

MERITS OF ENERGY HARVESTING BY COGENERATION WITH CHARACTERISTICS: A REVIEW

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Abstract

Power plants either give electrical power or heating/cooling at the time of single application. Considering in power units if either electrical power or heating/cooling is obtained it leads to unnecessary running cost of single plant and greater thermodynamic energy loss increase. With combination of two or more power plants (cogeneration) efficient energy utilization, lesser consumption of fuel for same degree of power/heating/cooling generation in comparison to separate usage of single plant thereby reduction of emissions of harmful gas due to burning of fuels are attained. Some other profits of cogeneration are variability of usage of fuel where waste heat, energy of low grade or from renewable sources can be utilized; reliable of obtaining energy in bad weather, natural catastrophes, and mechanized failures by giving as backup source; better life cycles of equipments with combination of cycles. Cogeneration meets the utility of simultaneous generation of electrical power, heating/cooling. Based on the different prime mover cogeneration systems are divided into followings: i) steam turbine based ii) gas turbine based iii) internal combustion engine based iv) fuel cell based v) micro gas turbine based vi) hybrid mixture of fuel cell and gas turbine/micro gas turbine based. In each of the different prime mover based cogenerations electrical power along with heating/cooling can be attained by consideration as bottoming plant for heating/cooling with respect to above mentioned systems as topping plant. Researchers are working for further improvement in the characteristics of cogeneration plants.

Keywords: Bottoming, Cogeneration, Energy, Low-grade.

1. INTRODUCTION

Cogeneration is simultaneous production of power and useful thermal energy from the same energy source. The thermal energy so produced can be used for process heating, producing process steam, producing chilled water for cooling and refrigeration.[1]

Cogeneration plants utilize energy more effectively and their utilization factor is as high as 80% or higher [2].

1.1 Advantages of cogeneration

- Reduced fuel consumption and running costs: Reduce fuel consumption by 10-40% or more.[3] It also reduces running costs by as much as by 40-50%.[4]
- Less environmental pollution: It showed pollution reduction by 14-28% compared to separate gas, oil, and coal plants.[5]
- Greater fuel usability
- Greater energy reliability: Due to Decentralized Generation, Grid Independence, reduced dependency on external sources.[6]
- Greater longevity of equipments

1.2 Disadvantages of cogeneration

- High investment and maintenance cost
- High operational costs
- Limited technical demand and applicability
- Limited fuel sources and system scale[7]

2.RECENT STATISTICS

2.1 Key data trends in 2020

- **Global Output:** Over 4,100 TWh electricity and 11,400 TWh heat, comprising greater than 15% of global electricity.
- **Efficiency:** High total/combined efficiencies (80-95%), much better than separate generation of heat and power
- **Growth:** Global CHP(combined heat and power) capacity grew approximately 18% (electricity) and 28% (heat) from 2010-2020 mainly in Asia-Pacific, Europe, and North America.
- **Fuel:** Primarily natural gas (31.8%) and coal (59.6%) being shifted to biogas, biomethane, and hydrogen. [8]

2.2 Key data trends in bagasse and non-bagasse cogeneration

TABLE 1.Cumulative capacity from 2014 to 2025 in bagasse and non bagasse cogeneration[9]

ENERGY SECTOR	CUMULATI-VE CAPACITY(Till 2014)	March	CUMULATI-VE CAPACITY(Till 2025)	October
Biomass(Bagasse cogeneration)	7419.23 MW		9821.32 MW	
Biomass(NonBagasse cogeneration)	531.82 MW		935.99 MW	
Waste to Energy	90.58 MW		309.34 MW	
Off-grid Waste to Energy	139.79 MW		546.28MW	

3.APPLICATIONS OF COGENERATION FOR BOTH POWER AND HEAT

3.1 Steam turbine based

3.1.1 Back pressure-non condensing type

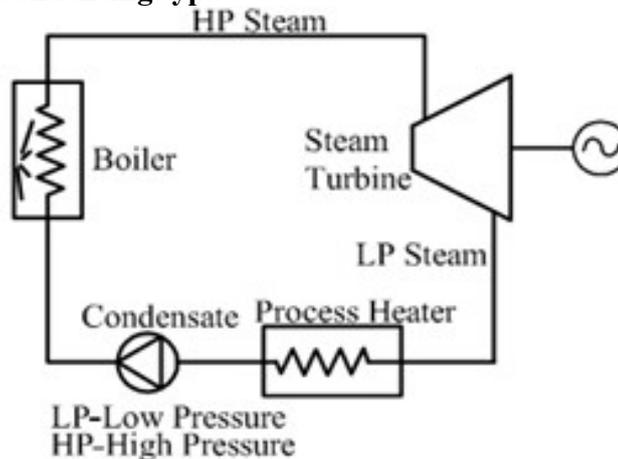


FIGURE 1. Steam turbine based cogeneration (back pressure type)[1]

Genovski and Hristov(2020)[10] used technologies for district water heating to the required temperature either in district heaters in case of steam turbine with adjustable steam extractions or in boiler-condenser in case of backpressure steam turbine installations.

Zhao et al(2020)[11] selected a 300 MW coal-fired subcritical combined heat and power system as the reference system, and modeled in EBSILON professional. Then, energy-based and exergy-based performances of the high back-pressure system and traditional combined heat and power system were compared under full operating conditions.

Chen et al(2019)[12] a novel concept of HBP(high back pressure) heating system with energy cascade utilization was developed and its probability examined. The extracted heating steam from

the intermediate-pressure turbine (IPT) was first drawn to an additional turbine where its excess pressure was converted into electricity, then steam with a lower pressure was employed to heat the supply water.

3.1.2 Extraction and condensing type

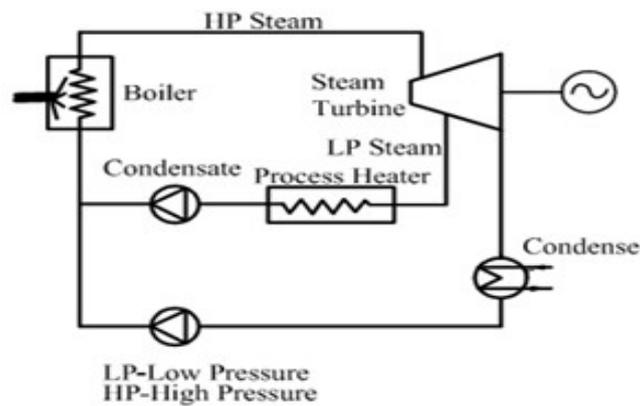


FIGURE 2. Steam turbine based cogeneration(extraction type)[1]

Verbruggen et. Al(2016)[13] explained a method and applied with numerical data, also revealing the flaws in regulations like optimal regulatory specificity attained through setting generic frameworks by technology, accommodating investment and operational decisions by plant owners. Urošević et. Al (2013)[14] made an analysis of the power loss coefficient of steam turbines for the generation of useful heat energy and electricity simultaneously applying to all cogeneration plants comprising extraction-condensing steam turbines and combined cycles (gas turbine and steam turbine) when heat is extracted prior to the bottoming cycle. Ohji & Haraguchi (2022)[15] included important information relating to design optimization for thermal power plants such as the Rankine cycle, thermal power cycle, and integrated gasification-combined cycle (IGCC) power plants.

3.2 Gas turbine(GT) based

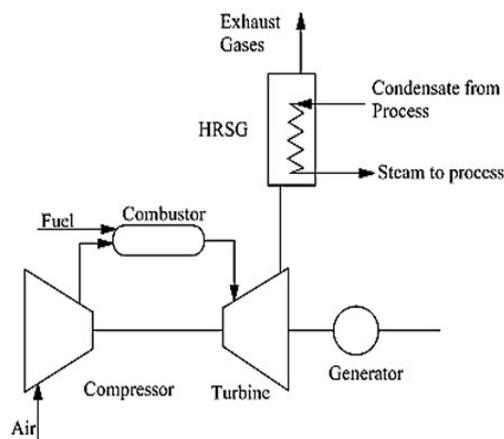


FIGURE 3. Gas turbine based cogeneration system[1]

Bade & Bandyopadhyay(2015)[16] proposed a methodology, based on pinch analysis to integrate gas turbine and regenerator with a process plant to minimize fuel consumption. Su et al(2020)[17] a biogas-fired cogeneration system based on chemically recuperated gas turbine cycle making the best use of both chemical and physical energy was studied and discussed. Li et al(2020)[18] a novel combined cooling, heating and power system consisting of carbon dioxide power cycle, absorption chiller and heaters was proposed for waste heat recovery of gas turbine.

3.3 Internal Combustion Engine(ICE) based cogeneration

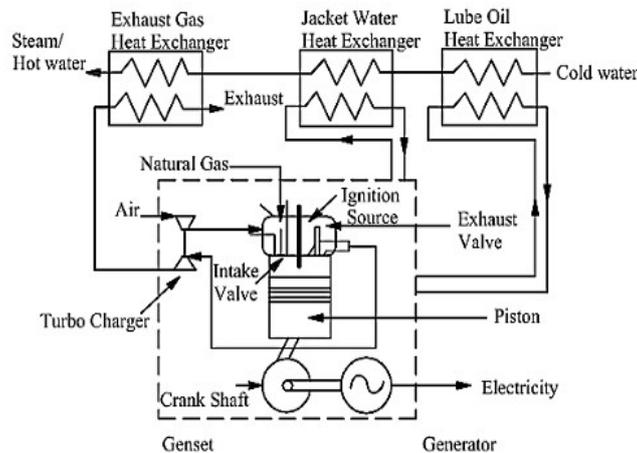


FIGURE 4. ICE based cogeneration system[19]

Pawlenka et al(2023)[20] relates to cogeneration, or combined heat and power systems (CHP) and its development based on an already used and low-cost internal combustion engine ICE with a fuel system redesigned for the injection of natural gas with heating and electricity production designed for small or medium-sized households or family houses. The maximum overall efficiency of the CHP reached to 87% in operation mode, with a heating power output of 15 kW and an electrical power output of 4 kW.

Kolienko & Akhmednabiev(2024)[21] dealt with the issue of developing a methodology for surveying the energy efficiency of CPs(cogeneration plants), determining the technical and economic indicators of the work, researching the factors influencing the energy efficiency indicators of CPs and ways to increase of their efficiency. Experimental results of thermal and environmental tests of a cogeneration plant (CP) based on a gas-piston internal combustion engine with a total nominal thermal capacity of 2.46 MW were presented, of which 1.26 MW was nominal thermal capacity and 1.2 MW was electrical.

Sachajdak et al (2025)[22] made an assessment of opportunities by using ammonia as a zero-carbon fuel for internal combustion engine-based cogeneration. A short review by using ammonia in internal combustion engines was presented. Then the issue of engine performance when fuelled with ammonia was discussed and the results with experiments were briefly outlined. In the next step, two scenarios of the evolution of the Polish energy system and the market were developed. In the last part of the study, the cogeneration technology was proposed for a base load for a sample district heating system.

3.4 Fuel cell based cogeneration

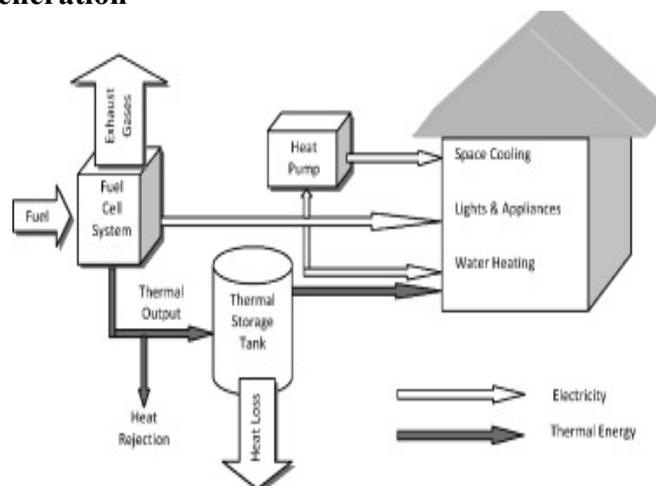


FIGURE 5. Fuel cell based cogeneration[23]

Facci and Ubertini(2018)[24] worked on a research project, called AutoRe, which utilized an automotive derivative fuel cell for a cogeneration plant creating a synergy between two non competitive industries (automotive and stationary plants) and realized a significant economy of scale that drastically cut the costs of fuel cell based cogenerative plants. Also thorough techno-economic analyses of the AutoRe (AUTomotive deRivative Energy system) power plant were performed. They considered 5 different building types (Office, Apartment district, Clinic, Hotel, Supermarket), 5 different climatic conditions (Hot, Cooling Based, Moderate, Heating based, Cold), and 2 different surrounding energy systems (USA and Europe) and the results showed that overall the proposed plant was economically sustainable and effective in reducing the energy costs and the primary energy consumption.

Qu et al(2021)[25] developed a hybrid power system i.e.heat recovery with proton exchange membrane fuel cell/battery-based hybrid power system, which is also known as a micro-combined heat and power (CHP) system for a micro-CHP applied to a residential house by supplying electric power and hot water simultaneously.

Asensio et al (2018)[26] focused on the development of a model for achieving optimal control of the cooling system of a polymer electrolyte membrane fuel cell (PEMFC)-based cogeneration system which was developed to help facilitating the development and application of control strategies for maximizing the energy efficiencies of PEMFCs, and reduction of the costs associated with electric and thermal generation.

3.5 Micro Gas Turbine(MGT) based cogeneration

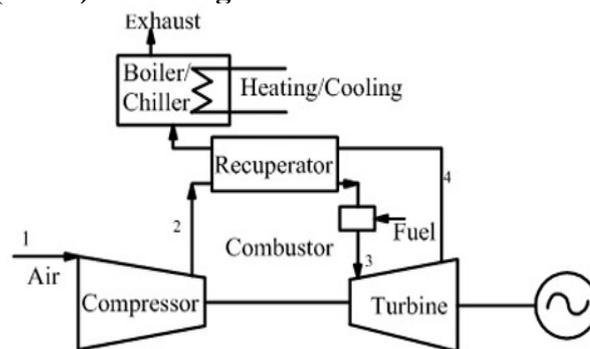


FIGURE 6. MGT based cogeneration system[27]

Balli et al(2021)[28] discussed the issues, opportunities, and benefits of a combined heat and power system, including a micro gas turbine engine (M-CHP) operated by natural gas, with an estimated sale price of \$245 000 producing 225 kW-net of electrical power and a 209.8 kW-net thermal power output in the industrial zone via thermodynamic indicators helping to measure the cost rate, the environmental, ecological effects, and sustainable growth.

Assadi(2022)[29] presented the redevelopment of a standard 100-kW micro gas turbine to run with methane/hydrogen blended fuel to enable micro gas turbines to run with hydrogen blended fuels. Results from the MGT operated with blended methane/hydrogen fuel were provided with hydrogen content varied from 50% to 100% (volume-based) and power outputs between 35kW to 100kW.

Banihabib and Assadi(2022)[30] made a review of micro gas turbines' characteristics promoting their role in future power and heat generation systems. An overview of the challenges to improve operational flexibility, reliability, and availability of MGTs to maintain low environmental impact and lowering the costs was presented. A model for an active monitoring and control system of the micro gas turbines was proposed which improved the reliability of MGT operation in the grid by means of AI methods.

3.6 Hybrid FC(fuel cell)–GT(gas turbine)/MGT(micro gas turbine) based cogeneration systems

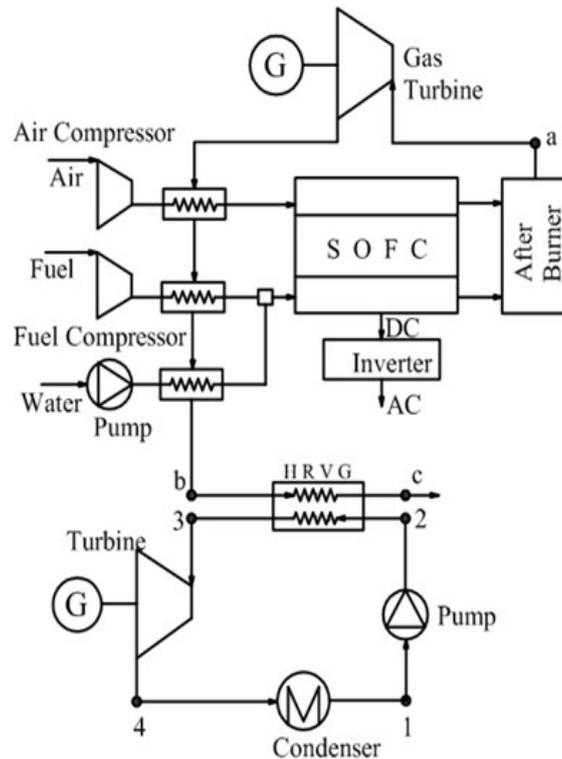


FIGURE 7. Combined SOFC(solid oxide fuel cell)–GT(gas turbine)–ORC(organic rankine cycle) hybrid power system[31]

Vignesh and Azhagumurugan[32] designed a hybrid system of fuel cell and gas turbine to overcome the need to use the conventional sources of fuel such as diesel and petrol used in the combustion that takes place in a Gas Turbine system to replace the combustion chamber with a fuel cell setup to produce electricity or power with higher efficiency which is achieved by using heat recovery techniques and use Hydrogen as a source of fuel.

Montazerinejad(2024)[33] evaluated compact cogeneration technologies for urban areas having varying energy demands, focusing on renewable fuels such as hydrogen and biogas, compared to fossil fuels like methane. Proton exchange membrane fuel cells (PEM fuel cells) and recuperated micro-gas turbines (MGTs) were identified as the most promising technologies and its performance under diverse scenarios, including control strategies, fuel choices, and operational conditions, was thoroughly modeled.

Huang (2024)[34] developed a simulation tool to conduct effective design optimization and off-design analysis of such hybrid systems and acquiring knowledge about mechanical equilibrium operation at a mechanism level. New energetic and operational insights were provided into three typical SOFC – GT systems: basic single-shaft layout, recuperative single-shaft layout and twin-shaft free turbine layout.

4. APPLICATIONS OF COGENERATION FOR BOTH POWER AND COOLING

Zhao et al(2020)[35] investigated an electricity and cooling power cogeneration system for harvesting low-grade heat below 80 °C, consisting of a two-bed adsorption-based desalination (AD) system for thermally separating the salt solution into diluted and concentrated solutions offering cooling power and a reverse electrodialysis (RED) system to convert the Gibbs free energy of mixing of the generated solutions into electricity. The effects of adsorption/desorption time, switching time, working concentration, working fluid mass, and adsorbents on the electric efficiency, coefficient of performance (COP) and exergy efficiency of the cogeneration system were

systematically evaluated.

Arabkoohsar and Andresen(2018)[36] proposed cooling production by coupling a station i.e. power productive gas expansion station (PPGES) with an absorption chiller where the chiller provided the heating demand of the expansion station. A case study in Denmark, i.e. Aarhus University (AU) hospital absorption chiller and Viborg gas station was done where the results showed a great enhancement in the levelized cost of energy (LCOE) in case of employing the hybrid system instead of the conventional chiller.

Zhao et al(2020)[37] presented an alternative adsorption-based power and cooling cogeneration system consisting of an adsorption-based desalination system for generating concentrated and diluted salt solutions as well as providing cooling power, and a pressure retarded osmosis system for converting the produced salinity gradient energy into electricity to harvest low-grade waste heat below 80 °C.

Cetin et al(2022)[38] proposed a combined power and cooling cogeneration system with cryogenic energy storage powered by geothermal energy and connected with the grid where the system was formed by integrating a turbine ejector cogeneration cycle with an air liquefaction cycle, a liquid air direct expansion cycle and a cryogenic organic Rankine cycle. A geothermal source at 180 °C with a flow rate of 100 kg/s was used as the heat source for the study, the cogeneration system having the ability to produce 15,470 kW of power and supply 4800 kW of cooling simultaneously. The system round trip efficiency was 41.07%, and the exergy efficiency of cryogenic energy storage was 60.43%.

Ebrahimi et al(2020)[39] developed a new integrated structure of power generation and refrigeration for the use and recovery of the stored liquid natural gas energy as a cryogenic energy storage system by employing Kalina power cycle, molten carbonate fuel cell, carbon dioxide power cycle, and absorption-compression refrigeration system using solar energy. The new integrated structure generated 161,287 kW power, 1964 kW refrigeration at 266 K through LNG(liquid natural gas) recovery with 4.066 kg/s mass flow rate and 8464 kW refrigeration at 218.5 K. Electrical, thermal and exergy efficiencies of the whole system were 57.92%, 61.66%, and 68.21%, respectively.

CONCLUSION

Cogeneration is an idea to get power and heating/cooling with a single plant. Although it has some shortcomings but it gives more added advantages than shortcomings. More research is going on to improve cogeneration as in future it will be a dominant technology.

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