Aeroderivative Gas Turbo engine in CHP Plant. Compatibility Problems

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Abstract: *The paper presents the possibilities to develop Combined Cycle Units based on aeroderivative Gas Turbo engines and on existing Steam Turbines. The specific compatibility problems of these components and the thermodynamic performances of the analyzed Combined Cycle Units are also presented.*

Key Words: Aeroderivative Gas Turbine, Combined Cycle Unit, existing components, compatibility.

1. INTRODUCTION

The actual technological level and concepts regarding the heat and electric power generation require the development of Combined Cycle Units (CCU).

The strategy of CCU development depends on the economy. For countries with a high economic level, the solution is to develop new CCU with a high performance. These CCU can operate alongside with the old units or can replace them. Countries with low capacity of investments, as Romania, are forced to upgrade gradually the existing units in order to transform them in Combined Cycle Units. In fact, this strategy imposes to make use as much as possible of the existing units components, or of those available or that can be manufactured in Romania. For example, at S.C. TERMICA R.A. - Botoşani a simple CHP unit, consisting of an aeroderivative GTE 2000 Gas Turboengine (available in Romania) and an existing CAF 6 hot water boiler has been developed [1], [2]. The positive results of this simple CHP unit project led to the further studies concerning the possibility to develop CCU with existing components.

The goal of this study is to establish the suitable types of Gas Turboengines (GT) and Steam Turbines (ST) – available or that could be made in Romania –to be connected so as to result a gas-steam CHP Unit (TMX or TMD). There are also presented the thermodynamic performances of these units when Heat Recovery Steam Generators (HRSG) are special designed for each possible combination. We mention that this kind of steam generators can be made in Romania.

Because of the high price of the electric power, the study refers just to the electric power generation even if the possibilities for CCU development are more restricted in this case.

2. AVAILABLE COMPONENTS FOR COMBINED CYCLE UNITS

Gas Turbo engines. The following aero derivative GT types are now available in Romania, among others: AI-20, TURMO-IV C, MK 701, VIPER-45, VK-1, R11-F300, and RD-9B.

The first two are turboprop engines (with power shaft) and the others are turbojet engines. A turbojet engine can be adapted to drive an electrical generator by substituting the exhaust nozzle with a compatible power turbine (proceeded also from available turbojet engines). This modification can be made in Romania [5], [6].

Steam Turbines. ST of 1…400 MW are now available or can be built in Romania. Considering the parameters of the available TG, five ST types were selected for this study, namely: AP-3-1, AKP-3, AKSR-6, RC-12 and AC-6. These turbines operate with steam mass flow rates of 7, 23…22, 83 kg/s while the usual steam parameters are 35 bar and 435°C.

Steam Generators. Steam generators with steam mass flow rate of 10…1035 t/h, rated pressures of 15…190 bar and steam temperatures of 350…540°C are currently operative or can be built in Romania. Heat Recovery Steam Generators with steam parameters in these ranges can be also made in Romania.

3. COMPUTER PROGRAM

In order to develop the study of CCU, an original calculation algorithm was conceived. Based on this algorithm, a computer program named ABURGAZ 3 was made.

The following parameters are used:

- η_{TG}, η_{TV} - thermal efficiencies of GT and ST, respectively;
- η_{ig}, η_{iv} - internal efficiencies of GT and ST, respectively;
- η_c - isentropic efficiency of the GT compressor;
- ε, n - GT compressor pressure ratio and number of the available GT, respectively;
- η_{TMX}, η_{TMD} - thermal efficiencies of CCU operating with the ideal GT and with n available GT, respectively;
- G_{aX}, G_a - inlet air mass flow rate of the ideal GT and of an available GT, respectively;
- G_v, G_{vD} - steam mass flow rate of ST on the rated capacity and steam mass flow rate that can be obtained with n available GT, respectively [kg/s];
- P_{TGX}, P_{TGD} - power generated by the ideal GT and n available GT, respectively;
- P_{TV}, P_{TVD} - power generated by ST on the rated capacity and power generated by ST when CCU operates with n available GT, respectively [kW];
- i_{2p}, i_3, i_1 - enthalpies of water at the saturation temperature, steam and condensate;
- T_T, T_E, T_P, T_F - gas temperature on the turbine inlet, on the HRSG entrance, on the economizer entrance, on the economizer exit;
- T_3, T_{2p} - steam temperature and saturation temperature of water;
- TMX, TMD - CCU operating with an ideal GT and with n available TG, respectively;
- X, D - characteristic indexes of CCU operating with an ideal GT and with n available TG (function by the adopted type of GT, "D" may be replaced with "AI-20", "MK-701", "VIPER-45"), respectively.

The input data of the program are i_3, i_1, i_{2p}, η_{ig}, η_{iv}, η_c, G_v, T_T and ε. Two conditions are met, as follows - $T_E > T_3$ and $T_P = T_{2p} + 8°$. The output data are η_{TMX}, η_{TGX}, P_{TGX}, G_v, P_{TV}, η_{TV}, T_{2p}, P_{TMX}.

Compared with any available GT, the ideal gas turbo engine (TGX) should operate with:

- the same ε, T_T and η_i;

- the suitable gas flow rate on the HRSG inlet in order to ensure for ST the rated steam mass flow rate (G_v) on the rated steam parameters.

For an available GT and a given ST operating on the rated parameters it was defined the parameter:

$$X = G_v / G_{aX} \tag{1}$$

The compatibility condition for an available GT and a given ST is

$$G_v / G_a = G_v / G_{aX} = X \tag{2}$$

It is very difficult to satisfy this condition. The only practical possibility is to couple two or more available TG with a given ST. In this case X become

$$X_D = G_v / n \cdot G_a \tag{3}$$

In order to keep p_3 and T_3 on the rated values, the compatibility condition for this case is:

$$X = G_v / G_{aX} = G_v / n \cdot G_a = X_D \tag{4}$$

Usually, $n \cdot G_a \neq G_{aX}$ and two cases can be separated:

1. $n \cdot G_a > G_{aX} \Leftrightarrow X_D < X$ – in this case thermal energy is exceeding; the excess thermal energy (+ΔQ) can be used for heating;
2. $n \cdot G_a < G_{aX} \Leftrightarrow X_D > X$ – in this case a thermal energy deficit appears; there are two possible solutions:

2.1. Reduction of the steam mass flow rate; consequently the ST power decreases.
In this situation the steam mass flow rate delivered by HRSG is:

$$G_{vc} = X \cdot n \cdot G_a \quad [kg/s] \tag{5}$$

The power and thermal efficiency of CCU are:

$$P_{TMD} = n \cdot P_{TGD} + X \cdot n \cdot G_a \cdot P_{TV} \quad [kW] \tag{6}$$

$$\eta_{TMD} = \eta_{TGD} + X \cdot n \cdot G_a \cdot P_{TV} / Q_1 \tag{7}$$

2.2. The use of supplemental firing in order to compensate the thermal energy deficit and to maintain the steam parameters on the rated values. The burned gas temperature rises up to a proper value – T_M. In this case the compensated thermal energy deficit is:

$$\Delta Q = n \cdot G_a \cdot (1 + \lambda \cdot L_0) \cdot \overline{c_p} \cdot (T_M - T_E) / \lambda \cdot L_0 \quad [kW] \tag{8}$$

The power and the thermal efficiency of CCU are:

$$P_{TMD} = n \cdot P_{TG} + P_{TV} \quad [kW] \tag{9}$$

$$\eta_{TMD} = \left(n \cdot P_{TG} + P_{TV}\right) / \left(Q_1 + \Delta Q\right) \tag{10}$$

The thermal energy Q_1 introduced in the TG combustion chamber corresponds to the necessary stoichiometric air [kg air/kg fuel]; λ is air excess coefficient.

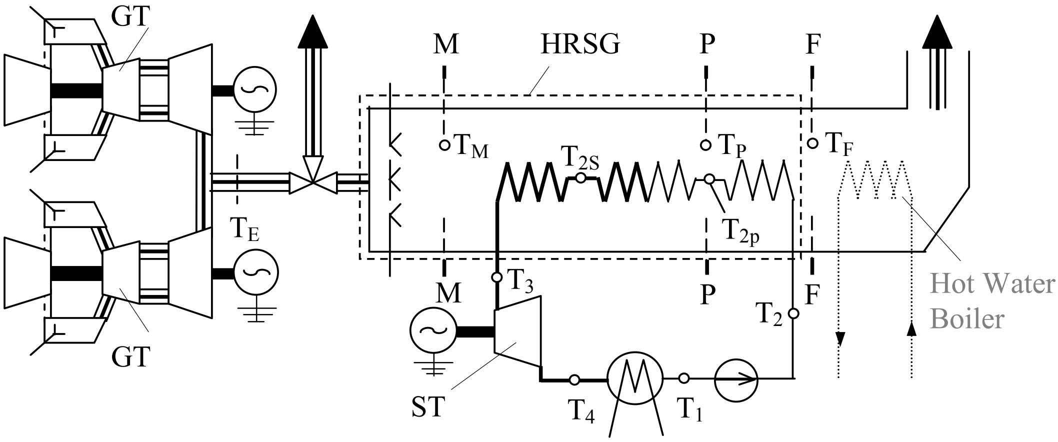

Fig. 1 – Analyzed CCU scheme

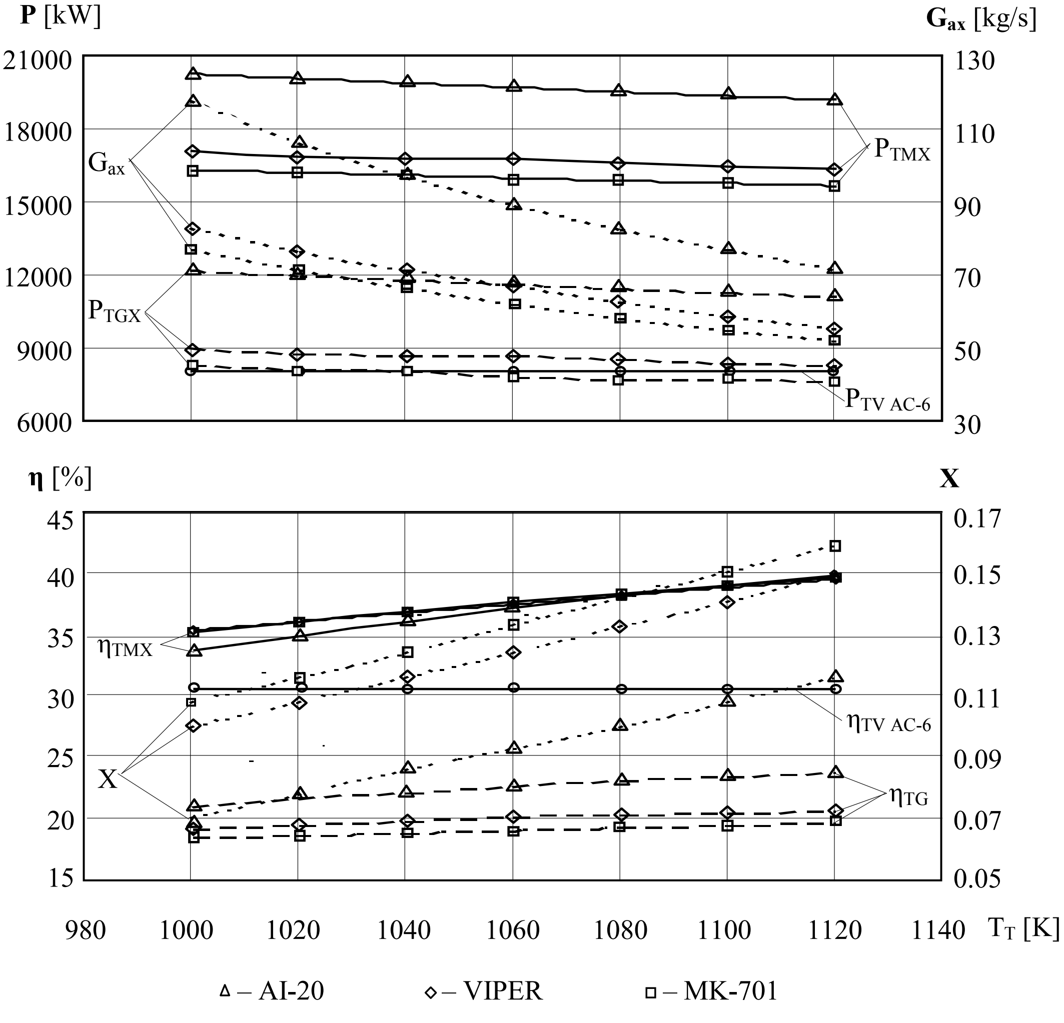

Fig. 2 – Variation of CCU characteristic parameters with T_T

The CCU versions analyzed in the paper are based on the scheme presented in fig. 1. This scheme consists of an existing ST and two existing GT. The Hot Water Boiler was also represented in fig. 1, but this component was not considered in the present analysis.
By using the ABURGAZ-3 computer program the operational parameters for nine CCU versions have been established. These versions were obtained combining three types of ST (AP-3-1, RC-12, AC-6) and three types of GT (AI-20, MK 701, VIPER-45).
The analysis indicates that highest performance of CCU is obtained when utilizing the ST type AC-6. The variation of CCU characteristic parameters with T_T for the three CCU versions based on ST AC-6 type (coupled with GT type AI-20, MK 701 and VIPER-45, respectively) is presented in fig. 2.

4. CONCLUSIONS

The analysis of the nine CCU versions leads to the following conclusions:

1. The power and the thermal efficiency of CCU versions consisting of an AC-6 ST are $\eta_{TMD} = 0.366...0.381$ and $P_{TMD} = 14500...16600\,kW$ (AC-6 / VIPER-45 combination can be realized most easily);
2. The thermal efficiency of CCU is always higher then the thermal efficiency of the individual GT or ST unit (16…18% more than GT and 6…8% more than ST). Thermal efficiencies of the studied CCU are higher than thermal efficiencies of the most efficient power units currently operating in Romania;
3. The condition regarding only the power generation is restrictive. The economic advantages are more significant when this restrictive condition is removed (when thermal energy and power are concomitantly generated, which means to take into consideration a Hot Water Boiler, as fig. 1 suggests). Besides, if this restrictive condition is removed it is easier to adapt an available turbojet engine (most used in Romania) in order to work with an existing ST in a CCU.
4. The performances of the simple unit or CCU based on existing components (or feasible in Romania) indicate this strategy as a significant one in the current conditions.

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