Unit - II -

Diesel, Gas Turbine & Combined cycle Power

Introduction:

It is a type of propulsion system for ships which need a maximum speed. For ships which need a maximum speed, particularly warships like modern cruise speed, particularly warships like modern frigates or corvettes. It consist of diesel engine for cruising & gas turbine for high speed transits.

In most cases, the difference of power output from the diesel engine alone is too large for controllable pitch. However, the new codage propelled the great ratio for diesel engines. For diesel only, change about 1:7:7. For diesel & turbine mode, some ships have 3 different gear ratio for diesel engine.
Turbine & Diesel on separate shafts

The engine arrangement of diesel engine and gas turbine with each system using its own shaft & propeller is also called C&DAG system. Since more propellers have to be used, they have to be smaller and thus less HP.

The propeller of idling system creates drag.

C&DAG system was developed by Blohm & Voss.

Another way to combine two types of engines is to connect them to a generator to drive propeller electrically as in diesel electric. This also permits propeller pods with propulsion motor.
Otto & Diesel Plants

The internal combustion engine, ICE, has been refined and developed over the last 100 years for a wide variety of applications. It is compact size and used to provide primary power in remote locations. For a general idea, it is used to provide standby electrical power.

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Exhaust

Diesel/Gas

Power

Gasoline

Bio-Diesel

Speed control

Vrataanage

Frequency

Available Power

Simplified

Can represent engine performance

Assumption made that no friction

Substance of the process
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\[ P = \frac{\text{F} \cdot \text{ma} \cdot n \cdot q_u (F/A)}{n_r} \]

- \( P \) = engine power \( \text{O/P} \)
- \( \text{F} \) = fuel conversion \( \text{H} / \text{c} \)
- \( \text{ma} \) = mass of air
- \( n \) = crankshaft rotation speed
- \( q_u \) = heat value of fuel
- \( (F/A) \) = fuel mass flow rate
- \( n_r \) = no of crank revolutions

Energy conversion efficiency:

The fundamental task of internal combustion engine is to convert chemical energy into mechanical energy in the cylinder and thermo dynamic efficiency.

Compression Ratio \( \gamma \) = thermal efficiency

\[ \gamma - 1 = \frac{1 - (1/q_u)^{n_r} \cdot 1}{1 - (1/q_u)^{n_r} \cdot 1} \]

\( n_r \) = compression ratio
Spark Ignition Engine -

Patented in 1876 by Niels Lauri August Otto until 1908 as Spark ignition engine used carburettor to vapourise fuel to mix it with air. They suck in low cylinder by downward movement.

Diesel Engines -

Patented in 1894 by Rudolf Diesel. Diesel engine are similar to the cycle engine but are designed to work at much high compression.
To do this they aspirate any air
and compression cycle introduced at
end of compression cycle.

The high compression of air
causes it temp 700 to 900 degree

Engine speed is control by

Varying fuel flow in Diesel engine

has no throttle valve to restrict

Otto/Diesel comparison:

conversion efficiency For

Petrol engine (Chemical to mechanical)

Complete inlet stroke avail for fuel

Air & unburnt Fuel mixture

High speed

Low compression ratio

Disadvantages

Useful for one limit to more

volatile hydro carbon
Diesel / Brayton Cycle

Diesel Cycle

- Invented by Rudolf Christian Karl Diesel in 1893
- First engine was patented by professor Niels Julius Mausing
- Achieved a compression ratio of 16:1
- Exploited, instead of the Otto cycle
- Faster working engine
- Disadvantage: 10% efficiency

Diesel Engine

- Also known as Compression Ignition Engine (CI)
- Can have engine "knock"?
- Difference from Otto Cycle?

Thermodynamic Diesel Engine

- Not only converts the fuel into work but also converts heat into work
- Diesel engine the fuel is consumed at around 15% efficiency

Bent-Cylinder Engine and the Thermodynamic Diesel Cycle

- First law: Energy Analysis

First Law Analysis of Diesel Cycle

- Equations: Power = ΔW
- Work done = ΔW

Thermal Efficiency

- Efficiency = 1 - (Power output / Heat input)
- Diesel engines are more efficient than Otto cycles

Diesel engines are more fuel-efficient.
Other applications of Brayton cycle
- Power generation - use gas turbines to generate electricity - very efficient
- Marine applications in large ships
- Automobile racing - late 1950s Indy 500 ETH supercharger

Schematic of simple cycle

Idealized Brayton Cycle

Brayton Cycle
- 1 to 2 (adiabatic compression)
- 2 to 3 (constant pressure heat addition; removes combustion products)
- 3 to 4 (adiabatic expansion in the turbine)
- 4 to 1 (constant pressure heat rejection)

Brayton cycle analysis
- 1 to 2 (adiabatic compression)
- 2 to 3 (constant pressure heat addition)
- 3 to 4 (isentropic expansion)
- 4 to 1 (constant pressure heat rejection)

Efficiency:
\[ \eta = \frac{W_{out}}{Q_{in}} \]

Heat rate:
\[ W_{in} = \dot{Q}_{out} - \dot{W}_{net} \]

Adiabatic process:
\[ W_{net} = h_3 - h_4 \]

Brayton cycle analysis

Brayton cycle analysis

1 to 2 (isentropic compression in compressor), apply first law

\[ W_{comp} = h_2 - h_1 \]

When analyzing the cycle, we know that the compressor work is in (negative). In book, they’ll give a positive sign and then subtract it when necessary.

\[ W_{comp} = h_2 - h_1 \]

Brayton cycle analysis

\[ W_{net} = \dot{W}_{net} - \dot{W}_{comp} \]

Substituting:
\[ W_{net} = (h_3 - h_4) - (h_3 - h_4) \]
Analyzing the optimization, there are many rotating components in a gas turbine. Among them, the radial turbine is critical because it is subject to high centrifugal load at high temp.

The optimization is carried out to limit maximum stress within safe limits. The value of the component varies, but must be high by always producing to achieve high efficiency and as a result, the misalignment is minimal. These gas turbines are well suited for power generation.

Today, this technology is demand which is emission free. It is a component of the gas turbine. To perform structural analysis, the deformation and actual load condition are important.
The modeling tool used is uniformal.

The material having centrifugal force rotating body the centrifugal force arise as a result of rotation. The force always are radially outward from axis of rotation.

Blade loads: - (Centrifugal force, Pressure forces) these cause due to change in these cause due to change in axial to tangential moment as fluid pass through passage.

Fluid pass through passage.

Non uniform temp local Intertial load since comp is rotating at 1,00,000 rpm.

Grid convergence: -

Process of successive mesh refinement to produce optimal result called convergence.

Design objective, Design variable, Design constraints.
Diesel electric plants

- Peak load plant
  - Diesel plants are used as peak load units in combination with hydro or thermal plants. They can be easily started and stopped to meet the peak load demand.
- Mobile plant
  - They can be mounted on trailers and used for temporary or emergency purposes such as supplying power to large civil engineering projects.

Diesel electric plants

- For generating electrical power, it is essential to rotate the rotor of an alternator by means of a prime mover. The prime mover can be driven by different methods. Using diesel engine as prime mover is one of the popular methods of generating power. When the prime mover of the alternator is diesel engine, the power station is called diesel power station.

Diesel electric plants

- Advantages of Diesel Power Station
  - This is simple in design point of view.
  - Resisted very small space.
  - Can also be designed for portable use.
  - It takes a very short time to start.
  - It can also be stopped as well as started from a dead state.

- Disadvantages of Diesel Power Station
  - As we have already mentioned, the cost of diesel is very high compared to coal. This is the main reason for which a diesel power plant is not getting advantage over other means of generating power. In the future, the running cost of this plant is higher compared to water and hydropower plants.
  - Cost of lubrication is high.
  - Maintenance is quite complex and costly.
**Diesel electric plants**

- **Fuel Supply System**
  - In fuel supply system there are one storage tank, where oil is stored.
  - Ballast: This oil ballast in dry tank, by means of transfer pump.
  - During transferring from main tank to smaller dry tank, the oil passes through diluter to remove solid impurities. From dry tank to main tank, there is another pipe connection. This is over flow pipe. This pipe connection is used to return the oil from dry tank to main tank in the event of over flowing.
  - From dry tank the oil is supplied in the diesel engine by means of fuel injection pump.

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**Diesel electric plants**

- **Air Intake System**
  - This system supplies necessary air to the engine for fuel combustion. It consists of a pipe for supplying of clean air to the engine. Filters are provided to remove dust particles from air.
  - **Exhaust System**
    - The exhaust gas is removed from engine, to the atmosphere by means of an exhaust system. A silencer is normally used in this system to reduce noise level of the engine.

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**Diesel electric plants**

- **Cooling System**
  - The heat produced due to internal combustion, drives the engine. But some parts of this heat raise the temperature of different parts of the engine. High temperature may cause permanent damage to the machine. Hence, it is essential to maintain the overall temperature of the machine below the limit. Cooling of the engine is done using water, oil or air. Cooling of the engine is done using water. The water pump delivers water to the engine and it becomes hot. The hot water is cooled by cooling towers and is re-circulated for cooling.

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**Diesel electric plants**

- **Lubricating System**
  - This system provides the water circulating system of the engine. Here lubricating oil is stored in main lubricating oil tank. The lubricating oil is drawn from the tank by means of oil pump. Then the oil is passed through oil filter for removing impurities. From the filtering point, this clean lubricating oil is directed to the different parts of the machine where lubrication is required. Lubrication is done of the stationary and moving parts. The temperature of the lubricating oil is to be possible.

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**Diesel electric plants**

- **Starting System**
  - For starting a diesel engine, initial rotation of the engine shaft is required. Until the firing start and the unit runs with its own power. For small DG set, the initial rotation of the shaft is provided by handles. But for large diesel power station, Compressed air is made for starting.

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**Diesel electric plants**

- **Starter System**
  - Diesel engines or compression ignition engines as they are called are generally classified as two stroke engine and four stroke engines. In diesel engine, air admitted into the cylinder is compressed, the compression ratio being 12:20. At threshold of compression stroke, fuel is injected. It burns and the burning gases expand and do work on the piston. The engine is directly coupled to the generator. The gases are then exhausted from the cylinder to atmosphere.
Diesel electric plants

- **Engine starting system:**
  The function of this system is to start the engine from cold condition (compressed air).

- **Fuel system:**
  Pump draws diesel from storage tank and supplies it to the small day tank through the filter. Day tanks supply the daily fuel need of engine. The day tank is usually placed high so that diesel flows to engine under gravity. Diesel is again filtered before being injected into the engine to the fuel injection pump. The fuel is supplied to the engine according to the load on the plant.

Diesel electric plants

- **Engine lubrication system:**
  Lubrication is essential to reduce friction and wear of engine parts such as cylinder and piston rings.

  Lubrication oil which gets heated due to friction of moving parts is lost before recirculation. The cooling water used in the engine is used for cooling the lubricant oil.

Diesel electric plants

- **Air intake system:**
  Air filters are used to remove dust from the breathing air. Air filters may be of dry type, which is made up of felt, wool or cloth. In oil bath type filters, oil is added over a bath of oil so that dust particles get coated.

- **Exhaust system:**
  In the exhaust system, silencer (muffler) is provided to reduce the noise.

  Engine cooling system:
  The temperature of burning gases in the engine cylinder is the order of 1800 to 2200°C. To keep the temperature at the permissible level, water is circulated inside the engine to water jackets which are arranged around the cylinder, piston, combustion chamber etc. The water leaving the jacket is sent to heat exchanger. Raw water is made to flow through the heat exchanger, where it takes the heat of jacket water. It is then cooled in the cooling tower and recirculated again.

Diesel electric plants

- **Advantages of diesel power plant:**
  Plant layout is simple. Hence it can be quickly installed and commissioned. While the erection and setting up of a steam power plant or hydro plant takes a fairly long time.

  Guiding, steering and easy pick-up of loads are possible in a very short time.

  Location of the plant is near the load center.

  Steam load operation is easy and requires minimum labor.

  Efficiency at plant loads does not fall as much as that of a steam plant.

  Fuel handling is easier and no problem or drain disposal wastes.

  The plant is smaller in size than steam power plant for same capacity.

  Diesel plants operate at high overall efficiency than steam.
Components of Gas Turbine power plants

A gas turbine is a machine delivering mechanical power or thrust. It does this using a gaseous working fluid. The mechanical power generated can be used by, for example, an industrial device. The output gaseous fluid can be used to generate thrust in the gas turbine, there is a continuous flow of the working fluid.

History of gas turbines

We can distinguish two important types of gas turbines. There are industrial gas turbines and there are jet engine gas turbines. Industrial gas turbines were developed rather slowly. This was because to use a gas turbine, a high initial compression is necessary. This rather troubled early engineers. Due to this, the first working gas turbine was only made in 1903, by the Frenchman Huret.

The ideal gas turbine cycle

When examining the gas turbine cycle, we do a few assumptions. We assume that the working fluid is a perfect gas with constant specific heats and so on. Also, the specific heat ratio (x) is constant. We also assume that the isentropic efficiency of the working fluid does not vary along the gas turbine. Finally, pressure losses, mechanical losses, and other kinds of losses are neglected.
Classification

The gas turbine can be classified into two categories: i.e. impulse gas turbine and reaction gas turbine. If the entire pressure drop of the turbine occurs across the fixed blades, the design is an impulse type, while if the drop is taken place in the rotating blades, the fixed blades serving only as deflectors, the design is called a reaction type.

Gas Turbine Power Plant

The simple gas turbine power plant mainly consists of a gas turbine rated for a certain type and output. A compressor is used to increase the pressure of the air taken from the atmosphere so that it can be used as a fuel for the combustion chamber. The combustion products of the fuel are expanded through turbines, which are connected to the compressor and the generator. The exhaust gases are then passed through the heat recovery steam generator and finally exhausted to the atmosphere.

Schematic Arrangement of a Simple Gas Turbine Power Plant

The basic construction of a gas turbine engine consists of the compressor, turbine, combustion chamber, and exhaust system. Air is drawn through the compressor, which increases its pressure and temperature. The air then enters the combustion chamber, where it is mixed with fuel and burned to produce hot gases. These gases expand through the turbine, driving it to rotate and generate electricity. The exhaust gases then exit the turbine and are vented into the atmosphere.

Construction

The basic construction of a gas turbine engine consists of the compressor, turbine, combustion chamber, and exhaust system. Air is drawn through the compressor, which increases its pressure and temperature. The air then enters the combustion chamber, where it is mixed with fuel and burned to produce hot gases. These gases expand through the turbine, driving it to rotate and generate electricity. The exhaust gases then exit the turbine and are vented into the atmosphere.

Accessories

There are several accessories fitted to the turbine. These are: a governor, driven through a gear box, an over-speed governor, a lube-oil system, and a fire extinguisher. The governor is mounted on the shaft and is actuated by the speed of the turbine. It automatically increases or decreases the speed of the turbine to maintain the firing point. The lube-oil system is used for lubricating the bearings of the turbine. The fire extinguisher is used to extinguish any fire that may occur in the turbine or its accessories.

Cont...

The power of the turbine depends upon the size, shape and the speed of the blades used. Multi-staged engines are employed to increase the power output of the turbine to the requirements of the generator. The efficiency of the turbine is increased by maintaining the correct pressure ratio, efficiency of the stage, and the velocity ratio of the turbine. The exhaust gases are extracted from the turbine and are used to drive the generator.

Compresors

A compressor is a device that is used to compress air or fuel. It is similar to a pump that increases the pressure of the fluid by reducing the volume of the fluid. The compressor is usually driven by a gas turbine or a steam turbine. The compressed air or fuel is then used in the combustion chamber to generate power.

Cont...

The power of the compressor depends upon the size, shape and the speed of the blades used. Multi-staged compressors are employed to increase the power output of the compressor to the requirements of the engine. The efficiency of the compressor is increased by maintaining the correct pressure ratio, efficiency of the stage, and the velocity ratio of the compressor. The compressed air or fuel is then used in the combustion chamber to generate power.
Cont.
The rotor-dynamic compressor may be of several types, and flow air or-
comprressor 01 types in
order to provide the required
pressure. The compressor is
powered by the turbine, which is
rotated by the high pressure
air. The gas turbine is a
compressor type, which is
rotated by high pressure air
from the compressor. The
compressor is designed to
obtain the required pressure
for the gas turbine to operate.

Combustor
A combustor is a device in
which the combustion of fuel
and air takes place. For an
efficient operation of the gas
turbine, it is necessary to
ensure good combustion
performance. A good
combustor should achieve complete combustion and the desired
pressure and temperature. Temperature
in the combustor directly affects combustion and high temperature is conducive to rapid
combustion.

Generator
It is a device that generates electricity. It is
coupled to the same shaft as the turbine and
runs at same speed to that of the turbine. The
capacity of generators depends on the
speed of the plant. The types of
open cycle gas turbines to be used depend on the
purpose for which electrical energy is to be
produced.

Types of Gas Turbine
POWER PLANTS

The gas turbine power plants can be classified
mainly into two categories. These are open
cycle gas turbine power plant and closed cycle
gas turbine power plant.

Open Cycle Gas Turbine Power Plant
In this type of plant, the compressor air is channeled to
the combustor and then to the
compressor, which also discharges to the
exhaust of the turbine. The exhaust
air is discharged to the atmosphere.

Closed Cycle Gas Turbine Power Plant
Another type of power plant, one which is
in constant or another suitable gas cycle as
working medium discharges through the
combustor.

OPEN CYCLE GAS TURBINE POWER PLANT AND ITS
CHARACTERISTICS

The schematic arrangement of a simple
open cycle gas turbine power plant is
shown in Figure in next slide.

SIMPLE OPEN GAS TURBINE POWER PLANT

Types of Gas Turbines:

- Axial Engines
  - Axial flow engines are gas turbines
designed to produce thrust from the exhaust
  gases. They are connected to the gas
turbine power plant and are used in
  power generation. Axial flow engines are
  often used in power plants, whereas tubular
  engines generate their thrust with the addition of a
ducted fan. Axial flow engines are often
  used in turboprop or (propfan) engines.
  Gas turbines are also used in many
  industries, such as aviation and
  marine applications. The gas turbine
  engine combines a gas producer or
  combustion engine and a turbine to
  produce a lightweight and high-
  pressure turbine, which is a
  conventional gas turbine.
Eirgrid Grid Code

- Grid Code contains general conditions and rules for general application. The specification and conditions for each equipment are subject individually.
- These information are included in Grid Connection O & A Agreements between developer and Transmission Operator O & A.
- GI: Each transmission connection and TSO must implement Grid Code specification during each stage of the project for project done "on site.
- The Grid Code may discontinue or terminate the Grid Connection Agreement if the Grid Code is not implemented by client.
- The implementation of the Grid Code may have significant impact on the cost of the Grid Connection.
- ESB Substation Electrical Safety Rules should be implemented.

Eirgrid Constraints

- Capacity of the transmission lines
- Breakdown of the high voltage lines
- Connections from Energy Load Centre (Wet Coast)
- High Cost of Design and planning permission for Shallow Connection significantly for 110kV
- Existing Restrictions regarding O&M Connection

Eirgrid Constraints-Plant Location

Grid Connection Costs

<table>
<thead>
<tr>
<th>Equipment</th>
<th>110 kV OHL Substation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site &amp; Steam Turbine Generator</td>
<td>210,000 KVA</td>
</tr>
<tr>
<td>2 kV 11{kV/22{kV  Substation</td>
<td>4,470 kVA</td>
</tr>
<tr>
<td>22{kV OHL 20 m</td>
<td>7,070,000 kVA (33 m)</td>
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<tr>
<td>11{kV OHL 20 m</td>
<td>5,520,000 kVA (50 m)</td>
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<tr>
<td>Rated Current 500 MVA</td>
<td>3,000 kVA</td>
</tr>
<tr>
<td>Total Cost</td>
<td>3,774,000 kVA</td>
</tr>
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</table>
Integrated basin based combined cycle systems:

Coal is gasified, either partially or wholly & synthetic gas produced after clean-up is burnt in combustion chamber of gas turbine. It is called IGCC. Coal & limestone are fed to pressure vessel, coal being gasified by oxygen & steam.

Use of air instead of oxygen produces low caloric value of gas. Several forms of gasifier are Texaco Shell, Dow, Lurgi & so on.

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Diagram:

- Gasifier
- Coal & limestone
- Oxygen
- Steam
- Rich solution
- Gas turbine
- Sulfur removed
- Gasifier
- Pressure 4-0.7 MPa/m²
- Temperature 1200°C - 1300°C
- Steam
- Condenser
- Gas to stack
British coal "Topping cycle" allows gas turbine inlet temperature to be raised considerably higher than 850°C by burning fuel gas by partial gasification of coal. Temperature of exhaust gas from gas turbine can be estimated as,

\[ T_e = 1200^\circ C = 1473k \quad \& \quad r = 16, \]

\[ 1473 - T_d = 0.85 \times 1473 \left( 1 - \left( \frac{r}{16} \right)^{0.25} \right) = 628 \]

\[ T_d = 847^\circ C \quad \text{or} \quad 574^\circ F. \]

Higher gas turbine exit temperature allows more heat recovery from exhaust gases & hence greater heat supply to steam cycle.

Just as combined cycles have already replaced steam cycles when noble fuels are used to generate electricity, they are likely to become predominant also when coal as fuel because integrated gasification into combined cycle yields higher operating efficiency as well as more environmentally benign conversion of coal to electricity.