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ANALYSIS OF COGENERATION SOLUTIONS FOR LOW AND MEDIUM POWER

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ABSTRACT

The paper analyses the simultaneous production of heat and electricity by cogeneration using two distinct solutions: with gas turbine and thermal engine. The analysis is made for cogeneration solutions for low and medium power. The advantages of cogeneration energy production are identified in both solutions, so the process of combined and simultaneous production of the two forms of energy achieves an effective primary energy saving (fuel) compared to the separate production of mechanical work (in a thermal power plant) and heat (in a thermal power plant). This fuel economy is reflected from an economic point of view, in the reduction of the fuel costs of the power plant and from an ecological point of view, in the reduction of the pollution of the environment. Conclusions are drawn on the opportunity of using the two solutions depending on maximum demand, power supply time, the degree of flattening (or non-uniformity) of the classified consumption curve and energy demand structure (electrical/thermal).

KEYWORDS: cogeneration, recovery, power, gas turbine, heat engine, engine cycle.

1. INTRODUCTION

Cogeneration represents the combined and simultaneous production of electricity and heat starting from a single primary energy source.

The process involves the existence of a thermal machine (steam turbine, gas turbine, heat engine) which (co)generates the two directly usable energy flows: thermal and electrical. The thermal machine operates on the basis of a direct thermodynamic cycle (engine cycle), taking a high temperature heat flow from "hot source" and eliminating a heat flow with lower temperature to "cold source".

Cogeneration consists of using at least part of the heat extracted from the cycle and using it in this form to power consumers, the latter taking over partially or in full the role of cold source of the thermodynamic motor cycle.

From a semantic point of view, various names are used for cogeneration around the world. In general, in Eastern European countries, including Romania, where cogeneration solutions are developed according to the Russian model, the notion of "district heating" has long been used. Lately, due to the fact that the name "cogeneration" is much closer to the physical meaning of the combined production, this name has been adopted in these states as well. In other countries the combined production of heat and electricity is named combined heat and power (CHP) or "cogeneration".

Why cogeneration? By its nature, the process of combined and simultaneous production of the two forms of energy achieves an effective primary energy saving (fuel) compared to the separate production of mechanical work (in a thermal power plant) and heat (in a thermal power plant) [1]. This fuel economy is reflected from an economic point of view, in the reduction of the fuel costs of the power plant and from an ecological point of view, in the reduction of the pollution of the environment. The energy, economic and ecological efficiency of cogeneration compared to separate production is summarized in this analysis.

Thus, cogeneration is one of the most economical technologies for reducing greenhouse gas emissions, a role officially recognized by the European Union, along with the use of renewable energies. At the opening of the Kyoto Conference, The Commission has identified cogeneration as the main measure leading to a reduction in greenhouse gas emissions with a potential of up to 180 million tons per year.

By its nature, the combined and simultaneous production process achieves an effective primary fuel economy compared to the separate production of mechanical work (in a thermal power plant) and heat (in a thermal power plant). This economy translates primarily into a reduction in the fuel costs of the manufacturing installation and secondly in a reduction in the pollution of the environment. Table 1. presents the essential elements for analysing the level of cogeneration in the EC and Romania from the perspective of consumer categories.

Table 1 Cogeneration solutions for various consumer categories

Cogeneration solution type	Installed power		Heat supply type	Consumer category
	EC	Romania		
Micro cogeneration	50kWe	50kWe	Individual (decentralized)	Buildings, tertiary consumers, schools, hospitals, shops
Mini cogeneration	50– 500kWe	50– 1MWe	Group (centralized)	Groups of urban consumers, tertiary consumers, small industrial consumers, hotels, hospitals, shops
Low cogeneration	500kWe – 3MWe	1 – 3MWe	Centralized	Areas of urban consumption and / or tertiary consumers, small industrial consumers
Medium cogeneration	3 – 10MWe	10 – 25MWe	Centralized	Small and medium cities, industrial consumers, small industrial areas integrated energy
High cogeneration	>15MWe	>25MWe	Centralized	Cities, large consumers or areas of industrial consumption

2. CLASSIFICATION OF LOW AND MEDIUM POWER COGENERATION SOLUTIONS

The classification of cogeneration solutions can be done according to various factors with major impact on their technical and economic performance. The main factors are [2]:

a. Scale of installed electrical power;

b. The degree of interconnection on the electrical side;

c. Technical solution (type of thermal engine).

a. The installed power scale – includes a wide range, ranging from tens of kW to hundreds of MW. From this point of view, cogeneration plants differ:

- Very low power;
- Low power;
- Medium power;
- High power.

These areas of electrical powers are not fixed, established by regulations, they differ from country to country even within the

European Community. Table 1. shows the general limits of the installed electric power domains (indicative values) considered at European level and at the Romanian level.

b. The degree of interconnection on the electrical side – under this aspect there can be distinguished the cogeneration installations:

- Isolated, island mode and ensuring the supply of a certain consumer;
- Interconnected, with available energy (feeding a certain consumer but also connected to the public network, which they have periodic energy exchanges with). In these situations, the installed electrical power corresponds to the maximum consumer demand;
- Interconnected, with available power and energy (feeding a certain consumer but also connected to the public network, which they have permanent or very frequent exchanges of energy with). In these situations, the installed power is higher than the maximum consumer demand.

The technical and economic conditions in which the exchange of electricity of a cogeneration power plant (CCG) takes place with the public network (in both directions), decisively influences the recovery rate of such an investment.

c. Technical solution (thermal machine type) - Thermal machine type determines the level of thermodynamic performance (mechanical work production efficiency) and technical performances (maximum degree of heat recovery discharged from the thermodynamic cycle), as well as some limitations (for example the maximum heat level obtained by recovery). Depending on this factor’s cogeneration, solutions are classified into:

- Cogeneration with gas turbines (TG);
- Cogeneration with thermal motors (MT).

In the following, the influence of environmental factors on low and medium power cogeneration solutions for modern equipment solutions will be studied, namely thermal motors (MT) and gas turbines (TG).

3. LOW AND MEDIUM POWER COGENERATION TECHNICAL SOLUTIONS

The type of thermal machine determines the level of thermodynamic performance (the mechanical work production efficiency) and technical (the maximum possible degree of heat recovery discharged from the thermodynamic cycle), as well as some limitations (for example the maximum thermal level of heat obtained by recovery).

Thermal basic configuration of cogeneration plants with gas turbines (TG) and with thermal motors (MT) are presented in Figure 1 and Figure 2. Cogeneration, in both cases, is based on the recovery of heat discharged from the thermodynamic cycle through the thermal machine.

In both cases of cogeneration, the heat

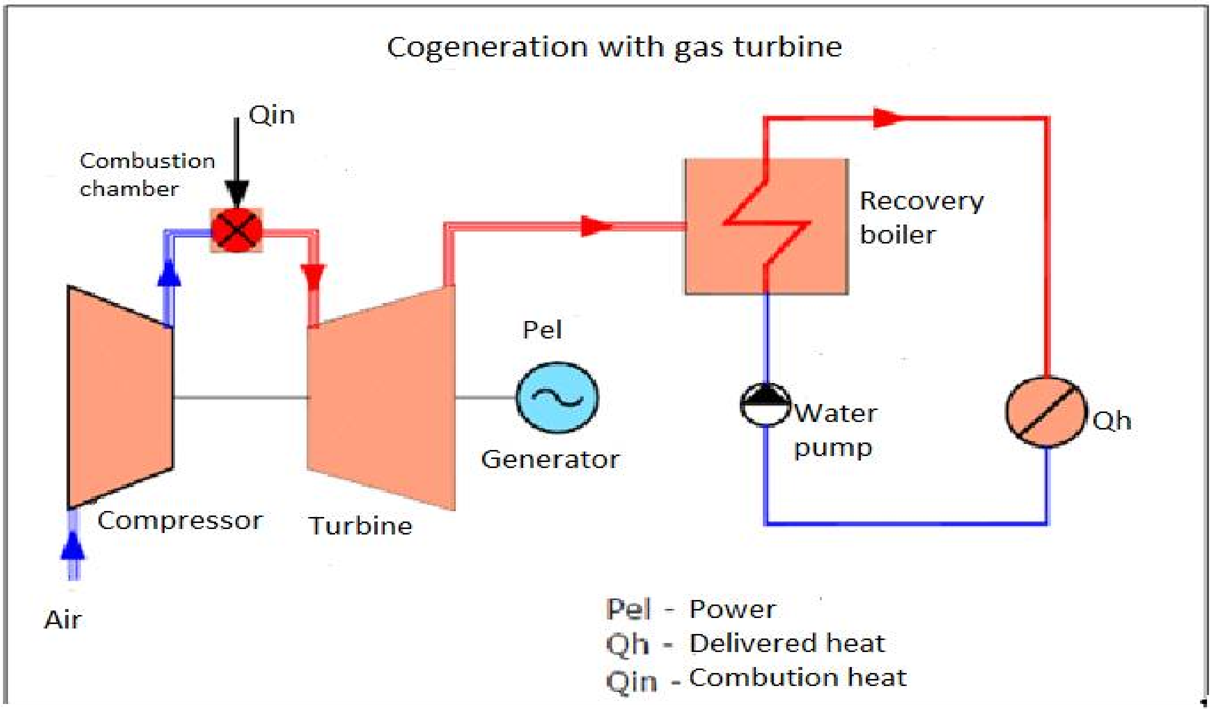

Figure 1 The scheme of the CCG with open circuit gas turbines

contained in the flue gases exhausted from the machine is recovered. The temperature at which the flue gases leave the gas turbine is generally between 450 and 600ºC, while for the heat engine, it is between 300 and 450ºC. For the gas turbine, the heat contained in the exhaust gases is the only recoverable energy flow, which simplifies the installation as a whole.

TG's (gas turbines) are thermal machines that convert chemical energy into mechanical energy, using as engine fluid the gases resulting from the direct combustion of the combustible into excess compressed air flow.

Unlike steam, turbines performance depends on ambient air pressure and temperature of air used in the combustion process. There were decreases of (2 – 4) % of TG capacity for every 300 m altitude. For every 10 ° C increase in the temperature of the aspirated air, the electrical power is reduced by (5.5 – 9) %. Each kPa of pressure lost on the suction circuit corresponds to a reduction of power by 2% and an increase in specific consumption by 0.4 %. Also, each pressure kPa lost on the gas exhaust circuit corresponds to a decrease in power by 0.61 % and an increase in specific consumption by 0.42 % [3].

The power produced by the expansion in the turbine and that consumed by the compressor are directly proportional to the absolute temperature of the flue gases passing through the turbine. That is why, it is desired to use TG at the highest possible gas temperature.

TG's can be used both as basic and semi-basic installations and also as peak or backup installations. A great advantage of these turbines is that the necessary investments are (51 – 60) % lower than those in steam turbines of the same capacity. In terms of cogeneration, TGs are mainly used in combined TG-steam turbine cycles.

From the point of view of the interaction between the thermal agent and the flue gases, installations with TG are distinguished in open circuit and in closed circuit, respectively. TGs in the open circuit are most often used.

From the point of view of conception, TGs are:

- Industrial TG (heavy-duty)
- Aeroderivative TG

It should be noted that TG's have excess air in the combustion chamber of (4,5 – 6) or even more. Under these conditions the flue gases can be used as a fuel. Thus, the recovery boilers can be transformed into peak thermal installations by introducing additional fuel to burn with the flue gases. In this case, they are called a recovery boiler with post-combustion (CRPA). If a higher amount of heat is desired than the one that CRPA can provide, fuel and additional combustion air can be introduced into the boiler, turning into a recovery boiler with additional combustion. CAF's or steam boilers can be used as peak installations, depending on the needs of the consumer.

Originally used as peak turbines when supplying electricity, gas turbines coupled with a recovery boiler are currently used in cogeneration for the base load. Excess oxygen in the flue gases also allows the use of additional fuel combustion in the recovery boiler, to increase flexibility.

The flue gas calculation temperature is required by considerations related to the dew point, acid deposits (when there is sulphur in the fuel) and dispersion in the atmosphere.

The recovery boiler will be dimensioned according to the temperatures on the tour and retour from the heating network.

The cost of heat is relatively independent of the tour or retour temperatures from the heating network.

Several schemes are possible depending on the type of gas turbine used. Microturbines can also be used in block-type plants, or gas turbines with steam injection (both in the turbine and in the combustion chamber).

The heat engine (Figure 2) allows the recovery of heat resulting from the water cooling of the engine block, as well as from the cooling of other subassemblies. The additional problem of the internal combustion engine is that the recovery of its technological cooling must not affect the thermal regime of the machine, as established by the manufacturer, which means an extra condition. For this reason, in certain situations one gives up the recovery of some of the technological cooling, accepting a lower degree of recovery of the heat discharged from the cycle.

Cogeneration with internal combustion engines is suitable for basic operation, in the power range up to 10MW. The heat is recovered from the flue gases, the engine cooling system, the oil cooling system, and the air cooling from the supercharging system. Heat recovery improves the total efficiency of the system from (37-39) % as it is for the production of electricity to over 90% if all recovered heat is used in a tour temperature heating circuit of about 90,7 ^{o}C [4].

The drop in retour temperature below the minimum value imposed by the manufacturer leads to a decrease in the amount of heat delivered, part of the heat in the cycle being used to raise the temperature to this minimum limit [5]. Cogeneration with internal combustion engines is suitable for heating systems with relatively low temperatures. The price of heat is slightly influenced by the temperature of the tour, because most of the heat recovered is that of the flue gases discharged, where there is sufficient gap on the temperature difference. Heat recovery in the case of thermal engines (and gas turbines) does not sacrifice part from the power produced as in the case of steam turbines.

For cogeneration installations with thermal engines, four-stroke motors with a speed of 1500 rpm are used for powers up to 5MW (maximum value for gas engines). Thermal engines have a good behaviour at partial loads, the heat recovered being practically constant (in value related to the nominal load) from the nominal load up to 50%, below this value.

For powers up to 5MW, spark ignition engines are used with equally good results.

Internal combustion engines can use a wide range of fuels: natural gas, biogas, biomass gas fuels, light liquid fuels and even fuel oil. Engines operating with both gas and liquid fuels are also available.

In order to bring the emissions below the imposed limits, Diesel engines require the installation of SNCR (Selective Non-Catalytic Reduction) type equipment before the flue gas is discharged to the chimney.

MT advantages:

-Heat and electricity can be generated near the consumer, thus eliminating losses in transmission networks, as is the case in large district heating systems;

-The total efficiency of a cogeneration with internal combustion engines increases to over 86%, given the final consumer, about 12 % higher than the conventional heating system;

-Reducing primary energy consumption by using heat from flue gases and engine cooling water with high efficiency;

-Reduction of environmental pollution through residual flue gas heat;

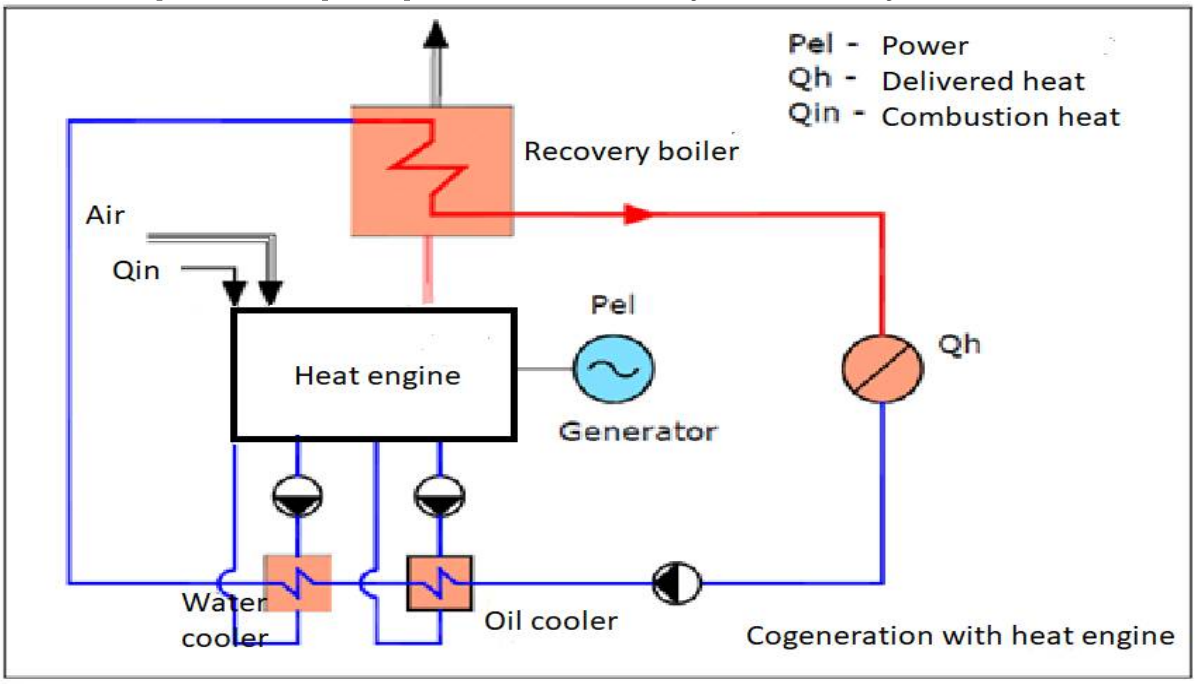

Fig. 2 The scheme of the CCG with heat engine

-The modular construction of cogeneration plants using several engine-generator blocks leads to better adaptation to power demand and easier maintenance;

-There are many producers on the market, so a richer offer.

MT Disadvantages

• Cogeneration based on thermal engines is suitable for heating systems with low tour temperature (118 ^{o}C).

The thermodynamic and technical performances of a thermal engine operating in cogeneration mode are [6]:

- increasing power generation efficiency;

- the maximum degree of heat recovery discharged from the thermodynamic cycle;

- improving the district heating index (the structure of energy production).

For a CCG made up of several units and which supplies heat to a certain consumer, the following sizes are also defined:

- the degree of cogeneration (which indicates the share of electrical power obtained in cogeneration in total electrical power);

- the heating coefficient (which indicates the share of heat produced in cogeneration in the total heat production of CCG);

- the structure index of the energy

production of the CCG.

4. CONCLUSIONS

Consumers of electricity and heat supplied by a cogeneration plant (CCG) with gas turbine or heat engine are characterized by four reference sizes, namely:

- maximum demand;
- power supply time;
- the degree of flattening (or non-uniformity) of the classified consumption curve;
- energy demand structure (electrical/thermal).

The simultaneity of electricity and heat demands also have an important effect on the performance of the cogeneration plant. A low degree of simultaneity reduces the positive effect of cogeneration and reduces the overall yield achieved.

It should be noted that the thermal machine is the basic heat production installation, because it takes over the base of the heat consumption curve. The installation that takes over the top of this consumption curve is called peak heat production installation. The overall efficiency of the CCG is higher as the share of heat produced in the basic installation is higher.

The nature of the fuel used by the hot source of the engine thermodynamic cycle is another important aspect in comparing the technical solutions. CCGs with TG or MT can only use superior fuels (natural gas, light liquid fuel). The new CCG's that replace or complete their own old power plants may use at least in part the fuel supply installations from the old power plants (natural gas, diesel). The in-service behaviour of cogeneration plants is another aspect that can influence the choice of a certain solution.

The situation of the internal combustion engine is more complicated in case of recovery of technological cooling, but the gas turbine can pass practically instantly from cogeneration to mono-generation (function only as a power source). At partial loads, the internal combustion engine behaves better than the gas turbine, their performance being less affected by the decrease of load.

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