CONTROL SCHEMES OF COGENERATING POWER PLANTS FOR DESALINATION

J. Dastych, Pickhardt and H. Unbehauen
Ruhr Universitat Bochum, Germany

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Summary

In this contribution, the operational behavior of combined cycle power plants has been studied. Starting with the common structures of gas turbines and combinations of steam turbines, the main control loops have been introduced. In this context, different concepts of operating modes of steam turbines are discussed.

The connection of combined cycle power plants with desalination units are represented for the back pressure and the extraction scheme of dual combined cycle power plants. Also the problems occurring when connecting power plants with a desalination process have been discussed.

1. Introduction to Combined Cycle Power Plants

In the last 20 years there has been a continuous development in the field of power generation. Extensive research and development in the field of steam and gas turbine design has led to an important improvement in thermal performance. The aim of this contribution is to describe the different basic structures and necessary control schemes of gas and steam turbines used in cogenerating power plants for desalination. There are various types of structures with regard to the different types of turbines. A very important type of combination consists in producing steam in a steam generator heated by the exhaust gases from gas turbines. This power plant system is named "Combined Cycle" (CC). With such a combined heat and power plant (Cogeneration), it is possible to produce both electricity and heat, the latter in the form of steam or hot water.

The main reason for introducing these types of power plants is the increasing overall efficiency. For standard steam turbine plants the overall efficiency is 35 to 40 per cent. For CC and cogeneration plants the overall efficiency is nearly 50 per cent. In applications featuring cogeneration of heat and power, high energy utilization factors can also be achieved by this type of power plant. In addition a considerable reduction of emissions, in particular of sulfur dioxide and nitrogen oxide emissions, can be achieved (Zorner 1994).

Before presenting a detailed description of combined cycle power plant units, first an introduction to gas turbine is given.

1.1. Gas Turbines in Power Plants

Natural-gas or oil-fired gas turbines today enjoy the highest efficiency compared with all other types of thermal power plants. The main unit of this type of power plant is the gas turbine. Figure 1 depicts the schematic diagram of a gas turbine. From Figure 1 it can be seen that the air for the gas turbine is taken in through a filter. The filtered air is led straight into the gas turbine compressor through an oblique steel fabricated duct, in which a silencer is installed. After the compressor, the air is mixed with the fuel and burned in the annular combustion chamber. This has circumferentially-positioned hybrid burners, in an arrangement called the hybrid-burner-ring. In the gas turbine the compressed hot gas is expanded and cooled down in order to drive the electric generator.

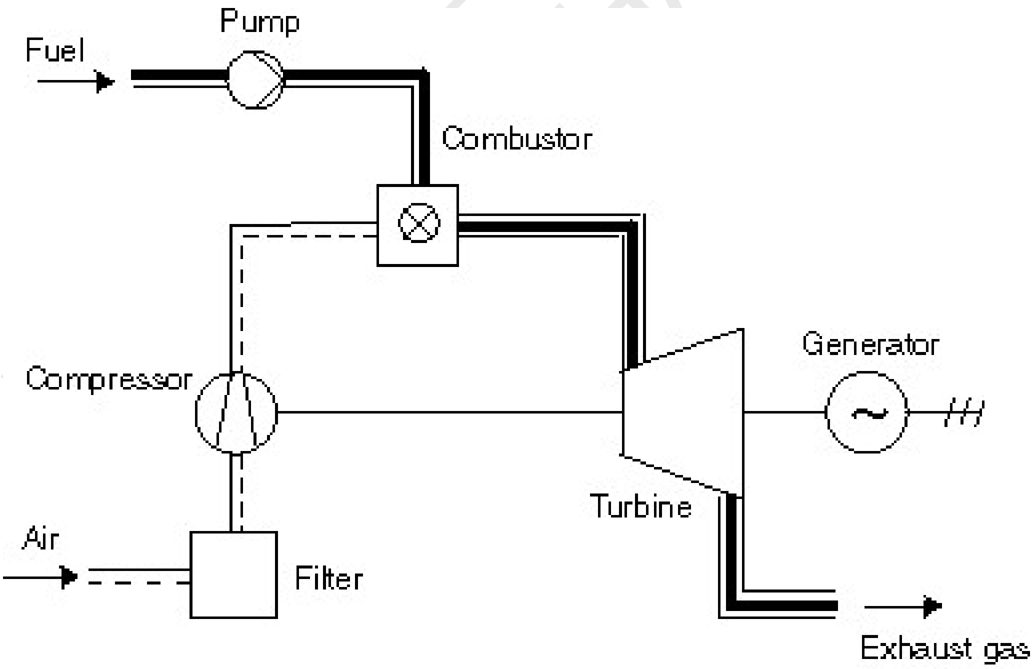

Figure 1. Schematic diagram of a gas turbine.

As the air and fuel are mixed prior to combustion, only a small amount of thermal nitrogen oxide is produced. The temperature distribution is remarkably uniform in the chamber, and the flame zone is located immediately in front of the first turbine stage.

The inside of the combustion chamber is protected by heat shields made of oxide-ceramic-coated high-alloy steel and flexibly attached to the colder casing. This permits deformation in response to temperature gradients, thus minimizing thermal stress.

Power turbines consist mostly of multistages (e.g. four stages). All the blades are air cooled with the exception for the last stage. Cooling air is provided at varying pressure and temperature levels from different compressor extractions to provide the best cooling effect. The air cools both the blade directly, and also, after exiting the blade through small holes, by making a protective cooling film of air around each blade (SIEMENS 1996). Contemporary gas turbines produce electric power in range up to 200 MW, and the outlet gas temperature is around 550°C when the combustion gas temperature reaches 1200°C.

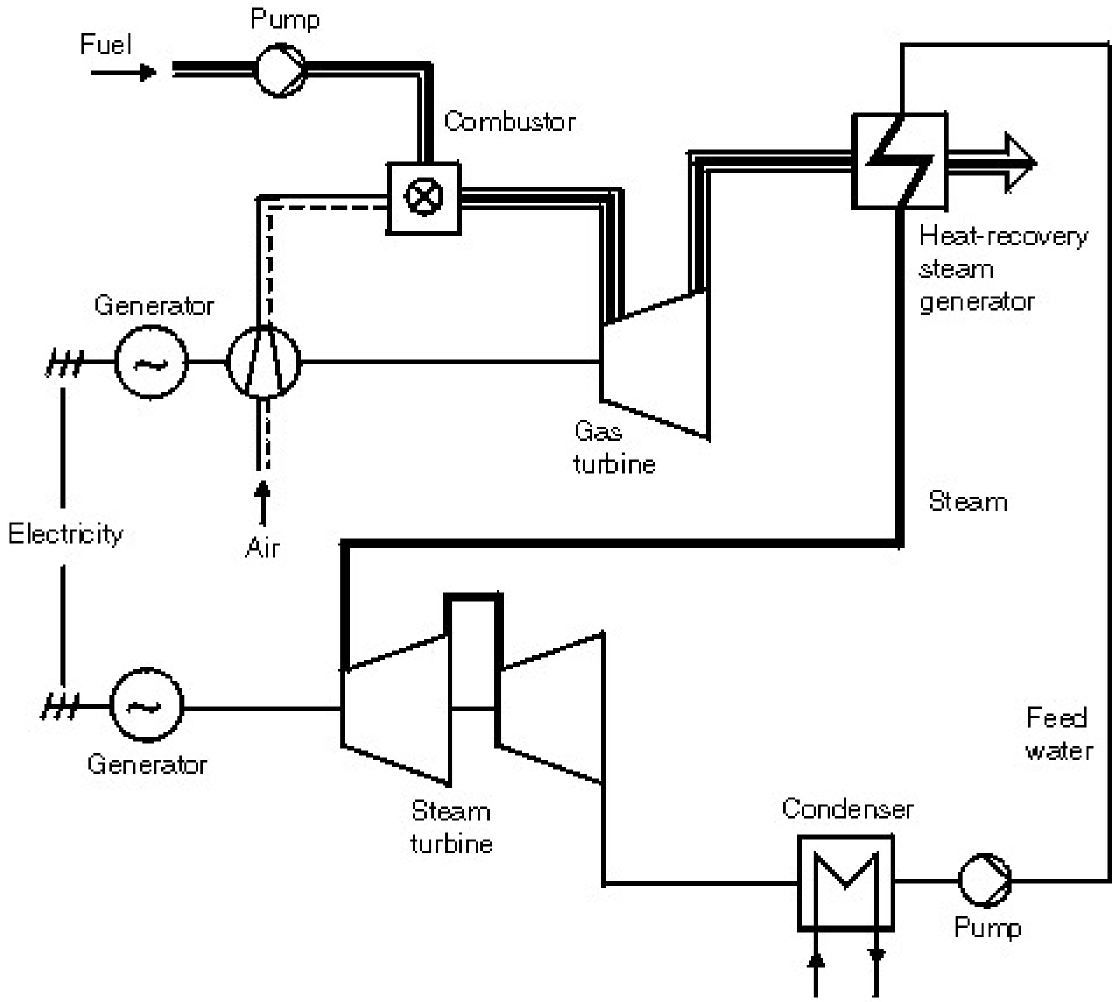

Figure 2. Flow diagram of a combined cycle power plant.

From Figure 1 some input and output variables of the gas turbine can be defined: on the input-side, the fuel flow, the air flow, the air temperature, the water injection flow and the parameters of the cooling system are of interest. The main output variables are the electric power produced and the frequency. In the CC process, the exhaust gas flow and the exhaust gas temperature is fed to an unfired convection-type heat recovery steam generator, where steam is produced without any extra fuel and forwarded to a steam turbine to generate additional electrical power. A principle flow diagram of a combined cycle power plant is given in Figure 2 (Haupt et al. 1993), where Figure 3 contains a simplified diagram of a combined cycle power plant which has been constructed in 1994 at Didcot (UK) for the British National Power Company.

For control purposes load and frequency are adjusted by changes in fuel flow. The fuel flow is also used to control the inlet gas temperature. The fuel flow regulates load and frequency and, at the same time, the exhaust gas temperature. Moreover, the temperature control system can override the frequency or load control. The turbine fuel system consists of two subsystems: the gas fuel system and oil fuel system. Most gas turbines also use inlet guide vanes to reduce load down to around 80 per cent and maintain high efficiency (SIEMENS 1996).

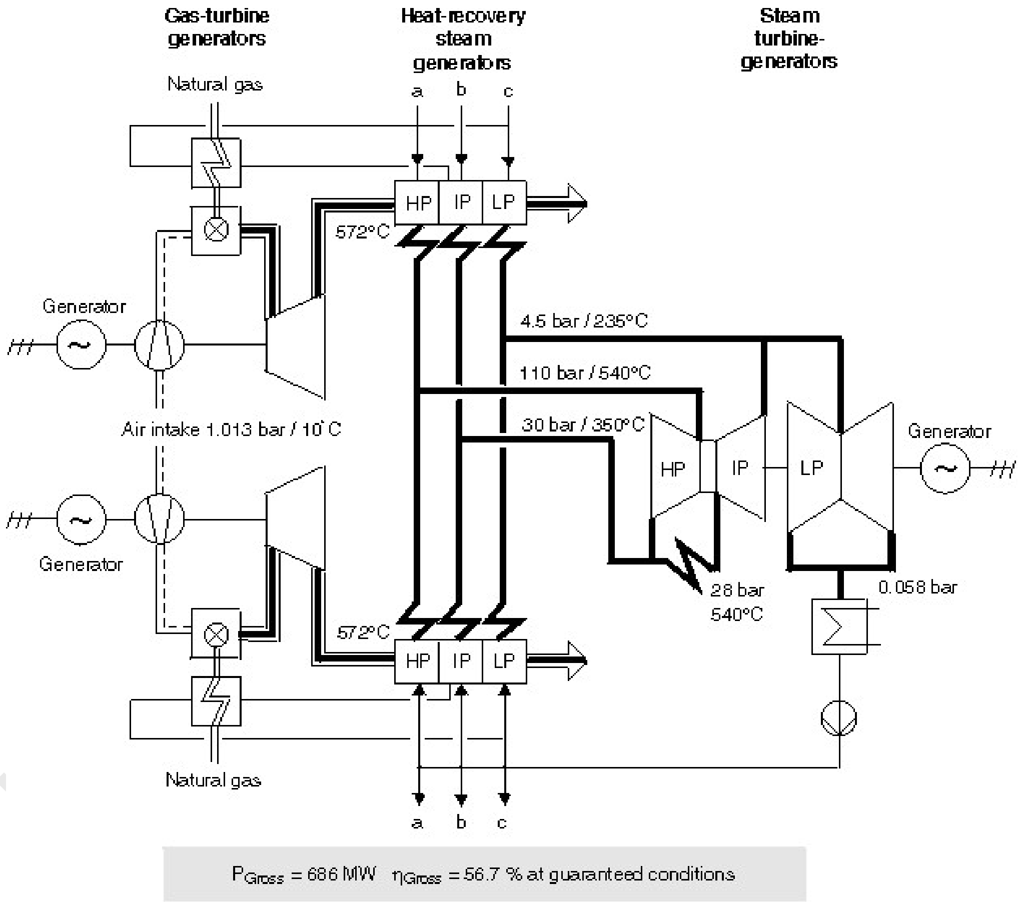

Figure 3. Simplified diagram of a CC-power plant with two gas turbines and triple pressure reheat steam cycle (designed 1994). HP High Pressure, IP Intermediate Pressure, LP Lower Pressure.

The most important control loops for gas turbines are:

- Control of fuel flow to achieve a desired load.
- Control of fuel/air ratio to provide a correct output gas temperature.
- Control of injected water flow to avoid nitrogen oxide emission.

- Control of lubricant oil flow and temperature.
- Control of inlet guide vanes.

The gas turbine cycle with the highest gas turbine inlet temperature and the steam turbine cycle with the lowest steam condensation temperature yield the highest efficiency of any type of power plant at date. This means that a CC-plant can achieve an overall efficiency of considerably greater than 50 per cent, and as high as 55 per cent using a steam cycle with a reheating stage. The pollutant emissions of CC-plants are more than 15 per cent lower than those of corresponding steam power plants. The difference is even greater under part-load operating conditions. While individual gas turbines, or entire blocks in CC-plants, can be shut down to allow the remaining turbines and blocks to continue to operate at high full-load efficiency, single large steam turbines of similar capacity must operate in an inefficient part-load mode with considerably higher pollutant emission per generated kilowatt-hour. Advances in gas turbine technology will further increase the efficiency advantage of CC-plants, since it is assumed that the upper limit of the gas turbine inlet temperature can be elevated beyond the present level of 1300°C.

Some other aspects are of interest when comparing gas turbines and steam turbines. The start-up procedure for a modern heavy-duty steam turbine takes around 6 h and involves the following stages:

- Warming up of main steam pipe line.
- Warming up of turbine parts.
- Turbine run up.
- Synchronization.
- Loading.

For a gas turbine the start-up procedure takes around a few minutes and involves following stages:

- Pumping lubricant oil to produce an oil layer under the rotor of the turbine to decrease static friction.
- Using a starter motor to initiate the rotation of the turbine.
- Supply oil fuel to the combustion chamber and establish a stable flame.
- Synchronization.
- Gradually changing from oil fuel to gas fuel.
- Increasing load to the required value.

1.2. Steam Turbines

As mentioned above, the steam turbine is one of the important units of combined cycle power plants. In practical applications, there are different types of steam turbines. The most important one is the *condensing-type turbine*. The steam leaves the turbine at almost vacuum conditions and then enters a condenser. In *back pressure steam turbines*, the steam exits the turbine at a given pressure and temperature and may be used further for heating or other industrial process purposes. In *reduction steam turbines* a part of the steam is directed to bypass the turbine. Nearly the same happens in an *extraction steam turbine*. A part of the steam is extracted from the turbine at a certain stage.

Modern steam power generation is based on the Rankine cycle. The process that comprise the ideal basic cycle consists of:

- Reversible adiabatic pumping process.
- Constant pressure transfer of heat in the boiler.
- Reversible adiabatic expansion in the turbine.
- Constant pressure transfer of heat in the condenser.

Different steam turbines consist of two or more parts, which are working together on a common shaft. The data for input pressure and temperature split the types of turbines into three groups, as depicted in Table 1.

Type of turbine	**Input pressure**	**Input temperature**
High pressure	50-260 bar	550°C
Intermediate pressure	30-40 bar	550°C
Low pressure	4-8 bar	250°C

Table 1. Characteristic values for the different types of turbines

In steam turbines, mechanical power is obtained through removing energy from the gas stream by expanding it to a lower pressure. In the case of a single reheat turbine, steam enters the high pressure stage via the main admission control valves. After passing through the high pressure stage, it is circulated through a high pressure feedwater heater to the boiler to be reheated at constant pressure. In the following steps the steam enters the intermediate pressure stage before returning to the condenser.

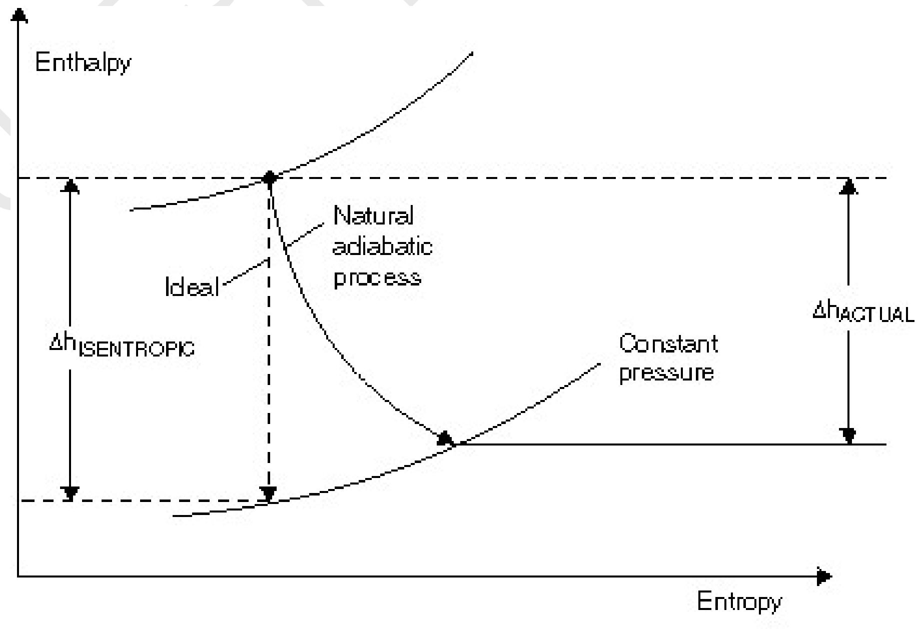

Figure 4. Enthalpy-entropy diagram for a steam turbine.

An ideally operating turbine would operate isentropically, or reversibly, so that a plot in Figure 4 of the static states of the expanding fluid within the turbine on a Mollier chart would be a vertical line (ideal).

This line would originate at the enthalpy and pressure of the entering steam and terminates at the isobar (constant pressure line) corresponding to the exhaust pressure of the turbine, maintaining the same entropy throughout the expansion. For a natural adiabatic process, entropy always increases whether the work of the process is done on the fluid or by the fluid.

Therefore, the losses or irreversibilities of the turbine expansion process move the expansion line to the right of the isentropic line on a Mollier chart. The end point of the irreversible process still lies on that constant-pressure line corresponding to the exhaust pressure.

From Figure 4 it is clear that an increase in entropy during expansion must decrease the work-output, since the change Δh_{ACTUAL} in enthalpy of the fluid is reduced from the ideal $\Delta h_{ISENTROPIC}$.

In presentation of the main units of the steam turbine in a plausible mathematical form, some important assumptions have to be made: (1) Treating of the superheated steam as an ideal gas. (2) Conversion of all the turbine stages (like high, low and intermediate pressures) to their equivalent nozzles - through which one-dimensional, uniform polytropic steam expansion is taking place. (3) Neglecting of the inlet kinetic energy of steam to each stage. (4) Taking energy storage volumes as lumped.

The principal block diagram is portrayed in Figure 5, where the variables *w* (steam flow), *T* (steam temperature) and *p* (steam pressure) have been marked with indices *i* (input) and *o* (output) (Ordis et al. 1994). The input variables are: *x* valve behavior, p_i inlet steam pressure and ρ_i the inlet steam density from the chest. The output variables are the power *P* on the high, intermediate and low pressure side of the turbine.

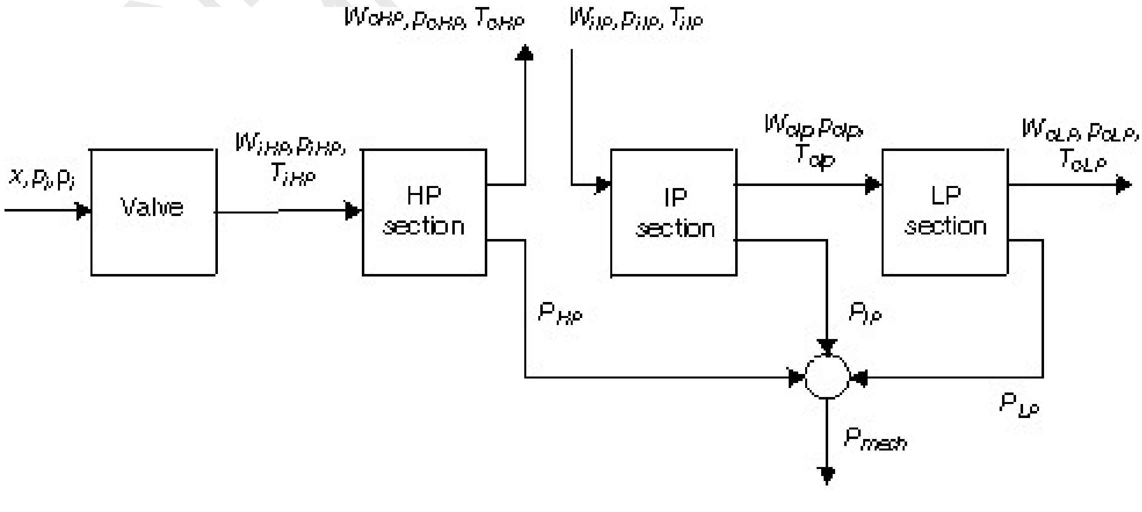

Figure 5. Block diagram of a steam turbine.

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Bibliography and Suggestions for further study

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