CHAPTER THREE
DIESEL GENERATORS

3.1 Introduction

A diesel generator (also known as diesel genset) is the combination of a diesel engine with an electric generator (often an alternator) to generate electrical energy. This is a specific case of engine-generator. A diesel compression-ignition engine is usually designed to run on diesel fuel, but some types are adapted for other liquid fuels or natural gas.

Diesel generating sets are used in places without connection to a power grid, or as emergency power-supply if the grid fails, as well as for more complex applications such as peak-lopping, grid support and export to the power grid.

3.2 Diesel Generator Set

The packaged combination of a diesel engine, a generator and various ancillary devices is referred to as a "generating set".

Set sizes range from 8 to 30 kW (also 8 to 30 kVA single phase) for homes, small shops and offices with the larger industrial generators from 8 kW (11 kVA) up to 2,000 kW (2,500 kVA three phase) used for large office complexes, factories, and other industrial facilities.

A 2,000 kW set can be housed in a 40 ft (12 m) ISO container with fuel tank, controls, power distribution equipment and all other equipment needed to operate as a standalone power station or as a standby backup to grid power.

These units, referred to as power modules, are gensets on large triple axle trailers weighing 85,000 pounds (38,555 kg) or more. A combination of these modules are used for small power stations and these may use from one to 20 units per power section and these sections can be combined to involve hundreds of power modules.

In these larger sizes the power module (engine and generator) are brought to site on trailers separately and are connected together with large cables and a control cable to form a complete synchronized power plant.

A number of options also exist to tailor specific needs, including control panels for autostart and mains paralleling, acoustic canopies for fixed or mobile applications, ventilation equipment, fuel supply systems, exhaust systems, etc.

Diesel generators are not only for emergency power, but may also have a secondary function of feeding power to utility grids either during peak periods, or periods when there is a shortage of large power generators. In the UK, this program is run by the national grid and is called STOR.

Ships often also employ diesel generators, sometimes not only to provide auxiliary power for lights, fans, winches etc., but also indirectly for main propulsion.

With electric propulsion the generators can be placed in a convenient position, to allow more cargo to be carried. Electric drives for ships were developed before World War I. Electric drives were specified in many warships built during World War II because manufacturing capacity for large reduction gears was in short supply, compared to capacity for manufacture of electrical equipment.

Such a diesel-electric arrangement is also used in some very large land vehicles such as railroad locomotives.

3.2.1 Diesel Engine

Figure 3.1 shows a diesel engine.

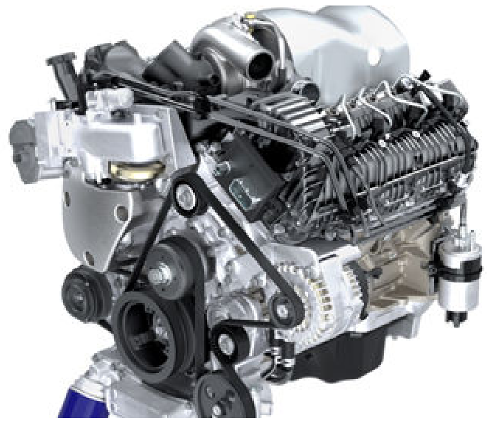

Figure 3.1: Diesel Engine

A diesel engine converts the chemical energy of fuel into thermal energy that charges a cylinder in consequence of self-ignition and combustion of the fuel after compression of air.

A slider crank mechanism converts the thermal energy into mechanical work using a crankshaft. The combustion process has some significant features.

In a gasoline engine the fuel and air mixture is drawn into the cylinder, compressed from (4: 1 to 10: 1), and ignited by a spark; in a diesel engine air alone is draw into the cylinder, compressed to a higher ratio (14: 1 to 25: 1), causing a rise in the air temperature in the range of 700 to 900° C, then diesel fuel is injected by a nozzle and ignites spontaneously.

A diesel engine has some advantages over spark ignition motors (gasoline or alcohol), such as better fuel economy and longer engine life (i.e., over the life of the engine, less money is spent with diesel, but the initial high cost of the engine must be taken into account). Therefore, only longtime operation enables with a favorable fuel economy will overcome the increased price of the engine.

Because of the weight to compression ratio, diesel engines have lower maximum rpm ranges than gasoline engines, making them suitable for high torque rather than high acceleration. This is a good feature for generators that have to rather operate at constant high speed.

Diesel engines are also considered to have high efficiency and can reach effective efficiencies of up to 55%,[8] compared to spark ignition engines because of a higher compression rate; the caloric energy conversion into mechanical work has lower losses at higher compression rate.

3.2.2 Alternator

An alternator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current.[9]

The ac generator or alternator is the second major part of the generator set. Nowadays most if not all of the alternators are brushless type with rotating excitation system. The alternator is selected during the configuration process. It should be matched mechanically to the diesel engine.

Electrically the alternator should be selected to provide the required KW at the specified voltage, frequency, ambient temperature, altitude and it should be capable to withstand the transient loads without exceeding the maximum allowable voltage dips.

Normally the automatic voltage regulator (AVR) is supplied as part of the alternator to ensure the compatibility. The brushless alternators use rotating exciter generator to generate the excitation (magnetization) current and voltage required by the main rotor to be excited (magnetized).

The AVR controls the amount of excitation given to the rotor based on sensing the generator output voltage. Alternators speed should match the diesel engine speed. The lower the speed the higher the number of rotor poles. This is to maintain fixed 50 Hz or 60 Hz regardless of the rotation speed. Figure 3.2 shows an alternator.

Figure 3.2 Alternator

3.2.3 Speed Governing

The two main parameters we must control in the diesel generator sets are speed and voltage.

Controlling the speed is controlling the diesel engine prime mover via controlling the fuel. On the other hand controlling the voltage is controlling the AC generator (alternator) via controlling the excitation of the rotor (magnetization of the rotor).

Speed governing or some time we call it speed control is like any other feedback control system. It consists of sensing part that measure the running speed of the diesel engine (magnetic pickups). Then the speed controller compares the actual running speed from the magnetic pickup with the set reference speed and produces an error.[10]

This error is then amplified and converted to an output signal to raise or lower the speed via the governor actuator. This is electronic type. The most famous control is known as PID (Proportional, Integral and Derivative). Governors can also be mechanical hydraulic type.

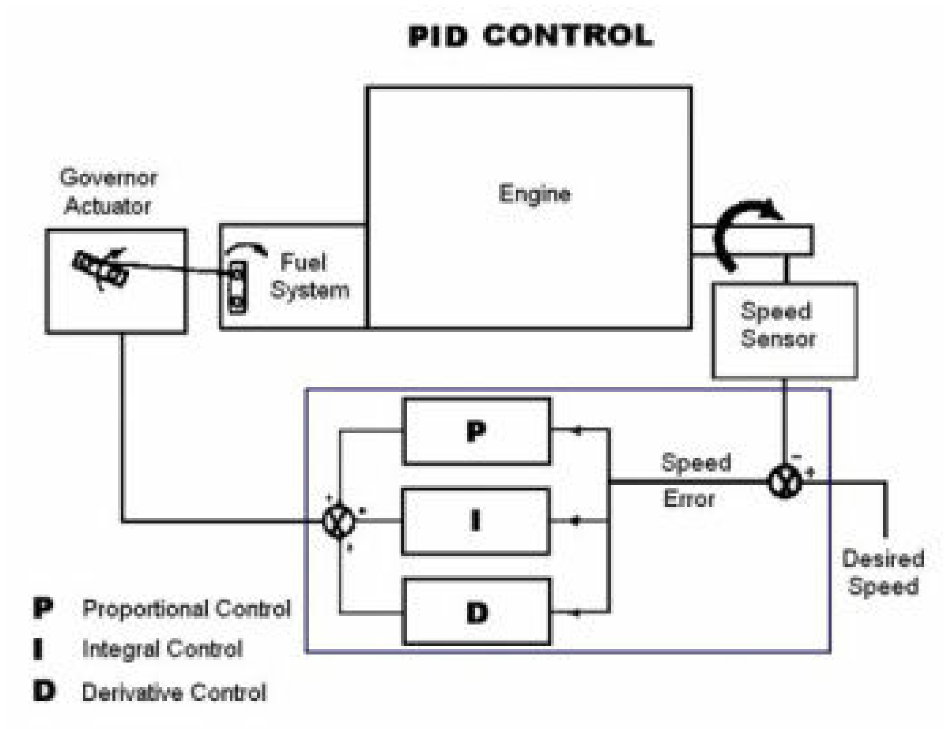

Figure 3.3: PID Control

3.2.4 Excitation Control

As mentioned elsewhere the excitation is simply magnetizing the rotor to produce magnetic field. During the rotation of the rotor the field flux lines intersect with the stator windings and electromotive force (emf) will be generated accordingly.[11]

Most of the alternators used nowadays are brushless type, where the DC current required to magnetize the rotor is produced by the exciter generator and then rectified using rotating rectifiers. To control the amount of excitation we need to control the exciter generator.

The voltage regulator is used to sense the output voltage of the alternator and then compares it with the setting to produce the error. This error is amplified and modulated to control the field of the exciter.

In some applications where the generator is to run in parallel with the mains the generator reactive power in this case must be controlled so that the generator will not be pulled to an overload situation. PF control is used.

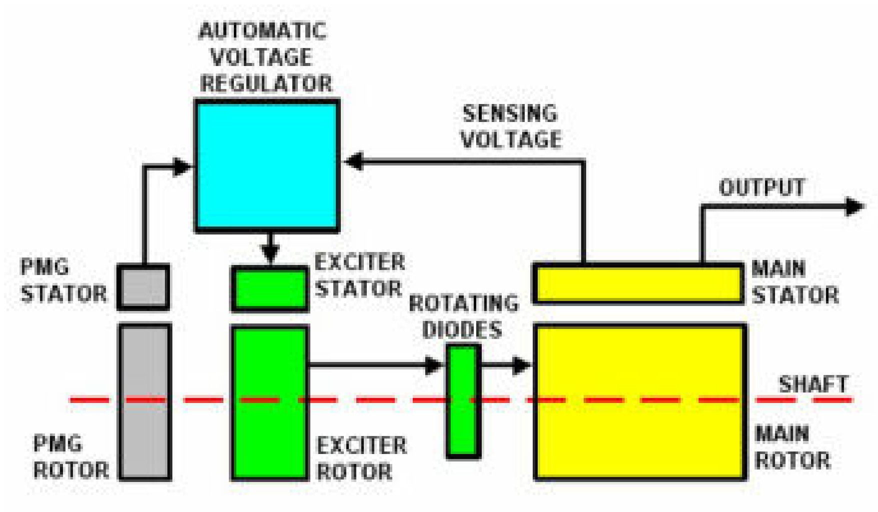

Figure 3.4: Excitation Control

3.2.5 Generator Set Sizing

As part of configuration process of a generator set is to answer the question: What is the size of this generator set in terms of KW rating and what is its reactive capability to withstand the transient loads.

The sizing process is started always by sizing the site load and defining the total running loads in KW and starting loads in KVA and then apply the other site load criteria such as maximum allowable voltage dip.

It should be emphasized here that the power factor is controlled by the load and it affects the generator by pulling more currents as the power factor drops. Loads which have high starting KVA's are simply have low starting power factors.

When sizing gensets it is advisable always to limit the starting KVA of the load by using lower voltage starting methods like star/delta or transformer tap or if this is not possible use sequencing. This is to switch the big starting KVA loads in sequence of 15 to 30 seconds intervals and not together.[13]

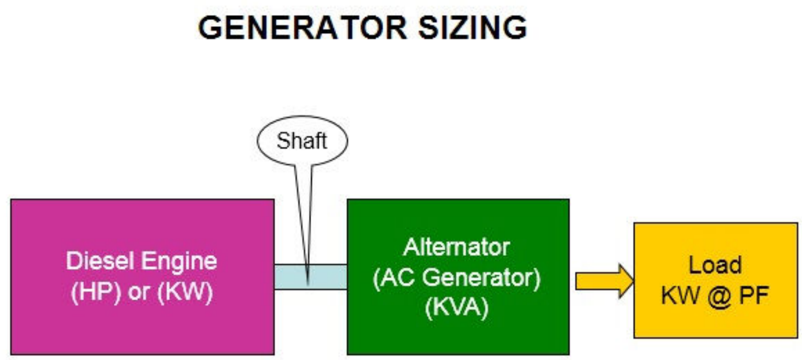

Figure 3.5: Generator Sizing

3.2.6 Generator Set Design

What are the different equipment and components which all together make the generator set and how they are put together as one system to give the required generator set with its pre-defined specifications. This is known as design process.

Some manufacturers design some or all of the generator set supporting systems such as the skid bases, control panels, circuit breaker panels, exhaust system, fuel tanks, weather enclosures,....etc for which these manufacturers should have engineering design office and produce shop floor drawings and bills of materials.

They should have quality control as after sales service system. design include electrical control schematic drawings, wiring diagrams, control panels and switchgear general arrangement drawings, components layout drawings, single line diagrams, wires and cables schedule, PLC ladder logic diagrams, controllers setup files, skid base production drawings, generator set general arrangement drawing, radiator and pipes layouts, P&ID, power house layout drawing, generator set enclosure drawing, generator set trailer drawing and many other detailed drawings which will be used by the manufacturer or his subcontractors for manufacturing and/or installation purposes. Figure 3.6 shows the components of a diesel generator set.

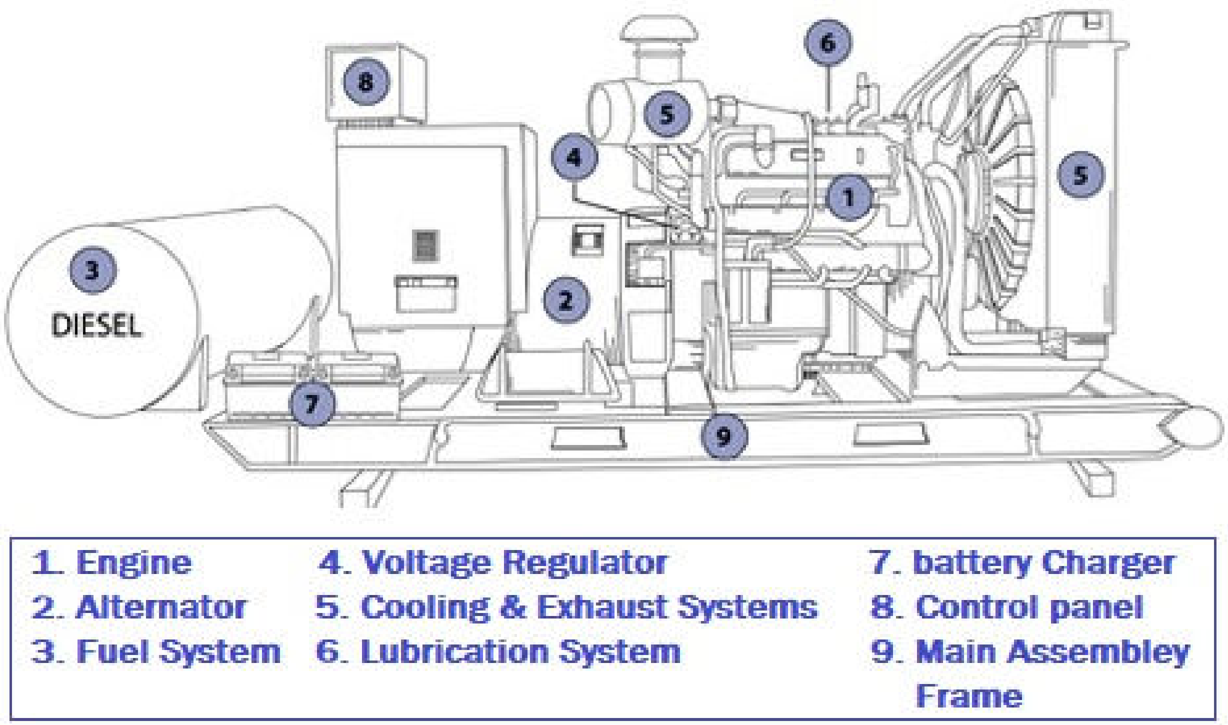

Figure 3.6: Diesel Generator Set

3.3 Paralleling and Load Sharing Diesel Generators

Based on the results of the load sizing we may need to have more than one generator set to operate in parallel to supply the load.

When generator sets operate in parallel they encounter problems not seen when they operate standalone. Some of these problems is how maintain the frequency of the system, how to share the site load, how to eliminate the reactive cross current and how to control the start and stop of these gensets when the site load increase or decrease and which generator set will be the duty generator set and which ones will be the non-duty and so on.

These challenges require installing paralleling and load sharing control system with load demand control.[14]

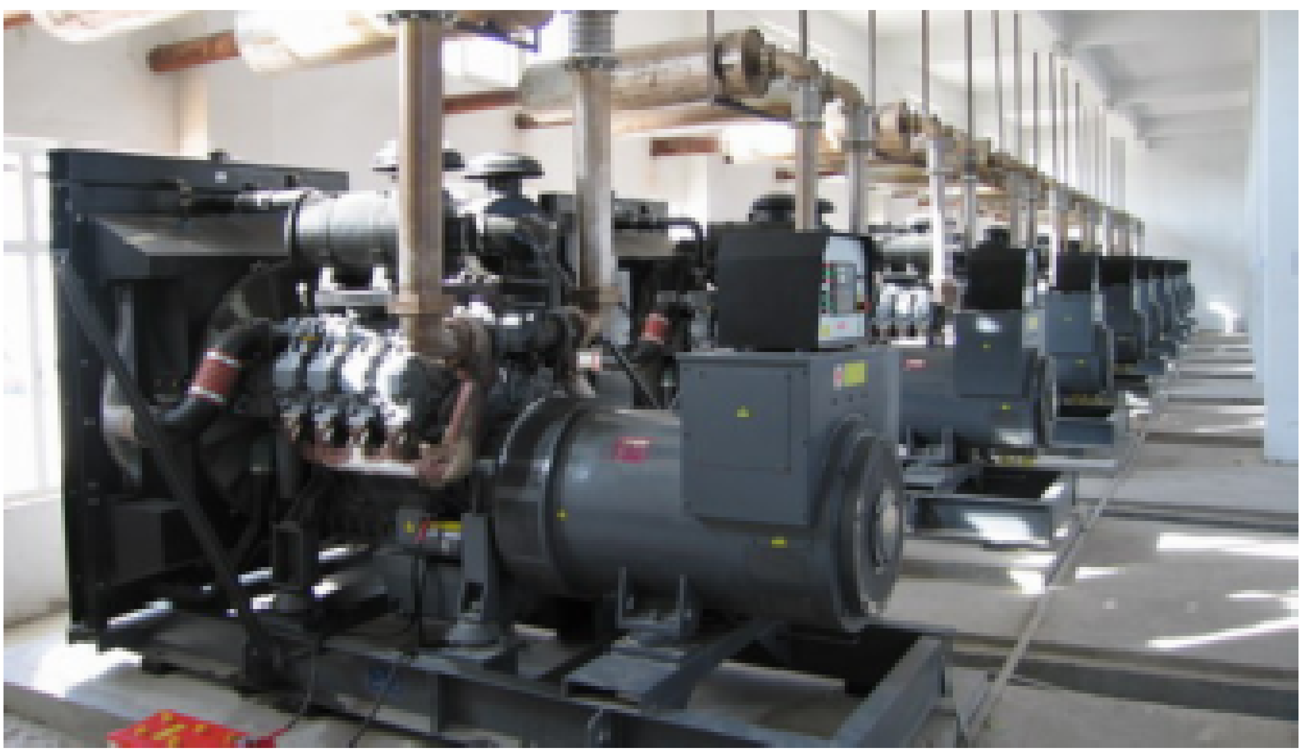

Figure3.7: Paralleling and Load Sharing Diesel Generators

3.4 Rating

Generators must provide the anticipated power required reliably and without damage and this is achieved by the manufacturer giving one or more ratings to a specific generator set model.

A specific model of a generator operated as a standby generator may only need to operate for a few hours per year, but the same model operated as a prime power generator must operate continuously. When running, the standby generator may be operated with a specified - e.g. 10% overload that can be tolerated for the expected short running time.

The same model generator will carry a higher rating for standby service than it will for continuous duty. Manufacturers give each set a *rating* based on internationally agreed definitions.

These standard rating definitions are designed to allow valid comparisons among manufacturers, to prevent manufacturers from miss-rating their machines, and to guide designers.

3.4.1 Standby Rating

Applicable for supplying emergency power for the duration of normal power interruption. No sustained overload capability is available for this rating.

Typical application - emergency power plant in hospitals, offices, factories etc. Not connected to grid.

3.4.2 Prime Rating

Should not be used for Construction Power applications. Output available with varying load for an unlimited time. Typical peak demand 100% of prime-rated e kW with 10% of overload capability for emergency use for a maximum of 1 hour in 12. A 10% overload capability is available for limited time. This rating is not applicable to all generator set models.

Typical application - where the generator is the sole source of power for say a remote mining or construction site, fairground, festival etc.

3.4.3 Continuous Rating

Applicable for supplying power continuously to a constant load up to the full output rating for unlimited hours. No sustained overload capability is available for this rating, and it is not applicable to all generator set models.

Typical application - a generator running a continuous unvarying load, or paralleled with the mains and continuously feeding power at the maximum permissible level 8,760 hours per year. This also applies to sets used for peak shaving /grid support even though this may only occur for say 200 hours per year.

As an example if in a particular set the Standby Rating were 1000 kW, then a Prime Power rating might be 850 kW, and the Continuous Rating 800 kW. However these ratings vary according to manufacturer and should be taken from the manufacturer's data sheet.

Often a set might be given all three ratings stamped on the data plate, but sometimes it may have only a standby rating, or only a prime rating.

3.5 Fuels

Diesel fuel is named after diesel engines, and not vice versa; diesel engines are simply compression-ignition engines, and can operate on a variety of different fuels, depending on configuration and location.

Where a gas grid connection is available, gas is often used, as the gas grid will remain pressurized during almost all power cuts. This is implemented by introducing gas with the intake air and using a small amount of diesel fuel for ignition. Conversion to 100% diesel fuel operation can be achieved instantaneously.

In more rural situations, or for low load factor plant, diesel fuel derived from crude oil is a common fuel; it is less likely to freeze than heavier oils. Endurance will be limited by tank size. Diesel engines can work with the full spectrum of crude oil distillates, from natural gas, alcohols, gasoline, wood gas to the fuel oils from diesel oil to cheaper residual fuels that are like lard at room temperature, and must be heated to enable them to flow down a fuel line.[12]

Larger engines (from about 3 MW to 30 MW) sometimes use heavy oils, essentially tars, derived from the end of the refining process. The slight added complexity of keeping the fuel oil heated to enable it to flow, whilst mitigating the fire risks that come from over-heating fuel, make these fuels unpopular for smaller, often unmanned, generating stations.

Other possible fuels include: biodiesel, straight vegetable oil, animal fats and tallows, glycerine, and coal-water slurry. These should be used with caution and due to the composition, normally have detrimental effects on engine life.

Figure 3.8 shows a fuel tank next to a backup generator.

Figure 3.8: Back up generator with fuel tank

3.6 Advantages of diesel generators

- Simple design and layout.
- Occupies less space & is compact.
- Can be started quickly & pick up load in a short time.
- Requires less water for cooling.
- Requires no operating staff.
- No standby losses.