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REVIEW ARTICLE

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DIFFERENT METHODS OF SHARING AND OPTIMIZING THE ENERGY IN THERMAL POWER PLANTS

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ABSTRACT

A Thermal power plant consist of various cycles and subsystems like air & flue gas cycle, main steamcycle , feed water & condensate water cycle , fuel & ash cycle, Equipment cooling water (ECW), auxiliary cooling water (ACW) system, Compressed air system ,Electrical auxiliary power & lighting system, HVAC system etc . In India, most thermal power plants employing sub critical technology are able to work only at 30 - 40 percent efficiency.Remaining 60 - 70 %is lost during generation, transmission and distribution out of which the predominant loss is in the form of heat. This paper demonstrates the major energy saving potential areas and methods to optimize the energy of thermal power plant.

Keywords- Cogeneration, Combined Cooling Heat and Power (CCHP), Combined Heat and Power (CHP), Energy, Trigeneration

1. INTRODUCTION

Energy in India describes energy and electricity production, consumption and import in India. Energy policy of India describes the politics of India related to energy. Electricity sector in India is the main article of electricity in India. The Ministry of New and Renewable Energy provides data in the form of an annual report regarding progress in the energy sector. India is net energy importer. India was 3rd top coal producer 2009. India imports oil and coal 80% of global population lives in developing areas. Of the 6.0 billion populations, in the OECD countries the total number is approximately 1.2 billion – North America (0.4), Europe (0.6), Asia Pacific (0.2). In the non-OECD countries, the population is the balance 80% and i.e. 4.8 billion consisting of Asia Pacific (3.2), Russia-Caspian (0.3), Middle-East (0.2), Africa (0.8) and Latin America (0.4). By the year 2030, the global population is projected to be 8.0 billion rising at the rate of 0.9% per year and in the year 2030, the OECD countries would consist of North America (0.5), Europe (0.6) and Asia Pacific (0.2), the total being 1.3 from the present level of 1.2 billion. The balance 7.7 billion would be in nonOECD countries. Therefore, during the period 2005-2030, the population rise in the non-OECD countries would be higher than the population growth in the OECD countries. And, as a result, by the year 2030, the global population in the OECD countries would be a little more than 16% and the balance about 84% would in the non-OECD countries. 2. As regards energy consumption, 16% of the global population in the OECD countries would consume, by the year 2030, more than 40% of energy and the balance about 84% of the global population in the non-OECD areas would consume a little less than 60% of the total energy consumed in the world. No doubt, during the period 2005 to 2030, the rate of growth of energy consumption in the non-OECD countries would be higher than in OECD countries and would vary between 1.3% in the Russian-Caspian area to 3.2% in the Asia Pacific areas, as opposed to the rate of growth of energy consumption during this period in the OECD countries being in the range of 0.6% in North America to 0.9% in the Asia Pacific region. Still as mentioned earlier, by the year 2030, 16% of global population would consume as much as 40% of the energy and the balance 84% of the global population would consume less than 60% of energy. Providing access to adequate energy to their people is really a challenge for developing countries.

Installed Capacity of Energy in India

In India generation and distribution on commercial basis started around a century back. However the planned development of power sector could start only after independence, when this sector received a high priority in planning process for the nation. The installed capacity of India was only 1713 MW at the time of first five year plan in 1951.The installed capacity increased to 9027 in 1966,with capacity addition of 982, 1958 and 4574 MW in first, second and third five year plans respectively. Subsequently as a result of after continuous planned efforts, installed power generating capacity of the nation has been increased to 16664 MW in 1974. With sincere efforts of our scientist, engineers, and policy makers the present installed capacity has been increased to 236.38 Giga watts (GW) as of March 2012 recording an increase of 14% over that of March 2011 including Hydro, Thermal, Nuclear and other nonconventional sources. The present total installed capacity and contribution of state, central and private sector is represented in Table (1) below

In the case of India, the installed capacity was only about 1,362 MW in 1947 and has grown to about 173,626 MW by March 2011. It is primarily thermal (65 percent) with maximum capacity from coal. The share of hydro is only about 22 percent despite the fact that hydro potential in India is about 84,000 MW at 60 percent load factor. Share of nuclear and renewable is small at 2.8 percent and 10.4 percent, respectively (Figure 1.1) These percentages, however, undergo a change when viewed in terms of energy generation, especially for hydro and renewable. Though hydro installed capacity is 22 percent of the total, its share in energy generation is only 14 percent. Similarly, renewable though having a share of almost 10 percent in capacity, its share in energy generation is only 2.4 percent. The reason is that the capacity factor for hydro and renewable is much below thermal plants.

Table 1. Grand Total Installed Capacity of India as on 31.12.2012 (source CEA)

	Coal	Gas	Diesel	Nuclear	Hydro	RES	Total	%age
State Sector	49933	5215.3	602.61	0	27395	3569.92	86715.85	41.10%
Central Sector	41995	6702.2	0	4780	9349	0	62826.63	29.78%
Private Sector	28945.38	6985	597.14	0	2595	22286.22	61409.24	29.11%
Total	120873.3	18903	1199.75	4780	39339.4	28856.14	210951.7	
%age	57.29%	8.96%	0.57%	2.27%	18.65%	12.26%		100%

On the issue of ownership, while it was predominantly private sector owned (about 60 percent) at the time of independence, the situation has completely changed today where 79 percent of the installed capacity is in the public sector (about 32 percent in the central sector and about 47 percent in the state sector). Private sector ownership is limited to 12 percent only. It is not only the type of ownership which has undergone a change; the ratio of thermal to hydro capacity has kept fluctuating between 23 percent and 45 percent. The ideal mix as far as India is concerned is 60:40

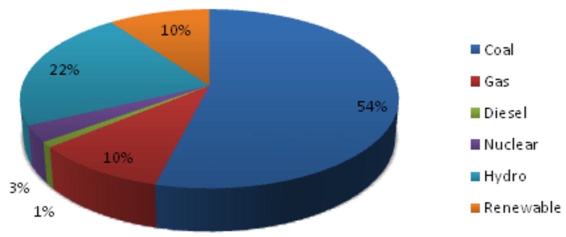

Fig. 1.1 Percentage share of different Resources in Electricity Generation (Source CEA)

In per capita terms, India's growth has been less than modest and today, India's per capita consumption is only about 733 units as compared to a world average of 2429 units. A perusal of the per capita consumption levels of some of the developed countries gives an idea of the extent of deprivation in India when it comes to electricity consumption (Figure 1.2).

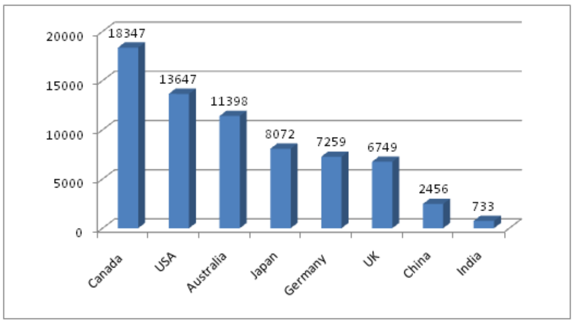

Fig. 1.2 Per capita consumption of electricity in India vis-à-vis some developed economies and China (2008-09) in kWh/year **(Source C E A)**

This is not to suggest that India's per capita consumption has been static over the years. It has been growing at about 7.3 percent per annum (Figure 1.3). What is important to note here is that there has been a noticeable change in the electrical consumption pattern across different consumer groups. The shares of domestic and agricultural sectors have gone up at the cost of industrial and commercial consumers. The share of the domestic sector has gone up from 10.8 percent in 1970-71 to 25 percent in 2008-09. The corresponding figures for the agricultural sector are 10 percent and about 21 percent, respectively. As compared to this, industrial consumption has dropped from 61.6 percent to about 38 percent during the same period.

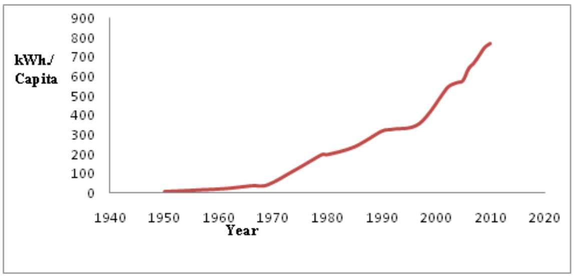

Fig. 1.3 Per capita consumption of electricity in India **(ARSPU& ED)**

2. Industrial Energy Usage

After the power sector, industry is the largest consumer of primary commercial energy in India The top six industries in India in terms of energy consumption are aluminum, cement, fertilizer, iron and steel, paper, and glass, which together account for about 40 percent of total industrial fuel consumption. An extensive engineering literature examines the energy efficiency of industries in India, most of which focuses on physical measures of energy intensity (i.e., energy per unit of output) and compares India with other countries. This literature, summarized below, generally indicates that India's industrial sector is less energy efficient (i.e., more energy intensive) than that in developed countries, although energy efficiency has improved in some industries over time. There is also considerable heterogeneity in energy efficiency across firms. Sathaye et al. (2005) and Schumacher and Sathaye (1998, 1999a, 1999b, 1999c, 1999d) estimate the payback period required for energy efficiency improvements in the aluminum, cement, fertilizer, iron and steel, and paper industries and the number of plants that have adopted these technologies. Schumacher and Sathaye, as well as Sanstad et al. (2006), estimate cost functions and share equations for energy-intensive industries in India using aggregate data for 1973–93. The results are used to estimate the rate of technical progress in each industry and to determine whether technical progress was energy saving or energy using. We summarize this literature below. To our knowledge, however, there are no econometric studies that explain which Indian firms have adopted energy-efficient technologies and which have not.

3. Energy Efficiency in Indian Industry, 1973–1994

Energy intensity is measured in physical terms as specific energy consumed per unit of output (SEC).2 in most cases SEC is compared with best practice to determine the percentage reduction in energy per unit of output that could be achieved by adopting best practices. When available, SECs for India are compared with values from other countries. All five industries addressed in Appendix B (aluminum, iron and steel, fertilizer, cement, and pulp and paper) were below world best practice in terms of energy efficiency during the 1973–94 period. The greatest opportunities for gains existed in iron and steel and pulp and paper, where reductions in energy per unit of output achievable (based on 1990s technology) were on the order of 40 to 50 percent. The percentage reduction in energy per unit of output possible in the cement and fertilizer industries was much smaller—on the order of 20 percent or less. In the aluminum industry, the most efficient plants in the mid-1990s compared well with international practice. How has energy intensity in Indian industry changed over time? It is difficult to obtain a time series on SEC for each of the five industries. To see how energy intensity has changed over time, Table 1 presents the rate of change in output per unit of energy (measured in constant prices) for each industry, for the period 1973–74 to 1993–94. Output per unit of energy showed a clear downward trend in the pulp and paper industry (implying that energy intensity has increased) but an upward trend in iron and steel, especially after 1985 and an upward trend in the fertilizer industry, until the end of the period. Energy intensity in cement exhibited little change over the period as a whole. Output per unit of energy fell in the case of aluminum industry, until 1988.

Energy audit and conservation is the burning issue nowadays due to the tremendous scarcity of electricity across the county. It is specifically quantifies as optimum use of electricity available. Normally it is extended to all the sectors viz, Industrial, commercial, residential as well as agriculture. Energy efficiency is a technique which needs to be adopted seriously and religiously for effective energy conservation. Energy saved by efficient use of energy of any electrically operated device not only leads to monetary saving but is extra energy generated for the use elsewhere.The energy process is an organized approach to identify energy waste in a facility, determining how this waste can be eliminated at a reasonable cost with a suitable time frame. Energy efficiency is widely used and many have different meaning depending on energy service companies. Energy audit of a building can range from a short a walkthrough of the facility to a detailed analysis. It is not only serves to identify energy use among the various services and to identify opportunities for energy conservation but it is also a crucial first step in establishing an energy management program. The efficiency will produce the data on which such a program is based. The study should reveal to the owner, manager, or management team of the building the options available for reducing energy waste, the costs involved, and the benefits achievable from implementing those energy conserving opportunities (ECOs).

4. Cogeneration and Trigeneration at a glance

The basic principle of this Thermo-Mechanical Energy Generation Equipment is: “Waste heat recovery to maximize the efficiency”. All Conventional Power Plants for Electricity Generation in which electricity is produced by burning coal, petroleum, natural gas produce a certain amount of heat during electricity generation. The excess heat, in conventional power plants, is discharged (and so wasted) in the natural environment through cooling towers, flue gas, or by other means. Cogeneration and Trigeneration systems capture some or all of the wasted heat for heating purposes. By capturing a portion of heat, Cogeneration and Trigeneration systems uses thermal energy that would be wasted in conventional power plants. Cogeneration and Trigeneration are thermodynamically efficient use of fuel. In a separate production of electricity and heat some of the primary energy must be rejected as waste heat, but in Cogeneration and Trigeneration this thermal energy is recovered. This means that less fuel needs to be consumed to produce the same amount of useful energy. In numbers this issue could be summarized as follows:

- In most heat engines, in conventional power plants, more than half of produced energy is lost and dissipated as excess heat during the production and distribution processes
- In Cogeneration and Trigeneration systems almost all the heat generated by combustion is not wasted, but rather utilized;
- Averagely the efficiency of Cogeneration and Trigeneration systems is reaching an efficiency of up to 90% compared with 50 – 55% for the best conventional power plants.
- Given the same electric and thermal energy consumption the energy released from the fuel is maximized to an overall efficiency of 90% while reducing energy bills and greenhouses gas emissions.

5 Cogeneration - Sharing the Energy

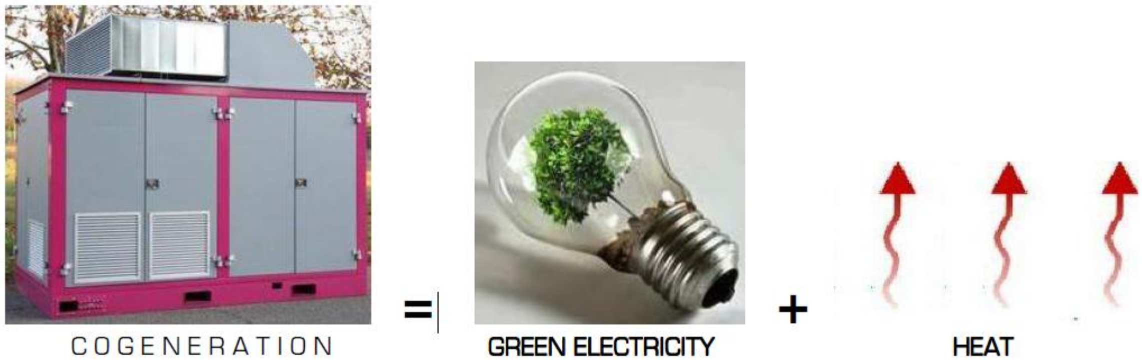

Fig. 1.4 Sharing of Energy by Cogeneration

Cogeneration consists in the simultaneous provision of electricity and useful heat, for multiple purposes. The acronym of Cogeneration is CHP (Combined Heat and Power production). Cogeneration Units are the combined production of electricity and heat, optimized by capturing and reusing the excess heat otherwise wasted, in independent plants installed closed to and directly used by the final user, for multiple purposes, and for emergencies or stand-by services. Said that Cogeneration Plants are ranging from large power stations to small local direct use of electricity and conditioning, the present, is focusing Mini-Cogeneration Units. We remain available for the Consulting and Engineering of larger and customized Cogeneration Plants. Mini-Cogeneration Units are the combined production of electricity and heat in small-sized independent plants installed closed to and directly used by the final user, for multiple purposes, and for emergencies or stand-by services. The size of such installations is usually more than 5 kW and less than 500 kW for buildings or medium sized business.

6 Trigeneration - Optimizing the Energy

Trigeneration consists in the simultaneous provision of electricity and useful heat and cooling, for multiple purposes. The acronym of Trigeneration is CCHP (Combined Cooling, Heating and Power production). Trigeneration Units are the combined production of electricity, heat and cooling, optimized by capturing and reusing the excess heat otherwise wasted, in independent plants installed closed to and directly used by the final user, for multiple purposes, and for emergencies or stand-by services. The acronym of Trigeneration is CCHP (combined cooling, heating, and power generation). Said that Trigeneration Plants are ranging from large power stations to small local direct use of electricity and conditioning, the present, is focusing Mini-Trigeneration Units. We remain available for the Consulting and Engineering of larger and customized Trigeneration Plants. Mini-Trigeneration Units are the combined production of electricity, heat and cooling in smallsized independent plants installed closed to and directly used by the final user, for multiple purposes, and for emergencies or stand-by services. The sizes of such installations are usually more than 5 kWe and less than 500 kWe for buildings or medium sized business.

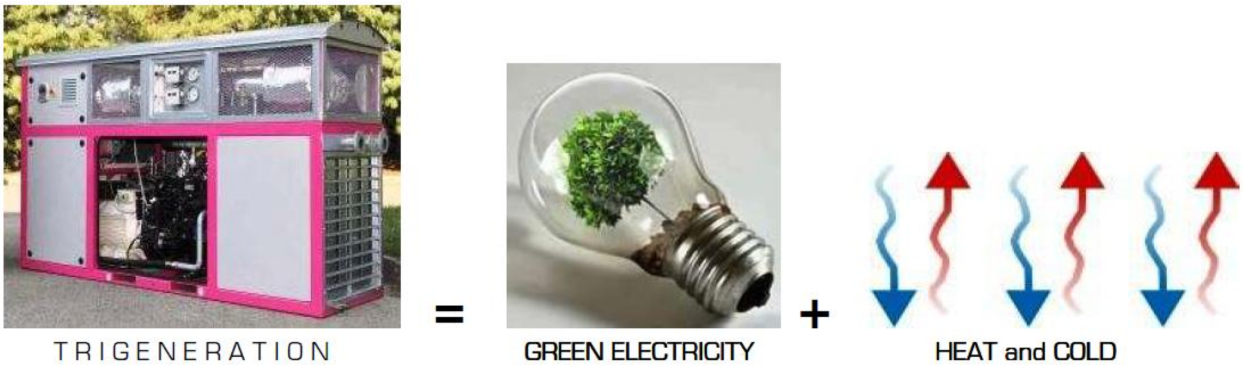

Fig. 1.5Optimization of Energy by Trigeneration

The combined generation of heat and power in a generation facility can save more than 30% of primary energy and CO2 emissions. To date only a few Cogeneration plants have been constructed in South Africa. Information about these and their contribution to sustainable economics is scarce. This brochure aims to provide information on how a wide range of South African industries and companies can benefit by implementing Co/ Tri-Generation strategies in their energy mix, thereby not only benefitting economically, but also significantly contributing to climate conservation. One of the main barriers to the widespread installation of Cogeneration plants is the perception of high start-up costs and the partly ambiguous or otherwise complex policy regulations regarding grid access, power purchase agreements and the claiming of carbon credits. An urgent need for further policy and regulatory frameworks exists to provide a conductive environment to enable the common use of Co-Generation /Tri-Generation.

The good practice examples listed in this brochure prove that, even in the context of South Africa's current energy policy situation, considering the upgrade of existing boilers to Cogeneration plants or even the new build of Cogeneration systems can be economically and environmentally feasible. It needs to be emphasized that especially with a view to further policy support of Cogeneration, as a form of energy efficient energy generation, Co/Tri-Generation has the potential to contribute meaningfully to South Africa´s energy policy objectives in terms of energy efficiency and climate protection. Cogeneration plants operate with significantly higher efficiencies and thus contribute positively to environmental requirements. Related to this, Cogeneration plants contribute significantly to saving of CO2 emissions. At the same time Cogeneration has the potential to strengthen companies' power independence and competitiveness. The South African-German Energy Programme (SAGEN) which is funded by the German Government and implemented by the Deutsche GesellschaftfürInternationale Zusammenarbeit (GIZ) GmbH has identified a lack of know-how on Cogeneration as an energy efficient technology in South Africa. As a result of this SAGEN has supported the set-up of a Facilitator for Energy Service Companies (ESCo) and Cogeneration at the South African National Energy Development Institute (SANEDI) to inform stakeholders on Cogeneration technology and related policies, to establish networks, to carry out workshops and to develop thisgood practice brochure.

Co/Tri-Generation is defined as the simultaneous production of more than one type of energy from a single fuel source. The production of heat and power at the same time is also known as Combined Heat and Power (CHP). When additionally producing cold next to electricity and heat, the process is called Trigeneration or Combined Cooling, Heat and Power (CCHP). Heating and cooling output may operate concurrently or alternately depending on need and system design. During the production of electrical or mechanical energy from a fuel, part of it is always lost in the form of thermal energy, called waste heat. Co/Tri-Generation processes the waste energy in form of thermal energy which is then used as process steam or steam for residential heating/cooling systems. In total, a higher percentage of the energy source (fuel) is used to generate energy on different quality levels (e.g. electricity, heat at a relatively low temperature for heating processes or heat at relatively high temperature for industrial processes).

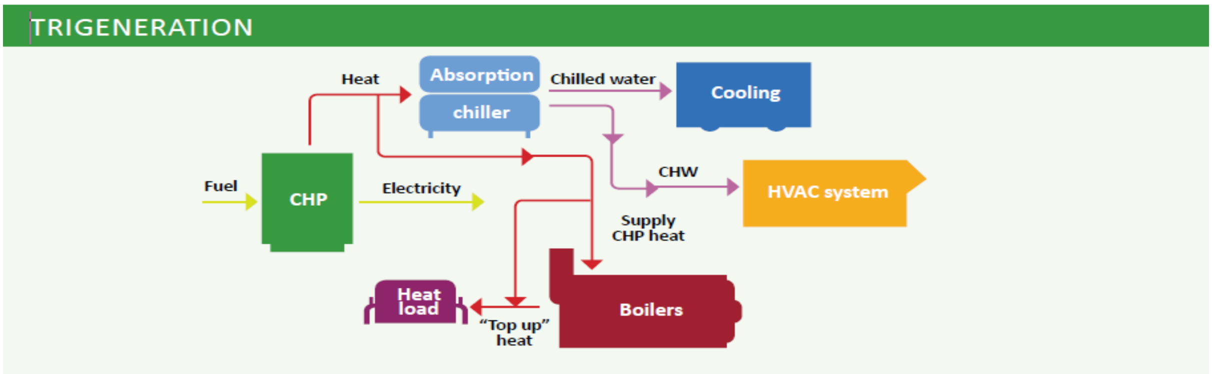

Fig. 1.6 Trigeneration Cycle

Cogeneration plants can range in size from as small as 1kW up to 1,000MW. The smallest plants, called micro- Cogeneration plants, are based on sterling motors. Used in domestic heating applications they have an electrical output of 1-3kW and a thermal output of approximately 20kW. Motor-operated Cogeneration plants range from 5kWel/30kWth up to 10MWel/10MWth. Here a variety of heat sources of piston engines are used including exhaust air recovery and motor oil waste heat. Gas turbine plants and combined-cycle plants offer a large number of alternatives for Cogeneration. Simple processes come with a gas turbine and a Heat Recovery Steam Generator (HRSG)

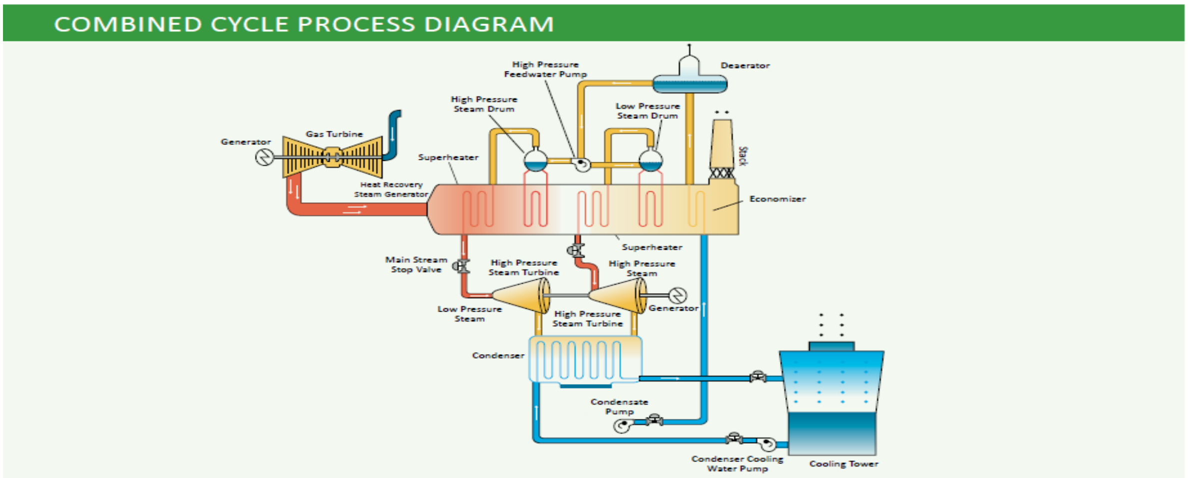

Fig. 1.7 Combined Cycles with HRSG

More sophisticated systems comprise gas turbines, HRSG and the full variety of steam turbines available in the market. State of the art systems are 1,000MWel combined-cycle plants with 61% efficiency and fuel efficiency of up to 93%. For solid fuels the various boilers can come with the full set of steam turbines. Typical plants start at 1MW; large plants are 1,000MW super-critical units with heat extractions.

7 Cogeneration plants classification

Cogeneration plants can further sub classified as

7.1 Heat Producing Plants with Electricity as By-Product

In this instance the heat output of the plant is controlled and following demand of heat consumers. Depending on the type of plant, electricity is produced proportional to the heat demand (Type 1) or electricity production is reduced or increased to follow varying heat demand (Type 2). Type 1 is typical for gas turbines with HRSG. Heat output is controlled by fuel input to the gas turbine. Electricity production is proportional to heat demand. Type 2 is typical for a condensing turbine in parallel to the heat consumers. Rising heat demand will reduce electricity production and vice versa.

7.2 Electricity Producing Plants with Heat as a By-Product

Under this scenario the electricity output is controlled and follows the electricity demand of the electric grid. Depending on the type of plant, heat is produced proportional to the electricity demand (equal to type 1 above) or heat production is reduced or increased to follow electricity demand (Type 2). Type 2 is typical for an uncontrolled heat source, e.g. solar-thermal field or waste heat from a process, feeding a steam turbine with controlled heat extraction. At constant heat production, varying electricity demand will yield varying heat supply.

7.3 Flexible Plants Meeting the Demand of Heat and Electricity Consumers

These systems need to be designed to consumer requirements. A typical plant comprises one or several steam boilers, often with different fuels capable of meeting steam and electricity demand. The steam boilers usually supply a steam header feeding a cascade of back-pressure steam turbines and condensing turbines. Heat and electricity demand will be met by changing heat production from the boilers utilizing steam storage properties of the steam headers. A special case is a single boiler with an extraction condensing type turbine. This indicates that the selection and operating scheme of a Cogeneration system is able to adjust to site-specific requirements.

8 Considerations

The following aspects should be considered when investigating Cogeneraiton or Trigeneration as a means to supply energy for this work

- The technology should only be considered once other priority energy efficiency measures are implemented to reduce the projected energy demand for the site.
- Savings projected in the short-term may not be replicated in the long-term due to fuel price volatility.
- Variations in a building's operation and energy demand will impact on system efficiency i.e. if demand for waste heat reduces, using gas to generate electricity for power only is far less efficient than importing from the national grid. If this occurs, the system could actually result in an energy cost for the project.
- Security of fuel supply may not always be certain.
- If upgrading an existing energy plant, it is vital the payback on capital investment and maintenance costs are realistic for the project.
- Connection requirements with the local electricity distributor should be determined.

8. Gas Fired Combined Cycle Power Plants

Combined cycle power plants (CCPPs) have been serving the growing demand for power since the 1970s. Over the past 40 years, needs have shifted from fast and low-cost power supplies towards sustainable and flexible power generation. Growth of this type of plant began in the 1980s when gas became widely available as an indigenous fuel in Europe and Asia, and the plants had low capital costs, could be quickly built and had low maintenance costs. They were increasingly used to serve the growing IPP (Independent Power Producer) market, but also to meet expanding utility requirements. Later in the 1990s, this plant concept gained further merit as the lowest emission generator other than nuclear power. Beginning around 2000, flexibility began to gain greater importance as a way to compensate for the growing share of fluctuating renewable generation in the system. Over the years, combined cycle plants have been optimized with further innovations in gas turbine, steam turbine and generator technologies, as well in the steam/water cycle in order to meet the growing trend toward sustainable technologies, reduce the consumption of resources and minimize fossil emissions. Combined cycle plants are used today, even if coal is abundantly available, as a means of diversifying primary energy and valuable back up capacity.

Gas-fired power plants with state-of-the-art gas turbines are highly sophisticated plant and technology concepts offering unmatched excellence in operation, reliability and environmental friendliness. The power industry can make substantial contributions – most notably massive resource savings and lower CO2 emissions – to the long term sustainability of fossil power generation only with such high innovation power. Comparing the efficiency and CO2 emission levels of all type of fossil power plants these gas turbine-based combined cycle power plants are the most sustainable, predictable and reliable power generation technology available at present. CO2 emissions from modern gas-fired combined cycle power plants are around 57% lower than those from state-of-the-art hard coal-fired plants.

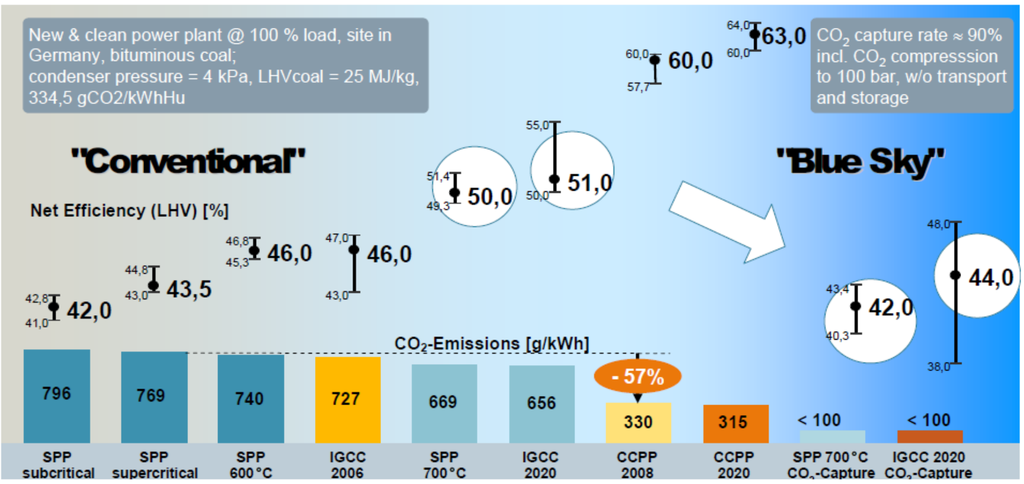

Fig. 1.8 Net Efficiency of current and future plant concepts

Advanced combined cycle technology is based on the latest developments in gas turbine technology that allow highest mass flow, lower losses in compressors, turbine inlet temperature above 1,500°C and optimized pressure ratios to meet also the requirements of a high-temperature steam end. These advances are supported by the use of improved and even new materials in all rotating equipment, ceramics in the combustion and turbine sections, and state-of-the-art design and calculation tools and innovations in other areas.

Fully water-cooled generators and high-temperature steam turbines also contribute to the lowest CO2, NOx and SO2 emissions as well to the highest efficiency for all fossil power plants. In the associated steam/water cycle, also here the use of new materials as well as innovative steam generators helped increase efficiency over the past 15 years from around 50% to today's proven record of 60.75% (LHV), which was measured in Germany's Ulrich Hartmann (Irsching 4) plant in mid-2011. The plant has since accumulated over 15,000 hours of commercial operation.

The CCPP plants in Andong and Daegu City, South Korea, are excellent examples of the success of this advanced technology in markets like Asia, which have high gas prices through supplies of LNG (Liquefied Natural Gas). Beginning in 2015, these two plants – with capacities from 400 to 420 MW and efficiencies in the range of 61% net – will provide electricity to around 200,000 urban households and will save gas and about 3.5 million tons of CO2 a year compared to existing power plants in the area.

In countries like Germany, this technology is also supporting the current energy transition towards renewable energy sources since the plant concept allows extremely flexible operation for backing up power for fluctuating wind and solar supplies and ensures grid reliability and stability. The term "combined cycle" describes the combination of two thermodynamic cycles, with the gas turbine (Brayton cycle) burning natural or synthetic gas from coal/residuals/oil, and its hot exhaust gas powering a small steam power plant (Rankine cycle). Combined Cycle Power Plants (CCPPs) can achieve a thermal efficiency higher than 60% today, compared to single cycle gas power plants which are limited to efficiencies of around 35 to 42%.

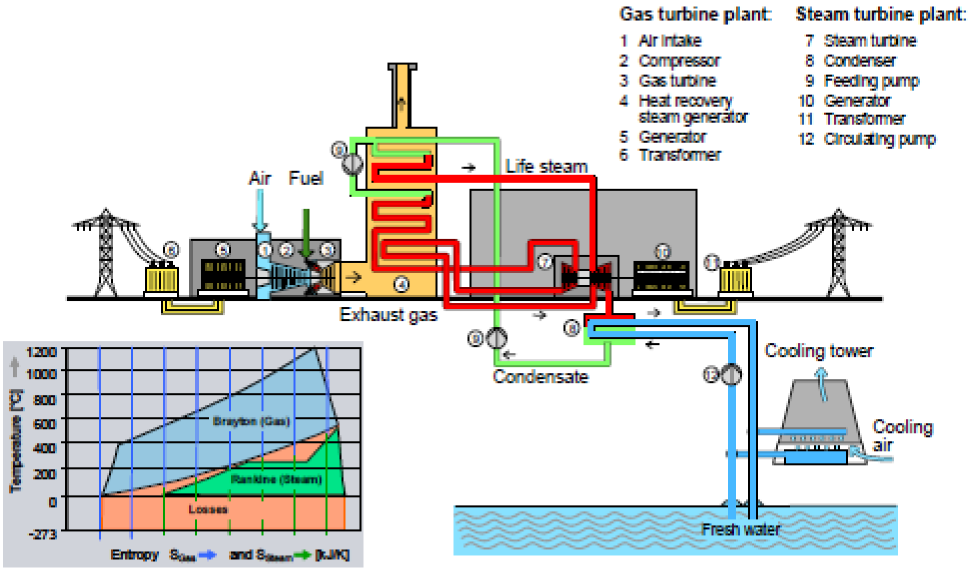

Fig. 1.9 Combined Cycle Technology

Efficiency, which is defined as the usable electrical energy generated from the plant's divided by fuel energy, is determined by the following factors:

- Efficiency of the gas turbine and other rotating equipment through their aerodynamic design, cooling technology and upper Brayton process temperature (turbine inlet temperature)
- Design efficiency of the Rankine cycle through the temperature and pressure of the steam generated from a single pressure to a triple pressure reheat cycle with the condenser pressure as the lower process temperature
- Cooling technology used as direct water-, to indirect air- and to direct air cooling.

CCPPs today achieve efficiencies ranging from 52 to 61%, depending on the above factors and on environmental conditions such as air inlet and cooling temperatures. The increasing efficiency achieved over the years demonstrates the huge innovation potential and development progress supporting this plant technology.

9. Conclusions

When considering installing a Cogeneration or Trigeneration system, there are a series of issues that need to be taken into account, all of which will differ according to project-specific parameters. It is recommended that an engineering firm be consulted for any project to review the application, costs and benefits. All of the following project characteristics must exist in order for the system to be worthwhile installing:

- A concurrent heat and power demand.
- Extended hours of operation.
- Existing inefficient systems (if installing in existing building) and applications for the new system.

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