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TECHNICAL REPORT

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Report on the development of cogeneration

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REPORT ON THE DEVELOPMENT OF COGENERATION

FOREWORD

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IEC TR 63388 has been prepared by IEC technical committee 5: Steam turbines. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
5/243/DTR	5/244/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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REPORT ON THE DEVELOPMENT OF COGENERATION

1 Background

1.1 Task following SMB decision

Following the Standards Management Board (SMB) decision 141/10, IEC Technical Committee 5 (Steam Turbine) was tasked to lead a joint working group with related IEC and ISO committees to explore potential standardization opportunities.

SMB decision 141/10reads as follows:

SMB decision 141/10 – SMB AhG 30: Co-generation – IEC involvement in joint work with ISO The SMB, further to having taken decisions confirming IEC's commitment to providing support to the areas of cogeneration technology within its area of competence in particular aspects related to electrical power generation, decided to instruct IEC TC 5 to be the primary point of contact, to follow this activity in coordination with TC 45 and TC 105. The SMB requests AhG 30 to submit a final report and recommendations on future work and any future activities by end July 2011, and decided to disband the SMB AhG 30 after submission of the report. Based on the AhG recommendations, SMB will then communicate an IEC perspective on this matter to ISO.

With the above SMB decision, IEC Technical Committee 5 established Joint Working Group 16 (Cogeneration Combined Heat and Power (CHP)) in 2012-09.

After IEC/TC5/JWG16 was established, working steps were proposed (see 5/168/AC) as follows:

No.	Working step	Remarks
1	Complete an overview on standards related to CHP technology.	Also include standards if they only partly cover CHP aspects
2	Clarification of status and application experience of Manual CWA 45547	Efficiency of CHP solutions is in focus for all applications. The Manual CWA 45547 from 2004 could be a basis for an IEC standardization project. There might be valuable feedback available from application of the Manual.
3	Screening of world-wide applied alternative methods for determination of CHP efficiency	
4	Clarification of the need for standards dealing with aspects different to efficiency such as safety, performance and installation. A differentiation between residential / commercial mass products and power plants should be considered. It should be identified where the current standardisation activities are going on in ISO or IEC and where the need for new coordination between IEC / ISO TCs is suggested.	Consider the different needs for the residential, commercial and industrial needs including the different power sizes. EN 50465:2008 GAS APPLIANCES – COMBINED HEAT AND POWER APPLIANCE OF NOMINAL HEAT INPUT INFERIOR OR EQUAL TO 70 KW? IEC62282 Fuel Cell Technologies Germany: FW308 July 2011 Status per 03-2012: The common aspects of safety related control are already covered by other IEC and ISO standards on Functional Safety. No additional aspects for standardization with respect to CHP identified. The common aspects of application of gas and oil valves are covered by other IEC and ISO standards. No additional aspects for standardization with respect to CHP identified.
5	Clarification if there is any other product/solution specific standardization need in the area of CHP	Possible aspects are also grid parallel operation of the CHP.
6	Update necessary liaisons with other TCs within IEC or ISO	IEC TC45 Nuclear instrumentation? IEC TC105 Fuel cell technologies? ISO TC192 Gas Turbines? ISO TC208 Thermal turbines for industrial application (steam turbines, gas expansion turbines)? Other TCs?
7	Prepare Proposal of standardization Work Item (PWI) for voting in TC5 and relevant other TCs	Proposal might include the target to align the context of the new IEC standard in a way that it later – as an EN IEC standard – can be harmonized with the EC Directive 2004/08 (Combined Heat and Power (CHP) Directive).
8	Clarification of which other IEC or ISO standards have to be adapted, when new IEC standard in CHP efficiency becomes valid. Preparation of requests to other TCs for adaptation/update of other standards.	Chapters on CHP efficiency in other standards for individual applications should be replaced by a reference on the new IEC standard. In C-type standards describing the efficiency of a certain technology relevant to CHP a reference on the new IEC standard on CHP efficiency should be included.
9	Clarification with CEN/CENELEC on withdrawal of Manual CWA 45547	

This technical report is intended to address the above items 1, 3, 4, 5, 7, and 8.

Other items will be addressed depending on the outcome of this report.

1.2 Scope

This document, which is a technical report, introduces the widely used technical scheme of cogeneration (also known as combined heat and power (CHP)), and gives the corresponding cases. The technical schemes of cogeneration covered in this technical report can be divided into two categories. One is cogeneration based on steam turbine, which is generally applied in thermal power plants; The other is cogeneration based on other prime movers, such as fuel cell, micro gas turbine, internal combustion engine, Stirling engine, ORC, etc.

This document gives some cases of cogeneration, mainly including:

- CHP based on extraction turbine;
- CHP based on back pressure turbine;
- Low-vacuum heating mode;
- LP cylinder steam bypassed heating mode;
- CHP based on steam turbine with synchro-self-shift clutches;
- Gas-steam combined cycle CHP;
- Micro gas turbine CHP;
- Stirling engine CHP;
- Fuel cell CHP; and
- ORC CHP.

The characteristics, components and technical requirements of these technical schemes are introduced in this document.

By collecting existing standards of CHP, this document also identifies the gaps of CHP standardization and put forward a roadmap for future CHP standards.

This document is prepared based on limited expert resources. Thus, some cogeneration cases could not be covered in this document, such as:

- Solar cogeneration; and
- Internal combustion engine cogeneration.

1.3 Purpose

Based on the decision of the SMB, the purpose of this document is to briefly introduce the technical characteristics and requirements of different cogeneration schemes, analyse the standard status and standard gap, put forward roadmap and suggestions for the development of cogeneration standards in the future.

2 Terms, definitions and abbreviated terms

2.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

2.1.1
combined heat and power (CHP)
energy efficient technology that generates electricity and captures the heat that would otherwise be wasted to provide useful thermal energy - such as steam or hot water - that can be used for space heating, cooling, domestic hot water and industrial processes

[SOURCE: "Combined Heat and Power (CHP) Partnership" from EPA]

2.1.2
cogeneration
simultaneous production in series of two forms of useful energy such as electrical energy first and then useful thermal energy from a single fuel source

Note 1 to entry: In this document, cogeneration refers to CHP.

2.1.3
primary energy
energy that has not been subjected to any conversion or transformation process

Note 1 to entry: Primary energy includes non-renewable energy and renewable energy. If both are taken into account it can be called total primary energy.

[SOURCE: ISO 52000-1:2017, 3.4.29]

2.1.4
heating
process of increasing the temperature of medium by the means of the transportation fluid from the heating plant over a heat exchanger

2.1.5
heating season
part of the year during which heating is needed to keep the indoor temperature within specified levels, at least part of the day and in part of the rooms

Note 1 to entry: The length of the heating season differs substantially from country to country and from region to region.

Note 2 to entry: This term is especially for district heating period of a year.

[SOURCE: ISO 17772-1:2017, 3.15]

2.1.6
heating system
system where the working fluid is heated by the transportation fluid coming from the CHP plant for any purposes, such as process, building heating, hot water, etc.

2.1.7
district heating
heating systems that distribute steam or hot water through pipes to a number of buildings across a district

Note 1 to entry: Heat is provided from a variety of sources, including geothermal, combined heat and power plants, waste heat from industry, or purpose-built heating plants.

[SOURCE: ISO 14452:2012, 2.23]

2.1.8
industrial heat supply
heat supply where the working fluid takes part with the industrial process or the heat of the working fluid is transferred to the industrial process over a heat exchanger

Note 1 to entry: In the former case, no residual heat is returned to the CHP system. In the latter case, the residual heat may be returned to the CHP system.

2.1.9
extraction turbine
turbine in which some of the steam is extracted part-way through the expansion using pressure control means for the extracted steam

Note 1 to entry: The control means are located inside the turbine flow path or in a cross-over line between turbine sections. The target is to provide process steam.

Note 2 to entry: Control of extraction pressure can be internal, external or combined internal/external. For externally controlled extractions the control means are located in the extraction steam line. The aim is to control steam parameters downstream of the control means, i.e. on the process side. In this case the turbine is not called an extraction turbine.

Note 3 to entry: If no means for controlling the pressure are used, this steam line is called a bleed, and the turbine is not called an extraction turbine.

[SOURCE: IEC 60045-1:2020 © IEC 2020]

2.1.10
back pressure turbine
turbine whose exhaust heat typically will be used to provide process heat (e.g. industrial process, district heating, post combustion carbon capture system and desalination), and whose exhaust is not directly connected to a condenser

Note 1 to entry: The exhaust pressure will normally be above atmospheric pressure.

[SOURCE: IEC 60045-1:2020© IEC 2020]

2.2 Abbreviated terms

CHP	combined heat and power
SMB	standardization management board
ORC	organic Rankine cycle
HP	high pressure
IP	intermediate pressure
LP	low pressure
HRSG	heat recovery steam generator

3 Overview of CHP

3.1 What is CHP?

CHP is an energy efficient technology that generates electricity and captures the heat that would otherwise be wasted to provide useful thermal energy - such as steam or hot water - that can be used for space heating, cooling, domestic hot water and industrial processes. A CHP system can be located at an individual facility or building, or be a district energy or utility resource. CHP is typically located at facilities where there is a need for both electricity and thermal energy. (Source: Combined Heat and Power Partnership, EPA)

Nearly two-thirds of the energy produced (or obtained) by conventional electricity generation is wasted in the form of heat discharged to the atmosphere. Additional energy is wasted during the distribution of electricity to end users. In contrast, in a combined heat and power process, the vaporizing heat input happens only once and the sensible heat (condensing heat) is used in the heating process. The total fuel efficiency of this combined process is then much better than the one for separate processes. By capturing and using heat that would otherwise be wasted, and by avoiding distribution losses, CHP can achieve efficiencies even over 80 %.

CHP applications cover a wide range of technology. Smaller heat demands are met by fuel cells, internal combustion engines, Stirling engines and so on. For higher demands solutions gas turbines, back pressure turbines and steam turbines with extractions are in use for CHP.

Its important significance is to improve energy efficiency by changing the production process of equipment, and at the same time enrich the types of products.

Two most typical CHP system configurations are:

- Steam boiler with steam turbine (as shown in Figure 1)
- Combustion turbine, or reciprocating engine, with heat recovery unit (as shown in Figure 2)

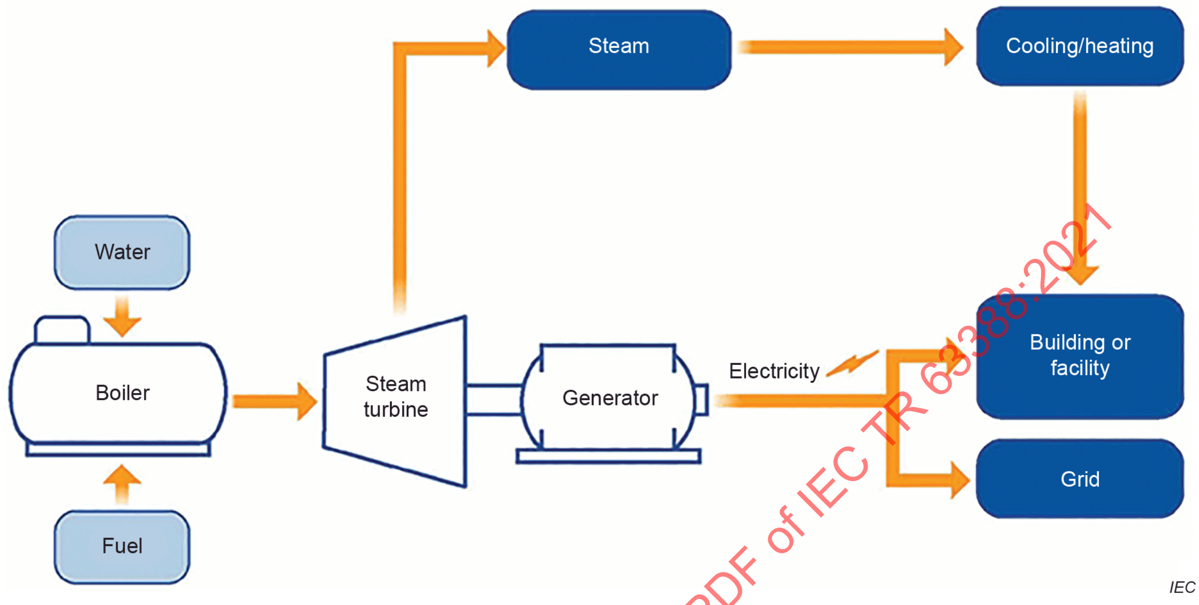


Figure 1 –CHP based on steam turbine

With steam turbines, the process begins by producing steam in a boiler. The steam is then used to turn a turbine to run a generator to produce electricity. The steam leaving the turbine can be used to produce useful thermal energy. These systems can use a variety of fuels, such as natural gas, oil, biomass, and coal.

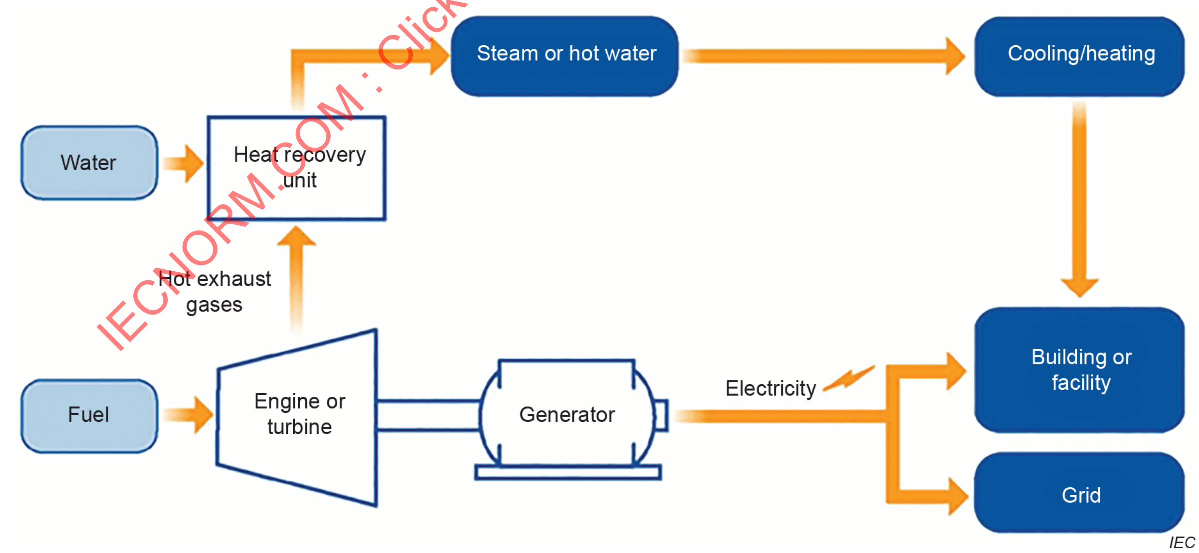


Figure 2 – CHP based on combustion turbine or reciprocating engine

Combustion turbine or reciprocating engine CHP systems burn fuel (natural gas, oil, or biogas) to turn generators to produce electricity and use heat recovery devices to capture the heat from the turbine or engine. This heat is converted into useful thermal energy, usually in the form of steam or hot water.

In this system configuration, the engine or turbine could be named the prime mover. It might be gas turbine, fuel cells, internal combustion engines, Stirling engines, micro turbine and so on.

3.2 Benefits of CHP

Energy conservation and emission reduction is an urgent issue for the whole world. With the growth of the world population and the rapidly increasing consumption of non-renewable energy, energy security and environmental protection are ever more important. The United Nations sustainable development goals (SDGs) include ensuring affordable, reliable and sustainable modern energy for people all over the world. CHP is an effective way to alleviate these problems.

CHP is an efficient and clean approach to generating power and thermal energy from a single fuel source. The average efficiency of fossil-fueled power plants in USA is 33 %, and has remained virtually unchanged for decades. This means that two-thirds of the energy entering the system is lost as waste heat. However, CHP systems typically achieve total system efficiencies of 60 to 80 %. CHP can effectively reduce the condensation heat loss of working fluid in thermal cycle; thus, less fuel is required to produce a given energy output than with the separate production of heat and power. Figure 3 shows an example revealing the extent to which CHP improves energy efficiency. (Source: Combined Heat and Power Partnership, EPA)

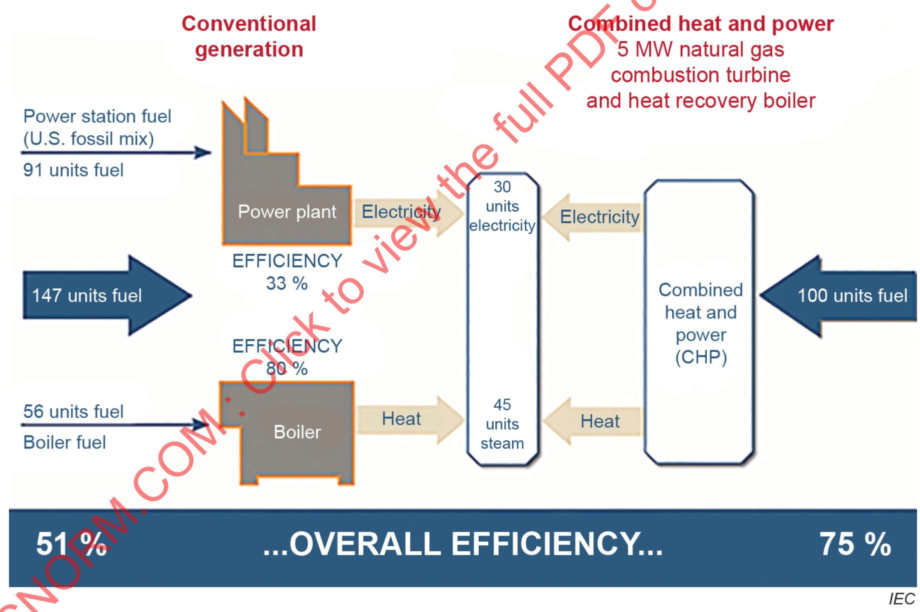


Figure 3 – Example of energy efficiency for different generating systems

NOTE This is just an example quoted from EPA website of America, which aims to illustrate the advantages of CHP system. The efficiency data mentioned in this figure do not necessarily represent the level of other countries.

Whether in developed or developing countries, the direction of energy system development is to effectively meet energy demand on the premise of reducing total energy consumption. At present, CHP has become one of the most important ways to achieve this goal.

Generally speaking, CHP is an optimal way of energy utilization. CHP offers a number of benefits compared to conventional electricity and thermal energy production, including:

- **Efficiency Benefits:** CHP system requires less fuel to produce a given energy output and avoids transmission and distribution losses that occur when electricity travels over power lines.

- **Environmental Benefits:** Because less fuel is burned to produce each unit of energy output, CHP reduces emissions of greenhouse gases and other air pollutants. Because water evaporation is reduced in recirculated water systems, CHP contributes to water conservation.
- **Economic Benefits:** CHP system can save facilities considerable money on their energy bills due to its high efficiency, and it can provide a hedge against electricity cost increases.
- **Reliability Benefits:** CHP system can be designed on-site to support continued operations in the event of a disaster or grid disruption by continuing to provide reliable electricity. It is a beneficial supplement to the traditional power production and is conducive to improving the reliability of energy supply.
- **Flexible operation Benefits:** Small-scale distributed CHP system can be flexibly and nearby configured according to the energy demand. It can supply a variety of different energy, and can meet the requirements of fast start and stop. Therefore, it has the advantage of flexible operation.

3.3 Efficiency of CHP system

CHP application involves the recovery of heat that would otherwise be wasted. In this way, CHP increases fuel-use efficiency.

Two normal measures are provided to quantify the efficiency of a CHP system: total system efficiency and effective electric efficiency.

- Total system efficiency is the measure used to compare the efficiency of a CHP system to that of conventional supplies (the combination of grid-supplied electricity and useful thermal energy produced in a conventional on-site boiler). If the objective is to compare CHP system energy efficiency to the efficiency of a site's conventional supplies, then the total system efficiency measure is likely the right choice.
- Effective electric efficiency is the measure used to compare CHP-generated electricity to electricity generated by power plants, which is how most electricity is produced. If CHP electrical efficiency is needed to compare CHP to conventional electricity production (i.e. grid-supplied electricity), then the effective electric efficiency metric is likely the right choice.

The total system efficiency (η_o) of a CHP system is the sum of the net useful electric output (W_e) and net useful thermal output (ΣQ_{TH}) divided by the total fuel energy input (Q_{FUEL}), as shown below:

$$\eta_o = \frac{W_e + \Sigma Q_{TH}}{Q_{FUEL}}$$

Note that this measure does not differentiate between the value of the electric output and the thermal output; instead, it treats electric output and thermal output as having the same value which allows them to be added.

In reality, electricity is considered a more valuable form of energy because of its unique properties. Therefore, another efficiency calculation method is given.

Effective electric efficiency (ξ_{EE}) can be calculated using the equation below, where W_e is the net useful electric output, ΣQ_{TH} is the sum of the net useful thermal output, Q_{FUEL} is the total fuel energy input, and α equals the efficiency of the conventional technology that would be used to produce the useful thermal energy output if the CHP system did not exist:

$$\xi_{EE} = \frac{We}{Q_{FUEL} - \Sigma(Q_{TH})}$$

For example, if a CHP system is natural gas-fired and produces steam, then α represents the efficiency of a conventional natural gas-fired boiler. Typical boiler efficiencies are 80 % for natural gas-fired boilers, 75 % for biomass-fired boilers, and 83 % for coal-fired boilers.

The calculation of effective electric efficiency is the CHP net electric output divided by the additional fuel the CHP system consumes over and above what would have been used by a boiler to produce the thermal output of the CHP system.

However, none of the proposed efficiency formulations enables a proper evaluation and comparison of the technical level of the equipment in terms of the efficiency of the conversion of thermal energy into electrical energy. If all low-potential heat is preserved and utilized as net useful thermal output, then values of both the proposed efficiencies will be close to 100 %, regardless of the proper efficiency of the conversion of thermal energy into electricity.

Therefore, as a compromise, other definition of thermal efficiency is needed, such as the definition adopted by PURPA ("Public Utility Regulatory Policy Act" approved by the US Congress in 1979). It formally attributes the heat produced only by one-half and thus takes into account the lower quality of the supplied head compared to the electricity – both in terms of energy and price (value).

$$\eta_{PURPA} = \frac{W_e + \frac{1}{2} \cdot \Sigma Q_{TH}}{Q_{FUEF}}$$

From a global perspective, there is a need for development of a standardized set of formulas valid for all types of CHP schemes – process, district heating, process heating, cold or warm heating, etc. – and for all kind of power generating systems which are present. That set shall enable a comparison, evaluation and verification of the performances between all the different applications.

4 Market situation of cogeneration

4.1 Global situation

In 2016, the total installed capacity of global CHP reached 755 GW. Among them, 46 % are installed in the Asia-Pacific region(mainly in China and Japan), 39 % are installed in Europe(mainly in Russia), and 15 % are installed in the Middle East, Africa and other regions (mainly in North and South Africa). By 2025, the global CHP capacity is expected to increase to 972 GW (an average annual growth of 2,8 %). Europe is the traditional market of CHP, and Asia-Pacific is the main growth market of CHP.

4.2 European situation

In June 2018, Cogen Europe published a report entitled "The role of cogeneration in Europe's future energy system", which introduced the development blueprint of European cogeneration to 2050. Cogeneration currently provides 11 % of electricity and 15 % of heat for Europe, contributing to the EU's 21 % CO_2 emission reduction target and 14 % energy efficiency target. By 2030, CHP will provide 20 % of electricity and 25 % of heat energy for Europe, and at least one third of CHP will come from renewable energy, which will contribute to the EU's 23 % CO_2 emission reduction target and 18 % energy efficiency target. By 2050, the European Union is expected to double the proportion of cogeneration in the overall power generation, and make the cogeneration industry the top priority in energy development.

The EU's development of CHP focuses on the application of renewable energy and small-scale distributed energy system to meet decentralized user needs, while achieving the best economic efficiency and energy efficiency. The share of renewable energy in CHP in EU has increased from 15 % in 2010 to 21 % in 2015, and the main fuel used is natural gas (44 % of CHP fuels in 2015).

Russia has rich experience in CHP. As early as in the age of Soviet Union, CHP was widely used. At that time, a large number of CHP units were installed in cities and large industrial centres to achieve economic heating in cold weather. Today, in Russia, CHP power plants still account for more than one-third of domestic electricity production, and nearly one-half of heating production.

Compared with thermal power plants, a distributed energy system is easier to realize flexible operation. According to the experience of some European countries, many small distributed units can be used to replace large CHP units and make them closer to energy users, so as to improve the energy efficiency. At present, the distributed CHP system is very popular in some European countries.

4.3 American situation

According to the statistics of the US Department of energy, by the end of 2018, the total installed capacity of cogeneration in the United States was 81,09 million KW, accounting for 19,43 % of the total power generation. From 2000 to 2018, the scale of cogeneration in the United States increased by 57,37 %, the installed capacity increased from 51,53 million kW to 81,09 million KW, and the number of power stations reached 5 637. Among them, the installed capacity of CHP with natural gas as raw material reached 58,0 389 million KW, accounting for 71,57 % of the total installed capacity of CHP; natural gas projects account for 68,38 % of the total quantity of cogeneration.

4.4 Asian situation

In the Asian region, China and Japan have the biggest CHP markets.

China has a huge quantity of CHP cases, and its technology development and application are very representative.

Figure 4 shows the proportion of different heating modes in urban areas of northern China. Coal-fired CHP accounts for 45 % of the heating area. Coal-fired boilers account for 32 %. Gas-fired boilers account for 11 %. Gas wall-mounted furnaces account for 4 %. Gas-fired CHP accounts for 3 %. In addition, there are electric boilers, various types of electric heat pumps (air source, ground source, and sewage source), fuel oil, solar energy, biomass and other forms of heat sources, a total of 5 %. (Source: Current Situation of Clean Heating in Winter in Northern Cities and Towns of China, by Liu Rong)

Further expansion of CHP will be one of the most important measures to alleviate haze weather in northern China.

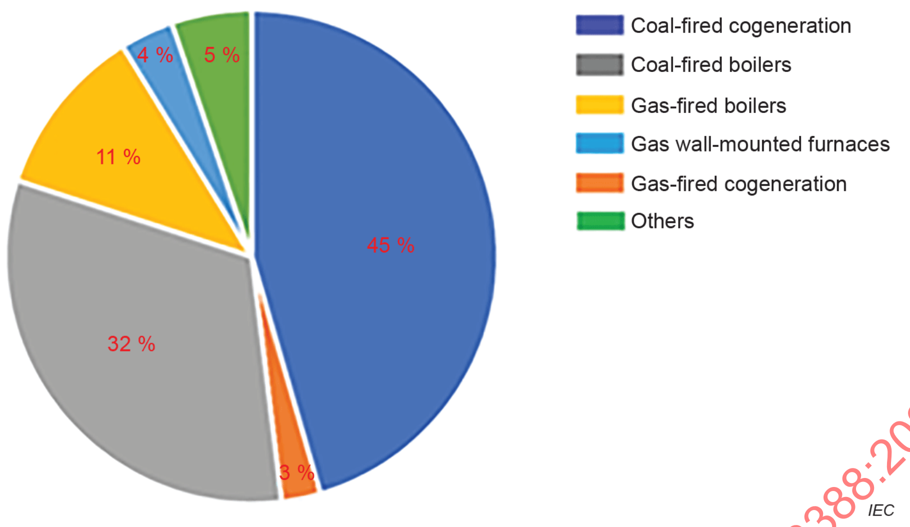


Figure 4 – Proportion of different heating modes in urban areas of northern China

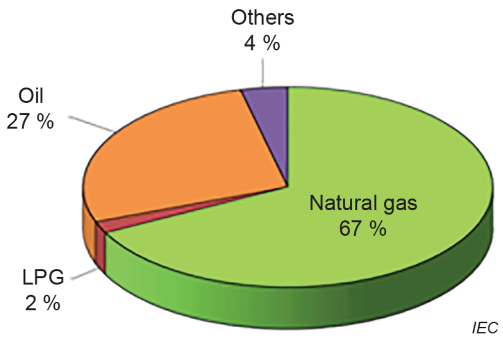
In addition to district heating, there is also a large demand for industrial heat supply. Industrial production, including chemical industry, papermaking, pharmaceuticals, textiles and non-ferrous metal smelting, requires the use of a large amount of high-temperature steam. At present, some large industrial enterprises supply steam by their own thermal power plants, and many enterprises supply steam by boilers. This leads to a very low efficiency of energy use.

Due to the requirements of environmental protection, industrial small boilers with high energy consumption and heavy pollution will be shut down gradually. In the future, industrial parks will be encouraged to concentrate industrial users, while CHP units with high efficiency and qualified emissions will be responsible for industrial heat supply. This will become the mainstream in China.

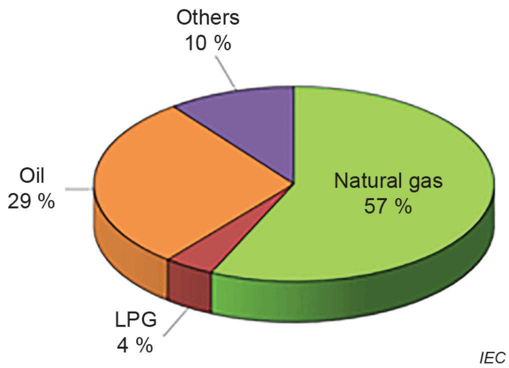
Unlike China, which relies mainly on coal, Japan has built a lot of cogeneration units with fuel of natural gas and oil. Table 1 shows the installed capacity of cogeneration units in Japan as of March 2020. It is classified according to the fuel. Figure 5 shows the percentage of installed capacity of different cogeneration units by fuel types. (Source: Advanced Cogeneration and Energy Utilization Center JAPAN)

Table 1 – Installed capacity of cogeneration units in Japan as of March 2020

Fuel Types	Commercial(MW)	Industrial(MW)	Total(MW)
Natural Gas	1 799	5 852	7 651
LPG	51	418	469
Oil	719	2 973	3 693
Others	99	1 063	1 162
Total	2 669	10 306	12 975



a) Commercial



b) Industrial

Figure 5 – Cogeneration status in Japan by fuel types

In the wake of the 2011 Tohoku earthquake and tsunami, cogeneration systems are attracting growing interest not only as means of saving energy and reducing carbon dioxide emissions, but also as distributed energy resources that can help prevent and mitigate disasters. Reflecting these rising expectations, in FY2015 the Japanese government announced a target of raising cogeneration capacity to 119 billion kilowatt-hours and the number of ENE-FARM residential fuel cell units installed to 5,3 million.

4.5 Summary

It is obvious that the global CHP market is very large and has great development potential. Most countries are vigorously promoting the application of CHP. Depending on the differences in energy structure and energy cost from country to country, different strategies in the development and application of CHP technologies are determined.

5 CHP based on steam turbine

5.1 General introduction

A steam turbine is one of the most versatile and oldest prime movers still in general production used to drive a generator or mechanical machinery. Unlike gas turbine and reciprocating engine CHP systems, a steam turbine is captive to a separate heat source and does not directly convert fuel to electric energy. The energy is transferred from the boiler to the turbine through high pressure steam that powers the turbine and generator.

The thermodynamic cycle for the steam turbine is known as the Rankine cycle. This cycle 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 elevated pressure, which is medium to high pressure, depending on the size of the unit and the temperature to which the steam is eventually heated. It is then heated to the boiling temperature corresponding to the pressure, boiled (heated from liquid to vapour), and then most frequently superheated (heated to a temperature above that of boiling). The pressurized steam is expanded to lower pressure in the turbine, then enters either to the condenser, or to an intermediate temperature steam distribution system that delivers the steam to the industrial or commercial application. The condensate from the condenser or from the industrial steam utilization system is returned to the feed water pump for continuation of the cycle.

In this report, cogeneration is divided into steam turbine cogeneration and non-steam turbine cogeneration. CHP based on steam turbine is mainly applied in thermal power stations.

For thermal power stations, their heat users mainly include industrial users and district heating users. Different users have different demands for heating steam parameters, which leads to the development of a variety of technical solutions.

The following cases are some of the most typical CHP methods based on steam turbine.

5.2 Technical characteristics

5.2.1 CHP based on extraction turbine

Extraction turbine is a kind of steam turbine in which some of the steam is extracted part-way through the expansion using internal pressure control means for the extracted steam.

An extraction turbine can be divided into high pressure section and low pressure section, which is equivalent to a combination of a back pressure turbine and a condensing turbine. The live steam works in the high-pressure section and then is divided into two parts after expanding to a certain pressure. One part is extracted out for heat users, the other part continues to work in the low-pressure section, and finally is discharged into the condenser.

For a new steam turbine under design, the extraction port can be reasonably designed according to the thermal parameters of itself. But for the retrofit cases, the choice of extraction port should consider many factors such as retrofit convenience and extraction capacity.

Figure 6 is an example of heating system based on extraction steam turbine. The extraction port is on the LP cylinder inlet pipe. In order to improve the capacity and stability of heat supply, butterfly valves are usually used for regulation. In order to ensure the safety and reliability of heat supply, safety valves, check valves, regulating valves, globe valves are usually installed on the heating extraction pipeline.

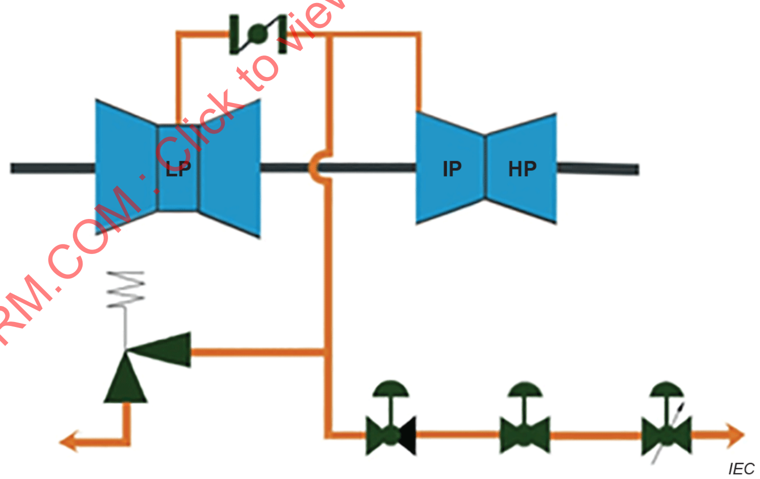


Figure 6 – Heating system based on extraction steam turbine

5.2.2 CHP based on back pressure turbine

A steam turbine, of which exhaust pressure is higher than atmospheric pressure, is categorized as back pressure turbine. The exhaust steam of back pressure turbine is usually used for heating or steam supply. Therefore, the design of exhaust parameters shall be based on the demand of users. Unlike pure condensing turbines, back pressure steam turbine doesn't have condenser, so its exhaust steam is entirely used for heating. The operating conditions of such back pressure turbines are entirely determined by the heating load.

Compared with condensing turbines with low exhaust pressure, back pressure turbines have higher exhaust pressure and smaller enthalpy drop of steam, so the steam required per unit power of back pressure steam turbines is larger than that of condensing turbines. However, all of the heat contained in the exhaust steam of back pressure turbine is used for heating, and there is no energy loss in the cold end. Therefore, the thermal efficiency of backpressure turbine is higher than that of condensing turbine in terms of utilization efficiency of fuel. Figure 7 is a typical back pressure turbine heating system.

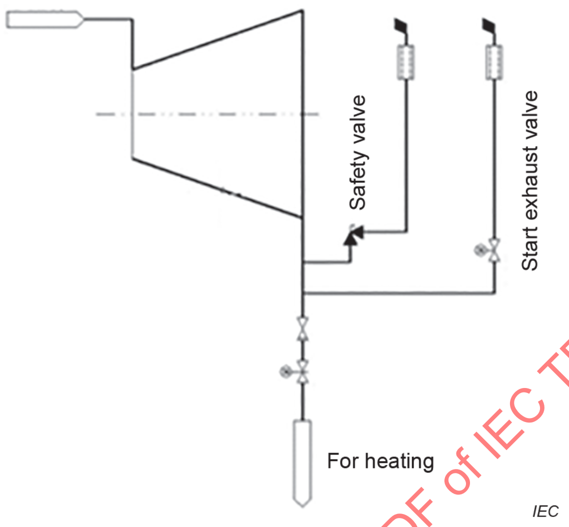


Figure 7 – Back pressure turbine heating system

A back pressure unit for CHP is simple in structure and does not need a condenser. Its energy utilization efficiency is very high. The disadvantage is that the heat and electricity produced by a back pressure unit cannot be regulated independently. Generally, the operating conditions of the unit are adjusted according to the heating load, that is to say, free heating load and forced electric power are formed. When the heating load of the unit changes, the electric power fluctuates sharply.

5.2.3 Low-vacuum heating mode

Low-vacuum heating is a kind of heating method in which the vacuum of a condensing turbine is reduced and the outlet temperature of circulating water is heightened. In this heating mode, the condenser becomes the first-stage heat exchanger of the heating system, which fully utilizes the latent heat of vaporization of the unit to heat the circulating water of the heating network, and the cold end loss of the unit can be reduced to zero, significantly improving the thermal efficiency of unit. This heating method can also increases the heating capacity of a unit by recovering the exhaust heat of steam turbine. Figure 8 is a typical diagram of a low-vacuum heating system. The low-vacuum heating method is also suitable for air cooling units.

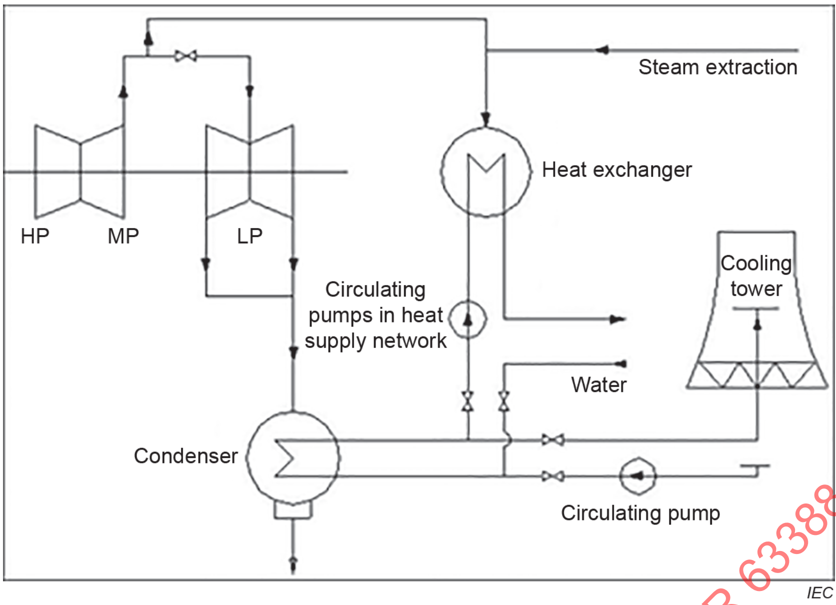


Figure 8 – Typical diagram of a low-vacuum heating system

In order to guarantee safe operation of steam turbine with low-vacuum, some technical measures should be taken. For example, two different LP rotors interchange method is widely adopted. During the heating season, the steam turbine uses a specially manufactured LP rotor for low-vacuum heating operation. Condenser circulating cooling system becomes a part of the district heating system. The original circulating cooling water system is out of operation. Circulating water from the heat network enters the condenser and absorbs waste heat of the steam turbine exhaust. In this period, the unit will operate with exhaust pressure mainly at 30 to 50 kPa. When the heating season is over, the original LP rotor is reassembled. The LP cylinder is restored to the original design style for pure condensing operation. The condenser circulating water is switched to the original cycle. In this period, the unit will operate with exhaust pressure mainly at 5 to 11 kPa. In order to meet the safety operation of low vacuum heating, it is necessary to check the safety of the condenser. If necessary, the condenser water chamber should be strengthened and reformed, and thermal compensation measures should be added to the cooling water pipe. In addition, at the end of the heating season, the cooling water pipes need to be washed and descaled.

Furthermore, a heat pump can be also used to extract waste heat of low-vacuum unit. In this heating system, the heat pump, not the condenser, becomes the first-stage heat exchanger of the heating system. The exhaust pressure of the unit does not need to be maintained above 30 kPa, but generally only needs to reach 8 to 15 kPa.

The low-vacuum heating mode is very efficient. It can fully exploit the heat supply potential of thermal power units. Therefore this method is widely used for district heating in China at present.

5.2.4 LP cylinder steam bypassed heating mode

Under the high vacuum operation condition of the low pressure cylinder, the original steam inlet pipe of the low pressure cylinder is shut off, and almost all of the medium pressure cylinder exhaust steam is used for heating. At the same time, a small amount of cooling steam is introduced into the low pressure cylinder through the newly added bypass pipe for cooling. It will take away windage heat generated by the rotation of the low-pressure rotor. This is a kind of low pressure cylinder steam bypass heating technology. This technology can improve the heating capacity as well as peaking capacity of the units. It is also good for the promotion of energy efficiency and reduction of coal consumption. For different types of units, this technology can increase the peaking capacity by around 15 to 30 %, achieve the peaking operation with 25 % of the rated load, and increase the heating capacity by around 20 to 40 %. Generally speaking, this technology can reduce coal consumption by more than 30 g/kWh compared to the traditional extraction turbine. The schematic of low pressure cylinder steam bypass heating technology is shown in Figure 9.

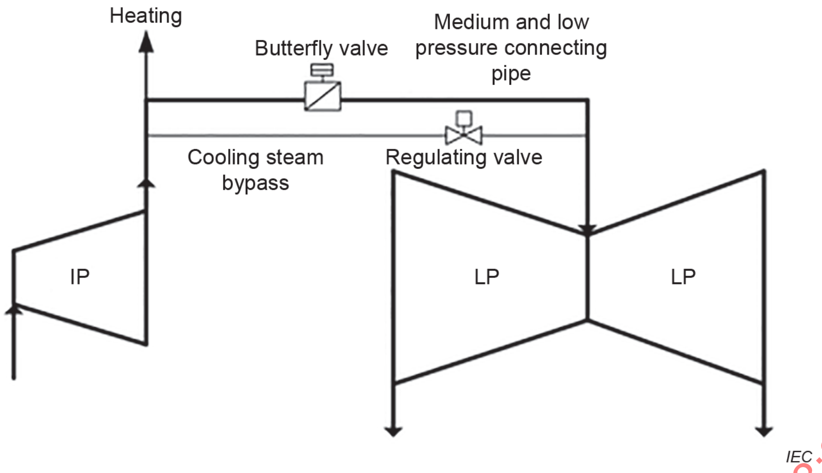


Figure 9 –Schematic of LP cylinder steam bypass heating technology

Different from the traditional extraction heating mode, LP cylinder steam bypassed heating mode can use almost all of the IP cylinder exhaust steam for heating, which greatly reduces cold-end loss.

The LP cylinder steam bypassed heating technology has great application in Denmark and Russia, and is completely applied to new-designed units that undertake large heating loads. In China, this technology is widely used in retrofit projects, mainly for CHP units with deep peaking requirements. The technology can greatly improve heating capacity as well as peaking capacity of the CHP units.

This scheme can be used for district heating as well as low parameter industrial heat supply.

5.2.5 CHP based on steam turbine with synchro-self-shift clutch

In order to take into account both the heating capacity during heating season and power generation efficiency in the rest time, steam turbines with ansynchro-self-shift clutch are developed for those CHP plants with a large heating load. They can flexibly switch between condensing operation, extraction condensing operation and back-pressure heating operation. During the heating season, when the heating demand is relatively small, the extraction condensing operation should be adopted. When the heating demand is large enough, the inlet steam into the low pressure cylinder can be cut off and the unit converts into a back-pressure heating operation. All of the IP cylinder exhaust steam will be introduced into an exchanger for heating and the LP cylinder will be out of operation. During the non-heating season, the unit switches to pure condensing operation, and the LP cylinder exhaust enters into the condenser.

This technology is suitable only for new-designed units. It needs to be specially designed and arranged. A steam turbine with a synchro-self-shift clutch can adopt a single-axis arrangement, in which the generator is arranged at the front side of the HP cylinder. The synchro-self-shift clutch shall be designed between the HP rotor and the LP rotor to realize the operation and removal of the LP cylinder. Synchro-self-shift clutch is the key to cut off the LP cylinder. Therefore, the synchro-self-shift clutch must have high reliability.

Steam turbines with a synchro-self-shift clutch can be used not only in common coal-fired units, but also in gas-steam combined cycle units. Figure 10 shows a heating turbine with an synchro-self-shift clutch in a gas-steam combined cycle unit.

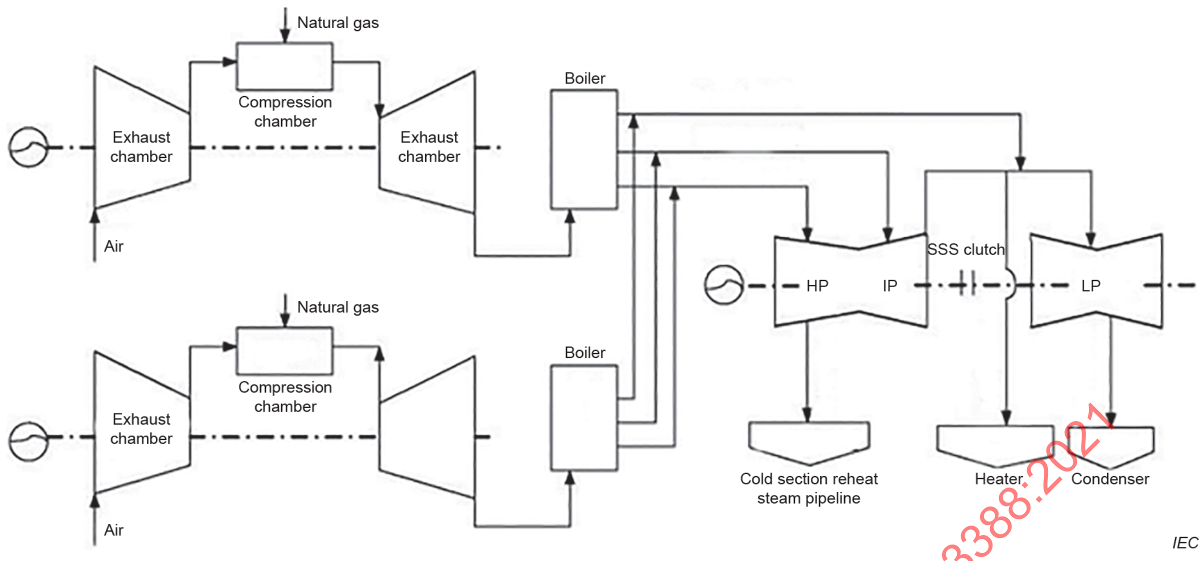


Figure 10 – Heating turbine with synchro-self-shift clutch

This scheme can be used for district heating as well as low parameter industrial heat supply.

5.2.6 Special case: gas-steam combined cycle CHP

A gas turbine engine is an internal combustion engine. Fundamentally speaking, the engine can be regarded as an energy conversion device, that is, the energy stored in the fuel is converted into useful mechanical energy in the form of rotating power.

Gas turbines have been in use for stationary electric power generation since the late 1930s. For general gas turbines, the residual heat of flue gas is of great quantity. The energy efficiency of pure power generation for gas turbines is not high. Basically, the residual heat of flue gas needs to be recovered by an HRSG (heat recovery steam generator). Thus the gas-steam combined cycle is formed.

For CHP of gas-steam combined cycle units, heating steam is generally extracted from a steam turbine in the bottom cycle. There are also some cases where residual heat is extracted for heating from HRSG directly.

From the technical point of view, there is no essential difference between the CHP technology of gas-steam combined cycle units and that of conventional coal-fired units. The CHP technologies of conventional coal-fired units can also be applied in gas-steam combined cycle units.

Figure 11 is a schematic diagram of combined cycle unit cogeneration. Heat could be extracted either from an HRSG or from a steam turbine.

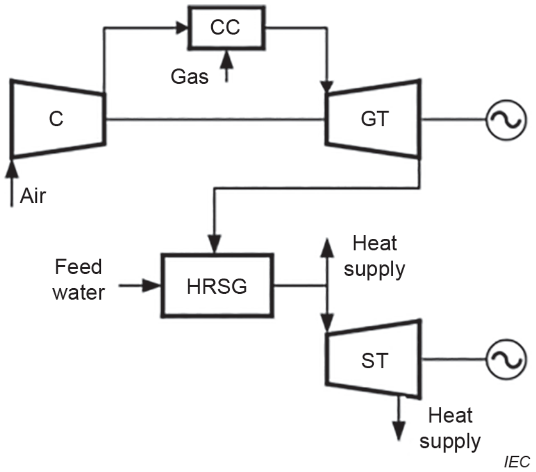


Figure 11 – Schematic diagram of combined cycle unit cogeneration

It should be noted that the waste heat of boiler flue gas can also be recycled for heating in an ordinary Rankine cycle, so as to realize energy saving. This is also one kind of cogeneration.

5.3 Components

For the CHP system based on a steam turbine, its typical work flow (as shown in Figure 12) generally includes:

- Fuel is burned in the boiler;
- Steam is generated by the boiler;
- Steam drives the steam turbine;
- Steam turbine drives generator and produce power;
- Steam is extracted from the steam turbine for heating or steam supply;
- Exhaust steam enters the condenser and condenses into water (note: back pressure turbine does not need condenser);
- Condensate or make-up water is boosted by pump and enters the boiler.

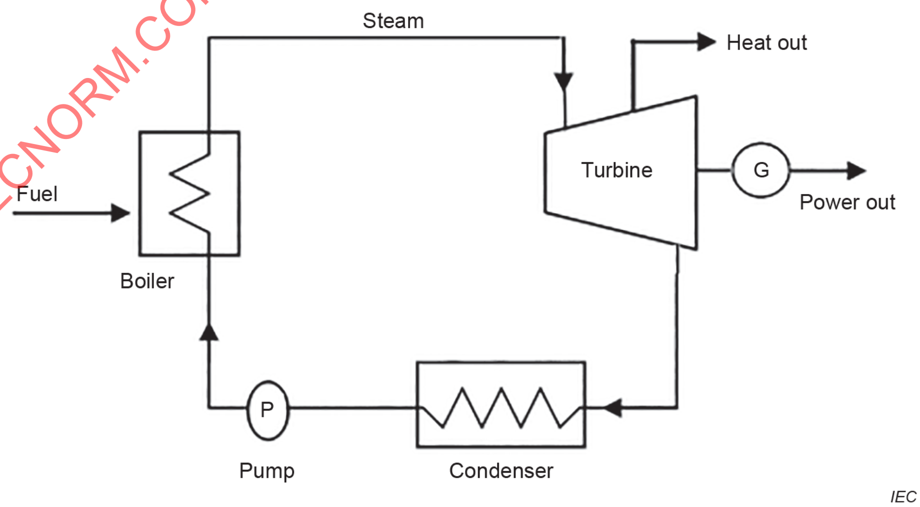


Figure 12 – Typical work flow of CHP system based on steam turbine

As can be seen from Figure 12, the main components of a CHP system based on steam turbine generally include boiler, steam turbine, generator, condenser and pump. However for a gas-steam combined cycle CHP system, there is a gas turbine in addition.

1) Boiler

Steam turbines differ from reciprocating engines, internal combustion engines, and gas turbines in that the fuel is burned in a piece of equipment, the boiler, which is separate from the power generation equipment. The energy is transferred from the boiler to the steam turbine generator by an intermediate medium, typically steam under pressure. This separation of functions enables the unit to operate with an enormous variety of fuels.

In addition to the common boiler, there is an HRSG. This kind of boiler is basically used in gas-steam combined cycle unit, and the HRSG and steam turbine are adopted in the bottom cycle.

Generally speaking, the boiler is an energy conversion equipment. It is one of the core equipment of the thermal power unit.

2) Steam turbine

A steam turbine is a kind of rotating machinery which obtains energy from high temperature and high pressure steam and converts it into mechanical energy. In the steam turbine, the steam is expanded to a lower pressure providing shaft power to drive a generator or run a mechanical process. According to different application scenarios, steam turbine can be designed as pure condensing type, extraction condensing type, back pressure type, etc.

The design speed of steam turbine is usually very high, which is helpful to reduce the cost of per unit of the capacity. The operating speed of steam turbine can be designed either as a constant value or as a variable value within a certain range.

A disadvantage of a typical condensing turbine is the huge cold end loss. This leads to the low efficiency of pure condensing thermal power unit. In order to improve the energy efficiency of the unit, some regenerative and reheating measures are usually adopted. In addition, cogeneration can be of a great help to solve this problem.

A steam turbine is one of the core equipment of thermal power unit. It is also the most important component of a CHP system based on steam turbine.

3) Generator

A generator is a kind of rotating machinery which converts mechanical energy into electrical energy. It is widely used in large power generation systems. It is one of the core equipments of the thermal power unit.

4) Condenser

A condenser is a specially designed heat exchanger. It condenses turbine exhaust steam into water through circulating cooling water. It is an essential auxiliary equipment for the condensing turbine.

5) Pump

Pumps are widely used in thermal power units. It is mainly used to pressurize condensate. However it is not a component to be focused on in this document.

6) Gas turbine

A gas turbine engine is an internal combustion engine. The working process of the gas turbine is as follows. The air is first drawn into the engine, compressed in the engine, mixed with the fuel and ignited. The resulting hot gas expands at high speed through a series of wing shaped blades, which transfers the energy generated by combustion to the output shaft to make it rotate. The residual heat in the hot exhaust can be used in many industrial processes.

A gas turbine is a widely used prime mover besides the steam turbine.

5.4 Requirements

For different kinds of steam turbines, there might be different technical requirements.

1) CHP based on extraction turbine

For this kind of CHP mode, in order to ensure safe and efficient operation, the following items need to be addressed:

- The extraction flow and extraction pressure control under different operating conditions;
- The minimum cooling flow of the LP cylinder;
- The reliability of the regulating butterfly valve and other regulating devices;
- The economic evaluation under different operating conditions; and
- The performance evaluation and acceptance of the heating system.

2) CHP based on back pressure turbine

For this kind of CHP mode, in order to ensure safe and efficient operation, the following items need to be addressed:

- The exhaust flow and exhaust pressure control under different operating conditions;
- The accident prevention measures for heating load rejection;
- The economic evaluation under different operating conditions; and
- The performance evaluation and acceptance of the steam supply system.

3) Low-vacuum heating mode

For this kind of CHP mode, in order to ensure safe and efficient operation, the following items need to be addressed:

- The exhaust flow and exhaust pressure control under different operating conditions;
- Transformation requirements for auxiliary equipment such as feed pump turbine and shaft seal heater (only for retrofit cases);
- The accident prevention measures for heating load rejection;
- The circulating water quality demand;
- The end difference control of condenser(Such as: ensure the cleanliness of cooling pipes, control of condenser circulating water temperature difference, etc.);
- The economic evaluation under different operating conditions; and
- The performance evaluation and acceptance of the heating system.

4) LP cylinder steam bypassed heating technology

When this method is applied in the new-designed units, it is necessary to improve the strength of the LP cylinder. Relatively short blades are recommended for the last stage in the LP cylinder.

When this method is adopted in retrofit project, the following works are generally required:

- Retrofit of LP cylinder inlet pipe;
- Adding cooling steam bypass pipe for LP cylinder;
- Retrofit of water-jet cooling system in LP cylinder;
- Safety check of blades in LP cylinder;
- Retrofit of DCS.

For this kind of CHP mode, in order to ensure safe and efficient operation, the following items need to be addressed:

- The extraction flow and extraction pressure control under different operating conditions;
- Safety monitoring of LP cylinder;
- The economic evaluation under different operating conditions; and
- The performance evaluation and acceptance of the heating system.

5) CHP based on steam turbine with synchro-self-shift clutch

For this kind of CHP mode, in order to ensure safe and efficient operation, the following items need to be addressed:

– The extraction flow and extraction pressure control under different operating conditions;
– Reliability requirements of synchro-self-shift clutch;
– The economic evaluation under different operating conditions; and
– The performance evaluation and acceptance of the heating system.

6) Gas-steam combined cycle CHP

For this kind of CHP mode, in order to ensure safe and efficient operation, the following items need to be addressed:

– The extraction flow and extraction pressure control under different operating conditions;
– The minimum cooling flow of the LP cylinder;
– The reliability of the regulating butterfly valve and other regulating devices;
– The economic evaluation under different operating conditions;
– The performance evaluation and acceptance of the heating system; and
– Other requirements related to gas turbine.

5.5 Summary

In this clause CHP methods based on steam turbine have been introduced. No matter what kind of method, the steam turbine is the core component that is the main subject of this clause.

Steam turbines used in the CHP system will significantly change the operating conditions compared to being used solely for the process of generating electricity. They also have a great impact on safety and efficiency. However, the operation mode of boiler, gas turbine and related auxiliary equipment hardly changes. They only need to adjust their output according to the operation conditions.

As a result, through the detailed analysis of this clause, we can see that as a prime mover, steam turbines used in the CHP system could involve several components and have a lot of special requirements.

Generally, steam turbine extraction capacity, extraction safety, calculation of heating operation economy, performance evaluation and acceptance of heating equipment and systems are the basis to ensure the effective application of large-scale CHP schemes.

6 CHP based on other processes

6.1 General

Besides CHP based on steam turbine, there are also other prime movers used in CHP, such as micro gas turbines, Stirling engines, fuel cells, ORC, internal combustion engines, etc. They are generally used in relatively small-scale and distributed CHP systems.

For some scattered, remote users, or disaster areas, distributed CHP systems are more effective. These CHP systems can be arranged close to the user, which greatly reduces the energy transmission cost. The fast start and stop characteristics also make them more flexible and reliable. Therefore, these distributed CHP methods are an important supplement to large-scale CHP based on steam turbine and gas turbine, and also an important development direction of energy system in the future. The main features of a distributed CHP system are as follows.

- It can meet the needs of various occasions for users in remote areas where the power grid is not suitable or distributed.

- It can make up for the inadequacy of power grid stability in safety aspects.
- It provides the possibility for the comprehensive cascade utilization of energy.
- It can reduce investment risk and operating cost.
- It shows good energy saving and environmental protection performance.
- It provides a new direction for the utilization of renewable energy.

For example, CHP is widely used to supply power and heat energy for hospitals. CHP is a superior energy resource for hospitals because it can provide all of a hospital's energy services efficiently and indefinitely during grid outages. For hospitals, losing electricity - even for short periods - can disrupt critical life support systems. When the power goes out, lives may be at risk. And with weather-related events becoming more frequent and severe, grid outages are becoming more common. CHP, an onsite generation resource, can enable hospitals to continue to provide all services during grid outages. In addition to providing reliable energy and making hospitals more resilient, CHP can help hospitals reduce costs and meet their sustainability and emissions reduction goals. Figure 13 shows the energy efficiency comparison between small-scale CHP system and traditional energy services in American hospitals. (Source: CHP for Hospitals, EPA)

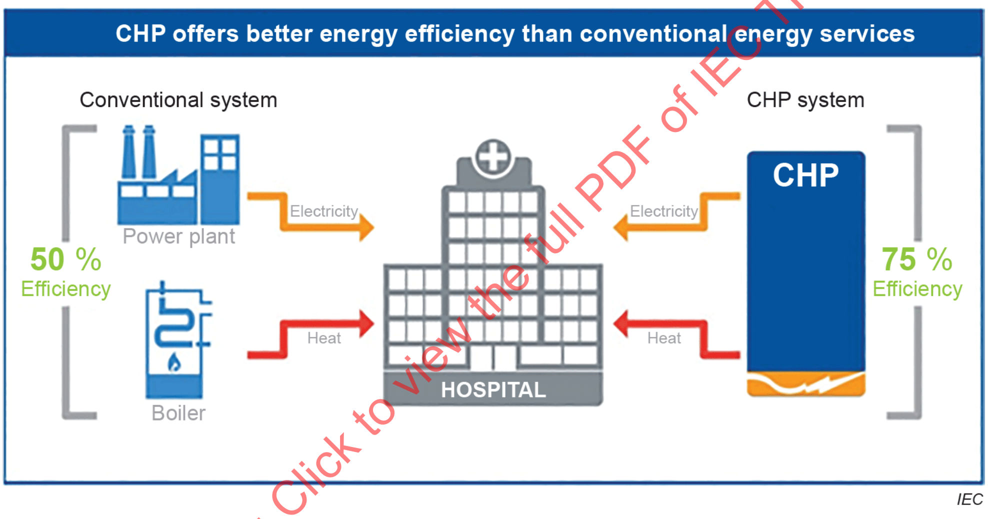


Figure 13 – Energy efficiency comparison between small-scale CHP system and traditional energy services

6.2 Technical characteristics

6.2.1 Gas turbine CHP

Gas turbine is characterized by high efficiency, low noise, low emission and low vibration. In addition to distributed generation, it can also be used for standby power plants, CHP, etc. It can be applied to the central city, the rural areas and even the remote areas. According to the technical requirements, different types of gas turbines can be adopted, such as micro gas turbines, STIG cycle gas turbines, etc.

The micro gas turbine has a simple structure, and its working principle is shown in Figure 14. Generally, radial turbo machinery and a single-stage centrifugal compressor are adopted. The pressure ratio is generally 3 to 5, and the rotating speed is up to 50 000 to 120 000 r/min. Generally, air bearing is used, and a lubricating oil system is not required, so the unit size is significantly reduced.

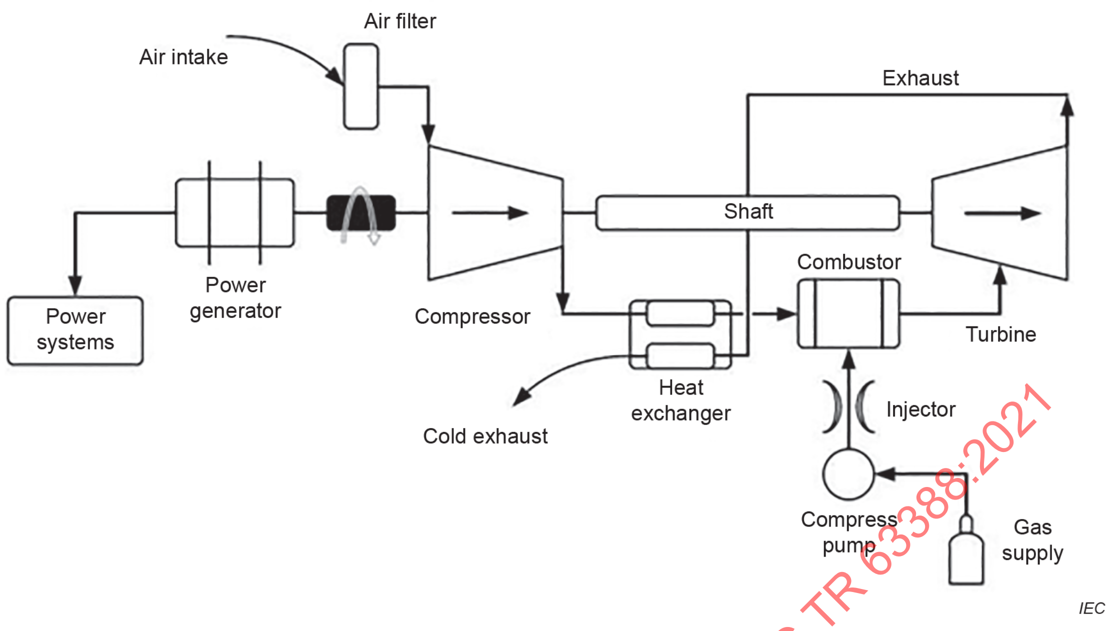


Figure 14 – CHP system based on micro gas turbine

In addition to the common micro gas turbine, a STIG (steam-injected gas turbine) cycle gas turbine can also be used for CHP. Figure 15 is a sketch map of a CHP system based on STIG.

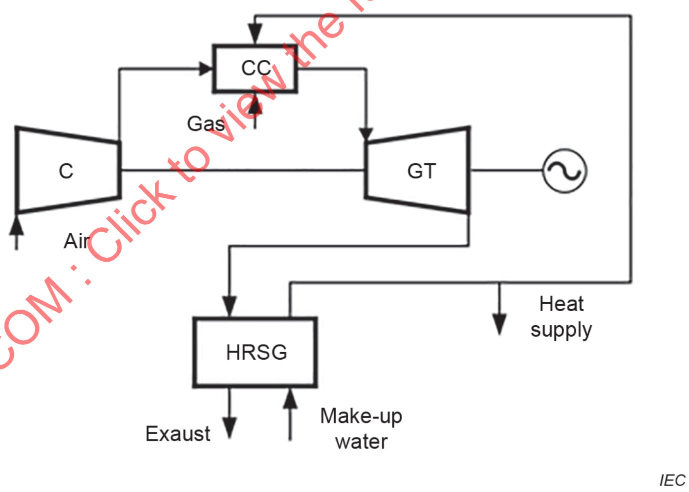


Figure 15 –CHP system based on STIG

6.2.2 Stirling engine CHP

A Stirling engine is a kind of external combustion, closed cycle thermal engine, which is different from an internal combustion engine. It is mainly composed of a compression chamber, expansion chamber, heater, cooler and regenerator. The working medium can be helium, hydrogen, nitrogen, etc. Through the mutual movement of the two pistons, the working medium is compressed isothermally in the cold chamber. The fuel is continuously and stably combusted in the combustion chamber outside the cylinder and transmitted to the working medium through the heater. The working medium does not participate in the combustion and does not need to be replaced. The piston is driven to move and drive the generator to generate electricity. The ideal thermodynamic cycle of the engine consists of two constant temperature processes and two constant volume processes.

At present, a Stirling engine mainly uses natural gas as fuel. Figure 16 shows the process flow of a typical Stirling engine CHP unit. Natural gas and air are mixed in the burner to produce high temperature flue gas. The high-temperature flue gas first heats the high-temperature chamber of the Stirling engine, and then enters the heater and exchanges heat with cold water to become low-temperature flue gas, which is discharged from the engine. The working medium circulates between the high temperature hot chamber and the low temperature cold chamber, and expands and drives the transmission mechanism to drive the generator to generate electricity. At the same time, the cooling water flowing through the low-temperature cold chamber heat exchanger is heated and then enters the hot water tank, which centrally outputs hot water to the user. The whole device outputs electric energy and thermal energy at the same time, achieving the purpose of CHP.

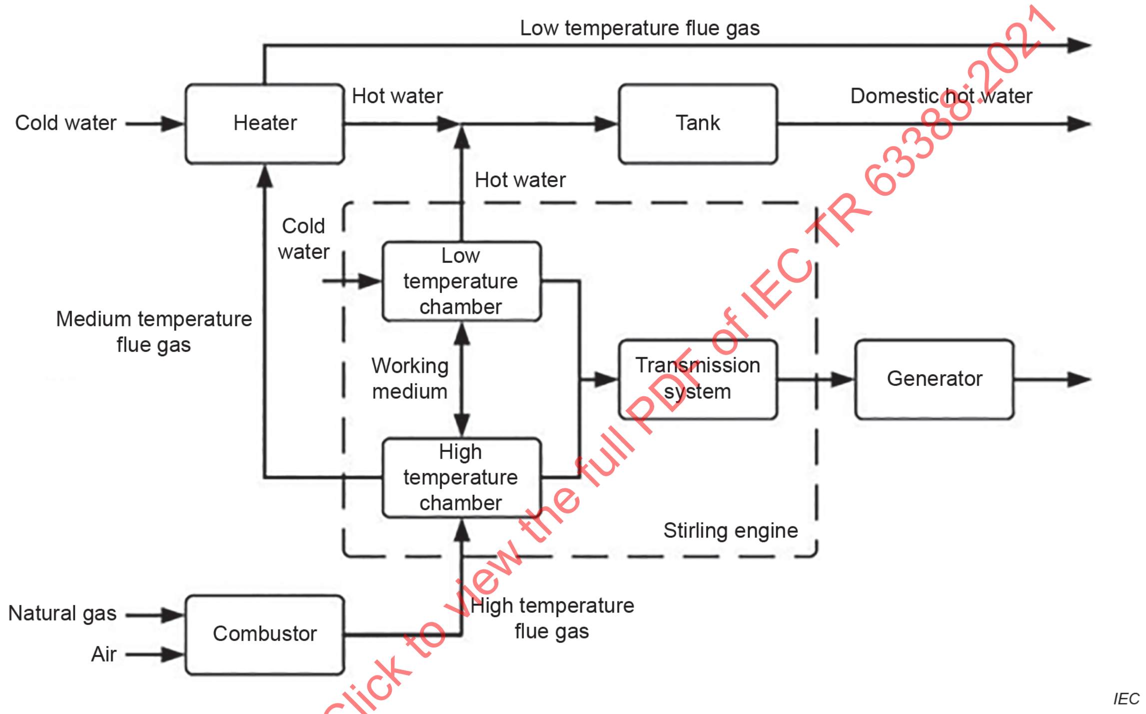


Figure 16 – Typical Stirling engine CHP unit process

6.2.3 Fuel cell CHP

A fuel cell is a chemical device that converts the chemical energy of fuel directly into electric energy, also known as an electrochemical generator. Fuel cells use fuel and oxygen as raw materials, there are no mechanical transmission components, so there is no noise pollution. From the point of view of protecting the ecological environment, the fuel cell is one of the most promising power generation technologies.

For a CHP system with fuel cell as the prime mover, the total thermal and power efficiency is more than 85 % and the power generation efficiency of fuel cell is relatively stable under different loads. Therefore, fuel cell CHP technology is a potential new energy utilization technology.

According to the different electrolyte materials, it can be divided into five categories: alkaline fuel cell (AFC), proton exchange membrane fuel cell (PEMFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC),and solid oxide fuel cell (SOFC). Among those available technologies, PEMFC is currently applied in the field of CHP.

With the integration of a natural gas hydrogen plant and PEMFC, CHP technology for power generation and heating is realized, as shown in Figure 17, the cascade utilization of energy is realized and the efficiency of energy utilization is improved. Today, with the increasing of energy consumption, this technology is an effective way to realize the power supply as well as heating for household and small commercial users, and to alleviate the energy shortage. It not only broadens the field of natural gas utilization, but also meets the overall requirements of energy saving and environmental protection.

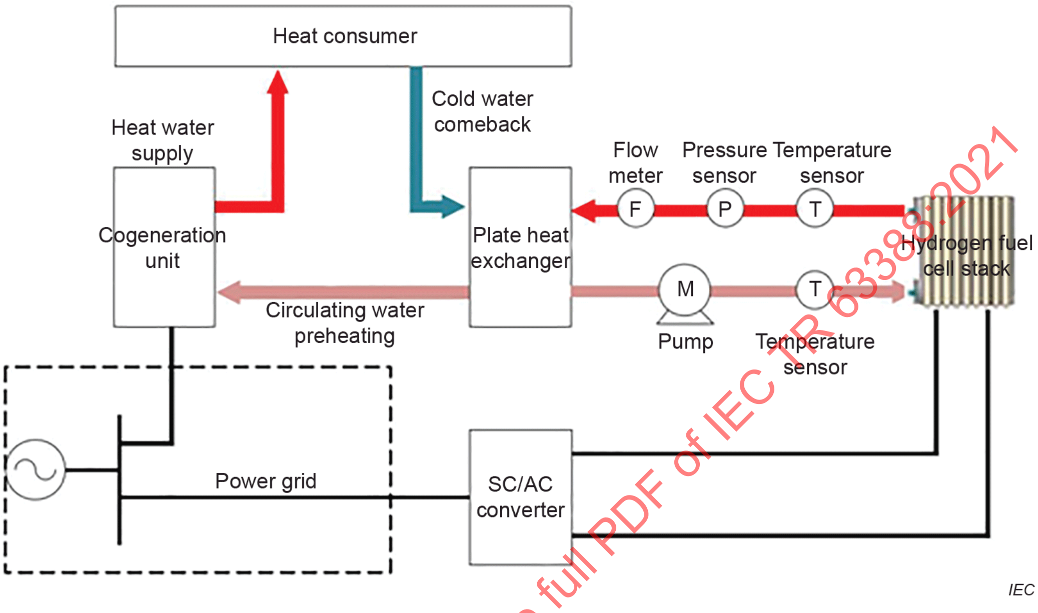


Figure 17 – Fuel cell CHP system

6.2.4 ORC CHP

The organic Rankine cycle (ORC) system is used to convert low-grade heat energy (generally lower than 200 °C) into electric energy. ORC has single cycle and double cycle. There are many kinds of working medium, such as n-butane, isobutene, chloromethane, ammonia and Freon series, which can be used as working medium of steam turbine.

The conventional Rankine cycle system uses water steam as a working fluid. There are four processes of constant pressure heating, adiabatic expansion, constant pressure exothermic and adiabatic compression. ORC is mainly used in the field of low temperature. As shown in Figure 18, the application fields of ORC power generation technology include biomass power generation, geothermal power generation, solar power generation, industrial waste heat power generation, etc. (Source: Techno economic survey of Organic Rankine Cycle (ORC) systems, "Renewable and Sustainable Energy Reviews")

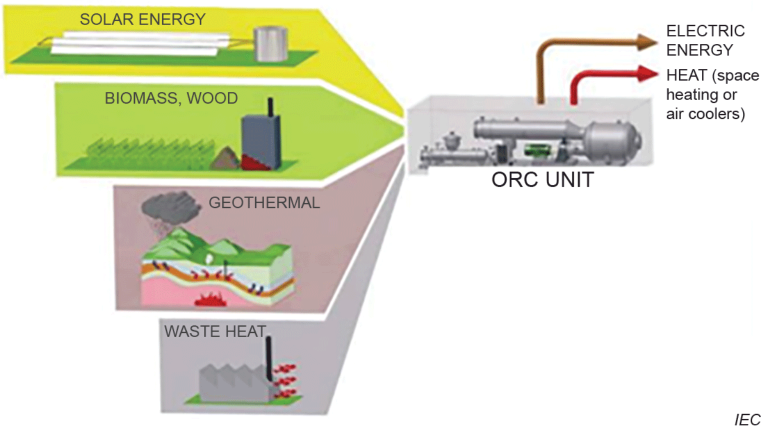


Figure 18 – ORC CHP system

6.3 Components

For this kind of CHP system, different technical solutions correspond to different prime movers. The prime mover is the core component.

The main components of different cogeneration technology schemes are given below.

1) Gas turbine CHP

   This scheme mainly involves the following components:
   – Compressor;
   – Combustor;
   – Gas turbine (Micro, STIG, HAT, etc.);
   – Generator; and
   – Heat exchanger.

2) Stirling engine CHP

   This scheme mainly involves the following components:
   – Combustor;
   – Stirling engine;
   – Generator; and
   – Heat exchanger.

3) Fuel cell CHP

   This scheme mainly involves the following components:
   – Fuel cell; and
   – Heat exchanger.

4) ORC CHP

   This scheme mainly involves the following components:
   – ORC turbine;
   – Boiler;
   – Generator; and
   – Heat exchanger.

6.4 Requirements

1) Gas turbine CHP

A gas turbine is the core component of this kind of CHP system. A gas turbine includes micro gas turbine and heavy-duty gas turbine.

A micro gas turbine basically aims at distributed generation and energy supply. Commercial power ranges from one kilowatt to hundreds of kilowatts, using a centripedal turbine and centrifugal compressor. Generally speaking, the features of micro gas turbine are as follows:

– Can be applied to multiple fuels (Oil, Gas, Alcohol, etc.);
– Small volume;
– Space saving;
– Easy to install;
– Low noise;
– High reliability;
– High degree of automation.

A heavy-duty gas turbine is quite different from micro gas turbine. The power of a heavy-duty gas turbine reaches tens to hundreds of megawatts. Generally speaking, the features for a heavy-duty gas turbine are as follows:

– High energy output;
– Low noise;
– High reliability;
– High energy conversion efficiency;
– Lower pollutant emissions;
– Combined with STIG cycle, flexible cogeneration can be realized.

For a gas turbine CHP system, in order to ensure safe and efficient operation, the following items need to be addressed:

– Efficient recovery of waste heat from the gas turbine;
– The reliability of the gas turbine;
– The economic evaluation under different operating conditions; and
– The performance evaluation and acceptance of the heating system.

2) Stirling engine CHP

A Stirling engine is the core of this kind of CHP system. Generally speaking, the requirements for Stirling engine are as follows:

– Can be applied to multiple fuels (Oil, Gas, Alcohol, etc.);
– The proportion of thermal and electrical output can be adjusted according to the needs of users;
– High reliability;
– High energy conversion efficiency;
– Improve the sealing performance of the working medium;
– Simplify the control system as much as possible.

For this kind of heating mode, in order to ensure safe and efficient operation, the following items need to be addressed:

– Efficient recovery of waste heat from the Stirling engine;
– The reliability of the Stirling engine;
– The economic evaluation under different operating conditions; and
– The performance evaluation and acceptance of the heating system.

3) Fuel cell CHP

A fuel cell is the core of this kind of CHP system. Generally, the requirements for the fuel cell are as follows:

– Can be applied to multiple fuels (Hydrogen, Oil, Gas, Alcohol, etc.);
– Fast to start up;
– Reliability;
– Energy conversion efficiency.

For this kind of heating mode, in order to ensure safe and efficient operation, the following items need to be addressed:

– Reliability of fuel cell power system;
– Economic evaluation under different operating conditions; and
– Performance evaluation and acceptance of the heating system.

4) ORC CHP

For this kind of heating mode, in order to ensure safe and efficient operation, the following items need to be addressed:

– The reliability of the ORC system;
– The stability of its working medium;
– The economic evaluation under different operating conditions; and
– The performance evaluation and acceptance of the heating system.

6.5 Summary

From the user's perspective, the selection of distributed CHP scheme mainly considers the fuel requirements, operation demand, output demand, installation condition, investment, etc.

Generally, the safety and flexibility of its core equipment, the calculation of heating operation economy, the performance evaluation and acceptance of heating system are the basis to ensure the effective application of a CHP scheme.

7 Standardization demand of CHP

7.1 Necessity to develop CHP technical standards

From a user's perspective, implementing a CHP project from conception to completion could be a challenge. It depends on the feature of the facilities and the performance objectives of a CHP system being considered. Factors to consider include the energy source, operation condition, power and thermal demand and the optional of CHP technology etc. The stakeholders involved are owner, consultants, vendors and manufacturer etc. Technical standards are a bridge between user's demand and CHP system vendors. They provide terms and definitions, requirements, tools, and a unified approach assisted in reaching an agreement between stakeholders and achieve the CHP project development process advance smoothly, as shown in Figure 19.

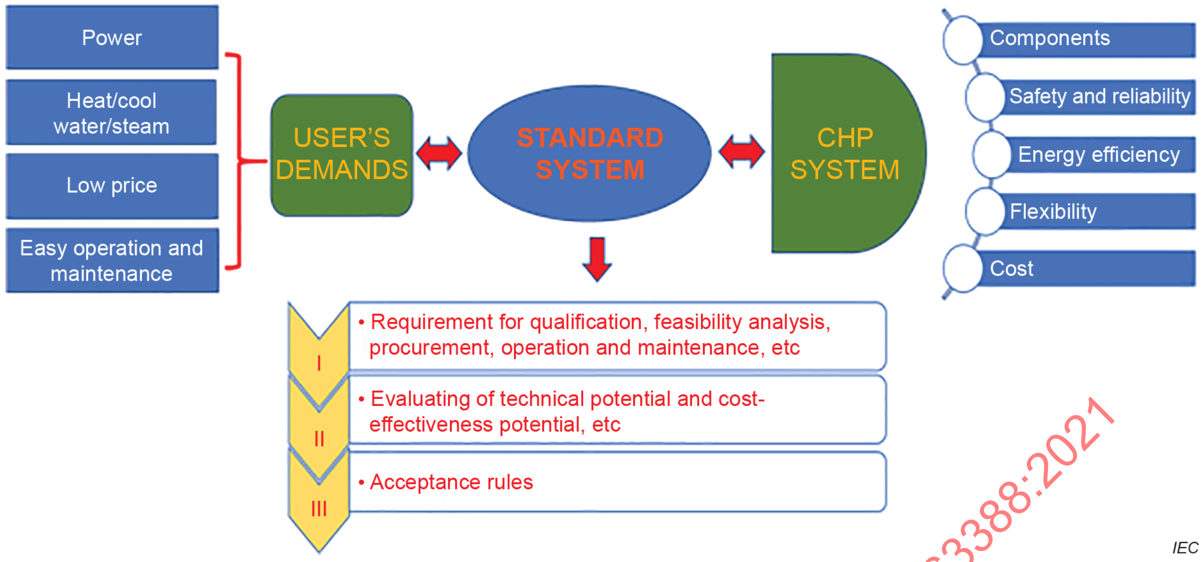


Figure 19 – Link between CHP system and user demands

The key to promoting the development of a CHP project includes: qualification, feasibility analysis, procurement, operations and maintenance, evaluating of technical potential and cost-effectiveness potential, equipment and overall acceptance rule etc. Technical standards could assist stakeholders to meet the requirements of the above factors and assist in the successful completion and operation of a CHP project. The following aspects of technical standards could be helpful.

- Technical requirements (or Specification) at system level
  - Establish terms used in procurement, operation and maintenance. Specifies the requirements for construction, installation, fitness for purpose, rational use of energy, marking, and performance measurement of these appliances.
  - Enabling users and vendors reach agreement and ensure the safety, reliability of the equipment.
- Evaluation criteria at system level
  - Establish methods for evaluating of technical potential and cost-effectiveness potential. Provides a procedure to obtain the satisfactory configuration for each project.
  - Enabling users to evaluate economic benefits or risk before project construction.
- Acceptance rule at system level:
  - Specifies standard rules for preparing, conducting, evaluating and reporting thermal performance tests.
  - Enabling users to have evaluation methods for selecting equipment in construction projects. It could also be a technical basis for executing purchase contracts between the user and vendors.

7.2 Current status of ISO/IEC standards related to CHP

7.2.1 General

The CHP system configuration could be varied, depending on different prime movers. Therefore, it is necessary to distinguish the technical characteristics of CHP system when developing standards.

From a system perspective (referring to document 5/204A/AC), the CHP standard system can be divided into CHP system level, CHP communication level and CHP component level.

There are already some published standards related to CHP. The classification of existing standards is also based on CHP system level, CHP communication level and CHP component levels.

7.2.2 CHP system level

ISO 26382:2010, CHP systems – *Technical declarations for planning, evaluation and procurement*, developed by ISO/TC192 could be regarded as a CHP system level standard.

The scope of ISO 26382:2010 is:

This International Standard describes the technical declarations for a CHP system (CGS) that simultaneously supplies electric power and heating and/or cooling, for planning, evaluation and procurement.

It applies to the identification of investigation items for project evaluation, CGS evaluation, and primary information works for CGS procurement.

It also specifies necessary check items in CGS planning, provides a procedure to obtain the satisfactory configuration of the CGS for each project, and includes a detailed process diagram of the key development steps.

CWA 45547:2004, *Manual for Determination of Combined Heat and Power*, a regional standard, presents a set of formulations and definitions for determination of CHP energy products and the referring energy inputs. The manual formulates the procedure for quantifying CHP outputs and inputs, such as CHP electrical energy, CHP mechanical energy, CHP heat energy and CHP fuel energy.

EN 50465-2015,Gas appliances – *Combined heat and power appliance of nominal heat input inferior or equal to 70 KW*, a regional standard, specifies the requirements and test methods for the construction, safety, fitness for purpose, rational use of energy and the marking of a micro combined heat and power appliance.

7.2.3 CHP communication level

IEC 61850-7-420:2009, *Communication networks and systems for power utility automation – Part 7-420: Basic communication structure – Distributed energy resources logical nodes*, developed by IEC/TC57, Power systems management and associated information exchange.

The standard defines information models to be used in the exchange of information with distributed energy resources (DER), which comprise dispersed generation devices and dispersed storage devices, including reciprocating engines, fuel cells, micro turbines, photovoltaic, combined heat and power, and energy storage. It utilizes existing IEC 61850-7-4 logical nodes where possible, but also defines DER-specific logical nodes where needed.

Considering the scope description, this standard can only be applied for small-scale (DER) CHP projects.

7.2.4 CHP component level

In terms of CHP core equipment, there are many existing standards. These international/regional/national standards which could support CHP equipment are listed in Table 2.

Table 2 – Status of CHP standards

IEC technical committee 5: Steam turbines.	**IEC technical committee 5: Steam turbines.**	**IEC technical committee 5: Steam turbines.**	**IEC technical committee 5: Steam turbines.**
Steam turbine	IEC/TC5	IEC 60045-1:2020 Steam turbines – Part 1: Specifications	This part of IEC 60045 is applicable primarily to land-based horizontal steam turbines driving generators for electrical power services. Some of its provisions are relevant to turbines for other applications. Generator, gear box and other auxiliaries which are considered as a part of the system are also mentioned in this document. Detailed specifications for this equipment are not included in this document. The purpose of this document is to make an intending purchaser aware of options and alternatives which it may wish to consider, and to enable it to state its technical requirements clearly to potential suppliers. Consequently, final technical requirements will be in accordance with an agreement between the purchaser and the supplier in the contract.
		IEC 60953-2:1990 Rules for steam turbine thermal acceptance tests. Part 2: Method B – Wide range of accuracy for various types and sizes of turbines (To be revised as: IEC 60953-0:— (edition 1) Rules for steam turbine thermal acceptance tests – Part 0: Wide range of accuracy for various types and sizes of turbines)	The rules given in this standard are applicable to thermal acceptance tests covering a wide range of accuracy on steam turbines of every type, rating and application. Only the relevant portion of these rules will apply to any individual case. The rules provide for the testing of turbines, whether operating with either superheated or saturated steam. They include measurements and procedures required to determine specific enthalpy within the moisture region and describe precautions necessary to permit testing while respecting radio logical safety rules in nuclear plants. Uniform rules for the preparation, carrying out, evaluation, comparison with guarantee and calculation of measuring uncertainty of acceptance tests are defined in this standard. Details of the conditions under which the acceptance test shall take place are included. Should any complex or special case arise which is not covered by these rules, appropriate agreement shall be reached by manufacturer and purchaser before the contract is signed.