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For actual values please refer to the Instruction Manual.
# Table of Contents

List of Technical Aids ............................................................................................................................................. 4  
Module Objectives .................................................................................................................................................. 5  
Overview................................................................................................................................................................... 6  
Gas Turbine Power Plant Overview ...................................................................................................................... 6  
  Gas Turbine Main Components and Functional Principle .................................................................................. 7  
  Generator Components and Functional Principle ............................................................................................... 8  
Steam Turbine Power Plant Overview ................................................................................................................... 10  
  Basic Components of a Steam Turbine Power Plant ......................................................................................... 10  
Combined Cycle Power Plant Overview ............................................................................................................. 11  
  Multi-Shaft Arrangement .................................................................................................................................... 11  
  Single-Shaft Arrangement .................................................................................................................................. 12  
Overview of a Combined Cycle Plant for CHE Supply ...................................................................................... 13  
  Multi-Shaft Arrangement .................................................................................................................................... 13  
Overview of a Combined Cycle Plant for CHE Supply ...................................................................................... 14  
  Single-Shaft Arrangement .................................................................................................................................. 14  
Control and Protection System Overview ........................................................................................................... 15  
Summary ................................................................................................................................................................ 18  
Figure 1: Simplified Overview of a Gas Turbine Power Plant, its Major Components and Systems.............. 19  
Figure 2: Simplified Overview of Steam Turbine Power Plant, its Major Components and Systems.............. 20  
Figure 3.1: Combined Cycle Power Plant Process Overview (Multi- Shaft) ..................................................... 21  
Figure 3.2: Combined Cycle Power Plant Process Overview (Single- Shaft) ................................................... 22  
Figure 3.3: Combined Cycle Plant for CHE Supply and Multi-Shaft Arrangement ......................................... 23  
Figure 3.4: Combined Cycle Plant for CHE Supply and Single-Shaft Arrangement ....................................... 24  
Figure 3.5: CHE Supply Plant ............................................................................................................................... 25  
Figure 4: Basic Scheme of the Control of a Combined Cycle Power Plant...................................................... 26  
Figure 5: Simplified Water Steam Cycle ............................................................................................................... 27
## List of Technical Aids

<table>
<thead>
<tr>
<th>Definitions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enclosure</td>
<td>Integral Standard Document</td>
</tr>
<tr>
<td>Attachment</td>
<td>Attached Site-Specific Illustration or Document</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Identification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attachment 1</td>
<td>Plant Operation and Control Concept</td>
</tr>
</tbody>
</table>
Module Objectives

Upon completion of this section, the trainee is able to:

- State why combined cycle power plants are used in preference for supplying electric energy.

- Explain why a gas turbine set includes:
  - A turbine
  - A combustion chamber
  - A compressor

- Give the reasons why the main electrical energy supply chain contains:
  - A generator
  - An exciter
  - Generator bushings
  - A generator breaker
  - A main step-up transformer
  - A grid breaker

- Justify the use of a boiler and a steam turbine within a steam turbine power plant.

- Explain the reasons why the following components are used within a combined cycle power plant:
  - Heat recovery steam boiler
  - Condenser
  - Deaerator and feed water storage tank

- Justify the use of a combined cycle plant as a process for combined heat and electricity (CHE) supply.

- State the reasons why a combined cycle power plant includes in its automation system the following components:
  - Gas turbine electronic controller (EGATROL)
  - Steam turbine electronic controller (TURBOTROL)
  - Steam Turbine generator set sequencer (TURBOMAT)
  - Voltage regulator (UNITROL)
  - Synchronizer (SYCHROTACT)
  - Generator protection (GSX or REG)
  - Heat recovery steam boiler controller (BOILERMAT)
Overview

CCPP as energy supplier

A relative newcomer to the field of energy supply is the combined cycle power plant (CCPP).

- CCPPs take the advantages of gas turbosets and steam turbosets and combine them in a system that provides electric power at a much higher efficiency than is possible with either system operating alone.

This section will briefly describe the process of typical ALSTOM gas and steam turbine power plants before summarizing how those processes are combined in a typical CCPP.

- The material does not describe all equipment, but rather focuses on major components, which are essential to an understanding of the overall process.

Gas Turbine Power Plant Overview

Basic components of a gas turbine power plant

Refer to Figure 1.

ALSTOM produces a variety of gas turbosets which differ in:

- configuration and
- electric power output.

However, the basic energy conversion process from chemical energy to mechanical energy to electrical energy is similar from machine to machine.

The supply of electric energy from a gas turbine power plant requires the use of:

- a gas turbine
- a generator
- an exciter
- generator bushings
- a generator breaker
- a generator step-up transformer and
- a grid breaker.

The role of each will be briefly described.
Gas Turbine Main Components and Functional Principle

Figure 1: Gas Turbine
The gas turbine is composed of three processing elements:
- an air compressor
- a combustion chamber and
- the turbine itself

The turbine itself:
- Converts the thermal energy contained in the combustion gas into mechanical energy at the coupling and
- Is the prime mover that drives the generator and the compressor.
- Is driven by hot, compressed combustion gas that strikes blading mounted on the rotor, and causes it to turn.
  - After the combustion gas passes through the turbine it is discharged to atmosphere and is called exhaust gas

The combustion gas that drives the turbine is supplied by the combustion chamber. The latter one:
- Converts the chemical energy of the fuel into heat and
- Is an enclosed, pressurized firing place where air and liquid and/or gaseous fuel are continuously burned.

The pressurized air required for combustion is delivered by the compressor. The latter one:
- Converts mechanical energy into pneumatic energy and
- Is driven by the turbine through a common shaft.
  - The air within the compressor is pressurized with the help of rotating and stationary blading.
  - Pressurized air is also used for sealing and cooling of the set.

Fuel Throughput Control
The fuel throughput to the combustion chamber is controlled by the appropriate setting of control valves, which can assume, hold and change to any position between fully closed and fully open.
Generator Components and Functional Principle

Figure 1

Generator

The generator:
- Is the driven machine and
- Converts the mechanical energy of the turbine into electrical energy.
- Is composed of
  - A non-movable part called the stator and
  - A movable part called the rotor.
  - The latter is coupled to the turbine rotor, either;
    - directly or
    - through a rotational speed reduction gear

The rotor:
- Is basically a magnet and
- Creates a rotating magnetic field inside the machine by means of the excitation or field winding, often referred to simply as the rotor winding.

The strength of the magnetic field must be adjusted to correspond to the electrical power output of the generator. The consequences of this measurement are:
- The generator is kept in synchronism with the grid and
- Both generator voltage and the reactive power supplied to the grid are kept within specified limits.

This is accomplished by means of a direct current:
- Referred to as an excitation current and
- Passed through the rotor field winding.

The automatic voltage regulator (AVR) equipment controls the excitation current in turn. The latter one controls both:
- The terminal voltage of the generator and
- The reactive electric power supply to the grid.

The stator contains fixed windings inside which an alternating voltage is induced by the rotating magnetic field.

(Continued next page)
Generator Components and Functional Principle (continued)

Figure 1

Exciter
The exciter provides the direct current (DC) for the windings of the generator’s rotating magnetic field.

- Two types of exciters are used:
  - brushless and
  - static

Both perform the same function.

Generator Bushings
The generator’s bushings:

- Provide the connection that enables the electric energy of the generator to be delivered to the outside world.
- Are mounted on the generator stator housing and
- Receive the high voltage (HV) output of the stator windings.

The Generator Breaker
The generator breaker provides the electrical connection between the generator’s bushings and the step-up transformer.

Main Step-up Transformer
The main step-up transformer:

- Is used to match the outlet voltage of the generator to the voltage of the grid or network.
- Also works like an electric buffer in case of short circuit in the grid, protecting the generator

Grid Breaker
The grid breaker:

- Provides the electrical connection between the substation and the grid or network.
- Disconnects the gas turboset from the grid in case of network failures, allowing it to run on island duty.
- Is an optional piece of equipment.
The supply of electricity from a steam power plant requires:

- a water steam cycle with:
  - a boiler
  - a steam turbine
  - a generator
  - an exciter
  - generator bushings
  - circuit breaker and
  - step-up transformer.

The role of each will be briefly described.

---

**Boiler**

The boiler:

- Is a place where an energy conversion takes place, namely from chemical energy of the fuel into heat energy.
- The latter one is carried by the combustion gas.
- Uses heat of combustion to convert water into steam, a physical conversion process.

To secure the integrity of the boiler, it must be fed continuously with water.

---

**Figure 2**

High pressure (HP) steam lines forward the steam raised in the boiler to the steam turbine. The steam massflow, which passes through the turbine, is regulated by the opening of control valves.

- As steam flows through the turbine it strikes blades on the rotor, causing them to turn.
- This is an energy conversion process from heat energy to mechanical energy.

The conversion from mechanical to electrical energy then takes place through the generator and exciter in a process, which is essentially the same as that described above for the gas turboset.
Combined Cycle Power Plant Overview
Multi-Shaft Arrangement

The objective of a combined cycle power plant with multi-shaft arrangement is to deliver only electricity.

To fulfil the above objective, the major components of a multiple shaft combined cycle power plant are:

- One or more gas turbosets.
- One or more heat recovery steam boilers (HRSB).
- One or more steam turbosets.
- The rest of the water-steam cycle.
- The balance of plant equipment:
  - mechanically and
  - electrically.
- Control equipment.

The process begins when the gas turboset is placed in operation.

- The gas turbine operates on a mixture of air and fuel, which is ignited in the combustion chamber.
  - The hot gas is expanded through the turbine, causing the shaft to rotate.
- The turbine-compressor rotor is connected to the generator rotor:
  - Either directly or
  - Through a rotational speed reduction gear.
- The generator converts the mechanical energy into electrical energy, which it supplies to the grid or network.

Exhaust gasses from the combustion process leave the gas turbine at a very high temperature.

- If the gas turbine is operated in single cycle, this heat energy is:
  - Discharged to atmosphere and
  - Thus wasted.
- However, if the gas turbine is operated in combined cycle, the hot gas flow is directed to an HRSB.
  - Here, the heat from the hot gas converts water in the HRSB into steam.
That is, the HRSB links together the gas turbine process and the water steam cycle.

When the steam is at the correct temperature and pressure, it is forwarded to the steam turbine where it expands through the turbine.

- Its mechanical power is transmitted via the shaft to the generator, which provides additional electric power for the grid.

(Continued next page)
Multi-Shaft Arrangement (continued)

Exhausted steam is directed to a condenser, where it is converted to water called condensate. The condensate is then directed to the feed water storage tank-deaerator. Here it is:
- Deaerated
- Preheated and
- Stored

The feed water is then used by the HRSB in the throughput demanded by gas turbineset electric power output.

Single-Shaft Arrangement

**Figure 3.2**

The objective of a combined cycle power plant with single-shaft arrangement is to deliver only electricity.

To fulfil the above objective, the major components of a single shaft combined cycle power plant are:
- A gas turbine.
- An alternator.
- A self shifting and synchronizing (SSS) clutch.
- A water steam cycle, mainly composed of:
  - A heat recovery steam boiler.
  - A steam turbine alternator set.
  - A condenser.
  - Condensate extraction pumps.
  - A deaerator feedwater storage tank.
  - Boiler feedwater pumps.
- Mechanical balance of plant equipment.
- Electrical balance of plant equipment.
- Control equipment.

The single shaft combined cycle power plant functions in the same way as the multiple shaft arrangement.
- The most important difference is the application of the SSS clutch. The latter one permits the ST:
  - To be accelerated AND
  - To be connected to the alternator, already being driven by the GT

The SSS clutch:
- Engages automatically as soon as the torque from the ST shaft becomes positive; that is:
  - As soon as the rotational speed of the ST tends to overtake that of the alternator
  - Disengages automatically as soon as the torque of the ST shaft becomes negative
Overview of a Combined Cycle Plant for CHE Supply
Multi-Shaft Arrangement

Figure 3.3
The objective of a combined cycle plant for CHE supply with multi-shaft arrangement is to deliver simultaneously:
- heat and
- electricity.
This process is known as combined heat and electricity (CHE) supply.

To fulfill the above objective, the major components of a multiple shaft combined cycle plant for CHE supply are:
- One or more gas turbosets.
- One or more heat recovery steam boilers (HRSB).
- One or more steam turbosets.
- One or more heating condensers.
- The rest of the water-steam cycle.
- The balance of plant equipment:
  - mechanically and
  - electrically.

All the previous descriptions apply to this type of combined cycle plant plus the following explanations:
- The heat supply happens normally with one of the two heat carriers:
  - steam or
  - water.
- Steam is normally extracted at some stage of the steam turbine.
  - This steam can then be used directly for heating purposes or
  - this steam can be used indirectly for heating purposes across a corresponding heat exchanger.
- Depending on heat demand, the supply of this energy form can be completely suspended.
  - In this case the combined cycle plant runs only delivering electricity.

Figure 3.5
An interesting alternative is the arrangement of a combined cycle plant for CHE supply, but without the steam turbine alternator set in the water steam cycle.
- The heat from the HRSB is used in this case directly for industrial processes like:
  - petrochemical plants,
  - sea water desalination plants,
  - district heating, etc.
- Normally in this case, the HRSB is equipped with supplementary inlet duct burners to secure the heat supply if the gas turbine alternator set is out of duty.
Overview of a Combined Cycle Plant for CHE Supply
Single-Shaft Arrangement

Figure 3.4

The objective of a combined cycle plant for CHE supply with single-shaft arrangement is to deliver simultaneously:

- heat
- electricity.

This process is known as combined heat and electricity (CHE) supply.

To fulfill the above objective, the major components of a single shaft combined cycle plant for CHE supply are:

- A gas turbine.
- An alternator.
- A self-shifting and synchronizing (SSS) clutch.
- A water steam cycle, mainly composed of:
  - A heat recovery steam boiler.
  - A steam turbine alternator set.
  - A condenser.
  - A heating condenser.
  - Condensate extraction pumps.
  - A deaerator feedwater storage tank.
  - Boiler feedwater pumps.
- Mechanical balance of plant equipment.
- Electrical balance of plant equipment.
- Control equipment.

All the previous descriptions apply to this type of combined cycle plant plus the following explanations:

- The heat supply happens normally with one of the two heat carriers:
  - steam or
  - water.
- Steam is normally extracted at some stage of the steam turbine.
  - This steam can then be used directly for heating purposes or
  - this steam can be used indirectly for heating purposes across a corresponding heat exchanger.
- Depending on heat demand, the supply of this energy form can be completely suspended.
  - In this case the combined cycle plant runs only delivering electricity.
Control and Protection System Overview

**Importance of automated control systems**

Today's complex power plants operate at very high efficiency because of the sophisticated design of the equipment used.

- To reach these high levels of efficiency and reliability, automation systems have become standard in the industry.
- ALSTOM's major control and protection systems are briefly outlined below.
- Details are provided in the respective gas and steam turbine modules.

**Figures 1 and 4**

**EGATROL**

EGATROL:

- Is the abbreviation for electronic gas turbine controller.
- Includes a sequencing program that automatically starts, “loads” and shuts down the gas turboset and its auxiliaries while observing ALSTOM protective limitations.
- Regulates during operation, the gas turboset by positioning the fuel control valves based on electric power output requirements.
- Includes a man machine interface (MMI):
  - For receiving data from the process.
  - To influence the process.
  - Activates the safety system.
    - The latter one, when it is actuated, protects the gas turboset from damage by tripping the fuel stop and control valves to their closed positions.
    - This immediately:
      - stops the fuel throughput to the combustion chambers
      - interrupts the combustion process and
      - shuts down the turboset

**Figures 2 and 4**

**TURBOTROL**

TURBOTROL:

- Is the steam turbine controller.
- Provides control and regulation of the steam turbines.
- Performs its function by positioning the steam control valves.
  - The latter ones regulate the steam throughput across the turbine, based on system requirements.
- Activates the safety system.
  - The latter one, when it is actuated, protects the steam turboset from damage by tripping the steam stop and control valves to their closed positions.
  - This immediately stops the flow of steam to the turbine.

(Continued next page)
Control and Protection System Overview (continued)

Figures 2 and 4  TURBOMAT
The TURBOMAT:
■ Is the steam turboset sequencer.
■ Is optional equipment.
■ When supplied is used to automatically start-up, “load”, and shut-down the steam turboset and its auxiliaries while observing ALSTOM limitations.

Figures 1 and 2  UNITROL
The UNITROL:
■ Is the excitation system for the alternators.
■ Includes a centerpiece that is the automatic voltage regulator (AVR). The latter one:
  ■ Maintains the outlet voltage of the generator at a constant value.
  ■ Influences the exciter and thereby the electric current through the windings of the magnetic field.
■ Has a back-up manual field current regulator (FCR). The latter one:
  ■ Fulfills the same task but requires manual input from the operator.
  ■ Adjusts the reactive electric power output of the generator, expressed in units of volt-ampere reactive (V·Ar).

Figures 1 and 2  SYNCHROTACT
The SYNCHROTACT:
■ Is the synchronizer of the turbosets.
■ Can be operated automatically or manually.
■ Interacts with:
  ■ Gas and steam turbine controllers and
  ■ UNITROL
■ Matches the following parameters of the generators and the grid:
  ■ outlet voltage
  ■ frequency and
  ■ phase sequence
When synchronization is completed, the generator breaker closes.

(Continued next page)
Control and Protection System Overview (continued)

Figures 1 and 2  GSX or REG:
The generator protection system:
- Protects the generator and its associated equipment from abnormal operating conditions.
  When the protection equipment detects a fault:
  - The generator breaker is opened and
  - The gas or steam control valves are tripped to their closed positions.
- Has the designation GSX or REG, depending the selected model.

Figure 4  BOILERMAT
Each HRSG has several function groups and drives.
The BOILERMAT:
- Is the boiler controller.
- Coordinates different control functions of the HRSB like:
  - start-up
  - shut-down and
  - open-loop controls
  - This coordination is made in respect with the open-loop controls of the gas and steam turbosets.
- Regulates during operation, the HRSB's drum level closed-loop controls.

Figure 4  Miscellaneous Controller
The miscellaneous controller takes care of the different components of the water steam cycle like:
- the condenser
- the condensate extraction pumps
- the deaerator
- the boiler feed water pumps

Figure 4  BOP Equipment Controller
BOP is the abbreviation for balance of plant. Practically each BOP equipment has its own controller. To indicate that their functions must be coordinated, the concept of the BOP equipment controller is introduced.
Figure 4 lists the most common BOP equipment's of a typical combined cycle power plant.

(Continued next page)
Control and Protection System Overview (continued)

Figure 4

BLOCKMASTER
The BLOCKMASTER:
■ Is the overimposed power plant controller.
■ Ensures that each major component in the CCPP process is brought into service or removed from service in the proper sequence.
■ Is also called UNITMASTER.
■ Includes several MMIs:
  ■ For receiving data from the process.
  ■ To influence the process.

Summary

This section:
■ Described the components used to deliver electricity from modern gas and steam turbine power plants.
■ Included information of how those single processes are joined to operate at higher efficiency in a combined cycle arrangement to deliver
  ■ only electricity or
  ■ simultaneously electricity and heat.

To ensure that you understand the material covered, review each of the Objectives (page 5).
Figure 2: Simplified Overview of Steam Turbine Power Plant, its Major Components and Systems
Figure 3.1: Combined Cycle Power Plant Process Overview (Multi-Shaft)
Figure 3.2: Combined Cycle Power Plant Process Overview (Single-Shaft)
Figure 3.3: Combined Cycle Plant for CHE Supply and Multi-Shaft Arrangement
Figure 3.4: Combined Cycle Plant for CHE Supply and Single-Shaft Arrangement

Combined Cycle Power Plants

Diagram shows a combined cycle power plant with a single-shaft arrangement. Key components include:
- Natural gas (fuel oil) entering the system
- Steam turbine
- Gas turbine
- Generator
- Condensate extraction pump
- Heating condenser
- Main condenser
- Condensate
- District heating system
- Steam boiler
- Flue gases
- Air inlet
- CW circulating pump
- Deaerator feedwater storage tank
- Boiler feedwater pump
- SSS clutch
- Electricity
- Condensate extraction pumps
- CW circulating pump
- Cooling water (CW)
- Deaerator feedwater storage tank

Legend:
- SSS: self synchronizing and shifting
- HRSB: heat recovery steam boiler
Figure 3.5: CHE Supply Plant

- Boiler
- Condensate extraction pump
- Circulating pump
- CW circulating pump
- Condensate
- Heat recovery steam generator (HRSB)
- Flue gases
- Air inlet
- Natural gas (fuel oil) system
- Generator
- Deaerator
- Feedwater storage tank
- Distilled water (CW)
- Electricity
- District heating system
- Self-synchronizing and shifting (SSS) system
- CHE: Combined Heat and Electricity
Figure 4: Basic Scheme of the Control of a Combined Cycle Power Plant

1: Air compressor
2: Combustion chamber
3: Gas turbine
4: Generator
5: Exhaust gas flap or by-pass
6: Heat recovery steam boiler
7: Steam turbine
8: Condenser
9: Condensate extraction pump
10: Deaerator and feedwater storage tank
11: Boiler feedwater pump
12: Supplementary firing

MMI: Man machine interface
- Information exchange signal
- Actuation signal
- Feedback signal

BOP: Balance of plant

Remark:
For simplicity reasons only one line is represented for:
- Information exchange
- Commands
- Feedback informations
Innovative cycle solution
Dual pressure reheat
Single shaft power train

Figure 5: Simplified Water Steam Cycle

ICS: Innovative cycle solution
DPR: Dual pressure reheat
SSPT: Single shaft power train