# APPLICATION OF THE LATEST AERODERIVATIVE GAS TURBINE TECHNOLOGY

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***Abstract—GE Energy has a 40-year history of continuously innovating on its Aeroderivative gas turbine products to help meet customers needs. Three distinct platforms have been developed to meet power needs ranging from 18 to 100 megawatts, and have been used in such diverse applications as combined cycle industrial parks, municipal cogeneration, and remote peak load dispatch. This paper will review the LM6000 Product Line innovations in the 35-65 MW range. The recent addition of several innovations on this platform has improved not only their efficiency but expanded their application suitability.***

## I. INTRODUCTION

Today's power industry has had many recent challenges that have changed the way 'business is done'. Examples of such challenges include grid systems that are looking to retire older less efficient and reliable generation, as well as the addition of renewables that further challenge the characteristics of the grid system. These changes are impacting the thermal generation in terms of what is needed to support the grid and the operating profile of said generation. Technology innovation is a key driver to meeting these and other key industry issues. Aeroderivative gas turbines currently play a key role in providing necessary flexible generation and are a major component to many operators' power generating portfolios. Recent innovations from GE Energy and GE Aviation, from new materials to new designs, has produced updated products that help to improve the units power and efficiency, and better position them for a wider range of applications.

In this paper, specific new innovations to the aeroderivative gas turbines in the 35-65 MWe range will be discussed and how application of these products can improve both system and plant efficiency. For example, the recent introduction of the LM6000 PG[1] offers a 25 percent simple cycle power increase compared to its predecessor, and its combined cycle power has increased into the 65 MWe range. The power increase comes from the same 4.5m X 21.5m package footprint based on existing 50 Hz LM6000 packages. As an example of utilizing the new technologies into broader applications, the new LM6000 PG has been incorporated into a 2-on-1 reference combined cycle plant that is designed to provide fast, flexible and efficient 135MWe at 52% efficient combined cycle power.

## II. TECHNOLOGY OVERVIEW

Since GE began industrializing the CF6-6 aircraft engine in 1971, there has been over $2 billion invested in the aeroderivative product lines that now constitute the GE Energy Aeroderivative business. Over the course of the past 40 years, GE has advanced the technology from the original 18MWe LM2500 products that were used on naval warships, to include 3 distinct product lines that are used on a diverse set of applications such as oil and gas platforms, to university cogeneration systems, and industrial park combined cycle installations. These 3 platforms provide customers the opportunity to leverage proven and efficient products for their specific project size and application. As investment continues in each of the platforms, they each have become more globally accepted and utilized in a diverse set of applications, with the latest technology innovations being no exception. The latest innovations for the LM6000 are the PG & PH versions of the existing product line. Denoted as the "PG" for the Standard Annular Combustor (SAC) and "PH" as the Dry Low Emissions (DLE) model, the gas turbines have 90% common parts to the proven LM6000 family of industrial Aeroderivative gas turbines, but provide more power and better efficiency in the same footprint. These improvements are being created courtesy of advanced materials, improved manufacturing process, and minor adjustments in design. Leveraging the broad experience of GE in gas turbine technology, many of these improvements have been imported from GE Aviation and the larger GE Energy aeroderivative product, the LMS100. By utilizing already proven technology, the latest updates to the LM6000 are expected to maintain comparable reliability numbers as the existing products.

As an example of one of the changes from GE Aviation, the High Pressure Turbine (HPT) rotor of the LM6000 PG has been modified based on the GE CF6-80E aircraft engine (common on many Airbus A330 fleets). The LM6000 PC, on the other hand, has a rotor based on the older GE CF6-80C2 engine. The updated HPT rotor design improvements include new higher temperature alloys and improved cooling patterns. This switch of rotor effectively raises the pounds of thrust from 60,000 to 70,000. As a result, the LP compressor can operate at higher speeds to increase the flow, and the pressure ratio has gone from 30 to 32. Additional design changes to the HPT rotor include a new bolt pattern between the rotors in the HPT that has significantly reduced material stresses. On the PC model, the HPT rotor is the cyclic life limiting part. With the updated material and design advances, the cyclic life was improved in excess of 40% for the PG model.

Overall the combination of better materials, manufacturing process, and improved cooling design enables the LM6000 PG to operate at a higher firing temperature. The LP inlet temperature, for example, has been increased by over 50° C and the compressor discharge by more than 40° C. These design changes, along with the increased flow through the engine, allow the gas turbine to run at 3930 RPM v 3600 RPM. This higher RPM is comparable to the true speed of an aircraft engine.

The net results of these changes are more power with the same or better efficiency within the same gas turbine footprint. Therefore with the recent introduction of the LM6000 PG & PH products, its unique new innovations will be highlighted in terms of its use and where the economic benefit can be seen. Specifically, the application discussion will include:

*A. Simple Cycle Enhancements*

Having delivered more 35-65MWe gas turbines in simple cycle than any other manufacturer[2], the LM6000 improvements further extends value to customers looking for more power in a compact plant area. Based on over 17 years of operating data for simple cycle operation, there is a growing need for gas-fired generation to operate efficiently over a wide spectrum of ambient temperatures and power ranges. The improvements in the LM6000 provide power providers the ability to meet this need for a wider operating profile. Additionally, many grid systems are experiencing frequency fluctuations that can adversely affect power distribution, even causing back outs. There are several drivers to this, including other generating units coming off-line, system frequency imbalance, or responding to variable wind or hydro generation; which causes a change in the interconnected system characteristics. The LM6000 gas turbine provides power producers an economical means to serve these changing load requirements.

### *B. Proven Cyclic Combined Cycle Generation*

Today's install base of combined cycle plants are experiencing a growing need to operate at part power, withstand voltage swings, and be capable of faster dispatching. Many of these market conditions have led to the use of GE Aeroderivative gas turbines to help address system loads while still addressing efficiency needs. Installations of 2-on-1 and 3-on-1 configurations have increased over the past 15 years to meet variable loads below 200MW. These systems, when utilizing once-through waste heat recovery systems, provide operators the flexibility of simple cycle operation in 10 minutes while the steam cycle comes to pressure and temperature. Additionally, with the once-through design, the integrated system can withstand cycling to compliment the cyclic capabilities of the gas turbine. Advancements in plant modularity and system integration are now available that further provide customer benefits when installing combined cycle Aeroderivative platforms.

### *C. Supporting Greener Generation*

Power generation portfolios are constantly challenged to reduce greenhouse gas emissions. The LM6000 builds upon its high simple cycle efficiency design to aid efforts by power gen operators to build greener portfolios. By conserving natural resources with advancements beyond just the gas generator, the LM6000 GTG positions itself as a cost effective greener solution in many power gen portfolios.

The following material will demonstrate how the robust heritage of aviation based industrial Aeroderivatives gas turbines provide a reliable platform with application experience and technology advancements to meet the diverse needs of the power industry. Several regional examples will be provided to demonstrate both applications of the units as well as innovation adoption.

## III. Simple Cycle Enhancements

### *A. Primary power*

The need for simple cycle generation has predominantly been driven by peak demand; however many of today's units also serve a critical role in maintaining system frequency in many countries. As the power industry is looking to retire many older inefficient and now unreliable assets, evaluating unit efficiency and dispatch characteristics are key to addressing peak demand. Table 1 shows a comparison between unit dispatch, efficiency, and frequency stabilization for various technologies. A power producer with a complete portfolio of generation equipment would evaluate which technology to dispatch based on forecasted need to meet the best economic return. For example, the available coal generation may be cycled to meet the variable demand, but it requires a substantial advanced notice and is the least efficient means to do so. System operators may consider dispatching highly efficient combined cycle units as they require less start-up time, but these units have limited part power efficiency and turn-down capability should the load not materialize as forecast. The next most economic alternative may be the open cycle Frame unit as they have more operational flexibility, at the expense of a less efficient alternative. These factors have led to the strong adoption of the Aeroderivative gas turbine as an efficient alternative that can swiftly meet variable load demands.

The recent commissioning of (12) LM6000 units for Kuwait provides an application example for simple cycle demand. The project required two 200-megawatt plants to be commercially available in twelve months to meet summer demands. This could be achieved because of the factory packaging approach that GE employs, where the units are assembled on skids and tested at our facility prior to shipment. The package design is both compact and takes into account maintainability features such as sight drains on lubrication systems, package mounted removal cranes and access areas. These features also allow for more efficient shipping of the power plant by utilizing standard shipping industry means of transportation whether by land or sea. Additionally, the customer team valued the benefit of witnessing the factory packaging and testing of the units to ensure a rapid site installation and construction time to meet their schedule.

| | Coal | CCGT | OCGT | | Recip |
|---|---|---|---|---|---|
| | | | Fr | AD | |
| Ramp rate (MW/min) | 8 | 11 | 10 | 50-100 | 1 |
| Start cycle (min to full load) | 300 | 30 | 10-15 | 10 | <10 |
| Efficiency | 33 | 57 | 35 | 43 | 45 |
| Rotating Inertia | H | H | H | L | L |

Table 1 Simple cycle alternatives

*B. Supporting simple cycle operation – grid stability*

The LM6000 platform has incorporated an improved control methodology that enables it to proactively increase power output in an under-frequency situation. This boost of power, Figure 1, helps to regain the grid frequency and prevent a blackout if grid instability occurs. This technological advancement utilizes the existing turbomachinery capability and was brought forth from a new control algorithm in the gas turbines fuel core.

This option is made up of a special control schedule and the communications integration within LM6000 gas turbine generator sets that provides a more effective, less costly, approach to achieving stable operation during transient stability upsets. The system will rapidly increase or decrease unit power output when the owner's grid or facility management system detects a severe change in system frequency or loading. The grid stability control system can support transient upsets in two ways; first, the controls can provide a quick power increase, within fractions of a second, helps preserve stability and maintain frequency control in transient situations where there is suddenly too much load connected. Secondly, it can support a rapid power decrease, while still remaining on line, which helps in situations with sudden large load reductions, such as tripping of an industrial process or a close-in grid transmission line fault.

Without this option, a generating unit relies on the traditional slower, governor droop control to react to frequency upsets. Since this option proactively responds to a direct input from the external high speed plant or power grid monitoring system, and responds more rapidly, a substantially greater contribution can be made toward preserving stability of the system. This overpower is done within a control time frame of no more than 15 seconds. This is enough time for the LM6000 to absorb the transient situation on the grid, yet will not have an adverse affect on the life of the gas turbine. There is no impact to the standard maintenance intervals of a LM6000 with this option.

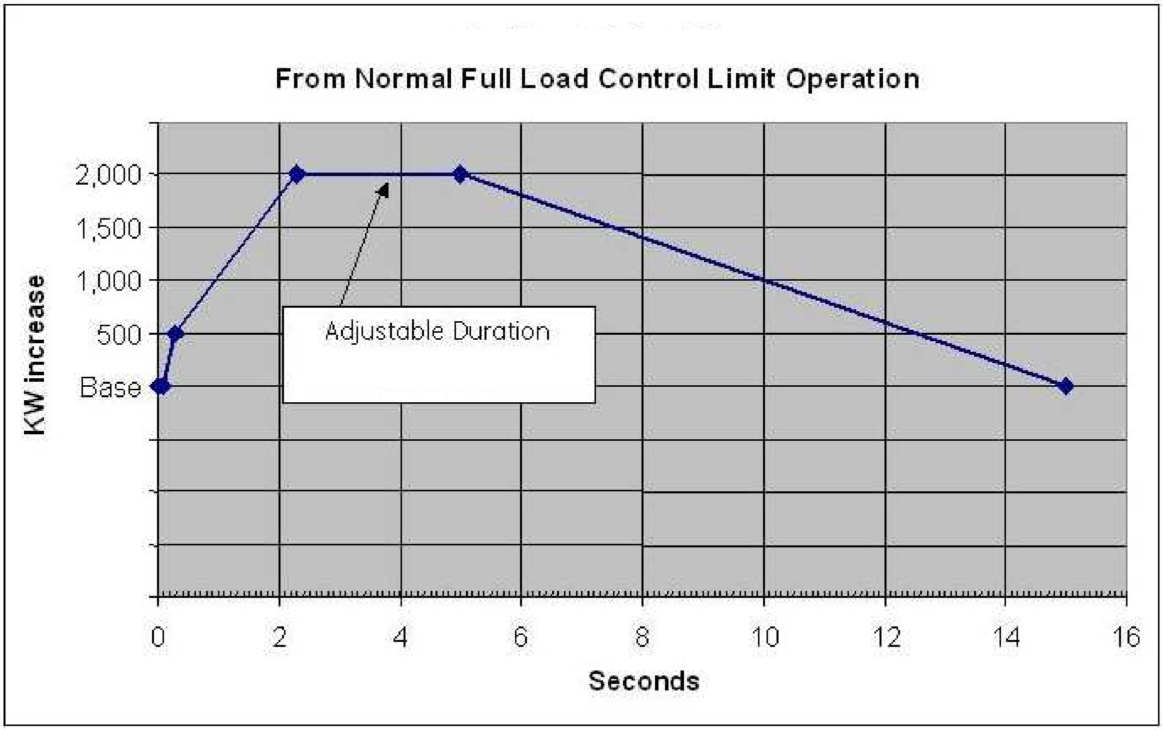


Figure 1 - Power Increase Above Control Limit

## IV. CYCLIC COMBINED CYCLE

Having demonstrated the ability to improve upon the installation of the gas turbine generator equipment through the use of factory packaging, the same approach has been taken to the remaining equipment for a Combined Cycle (CC) installation. Several reference combined cycle plant updates have been developed to aid in the design and construction of a modular Aeroderivative combined cycle power island. Distinct advantages of the system include factory packaging of the steam turbine, fast start capability with a dry boiler design, and a rapid field installation with maximum pre-assembled plant equipment. The reference plant has been designed with these primary components to ensure maximum flexibility with the fastest start-time, part power efficiency, and cyclic capabilities.

The aforementioned advancement to the GE LM6000 gas turbine product line brings an 18% increase in the exhaust energy and 25% increase in power; which in the combined cycle configuration makes the reference 2-on-1 LM6000 capable of providing 135MWe net power at 52% efficiency. Efficiency can reach as high as 56% using GE's Dry Low Emission (DLE) technology, but the power output will be slightly less. Additional output can be added to the plant through duct firing.

The modular approach to a 2-on-1 LM6000 CC plant centers around a power island with 2 LM6000 Gas Turbine Generator (GTG) sets, 2 Once Through Steam Generator (OTSG), and 1 skid mounted Steam Turbine Generator (STG). Recognizing that each site location will require unique considerations, the power island reference plant materials are offered as an Engineered Equipment Package (EEP), and is used for a basis to guarantee plant output and heat rate when adhered to, regardless of the role GE has in the procurement and construction phase of the project.

The LM6000 reference plant will have options, including different LM6 engine configurations, BOP adders like chilling, or the ability to dry cool the major components around the plant. A regional example of utilizing various options has been the country of Turkey. The installations of the LM6000 has been growing in Turkey since the mid 1990's, from applications ranging from summer peaking to industrial park combined cycle plants. Recently a 2-on-1 LM6000 PC plant going into Burdur, Turkey followed the reference power island design. Like the reference plant in Figure 2, the facility will use once through boilers and dry secondary cooling to minimize water usage and maximize flexibility.

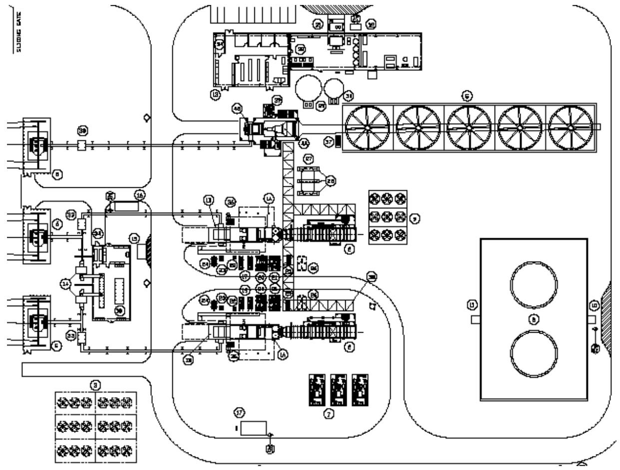

Figure 2 - GE 2-on-1 Reference Plant

Proven benefits from existing 2-on-1 LM6000's in combined cycle have been full power in 45 minutes or less. Additionally, other benefits include improved part power efficiency, and the ability to cycle the CC plant without a maintenance cost increase. Based on existing experience a LM6000 CC reference plant has been developed to show a potential Installation and Commissioning (I&C) cycle time of 24 months, including time for engineering design and product delivery. Benefits of a modular construction design include reduced development time, reduced installations costs, and reduced risk.

## V. Supporting Greener Generation

In the U.S., although the cost of wind energy is becoming increasingly competitive with other power generation such as natural gas and coal, it has penetrated less than 1 percent of U.S. generated electricity. However, it has been stated that wind energy could one day supply up to 20 percent of the United State's power. In Europe the targets for wind power growth are substantial. Wind is projected to deliver 33 percent of all new electricity generation capacity and provide electricity for 86 million Europeans by 2010[3].

### *A. Wind Firming*

Despite increasing momentum towards wind power globally, wind cannot supplant baseload generation over the long term. On a hot summer day when customer demand is at its maximum, wind availability may be limited. Therefore, where wind works best is when it is matched with a controllable peaking power source like natural gas combustion turbines, which can be ramped up or down to respond to the varying loads inherent in wind farms[4].

With increases in wind power in many power generation portfolios, the need to stabilize the power onto the grid has proven a need for supporting power generation with operational flexibility[5]. Wind power in general has a major contribution during low load hours, but only a small contribution during peak hours. Additionally, wind itself can be intermittent. The

LM6000's quick start and grid stability controls makes for a stabilizing effect on the grid. Additionally, with the necessity for quick and frequent starts/stops to support the variable generation, the Aeroderivative technology can cycle from on to off, on to part load, and from full load down to spinning reserve to meet the variable demand.

Also to support quick and frequent starts/stops, the LM6000 standard 10 minutes start time can be improved to just 5 minutes. The 10-min start is outlined in Figure 3, and shows the sequence that includes purge time, warm-up time, and finally gas turbine ramp time. By properly maintaining the package purge requirements, and by keeping the lube oil 'warm', approximately 2 minutes can be removed from the 10-min start sequence. Then the gas turbine acceleration rate to full load can be increased from 12MW/min to 50MW/min, reducing the time from sync idle to full load from 4 minutes down to approximately 1 minute. This reduced start time greatly enhances the LM6000's ability to get online quickly to support a reduction in load from the wind farm due to sudden changes in wind conditions.

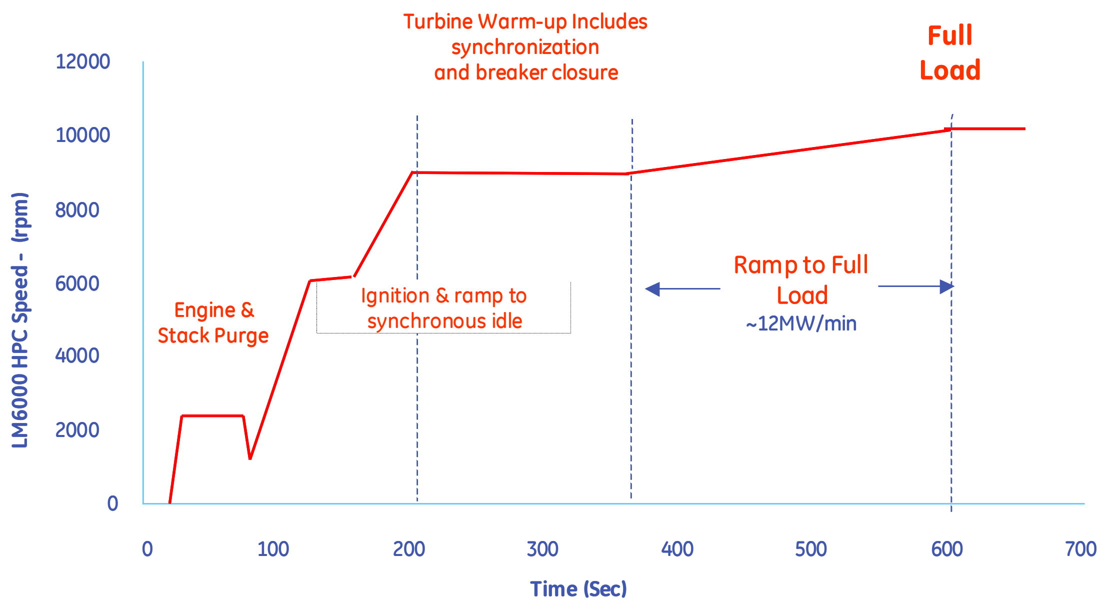


Figure 3 – LM6000 Ten-Minute Start

Once online, the Aeroderivative technology can utilize its aircraft engine heritage and throttle up and down to follow the wind firming demands. Figure 4 shows a typical LM6000 in a load following application. The LM6000 can adjust from sync idle to full load in under a minute, as well as make adjustments to load variation requirements in seconds. A key for the GTG life management tracking is an accurate count of cycles, and the LM6000 has built-in cyclic count tracking in the package software.

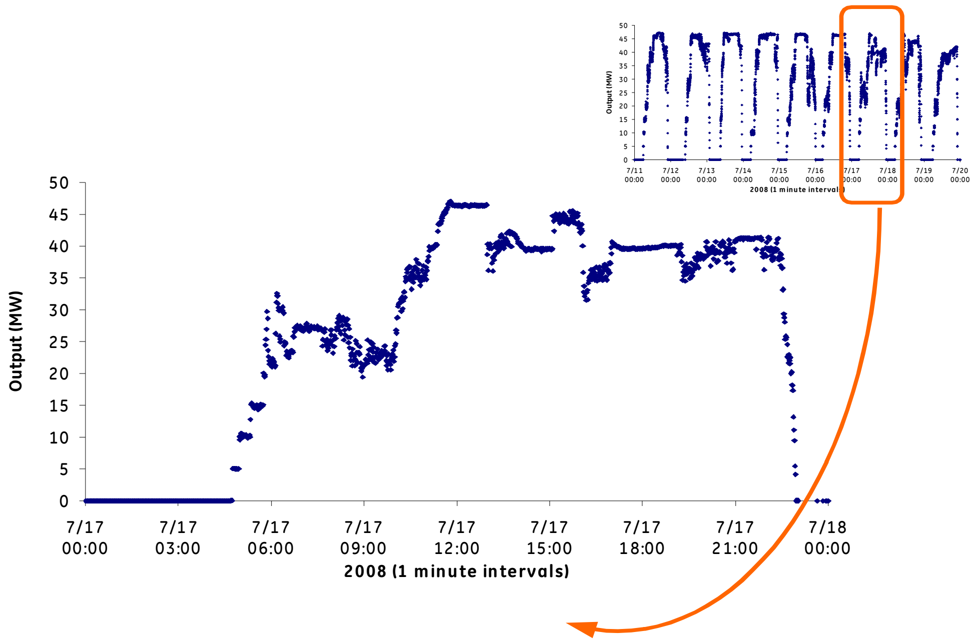


Figure 4 - LM6000 in load following mode

The wind firming benefits are standard feature to a LM6000 gas turbine, and thus do not affect the planned maintenance schedule (based on fired hours) or have an adverse effect on maintenance cost. There are additional cyclic counts added to the cyclic limited components of the gas turbine, but current standards on cyclic duty for the existing LM6000 products are in excess of 6400 cycles. In addition, the design changes on the PG/PH have extended the cyclic life of the gas turbine by 40%. This makes for a good fit into wind power generation support.

*B. Water*

Another advancement in the controls of a gas turbine is in the use of water. For the LM6000, water can be used for both NOx reduction and power augmentation. Most often the discussion on gas turbine efficiency is based on fuel consumption (heat rate, efficiency), but with many global water scarcity issues, the efficient use of water can be a critical operating profile consideration. An updated control algorithm in the fuel core manages water usage for maximum efficiency for preset conditions such as NOx output, power output, and grid frequency.

For a Single Annular Combustor (SAC) LM6000 model, water usage can be up to 13,400 l/hr during full load operation (not including any water used for cooling or inlet conditioning around the package). This water usage amount accounts for NOx abatement and for a power augmentation option called SPRINT®. Roughly 2/3 of the water consumption is for NOx abatement, and the rest is used for SPRINT®. In the control system, the water table algorithm controls water usage during key transitions of the gas turbine where excess water could be consumed. Such transitions include ramping up to full power, part power operation, and SPRINT® operation turning on/off. Figure 5 has an example of SPRINT utilization running the gas turbine at part power.

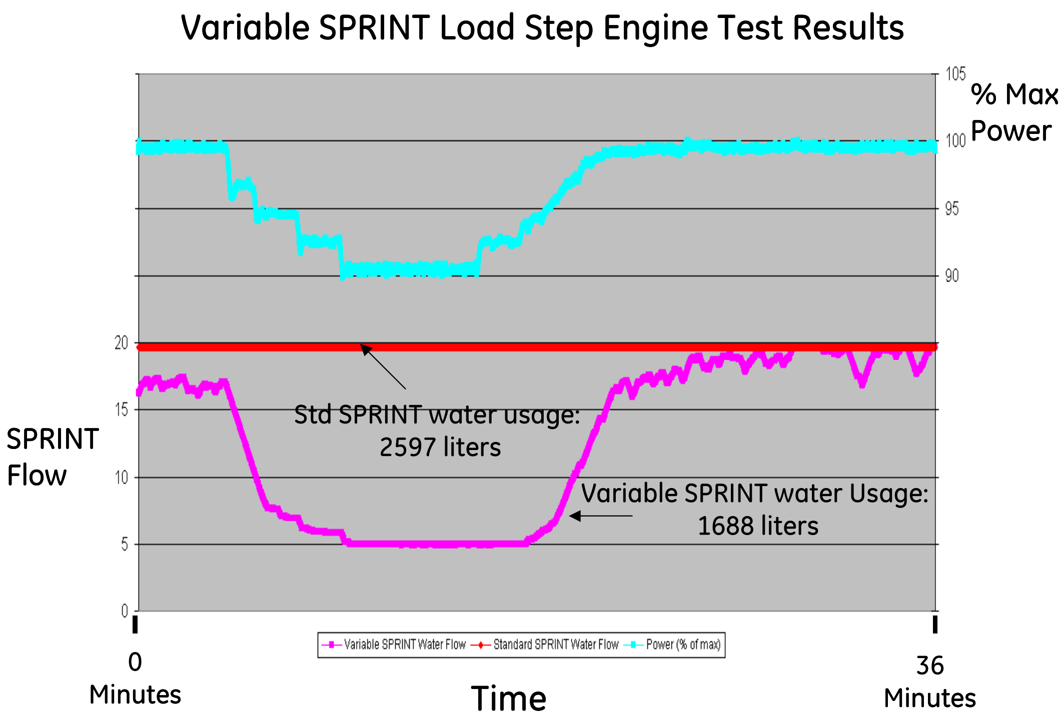


Figure 5 – Variable SPRINT®

As mentioned, plant efficiency analyses on operating costs are starting to analyze water consumption as well as fuel consumption. The example shown in Figure 5 represents a 35% decrease in water usage for SPRINT®. If a plant operation profile includes constant starts and stops, as well as part power operation, the savings in water can be substantial. Additionally, with improved water optimization at part power comes improved fuel efficiency seen through improved heat rate of the gas turbine. All this leads to improved operating costs for the power producer.

## VI. Conclusions

The results of applying many decades of technology from the GE Aviation business to industrial applications has provided customers of the GE Aeroderivative products a robust, efficient, and reliable product. The innovation continues with expanded reach and development, and the innovative technologies have been applied to not only the gas turbine, but to all aspects of the power plant; from packaging design to product application. The power generation market is going through substantial changes at this time and operational flexibility is a key for power generators to maximize profitability and still provide meet customer satisfaction goals. By utilizing Aeroderivative gas turbines, many power providers are finding new ways to profit from a proven technology. The LM product lines have withstood many market cycles, and the investments being made today ensure it will provide customers many benefits for years to come.

## References

1. PowerGen Europe launch, http://www.gepower.com/about/press/en/2008_press/060408b.htm
2. McCoy Power Reports, 2009
3. http://ge.ecomagination.com/products/wind-turbines.html
4. Wind Power Integrates with Natural Gas Plant at Emporia Energy Center Peaking Facility, Ramona Vassar, RMEL Electric Energy, Fall 2009
5. Advantages of Flexible Thermal Generation in High Wind Penetration Grids, Nicholas Miller, VGB Konferenz Kraftwerke, April 2009

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