The Air Injection Power Augmentation Technology Provides Additional Significant Operational Benefits

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Introduction
The AI Power Augmentation technology (HAI for humid Air injection and DAI for dry air injection) has primary benefits of increasing power of combustion turbine/combined cycle (CT/CC) power plants by 15-30% at a fraction of the new plant cost with coincidental significant heat rate reductions (10-15%) and NOx emissions reductions (for diffusion type combustors up to 60%) (See References 1, 2, 3):

Figure 1 is a simplified heat and mass balance for the PG7241 (FA) combustion turbine (CT) with HAI and is self-explanatory. Figure 2 presents the heat and mass balance for the PG7142 CT based combined cycle (CC) power plant with HAI. This is similar to that presented on Figure 1 except that the humid air is created by mixing of steam, extracted from the steam turbine, with the supplementary airflow from the auxiliary compressor.

Figure 1: Heat and mass balanced for the CT-HAI Plant based on PG7241 (FA) combustion turbine.
The latest project development by ESPC in cooperation with CT/CC users and OEMs identified a number of additional effective operational benefits of the AI technology that sometimes are driving factors for the AI technology applications in addition to the prime application for power augmentation. These additional operational benefits are generic and applicable to variety of CT/CC plants and for variety of power generation markets.

This paper describes technical and commercial findings of these specific operational benefits of the AI technology based on its application for the power augmentation of M501F based 2x1 combined cycle power plant with capacity of approximately 500 MW - a Mitsubishi Heavy Industry (MHI) project in South America. In this paper, the estimated by ESPC benefits of the application of the AI technology are based on the performance characteristics and the equipment and operating limits provided by MHI. It should be expected that MHI will identify additional operating and equipment capabilities limits particularly for specific projects, such as GT generator limits, etc.

The main operational benefits of the AI technology could be summarized as follows:

- The incremental power introduced by the AI technology meets the spinning reserve requirements and allows CT/CC plants operate at full load with the best efficiency.
- The AI technology power augmentation provides the opportunity for CC/CT plants to deliver the required power at lower turbine Firing Temperatures (FT) as compared to a CC/CT without the AI technology with significant increase of “hot” components life and operational performance benefits.
- The AI technology can function as the load management plant

**HAI Provides Spinning Reserve**

Typical combined cycle power plants operate at 93-95% load factor to meet the spinning reserve requirements, i.e. the 7-5% of valuable capital cost and operational assets are not being effectively used.

The application of the AI power augmentation technology can augment/increase the combined cycle power plant power by 15%-20% within seconds thus allowing users to run CTs or primarily the highest efficiency combined CC power plants at full load with the design point efficiency.
In order to quantify the effects of the use of the AI technology as a spinning reserve, ESPC conducted economic analysis of the application of the AI technology as the spinning reserve for operating the Mitsubishi M501F based on 2x1 CC power plant with total capacity of approximately 500 MW at 92°F and 60%RH ambient conditions. Figure 2 presents estimated performance characteristics of the CC power plant for two modes of operations: two curves represent the power and heat rate of the CC plant operating at a reduced load to meet spinning reserve requirements and another two curves represent the power and heat rate of the CC plant operating at a full load with the AI system to meet the spinning reserve requirements as well as providing a significant power augmentation.

Figure 2- CC operations with Spinning reserve margins and with the AI for the spinning Reserve

The basic analysis of economic benefits of using the AI technology to provide a spinning reserve (as well as power augmentation) and utilizing the full 500 MW M501F based 2x1 combined cycle power plant capacity (otherwise operating at 92% load factor to provide the spinning reserve capacity) could be summarized as a follows:

Capital Assets Recovery:
- If the 500 MW CC plant operates at 92% load factor, approximately $30M capital value associated with the unused approximately 40MWs are practically not utilized and kept as the spinning reserve. The AI technology functioning as a spinning reserve allows the combined cycle power plant to operate at full load with full utilization of the capital assets. The capital cost of the 40 MW power augmentation of the M501F based 2x1 CC plant using the AI technology are estimated as approximately $8M. Thus, the application of the AI power augmentation for the spinning reserve allows the recovery of approximately 22 MWs of stranded assets’ and capital cost.

Additional revenues:
- Additional revenues associated with full utilization of the M501F based 2x1 CC plant (additional 40 MW) could be as high as $24M/year (based on 6000 hrs/year and $100/MWh electricity costs)
During peak demand situations the M501F based 2x1 CC plant can operate at full capacity (500MW) plus additional the AI power augmentation of 40MW for a total power of 540MW. This capability adds additional strategic and operational flexibility and revenues.

Fuel Saving:
The increase in the CC load from 92% to 100% will reduce the heat rate by approximately 1%.

Economic evaluations for various installations have shown that, for application of the AI power augmentation for the spinning reserve of CC power plants, the payback period will be less than a year.

The AI Technology Allows Reduction of the FT with Significant Reduction of Maintenance Costs, NOx Emissions and Fuel Savings

The AI technology provides other significant operational and performance benefits by the fact that it allows CT/CC power plants to operate at lower FT as compared to the plants without the AI technology. Figure 3 represents the performance parameters of the Mitsubishi M501 F operating at 35C (95F) ambient temperature over a wide range of loads with and without the AI power augmentation technology. Figure 3 demonstrates that the AI technology increases power from approximately 170 MW (design load) to approximately 200-210 MW with the heat rate reduction by approximately 700-1000 kJ/kWh.

Figure 3, also, shows that the CT with the AI technology operates with the reduced firing temperatures over the whole range of operating loads with coincidently reduced heat rates. For example, at the design point of approximately 170 MW and at lower loads the FT is reduced by approximately 110C (200F), as compared to the FT without the AI technology, with approximately 500-700 kJ/kWh heat rate reduction.

These benefits of the AI technology are similarly applicable to the various heavy duty as well as aircraft-derivative CTs of various sizes.

Figure 3 TIT and Heat Rates of M501F Operating without and with the AI technology

The reduction of the TIT provides the following additional benefits of the AI technology:

- It significantly increases the life of CT blades and other “hot” components and consequently reduces maintenance costs of CT/CC plants;
• It provides significant fuel savings;
• It further reduces NOx emissions.

Reduction of the FT Increases lives of CT blades and other “hot” Components and Reduces of Maintenance Costs of CT/CC plants

A number of papers by OEMs and operators quantify the significant effect of the increase/reduction of the FT on the component life. For example the leading OEM, GE, concludes that “Significant operation at peak load, because of the higher operating temperatures, will require more frequent maintenance and replacement of hot-gas path components. For a MS7001EA turbine, each hour of operation at peak load firing temperature (+100°F/56°C) is the same, from a bucket parts life standpoint, as six hours of operation at base load. This type of operation will result in a maintenance factor of six. Figure 12 defines the parts life effect corresponding to changes in firing temperature. It should be noted that this is not a linear relationship, as a +200°F/111°C increase in firing temperature would have an equivalency of six times six, or 36:1”. GE Publication: GER-3620k, “Heavy-Duty Gas Turbine Operating and Maintenance Considerations”, Dec., 2004.

Other operator concluded that “Each hour of operation at 100°F/56°C under base conditions is equivalent to 0.2 hours of operation at the base load” Paper No: 05-IAGT-2.2

Based on data provided by OEMs and users, ESPC developed Figure 4 representing generic correlations between FT increase/reduction from design level and the maintenance interval changes for major “hot” section inspections of CTs with conservatively diminished effects of the reduced FT on maintenance. This Figure 4 demonstrates that the reduction of FT by the AI technology by approximately 110C (200F) increases maintenance intervals by a factor of two (2), i.e. reduces maintenance costs also by a factor of 2. With the typical maintenance costs of $2.5-3/MWh the associated saving will be approximately $1.25-1.5/MWh

Reduction of the FT Provides Fuel savings.

As it was mentioned above, Figure 3 shows that at the design load of approximately 170 MW the AI technology, with the reduced FT of approximately 100 C, allows reduction of the heat rate by approximately 500-700 kJ/kWh (i.e. approximately 5-7% heat rate reduction). This FT and heat rate reductions take place over the whole range of part load operations.

In addition,” hot” gas path components are cleaner for longer duration; this contributes to fuel savings of approximately 1.0 to 1.5% as an average between maintenance intervals.

Therefore the reduction of the FT will reduce currently very high fuel costs (approximately $10-12 /MWh) by 6-8%.
Figure 4: Correlations between FT Changes and Intervals for “Hot” Sections Inspections

Reduction of the FT Reduces NOx Emissions.

The AI technology reduces the NOx emissions as demonstrated by two independent diffusion combustor tests conducted by Textron and Aero Industrial (USA) technology (Britain) and presented in the Figure 5. (see Reference 4)

Figure 5. Tested Combustors NOx Emissions as Function of the Humidity
Figure 6. NOx Concentration vs. Flame Temperature

Based on the general theory the NOx production by combustors is directly proportional to the residence time of mass particles in the combustor and exponentially proportional to the flame temperature. The injection of the humid/dry air flow (approximately 10-15%) upstream of combustors increases the total mass flow through the combustors and reduces (by approximately 10-15%) the residence time of the flow particles in combustors and, therefore, reduces (by approximately 10-15%) NOx emissions.

The reduction of the operational FT by 110C/200F for a given combustor will provide similar reduction of the flame temperature and associated additional reduction of NOx emissions as shown on the figure below.

References.

1. Air Injected Power Augmentation is Validated By Fr7FA Peaker Tests, GTW, March-April, 2002.
3. Injecting Humidified and Heated Air to meet peak Power Demands, 2000-GT-0596.