**SHIP GENERATORS**

The electrical power demand on board ship will vary according to the ship type and its day-to-day operational needs (at sea or in port). To meet the power demand, two or more main generators are used, which are backed up by an emergency generator and an emergency battery service.

**Construction of Generators**

The two main parts of any rotating АС machine are its stator and rotor. The fabricated steel stator frame supports the stator core and its three-phase windings. The stator core is assembled from laminated steel, with the windings housed in slots around the inner periphery of the cylindrical core.

The stator coils are interconnected (in the end-winding regions) to form three separate phase windings with six ends. These phase ends are found in the stator terminal box, as shown in the Figure “Generator terminal box”.

Occasionally, only three terminals are available in the terminal box and, if this is the case, the neutral or star point connection is an internal part of the stator winding arrangement.

The rotor of а main АС generator provides the field excitation from its electromagnetic poles. Rotor and Armature coils are the 2 main parts of an alternator. Rotor produces a rotating magnetic field. Armature coils are stationary and rotating magnetic flux associated with the rotor induces electricity in the armature coils.

The kind of rotor is known as Salient pole rotor. For gaining better insight of its working let’s consider a rotor with just 4 poles. Rotor coils are excited with a DC power source. Magnetic field produced around it would be "4 pole salient pole rotor and magnetic field produced around it when excited by a DC power supply”.

The rotor is made to rotate by a prime mover. This makes the rotor flux also rotate along with it, at the same speed. Such revolving magnetic flux now intersects the armature coils, which is fitted around the rotor. This will generate an alternating electromagnetic field (E.M.F) across the winding.

- Rotor is designed to withstand the vibration and stresses appearing up to 120 % of rated speed.

- Critical rotational speed is at least 1.5 times the nominal speed.

- Shaft is made of forged steel and salient poles are bolted to the rotor hub.

- Poles are constructed of punched and stacked steel plates and provided with damper winding.

- Cooling and supporting of windings by aluminum profiles.

The main outgoing cables connected to these terminals conduct the generator's electric power to its circuit breaker at the main switchboard. Two constructional forms of rotor are, “Generator rotors, salient and cylindrical construction”.

The salient pole type has projecting poles bolted or keyed onto the shaft hub. Field excitation windings are fitted around each pole. This type of rotor is used with medium and slow shaft speeds (1800 rpm and below) and is the most common arrangement for marine generators.

Cylindrical type.

Cylindrical type rotors are generally used with large power, high speed (1500-3600 rpm) steam/gas turbine drives. The excitation windings are wedged into axial slots around the steel rotor. Unwound sections of the rotor form the pole faces between the winding slots.

The shaft bearings of large generators are usually insulated to prevent stray currents from circulating through. Unbalanced (stray) end-winding magnetic flux induces an emf along the steel shaft. This will cause а current to circulate through the shaft, bearings and bedplate to produce arcing across the bearing surfaces and degradation of the oil layer. Under unbalanced fault conditions, the bearing problem may be severe.

To prevent the flow of shaft current, one bearing (usually the non-drive end) is electrically isolated from earth by а thin layer of insulating material beneath the bearing pedestal. The pedestal holding down bolts must also be insulated by suitable sleeving.

ln normal operation, the effectiveness of the pedestal insulation can be checked by measuring its voltage to earth, which may show as а few volts.

The rotor winding (main field) is supplied with DC from an exciter. If the exciter equipment is а conventional DC generator, or is static, the DC excitation current is fed into the field windings via carbon brushes on а pair of shaft-mounted slip rings.

To eliminate the maintenance problems associated with rotating contacts, а brushless arrangement is usual for marine generators. All brush gear, commutators and slip ring assemblies are eliminated by using an АС exciter, with its output being rectified by а shaft-mounted rotating rectifier, “Rotor diode plate”. The diodes are connected as а three-phase АС/DС bridge circuit.

The six diodes, mounted on the shaft, convert the АС exciter output to DC, which is then fed directly into the main generator rotor field windings. The АС exciter has its own DC field poles fitted on its stator while the rotor carries its three-phase АС exciter output windings. This construction layout is inverted compared with that of the main generator.

**Cooling**

Three commonly used cooling methods:

- Open air

- Air-to-water

- Air-to-air

Power losses, typically 10% of the generator rating, cause internal heating in the windings and magnetic cores of both the rotor and the stator. This heat must be continuously transferred out of the generator to prevent excessive temperature rise causing breakdown of the winding insulation.

Forced air circulation in а closed circuit (to prevent ingress of dirt), via an air cooler, is pressurized by а fan on the rotor shaft.

Cooling air is forced through ventilation ducts in the stator core, between rotor poles and through the air gap (а few millimeters) between the stator and rotor.

Water cooling of the circulating air may also be used for generators with а large power rating.

Temperature detectors (often RTDs such as Pt 100) are used to monitor the temperature of stator windings, bearings and the cooling air/water of the generator. Single or grouped temperature alarms are activated at the main watchkeeping position.

While the generator is stopped during standby or maintenance periods, low power electric heaters within the machine prevent internal condensation forming on the winding insulation. These heaters may be switched on manually or automatically from auxiliary contacts on the generator circuit breaker.

Heater power supplies are normally 220 VАС single-phase, supplied from а distribution box local to the generator.

**Excitation Methods**

- Generators and propulsion motors are with brushless excitation.

- Exciter rotor windings are wound with enameled wire, impregnated, and shrink fitted to the shaft. Secured with a key.

- Mounting inside the motor frame with removable inspection covers.

- Mind tightening torques when inspecting or replacing semiconductors and rectifier bridge components.

- Diode bridge is mounted on the exciter rotor hub that is shrink fitted on to the shaft.

The two factors essential to produce а generated emf in an АС generator are rotational speed No and magnetic flux (Ф). Field windings on the rotor create strong magnetic field poles when direct current is passed through them. Various methods have been devised to supply the correct DC field (excitation) current to produce the required АС output voltage from the stator terminals. The excitation must be continually regulated to maintain the generator output voltage as the load power demand fluctuates.

Excitation methods are either rotary or static. А rotary method utilizes an exciter, which is shaft-mounted and rotates with the main generator rotor. The most common arrangement is to use а shaft-mounted АС exciter.

ln some applications, а small additional rotary pilot exciter may be used to supply current to the main exciter field. А pilot exciter is а small permanent magnet АС generator that is driven from the generator shaft. Its output voltage is generally at а high frequency (eg 1000 Hz) but this is changed to DC before being fed into the main exciter field.

Brushless excitation system

The absence of brushes, brush gear and carbon dust improve reliability and considerably reduces generator maintenance. Rectification of the АС exciter voltage is achieved by six shaft mounted silicon diodes that form а three-phase rotating rectifier. The suppression varistor is a protection device which connected across the main generator field and prevents high voltage transients from damaging the main rectifier diodes. High Voltage transients are created by fault conditions in the distribution system. The transient returns to the Generator via the output terminals, enters the main stator windings, and by mutual inductance, (transformer reaction), is transferred to the main rotor windings, and then the main rectifier assembly. The Surge Suppressor can be tested with a Multimeter on the megohms range.

Although diode failures are rare, some generator field systems are fitted with an electronic detector relay to give an alarm and/or trip signal to the generator's circuit breaker should such а fault occur. Usually, the detector monitors the exciter field current, whose size and shape are noticeably affected by а diode failure.

Generators with rotary exciters, conventional or brushless, have а relatively sluggish response to sudden load changes. For example, it may take up to one second to correct а 15% voltage dip caused by the startup of а large pump motor.

The transient voltage response of а generator can be improved by eliminating the rotary exciter in favor of а static excitation method. ln this arrangement, the generator field draws its DC current via а static excitation transformer/rectifier unit fed directly from the generator voltage and current output. This arrangement is known as compounding as it is controlled by voltage (shunt effect) and current (series effect) feedback. Response times as low as 0.1 second to correct а 15% voltage dip are common with static excited compound generators. This fast response is desirable where heavy and frequent load surges arise from the deck machinery. However, despite advantages, this excitation method is utilized less frequently on board than the rotary method explained in the paragraph above.

Static excitation equipment may be located within the generator casing or inside the main switchboard. This type of generator has two shaft slip rings and brush gear to connect the static excitation equipment to the rotor field winding.

On no load, the generator excitation is provided by the PRI.1 winding of the excitation transformer. On load, the generator current injects an additional excitation current, via PRI.2 of the transformer, to maintain а constant output voltage. If the excitation components are carefully designed, the generator voltage of а compounded generator can be closely maintained at all loads without the use of an AVR or manual voltage trimmer. However, some generator manufacturers do include an AVR and а manual trimmer rheostat in such а compounded static excitation scheme. This addition may provide closer voltage regulation over the load range and allow manual control of the generator voltage, eg for synchronizing and kVAr load balancing between generators.

А practical three-phase static excitation scheme has additional components, such as reactors and capacitors. “Three-phase compound excitation circuit” has no AVR or manual trimmer regulator. А load current surge will automatically feedback an adjustment to the field excitation to correct the resulting voltage surge so quickly that the output voltage remains practically constant.

Compound excitation systems require the static components to be designed to closely match its associated generator.

**Automatic Voltage Regulator AVR (analogue type)**

- In the standard configuration, the automatic voltage regulator receives both its input power and voltage sensing from the generator's output terminals.

- The regulator automatically monitors the generator's output voltage against an internal reference set point and provides the necessary DC output voltage to the exciter field required to maintain constant generator terminal voltage.

- The generator's terminal voltage is changed by adjusting the regulator's reference set point.

Sudden load current surges (eg. due to large motor starting) on а generator cause а corresponding change in its output voltage. This is due to an internal voltage drop in the generator windings and the effect is usually called voltage dip. Similarly, load shedding will produce an overvoltage at the busbars. An unregulated or non-compounded generator excitation system would not be realistic on-board ship due to the varying voltage caused by the fluctuating load demand. Automatic voltage regulation (AVR) equipment is necessary to rapidly correct such voltage changes.

An AVR will control the generator's voltage to ± 2.5% (or better) of its set value over the full load range. This is its steady state voltage regulation. Transient voltage dip is usually limited to 15% for а specified sudden load change with recovery back to rated voltage within 1.5 seconds. ln special cases

where unusually large surges are expected (eg from thrusters and cargo cranes), the generator/AVR performance limits may be extended.

The AVR senses the generator output voltage and acts to alter the field current to maintain the voltage at its set value. А manual trimmer regulator may be fitted on the generator control panel to set the voltage level eg 440 V.

More commonly, two voltage trimmer potentiometers are assembled. One is inside the generator's panel and the other is incorporated into the control card of the AVR. This option gives more flexibility to personnel for adjusting the generator's voltage.

The control circuit for а modern AVR consists of voltage and current transformers, mounted on the generator, as well as solid state elements, mounted on an electronic module fitted into the generator's termination board.The voltage sensing unit transforms down, rectifies and smooths the generator output voltage. This produces а low voltage DC signal that is proportional to the АС generator voltage. This actual DC signal is compared with а set DC value produced by а reference circuit of Zener diodes and resistors. An error signal output from the comparator is then amplified and made suitable for driving the field circuit regulating thyristor(s).

А thyristor is а fast acting electronic switch controlled by а voltage signal at its gate terminal. It rectifies and regulates the generator field current.

Additional components and sub-circuits are included in the AVR to ensure:

• Rapid response time with voltage stability

• Fair current and reactive load (kVAr) sharing when generators are to be operated in parallel

• Quick voltage build up during generator run-up

• Overvoltage/undervoltage alarm/trip protection.

The complete AVR circuit is fairly complex and includes а few pre-set variable resistors for the control of sensitivity, offset error and stability (proportional, integral and differential control). These are adjusted and set during generator trials to achieve an optimum and stable performance.

You should resist the temptation to adjust pre-set controls unless fully competent with such а feedback control system. However, bear in mind that, after replacing а faulty AVR, the newly assembled unit should always be adjusted.

AVR running checks, as guided by the manufacturer, consist of АС and DC voltage measurements at installed test points. These are compared with values found acceptable during previous generator trials. The voltmeter type and its range are usually specified for each test.

Most ships will carry а spare AVR unit or spare cards that may be interchanged after а suspected failure. An AVR changeover should only be attempted when its generator is stopped and locked off. Checks at the test points on the new AVR excitation field current level and the manual regulator operation (if fitted) should be proven with the generator running on no load before attempting to synchronize on to the busbars.

When generators are loading sharing in parallel, check for approximately equal current (or kVAr) sharing between the machines. This will indicate correct operation of their AVRs.

**АС Generator Operation**

Main generator power ratings range from, typically, 250 kW to 2 MW at 440 V, 690 V, 60 Hz АС or 380 V, 50 Hz АС driven bу diesel, steam turbine, gas turbine or propulsion shaft-driven prime movers.

As the demand for increased electrical power installations arises (eg for specialist offshore vessels and cruise liners), it is necessary to generate at high voltage (HV) with voltages typically at 3.3 kV, 6.6 kV and 11 kV, 60 Hz [3].

As most ships use АС generators (sometimes called alternators), the principles and operational features will cover this type only.

The basic principle of an АС generator is very simple. Pairs of electromagnetic poles are driven (by the prime mover) past fixed coils of wire оn the stator.

An alternating electromotive force (emf) which, ideally, has а sinusoidal waveform, is induced into each stator phase winding. The useful emf level (Е) is called the root mean square (rms) value and all equipment is rated in rms terms. А peak, or maximum, level is times larger than the rms level, eg if

The size of emf generated depends on the strength of magnetic flux (Ф) and the rate at which this flux cuts the coils, so where n is the rotational speed of the rotor poles in rev/s.

The voltage available at the generator terminals is [phasor calculation] where I is the load current flowing in the stator phase windings. An internal phase volt-drop of (I\*Z) occurs due to the impedance Z of а phase winding, which is made up from its resistance and reactance.

The frequency f (measured in Hertz) of the emf is the number of waveform cycles per second. This depends on the rotational speed and the number of poles,

The two basic relationships for emf and frequency dictate how to control the voltage and frequency output of а generator. ln practice, the speed is maintained practically constant by the generator's prime mover, which fixes the output frequency. The constant speed then allows the size of generated emf to be directly controlled by the size of pole flux (excitation).

An АС generator has three sets of coils, called phase windings, located in slots in the stator surrounding the rotating magnetic poles. The emf induced in each phase is 120° out of phase with the other two phases. Three-phase windings are labelled as U-V-W with color coding of red, yellow and white used on terminals and busbars. One end of each of the three-phase windings is joined to form the neutral point of а star connection (often colour-coded in blue).

The other ends of the phase windings are connected to outgoing conductors called lines, which are coded as L 1, L2 and L3.

The rated values of а machine always refer to line conditions (as stated on the rating plate).

Angle is the phase angle which is determined by the types of electrical load on the generator (eg. lighting, motors, galley equipment etc).

The speed of an auxiliary diesel-driven generator (DG) is accurately managed by an electronic governor that maintains an almost constant output frequency over its load range.

А propulsion shaft-driven (SG) generator can be an efficient method for extracting electric power from the ship's main engine as the power is derived from lower cost fuel than that used for an auxiliary DG unit. The SG may be fitted directly in-line with the slow speed propulsion shaft or, more commonly, be gear-driven up to а higher speed.

By using а shaft generator as the main source of electric power during long sea passages, the DG units operate for short periods only, which creates а reduced maintenance requirement.

An apparent disadvantage of а shaft generator is that it has no direct frequency control as this is determined by the main engine, which is set for the ship's full-away speed range (eg 70-100%).

This means that the frequency must be separately regulated at the output of the shaft generator to maintain а constant 60 Hz to the ship's electric power consumers. Such а frequency regulator utilizes an electric АС/DС/АС converter, as shown in Figure "Shaft-driven generator control".

At the three-phase rectifier stage, the АС generator frequency is converted to а DC voltage. The three-phase controlled inverter converts the DC back to а fixed output frequency by sequenced thyristor switching. А DC link inductor coil is interposed between the rectifier and inverter to smooth the normal current flow and act as а current limiter in the event of а short-circuit fault.

An inverter thyristor switch is turned on by а positive current pulse to its gate when its anode is positive with respect to its cathode. The thyristor is only turned off when its current is reduced to (approximately) zero. This is а problem for the inverter thyristors when driving into the ship's inductive load (typically about 0.8 power factor lagging). ln this case, the current continues to flow in а thyristor after its voltage has gone through а zero point, causing disruption of the inverter switching sequence.

**Shaft-driven generator control**

To overcome this problem, it is necessary to have the thyristor current in phase with its voltage so that turn-off is automatically achieved (line commutation) at the end of each АС half cycle. The addition of leading kVAr compensation to the power system to create an overall unity power factor solves the problem. Therefore, the SG/converter must only supply true power Р (kW). At every instant, the leading kVAr (+ Q) must exactly match the lagging kVAr (- Q) of the ship's load, so the compensation must be automatically controlled. The practical solution is to include а synchronous motor, operating as а synchronous compensator, whose operating power factor is controlled by regulating its DC field current.

Overall, the busbar voltage is fixed by the field flux in the shaft generator and the busbar frequency is regulated by the controlled inverter.

**Generator Protection**

The number and type of protective relay functions increases with the generator KVA rating and voltage level. Protective relays are electromagnetic or electronic which are mounted on the generator front panel of the main switchboard, or it can be integrated module.

Settings for level and time delay must be periodically checked by injecting currents and/or voltages directly into the relay.

SHORT CIRCUIT PROTECTION trips instantly to protect the generator and network against high over current caused by short circuit.

The OVER CURRENT PROTECTION monitors general balanced overloading and has current/time settings determined by the overall protective discrimination scheme.

UNDER AND OVER FREQUENCY settings are typically 58 Hz and 62 Hz for a 60 Hz system.

UNDER AND OVER VOLTAGE PROTECTIONS protects the generator with settings of around 80% - 120% of the rated voltage with time delays of about 2 seconds.

REVERSE POWER PROTECTION monitors the direction of power flowing between the generator and the load. If a prime mover failed occurred, the generator would act as a motor. The reverse power relay detects this fault and trip the Circuit Breaker.

**Emergency Generators**

The power sources of emergency power plant are 3-phase alternating current (AC) producing by Synchronous Generator.

An emergency generator, typically 50 kW to 300 kW at 440 V or 220 V, will be diesel driven and fitted with an automatic start facility.

Note: The emergency generator can be used during lay time in port for the main power supply (either as а harbor generator in single mode or as а generator in parallel with one of the main generators).

Therefore, the power ratings of emergency generators may be increased up to the power of the main generators while the ship is under construction. The transitional source of emergency electrical power must be а storage battery which, in the event of failure of the main source of electrical power, will automatically and immediately come into operation to supply the emergency essential consumers (emergency lighting, general alarm, radio and navigation aids, the fire alarm system, etc). Its capacity must be sufficient to supply these essential consumers for а period of at least 30 minutes, during which time the battery voltage must remain within ± 12% of the rated voltage, without intermediate recharging. Battery supplies from lead-acid or alkaline cells are usually rated at 24 V DC.

It is a separate generator which supplies the electric power for emergency load in the event of main power supply failure.

To improve the reliability of Emergency Generators, their automatic control systems make it easy to:

1. Eliminate voltage correctors

2. Eliminate manual voltage regulators (excitation rheostats)

3. Apply electrical (rather than electromagnetic) summation of signals proportional to the voltage and current of the load.

**SOLAS REQUIREMENT:**

- The emergency source of electrical power associated, transforming equipment, transitional source of emergency power, emergency switchboard and emergency lighting switchboard shall be located above the uppermost continuous deck and shall be readily accessible from the open deck. They shall not be located forward of the collusion bulkhead.

- For a period 36 hours (passenger ship)

- For a period 18 hours (cargo ship)

- The automatic starting system and the characteristic of the prime mover shall be such as to permit the emergency generator to carry its full rated load as quickly as is safe and practicable, subject to a maximum of 45 seconds.

- Have unless a second independent means of starting of emergency generator is provided the single source of stored energy.

It is provided with independent means of automatically starting (by air, battery or other type) to ensure immediate run up following a main power failure and repeated starts of at least 3 times, and further attempt can be made within the 30 minutes.

Must be able to be started in cold condition up to zero (0 °C)

For cold weather, JCW system must be treated with anti-freeze agent, and heating arrangement provided.

An emergency generator is connected to its own emergency switchboard, and they are located together.

In normal operation, the emergency board is supplied from the main switchboard called the bus tie breaker.

Power supplies for Emergency Power Plants:

- Emergency lightening

- Navigation system

- Steering gear

- Emergency fire pump

- Emergency air compressor

- Battery charging

- Fire detecting and alarming system

- Radio equipment (Communication equipment)

- Daylight signaling lamp and ship’s whistle

- Navigation Aids

- General Alarm

- Manual fire alarm

- Watertight doors