9. DIESEL / NATURAL GAS POWER GENERATING SYSTEM

Factors affecting selection, Waste heat recovery, Energy performance assessment of DG sets, Diesel conservation opportunities.

9.1 Introduction

Reciprocating engines produce electricity using a combustible fuel and generator. In addition to producing electricity, useful heat can be recovered from the exhaust gas using a heat recovery steam generator (HRSG), or heat recovery system for hot water (Figure 9.1). Heat can also be recovered from the lubricating oil cooler, the jacket water cooler and/or the charge air cooler, and this recovered "waste" heat can be provided to a heating load. In this case, the reciprocating engine power plant would be operating in a Combined Heat & Power (CHP) or cogeneration mode. The energy performance of a reciprocating engine is influenced by a number of factors such as the type of fuel, availability, the reciprocating engine power capacity, minimum capacity, heat rate and heat recovery efficiency.

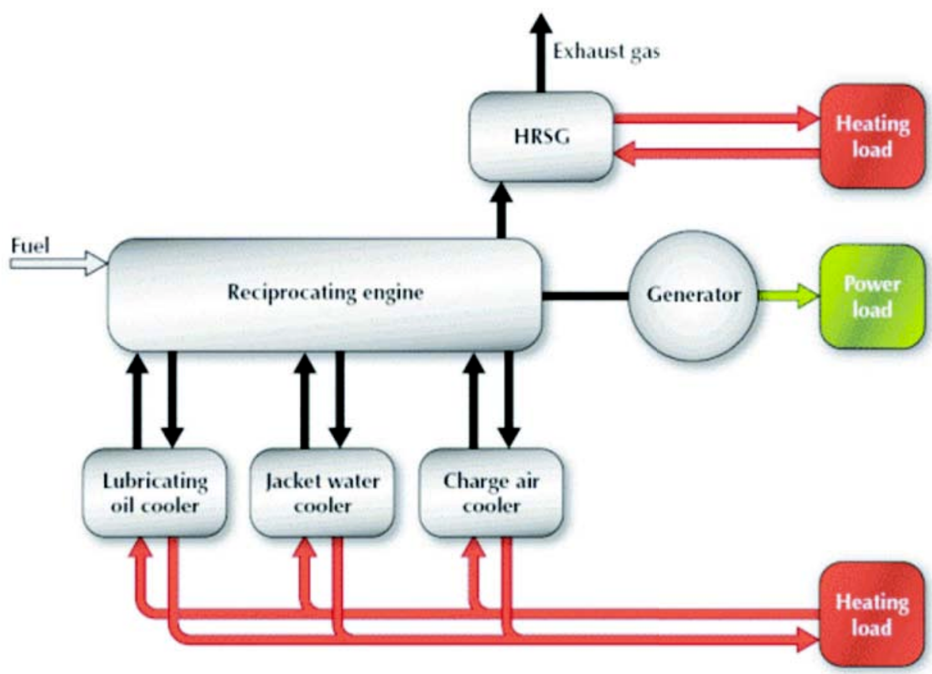

Figure 9.1 Reciprocating Engine Cogeneration

There are two basic types of reciprocating engines - spark ignition and compression ignition. Spark ignition engines use a spark (across a spark plug) to ignite a compressed fuel-air mixture. Typical fuels for such engines are gasoline, natural gas and sewage and landfill gas. Compression ignition engines compress air to a high pressure, heating the air to the ignition temperature of the fuel, which then is injected. The high compression ratio used for compression ignition engines results in a higher efficiency than is possible with spark ignition engines. Diesel/heavy fuel oil is normally used in compression ignition engines, although some are dual-fueled (natural gas is compressed with the combustion air and diesel oil is injected at the top of the compression stroke to initiate combustion).

Diesel Engine Cycle

Diesel engine is the prime mover, which drives an alternator to produce electrical energy. In the diesel engine, air is drawn into the cylinder and is compressed to a high ratio (14:1 to 25:1). During this compression, the air is heated to a temperature of 700–900^{0}C. A metered quantity of diesel fuel is then injected into the cylinder, which ignites spontaneously because of the high temperature. Hence, the diesel engine is also known as compression ignition (CI) engine.

DG set can be classified according to cycle type as: two stroke and four stroke. However, the bulk of IC engines use the four stroke cycle. Let us look at the principle of operation of the four-stroke diesel engine.

The 4 stroke operations in a diesel engine (Figure 9.2) are: induction stroke, compression stroke, ignition and power stroke and exhaust stroke.

1st : Induction stroke - while the inlet valve is open, the descending piston draws in fresh air.
2nd : Compression stroke - while the valves are closed, the air is compressed to a pressure of up to 25 bar.
3rd : Ignition and power stroke - fuel is injected, while the valves are closed (fuel injection actually starts at the end of the previous stroke), the fuel ignites spontaneously and the piston is forced downwards by the combustion gases.
4th : Exhaust stroke - the exhaust valve is open and the rising piston discharges the spent gases from the cylinder.

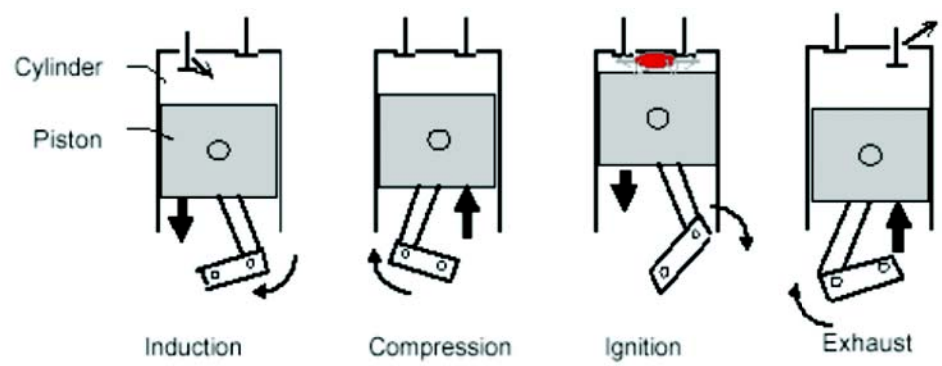

Figure 9.2 Schematic Diagram of Four-Stroke Diesel Engine

Since power is developed during only one stroke, the single cylinder four-stroke engine has a low degree of uniformity. Smoother running is obtained with multi cylinder engines because the cranks are staggered in relation to one another on the crankshaft. There are many variations of engine configuration, for example, 4 or 6 cylinder, in-line, horizontally opposed, vee or radial configurations.

Gas Engines

A typical spark-ignited lean-burn engine is depicted in Figure 9.3. In this process, the gas is mixed with air before the inlet valves. During the intake period, gas is also fed into a small prechamber, where the gas mixture is rich compared to the gas in the cylinder. At the end of the compression phase, the gas/air mixture in the prechamber is ignited by a spark plug. The flames from the nozzle of the prechamber ignite the gas/air mixture in the whole cylinder. Combustion is fast. After the working phase, the cylinder is emptied of exhaust and the process starts again. Reciprocating engines with modern lean-burn technology reach close to 45% electrical efficiency.

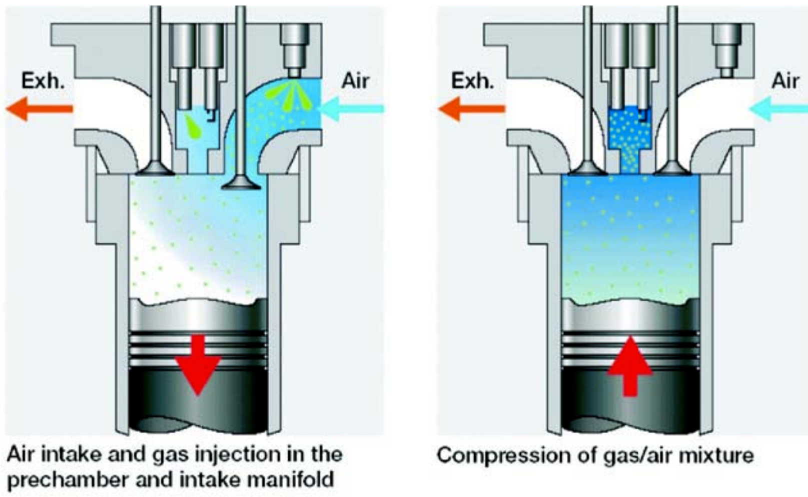

Figure 9.3 Natural Gas Engine

DG Set as a System

A diesel generating set (Figure 9.4) should be considered as a system since its successful operation depends on the well-matched performance of the components, namely:

a) The diesel engine and its accessories.
b) The AC Generator.
c) The control systems and switchgear.
d) The foundation and power house civil works.
e) The connected load with its own components like heating, motor drives, lighting etc.

It is necessary to select the components with highest efficiency and operate them at their optimum efficiency levels to conserve energy in this system.

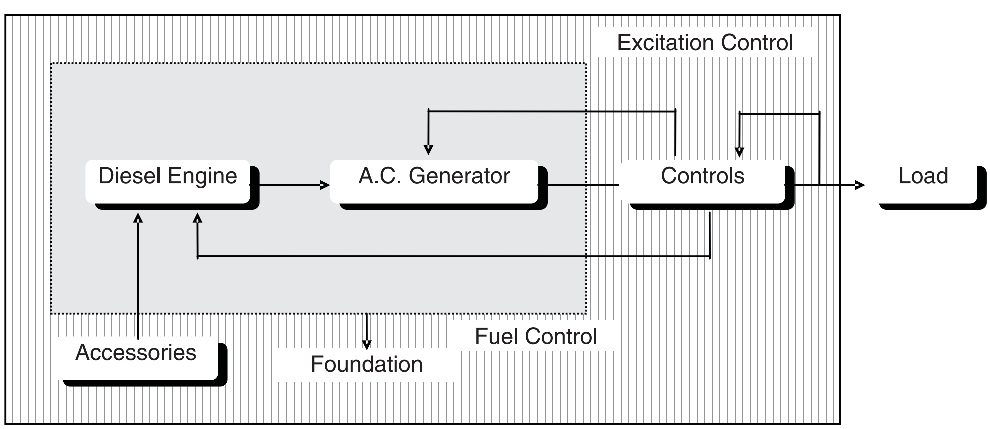

Figure 9.4 DG Set System

Selection Considerations

To make a decision on the type of engine, which is most suitable for a specific application, several factors need to be considered. The two most important factors are: power and speed of the engine.

The power requirement is determined by the maximum load. The engine power rating should be 10-20 % more than the power demand by the end use. This prevents overloading the machine by absorbing extra load during starting of motors or switching of some types of lighting systems or when wear and tear on the equipment pushes up its power consumption.

Speed is measured at the output shaft and given in revolutions per minute (RPM). An engine will operate over a range of speeds, with diesel engines typically running at lower speeds (1300 - 3000 RPM). There will be an optimum speed at which fuel efficiency will be greatest. Engines should be run as closely as possible to their rated speed to avoid poor efficiency and to prevent build up of engine deposits due to incomplete combustion - which will lead to higher maintenance and running costs. To determine the speed requirement of an engine, one has to again look at the requirement of the load.

For some applications, the speed of the engine is not critical, but for other applications such as a generator, it is important to get a good speed match. If a good match can be obtained, direct coupling of engine and generator is possible; if not, then some form of gearing will be necessary - a gearbox or belt system, which will add to the cost and reduce the efficiency.

There are various other factors that have to be considered, when choosing an engine for a given application. These include the following: cooling system, abnormal environmental conditions (dust, dirt, etc.), fuel quality, speed governing (fixed or variable speed), poor maintenance, control system, starting equipment, drive type, ambient temperature, altitude, humidity, etc.

Suppliers or manufacturers literature will specify the required information when purchasing an engine. The efficiency of an engine depends on various factors, for example, load factor (percentage of full load), engine size, and engine type.

Diesel Generator Captive Power Plants

Diesel engine power plants are most frequently used in small power (captive non-utility) systems. The main reason for their extensive use is the higher efficiency of the diesel engines compared with gas turbines and small steam turbines in the output range considered. In applications requiring low captive power, without much requirement of process steam, the ideal method of power generation would be by installing diesel generator plants. The fuels burnt in diesel engines range from light distillates to residual fuel oils. Most frequently used diesel engine sizes are between the range 4 to 15 MW. For continuous operation, low speed diesel engine is more cost-effective than high speed diesel engine.

Advantages of adopting Diesel Power Plants are:

- Low installation cost
- Short delivery periods and installation period
- Higher efficiency (as high as 43 -45 %)
- More efficient plant performance under part loads

- Suitable for different type of fuels such as low sulphur heavy stock and heavy fuel oil in case of large capacities.
- Minimum cooling water requirements,
- Adopted with air cooled heat exchanger in areas where water is not available
- Short start up time

A brief comparison of different types of captive power plants (combined gas turbine and steam turbine, conventional steam plant and diesel engine power plant) is given in Table 9.1. It can be seen from the Table that captive diesel plant wins over the other two in terms of thermal efficiency, capital cost, space requirements, auxiliary power consumption, plant load factor etc.

Table 9.1 Comparison of Different Types of Captive Power Plant

Description	Units	Combined GT & ST	Conventional Steam Plant	Diesel Engine Power Plants
Thermal Efficiency	%	40 - 46	33 - 36	43 - 45
Initial Investment of Installed Capacity	Rs./kW	8,500 - 10,000	15,000 -18,000	7,500 - 9,000
Space requirement		125 % (Approx.)	250 % (Approx.)	100 % (Approx.)
Construction time	Months	24 - 30	42 - 48	12 - 15
Project period	Months	30 - 36	52 - 60	12
Auxiliary Power Consumption	%	2 – 4	8 - 10	1.3 – 2.1
Plant Load Factor	kWh/kW	6000 - 7000	5000 - 6000	7200 - 7500
Start up time from cold	Minutes	About 10	120 - 180	15 - 20

Diesel Engine Power Plant Developments

The diesel engine developments have been steady and impressive. The specific fuel consumption has come down from a value of 220 g/kWh in the 1970's to a value of around 160 g/kWh in present times.

Slow speed diesel engine, with its flat fuel consumption curve over a wide load range (50%-100%), compares very favorably over other prime movers such as medium speed diesel engine, steam turbines and gas turbines.

With the arrival of modern, high efficiency turbochargers, it is possible to use an exhaust gas driven turbine generator (Figure 9.5) to further increase the engine rated output. The net result would be lower fuel consumption per kWh and further increase in overall thermal efficiency.

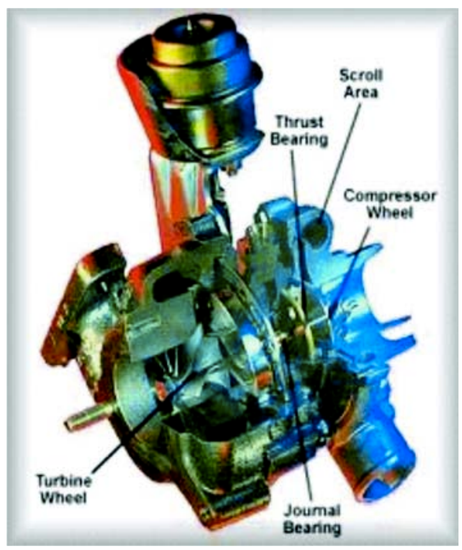

Figure 9.5 Turbocharger

The diesel engine is able to burn the poorest quality fuel oils, unlike gas turbine, which is able to do so with only costly fuel treatment equipment.

Slow speed *dual* fuel engines are now available using high-pressure gas injection, which gives the same thermal efficiency and power output as a regular fuel oil engine.

9.2 Selection and Installation Factors

Sizing of a Genset:

a) If the DG set is required for 100% standby, then the entire connected load in HP / kVA should be added. After finding out the diversity factor, the correct capacity of a DG set can be found out.

Example :

Connected Load	=	650 kW
Diversity Factor (Demand / Connected load)	=	0.54
Max. Demand	=	650 x 0.54 = 350 kW
% Loading	=	70
Set rating	=	350/0.7 = 500 kW
At 0.8 PF, rating	=	625 kVA

b) For an existing installation, record the current, voltage and power factors (kWh / kVAh) reading at the main bus-bar of the system at every half-an-hour interval for a period of 2-3 days and during this period the factory should be having its normal operations. The non-essential loads should be switched off to find the realistic current taken for running essential equipment. This will give a fair idea about the current taken from which the rating of the set can be calculated.

For existing installation:

kVA	=	$\sqrt{3}$ V I
kVA Rating	=	kVA / Load Factor
where Load factor	=	Average kVA / Maximum kVA

c) For a new installation, an approximate method of estimating the capacity of a DG set is to add full load currents of all the proposed loads to be run in DG set. Then, applying a diversity factor depending on the industry, process involved and guidelines obtained from other similar units, correct capacity can be arrived at.

High Speed Engine or Slow/Medium Speed Engine

The normal accepted definition of high speed engine is 1500 rpm. The high speed sets have been developed in India, whereas the slow speed engines of higher capacities are often imported. The other features and comparison between high and medium / slow speed engines are mentioned in Table 9.2 below:

Table 9.2 Comparison of High and Slow Speed Engine

Factor	Slow speed engine	High speed engine
Break mean effective pressure - therefore wear and tear and consumption of spares	Low	High
Weight to power ratio- therefore sturdiness and life	More	Less
Space	High	Less
Type of use	Continuous use	Intermittent use
Period between overhauls*	8000 hours	3200
Direct operating cost (includes lubricating oils, filters etc.)	Less	High

* Typical recommendations from manufacturers

Keeping the above factors and available capacities of DG set in mind, the cost of economics for both the engines should be worked out before arriving at a decision.

Capacity Combinations

From the point of view of space, operation, maintenance and initial capital investment, it is certainly economical to go in for one large DG set than two or more DG sets in parallel.

Two or more DG sets running in parallel can be a advantage as only the short-fall in power – depending upon the extent of power cut prevailing - needs to filled up. Also, flexibility of operation is increased since one DG set can be stopped, while the other DG set is generating at least 50% of the power requirement. Another advantage is that one DG set can become 100% standby during lean and low power-cut periods.

Air Cooling Vs. Water Cooling

The general feeling has been that a water cooled DG set is better than an air cooled set, as most users are worried about the overheating of engines during summer months. This is to some extent is true and precautions have to be taken to ensure that the cooling water temperature does not exceed the prescribed limits. However, from performance and maintenance point of view, water and air cooled sets are equally good except that proper care should be taken to ensure cross ventilation so that as much cool air as possible is circulated through the radiator to keep its cooling water temperature within limits.

While, it may be possible to have air cooled engines in the lower capacities, it will be necessary to go in for water cooled engines in larger capacities to ensure that the engine does not get over-heated during summer months.

Safety Features

It is advisable to have short circuit, over load and earth fault protection on all the DG sets. However, in case of smaller capacity DG sets, this may become uneconomical. Hence, it is strongly recommended to install a circuit protection. Other safety equipment like high temperature, low lube oil pressure cut-outs should be provided, so that in the event of any of these abnormalities, the engine would stop and prevent damage. It is also essential to provide reverse power relay when DG sets are to run in parallel to avoid back feeding from one alternator to another.

Parallel Operation with Grid

Running the DG set in parallel with the mains from the supply undertakings can be done in consultation with concerned electricity authorities. However, some supply undertakings ask the consumer to give an undertaking that the DG set will not be run in parallel with their supply. The reasons stated are that the grid is an infinite bus and paralleling a small capacity DG set would involve operational risks despite normal protections like reverse power relay, voltage and frequency relays.

Maximum Single Load on DG Set

The starting current of squirrel cage induction motors is as much as six times the rated current for a few seconds with direct-on-line starters. In practice, it has been found that the starting current value should not exceed 200 % of the full load capacity of the alternator. The voltage and frequency throughout the motor starting interval recovers and reaches rated values usually much before the motor has picked up full speed.

In general, the HP of the largest motor that can be started with direct on line starting is about 50 % of the kVA rating of the generating set. On the other hand, the capacity of the induction motor can be increased, if the type of starting is changed over to star delta or to auto transformer starter, and with this starting the HP of the largest motor can be upto 75 % of the kVA of Genset.

Unbalanced Load Effects

It is always recommended to have the load as much balanced as possible, since unbalanced loads can cause heating of the alternator, which may result in unbalanced output voltages. The maximum unbalanced load between phases should not exceed 10 % of the capacity of the generating sets.

Neutral Earthing

The electricity rules clearly specify that two independent earths to the body and neutral should be provided to give adequate protection to the equipment in case of an earth fault, and also to drain away any leakage of potential from the equipment to the earth for safe working.

Site Condition Effects on Performance Derating

Site condition with respect to altitude, intake temperature, cooling water temperature and derate diesel engine output as shown in following Tables: 9.3 and 9.4.

Table 9.3 Altitude and Intake Temperature Corrections

Correction Factors For Engine Output				
Altitude Correction			Temperature Correction	
Altitude Meters over MSL	Non Super Charged	Super Charged	Intake ^{o}C	Correction Factor
610	0.980	0.980	32	1.000
915	0.935	0.950	35	0.986
1220	0.895	0.915	38	0.974
1525	0.855	0.882	41	0.962
1830	0.820	0.850	43	0.950
2130	0.780	0.820	46	0.937
2450	0.745	0.790	49	0.925
2750	0.712	0.765	52	0.913
3050	0.680	0.740	54	0.900
3660	0.612	0.685		
4270	0.550	0.630		
4880	0.494	0.580		

Table 9.4 Derating due to Air Inter Cooler Water Inlet Temperature		
Water Temperature ^{o}C	Flow %	Derating %
25	100	0
30	125	3
35	166	5
40	166	8

9.3 Operational Factors

Load Pattern & DG Set Capacity

The average load can be easily assessed by logging the current drawn at the main switchboard on an average day. The 'over load' has a different meaning when referred to the D.G. set. Overloads, which appear insignificant and harmless on electricity board supply, may become detrimental to a D.G.set, and hence overload on D.G.set should be carefully analysed. Diesel engines are designed for 10% overload for 1 hour in every 12 hours of operation. The A.C. generators are designed to meet 50% overload for 15 seconds as specified by standards. The D.G.set/s selection should be such that the overloads are within the above specified limits. It would be ideal to connect steady loads on DG set to ensure good performance. Alongside alternator loading, the engine loading in terms of kW or BHP, needs to be maintained above 50%. Ideally, the engine and alternator loading conditions are both to be achieved towards high efficiency.

Engine manufacturers offer curves indicating % Engine Loading vs Fuel Consumption in grams/BHP. Optimal engine loading corresponding to best operating point is desirable for energy efficiency.

Alternators are sized for kVA rating with highest efficiency attainable at a loading of around 70% and more. Manufacturer's curves can be referred to for best efficiency point and corresponding kW and kVA loading values.

Sequencing of Loads

The captive diesel generating set has certain limits in handling the transient loads. This applies to both kW (as reflected on the engine) and kVA (as reflected on the generator). In this context, the base load that exists before the application of transient load brings down the transient load handling capability, and in case of A.C. generators, it increases the transient voltage dip. Hence, great care is required in sequencing the load on D.G.set/s. It is advisable to start the load with highest transient kVA first followed by other loads in the descending order of the starting kVA. This will lead to optimum sizing and better utilisation of transient load handling capacity of D.G.set.

Load Pattern

In many cases, the load will not be constant throughout the day. If there is substantial variation in load, then consideration should be given for parallel operation of D.G.sets. In such a situation, additional D.G. set(s) are to be switched on when load increases. The typical case may be an establishment demanding substantially different powers in first, second and third shifts. By parallel operation, D.G. sets can be run at optimum operating points or near about, for optimum fuel consumption and additionally, flexibility is built into the system. This scheme can be also be applied where loads can be segregated as critical and non-critical loads to provide standby power to critical load in the captive power system.

Load Characteristics

Some of the load characteristics influence efficient use of D.G.set. These characteristics are entirely load dependent and cannot be controlled by the D.G.set. The extent of detrimental influence of these characteristics can be reduced in several cases.

- **Power Factor:**

The load power factor is entirely dependent on the load. The A.C. generator is designed for the power factor of 0.8 lag as specified by standards. Lower power factor demands higher excitation currents and results in increased losses. Over sizing A.C. generators for operation at lower power factors results in lower operating efficiency and higher costs. The economical alternative is to provide power factor improvement capacitors.

- **Unbalanced Load:**

Unbalanced loads on A.C. generator leads to unbalanced set of voltages and additional heating in A.C. generator. When other connected loads like motor loads are fed with unbalanced set of voltages additional losses occur in the motors as well. Hence, the load on the A.C. generators should be balanced as far as possible. Where single phase loads are predominant, consideration should be given for procuring single phase A.C. generator.

- **Transient Loading:**

On many occasions to contain transient voltage dip arising due to transient load application, a specially designed generator may have to be selected. Many times an unstandard combination of engine and A.C. generator may have to be procured. Such a combination ensures that the prime mover is not unnecessarily over sized which adds to capital cost and running cost.

- **Special Loads:**

Special loads like rectifier / thyristor loads, welding loads, furnace loads need an application check. The manufacturer of diesel engine and AC generator should be consulted for proper recommendation so that desired utilisation of DG set is achieved without any problem. In certain cases of loads, which are sensitive to voltage, frequency regulation, voltage wave form, consideration should be given to segregate the loads, and feed it by a dedicated power supply which usually assumes the form of DG motor driven generator set. Such an alternative ensures that special design of AC generator is restricted to that portion of the load which requires high purity rather than increasing the price of the D.G.set by specially designed AC generator for complete load.

Waste Heat Recovery in DG Sets

For combined heat and power applications, waste heat from reciprocating engines can be tapped mainly from exhaust gases and cooling water that circulates around cylinders in the engine jackets, with additional potential from oil and turbo coolers. While engine exhaust and cooling water each provide about half of the useful thermal energy, the exhaust is at much higher temperature (around 450 ^oC versus 100 ^oC) and hence is more versatile. A typical energy balance in a reciprocating engine generator using Diesel and Natural gas is given in Table 9.5 below.

Table 9.5 Energy Balance for Reciprocating Engine

	Conventional cooling system		Cooling system with engine jacket and exhaust heat recovery		
500-kW natural gas engine generator*					
Electric power	30%			30%	
Jacket-water heat	38%	70% wasted		38%	54% recoverable
Exhaust heat	24%		Exh recoverable	16%	
			Exh lost	8%	16% wasted
Radiated heat lost to atmosphere	8%			8%	
	100%			100%	
500-kW diesel engine generator†					
Electric power	35%			35%	
Jacket water	32%	65% wasted		32%	48% recoverable
Exhaust heat	24%		Exh recoverable	16%	
			Exh lost	8%	17% wasted
Radiated heat lost to atmosphere	9%			9%	
	100%			100%	

The table reveals that for natural gas generator more thermal energy (54%) can be recovered from the reciprocating engine compared to an electrical energy conversion of 30%.

It would be realistic to assess the Waste Heat Recovery (WHR) potential in relation to quantity, temperature margin, in kCal/hr as:

$$\text{Potential WHR} = (\text{kWh Output/hour}) \times (8 \text{ kg Gases / kWh Output}) \times 0.25 \text{ kCal/kg}^oC \times (t_g - 180^oC)$$

Where, t_g is the gas temperature after Turbocharger, (the criteria being that limiting exit gas temperature cannot be less than 180^{o}C, to avoid acid dew point corrosion), 0.25 being the specific heat of flue gases and kWh output being the actual average unit generation from the set per hour. For a 1100 kVA set, at 800 kW loading, and with 480^{o}C exhaust gas temperature, the waste heat potential works out to:

$$800 \text{ kWh} \times 8 \text{ kg gas generation / kWh output} \times 0.25 \text{ kCal/kg }^oC \times (480 - 180), \text{ i.e., } 4{,}80{,}000 \text{ kCal/hr}$$

While the above method yields only the potential for heat recovery, the actual realisable potential depends upon various factors and if applied judiciously, a well configured waste heat recovery system can tremendously boost the economics of captive DG power generation.

The factors affecting Waste Heat Recovery from flue gases are:

a) DG Set loading, temperature of exhaust gases
b) Hours of operation and
c) Back pressure on the DG set

Consistent DG set loading (to over 60% of rating) would ensure a reasonable exit flue gas quantity and temperature. Fluctuations and gross under loading of DG set results in erratic flue gas quantity and temperature profile at entry to heat recovery unit, thereby leading to possible cold end corrosion and other problems. Typical flue gas temperature and flow pattern in a 5 MW DG set at various loads are given in Table 9.6.

Table 9.6 Typical Flue Gas Temperature and Flow Pattern in a 5-MW DG Set at various Loads

100% Load	11.84 kg/sec	370°C
90% Load	10.80 kg/sec	350°C
70% Load	9.08 kg/sec	330°C
60% Load	7.50 kg/sec	325°C
If the normal load is 60%, the flue gas parameters for waste heat recovery unit would be 325°C inlet temperature, 180°C outlet temperature and 27180 kg/hour gas flow. At 90% loading, however, values would be 350°C and 32,400 kgs/Hour, respectively.		

* Number of hours of operation of the DG Set has an influence on the thermal performance of waste heat recovery unit. With continuous DG Set operations, cost benefits are favourable.

* Back pressure in the gas path caused by additional pressure drop in waste heat recovery unit is another key factor. Generally, the maximum back pressure allowed is around 250-300 mmWC and the heat recovery unit should have a pressure drop lower than that. Choice of convective waste heat recovery systems with adequate heat transfer area are known to provide reliable service.

The configuration of heat recovery system and the choice of steam parameters can be judiciously selected with reference to the specific industry (site) requirements. Much good work has taken place in Indian Industry regarding waste heat recovery and one interesting configuration, deployed is installation of waste heat boiler in flue gas path along with a vapour absorption chiller, to produce 8°C chilled water working on steam from waste heat.

Trigeneration Technology

In order to further optimize fuel utilization Trigeneration systems are developed which involves the simultaneous production of electricity, heat and cooling. The prime mover used for power generation includes diesel engines/gas engines. The waste heat recovery system in captive power generation units consists of waste heat recovery boiler for generating steam and use of jacket cooling water for operating Vapor Absorption Machines (VAM) to meet air conditioning requirements.

9.4 Energy Performance Assessment of DG Sets

Routine energy efficiency assessment of DG sets on shop floor involves following typical steps:

1) Ensure reliability of all instruments used for trial.
2) Collect technical literature, characteristics, and specifications of the plant.

3) Conduct a 2 hour trial on the DG set, ensuring a steady load, wherein the following measurements are logged at 15 minutes intervals.
   a) Fuel consumption (by dip level or by flow meter)
   b) Amps, volts, PF, kW, kWh
   c) Intake air temperature, Relative Humidity (RH)
   d) Intake cooling water temperature
   e) Cylinder-wise exhaust temperature (as an indication of engine loading)
   f) Turbocharger RPM (as an indication of loading on engine)
   g) Charge air pressure (as an indication of engine loading)
   h) Cooling water temperature before and after charge air cooler (as an indication of cooler performance)
   i) Stack gas temperature before and after turbocharger (as an indication of turbocharger performance)

4) The fuel oil/diesel analysis is referred to from an oil company data.

5) Analysis: The trial data is to be analysed with respect to:
   a) Average alternator loading.
   b) Average engine loading.
   c) Percentage loading on alternator.
   d) Percentage loading on engine.
   e) Specific power generation kWh/liter.
   f) Comments on Turbocharger performance based on RPM and gas temperature difference.
   g) Comments on charge air cooler performance.
   h) Comments on load distribution among various cylinders (based on exhaust temperature, the temperature to be ± 5% of mean and high/low values indicate disturbed condition).
   i) Comments on housekeeping issues like drip leakages, insulation, vibrations, etc.

A format as shown in the Table 9.7 is useful for monitoring the performance

Table 9.7 Typical Format for DG Set Monitoring

DG Set No.	Electricity Generating Capacity (Site), kW	Derated Electricity Generating Capacity, kW	Type of Fuel used	Average Load as % of Derated Capacity	Specific Fuel Cons. Lit/kWh	Specific Lube Oil Cons. Lit/kWh
1.	480	300	LDO	89	0.335	0.007
2.	480	300	LDO	110	0.334	0.024
3.	292	230	LDO	84	0.356	0.006
4.	200	160	HSD	89	0.325	0.003
5.	200	160	HSD	106	0.338	0.003
6.	200	160	HSD			
7.	292	230	LDO	79	0.339	0.006
8.	292	230	LDO	81	0.362	0.005
9.	292	230	LDO	94	0.342	0.003
10.	292	230	LDO	88	0.335	0.006
11.	292	230	LDO	76	0.335	0.005
12.	292	230	LDO	69	0.353	0.006
13	400	320	HSD	75	0.334	0.004
14.	400	320	HSD	65	0.349	0.004
15.	880	750	LDO	85	0.318	0.007

Table 9.7 Typical Format for DG Set Monitoring						
DG Set No.	Electricity Generating Capacity (Site), kW	Derated Electricity Generating Capacity, kW	Type of Fuel used	Average Load as % of Derated Capacity	Specific Fuel Cons. Lit/kWh	Specific Lube Oil Cons. Lit/kWh
16.	400	320	HSD	70	0.335	0.004
17.	400	320	HSD	80	0.337	0.004
18.	880	750	LDO	78	0.345	0.007
19.	800	640	HSD	74	0.324	0.002
20.	800	640	HSD	91	0.290	0.002
21.	880	750	LDO	96	0.307	0.002
22.	920	800	LDO	77	0.297	0.002

9.5 Energy Saving Measures for DG Sets

a) Ensure steady load conditions on the DG set, and provide cold, dust free air at intake (use of air washers for large sets, in case of dry, hot weather, can be considered).

b) Improve air filtration.

c) Ensure fuel oil storage, handling and preparation as per manufacturer's guidelines/oil company data.

d) Consider fuel oil additives in case they benefit fuel oil properties for DG set usage.

e) Calibrate fuel injection pumps frequently.

f) Ensure compliance with maintenance checklist.

g) Ensure steady load conditions, avoiding fluctuations, imbalance in phases, harmonic loads.

h) In case of a base load operation, consider waste heat recovery system adoption for steam generation or refrigeration chiller unit incorporation. Even the Jacket Cooling Water is amenable for heat recovery, vapour absorption system adoption.

i) In terms of fuel cost economy, consider partial use of biomass gas for generation. Ensure tar removal from the gas for improving availability of the engine in the long run.

j) Consider parallel operation among the DG sets for improved loading and fuel economy thereof.

k) Carryout regular field trials to monitor DG set performance, and maintenance planning as per requirements.

QUESTIONS	
Objective Type Questions	
1.	The compression ratio in diesel engines is in the range of: a) 10:1 to 15:1 b) 14:1 to 25:1 c) 5:1 to 10:1 d) 1:2 to 3:1
2.	Present specific fuel consumption value of DG sets in industries is about _______. a) 220 g/kWh b) 100 g/kWh c) 160 g/kWh_ d) 50 g/kWh
3.	The rating required for a DG set with 500 kW connected load and with diversity factor of 1.5, 80% loading and 0.8 power factor is ___ a) 520 kVA b) 600 kVA c) 625 kVA d) 500 kVA
4.	The waste heat potential for a 1100 kVA set at 800 kW loading and with 480 °C exhaust gas temperature is __ a) 4.8 lakh kCal/hr b) 3.5 lakh kCal/hr c) 3 lakh kCal/hr d) 2 lakh kCal/hr
5.	For a DG set, the copper losses in the alternator are proportional to the: a) current delivered by the alternator b) square of the current delivered by the alternator c) square root of the current delivered by the alternator d) none of the above
6.	The capacity of largest motor that can be started in the given DG set is a) 25% b) 50% kVA rating of DG set c) 75% d) 100%
7.	The jacket cooling water in a diesel engine flows at 12.9 m^3/hr with a range of 10^oC and accounts for 30% of the engine input energy. The power loss in cooling water is a) 430 kW b) 500 kW c) 387 kW d) 150 kW
8.	The operating economics of trigeneration primarily depends on the a) capacity of generator b) capacity of waste heat boiler c) capacity of VAM d) cost of fuel
9.	The efficiency of a Diesel Generator Power plant ranges between: a) 20 – 25% b) 0 – 20% c) 40 – 45% d) 60 – 70%
10.	A spark ignition engine is used for firing which of the following fuels a) high speed diesel b) light diesel oil c) natural gas d) furnace oil
Short Type Questions	
S-1	A 5 MW DG set with an average load of 3 MW running in parallel with the grid was found to be exporting 100 kVAr. Without calculating, explain what could be the possible reasons for the export of reactive power to the grid. List advantages/disadvantages of the above situation.
S-2	A DG set is operating at 750 kW loading with 440^oC exhaust gas temperature. The DG set generates 8 kg gas/ kWh generated, and specific heat of gas at 0.25 kCal/ kg ^oC. A heat recovery boiler is installed after which the exhaust gas temperature reduces to 190^oC. How much steam will be generated at 3 kg/ cm^2 with enthalpy of 650 kCal/ kg. Assume boiler feed water temperature as 70^oC.

S-3	The connected load of a plant is 1200 kW and Diversity factor is 1.8. What is the desirable set rating with respect to 0.8 PF and the set load factor of 75%?
S-4	What are the sources of waste heat recovery in a DG set?. Waste heat recovery from which source is more economically attractive. Why?
S-5	Explain the principle of a four stroke diesel engine?
Long Type Questions	
L-1	A cement industry has installed 6 MW DG set and is operated by furnace oil. The cost of furnace oil is Rs.28 / liter. The average loading on the DG set is 5 MW and the hourly furnace oil consumption is 1230 liters. Estimate the cost of power generation in Rs./kWh. The plant management is planning to convert the existing DG set to gas operated DG set. The estimated cost of gas is Rs.20/Sm^3. If the power generation is 3.7 kWh / Sm^3. Calculate the generation cost per kWh with gas as fuel.
L-2	The process plant has installed 3.5 MW DG sets. Furnace oil is used as a fuel in DG sets. The load factor of the DG sets 80% and DG set is operated for 7000 hours in a year. Calculate the energy generated and the waste heat recovery potential from exhaust gas.

REFERENCES

1. Proceedings of National Workshop on Efficient Captive Power Generation with Industrial DG Sets
2. NPC Case Studies