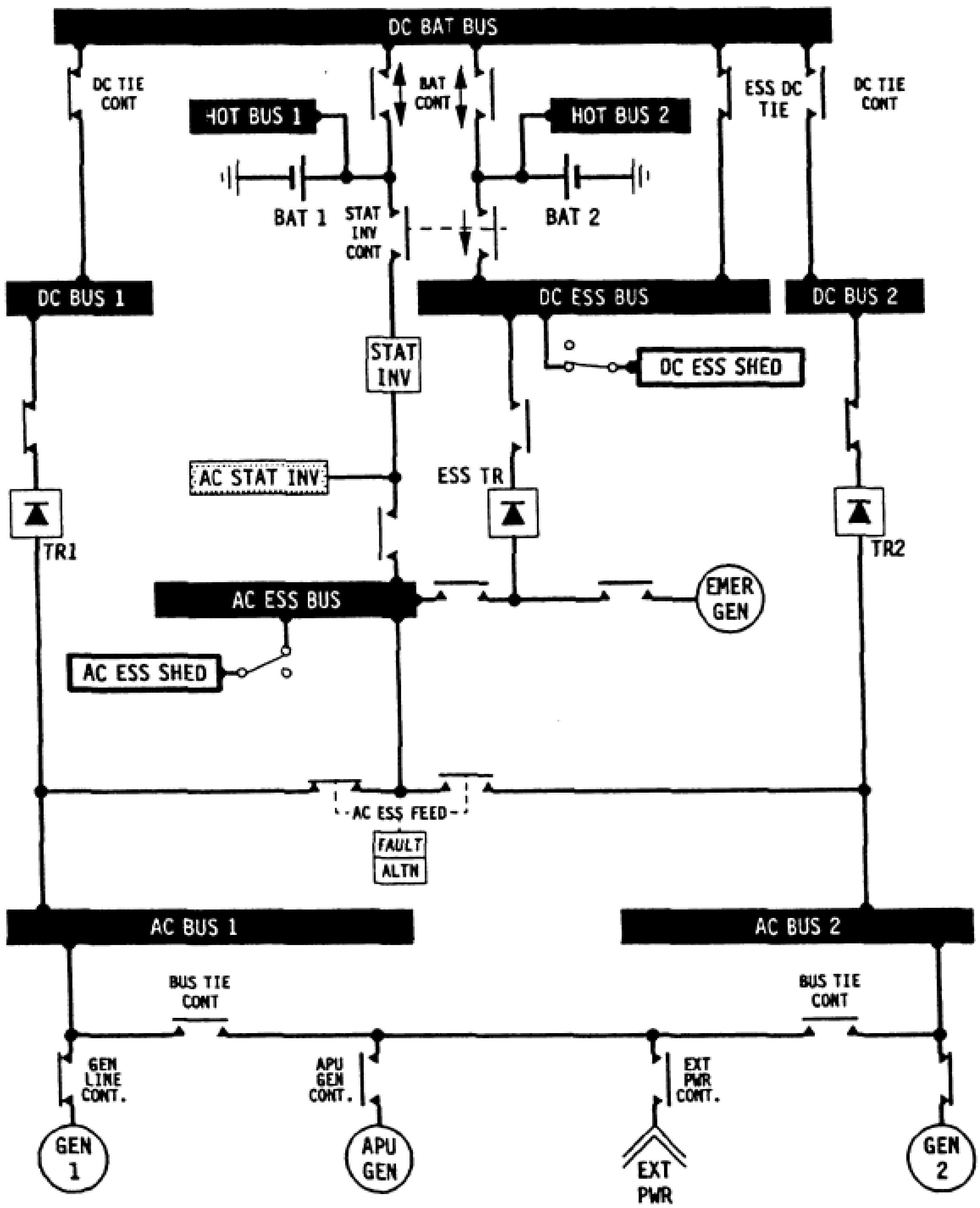

Figure 3.6 A321 electrical system diagram

A321 power distribution encompasses (Figure 3.6):

- The *distribution network 1*, which consists of: AC BUS 1, AC ESS BUS, AC ESS SHED. The AC ESS SHED may be shed due to a lack of power in an emergency.
- The *distribution network 2*, which consists of AC BUS 2.
- The *transformer rectifier 1* (TR 1), which is powered from the AC BUS 1 supplies through its contactor: DC BUS 1, DC BAT BUS, DC ESS BUS, DC ESS SHED. The DC ESS SHED may be shed due to a lack of power in an emergency.

- Two *batteries*, which are associated with the DC BAT BUS.
- The *transformer rectifier 2* (TR 2), which is powered from the AC BUS 2 supplies through its contactor the DC BUS 2.
- A third *essential transformer rectifier* (ESS TR), which could be powered from the AC BUS 1 or the emergency generator (EMER GEN) may supply through its contactor the DC ESS BUS and the DC ESS SHED only in certain failure cases.

In failure cases, various possibilities for reconfiguration exits.

Each engine high-pressure stage drives its associated **integrated drive generator** (IDG) through the accessory gearbox (Figure 3.7). The drive speed varies according to the engine rating. The IDG provides a 115/200 V, three-phase, 400 Hz AC supply. The IDG consists of two parts: the *constant-speed drive* (CSD) and the *generator*. The hydromechanical CSD drives the ac four-pole generator at a nominal speed of constant 12000 rpm.

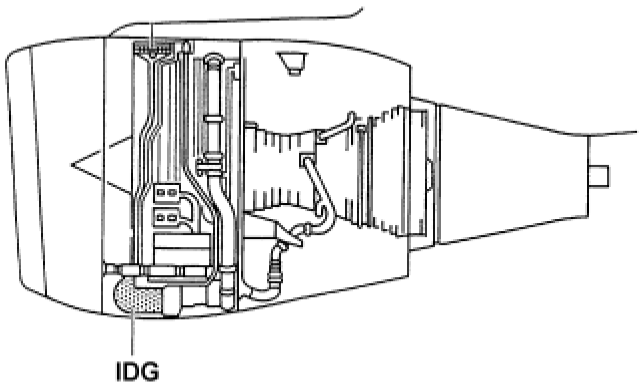

Figure 3.7 A321: Location of the integrated drive generator (IDG)

The **constant speed drive** (CSD) consists of a mechanical differential gear that transmits power to the generator of the IDG. The output speed of the differential gear is modified by two mechanically coupled twin hydraulic subassemblies: a pump and a motor. Each subassembly includes a hydraulic swashplate: the pump is equipped with a variable-angle swashplate, and the motor is equipped with a fixed swashplate. A governor controls the CSD output speed by the swashplate angle of the pump (Figure 3.8).

The **generator** is a three-stage assembly that includes three machines connected in cascade. The *first machine* is a 12-pole permanent magnet generator (PMG). The *second machine* is a 10-pole stator and receives its field excitation from the first machine via the voltage regulator in the generator control unit (GCU). Its dc output feeds the rotating field of the *third machine* (the main alternator). The main alternator has a three-phase star-connected stator winding. The three phases and star point are taken to the generator output terminal block.

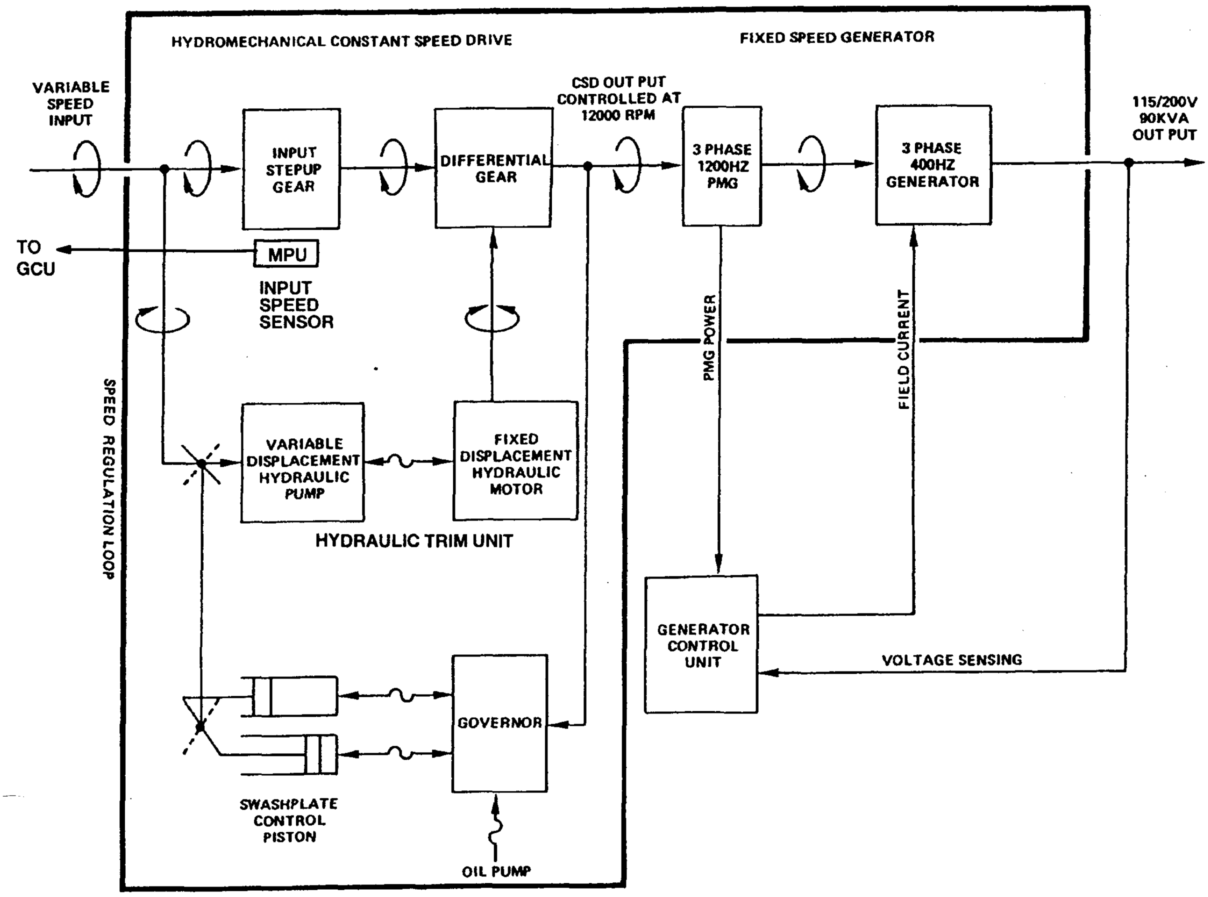

Figure 3.8 A321 integrated drive generator (IDG): speed conversion and power generation