2. COGENERATION

2.1. Introduction to Cogeneration

Cogeneration is defined as the sequential use of a primary energy stream to produce two useful energy forms, i.e. - thermal and power. It is an energy conversion process and is, in itself, independent of

1) Form of the output – power can be either electricity or shaft horsepower, thermal energy can be either heating or cooling
2) Disposition of the power – it can be sold to a utility or can be used at the site
3) Ownership – a cogeneration system can be owned by a regulated utility, an energy end user or an independent developer
4) Size of the cogeneration system can be viable in modules as small as a few kilowatts and as large as several hundred megawatts. [5]

At the beginning of cogeneration, technology had been applied in district heating. Waste heat from the prime movers had been captured and made low-pressure steam, that steam had been piped throughout the district for heating homes and businesses.

Cogeneration system consists of prime movers, generators, heat recovery systems and electricity interconnections. Prime movers used in cogenerations systems are reciprocating engines, combustion or gas turbines, steam turbines, micro turbines, and fuel cells. These prime movers can be used to burn variety of fuels, including natural gas, coal, oil and alternative fuels to produce shaft power or mechanical energy.

Benefits of Cogeneration:

1. Increases efficiency of energy conversion and use.
2. Lower emissions to the environment, reduces emission of green house gases like carbon dioxide.
3. Large cost savings, providing additional competitiveness for industrial and commercial users, while offering affordable heat for domestic users.
4. Reduce foreign currency outflow from the countries, lot of countries spend heavily on fuel imports.
5. Fuel is a depleting resource; savings will extend the life of fuel supply to future generations.
6. An opportunity to increase the diversity of generation plant, and provide competition in generation. Cogeneration provides one of the most important ways for promoting liberalization in energy markets.

Types of cogeneration systems used are, steam turbine cogeneration systems, gas turbine cogeneration systems and reciprocating engine cogeneration systems. Classification of cogeneration systems has done based on the sequence of energy used.

2.2. Steam Turbine Cogeneration Systems

Technology of steam turbine has been in use for about 100 years. Before steam turbines, there were reciprocating steam engines. With compared reciprocating engines, steam turbines has higher efficiencies and lower costs. The capacity of steam turbines can range from 50 kW to several hundred mega watts or large utility power plants. Steam turbines are widely used for combined heat and power (CHP) applications. The thermodynamic cycle for the steam turbine is the Rankine cycle. This is the basis for conventional power generating stations and consists of a heat source (boiler) that converts water to high-pressure steam. In the steam cycle, water is first pumped to medium to high pressure. It is then heated to the boiling temperature corresponding to the pressure, boiled (heated from liquid to vapor), and then most frequently superheated (heated to a temperature above that of boiling). A multistage turbine expands the pressurized steam to lower pressure and the steam is then exhausted either to a condenser at vacuum conditions or into an intermediate temperature steam distribution system that delivers the steam to the industrial or commercial application. The condensate from the condenser or from the steam utilization system returns to the feed water pump for continuation of the cycle [6].
The two types of steam turbines most widely used are the backpressure and the extraction-condensing types. The choice between backpressure turbine and extraction-condensing turbine depends mainly on the steam requirements of the factory. The extraction points of steam from the turbine could be more than one, depending on the temperature levels of heat required by the processes.

2.2.1. Rankine Cycle

This is a mathematical model developed to predict the performance of steam engines and it is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work. The heat is supplied externally to a closed loop. Water is used as the working fluid. This is a widely used technology in the world and in the form of steam cycles generates about 90% of all electric power used throughout the world, including all solar thermal, biomass, coal and nuclear power plants. It was given its name after William John Macquorn Rankine, a Scottish polymath and Glasgow University professor. [7]

Feed pump is used to pressurize the liquid condensate received from the condenser, instead of pressurizing a gas. Pumping the working fluid through the cycle as a liquid requires a very small fraction of the energy needed to transport it as compared to compressing the working fluid as a gas in a compressor.

This is one of the principal advantages of the Rankine cycle. By condensing the fluid, the work required by the pump consumes only 1% to 3% of the turbine power and contributes to a much higher efficiency for a real cycle. The efficiency of a Rankine cycle is usually gets constrained by the working fluid.
Figure 2.1: Rankine Cycle

Figure 2.2: Temperature and Entropy diagram for Rankine Cycle
2.2.2. Back Pressure Steam Turbine

Steam draws from the exit of the steam turbine for other processes at a pressure higher or at least equal to the atmospheric pressure. Pressure depends on the needs of the thermal load. Because of aforesaid reason, this turbine calls as back pressure type. If necessary, there is a possibility to extract steam from intermediate stages of the steam turbine, as per the required pressure and temperature for the thermal load. Steam taken from the turbine is fed to the load, where it releases heat and is condensed. Flow rate of the condensate can be lower than the steam flow rate, if steam mass is used in the process or if there are losses along the piping. Make-up water retains the mass balance.

The back-pressure system has the following advantages:

1. Simple configuration with few components.
2. The costs of low-pressure stages are expensive. But, in back pressure systems, this can be avoided.
3. Low capital cost.
4. Reduced or even no need of cooling water.
5. High total efficiency, because there is no heat rejection to the environment through condenser.

The back-pressure system has the following disadvantages:

1. The enthalpy difference for the steam turbine is low. Therefore, larger turbine required for the same power output.

2. The steam mass flow rate through the turbine depends on the thermal load. Consequently, the electricity generated by the steam is controlled by the thermal load, which, results in little or no flexibility in directly matching electrical output to electrical Load.
Increased electricity production is possible by venting steam directly to the atmosphere, but this is very inefficient. It results in a waste of treated boiler water and, most likely, in poor Economical as well as energetic performances.

2.2.3. Extraction Condensing Steam Turbine

In extraction type systems, Steam obtained by extraction from one or more intermediate stages at the appropriate pressure and temperature. The remaining steam is exhausted to the pressure of the condenser, which can be as very low pressure vacuum with a corresponding condensing temperature. This exhausted steam cannot be used for other applications, because of low temperature and pressure. In comparison to the back-pressure system, the condensing type turbine has a higher capital cost and, in general, a lower total efficiency. However, to a certain extent, it can control the electrical power independent of the thermal load by proper regulation of the steam flow rate through the turbine.

Figure 2.3: Extraction Condensing Steam Turbine