CHAPTER 1

Plants, processes, measurement and control

We are aware of the all pervasive influence of the industrial revolution in our daily lives. As an example, consider the forms of energy that we employ. Electricity, gas and oil are what changed our life styles and the demographic nature of countries. We now use products that depend to a large extent on energy. Plastics for everyday use, petrol for transport, consumer electronic devices are all based on industrial manufacturing activities. It can be appreciated that the manufacture of such products would involve a close monitoring and control of several parameters. A true appreciation for the breadth and depth of instrumentation required for controlling an industrial process can only be obtained from practical experience. To get an idea about the types and ranges of the variables involved, we briefly describe a power plant.

1.1 Power cycle (Rankine Cycle)

Consider the physics involved in generating electricity from heat energy. A power cycle is used to produce a net power on a continuous basis from heat energy. Fig.1.1 shows how a heat engine can be used to receive heat energy at the rate $\dot{Q}_H$ from a high temperature energy source and produces net power $\dot{W}_{net}$. As a consequence of its operation, it rejects heat energy in the local surroundings at the rate of $\dot{Q}_L$.

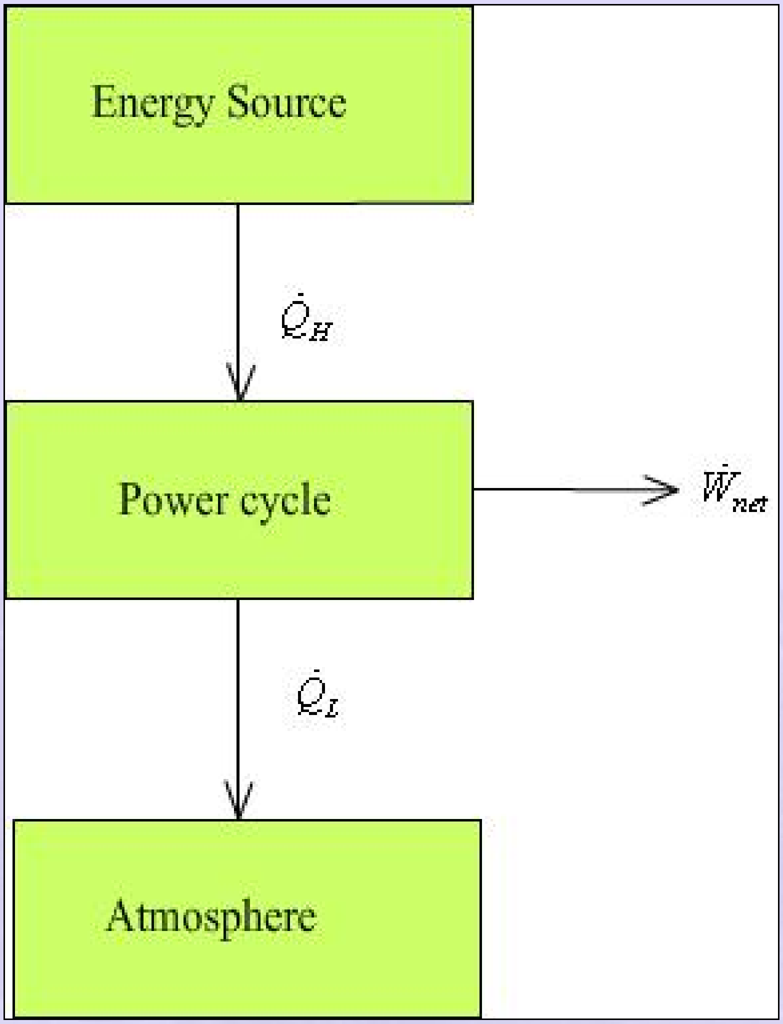

Fig 1.1: Principle of a Power cycle

A useful figure of merit for a plant is thermal efficiency. The efficiency is defined as

$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_H} \qquad (1.1)$$

The maximum thermal efficiency any power cycle can have while operating between a source at T_H and its surrounding at T_L is given by its Carnot efficiency as

$$\eta_{\max} = \frac{T_H - T_L}{T_H} \qquad (1.2)$$

where the temperatures are expressed in the absolute scale. Figure 1.2 shows a simple vapour cycle.

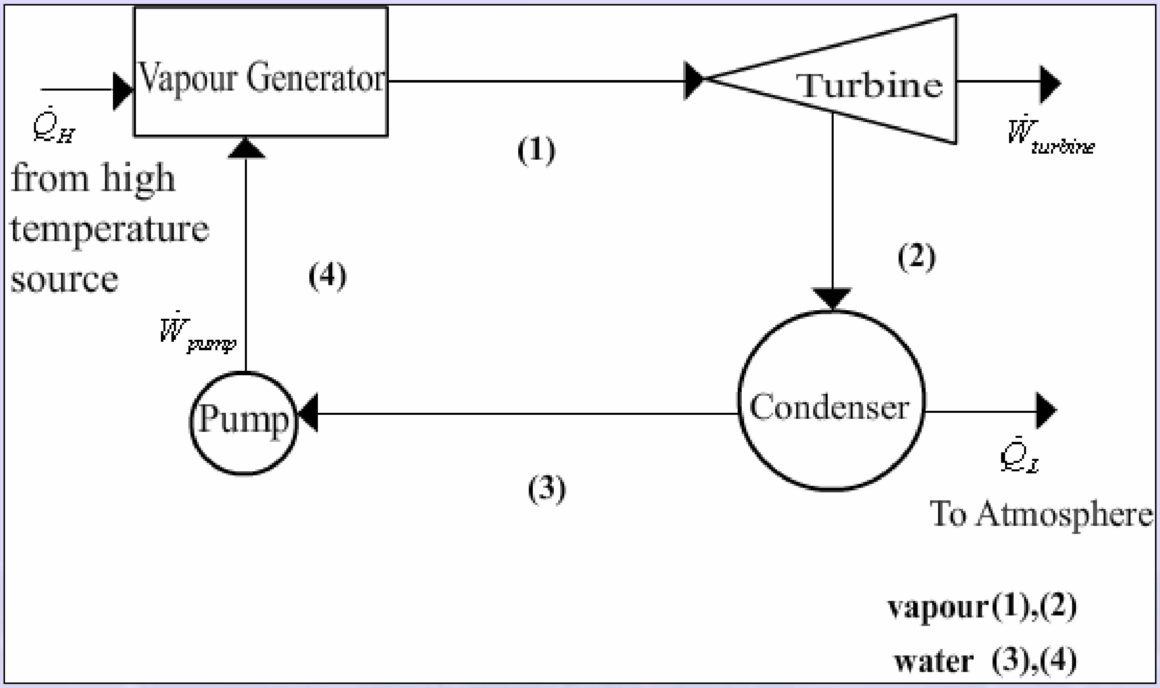

Fig 1.2: A Vapour power cycle

[**Figure 1.2 – Click for Animation here**]

The vapour generator delivers high temperature vapour at state 1 to the turbine. The vapour expands through the turbine producing work (at the state1) and exists at state 2. The vapour is condensed to liquid state 3 as it passes through a condenser where it leaves as a liquid. The pump which consumes power compresses the liquid from state 3 to state 4, the state at which it enters the vapour generator. Thus the working fluid executes a cycle. This can be shown as in fig.1.3 on a T- S diagram which illustrates the start and end states of a 660MW steam power plant.

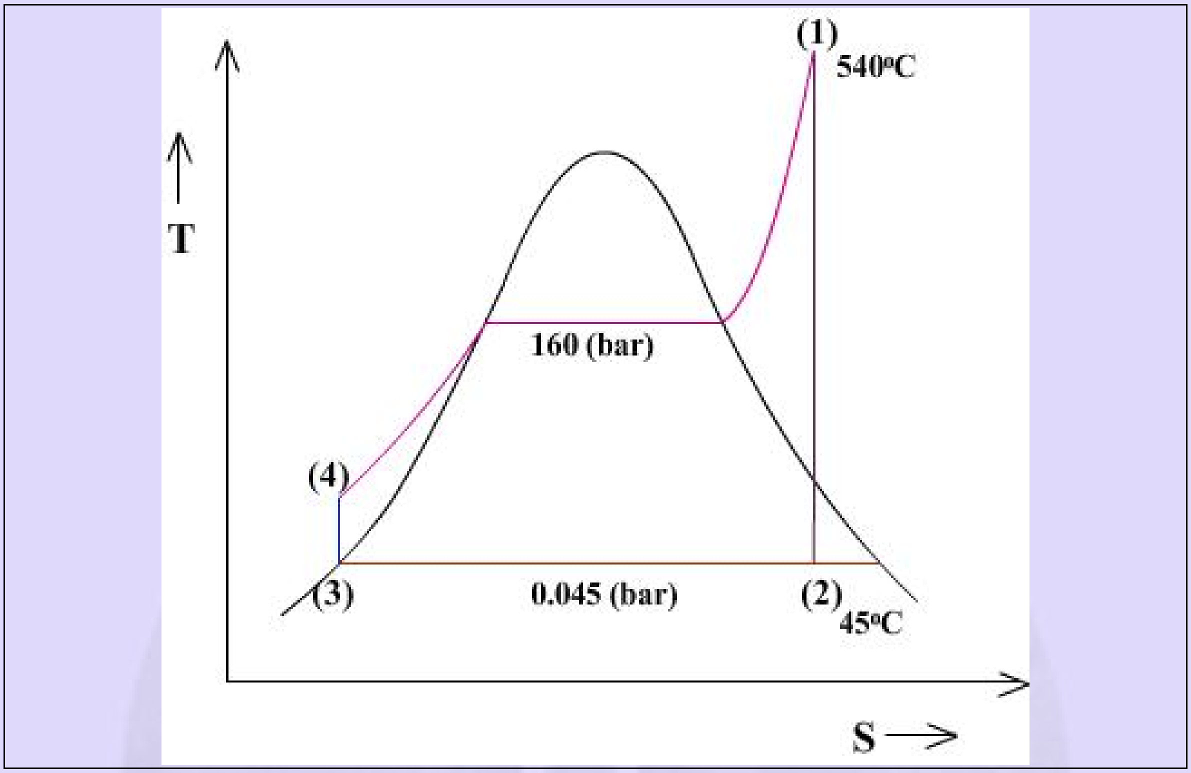

Fig1.3: T-S diagram for steam power cycle for a 660MW plant

A more detailed figure showing the principal components in shown in figure 1.4.

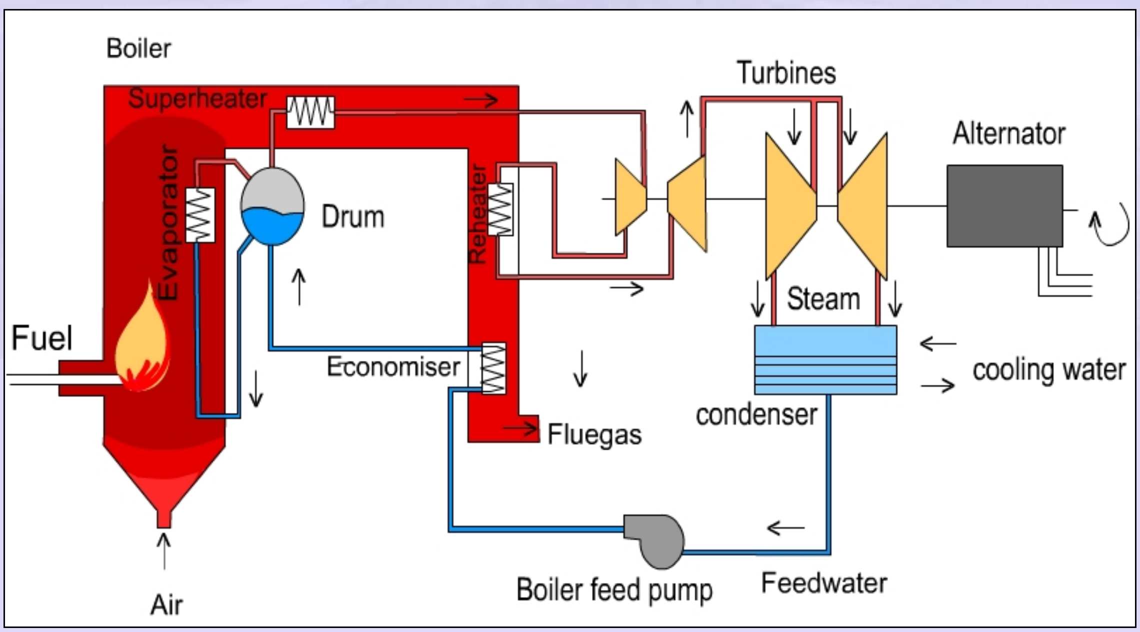

Figure 1.4: Schematic of a steam power plant

1.2 Combined Cycle Power Plant

The gas turbine is a relatively new prime mover in the history of energy conversion. A gas turbine has a compressor to draw in and compress gas (usually air), a combustor (burner) to add fuel to heat the compressed gas, and a turbine to extract power from the hot gas flow.

In an aircraft engine, all the turbine power is used to generate thrust. The gas flow leaving the turbine is then accelerated to the atmosphere in an exhaust nozzle to provide thrust.

In a combined cycle gas plant, the gas turbine exhaust energy is used to produce steam in a heat exchanger to supply a steam turbine. This yields significant improvement in thermal efficiency over conventional power plants. Fig 1.5 shows a typical CCGT(combined cycle gas turbine) plant.

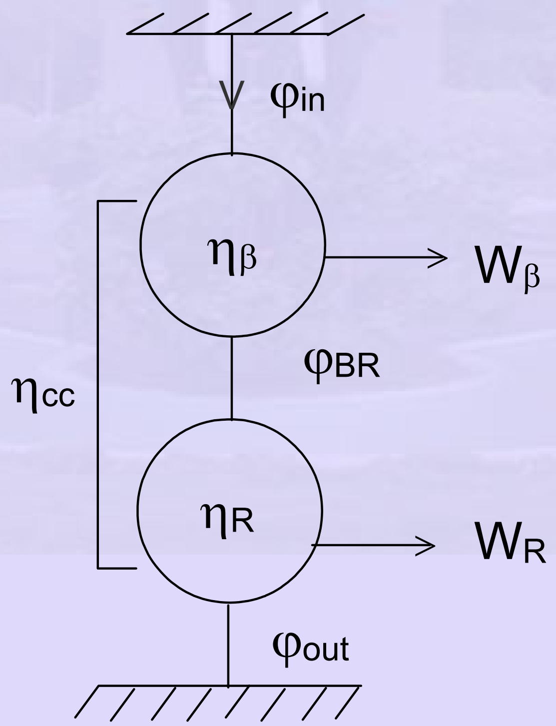

Figure 1.5: Schematic of a Combined Cycle (CC). Brayton (β) and Rankine(R) heat engines, showing heat(φ) input and work(W) output.

It can be shown that the efficiency of the combined cycle plant, ζ_{cc} is given as,

$$\eta_{cc} = \eta_\beta + \eta_R - \eta_\beta \eta_R \tag{1.3}$$

$$If \quad \eta_\beta = 40\%, \; and \; \eta_R = 30\%,$$
$$then \; \eta_{cc} = 58\%$$

1.3 Conclusion

In this chapter, we have seen the need for measurement of several variables such as pressure, temperature, flow, level etc. For operating a power plant such as the one we described, we need to accurately measure a number of physical variables such as the fuel flow rate, air inflow to the combustion chamber, boiler pressure, water level in the boiler, steam and exhaust flow rates etc. The speed of rotation of the turbines, the torque developed, the temperature of the condenser etc are also some other quantities that need to be measures.

It can be seen that most of the quantities of interest are mechanical or physical variables. It is necessary that the qualities are available in a form that can be easily measured. Transducers are the principal elements used to convert physical variables into electrical forms. We will be discussing about the operating principles and application scenarios of a few such transducers in the subsequent chapters.