GAS ENGINE AND GAS TURBINE COGENERATION UNITS

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ABSTRACT

This paper describes the basic factors influencing the selection of cogeneration plants based on Gas-Turbine-Based Cogeneration Plant (GTCP) and Gas-Engine-Based Cogeneration Plant (GECP). The main reasons of Gas Turbine (GT) and Gas Engine (GE) usage were defined. Also the paper involves classification of GECP and GTCP and gives recommendations for selection in a modern market conditions.

1. INTRODUCTION

Nowadays the trend for a traditional centralized heat and power supply from large scale sources is becoming less actual. That was caused by new socially oriented market relations, constantly increasing inflation rate and lack of basic generating power.

Decentralized complex heat and power sources are becoming more and more popular, since they could be installed both on already acting heating boiler plants and on new constructed heat sources.

One of the possible solutions of that problem is installation of local heat and power systems with gas turbine or gas engine units which runs on natural gas, propane, biogas or another type of a gas fuel.

2. REASONS FOR CHP UNITS APPLICATION

Construction of Combined Heat and Power (CHP) units is possible to realize both from the very beginning and on the basis of heating or industrial boiler plants.

The construction of a decentralized power station might be caused by one of the following reasons:

1) Heat or power supply costs are comparable to the expanses for decentralized power station construction (new building);

2) There are problems with region grids or with price for extra energy (power extension);

3) Power availability and quality is critical in terms of technical process stability or technology violation;

4) Charges for the following atmospheric gas emissions are comparable to costs of facility for electrical stations (oil producing companies);

5) Possible electric power rate rising;

7) It is possible to use profitable biogas (agricultural companies, disposal works and private organizations).

3. GAS-ENGINE-BASED COGENERATION PLANT

Currently power stations based on GE (power rate 100 kW – 9 MW) are the most common source of constant energy for housing sector, industrial companies, coal-milling and oil organizations. The different gas fuel types usage (natural, oil, bio-, pit gas) has an impact both on construction characteristics and on basic parameters (compression rate, average effective pressure and as a consequence aggregate power) of Gas-Engine-Based Cogeneration Plant.

Table 1: Direct producers of GECP*

Manufacturer	Power range, MW
Caterpillar S.A.R.L.	0.07 – 5.9
Cummins Inc.	0.016 - 2
FG Wilson (Engineering) Ltd.	0.01 - 1
Ford Power Products	< 1
GE Energy Jenbacher	0.3 - 4
General Motors Corporation	< 1
Guascor S.A.	< 1,2
Iveco Motors S.p.a.	< 1
Lister Petter Ltd.	< 1
MAN B&W Diesel A/S	0.047 – 8.1
MAN Nutzfahrzeuge AG	< 1
Mitsubishi Heavy Industries Ltd.	0.38 – 5.75
MTU Onsite Energy	0.116 - 2
MWM, GmbH	0.18 – 4.3
Niigata Power Systems Co. Ltd.	1.1 – 5.4
Perkins Engines Company Ltd.	0.307 – 1
Rolls-Royce Power Engineering Plc	1.19 – 8.75
TEDOM, s.r.o.	0.026 – 5.9
Volvo Penta	< 1
Wartsila Finland Oy	4.14 – 22.4
Waukesha Engine Dresser Inc	0.75 – 3.25

* Values of generated power of GECP producers are given according to information from official websites of each company particularly

On the world market there are a number of companies producing GECP. The major ones, producing GECP of an average power from 100 kW to 16.6 MW are Caterpillar S.A.R.L., Cummins Inc. and Waukesha EngineDresser Inc. (USA), MWM, GmbH and MTU Onsite Energy (Germany), GE Energy Jenbacher gas engines (Austria), TEDOM Ltd. (Czech Republic) (Table 1). The rest organizations produce GECP of a low power (less then 1 MW) or high power (more then 4 MW) or complete GECP with engines from other producers.

Combustion engines acting on gas fuel can be divided into four groups:

1) **Dual – fuel diesel.** During exploitation the consumption of oil-fuel could be varied from 100 % to 10-15 %. The rest part of a fuel is nature gas which is mixed with air at the entry to the engine. At that, initiation of fuel combustion is the result of the temperature rising or it is caused by a constant ignition source.

2) **Dual – fuel gas reciprocating engines.** The main fuel for them is gas, but a small portion of a liquid fuel ("pilot fuel") is injected into a cylinder or commonly into a special pre-ignition chamber for combustion initiation of an air-gas mixture. By means of the mentioned methods the pilot fuel is inflamed.

3) **Gas engine,** is working only on a gas fuel, without the pilot fuel usage. The factors that distinguish them are low compression rate and generally less economical efficiency. The inflammation source is candle.

4) **Tri-fuel technology -** It can be run either on natural gas or on light fuel oil (LFO) or on heavy fuel oil (HFO). The engine can smoothly switch between fuels during engine operation and is designed to give the same output regardless of the fuel. The engine operates on

the lean-burn principle. Lean combustion enables high compression ratio which increases engine efficiency (up to 47.3 %) and reduces peak temperatures, and therefore also reduces NOx emissions [2].

4. GAS-TURBINE-BASED COGENERATION PLANT

Nowadays there three basic types of GTCP:

1. based on aero-derivative GT engines;
2. based on gas-turbine engines intended for the marine usage;
3. for energetic usage, or heavy-duty GT.

The first and the second types could be combined into one group with a conventional name aero-derivative GT [3].

4.1. THE FIRST AND THE SECOND TYPE GT

Aeroderivative GT (AGT) are more up rated and don't have a considerable unit weight (kg/kW), easy to service, less demanding for infrastructure, but at the same time have a shorter operation life cycle. Commonly the total number of independent shafts for GT based on aero- or marine- engines is between one and three, besides shafts being placed in a gas-generator, could rotate with a different rotation speed (6000-14000 rpm.) depending on an applied load. The power rate of such plants is varied from 2,5 MW to 20 MW.

Marine engines being converted for a gas fuel application compose so called "intermediate class" of engines, as in gas turbine equipment they are on the niche between converted aero-engines and engines designed for an energetic field usage. The GT plants have all benefits of aero-engines, such as weight and dimensions, replaceable engine module and high overload capacity. Beside this due to technologies, materials and coatings being applied it is possible to use them in marine climate conditions.

4.2. GT OF THE THIRD TYPE

GT of the third type are much heavier, and as a rule have only one shaft rotating with a constant speed equal to rotation speed of a generator. To provide reliability, heat efficiency, to reduce price and exploitation costs, the power GT are designed according to the simplest cycle. The construction of these plants corresponds to the traditional power manufacturing principles: heavy rigid shaft, friction bearing, blades of constant profile located on the basic span of a wheel space, etc. The main coolant for working blades and nozzles blades is air. In a case of a heavy-duty GT, there are much more demands for a construction work as well as for infrastructure.

The life span of those plants is quite long and could be compared to the operation life of steam-turbine plants. AGT take the basic niche on the plant market when power is varying from 2,5 MW to 20 MW, but heavy-duty GT prevail when the power rate is more then 100 MW.

Companies, producing and designing aero - and marine gas-turbine engines are on the leading positions of power gas-turbine plants producing.

Table 2: Direct producers of GTCP*

Manufacturer	Power range, MW
LMW (Russian)	160
ABB Stal	16.9/24.6
Ansaldo Energy	63/156/222
European Gas Turbines	21.87/34.2/123.4/226.5
Fiat Auto	21.87/134.2/143.1/237.5
General Electric Marine & Industrial	13.4 – 50
General Electric Power Generation	26.3/38.3/70.1/123.4/226.5
Hitachi	26.3/38.3
John Brown Engineering	26.3/70.1/123.4/226.5
Mitsubishi Heavy Industries	130.5/136.9/158.6
Nuovo Pignone - Turbotechnica	9.9/13.4/22.3/123.4/226.5
Allison Rolls-Royce	2.7 – 5.7
ABB-Alstom	3.9 – 265
Siemens AG	5 - 375

* Values of generated power of GTCP producers are given according to information from official websites of each company particularly

They have successfully developed the energetic market due to a strong production and science-research foundation (Table. 2).

The alternative solution for energy consumer less then 1MW is micro-turbine plants “Capstone” with air bearing and power rate equal from 30 to 1000 kW. Construction and exploitation particularities (benefits) of micro-GT provide low noisiness, long life cycle, load flexibility, cost efficiency, easy servicing, ecological compatibility (emissions level is less then 9 ppm). However, the development of turbines of that type is suppressed by high incremental cost of investments (euro 1200-2000 for kW) [4].

SUMMARY

The aim of the research work is the comparative analysis of GECP and GTCP characteristics and the following recommendations for the specific power plan selection. There are 5 groups of cogeneration unites to be pointed out according to the electrical power output:1) micro-CHP – up to 200 kW; 2) mini-CHP – up to 700 kW; 3) small-CHP – up to 1,5 MW; 4) average-CHP – up to 50 MW; 5) big-CHP – above 50 MW. Concerning the fact that GECP and GTCP are limited by the following power rates 10 kW - 22,4 MW and 1,2 MW-265 MW respectively, the CHP plans of average and big class will be compared. Main criterions assessment such as technological, constructive and economical parameters is shown in Table 3.

Table 3: Production conditions analysys*

№	Parameter	Dimension	GECP	GTCP
Process conditions [1,4]				
1	Electrical power	[MW]	1.05 – 22.4	1.2 – 375 (570)**
2	Ratio of heat to electrical energy	-	from 0.5:1 to 1:1	from 2:1 to 1.5:1
3	Overload capacity	[%]	110	110
4	Power-control band	[%]	50 - 100	20 – 100
5	Heat rate	[MW]	1.3 - 24	2.33 – 570
6	Net efficiency	[%]	38.1 – 47,3	24.3 – 40 (60)**
7	Combustion efficiency	[%]	75 - 94	70 - 90
8	Fuel Input (Hu=48744 kJ/kg)	[Nm3/kW*hr]	0.276 – 0.251	0.474 – 0.618
9	Unit oil consumption	[g/kW*hr]	0.3 – 0.5	0.04 - 2
10	Emission NOx	[ppm]	121.7 – 244.5	24.3 – 25
11	Number of starts	-	unlimited	200 - 450 per year
Design factors, mass and dimensions parameters [1,4]				
12	Specified life / overhaul life	[eng. hr]	100/45-72 – 400/96	100/50-25 - 250/50 - 25
13	Unit weight of CHP units	[kg/kW]	44 – 18.9	8.31 - 1.17
14	Net weight	[T]	17.67 - 424	9.98 - 440
15	Unit size of CHP units	[m3/kW]	0.07 – 0.037	0.016 – 0.00088
16	Use factor of CHP unit	[%]	65.5 – 70	68.5 – 90
Economic effectiveness criterion [3]				

17	Cost per unit	[eur/kW]	650 - 1400	1500-200
18	Pay-back period (operation period 8000 hr, plant load from 55% to 95%)	at an annual rate	2 – 7	4 – 10 (15 - 25)**
19	Profitability index, PI	-	PI (the 2th exploitation year) > 1	PI (the 5th exploitation year) >1

* - Range of magnitudes evaluated by ISO standard is given in the rows, where minimum and maximum values are the row limits
** - Siemens Combined Cycle Power Plant SCC-8000H 1S [5]

According to the data from table, the following can be concluded:

1. The GECP is distinct in high efficiency, which remains stable at temperature from -30ºC to +30ºC. Moreover, generally it consumes less fuel; has an unlimited number of starts and less cost per unit, what ensure reduction of a payoff period and financial risks.
2. Conversely, GTCP is more ecologically friendly and don't need an additional cleaning equipment to be applied. Besides, it consumes much less lubrication and has 10 times less coefficient of metal consumption. Moreover GTCP generates more heat energy, what makes it possible to use combined cycle plant, and thus make up losses in energy generation efficiency with driving efficiency to more then 60%.

Having made a decision to purchase a cogeneration unit, an investor must know the answers for the following questions:

1. To define the operating conditions of a cogeneration unit;

- Climate service environment of the plant. The temperature of outside air for GTCP must be from -30 ºC to +10 ºC, and for GECP is between -30ºC and +30ºC;
- In terms of the geographical position, the altitude of GECP location must not exceed 300 and for GTCP - 2000 meters above the see level respectively;
- GT is advisable to utilize in main, continuous and load control operating mode, because of the limited starts number of a gas turbine;
- Definition of planed operation hours in a year at the nominal power rate;

2. Select single-, dual- or tri-fuel technology and define a fuel cost for cogeneration units;
3. The availability of service centers from cogeneration unites producers;
4. When choosing a concrete model among plants with the same power rate, it is necessary to compare: electrical and full efficiency, fuel utilization coefficient, the specified life or overhaul life, the capital repair costs, dependence of plant efficiency on electric load change and environment, the plant configuration, as some differences may exist in plants configuration with the same price. It is necessary to look through different plans utilization review.

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