MORE POWER & EFFICIENCY ON A 7FA IN THE MIDDLE EAST AT 50°C

POWERPHASE®
GENERATION SMART

COUNTRY
SAUDI ARABIA

PROJECT SUMMARY

Powerphase collaborated with the Tamimi Group of Companies and Saudi Electricity Company (SEC) to demonstrate Turbophase system's ability to boost F-class gas turbine (GT) power output at the high ambient air temperatures that Saudi Arabian summers are known for. Besides demonstrating the technical goals of boosting GT efficiency, the demonstration showed that Turbophase can be flexibly and quickly deployed to accommodate an accelerated schedule and unexpected conditions at the plant.

The project operated from mid-July to early October 2015. Two Turbophase modules were connected to a GE-MS7001FA-(7FA.03) GT at the Faras Power Plant in the Eastern Operating Area, to demonstrate performance and extrapolate the outcome to provide insight into how a full Turbophase system deployment would affect plant performance.

The project was approved in Spring 2015, with just 4 months to design, install, and commission the Turbophase demonstration. The system was installed and commissioned by mid-June. It operated from mid-June to early October, with two performance tests to ascertain how the Turbophase modules were boosting GT power output and heat rate.

As measured during the two performance tests, the demonstration met the predicted system performance boost. Each Turbophase module added 4.25 MW at 8,650 BTU/kWh to the GT, for a total of 8.5 MW at 8,100 heat rate. By extrapolating the Turbophase output from the current firing

BY THE NUMBERS

Engine Type	GE 7FA.03
Configuration	Simple Cycle
Megawatts As Installed	8.5 MW Per CT
Megawatts Potential	31.5 MW Per CT
Efficiency Improvement As Installed	0.71%
Efficiency Improvement Potential	5%

MARKET BACKGROUND

In the Middle East, gas turbine efficiency at high ambient temperatures is crucial. Demand for fuel oil for power generation during a Saudi Arabian summer reaches between 420,000 and 430,000 barrels per day. With 58 percent of global use, the nation is the world's largest user of crude oil for generating power. Iraq, Kuwait and the UAE were ranked third, fourth, and fifth, respectively; together with Saudi Arabia, these countries account for almost 80 percent of the crude oil that is burned for power generation worldwide. A 5% fuel efficiency improvement would save 18 million barrels of oil equivalent.

Middle Eastern power plants typically use chillers to improve gas turbine performance. Chillers effectively cool the gas turbine inlet to allow it to generate additional mass flow. However, they are only available 6 hours a day because they require 16 to 18 hours to chill water. The Turbophase solution is available 24 hours a day.

CUSTOMER CHALLENGES

Generating electricity with combined cycle gas turbines (CCGT) in Saudi Arabia can be an expensive endeavor. The hot climate leads to turbine inefficiencies because hotter ambient temperatures reduce air density and GT combustion efficiency. CCGT plant operators need a reliable solution that can boost GT combustion efficiencies in the heat and reduce maintenance costs.

To date, plant operators in the Kingdom have used two expensive options to increase GT power production. One option is a chiller to cycle cold water from a cold tank to a hot tank through the turbine's inlet to boost power production. However, the chillers draw power from the turbine to refrigerate the water for 16 to 18 hours a day. Therefore, the chiller can only run 6 hours a day while parasitically reducing electricity output from the turbine. Another option is aeroderivative gas turbine technology that can be quickly dispatched to meet peak demand with traditional CCGT serving baseload. However, installing new aeroderivative gas turbines is expensive and these turbines also have thermal inefficiencies when the ambient air temperature rises.

The Turbophase module is a less expensive investment than a new peaking gas turbine. It can also be deployed much faster than a peaking plant because it can be added to an existing plant. Therefore, there is no need for design, permitting, commissioning, and interconnection to the grid as there would be with a new plant. The Turbophase module is also a superior substitute to a chiller, as it is available 24 hours a day to boost air flow to the CCGT. It is also a more flexible solution because it can integrate with any GT in a CCGT plant whereas a chiller must be sized and fixed to a specific GT.

PROJECT MILESTONES

Powerphase demonstrated two Turbophase modules on a GE 7F4A GT at the SEC Faras power plant in 2015. The technology proved to be flexible, highly available, and that it could improve GT heat rate performance by 5% during Saudi Arabian summers. The project kicked off on April 22, 2015, which only gave the engineers three months to deliver, integrate, and commission the Turbophase modules before summer began.

On May 9, the GE 7F4A GT was shutdown to install the tie-ins, and the Turbophase modules arrived on May 21 and June 14. The Turbophase modules were connected in just three days – they were fully integrated by July 17. Typically, a GT must be down for six weeks or more when a new hot gas path or inlet cooling system is installed because it requires significant changes to the plant. Turbophase modules can be installed quickly because they just need one air pipe that ties into the GT. On July 20 the Turbophase modules injected air into the GT for the first time.

After the first injection, the Turbophase modules were hot commissioned by performing injection tests at varying inlet temperatures. On July 28 and October 2, performance tests were administered. The tests were conducted by Powerphase personnel operating the Turbophase system and plant personnel operating the GT. SEC plant management and SEC East region technical staff witnessed the tests. The Turbophase system achieved its stated output and heat rate targets of 4.5 MW per Turbophase module and 5% heat rate improvement for a full installation. These values are based on the measured performance corrected for firing temperature and extrapolated to a full installation. A full installation of seven Turbophase per GT at Faras Power Plant would generate 31.5 MW and a 5% heat rate improvement to the entire gas turbine. Additionally, the system demonstrated as high as 99.3 percent availability in ambient conditions up to 131°F (55°C). The fuel efficiency improvement was demonstrated at both baseload and part-load operating conditions.

NEXT STEPS

Following on the successful demonstration of Turbophase modules on the GT, SEC could expect a standard installation of five to seven Turbophase modules to provide significant benefits. At the as-found conditions of the GT, each Turbophase module adds 4.25 MW at 8,650 BTU/kWh to the GT, for a total of 8.5 MW at 8,100 heat rate. Performance calculations show the heat rate closer to 8,000 BTU/kWh. By extrapolating the Turbophase output from the current firing temperature of 2,370F to the design point of 2,420F, the output increases to 4.5 MW at 7,600 BTU/kWh heat rate. An installation of 5 modules would result in an output increase of 22.5 MW. At 122°F (50°C) ambient air temperature, this results in a 19% output increase and 3.5% heat rate improvement. An installation of 7 modules would result in an output increase of 31.5 MW. At 122°F (50°C) ambient temperature, this results in a 26% output increase and a 5% heat rate improvement.

Overall, during Summer 2015 operations, the Turbophase modules were over 97 percent available and enhanced the GT output by additional 3.2 GWh. Turbophase module availability was mainly impacted by diesel power supply, water supply, and Turbophase module cooldown time after operations that limited it to a 12-hour shift. There were also failed Turbophase module starts that were solved with a new control upgrade and a lower ramp rate; Turbophase module trips caused by pressure sensor malfunction which was resolved by replacing it, and high gas temperature which was addressed by replacing the gas solenoid valve with a pneumatic valve.

In addition to conducting a successful Turbophase module demonstration, Powerphase also helped SEC identify additional operating and equipment inefficiencies. The Powerphase team discovered that the GT was heavily eroded with significant gaps between stationary and rotating parts which significantly decrease efficiency and output of the gas turbine. They alerted SEC plant personnel, so that the SEC could decide whether to replace the part. The Powerphase team also found that the GT was not operating at the designed firing temperature of 2420°F. They estimated that the GT was operating at firing temperature of 2370°F, confirmed by site operations and validated with a ThermoFlow model matching the site operating conditions. Operating at a lower temperature reduced overall efficiency, including air intake, such that if the GT was firing at its designed firing temperature, the Turbophase modules would have boosted the GT power output by an additional 0.2 MW.

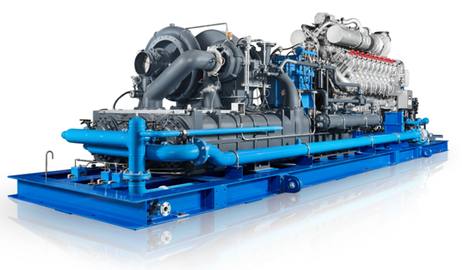
HOW IT WORKS

The Challenge for Gas Turbine

Gas Turbines draw ambient air into their axial flow compressor, increasing the temperature and pressure of the air. The air then flows into the combustor where fuel is added proportionate to the amount of air mass flow and the mixture is ignited. This high-energy gas now expands through the turbine stages, creating mechanical torque to drive the gas turbine's compressor and the net torque drives the generator producing electrical power.

The challenge faced by all gas turbines is that as ambient temperature or elevation rises, the density of the air naturally decreases, reducing the mass flow into the gas turbine. This reduced mass flow results in reducing the fuel flow proportionately to hold turbine inlet temperatures constant. This results in lower output.

Turbophase restores the mass flow that is naturally missing by injecting air into the compressor discharge. The gas turbine control system reacts naturally and adds a proportionate amount of fuel to account for the increase air mass flow, resulting in constant combustion and turbine inlet temperatures. The increased mass flow through the turbine section increases the mechanical torque to the compressor and generator.



How Turbophase Meets the Challenge

Turbophase is a packaged system with a reciprocating engine driving a multi-stage, intercooled centrifugal air compressor. Air is drawn into system to ventilate the system and provide air to the compressor. The compressor air filtration system mirrors the air quality of the gas turbine and then is compressed by the first stage of the air compressor and then cooled. The inter-cooled process is repeated through four or five stages, depending on the desired pressure, resulting in less power required per pound of air compressed compared to the axial compressor in a gas turbine.

How Turbophase Modules are Installed at a Power Plant

A Turbophase system can have several modules and each module produces a certain mass flow of pressurized hot air. Each module is factory acceptance tested to ensure quality including correct air pressure and temperature prior to shipment to the power plant site. Depending on the size of the gas turbine, and the requirements of the power plant, a Turbophase system may have 1 module or more than 10 modules. Each module is approximately 32 feet long by 8 feet wide by 18 feet tall at its highest point. A typical Turbophase installation requires no unplanned outage at the plant.