PWPS/Aeroderivative Gas Turbine for Fast Demand Response in Coming Ancillary Market

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The introduction of large-scale renewable energy projects such as solar and wind power generation has become a global trend. However, as is well known, renewable energy is very unstable, and solar power cannot be generated after sunset. This has already become a major problem, and in some regions, solar power generation has to be restricted for the stable operation of the electric grid system. To further expand the introduction of renewable energy in the future, it is essential to install thermal power sources to compensate for load fluctuations in the electric grid system. This power supply requires fast startup and ramp rate characteristics and high efficiency with lower CO_2 emissions, and the aeroderivative gas turbine (Aero GT), which is most suitable for these requirements, will be introduced here.

In Japan, the market is expected to shift to full liberalization through the separation of power generation and transmission, and the capacity and adjusting capacity market as Ancillary market will be developed based on power system stabilization at the time of renewable energy introduction. The Aero GT is a promising product for this market and this paper describes the characteristics of the Aero GT and examples of its activities in Europe and the U.S.A.

1. Characteristics of PWPS aeroderivative gas turbine

PW Power Systems, Inc. (PWPS) is a manufacturing and sales company of Aero GT that was established in 1961. PWPS was acquired by Mitsubishi Heavy Industries, Ltd. (MHI) in 2013, and became a wholly-owned subsidiary of Mitsubishi Hitachi Power Systems, Ltd. (MHPS) in 2017.

Aircraft engines are required to be compact, lightweight, and have a large amount of thrust (power). Therefore, the Aero GT derived from this engine is smaller, lighter and has a smaller footprint than heavy-duty gas turbines designed exclusively for power generation. In addition, high load responsiveness is required for aircraft engines because of the need to quickly change a large amount of output in response to environmental changes during takeoff and landing or during flight. In addition, it is necessary to cope with the operation of repeating the frequent starts and stops, and high reliability of ignition startup is also required. On the other hand, since it is necessary to reduce the influence on the main body's life against such severe operation, the casing and the rotor have a thin structure. The Aero GT, which is based on this technology and structure, has a small impact on the life consumption of high-temperature parts despite its short starting time.

Air compressors with high load and high pressure ratios are used for aircraft engines to obtain a large amount of thrust efficiently, and this compressor is also used for Aero GT, so that the simple cycle efficiency of Aero GT is higher than that of a heavy-duty gas turbine.

In terms of maintenance, the entire engine is replaced at the site by modularized periodic inspection in the same manner as the aircraft engine, so it can be replaced in just a few days, and a high availavility of the plant is realized. **Figure 1** shows a comparison of the appearance of an aircraft engine and Aero GT.

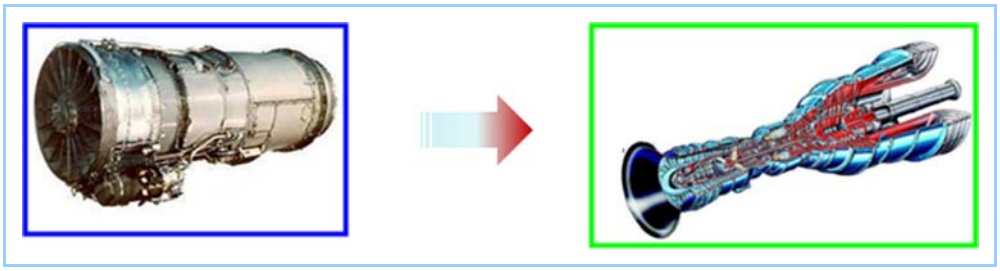

Figure 1 Aircraft engine and Aero GT

2. Aero GT lineup

The Aero GT of PWPS is characterized by its high efficiency (40% on simple cycle), thin and lightweight construction, rapid start (within 5 minutes), quick load response (50%/min), and no turning operation before start. It has 2 models, the 30 MW class FT8 and the 60 MW class FT 4000.

The FT 4000 is the latest model, and the core is based on the PW 4000 turbofan engine, which has a good track record, and the low-pressure compressor (LPC) and the power turbine (PT) are uniquely designed for aeroderivative use. The factory test of the first machine was successfully completed at the West Palm Beach factory in the U.S.A. in 2014, and 3 units are already in commercial operation in the U.S.A. and Argentina, smoothly contributing to electric power demand.

Two unique product solutions specific to PWPS using these engines are introduced below. **Table 1** describes these performance characteristics

Table 1 Performance specifications

GT model	FT8	FT4000	
1. Model	Mobilepac (Mobile type)	SP60 (Fixed)	SP120 (Fixed)
2. Number of Engines	1	1	2 (Twinpac)
3. Gross Generator output (kW)	30,941	70,836	141,567
4. Gross Thermal efficiency (% LHV)	36.7	41.3	41.4
5. NOx control	Water injection	Water injection	Water injection

Remarks: 1013 mbar x 15°C, gas fuel, 60 Hz

(1) Mobilepac

Mobilepac with FT8 is the world's largest capacity mobile power supply facility of 30 MW. Since the GT and the generator are contained in the same trailer, the coupling alignment adjustment for each movement is unnecessary. In addition, concrete foundation work may also be unnecessary depending on the bearing capacity of the soil, and it is possible to complete the installation work in the very short period of several days (**Figure 2**) .

Figure 2 FT8Mobilepac

In terms of technical characteristics, FT8-Mobilepac is a dual fuel combustor which can use both oil and gas fuel, and features dual-frequency specifications that can be operated in 50 Hz districts and 60 Hz districts using the same Mobilepac. After the Great East Japan Earthquake in 2011, the problem of the transmission of electricity from 60 Hz districts to 50 Hz districts surfaced, but this Mobilepac can generate electricity in both frequencies by moving

from district to district, so it is an effective solution for future disaster mitigation countermeasures and national resilience.

(2) Twinpac

The FT 4000, if used with a shaft configuration in which one generator is driven by two engines, is the world's largest Aero GT package with a generating capacity of 140 MW. Although it is compact, it has a large amount of output, so it offers significant advantages in terms of the reduction of construction cost and installation area.

In addition, since one of the two engines can be operated separately from the other, the partial load efficiency can be maintained at a high level (**Figure 3**), and a combination of two gas turbines and one heat recovery boiler can be used in common, contributing to a reduction in construction costs.

Figure 3 140 MW class FT 4000 Twinpac

3. GT solutions for capacity and regulating capacity markets

In Europe and the U.S.A., the energy market (MWh) and the ancillary market (Capacity MW and Regulating CapacityΔMW/Δh Market) are operated to stabilize the frequency and voltage of the power system following the separation of power generation and transmission, and Japan is considering its introduction. The ancillary market (**Figure 4**) is closely related to the stabilization of the electric grid system in response to the expansion of renewable energy. In Europe and the U.S.A, the penetration rate of Aero GT in this market is high because of its rapid start characteristics. Here are some examples of Aero GT solutions.

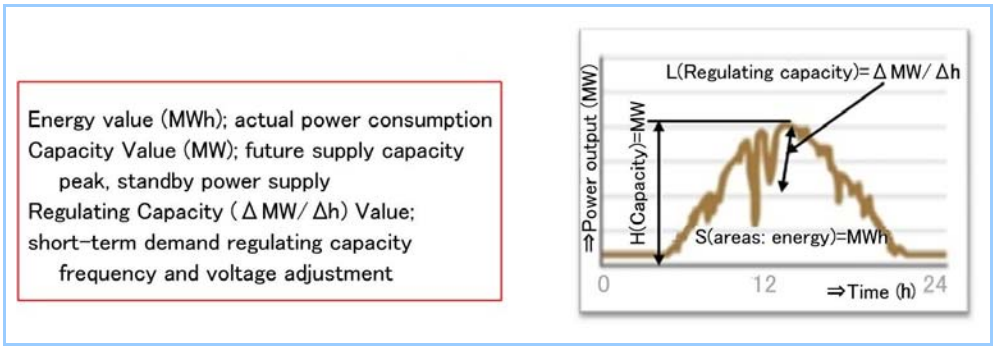

Figure 4 Ancillary Market Investment Concept

(1) Spinning reserve and condensing operation

If the output of renewable energy drastically decreases due to a sudden change in the weather, the power supply becomes insufficient and the system frequency fluctuates. To maintain the system frequency properly, it is necessary to make up for the shortage of supply power quickly with a backup power supply, etc. Thermal power generation with a short generation time of 1 minute or even 1 second is required. In addition, it is preferable that the operations before starting and after stopping are simple and there are few auxiliary units. Because the Aero GT is completely air-cooled, including the generator, it is suitable for running the spinning reserve (instantaneous output) from the perspective of operation and maintenance, and many systems have been introduced in Europe and the U.S.A. As shown in **Figure 5**, PWPS's Aero GT has a Free Turbine configuration in which the PT (power turbine for

generator drive) is separated from the GG (Gas Generator). Therefore, when the generator is connected to the electric power system as a synchronous motor without a clutch, power factor improvement and phase adjustment operation of voltage adjustment are possible. Taking advantage of these characteristics, in addition to power generation operation, the Aero GT offers double benefit with a single unit for not only power generation operation, but also power system stabilization by condensing operation at the renewable power generation operation.

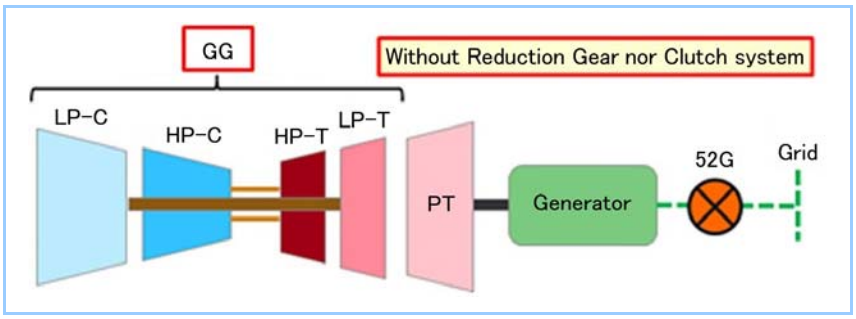

Figure 5 PWPS/Aero GT shaft configuration

(2) Hybrid system (GT + Battery)

In the spinning reserve, there is demand to supply electric power instantaneously by a start command and it is necessary to always perform standby operation of the GT with the minimum load. In the meantime, this is uneconomical because fuel is burned on no-load as standby fuel, and it is also environmentally undesirable in terms of CO_2 emissions. A hybrid system combining GT and a battery has recently attracted attention as a system capable of cutting this standby fuel and instantaneously supplying electricity. The basic configuration of this system is shown in **Figure 6**.

Figure 6 Hybrid System (GT + battery)

This system is composed of Aero GT and a battery (including power conditioner). Its control unit factors in weather conditions, which affect the renewable energy output, the market trends of the electric price and the fuel price and starts and stops the system in consideration of electric power grid stabilization and economic factors. Furthermore, since the battery can also serve as an emergency generator during a blackout, a diesel generator for blackouts is unnecessary.

Table 2 shows a comparison between the hybrid system and the GT/battery stand-alone system. This system has already been put into practical use in the U.S., and is effective for both demand for the further expansion of renewable energy introduction and electric power grid stabilization in Japan. A significant drop in battery prices is expected in the future, and the introduction of hybrid systems is anticipated to be even faster.

Table 2 Comparison of Hybrid and Other Systems

System	GT only	ESS only	GT + ESS
1. CAPEX	Base	Expensive	Somewhat expensive
2. OPEX	Base	Cheap	Cheap
3. Standby fuel	Yes (at All Combined Use Time)	None	None
4. CO_2 Credit	None	Yes	Yes
5. Instantaneous Power Generation	Yes (at synchronized operation)	Satisfactory	Satisfactory
6. Response Speed	Base	Fast	Fast
7. Measures for Surplus Power from Renewable Energy Sources	No	Yes (CHARGE)	Yes (CHARGE)
8. Blackout Emergency D/G	Required	Not Required	Not Required
9. Condensing Operation	Satisfactory	No	Satisfactory
10. Long-term Continuous Operation	Satisfactory	Unsuitability	Satisfactory

4. Future developments

The Aero GT, which has excellent quick start characteristics and fast load change characteristics, is a power generation system suitable for the ancillary market. As a result, it is possible to contribute to environmental load reduction and power grid stabilization by expanding the introduction of renewable energy.

To respond to the diversifying needs of the electric power market, we will make further efforts to improve the startup performance and operability.