# Aeroderivative Pratt & Whitney FT8-3 gas turbine – an interesting solution for power generation

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***Abstract:*** *The intermediate load electric power stations become more and more interesting for the electric power market in Romania. In this context, the Combined Cycle Power Plants came as a very attractive solution. This paper presents the results of a study regarding the use of the aeroderivative Pratt & Whitney FT8-3 gas turbine, available in Romania, for the electric power generation in a Combined Cycle Power Plant. It is also analyzed the Combined Heat in Power generation with FT8-3 gas turbine when saturated steam or hot water are required.*

*Key Words: electric power, combined cycle, combined heat and power, efficiency*

## 1. INTRODUCTION

Maximum efficiency and minimum pollution are the main objectives of the development and design processes of energy systems. From both points of view, the Gas-Steam Combined Cycle Power Plants (CCPP) is the current leader in the medium and high powers field.

As long as the current Gas Turbine Power Plants (both frame type or aeroderivative) operate with efficiencies up to 40%, the highest cost / highest efficiency combined cycles, optimized for the basic load needs, reach an efficiency of even 60% [1], [2].

In this context, CCPP came as a very attractive solution for the Romanian electric power market, which is opened for 25…,40 MW power stations.

The CCPP solution analyzed in the paper corresponds to the principle "higher cost / higher efficiency" and is based on the aeroderivative Pratt & Whitney FT8-3 Gas Turbine (GT), which is available in Romania. The Combined Heat and Power (CHP) generation with FT8-3 GT for cases when saturated steam or hot water are required was also analyzed.

The analysis of CCPP takes into consideration only the electric power generation (the thermal power generation is neglected).

## 2. PRESENTATION OF THE POWER PLANT

Schematic of the CCPP is presented in fig. 1 a. As mentioned above, CCPP is based on the FT8-3 GT. A steam cycle with one pressure level was considered.

Schematic of the CHP Plant is presented in fig. 1 b). The scheme includes the evaporator (EV) only when CHP Plant produces saturated steam. When CHP Plant produces hot water HRSG is replaced by HWB. Obviously, EV is absent in this case.

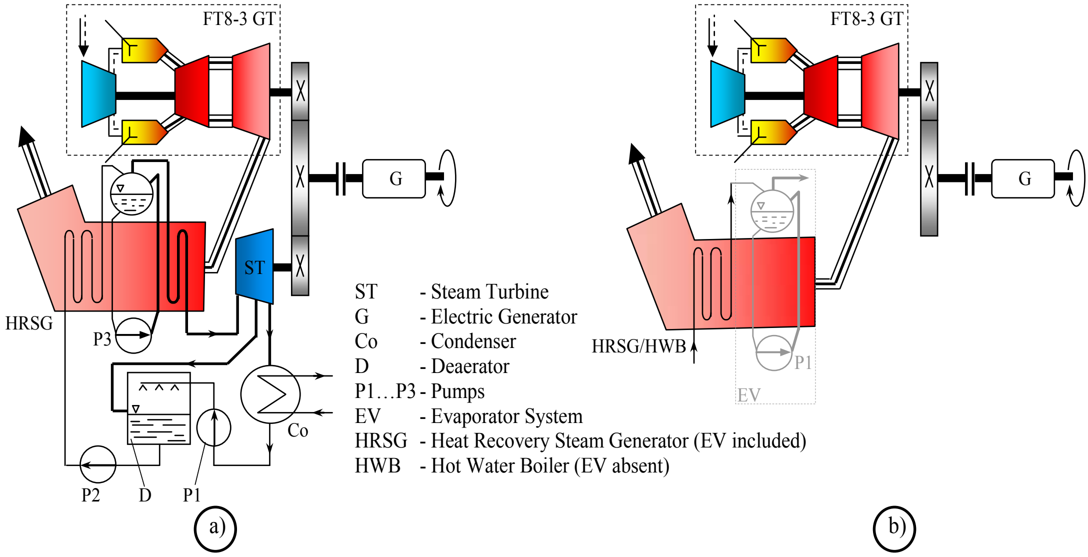


Fig. 1 – Analyzed configurations of CCPP and CHP

The FT8 is a 25 MW GT consisting of a gas generator derived from the JT8D-219 aircraft engine and a separate power turbine. Power turbines are available optimized for electric power generation (3000 or 3600 RPM) or mechanical drive (5500 RPM nominal speed). The FT8-3 GT is an updated model of FT8 which increases hot day power (35°C ambient temperature) by 15% [2].

The FT8-3 GT operates with gas fuel, LHV = 48078 kJ/kg. At $p_0$ = 1.013 bar and $T_0$ = 288 K (ambient conditions) the characteristic parameters of FT8-3 are:

- fuel consumption - FC = 6335 kg/h
- exhaust gas mass flow rate - $G_g$ = 91.42 kg/s
- exhaust gas temperature - $T_i$ = 759 K
- output – individual operation - $P_{GT}$ = 30480 kW
- specific fuel consumption - $SFC_{GT}$ = 0.208 kg/kWh

## 3. POWER PLANT PERFORMANCE ESTIMATION

The analysis was made for following parameters:

- GT output loss (caused by HRSG passing) - $\Delta P_{GT} = 0.05 \cdot P_{GT}$
- HRSG exhaust temperature (minimum admitted value) - $t_e$ = 120°C
- heat transfer efficiency (for HRSG heat exchangers) - $\eta_x$ = 0.95
- bled steam pressure - $p_{BS}$ = 1.2 bar
- condensing pressure - $p_C$ = 0.05 bar
- pinch point (minimum admitted value) - $\Delta t_p$ = 25 deg

- steam turbine isentropic efficiencies - $\eta_S = 0.86$
- steam turbine mechanical efficiencies - $\eta_m = 0.99$

We mention that HRSG inlet gas temperature is 759 K / 486°C – equal with GT exhaust gas temperature, because there is no supplemental firing.

The parameters of steam and hot water had been established according to STAS 2764-86.

In order to estimate the performances of CCPP the following parameters had been calculated [3], [4], [5], [6]:

- GT efficiency – simple cycle

$$\eta_{GT-SC} = 3.6 \cdot 10^3 \cdot \frac{P_{GT}}{FC \cdot LHV} \tag{1}$$

$$\eta_{GT-SC} = 0.36$$

- GT efficiency – combined cycle

$$\eta_{GT-CC} = 3.6 \cdot 10^3 \cdot \frac{P_{GT} - \Delta P_{GT}}{FC \cdot LHV} \tag{2}$$

$$\eta_{GT-CC} = 0.342$$

- Steam Turbine output

$$P_{ST} = \left[ G_w \cdot \left( i_S - i_{BS} \right) + G_{co} \cdot \left( i_{BS} - i_{co} \right) \right] \cdot \eta_m \quad [\,kW\,]\ , \tag{3}$$

where: $G_{co}$ - steam mass flow on the steam turbine exhaust [kg/s];
$i_S$ - steam turbine inlet enthalpy [kJ/kg];
$i_{BS}$ - bled steam enthalpy [kJ/kg];
$i_{co}$ - steam turbine exhaust enthalpy [kJ/kg];
$G_w$ - steam mass flow delivered by HRSG [kg/s]; it is calculated with the following formula

$$G_w = \frac{Q_u}{i_S - i_w} = \frac{G_g \cdot \left( i_i - i_e \right) \cdot \eta_x}{i_S - i_w} \quad [\,kg/s\,]\ . \tag{4}$$

In (4) we denoted:
$Q_u$ - heat absorbed in HRSG [kW];
$i_w$ - HRSG feed water enthalpy [kJ/kg];
$i_i$ - HRSG inlet enthalpy [kJ/kg];
$i_e$ - HRSG exhaust enthalpy [kJ/kg].

- Steam Turboengine efficiency

$$\eta_{ST} = \frac{P_{ST}}{G_g \cdot \left( i_i - i_e \right)} \tag{5}$$

- CCPP overall output

$$P_{CC} = \left( P_{GT} - \Delta P_{GT} \right) + P_{ST} \quad [\,kW\,] \tag{6}$$

- Specific fuel consumption of CCPP

$$SFC_{CC} = FC / P_{CC} \quad [kg / kWh] \tag{7}$$

Table 1 – Parameters of the CCPP based on FT8-3 GT

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Steam pressure | gauge | [bar] | 15.7 | 15.7 | 14.7 | 14.7 | 14.7 |
| | absolute | [bar] | 16.7 | 16.7 | 15.7 | 15.7 | 15.7 |
| Steam temperature | | [°C] | 320 | 250 | 350 | 300 | 250 |
| Drum pressure | gauge | [bar] | 16.6 | 16.6 | 15.5 | 15.5 | 15.5 |
| | absolute | [bar] | 17.6 | 17.6 | 16.5 | 16.5 | 16.5 |
| Saturation temperature | | [°C] | 206 | 206 | 203 | 203 | 203 |
| HRSG exhaust gas temperature ($t_e$) | | [°C] | 176 | 172 | 176 | 173 | 170 |
| Pinch point ($\Delta t_p$) | | [°C] | 25 | | | | |
| Heat absorbed in HRSG ($Q_u$) | | [kW] | 29364 | 29730 | 29364 | 29638 | 29912 |
| HRSG feed water temperature | | [°C] | 100 | | | | |
| Steam production ($G_w$) | | [t/h] | 39.8 | 42.9 | 38.8 | 40.8 | 43.1 |
| Steam Turbine output ($P_{ST}$) | | [kW] | 8792 | 8697 | 8815 | 8731 | 8670 |
| Steam Turboengine efficiency ($\eta_{ST}$) | | - | 0.284 | 0.278 | 0.285 | 0.280 | 0.275 |
| CCPP overall output ($P_{CC}$) | | [kW] | 37748 | 37653 | 37771 | 37687 | 37626 |
| Specific fuel consumption ($SFC_{CC}$) | | [kg/kWh] | ***0.168*** | | | | |
| CCPP overall efficiency ($\eta_{CC}$) | | - | ***0.446*** | ***0.445*** | ***0.446*** | ***0.445*** | ***0.445*** |

Table 2 – Parameters of the CHP consisting of FT8-3 GT and HRSG for saturated steam

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steam pressure | gauge | [bar] | 68.7 | 22.5 | 19.6 | 14.7 | 12.7 | 7.85 | 3.9 | 0.7 |
| | absolute | [bar] | 69.7 | 23.5 | 20.6 | 15.7 | 13.7 | 8.9 | 4.9 | 1.7 |
| Saturated steam temperature | | [°C] | 285.5 | 220.7 | 213.9 | 200.5 | 194.1 | 174.7 | 151.2 | 115.4 |
| Feed water temperature | | [°C] | 100 | 100 | 100 | 100 | 100 | 40 | 40 | 40 |
| HRSG exhaust gas temperature ($t_e$) | | [°C] | 209 | 176 | 173 | 166 | 163 | 120 | 120 | 120 |
| Pinch point ($\Delta t_p$) | | [°C] | 25 | 25 | 25 | 25 | 25 | 27.3 | 36.6 | 50.8 |
| Heat absorbed in HRSG ($Q_u$) | | [kW] | 26349 | 29377 | 29652 | 30291 | 30566 | 34468 | 34468 | 34468 |
| Steam production ($G_w$) | | [t/h] | 40.4 | 44.5 | 44.9 | 46 | 46.5 | 47.6 | 48.1 | 49 |
| CHP overall output ($P_{CHP}$) | | [kW] | 55305 | 58333 | 58608 | 59247 | 59521 | 63424 | 63424 | 63424 |
| Specific fuel consumption ($SFC_{CHP}$) | | [kg/kWh] | ***0.115*** | ***0.109*** | ***0.108*** | ***0.107*** | ***0.106*** | ***0.1*** | ***0.1*** | ***0.1*** |
| CHP efficiency ($\eta_{CHP}$) | | - | ***0.654*** | ***0.689*** | ***0.693*** | ***0.7*** | ***0.704*** | ***0.75*** | ***0.75*** | ***0.75*** |

Table 3 – Parameters of the CHP consisting of FT8-3 GT and Hot Water Boiler

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Inlet water temperature | [°C] | 70 | 70 | 70 | 70 | 90 | 70 |
| Outlet water temperature | [°C] | 160 | 150 | 130 | 120 | 130 | 90 |
| HRSG exhaus gas temperature ($t_e$) | [°C] | 120 | | | | | |
| Heat absorbed by water ($Q_u$) | [kW] | 34468 | | | | | |
| Hot water production ($G_w$) | [t/h] | 325.2 | 366.4 | 490.1 | 589.0 | 733.3 | 1478 |
| CHP overall output ($P_{CHP}$) | [kW] | 63424 | | | | | |
| Specific fuel consumption ($SFC_{CHP}$) | [kg/kWh] | ***0.1*** | | | | | |
| CHP efficiency ($\eta_{CHP}$) | - | ***0.75*** | | | | | |

- CCPP overall efficiency (electrical)

$$\eta_{CC} = 3.6 \cdot 10^3 \cdot \frac{P_{CC}}{FC \cdot LHV} \tag{8}$$

The results of the calculus are presented in Table 1.

In the case of a CHP Plant, the overall electrical efficiency is calculated with formula (2). For CHP versions with Hot Water Boiler, the hot water mass flow is also given by formula (4) but, in this case, $i_S$ and $i_w$ are the outlet / inlet water enthalpies.
The CHP Plant performances are indicated by the following parameters:

- CHP overall output

$$P_{CHP} = \left(P_{GT} - \Delta P_{GT}\right) + Q_u \quad [kW] \tag{9}$$

- Specific fuel consumption of CHP Plant

$$SFC_{CHP} = FC / P_{CHP} \quad [kg / kWh] \tag{10}$$

- CHP overall efficiency (electrical + thermal)

$$\eta_{CHP} = 3.6 \cdot 10^3 \cdot \frac{\left(P_{GT} - \Delta P_{GT}\right) + Q_u}{FC \cdot LHV}\,. \tag{11}$$

In Table 2 and Table 3 the values of the CHP characteristic parameters for both saturated steam and hot water versions are presented.

## 4. CONCLUSIONS

1. Compared with the most advanced CCPP, which operate with $\eta_{CC}$ up to 60%, the analyzed CCPP seems to be modest in terms of performance point of view; but, as long as it has $\eta_{CC}$ = 0.446, the analyzed CCPP outmatches all the Power Plants that operating now in Romania. Besides, the analyzed configuration corresponds to the principle “higher cost / higher efficiency” and not “the highest cost / the highest efficiency”, which is applied in the case of the most advanced CCPP.
2. For FT8-3 GT in single operation, $\eta_{GT\text{-}SC}$ = 0.36 and $SFC_{GT}$ = 0.208 kg/kWh; as long as the analyzed CCPP operates with $\eta_{CC}$ = 0.446 and $SFC_{CC}$ = 0.168 kg/kWh it can be concluded that steam cycle improves the Power Plant performances with 24%.
3. CHP Plant based on FT8-3 GT can generates 40.4 to 49 t/h of saturated steam or 325.2 to 1478 t/h of hot water, function by the steam / water thermodynamic parameters.
4. As long as the minimum admitted value of $t_e$ (120°C) can be achieved, CHP Plant performances are highest ($\eta_{CHP}$ = 0.75, $SFC_{CHP}$ = 0.1 kg/kWh). When CHP Plant produces hot water, this condition is always fulfilled; when Power Plant produces saturated steam, this condition is broken when steam pressure increases and minimum pinch point condition can not be fulfilled anymore for $t_e$ = 120°C. In this case $t_e$ increases and CHP performances are consequently reduced. The worst case is the one represented by column 1 in the Table 2, when the absolute pressure of steam is of 69.7 bar and the saturation temperature is 285.5°C. In this case, the minimum admitted pinch point condition imposes $t_e$ = 209°C, which leads to $\eta_{CHP}$ = 0.654 and $SFC_{CHP}$ = 0.115 kg/kWh.

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