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DEVELOPMENT OF INTEGRATED USE OF GAS IN ENERGETICS

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Abstract

Natural gas as the finest source of energy may be widely used also in energetics within integrated systems either in the direct or in the coupled energy production providing a better efficiency. There is a wide range of the coupled energy production with better efficiency depending mainly on demands' size and the way of realization.

Keywords: gas engine, heat pumps, energetic, turbine.

1. Gas Engine Systems

Natural gas as the finest source of energy may be widely used also in energetics within integrated systems either in the direct or in the coupled energy production providing a better efficiency. There is a wide range of the coupled energy production with better efficiency depending mainly on demands' size and the way of realization.

One of the extreme cases is the coupled electric energy supply and heating of small consumers (detached houses, farms, villas). Inventor and entrepreneur Ádám Kovács, famous for Celladam, has a rather interesting and promising initiation for coupled energy supply of small consumers on the basis of Wartburg engines fuelled by gas. The pilot unit drives a three-phase generator with the performance of 15 kW_e. The heating system consists of the engine's cooling water system, heat exchanger of the engine's flue gases and the independent gas fuelled heat exchanger. This latter allows also a direct heat production in the case of engine failure or electric power cut. This announced ambitious project sets out to replace an electric performance of 1500 MW, which corresponds to a new average basic power plant. The full project counts with implementation of 100,000 units comprising detached houses, farms and villas. Gas network is no precondition for farms and agricultural buildings, the local biogas production will also do. When firing with gas, the two-cycle engine meets even the rigorous environmental prescriptions due to the afterburning supplementary combustion included. Simplicity, cheapness and the relative high specific litre perfomance vote for the two-cycle Wartburg engine, production of which is over. The chosen generator performance means a partial loading for the engine, which ensures an acceptable service life of several thousand hours.

This integrated system is thermodynamically advantageous because the high burning temperature maintainable in the internal combustion engine allows a favourably high value of electric performance P_e related to the output heating performance Q_f, i.e. the energetical ratio P_e/Q_f is advantageous.

In comparison to the direct heat production, this system only requires the surplus gas corresponding to the thermal equivalent of electric energy, this means that heat losses, which can be characterized by the thermal efficiency within the direct electric energy production, do not burden the electric energy production.

Prototype of this system is developed under direction of associate professor Dr. Zoltán Fülöp at the Department of Heat Engines, Technical University of Budapest.

This gas engine system brings up some other questions in addition to its indisputable energetic advantages.

Energetic and economic advantages of this system occur mainly when applying it as the alternative to the electrification of farms (energy farm), i.e. in isle mode of operation, in lack of electric network, first of all, just because considerable expenses of network building fall out. In this case, a rather close frequency and voltage control are required so that electrical appliances may not be damaged and their operation may remain enjoyable (e.g. for entertainment electronics).

Automatic operation without supervision is desirable.

The isle mode of operation is anachronistic in an electrified environment, however, the parallel operation raises questions of synchronization, one-phase–three-phase connection, as well as problems of accounting (sale and purchase), metering and tariffing.

The acceptable service life is precondition of the cost-efficient operation. Unfortunately, service life of internal combustion engines is in generator operation moderate in comparison to the service life of combustion: several thousands of hours, which can be increased by partial loading of the engine.

Gas engines' service life may be considerably enlarged by application of the heavy and stable construction for the larger unit performances in MW order of magnitude. However, this applies already to another consumer category, to group consumers.

Rather favourable energetic conditions can be reached with stable gas engines when driving heat pumps' turbo-compressors by gas engines. One unit of gas energy consumed by the gas engine yields 1.6 units of combustion heat output 0.7 of which comes from surroundings waste heat. Just because of this, the integrated system is more advantageous than the heating system with boiler (steam, hot water), where one unit of gas energy results in 0.9 unit of combustion heat in accordance with the boiler's efficiency. This means that heat pumps considerably, by almost 80%, raise the heat output, therefore, they may play an outstanding role in gas-based integrated systems.

2. Heat Pump Systems

Heat pumps operate with the heat cycle and working medium of the refrigerating machine, with the only difference that they use the output heat of condensers for heating. They are widely used in the Scandinavian countries, e.g. in Stockholm 60% of heating demands are met by heat pumps. Even the smaller units are popular there, i.e. they are also applied for heating houses and detached buildings. One unit of input electric energy yields three units of heating heat on average. The larger appliances are cooling-heating units, condensers are used for heating while evaporators supply an air-conditioning distance cooling network. In this way, twice of the input energy can be utilized for cooling, consequently, fivefold quantity of the input electric energy appears in form of thermal energy, and within it unit price of heat extraction for cooling may be considered to be equal with unit price of the electric energy. The large units for public purposes have a heating performance of 20 to 25 MW_t while the larger heat pump plants consist of 4 to 6 units. The large heat pumps are turbo-compressor units driven by electric engines, have a cooling medium harmless to nature, their nominal service life of 25 years is rather favourable, their competitive specific investment costs (34,000 Ft/kW_t) can be compared with those of combined cycle gas turbines (55,000 Ft/kW_e) [2, 3].

Heat pumps are electrically driven for economic and environmental reasons. In Sweden, where products of the famous compressor manufacturer ABB Stal are used, the fully smoke-less electric drive is the most appropriate, on one hand, due to the rigorous environmental prescriptions, on the other hand, because of the electric energy's low price in consequence of the numerous hydraulic and nuclear power plants, even more, heat pumps may come in handy for the little over-developed electric energy system. Gas supply and heat pumps get in touch in places where electric energy is more expensive than in Sweden – just like in Hungary – and heat pumps with electric drive would not be cost-efficient. However, with natural gas a relative cheap current (at the world market price) can be produced on the application site of heat pumps by the help of gas turbines or gas engines waste heat of which can also be utilized. Thus, the efficiency of 85 to 90% can be achieved instead of the efficiency of the direct electricity production of 33 to 35 %. This means that heat pumps are driven by gas turbines or gas engines through transmissions. Although gas turbines with high r.p.m. could even drive heat pumps through a direct coupling, the separate driving axe in electric power transmission is advisable because the independent electric operation of gas turbines is for the peak energy production economically justified.

An advantageous feature of heat pumps is that 2/3 of their output heat comes from the environmental waste heat, thus, all in all, they reduce fuel consumption and emission of combustion products. Cold side of heat pump systems may back on surrounding water sources, rivers, lakes and in towns to sewage network or waste waters from thermal power plants.

Heat pumps are more cost-efficient in thermal aspects with lower heating water temperatures and higher surrounding heat source temperatures, that is why their use is more advantageous in summer operation of distance heating systems for utility hot water production. *Fig. 1* shows the thermal efficiency of a heat pump, ratio of the output heat and driving energy in function of the temperature difference to cover.

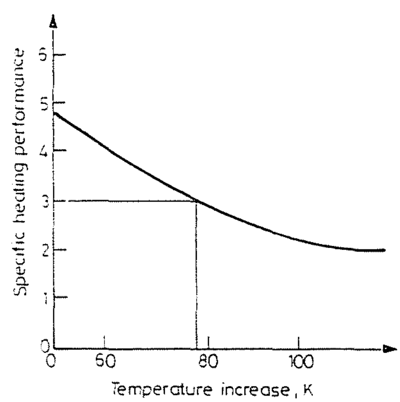

Fig. 1.

That is why it is not advisable to fully warm up the heating water by heat pumps, instead, another preheating stage is necessary at any case. This may be a heat exchanger with steam heating, hot water boiler or heat utilizing boiler of a gas turbine. This latter is favourable in places where gas turbines are applied for transmission drive of heat pumps.

3. Systems Combined with Gas Turbines

Fundamental fuel of gas turbines alternatively fuelled by natural gas and gas oil is natural gas under the Hungarian price conditions. The best efficiency can be reached within this system by joining the gas turbine and steam turbine units and by utilization of the exhaust steam for heating. Thus, first of all, we can expect appearance of this type of units, which can also solve the reconstruction of the aged town heating centres. The announced program for erecting power plants with gas turbines in Hungary reckons before the construction of the new basic power plant with establishment of a capacity of about 700 MW_e by gas turbines able to elastically adjust to demands and to be built easily. The first 150 MW_e unit has already been built in the Dunamenti Power Plant. Another unit of the same type would be necessary there and the other ones should be implemented in urban heating power plants.

Considering all this, let's review the possible solutions. We take the example of the Power Plant in Kelenföld, where the reconstruction for gas turbine will start this year. *Fig. 2* contains the annual diagram of the total heat demand (hot water and steam) of the heating power plant.

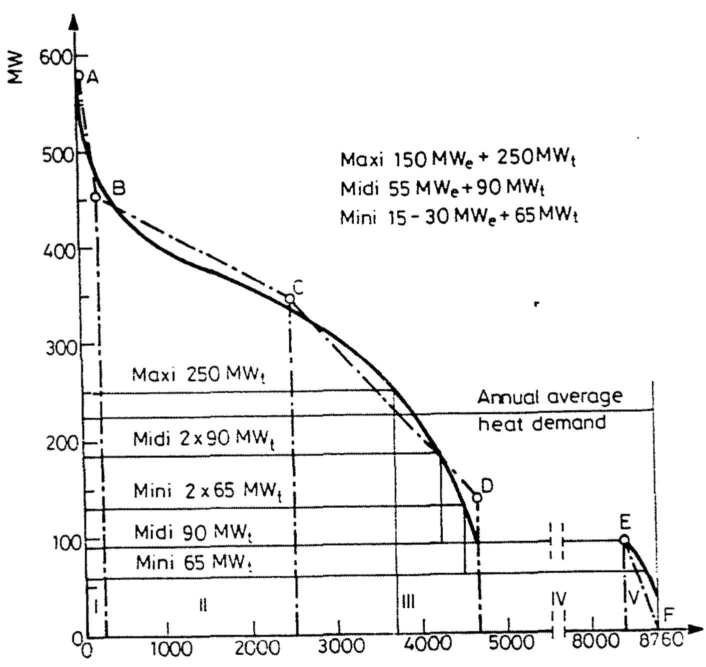

Fig. 2. Heat demand diagram

Heat utilizing boilers of the gas turbines are fit for steam and hot water production alike by implementation of the appropriate bundle of tubes, consequently, in choice of gas turbines the total heat demand is decisive. The following three versions are possible when choosing the gas turbine:

I. Gas Turbine Unit with the Largest Performance (Maxi Version)

This can be chosen starting from the condition that the gas turbine should meet the basic loading by the winter heat demand without supplementary combustion. By this condition, service hours of the gas turbine in heating operation are limited to the value of about 4000 hours a year. Neither can run the gas turbine at the low-efficiency partial loading in summer, or its run requires a steam receiving facility independent of heat consumers, e.g. in form of a condensation steam turbine. However, this cannot be recommended in urban areas for environmental reasons. Fuel consumption and pollutant emission are with the maxi version the largest. However, it is true that this gives the highest energetic index, which thermodynamically votes for the maxi version.

Modern gas turbines with gas combustion are rather clean power machines; with water/steam injection hybrid burners even the 25 ppm NO_x concentration can be reached almost with all the market-rife types. Despite this, because of the vast flue gas quantity, environmental protection considers the annual absolute emission, which may reach 1000 t a year, rather than this concentration.

Another disadvantageous feature of this version is that due to the large unit performance, the existing, usually, 6-bar pressure gas supply system of the power plant does not fit. Establishment of a new, expensive, high-pressure gas pipeline (with nominal pressure of 40 bar) and gas supply system joinable to 12 to 16 bar work processes of gas turbines is necessary.

A further drawback is that the summer operation of the high performance heating gas turbines is not solved or it is disadvantageous, thus, they cannot operate just in periods when gas is available for power plants' purposes. In winter, when conditions for their cost-efficient operation are guaranteed, gas quantity available for power plants' purposes is limited. Supplementary gas oil is rather expensive, it costs about three times the natural gas price, this way strongly worsening cost-efficiency of gas turbines' winter run. We note here that this problem is not so sharp with the G1 block of the Dunamenti Power Plant because the industrial steam supply also provides for the summer operation.

As a disadvantage we mention that the large gas turbine unit simultaneously requires a large reserve capacity (in gas and heat production).

We have to reckon with a reserve capacity of 80%, which requires the complete reconstruction of the existing and outworn steam power plant, which is rather expensive.

Because of the gas turbine performance of 110 to 150 MW_e prescribed in the tender for the Kelenföld power plant the maxi version outlined above was chosen. Performance of its heat utilizing boiler is 250 MW_t, which considerably surpasses the system's summer heat demand of 90 MW_t. This is what causes problems in summer operation of the maxi gas turbine unit.

II. Medium-performance Gas Turbine Unit (Midi Version)

It originates from the condition that the gas turbine unit should provide for the summer heat demands without supplementary combustion. In the case of one single unit it can be utilized all over the year. For reserve purposes or economic considerations two identical units can also be used. However, exploitation of the second unit is only 4000 hours a year just as with the maxi version. This midi version would mean in the case of the cited example in Kelenföld a gas turbine with a 50 MW_e performance and a heat utilizing boiler with 90 MW_t heat performance.

With this version the advantage of the favourable summer gas supply of the gas turbine can be taken and the establishment of a new, high-pressure natural gas system is not necessary. Gas turbines of this size can be supplied by gas from the existing 6-bar pressure system by implementation of 1 to 2 pressure increasing bolt compressors. The pollutant emission of the midi version with one unit is less than that of the maxi version, however, its energetic index is also lower, although the economic objective is not this. The economic objective is to reach the lowest specific cost of heat production.

III. The Smallest Gas Turbine Unit (Mini Version)

Heat supply can also be solved by small-performance gas turbines within a mini version if the gas turbine unit is chosen small enough to meet even summer demands with supplementary combustion of a heat utilizing boiler and with the use of heat pumps. In the case of our example in Kelentföld the heat utilizing boiler of the 30 MW_e performance gas turbine unit would have a heating performance of 65 MW_t with the supplementary combustion. As this does not reach the summer heat demand of 90 MW_t. the difference could be covered by a heat pump with a 25 MW_t heating performance, which would provide for the summer utility water supply. Heat utilizing boiler of the gas turbine unit would supply the industrial steam.

In the case of a back-pressure power plant (like our example in Kelenföld) supplementary combustion necessary in the mini version does not worsen the efficiency as mass flow and outgoing temperature of the flue gas practically do not change with the supplementary combustion, and thus, neither does the flue gas loss.

The mini version implies the smallest natural gas consumption and pollutant emission because in meeting heat demands it also uses surrounding waste heat by the help of heat pumps, which is rather favourable for the environmental protection. Energetic index of this version is the lowest, however, in an urban site we may not set as objective to increase electric energy production and, on the other hand, the economic objective also prescribes minimization of the specific cost for heat production.

Just as with the midi version, economical utilization of the capacity of the equipment can be ensured, furthermore, the existing 6-bar pressure gas supply system with pressure increasing bolt compressors works even better here.

Due to the smaller gas turbine units, the demands for reserve steam and heat production are smaller with the midi and mini versions, thus, they are less expensive.

IV. Gas Turbines Coupled before Hot Water Boilers

This concept has been prepared by the team of the Department of Heat Engines. This again implies the integration of heat and electric energy production, however, it is a mini gas turbine version. This is a cost and gas saving solution, gas supply is provided by the help of bolt compressors. This suggestion contains use of a 10 MW preceding gas turbine with hot water boilers PTVM-100 and 20 MW preceding gas turbine with PTVM-180 hot water boilers, in addition to the supplementary combustion with hot water boilers [1].

The electric performance of the mini gas turbine unit covers abundantly the power input of the heat pump. There is a possibility for separating electric energy production and utilization in time by producing electric energy in the more valuable peak hours and getting input power in cheaper time periods, which considerably raises the cost-efficiency (peak operation).

For reserves and economic reasons it is advisable to implement two pieces of mini units. The unit performance specified in tender for gas turbines in Kelenföld did not allow midi and mini units for producers.

Upon request of the Ministry for Industry and Trade, the ABB-Láng Co. Ltd. elaborated the mini gas turbine version with heat pump. Within a simplified cost estimation we will tabulate below the economic characteristics of the possible solutions with gas turbines comparatively analysing their annual costs. The individual versions are almost the same regarding the minimum unit cost of heat production as objective. That is why we find expedient for decision making a wide-range and correct examination, and permitting participation of all the versions by the tender specs. In addition we note that the almost identical specific heat production cost was achieved with the completely gas firing within the version shown. When considering also the gas oil firing within a more precise analysis, the maxi version becomes the most expensive as the gas turbine in that version does not work in summer.

Due to changes in the industrial structure, the trend of decreasing industrial steam systems can be observed, which is most harmful again for the maxi version. Within the mini gas turbine version we did not estimate the possible sales receipts from distance cooling, taking also this into account, this version may become the cheapest.

4. Fitting into the Electric Energy System

With growing demand for electric energy, performance of both gas engines and gas turbines could be utilized without any problem by replacing import, elimination of worn out power plants and postponement of the construction of the new basic power plant.

Trend prediction is rather difficult due to temporary processes of the economic system change and structure change as well as because of the world economic recession. For the time being, demands for electric energy continue to fall – like the trends in the last 3 to 4 years – even if at a decelerating rate. The same trend can be observed in volume of GDP which is in close connection with the electric energy consumption. According to predictions for GDP, its 1989 level will be attained only about the turn of the millenium or afterwards, which we may refer also to the electric energy consumption.

Within these economic circumstances, realization of the gas engine and gas turbine programs would result in replacement of the coal-based power plants working with a relatively high cost level. This would lead to coal mining reduction and sharp employment problems. In this respect, spread of maxi gas turbine heating units would cause higher stresses than that of smaller ones. As they are more favourable also in environmental and economic aspects, furthermore, they meet our special economic condi-

Table 1
Comparison of gas turbine versions
(through the example of the Kelenföld power plant)

Versions		Maxi	Midi		Mini
Gas turbine performance	MW_e	1×150	1 × 50	2 × 50	2 × 30
Investment costs	10^9Ft/year	10.0	6.69	9.4	8.4
Annual plan of investment and maintenance (12+2.5%)	10^9Ft/year	1.45	0.97	1.363	1.218
Output electric energy	GWh/year	909	707.5	938	586
Sales receipts (3.7 Ft/kWh)**	10^9Ft/year	3.363	2.617	3.47	2.168
Fuel consumption	TJ/year	12.169	11.375	12.353	9.986
Fuel costs (375 Ft/GJ)**	10^9Ft/year	4.563	4.265	4.632	3.744
Heat output	TJ/year	7,000	7,000	7,000	7,000
Costs for heat ouput	10^9Ft/year	2.65	2.618	2.525	2.793
Unit cost of heat production	Ft/GJ	378.6	374	360.7	399.1*
Share of gas turbines in heat production		0.556	0.33	0.564	0.441
Share of heat pumps in heat production		—	—	—	0.195
Share of waste heat in heat production		—	—	—	0.130
Share of gas turbines in electric energy		0.727	0.676	0.755	0.676
Share of gas turbines in peak heat performance		0.417	0.142	0.248	0.216
Share of electric energy in heat production		—	—	—	0.065

* Without sales receipts by the possible distance cooling
** at unit prices of the Symposium Cogen Turbo (1991)

tions better, we suggest the use of these types. Of course, with economic growth, considerations may change, and the maxi version can step forward, however, even then we can reckon with a strong competition with regard to the minimum specific unit cost of heat production, first of all, with versions with heat pumps, especially, when demands for distance cooling in summer will rise.

At present, development plans with gas turbines are prepared for all the important heating power plants of the country according to the maxi version. Their realization is hampered not only by the lack of capital but also by the limited natural gas volume available for power plants as well as the diminishing tendency of electric energy consumption. We also have to take the fact into account that even the ambitious gas engine program sets out to be realized with decreasing use. These contradictions should be compared and regulated within a comprehensive energetic concept because this spontaneous development foretells a lot of conflicts.

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