04 Gas Turbine, Simple-Cycle

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Qualitative description

Brief technology description

The major components of a simple-cycle (or open-cycle) gas turbine power unit are: a gas turbine, a gear (when needed) and a generator. For cogeneration (combined heat and power production), a flue gas heat exchanger (hot water or steam) is also installed, see the diagram below.

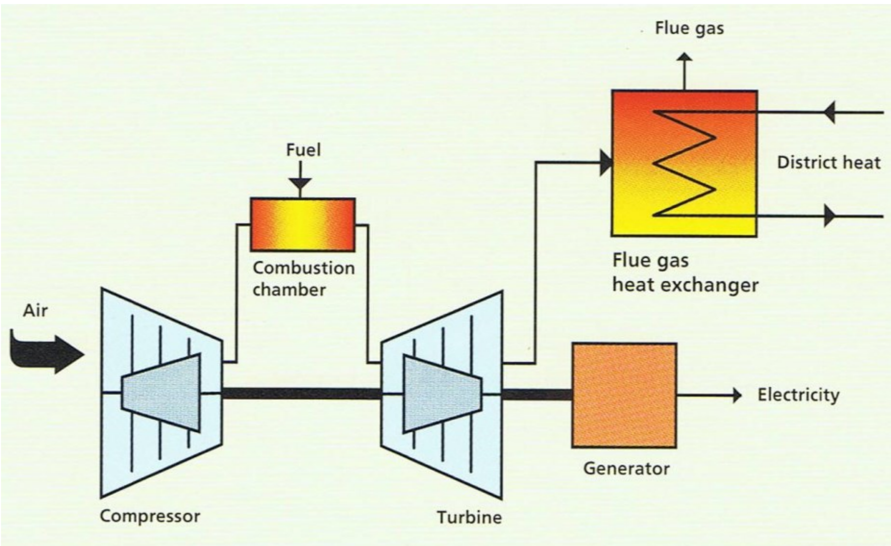

Figure 1 Diagram of a simple cycle plant designed for combined heat and power production.

If applying heat pumps for extra cooling of the exhaust gas, even higher total fuel efficiency can be reached. Depending on priorities, the flue gas heat pumps can be electrical or absorption type.

Simple cycle gas turbines can be used for preheating the feed water of steam power plants. This is the case at the Danish Avedøre 2 power station.

There are in general two types of gas turbines;

1. industrial turbines (also called heavy duty)
2. aero-derivative turbine

Industrial gas turbines differ from aero-derivative turbines in the way that the frames, bearings and blading are of heavier construction. Additionally, industrial gas turbines have longer intervals between services compared to the aero-derivatives.

Aero-derivative turbines benefit from higher efficiency than industrial ones and the most service-demanding module of the aero-derivative gas turbine can normally be replaced in a couple of days, thus keeping a high availability.

Gas turbines can be equipped with compressor intercoolers where the compressed air is cooled to reduce the power needed for compression. The use of integrated recuperators (preheating of the combustion air) to increase efficiency can also be made by using air/air heat exchangers - at the expense of an increased exhaust pressure loss. Gas turbine plants can have direct steam injection in the burner to increase power output through expansion in the turbine section (Cheng Cycle). Direct steam injection is not common for turbines in Denmark

Small (radial) gas turbines below 100 kWe are now on the market, the so-called micro-turbines. These are often equipped with preheating of combustion air based on heat from gas turbine exhaust (integrated recuperator) to achieve reasonable electrical efficiency (25 - 30 %).

Input

Typical fuels are natural gas and light oil. Some gas turbines can be fuelled with other fuels, such as LPG, biogas etc., and some gas turbines are available in dual-fuel versions (gas/oil).

Gas fired gas turbines need an input pressure of the fuel (gas) of 20-60 bar, dependent on the gas turbine compression ratio, i.e. the entry pressure in the combustion chamber. Typically, aero derivative gas turbines need higher fuel (gas) pressure than industrial types.

Output

Electricity and heat (optional). All heat output is from the exhaust gas and is extracted by a flue gas heat exchanger (heat recovery boiler).

The heat output is usually either as steam or hot water.

Typical capacities

Simple-cycle gas turbines are available in the 30 kWe – 450 MWe range [1].

The enclosed data tables cover large scale (40 – 125 MW), medium and small scale (5 - 40 MW) installations. Data on micro gas turbines (0.03 – 0.100 MW) is also presented.

All data are for gas turbines operating in simple cycle cogeneration mode without flue gas condensation, if no additional notes are made.

Regulation ability and other power system services

A simple-cycle gas turbine can be started and stopped within minutes, supplying power during peak demand. Because they are less power efficient than combined cycle plants, they are in most places used as peak or reserve power plants, which operate anywhere from several hours per day to a few dozen hours per year.

However, every start/stop has a measurable influence on service costs and maintenance intervals. As a rule-of-thumb, a start costs 10 hours in technical life expectancy [5].

The flue gas heat exchanger (heat recovery boiler) may lead to some constraints on start-up gradients. This can be solved by including a flue gas bypass.

Gas turbines are able to operate at part load. This reduces the electrical efficiency and at lower loads the emission of e.g. NOx and CO will increase. The increase in NOx emissions with decreasing load places a regulatory limitation on the regulation ability. This can be solved in part by adding de-NOx units.

The heat produced from cooling of the exhaust gas can be either hot water (for district heating or low-temperature process needs) or steam for process needs. Variations in steam production may be achieved by varying the gas turbine load, by supplementary firing in the heat recovery boiler or via a bypass stack.

To operate a simple cycle gas turbine of a cogeneration plant in power-only mode, the exhaust gas is directed to a bypass stack.

Most simple cycle gas turbine plants installations for CHP include short time heat storage. This leads to more flexibility in production planning.

Advantages/disadvantages

Advantages

Simple-cycle gas turbine plants have short start-up/shut-down time, if needed. For normal operation, a hot start will take some 10 - 15 minutes [5,6]. Construction times for gas turbine based simple cycle plants are shorter than steam turbine plants [6].

Disadvantages

Concerning larger units above 15 MW, the combined cycle technology has so far been more attractive than simple cycle gas turbine, when applied in cogeneration plants for district heating [3]. Steam from other sources (e.g. waste fired boilers) can be led to the steam turbine part as well. Hence, the lack of a steam turbine can be considered a disadvantage for large-scale simple cycle gas turbines.

Environment

Gas turbines have continuous combustion with non-cooled walls. This means a very complete combustion and low levels of emissions (other than NOx). Developments focusing on the combustors have led to low NOx levels as stated elsewhere. To lower the emission of NOx further, post-treatment of the exhaust gas can be applied, e.g. with SCR catalyst systems.

Research and development perspectives

Increased efficiency for simple-cycle gas turbine configurations has also been reached through inter-cooling and recuperators. Research into humidification (water injection) of intake air processes (HAT) is expected to lead to increased efficiency due to higher mass flow through the turbine.

Additionally continuous development for less polluting combustion is taking place. Low-NOx combustion technology is assumed. Water or steam injection in the burner section may reduce the NOx emission, but also the total efficiency and thereby possibly the financial viability. The trend is more towards dry low-NOx combustion, which increases the specific cost of the gas turbine [3]

Examples of market standard technology

The best technology on the marked today is a medium size gas turbines with integrated recuperator that can reach approx. 38 % electrical efficiency (5 MWe unit).

Prediction of performance and costs

Gas turbine technology is a well-proven commercial technology with numerous power generating installations worldwide, making simple cycle gas turbines a category 4 technology. Technological improvements are continuously being made; new materials, new surface treatments or improved production methods can lead to higher electrical efficiency, improved lifetime and less service needs.

Developments now also focus on broader gas quality acceptance during operation and improved dynamic performance.

The efficiency of the simple-cycle turbine can be increased, if inlet temperatures to the turbine section can be increased. Therefore development of ceramic materials that can withstand high temperatures used in the hot parts of the gas turbine is taking place.

However, the expectations for the gas turbine market in Denmark are limited, since gas turbines are currently predominantly used in the reserve power market. This means that no significant reductions in investment and/or operation/maintenance costs are expected to be seen in the years to come. In a longer perspective, gas turbines may become relevant for green gas based power production.

Uncertainty

Uncertainty stated in the tables both covers differences related to the power span covered in the actual table and differences in the various products (manufacturer, quality level, extra equipment, service contract guarantees etc.) on the market.

A span for upper and lower product values is given for the year 2020 situation. No sources are available for the 2050 situation. Hence the values have been estimated by the authors.

Additional remarks

Figures for service and maintenance costs are usually based on generated electricity. Service contract may also be on this basis; pricing may be influenced by the number of starts/stops.

Data sheets

Technology	Gas turbine, simple cycle (large), back pressure									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MW)	40 - 125								F	
Electricity efficiency (condensation mode for extraction plants), net (%)	41	42	43	45	38	42	40	44		6, 12
Electricity efficiency (condensation mode for extraction plants), net (%), annual average	39	40	41	43	36	40	38	42		6, 11
Cb coefficient (50°C/100°C)	0.95	0.96	1	1	0.8	1.2	0.8	1.2		6, 12
Cv coefficient (50°C/100°C)	-	-	-	-	-	-	-	-	J	
Forced outage (%)	2	2	2	2	2	3	2	3		6
Planned outage (weeks per year)	3	3	2.5	2.5	2	3.5	1.5	3		6
Technical lifetime (years)	25	25	25	25	25	>25	25	>25	E	6, 7
Construction time (years)	1.5	1.5	1.5	1.5	1	2	1	2		6
Space requirement (1000m2/MW)	0.02	0.02	0.02	0.02	0.015	0.03	0.015	0.03	G	7
Plant Dynamic Capabilities										
Primary regulation (% per 30 seconds)	0	0	0	0	0	0	0	0	I	
Secondary regulation (% per minute)	20	20	20	20	20	50	20	50	C	6
Minimum load (% of full load)	25	23	20	20	20	25	20	25	A	6
Warm start-up time (hours)	0.25	0.23	0.2	0.2	0.1	0.5	0.1	0.4		5, 6, 8
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.4	1	0.4	1		5, 6, 8
Environment										
SO_2 (degree of desulphuring, %)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	20	15	10	10	10	30	7.5	20	D	7, 9
CH4 (g per GJ fuel)	1.5	1.5	1.5	1.5	1	8	1	8	G	9
N2O (g per GJ fuel)	1.0	1.0	1.0	1.0	0.7	1.2	0.7	1.2	G	9
Financial data										
Nominal investment (M€/MW)	0.6	0.59	0.56	0.52	0.4	0.9	0.35	0.85		6, 10
- of which equipment	NA	NA	NA	NA	NA	NA	NA	NA	K	
- of which installation	NA	NA	NA	NA	NA	NA	NA	NA	K	
Fixed O&M (€/MW/year)	20,000	19,500	18,600	18,000	NA	NA	NA	NA	B	6
Variable O&M (€/MWh)	4.5	4.4	4.2	4	4	6	3	5		6

Technology	Gas turbine, simple cycle (small and medium scale plant) , back pressure									
	2015	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data					**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MW)	5 - 40								F	
Electricity efficiency (condensation mode for extraction plants), net (%)	36	37	39	40	32	40	34	42	G, H	6, 12
Electricity efficiency (condensation mode for extraction plants), net (%), annual average	34	35	37	38	30	38	32	40		6, 11
Cb coefficient (50ºC/100ºC)	0.71	0.73	0.8	0.8	0.61	0.8	0.7	0.9		6, 12
Cv coefficient (50ºC/100ºC)	-	-	-	-	-	-	-	-	J	
Forced outage (%)	2	2	2	2	2	3	2	3		6
Planned outage (weeks per year)	3	2.8	2.5	2.5	2	3.5	1.5	3		6
Technical lifetime (years)	25	25	25	25	25	>25	25	>25	E	6, 7
Construction time (years)	1.5	1.5	1.5	1.5	1	1.5	1	1.5		6
Space requirement (1000m2/MW)	0.04	0.04	0.04	0.04	0.03	0.07	0.03	0.07	G	7
Plant Dynamic Capabilities										
Primary regulation (% per 30 seconds)	0	0	0	0	0	0	0	0	I	
Secondary regulation (% per minute)	20	20	20	20	20	50	20	50	C	6
Minimum load (% of full load)	25	23	20	20	20	25	20	25	A	6
Warm start-up time (hours)	0.25	0.23	0.2	0.2	0.1	0.5	0.1	0.4		5, 6, 8
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.4	1	0.4	1		5, 6, 8
Environment										
SO_2 (degree of desulphuring, %)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	20	15	10	10	10	30	8	20	D	7, 9
CH4 (g per GJ fuel)	1.5	1.5	1.5	1.5	1	8	1	8		9
N2O (g per GJ fuel)	1.0	1.0	1.0	1	0.7	1.2	0.7	1.2		9
Financial data										
Nominal investment (M€/MW)	0.75	0.73	0.70	0.68	0.6	1	0.55	0.95		6, 10
- of which equipment	NA	NA	NA	NA	NA	NA	NA	NA	K	
- of which installation	NA	NA	NA	NA	NA	NA	NA	NA	K	
Fixed O&M (€/MW/year)	20,000	19,500	18,600	18,000	NA	NA	NA	NA	B	6
Variable O&M (€/MWh)	5.5	5.4	5.1	4.6	5	7	4	6		6

Technology	**Gas turbine, simple cycle (micro) , back pressure**									
	2015	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data					**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MW)	0.015 - 0.200									
Electricity efficiency (condensation mode for extraction plants), net (%)	30	30	30	30	23	32	25	35	M	7
Electricity efficiency (condensation mode for extraction plants), net (%), annual average	28	28	28	28	21	29	23	33		
Cb coefficient (50ºC/100ºC)	0.6	0.6	0.6	0.6	0.4	0.85	0.4	0.85		7, 13
Cv coefficient (50ºC/100ºC)	-	-	-	-	-	-	-	-	J	
Forced outage (%)	5	5	5	5	NA	NA	NA	NA		
Planned outage (weeks per year)	NA	NA	NA	NA	NA	NA	NA	NA		
Technical lifetime (years)	15	15	15	15	10	20	10	20	L	
Construction time (years)	0.5	0.5	0.5	0.5	0.3	0.8	0.2	0.7	L	13
Space requirement (1000m2/MW)	0.06	0.06	0.06	0.06	0.05	0.15	0.05	0.15		7
Plant Dynamic Capabilities										
Primary regulation (% per 30 seconds)	0	0	0	0	0	0	0	0		
Secondary regulation (% per minute)	0	0	0	0	0	0	0	0		
Minimum load (% of full load)	40	40	40	40	30	50	25	50	L	7, 13
Warm start-up time (hours)	0.25	0.25	0.25	0.25	NA	NA	NA	(NA)		
Cold start-up time (hours)	0.5	0.5	0.5	0.5	NA	NA	NA	(NA)		
Environment										
SO_2 (degree of desulphuring, %)	0	0	0	0	0	0	0	0		13
NO_X (g per GJ fuel)	10	10	10	10	6	15	6	15		7, 13
CH4 (g per GJ fuel)	6	6	6	6	NA	NA	NA	NA		13
N2O (g per GJ fuel)	NA	NA	NA	NA	NA	NA	NA	NA		13
Financial data										
Nominal investment (M€/MW)	1.2	1.2	1.1	1.0	NA	NA	NA	NA		13, 14
- of which equipment	0.85	0.85	0.8	0.7	NA	NA	NA	NA		13, 14
- of which installation	0.35	0.35	0.3	0.3	NA	NA	NA	NA		13, 14
Fixed O&M (€/MW/year)	NA	NA	NA	NA	NA	NA	NA	NA		
Variable O&M (€/MWh)	15	15	14	13	10	15	8	15		13

Notes:

A Very low efficiency at low loads and often increased Nox emisison

B Insurance excluded, unknown. Daily start assumed

C Power related

D Based on Dry Low NOx (DLN) techniques

E Technical- and design life most often > 25 years

F Electrical output

G Combined with DGC assumptions, CHP configuration

H GT's (5 MWe) are available including internal recuperator; the electrical nominal efficiency is then 37 % (LCV basis)

I No data available, no known use

J Not relevant for this CHP configuration

K No data available

L DGC Estimate

M Air preheating by internal recuperation included

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