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PEAKING GAS TURBINE PACKAGE ENHANCEMENTS FOR MAXIMUM RELIABILITY AND EFFICIENCY

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Abstract

Decarbonization goals have dramatically increased renewable power generation and with it the crucial need for peaking facilities. The intermittent nature of renewables—and the continued phase-out of coal and other fossil-fuel, base-loaded generating facilities—has expanded the need to meet gaps in energy demand with fast, flexible, reliable peaking power. In fact, aeroderivative turbines usage has increased because of attributes such as fast-starts, reduced-emissions, rapid load-following, high availability/reliability, and attractive merchant ancillary services, which include frequency regulation, responsive reserves, and non-spinning reserve.

Now, peaking-facility resiliency, reliability, and efficiency is critical to public safety and economic stability, especially during times of extreme weather events. Conversely in a cost-competitive market, both developers and existing owners must holistically consider design requirements for their aeroderivative turbine facility to ensure the economic viability of a project. They must prepare turbine packages to operate in extreme ambient conditions with the maximum efficiency and reliability that can be realistically achieved within the project budget.

This paper will review enhancements made to an LM6000 aeroderivative peaking gas-turbine package design. The author will discuss improvements to plant efficiency and reliability across 2.4 GW of LM6000 peaking units to include a net present value (NPV) financial analysis, thermal efficiency calculations, and empirical field data. Topics, which are applicable to any aeroderivative peaking gas-turbine package, will include the following:

1. **Emissions control system.** Hot-gas recirculation for ammonia vaporization eliminates the need for electric heaters, and advanced catalyst materials allow for open-cycle operation without air tempering fans.
2. **Recirculated turbine enclosure air inlet anti-icing system.** Weatherization technology eliminates complexity and parasitic load associated with traditional glycol systems.
3. **Performance augmentation.** Fogging eliminates cost and complexity associated with evaporative cooling and mechanical chilling alternatives, while

harmonized water treatment systems and simplified inlet air filter house design reduce cost and operational risk.

4. **Improved maintenance access & constructability.** Wider turbine doors, generator maintenance ways, and hinged door VBV duct access improve user accessibility. A consolidated auxiliary skid simplifies winterization measures, reduces installation costs, and streamlines maintenance with features that include a gearbox-less NOx water pump.

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1.0 Introduction: The Need for Peaking Power

In recent years, the global energy landscape has undergone a remarkable transformation, driven by a growing awareness of the urgent need to reduce greenhouse gas emissions and mitigate the impact of climate change. The widespread adoption of renewable energy sources, such as wind and solar power, has played a pivotal role in this transition by offering cleaner alternatives to traditional fossil fuel-based electricity generation. However, the intermittent and non-dispatchable nature of these renewable options presents a unique challenge to grid operators and energy planners worldwide.

As renewable energy installations continue to expand, the inherent variability in their generation capabilities creates significant challenges for grid stability and reliability. During periods of high demand or unfavorable weather conditions, when renewable power generation falls short, reliable and flexible peaking power solutions can quickly bridge the supply-demand gap. The need is particularly crucial to ensure uninterrupted power supply, stabilize power grids, and avoid potential blackouts. Although improvements in interconnection help mitigate this variability, a study published in Energy & Environmental Science found that even with a comprehensive continental distribution network connecting wind and solar sources across the US, 20% of the country's electrical demand would remain unmet without some peaking or storage capacity [1].

This situation is best understood through net supply vs. demand curves that the balance of output-controllable power facilities must now meet. The California Independent System Operator (CISO) coined the phrase 'the duck curve' to describe the shape of its demand profile, which peaks in the evening but remains relatively low mid-day when solar energy is in high supply. These curves will change by regional climate and renewable energy makeup, but in most cases, these net demand curves are more volatile than demand-only curves, which results in an increased need for rapid dispatch cycling facilities that can provide electricity when solar and wind energy assets are not producing. Refer to Figure 1 below to view the contrast of the two curves (demand vs. net demand).

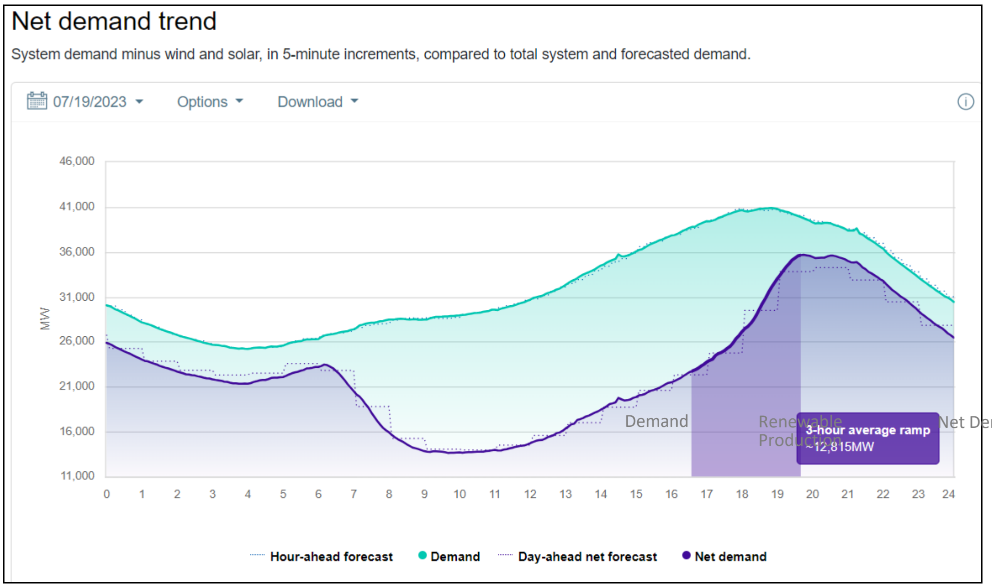

Figure 1: CAISO Net Demand Curves [2].

Peaking gas turbines have emerged as a viable and efficient solution to meet the rising demand for flexible, fast-start, and high-performance power generation. These gas turbines, specifically designed to provide electricity during peak demand periods, offer a range of benefits including rapid start-up and shutdown, excellent load-following capabilities, and high thermal efficiency. With their ability to swiftly respond to fluctuations in electricity demand, peaking gas turbines complement the intermittent nature of renewable energy sources, thereby enhancing grid stability and reliability.

When adding peaking gas turbines to any electrical grid system, only cost-competitive solutions will keep investment decisions positive. The increasing fluctuations and severity of climate conditions make it a challenge to include the appropriate weatherization and resilience measures without greatly impacting the capital expense. A standard plant solution developed by PROENERGY improves the resilience of a peaking-power gas-turbine facility in a cost-effective way. Known as PowerFLX, the solution uses the LM6000PC aeroderivative gas turbine and has been deployed across 2.4 GW of applications since 2020. The following paper will review various methods that make the successful implementation of these standardized LM6000 peaking power plant facilities possible and will use empirical demonstrations to support.

2.0 Emissions Control System Optimizations

The production of nitrogen oxides (NOx) emissions during combustion from gas turbines contributes to air pollution and environmental degradation. To address this issue, selective catalytic reduction (SCR) systems are employed in certain gas turbines for NOx emissions control. The catalysts are extruded ceramic honeycomb structure with high geometric surface area per unit volume. This high void fraction reduces pressure loss. The catalyst formulation is tailored for use in each specific SCR system application but is typically comprised of a titanium-tungsten based material that is highly reactive to NOx. These systems utilize the catalyst material to facilitate a chemical reaction between the exhaust gases and a reducing agent, typically ammonia or urea.

The ammonia (NH_3), often introduced as a 19% aqueous solution, must be vaporized prior to its introduction into the exhaust stream. The NH_3 is mixed thoroughly with the flue gas before the catalyst face. The mixing assures even distribution of the temperature and reaction components. The catalyst, by providing active reaction sites, enables the reaction to occur at temperatures between 300°F and 950°F. The NH_3 diffuses into the catalyst pore structure and is adsorbed onto an active catalyst site. The NO_X then reacts with the adsorbed NH_3 to complete the reaction. The reaction depends primarily on available active sites (a function of geometric surface area, pore volume, and concentration of active catalyst component), flue gas temperature, and reagent concentration. A well-balanced process will maintain appropriate output levels of residual NO_X and NH_3. This reaction converts the harmful NOx emissions into nitrogen and water vapor, significantly reducing their environmental impact.

SCR catalyst systems offer a highly effective means of achieving stringent emissions regulations while maintaining the efficiency and performance of peaking gas turbines. This capability makes them crucial technology in the pursuit of cleaner and more sustainable energy from gas-fired peaking power production. Figure 2 below shows a typical SCR and CO emissions control system downstream of an LM6000 gas turbine installed in the standard PowerFLX configuration.

Figure 2: Typical SCR/CO Emissions Control System Behind an LM6000.

Traditional SCR systems have two critical efficiency and reliability related areas of concern:

(1) Parasitic load and failures associated with the tempering air fan, and
(2) Parasitic load and failures associated with the electric heater on the ammonia flow control skid.

The standardized LM6000 peaking power plant solution eliminates both the tempering air fan and ammonia electric heater from its design. This change results in a compact and simple ammonia flow control skid as seen in Figure 3 below.

The following sections consider the reasons for these changes in the standardized design and explain their positive operational and financial impacts.

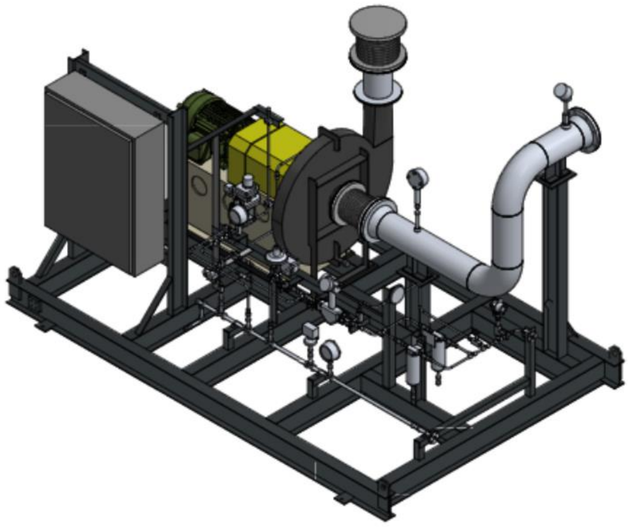

Figure 3: Ammonia Flow Control Skid in a Standard Peaking Power Solution.

2.1 Tempering Air

The tempering air fan in traditional designs controls the exhaust temperature entering the SCR system and keeps it within an optimal range for efficient NOx reduction. Temperatures that are too high can lead to excessive ammonia slip (short term) or catalyst degradation (long term), the latter of which is called sintering. Tempering air fans introduce controlled amounts of ambient air into the exhaust stream, which enables plant designers to adjust the catalyst face temperature to the optimal range and maintain consistent operating conditions for the SCR catalyst.

The standardized LM6000 peaking power solution includes a medium-temperature catalyst design that negates the need for tempering air fans entirely. This unique configuration is possible due to the relatively cool exhaust temperatures from the LM6000 combined the with peaking plant limited run time operating profile. PROENERGY has installed more than 40 peaking LM6000s with SCR systems that do not use tempering air to control the turbine exhaust temperature. Modern-day titanium vanadium catalyst systems can easily withstand the full exhaust temperatures of the LM6000PC, even in ambient temperatures more than 110°F. Refer to Table 1 below, which illustrates the degraded exhaust temperature maximum of 865°F in the 115°F ambient condition with the typical water systems in operation. Exhaust temperatures above 890°F are not expected, even scenarios in which all the inlet conditioning is disabled and the engine has undergone expected degradation over time.

Table 1: Exhaust Temperature at 115°F and 10% RH Ambient Condition.

Case #	Fogging	WSPA	NOx Water	Exhaust Temperature (°F) (new/degraded)
1	X	X	X	865/873
2		X	X	868/871
3			X	855/856
4				882/885

The medium-temperature catalyst deployed into the standardized LM6000 peaking power plant configuration features a 15,000-hour warranty, or 48-months from first fire without the need for air tempering, although experience has shown the 48-month systems to reach 80+ months in clean gas applications. Sourced from Cormetech, this medium-temperature catalyst will allow excursions up to 932°F for a recommended maximum of 500 hours over its life. In addition, twenty (20) hours per year at 920°F falls within the limits of the medium formulation product. Based on the experience of PROENERGY and confirmed by the exhaust temperatures modelled above in Table 1, it is unlikely an LM6000PC SCR system will ever endure these temperatures at continuous base load unless a critical fault exists in the control system. The tempering air fan has a parasitic load of roughly 175 kW when in use.

The following sections present the savings associated with eliminating the tempering air system and electric heater from traditional designs.

2.2 Life-Cycle Cost Analysis on Elimination of the Tempering Air System

To illustrate the financial merit of eliminating the tempering air, the following case study considers the hypothetical scenario in which accelerated degradation is observed due to extended high-temperature operation:

- Assume 20 hours per year, per unit of operation at 940°F. Equivalent to 4 days per summer when dispatched 5 hr/day in extreme summer conditions where control of the exhaust temperature is lost.
- This operation may reduce the anticipated catalyst life from 15,000 to 10,000 hours and reduce expected catalyst life from roughly 10 to 7 years assuming a 17% capacity factor (or 1,500 hr/year of operation).
- In this scenario, over a 25-year period, the SCR catalyst will need to be replaced three times instead of two times due to accelerated degradation.
- Using an 8% weighted average cost of capital. A low-temperature catalyst cost of USD$220K, a high temp catalyst cost of USD$275k, and an initial tempering air fan cost of $450K installed.
- Assume an average cost of electricity of USD$0.1/kWh and tempering air fan parasitic load of 175 kW.

Table 2 below shows the result of the NPV analysis:

Table 2: NPV Analysis Comparing Tempering Air Vs. Medium-Temp. Catalyst.

		With Tempering Air				Without Tempering Air			
Year	Cumulative run hours	SCR CAPEX (delta) and replacement cost	SCR OPEX (delta) - fan aux load	Total Cost $/year		SCR CAPEX (delta) and replacement cost	SCR OPEX (delta) - N/A	Total Cost $/year	
0		$ 670,000		$ 670,000		$ 275,000		$ 275,000	
1	1500	$ -	$ 26,250	$ 26,250				$ -	
2	3000	$ -	$ 26,250	$ 26,250				$ -	
3	4500	$ -	$ 26,250	$ 26,250				$ -	
4	6000	$ -	$ 26,250	$ 26,250				$ -	
5	7500	$ -	$ 26,250	$ 26,250				$ -	
6	9000	$ -	$ 26,250	$ 26,250				$ -	
7	10500	$ -	$ 26,250	$ 26,250		$ 275,000		$ 275,000	
8	12000		$ 26,250	$ 26,250				$ -	
9	13500		$ 26,250	$ 26,250				$ -	
10	15000	$ 220,000	$ 26,250	$ 246,250				$ -	
11	16500		$ 26,250	$ 26,250				$ -	
12	18000		$ 26,250	$ 26,250				$ -	
13	19500		$ 26,250	$ 26,250				$ -	
14	21000		$ 26,250	$ 26,250		$ 275,000		$ 275,000	
15	22500		$ 26,250	$ 26,250				$ -	
16	24000		$ 26,250	$ 26,250				$ -	
17	25500		$ 26,250	$ 26,250				$ -	
18	27000		$ 26,250	$ 26,250				$ -	
19	28500		$ 26,250	$ 26,250				$ -	
20	30000	$ 220,000	$ 26,250	$ 246,250				$ -	
21	31500		$ 26,250	$ 26,250		$ 275,000		$ 275,000	
22	33000		$ 26,250	$ 26,250				$ -	
23	34500		$ 26,250	$ 26,250				$ -	
24	36000		$ 26,250	$ 26,250				$ -	
25	37500		$ 26,250	$ 26,250				$ -	
			NPV	$1,017,885	per unit		NPV	$540,479	per unit
			NPV Delta	$477,407	per unit				

The analysis reveals that over a 25-year period, the medium-temperature catalyst saves almost USD$500K on an NPV basis despite having an additional catalyst replacement event. The medium-temperature catalyst could even be replaced an additional time (four replacements vs. two) and still yield the same conclusion favouring the medium-temperature catalyst without tempering air vs. a traditional low-temperature catalyst and tempering air system.

2.3 Life-Cycle Cost Analysis on Elimination of the Electric Heater

Using electric heating elements to vaporize the 19% aqueous ammonia is the most common solution in peaking facilities. Although relatively simple and fast acting, these systems represent a continuous parasitic load and possible failure point in the design. The standardized LM6000 peaking power solution diverts a small portion of the exhaust gas, typically around 850ºF, which mixes with the aqueous ammonia mixture and vaporizes the ammonia. This solution saves on the parasitic load of a traditional electric heater, which is approximately 150 kW/unit. The life-cycle savings can be approximated based on the following assumptions:

- 8% weighted average cost of capital
- 1,500 operating hr/year
- $0.1/kWh price of electricity and 150 kW of parasitic load

Table 3 below shows the results of the NPV analysis of the annual operating costs of a traditional electric heater for ammonia vaporization.

Table 3: NPV Analysis on Electric Vaporizer Costs.

Year	Run hours per year	Annual cost of vaporization	
0			
1	1500	$ 22,500	
2	1500	$ 22,500	
3	1500	$ 22,500	
4	1500	$ 22,500	
5	1500	$ 22,500	
6	1500	$ 22,500	
7	1500	$ 22,500	
8	1500	$ 22,500	
9	1500	$ 22,500	
10	1500	$ 22,500	
11	1500	$ 22,500	
12	1500	$ 22,500	
13	1500	$ 22,500	
14	1500	$ 22,500	
15	1500	$ 22,500	
16	1500	$ 22,500	
17	1500	$ 22,500	
18	1500	$ 22,500	
19	1500	$ 22,500	
20	1500	$ 22,500	
21	1500	$ 22,500	
22	1500	$ 22,500	
23	1500	$ 22,500	
24	1500	$ 22,500	
25	1500	$ 22,500	
	NPV	$240,182	per unit

By using waste heat from the exhaust gas to vaporize ammonia, the ammonia flow control skid becomes smaller, simpler, and as seen above, results in notable life-cycle cost savings through the elimination of the electric heating parasitic load.

3.0 Recirculated Turbine Enclosure Air Inlet Anti-Icing System

Anti-icing systems are crucial for gas-turbine air intake systems, especially in environments where cold weather or high humidity can lead to the formation of ice on the intake components. Ice accumulation on the intake components, such as inlet guide vanes and air filters, can obstruct the airflow into the gas turbine. Reduced airflow can degrade turbine performance and efficiency, potentially leading to power output reduction, increased fuel consumption, and decreased overall operational reliability. Furthermore, ice formation can cause mechanical stress and damage to the gas-turbine components. The expansion and contraction of ice during temperature fluctuations can lead to blade deformation, erosion, or even mechanical failure. Anti-icing systems help safeguard the integrity and longevity of critical turbine components.

Anti-icing systems are often accomplished through the use of an external glycol heating loop, which is piped to the air inlet filter house of the gas turbine. These systems introduce a parasitic load for the heating process and reduce the gross output of the gas turbine due to the additional pressure loss imposed by the coils within the air intake.

The standardized LM6000 peaking power solution accomplishes inlet air heating by extracting heated air from the package turbine enclosure. The heated air is recirculated via ducting and injected upstream of the inlet air filters. This action promotes thermal mixing and inhibits ice formation in downstream components. The system minimizes performance and efficiency losses as compared to alternative technologies that extract high-energy air from the high-pressure compressor (HPC) of the turbine or consume electricity for an external glycol heating loop.

The package ventilation air is filtered by the same filters as the gas-turbine combustion air. The package ventilation fans discharge into a plenum above the silencers, which exhaust the air to the atmosphere during normal operation. When the ambient temperature drops below 40°F, the package ventilation air is redirected via ducts to the combustion air inlet filter modules before the filter canisters. The package airflow is warmed sufficiently by the heat rejected from the turbine to ensure at least a 10°F temperature rise in the combustion air temperature. This rise is adequate to prevent icing in the inlet system. Figure 4 below shows an indicative isometric view of the plenum and ducts that convey the package ventilation air to the inlet air filter modules.

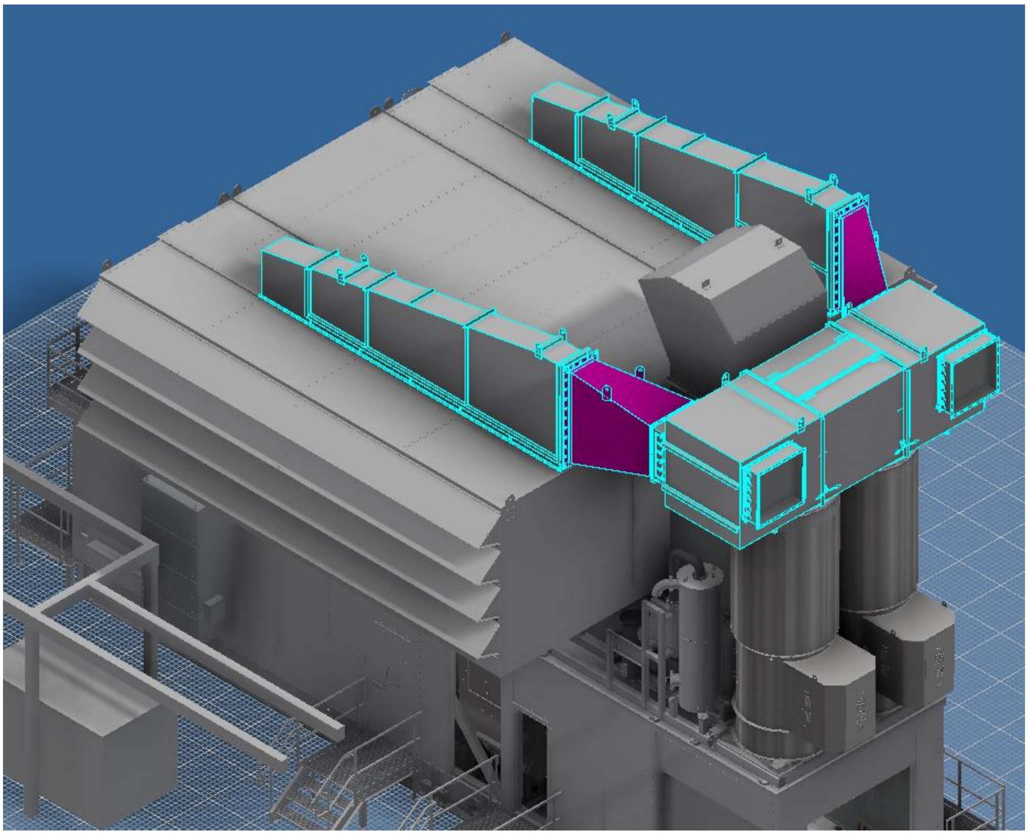

Figure 4: Inlet Air Heating System via Recirculated Turbine Enclosure Air.

The anti-icing system ensures that the temperature measured at the gas-turbine compressor inlet (typically, at T2 on the engine) or in the inlet plenum (measured above TE-64259, mounted in the air-filter assembly) meets the defined envelope shown in Figure 5 below.

As indicated in the figure, icing risks develop with an increase in humidity and a decrease in temperature. If the relative humidity is higher than 70% and the ambient temperature is 36°F or below, ice forms wherever turbulence and flow path changes cause a local pressure drop. The air pressure drops as it flows through the filter, inlet plenum, inlet volute, and turbine inlet guide vanes. The air temperature drops because of the reduction in static pressure as the air is accelerated toward the compressor inlet—this temperature drop is approximately 4°F.

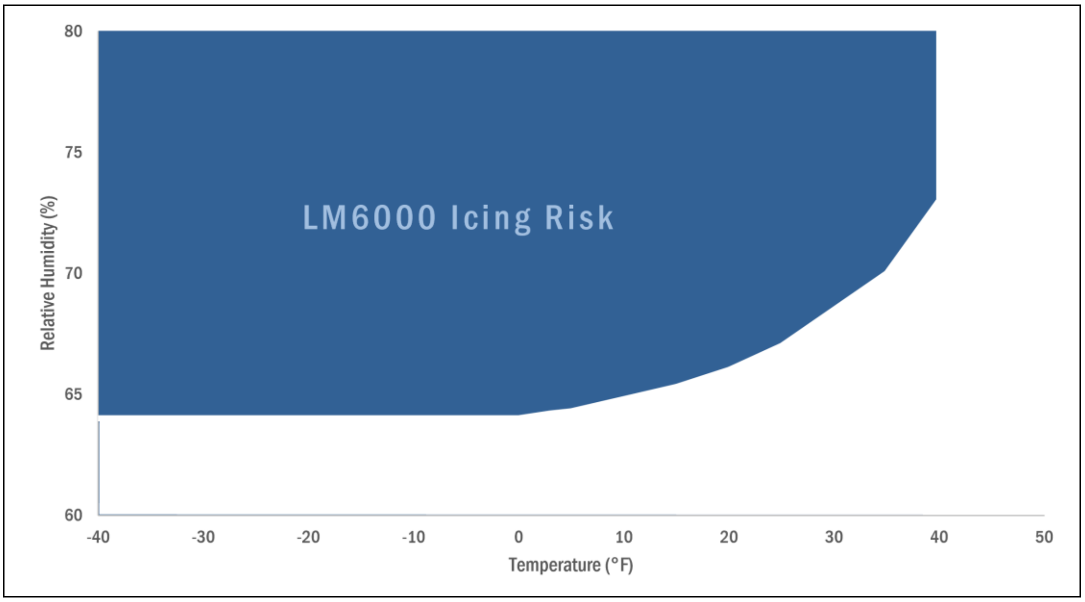

Figure 5: Icing Conditions Are Observed at 40°F and Lower.

The anti-icing solution in most applications prevents the ice from forming by heating the inlet air a conservative 10°F above ambient temperature. The source of this heat is where the variations in inlet heating options comes from. Generally, no heating is required for ambient temperatures above 40°F. The control system monitors both ambient temperature and T2 temperature and alerts when the anti-icing system should be used. If the humidity is less than 70%, the operator may decide not to use the anti-icing system with minimal risk to the turbine.

3.1 Estimated Thermal Performance Impact of Inlet Air Heating

As compared to competing technologies, the turbine enclosure, recirculated-air, anti-icing system minimizes the negative impact on gas-turbine power output and heat rate.

The package-air recirculation anti-icing system is demonstrated to decrease gas turbine output by no more than 0.3% during operation, which is roughly 135 kW during winter months only. In contrast with a traditional heated glycol loop, the package-air recirculation anti-icing system then improves turbines net output by 165 kW per unit by eliminating the inlet coils and the associated pressure drop, which is present year-round. An additional 265 kW per unit is saved in winter operation when the glycol heaters would be required to operate. The life-cycle savings can be approximated based on the following assumptions:

- 8% weighted average cost of capital
- 450 winter operating hours per year
- USD$0.1/kWh price of electricity and 150 kW of parasitic load
- 265kW – 135kW = 130kW in parasite load savings in winter
- 165kW in parasitic load savings year round

Table 4 below shows the results of the NPV analysis of the delta in annual operating costs when comparing a glycol heat loop to an inlet air recirculation heating system.

Table 4: NPV Analysis on Inlet Heating Design Savings

Year	Winter run hours per year	Savings in parasitic load cost (package air recirc vs glycol loop - heater only) ($ USD)	Run hours per year	Parasitic load cost year round due to inlet coils ($ USD)	
0					
1	450	$ 5,850	1500	$ 24,750	
2	450	$ 5,850	1500	$ 24,750	
3	450	$ 5,850	1500	$ 24,750	
4	450	$ 5,850	1500	$ 24,750	
5	450	$ 5,850	1500	$ 24,750	
6	450	$ 5,850	1500	$ 24,750	
7	450	$ 5,850	1500	$ 24,750	
8	450	$ 5,850	1500	$ 24,750	
9	450	$ 5,850	1500	$ 24,750	
10	450	$ 5,850	1500	$ 24,750	
11	450	$ 5,850	1500	$ 24,750	
12	450	$ 5,850	1500	$ 24,750	
13	450	$ 5,850	1500	$ 24,750	
14	450	$ 5,850	1500	$ 24,750	
15	450	$ 5,850	1500	$ 24,750	
16	450	$ 5,850	1500	$ 24,750	
17	450	$ 5,850	1500	$ 24,750	
18	450	$ 5,850	1500	$ 24,750	
19	450	$ 5,850	1500	$ 24,750	
20	450	$ 5,850	1500	$ 24,750	
21	450	$ 5,850	1500	$ 24,750	
22	450	$ 5,850	1500	$ 24,750	
23	450	$ 5,850	1500	$ 24,750	
24	450	$ 5,850	1500	$ 24,750	
25	450	$ 5,850	1500	$ 24,750	
	NPV	$62,447	NPV	$264,201	savings per unit
			$326,648	total Savings per unit	

In some instances, at or above 40°F ambient temperature, raising the inlet temperature with this system may increase power output and maintain heat rate. Additionally, the system can help to achieve higher performance by enabling the use of low-pressure (LP) spray for power augmentation at temperatures lower than 45°F (when the turbine controls would normally disallow LP spray power augmentation operation).

4.0 Performance Augmentation

Gas-turbine performance is greatly impacted by ambient conditions. The implementation of performance augmentation techniques, such as an inlet fogging system, holds paramount importance in sustaining gas-turbine output during the sweltering summer months when electricity demand reaches its peak. As elevated temperatures reduce air density and consequently lower the mass flow rate through the gas turbine, power generation capabilities can suffer. An inlet fogging system addresses this challenge by introducing a fine mist of water droplets into the incoming air stream. As these droplets evaporate, they absorb heat from the air, significantly cooling it and increasing its density. This augmented air density leads to higher mass flow rates and improved compressor efficiency, ultimately bolstering power output. By ensuring consistent and optimal turbine performance, particularly when electricity demand is at its peak due to air conditioning and other cooling needs, inlet fogging systems contribute significantly to stabilizing power grids, meeting consumer energy needs, and preventing disruptions during critical periods.

Figure 6 below shows the relative impact of various forms of performance augmentation when sequentially applied to a single LM6000PC gas turbine.

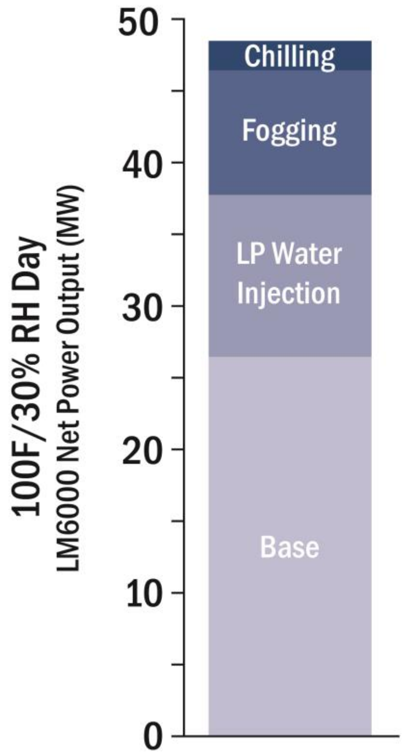

Figure 6: Relative Net Output Improvement from Performance Augmentation on the Same LM6000C.

The above shows the diminishing returns when adding additional forms for performance augmentation to a single LM6000PC. Since the turbine is mass-flow limited corresponding to a peak output of roughly 50 MW, it becomes important to choose the ideal form of performance augmentation initially to have the optimal $/kW investment per incremental performance improvement.

Table 5 shows the performance impact and relative cost when comparing inlet fogging to mechanical inlet chilling on an LM6000PC on a 100°F and 40% relative humidity (RH) day.

Table 5: $/kW Incremental Improvement for Fogging vs. Inlet Chilling.

1xLM6000PC WSPA		Base Case	Fog Case	Chill Case
Fuel		NG	NG	NG
Elevation	ft (ASL)	0	0	0
Inlet Conditioning		WSPA Only	Fogging	Chilling (1000T)
Ambient Temperature	°F	100	100	100
Relative Humidity	%	40	40	40
Net Power	kW	37,987	44,185	46,174
Heat Rate(LHV)	BTU/kWh	9,117	8,876	9,017
Net Efficiency	%	37.43	38.44	37.84
Demin Water Consumption-plant	gpm	53.9	59.2	57.3
Incremental Performance gain (over WSPA only option)	kW	N/A	6,198	8,187
Cost to implement	$	INCL	$ 450,000	$ 2,400,000
	$/kW	N/A	$ 73	$ 293

Since the facility will have already made provision for both water treatment and storage to account for NOx water and demineralized water demand for water-spray injection, the incremental investment to add an inlet fogging system is minimal.

An inlet fogging system for a gas turbine can be a superior decision over an inlet chiller, primarily due to its cost-effectiveness and minimal impact on overall efficiency. Unlike an inlet chiller that involves substantial capital and operational expenses, including the installation and maintenance of complex refrigeration systems, the fogging system offers a more economical solution. Additionally, inlet chillers impose parasitic losses on the gas turbine due to pressure drop caused by coils located in the inlet air filter house of the turbine. This is represented by the difference in heat rate shown in the table above, which also includes the electrical parasitic load of the chiller.

The fogging system requires the same quality of water as the LP water injection to compressor and NOx water injection. This simplifies the balance-of-plant design because it calls for producing only a single source of demineralized water. This source can be economically achieved through the use of a reverse osmosis and electrodeionization (EDI) system in series. Furthermore, fogging systems may be pushed to their limits by introducing wet compression into the gas turbine, thereby achieving the highest levels of saturation and mass flow through the system.

5.0 Improved Maintenance Access and Constructability

Maintenance access considerations are critical design aspects in peaking gas-turbine power plants because of the associated expectations around their rapid response and reliability. These plants play a crucial role in meeting sudden surges in electricity demand. Ensuring convenient and efficient access to critical components for maintenance and repair activities is vital to minimizing downtime and maximizing operational availability. Gas-turbine systems require regular inspections, preventive maintenance, and occasional repairs to guarantee their optimal performance. Designing the plant layout with strategic access points, well-organized walkways, and appropriately positioned equipment facilitates swift maintenance procedures. This streamlined approach not only reduces the time needed for inspections and repairs but also enhances the overall operational readiness of peaking gas turbine power plants. By prioritizing maintenance access, these plants can swiftly respond to fluctuating demand while maintaining their reputation for reliability and providing consistent power supply during peak periods.

Aeroderivative gas turbines, and specifically the LM6000, have a unique advantage: an entire turbine (engine) can be replaced in less than 24 hours if a critical failure occurs. As shown in Figure 7 below, the standardized LM6000 peaking solution package features turbine doors with an additional 4 inches of clearance. Although it may not seem like a significant change, it allows for technicians to access, rotate, remove, and load the turbine more efficiently, and it reduces the risk of impact with the package.

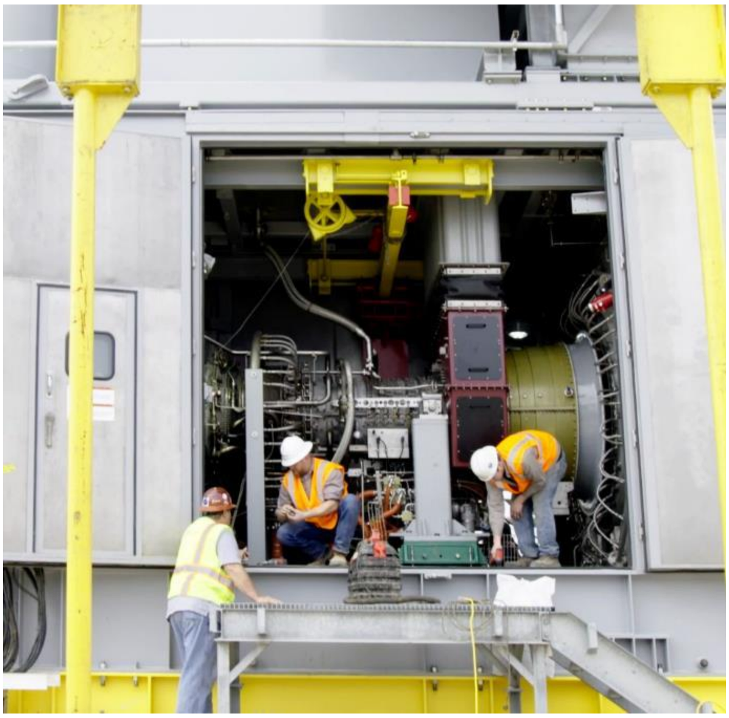

Figure 7: LM6000 Turbine Access Doors.

In addition to wider turbine doors, the package includes additional maintenance access ways on the sides of the generator enclosure. Figure 8 shows these access ways, which allow for operators and technicians to troubleshoot failures more easily by providing free access to the termination points within the generator package.

Figure 8: Generator Enclosure Maintenance Access.

Another maintenance improvement in the package is shown in Figure 9: the hinged access doors to the variable bypass valve (VBV) duct. This simple change saves operators from needing to unbolt 30+ bolts and handle the removal of the door each and every time access to the VBV duct is required.

Figure 9: Hinged VBV Access Doors.

One of the objectives of the standardized plant design is to simplify installation and activities as well. The standard auxiliary skid, shown in Figure 10, is a single shop-assembled piece that consolidates the following systems:

- Hydraulic starter motor system
    - Hydraulic start piping assembly and panel
- Turbine lube-oil reservoir and piping assembly
    - Water separator
- Water wash piping and reservoir
- NOx water pump and motor assembly
- Auxiliary skid gauge panel

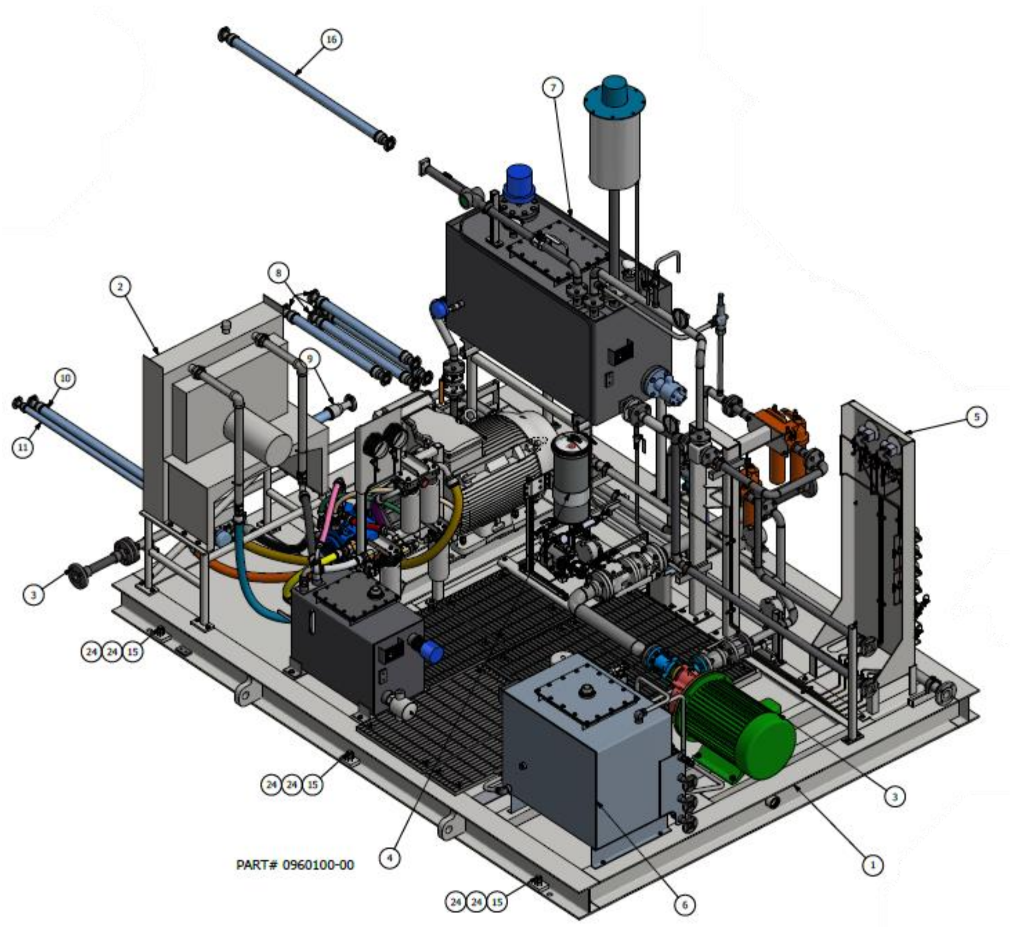

Figure 10: Standardized Consolidated Auxiliary Skid.

This consolidated auxiliary skid saves hundreds of hours during installation. For cold weather climates, this single skid can be easily contained with a common heated enclosure, which greatly simplifies the winterization design by eliminating costly and complex runs of heat tracing and insulation between multiple skids.

5.1 Review of Equivalent Forced Outage Rate (EFOR)

Any cost optimization decisions should not compromise the reliability of the peaking plant. Despite most peaking facilities running 2,000 hours per year or less, it is critical that the plant runs when called upon as these are typically the times of greatest demand. The following is a summary of the previous operating year's statistics for the first eighteen (18) LM6000 gas turbines deployed in the standardized LM6000 design configuration. These plants feature each of the modifications/improvements discussed within this paper.

NET CAPACITY FACTOR					
HO Clarke full site	11.7%	HO Clarke contracted	12.2%	HO Clarke merchant	6.3%
Topaz full site	8.3%	Topaz contracted	9.0%	Topaz merchant	5.7%

START RELIABILITY					
HO Clarke full site	98.0%	HO Clarke contracted	97.9%	HO Clarke merchant	98.8%
Topaz full site	97.9%	Topaz contracted	97.7%	Topaz merchant	98.5%

EQUIVALENT AVAILABILITY FACTOR					
HO Clarke full site	97.2%	HO Clarke contracted	97.0%	HO Clarke merchant	99.4%
Topaz full site	99.4%	Topaz contracted	99.4%	Topaz merchant	99.6%

EQUIVALENT FORCED OUTAGE RATE DEMAND					
HO Clarke full site	1.4%	HO Clarke contracted	1.4%	HO Clarke merchant	0.8%
Topaz full site	1.8%	Topaz contracted	2.0%	Topaz merchant	0.7%

With a typical EFOR of 1.5% or less, these peaking plants are achieving industry-leading reliability. An acceptable EFOR for a peaking gas-turbine plant can vary depending on several factors, including the specific technology, operational, and maintenance practices, and the overall reliability goals of the power plant. However, generally speaking, a competitive and well-maintained peaking gas-turbine plant would aim for an EFOR of less than 2%. A lower EFOR signifies that the plant experiences fewer forced outages due to technical issues or maintenance needs. EFOR is typically expressed as a percentage, with lower percentages indicating better reliability.

It is important to note that peaking gas-turbine plants are designed to respond quickly to changes in demand, and reliability is crucial to their effective operation. Therefore, efforts to minimize EFOR are important to ensure that these plants can reliably provide power during peak demand periods.

6.0 Conclusions

In an evolving energy landscape characterized by the increasing concentration of non-dispatchable renewables, the imperative to drive down costs and enhance reliability in peaking gas-turbine power-plant design takes on heightened significance. As the contribution of renewables like solar and wind power increases, grid stability becomes more susceptible to fluctuations in weather conditions. Peaking gas-turbine power plants, with their ability to rapidly respond to demand variations, play a pivotal role in maintaining grid stability. By reducing costs, these plants can offer competitively priced electricity while complementing intermittent renewables, thus ensuring a reliable power supply during peak demand periods. Simultaneously, bolstering reliability through well-designed, easily maintainable systems ensures that these gas turbines are readily available to counterbalance renewable energy variability. The standardized LM6000 power plant design, now implemented across more than forty (40) units in the United States, has demonstrated that there is a more cost-effective peaking solution that is available at a price point that continues to attract investment.

The standardized LM6000 peaking plant not only offers savings on the initial capital expense, but the notable operational benefits of the design improvements covered within this paper. These benefits include the elimination of the SCR tempering air fan, elimination of the electric ammonia heater, and the replacement of the traditional glycol inlet heating system with the package air recirculation inlet heating system. The sum of these changes results in approximately 620kW and USD$1.045M/unit in savings on an NPV basis over a 25-year period when considering a very conservative aggregate cost of electricity of USD$0.1/kWh. An alternative view is to consider the parasitic load savings' impact on the price of the capacity, which is more representative of how peaking power plants are analysed. Based on 620kW in savings and a $15/kW-mo capacity price, this is an annual savings USD$111,600/year per unit.

All of the savings as a result of these peaker package improvements work to address the need for cost-efficient peaking solutions. Ultimately, the ongoing pursuit of cost-efficiency and reliability in peaking gas-turbine power-plant design aligns with the broader energy transition objectives, in which renewables and gas turbines collaborate harmoniously to underpin grid stability and secure energy access for all.

References

[1] Shaner M, Davis S, Lewis N, and Caldeira K. Geophysical constraints on the reliability of solar and wind power in the United States. *Energy & Environ. Sci.*, 2018, Vol. 11, pp 914-925

[2] California ISO Data Reporting, July 19, 2023, https://www.caiso.com/TodaysOutlook/Pages/default.aspx#section-net-demand-trend