Air Distribution

Will the introduction of the air injection be evenly distributed?

Since the air injection is into the combustor wrapper, it will fully cool the transition piece and liner. Also, the air will have a much better chance to distribute and therefore maldistribution effects will be minimized. The IBH system is designed to bleed 5% air, therefore, the distribution of this bleed and the distribution of the injection will be similar and is proven to be acceptable by the bleed system.

Air Pressure

What is the pressure of the air injected into the Gas Turbine?

The injection air is pressurized to 250 PSI.

Air Temperature

What is the temperature of the air that you inject?

The temperature of the air that is injected into the Gas Turbine is 700 degrees F or about 371 degrees Celsius.

AutoTune

What are the effects of Turbophase on AutoTune? Will my emissions go up?

An experienced gas turbine combustor tuner will be present during commissioning. Combustion zone temperatures are not going to change as a result air injection and therefore combustor tune should not need to be changed. Combustion dynamics will be measured and therefore if there is a need to tune the engine to avoid elevated combustion dynamics (and potential flame out), the engine will be tuned as part of commissioning the system. Turbophase should not negatively impact the PPM level of the GT, however, since there is more fuel flow in the GT, the tons/hour will increase. Therefore, even if PPM level stays constant, the emission levels will be impacted and depending on permit conditions (tons/hr, max annual tons limit) the operating scheme of the Turbophase system needs to be evaluated to determine if permitting is required.

Backpressure

What are the backpressure effects? For example, flow splits to combustor and back to CDC?

The incremental air flow splits to the combustor will be very evenly distributed. Any flow maldistribution that is introduced by air injection is also introduced by the inlet bleed system, and there are no issues with this system. So by similarity, any air injection maldistribution is acceptable. There will be an increased backpressure on the CDC, however, this is no different than steam injection backpressure, and therefore, is acceptable to the Gas Turbine.

Baseload Generation / Continuous Operation

Are the Turbophase modules at Morris Cogeneration operating in peak service or have they been continuously operated? Any issue with base-loading the system?

The Turbophase system at Morris Cogen is primarily being used to increase the speed of the plant within the context of the PJM regulation market. Additionally the system will likely be used for peak service in the energy market. Turbophase is designed to be a continuous operation system operating for baseload generation. Because the Turbophase system is modular, in the event of the failure of a single module, the other modules in the system can make up for the lost air-flow, making the entire system highly reliable.

Cooling Water

What is the design temperature of the cooling water required?

85 F. Higher temperature will decrease the efficiency of our compressor. Lower temperatures will increase it. Turbophase can easily tap into the plants existing cooling water with very little effect on power plant cooling.

Combustion Dynamics & Flame Stability

How will Mk VI know how to tune air flows to mitigate dynamics?

Combustion stability is a function of average flame temperature, assuming there is adequate mixing. Turbophase air injection into the wrapper will maintain current mixing. Also, typically, the air injected will be approximately 100 degrees F below the CDC temperature (above 500F), and therefore the air mixture being heated to the firing temperature will require a fractional amount more fuel, resulting in a slightly hotter combustion zone average temperature, which actually improves the combustion dynamics. The slightly hotter combustion zone temperatures help offset the fact that on hot day, when the GT's CDT is elevated, the combustion zone average temperature is reduced. In general, the controls look at exhaust temperature and CDP so determine fuel flow. In the new model base controls, a transfer function will be implemented outside the Marc VI controller that will tell the GT that there is additional air in the GT, and therefore, the appropriate model parameters will be used to fire the unit. Additionally, all of the critical GT parameters are available, including combustion dynamics.

Compressor Efficiency

How is the efficiency of the compressor in the Turbophase system different from that in the gas turbine system?

Turbophase uses a highly efficient, multi-stage, intercooled centrifugal compressor. The compressor used in Turbophase employs a high speed rotating impeller with intercooling between stages, resulting in a more efficient compression process than employed in a standard combustion turbine. A gas turbine uses a fixed volume flow axial compressor, an airfoil-based compressor in which the gas or working fluid principally flows parallel to the axis of rotation.

Compressor Response

How does the compressor respond to higher backpressure caused by air injection?

The gas turbine response to increased back pressure will be to slightly increase the work to produce a relatively constant flow from the Gas Turbine compressor, and consequently the CDT will increase slightly. These effects are incorporated in our analysis. The Turbophase compressor will respond similarly and has much more compressor pressure ratio margin in general than the Gas Turbine's compressor, and therefore is not limting. In addition, as ambient temperatures change, the Turbophase pressure capacity changes and in general follows the Gas Turbines CDP. In other words, as the ambient temperature drops and the Gas Turbine's baseline CDP increases, the maximum pressure in the Turbophase compressor also increases by approximately the same amount.

Connecting to the Combustion Turbine

How are the connections made to the CT?

Flanged connection of stainless steel piping into the compressor discharge. The exact location will vary depending on the engine type.

Constant Performance at all Ambient Temperatures

What is the impact of ambient temperature on Turbophase performance, if any?

Ambient temperature has little to no effect on Turbophase performance. Turbophase systems add a consistent power boost from 32ºF (-17ºC) to 122ºF (50ºC).

Constant Power Boost

Why does your power boost stay constant?

Gas Turbine power output is proportional to air mass flow through the gas turbine. The Turbophase system provides a constant incremental mass flow over wide ambient temperature & elevations. Therefore, the incremental power from the gas turbine that the Turbophase system provides is constant.

The Turbophase prime mover is a turbocharged gas or diesel reciprocating engine. The turbochargers on these engines make up for changes in ambient temperature and altitude and consequently the engine delivers constant power over wide ambient and altitude conditions.

If the Turbophase system is designed to operate in extreme cases, special turbochargers can be retrofitted to the reciprocating engine, again causing the engine to produce constant power.

The Turbophase module power and compressor flow are proportional and therefore constant power means constant airflow from the system. Therefore a constand power boost from the gas turbine is realized.

There are also 2 other secondary effects that counter-balance each other:

- On colder days, or lower altitudes, where the air is more dense, the gas turbine itself is has a higher compressor discharge pressure causing the Turbophase system to delivery slightly less airflow at constant horsepower. The effect is counter balanced by:
- The cooler days provide a lower coolant temperature to the Turbophase intercooled compression process, which results in slightly higher flow for the same horsepower.

Consequently, these 2 effects balance each other out and the Turbophase module delivers constant flow over wide ambient and altitude conditions.

Duct Burners

How does Turbophase effect Duct Burners incremental MWs from the Steam Turbine?

If the steam turbine is flow limited on hot days, then some of the duct burner capacity may be displaced by the Turbophase module and an improved heat rate. At most 7FA Combined Cycle Power Plants, no Duct Burner capacity will be displaced by Turbophase. Most 7FA Combined Cyccle Power Plants, duct fire systems are limited by exhaust temperature, and since Turbophase reduces the exhaust temperature (higher turbine pressure ratio), the duct capacity is actually increased approximately 3MW an no cost. (for a 25MW system)

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When evaluating Turbophase in this scenario, the 25MW from Turbophase plus the extra 3MW from the duct burners should be evaluated on the $/kW for incremental capital cost.

Another very significant enhancement Turbophase can provide is on a 3×1 Combined Cycle Power Plant Plant where it takes 2 Gas Turbines at minimum load (on at base is not enough) to keep the Steam Turbine operating, the Turbophase system will provide additions Steam Turbine steam flow which may allow only one unit at base load to keep the steam turbine running.

Effects on Plant Cooling System

Will Turbophase cause over pressurization of the cooling system and or casue disk rim cavity temperature imbalances?

Current GE Gas Turbine performance characteristics, GER 3567-H, on page 14 describes the effects of steam injection on the gas turbine and says " GE gas turbines are designed to allow up to 5% of the compressor air flow for steam injection to the combustor and compressor discharge". From a cooling pressure potential, there is practically no difference in the pressure changes throughout the combustor, compressor, and turbine of injection of 5% steam or injecting 5% air (Turbophase). In other words, GE's gas turbines are designed with 5% injection in mind, therefore, there are no unallowable effects on the disk rim cavity temperature or pressure effects on the turbine cooling. This stands to reason because as the air injection is ramped to 5%, the pressure in the compressor discharge case goes up approximately 16psi, or about 7.4%. Since the ambient pressure at the inlet of the gas turbine is unchanged, both the compressor and turbine pressure ratio go up by 7.4% Since the flow from the compressor and through the turbine are controlled by a fixed flow areas in various parts of the gas turbine, the incremental cooling flow rate and pressure go up similarly and balance each other. So, while there is a slightly higher pressure in the turbine section, there is also a slightly higher pressure in the cooling circuit and the two balance out to approximately the same cooling effectiveness. Additionally, there are disk rim temperature measurements that are part of the control system and adverse pressure situation will result in unacceptable temperature in the rim cavity which are readily measured.

Emission Handling

How are the Emissions from Turbophase engine handled?

Emissions limits, including Nox, are a very site specific calculation that the customer must perform. Emissions can be limited by PPM, tons/hour, annual tons and there may be adjustments in some of the values for summer and winter conditions. The exhaust from the Turbophase system can be ported to the GT's exhaust if it makes sense from a permit standpoint, especially if the GT has an SCR, which will also work on the Turbophase exhaust. Also, the reciprocating engine will most likely have to be permitted separately, and they are not typically permitted based on PPM levels of pollutant, but rather grams/horsepower hour and are currently subject to Tier 4 interim requirements in the US. The gas engine in the Turbophase units complies with Tier 4 interim requirements. Although the emissions source may be permitted separately from the GT, the site permit will most likely require that they be added together. An independent SCR can be added to the Turbophase module and reduce the emissions by approximately a factor of 10 if required. In summary, the emissions strategy will have to be developed and a plan figured out that stays within the permits and then followed in practice.

Emission Requirements – South Coast Air Quality Management District

Have you collaborated with air districts including the South Coast Air Quality Management District in Southern California? Does the emissions of the Turbophase System meet the SCAQMD emissions requirements?

The TPM Emissions meet the EPA requirements for stationary spark ignition internal combustion engines. Per SCAQMD Regulation IX, they have adopted the same standards as the EPA. The TPM emissions meet the 1g/hp-hr NOx requirement and has the ability to go as low as 0.5 g/hp-hr NOx (half of the EPA requirement).

Energy Storage

Can the Turbophase system provide Energy Storage?

An option to the basic Turbophase system is the Turbophase GSX, which provides energy storage and additional regulation to the plant. The GSX system doubles the MW output of the basic Turbophase system for 30-60 minutes.

Engine Maintenance

When is the first major engine overhaul scheduled?

The first major engine overhaul is schedule at 36,000 hours. The expected engine life is 72,000 hours.

What is the expected engine life?

The maintenance cost of Turbophase is less than the maintenance cost on a $/kW basis than the gas turbine.

Exhaust Gas

What will be the effect on exhaust structure due to Increase in exhaust gas velocities?

Although exhaust flow is increased approximately 5%, this same exhaust flow increase is realized at cooler ambient temperatures already. In addition, because of the increased pressure ratio across the turbine, the exhaust temperature is cooler by approximately 25F. The reduced exhaust temperature outweighs the increased flow from a thermal fatigue and oxidation, therefore, the exhaust duct should actually have an increased life with the Turbophase system. The exhaust temperature will be detected by the existing thermocouples so the reduced temperatures are detectable.

Gas Turbine Air Injection Temperature

Is the injected air temp held at a constant and if so what is that temp?

Injected air temperature is held constant at around 600ºF, just slightly cooler than gas turbine compressor discharge air.

Footprint & Spacing

What spacing between the Turbophase units is recommended?

Spacing between Turbophase units is recommended to be a minimum of 6′ for maintenance purposes. Several different layouts are possible. In general, the Turbophase system is 10x more power dense than the power plant itself. The typical skid size is approximately 30′feet long, 8.5′ wide and 15′ tall (with the recuperator on the roof). See the sample layout of a 2×1 7FA with 50MW of Turbophase.

Gas Turbine Hardware Life

Does Turbophase create a hardware debit to the gas turbine or other parts of the power plant?

No. Turbophase simply adds back in the air that would be running through the Gas Turbine on a cooler day. The Gas Turbine is designed to handle that amount of air. NO STEAM INJECTION occurs with Turbophase. Turbophase ONLY injects AIR into the Gas Turbine.

Gas Turbine OEM Installs / New Power Plants

Can gas turbine OEMs or gas turbine facility developers install a Turbophase System from initial construction?

Yes. Turbophase Modules can be installed on new or existing gas turbines.

Gas Turbine Part-Load Operation

Are there benefits to injecting into the gas turbine when it is operated at part load?

Very little. In simple cycle applications a small improvement in heat rate for the same power level might be observed. Since the GT Firing Temperature is falling as the GT turns down in load, the amount of incremental power per lb/sec of additional airflow decreases.

GE 7EA Gas Turbines

Can the system be used with a GE 7EA?

Yes. Turbophase works will all Gas Turbines 25 MW or larger, including GE 7EA Gas Turbines.

GE 7FA Gas Turbines

On a 7FA machine rated at ~ 171 mw @ ISO what would be the expected mw gain?

The answer depends on plant configuration (simple cycle/combined cycle) and how many Turbophase modules (how much air flow) you decide to inject into the gas turbine. As a nominal example on a 7FA.04 2×1 Combined Cycle plant, applying 4 Turbophase modules per gas turbine (a total of 8 Turbophase modules), we would expect to provide 40 MW of incremental capacity at ISO.

GE LM Model Gas Turbines

Will the system work on General Electric LM models of engines (LM6000, LM2500, LMS100)?

Yes. Turbophase works with GE LM Model Gas Turbines.

GE LM6000PF

Will the system work on a GE LM6000PF Gas Turbine?

Yes, the system will work on a GE LM6000PF and every other gas turbine in the world 25 MW or larger.

H-Class Gas Turbine Operation

Can the standard size Turbophase module be operated on an H-Class gas turbine?

Yes, Turbophase can be on any gas turbine. For higher pressure ratio machines, a 5th or even 6th stage would be added to the compressor. These extra stages still fit within the standard size Turbophase module

Heat Balance

Is there a heat balance for Turbophase on a 7FA Gas Turbine?

Please refer to this link for a presentation covering Turbophase Heat Balance on a 7FA.

Covered in the presentation are:

- 7FA Gas Turbine Heat Balance without Turbophase
- Turbophase Factory Acceptance Test Heat Balance
- 7FA Gas Turbine Heat Balance with Turbophase

Heat rate for incremental power at simple cycle gas turbines

Does your simple cycle heat rate calculation include the fuel for the Turbophase modules?

All heat rate calculations include both the fuel for the Turbophase module and the gas turbine. All incremental fuel burned to produce the incremental MW is included in our heat rate calculations.

Heat Rate Format

Are heat rates quotes on an HHV or LHV basis?

Numbers shown are at LHV. We can provide equivalent HHV numbers upon request

Impact of ambient temperature on gas turbine performance

In the performance report why does it looks like output from the Gas Turbine is fluctuating when the Turbophase system is running?

The output variation you see is due to the scaling and some ambient temperature effects. The ambient conditions were moving around some on during testing which was causing the variation to be more than normal during steady state conditions. One can see that the output variation with and without air injection is the same.

Initial Tuning & Mapping Setup Time

How long does the initial tuning and mapping require as it relates to grid stability?

An experienced tuner will be present at full scale implementation. No tuning is expected to be required, however, if required, typically tuning can take several hours depending on the severity and nature of combustion dynamics. The existing combustor dynamics monitoring system will detect any issues.

Inlet Air Filtration

Is inlet air filtration for the Turbophase the same quality as the inlet filter house for the gas turbine?

Yes. The Turbophase inlet filtration system produces air quality as good or better than is received by the gas turbine.

Installation without Inlet Bleed Heat Piping

How much more complicated or costly is the installation if you have a warm weather GT module that does not have IBH piping?

Not much. IBH piping just reduces the amount of piping that is required since the piping is already routed from the compressor discharge chamber to outside the enclosure. If the GT does not have existing IBH piping, it would be added.

Load Gradient

Which is the load gradient obtainable with TPM (in terms of % of GT Nominal Load per minute or MW/minute)?

This will depend on your particular gas turbine. The same limiting factors that your gas turbine has during ramping up and down will hold with the TPMs. The TPM will never been the limiting factor when it comes to ramp rates. If your current ramp rate is 10 MW/min, the TPMs will be set to inject at the same rate.

Maintenance Penalty

Does Turbophase cause greater maintenance to the Gas Turbine it is connected to?

Because Turbophase uses hot air injection, it simply allowing the Gas Turbine to behave on a hot day as it normally would on a cold day. The Gas Turbine is designed to handle this additional output. Turbophase is simply adding the extra air back into the Gas Turbine. There is no maintenance penalty with Turbophase.

Mass Flow & Pressure on a 7EA

What is the mass flow and pressure of the air leaving the Turbophase module for a 7EA system?

The system can produce 260psi at 11.0 lb/sec. As the pressure requirement decreases the flow increases. For a 7EA CDP ~200psi the system will get closer to 12lbs/sec.

Mechanical Drive Gas Turbine

Any considerations been given to apply this system to a mechanical drive gas turbine?

Yes. The system works the same with a generating GT and a mechanical drive GT. We have seen some interest in this.

Minimum Sized Gas Turbine

What is the minimum sized gas turbine that you would recommend for a Turbophase system?

We recommend that Turbophase be operated on gas turbines 25MW or larger to maximize economic return on investment.

Mobility

Can the Turbophase Module be permanently mounted on a trailer?

Yes, the Turbophase system can be mounted permanently on a production, commercially available trailer based on the customer's requirements. When the system is trucked between sites, a typical alignment procedure, which takes a few hours, will have to be repeated each time the unit is relocated.

Modular Power Generation

Does Turbophase come in one size and you buy as many as needed based on the size and quantity of GTs served?

Yes. Each Turbophase module comes in one size; each Turbophase module sound enclosure is about 40 feet (12.2 meters) x 8 feet (2.4 Meters). A Turbophase system is composed of one or many Turbophase modules depending on the size of the gas turbine and the requirements of the power plant.

Natural Gas Pressure

What Natural Gas Pressure is required at the site for the Turbophase Modules?

Natural gas pressure limits required by the Turbophase system are significantly lower than the GT and will never be an issue. The typical requirement is 30psi.

OEM LTSA

What is the impact of Turbophase on an OEM LTSA?

Per GER 3567h, “steam injection for power augmentation has been an available option on GE gas turbines for over 30 years. When steam is injected for power augmentation, it can be introduced into the compressor discharge casing of the gas turbine as well as the combustor. GE Gas Turbines as designed to allow up to 5% of the compressor airflow for steam injection to the combustor and compressor discharge.” Click here to read the full GER 3567h from General Electric.

Operations and Maintenance Costs

What are the O&M costs of the Turbophase System?

Operation a maintenance costs are approximately $3.50 per MWh. Maintenance contracts for a fixed $/MWh price are available.

Payback

How fast will a Turbophase system pay for itself?

Payback on a Turbophase system is calculated based on how much the Gas Turbine that Turbophase is connect to runs & how much the operator chooses to dispatch Turbophase. Payback is also dependent on the market conditions. For example some markets have a capacity payment. It is interesting to note that because Turbophase can ramp fully in 60 seconds & adjust its output significantly in as little as 10 seconds, there may be opportunities to take advantage of short term fluctuations in supply, for example the Responsive Reserves Ancillary Service Market in ERCOT.

Performance on Different Gas Turbines / Combustion Turbines

Does your system work with ALL Gas Turbines?

The Turbophase system works on all gas turbines 25MW and larger.

Piping Losses

How significant is the effect of piping losses in overall performance?

Increase in piping losses result in higher backpressure on our compressor, which results in lower flow. While this does have an impact, it has to be outside all design characteristics in order for the impact to be noticed. We take pipe losses into account when designing the air injection piping to the gas turbine and optimize it for that site's operation.

Plant Performance in hot climates – high ambient temperature

What would the performance be at 122ºF / 50ºC?

Turbophase systems are designed to let the gas turbine operate up to its electrical limits in all ambient conditions, even temperatures at high as 122ºF / 50ºC.

Power Plant Economics / Economic Payback

What would be typical payback period of this investment based on some previous successful projects?

Payback period ranges depending on local economics. However, because Turbophase is ½ to ⅓ the cost of adding a new gas turbine, capacity generated from Turbophase will carry a much shorter payback when compared to siting a gas turbine in the same market. Turbophase will also have a much shorter payback compared to an OEM upgrade. When comparing Turbophase to a chiller with storage, the payback is also much shorter. Assuming a similar capital cost/efficiency to a chiller with storage ($/kW), Turbophase payback is shorter because chillers with storage are typically sited to store energy for 18 hours/day and discharge for 6 hours/day. Because Turbophase can be operated continuously, the run-time hours will be much greater than chillers with storage. Since run-time hours are a primary driver of payback, Turbophase has a much shorter payback than chillers with storage unless the operator only plans to run the Turbophase system for 6 hours per day and only in hot climates. Turbophase offers continuous capacity in all ambient conditions and is not tied to a specific gas turbine, making it a more economically desirable and flexible option for increasing plant capacity.

Power Plant Electrical System

What modifications need to made to the plant electrical system?

Because a Turbophase module is driven by a reciprocating engine, the electrical load (parasitic load) is very small. Each Turbophase module requires 100 amps, 480 VAC, 3 phase electrical.

Power Plant Insurance

How do adding Turbophase modules affect the plant's insurance?

Adding Turbophase to a plant is like adding chillers from a risk standpoint. In both cases the systems are not prime reliable so the GT can still operate without the systems. The TPMs are injecting dry air into the gas turbines. If the GT OEMs allow steam injection on your machine (see GER3567H for example) than injecting the same amount of dry air is within the GT design parameters.

Ramp Rates

What are the Turbophase system ramp rates – both up & down?

The ramp rates of the existing gas turbine will not be impacted. Final ramp rates of the Turbophase will be set to provide the

Turbophase ramp rate equivalent (MW/min) to the GT. Because the Turbophase system makes 10% more power with 5% fuel and air, the physical ramp rates of the fuel and air associated with the power from the Turbophase system at the equivalent MW/min ramp rate will be half of the Gas Turbine fuel & air requirements. The electronic air injection control valves will be preset such that no rapid opening or closing of the valves is possible which is an added safety feature. Much higher ramp rates are available. We have successfully ramped the Turbophase module in less than 1 minute at factory acceptance tests.

Reciprocating Engine Speed

What is the speed of the reciprocating engine?

1500-1800 rpm depending the model used (Diesel/Natural Gas and the design frequency 50/60Hz). In either case, a gearbox is used to bring the speed up to 3600-rpm input to the compressor.

Reciprocating Engine vs. Electric Motor

Why did you choose to run the compressor off a gas reciprocating engine versus an electric motor?

For a few reasons: First, using an electric engine means you will have an "netting" effect when running the system. While a 2 MW electric motor driving the compressor would give you 5 MW on the GT, the resulting increase of 2 MW house load would only leave 3 MW to the grid. Thus true $/kW of the system would increase. Second, since the compressor is intercooled to maximize flow, the exit temperature of our compressor is normally around 250 F. Injecting air of this temperature into the GT would potentially "shock" the combustion system as well resulted in more fuel burn to hold the same firing temperature. By using a reciprocating engine the waste exhaust energy can be used to get the air injection temperature up to a level closer to the GT compressor discharge temperature.

Siting at space constrained power plants

Can Turbophase modules be stacked on top of each other?

Yes. Turbophase modules can be stacked in space-constrained environments. Also Turbophase modules can be sited up to 1 kilometer from the gas turbine, providing installation flexibility for a variety of site scenarios.

Slab for Turbophase Foundation

What kind of slab do I need for Turbophase?

Typical slab spec is 18 inches thick x the unit footprint, which is approximately 8 feet wide x 30 feet long. Also, in areas where frostline is a consideration, our unit can be connected to the plant with flexible connections so that pilings or sub frost level footers are not required.

Steam Quality

What would be the impact of Turbophase on steam quality?

Turbophase has no impact on steam quality during a cogen process.

Steam Turbine MW

What happens to steam turbine MWs when GT MWs are increasing?

The ST MWs will increase as well holding everything else constant. The amount of increase will vary some from site to site.

On exhaust control, the GT CDP will rise during injection which will cause the average exhaust temperature to drop slightly but the increase in mass flow will be such that the total energy leaving the GT will be higher than without air injection

Steam Turbine Performance

Is STG output increased in unfired mode?

Yes. The Steam Turbine MWs will increase as well holding everything else constant. The amount of increase will vary some from site to site. On exhaust control, the Gas Turbine CDP will rise during injection which will cause the average exhaust temperature to drop slightly but the increase in mass flow will be such that the total energy leaving the GT will be higher than without air injection.

System Operating Costs

What is the total operating cost of the Turbophase system?

Fuel costs and maintenance costs are approximately the same on a $/MWh basis as a modern combined cycle plant.

System Trip

What will happen with Instantaneous loss of Turbophase Air? For example, a system trip?

If a Turbophase compressor trips off line, that would represent a fractional reduction in air injection. Typically flame stability and blow out are caused by cool flames or reduction in flame temperature. Since this failure mode results in a richer flame momentarily, the likely hood of a flame out is reduced dramatically (as opposed to if the flame was leaned out). The increase flame temperature caused by this type of failure mode will be detected by the exhaust temperature probes and the fuel will be adjusted accordingly. The control adjustment will happen within one second and the metal temperatures reactions will be transient and very small, estimated less than 2 degrees F.

Test Protocol

What test protocol to you user to determine Turbophase performance?

The Turbophase Test Protocol outlines the procedure for testing the system and determining the incremental power and heat rate. You will notice that we do not specify the ambient conditions at which the test is performed. The Turbophase system delivers constant incremental power and heat rate independent of ambient conditions. We simply require the plant to be at steady state conditions and then inject the air and measure the incremental power and combined incremental fuel burn. The combined incremental fuel is made up of approximately 1/2 Turbophase fuel and 1/2 incremental gas turbine fuel. The extra gas turbine fuel resulting from the air injection is required to maintain firing temperature.

Thermal Efficiency

How efficient is Turbophase?

Turbophase is more efficient than a Simple Cycle (Open Cycle) Gas Turbine, so Turbophase offers peaking power at a lower capital cost & at a better heat rate than a Simple Cycle Gas Turbine. For a utility looking to add peaking resources, Turbophase costs less up front, less to operate & less to maintain.

Thermoflow

Are cycle deck runs available for specific Gas Turbines, Power Plant Configurations, Power Plant Ambient Temperature & Altitude?

Powerphase can provide ThermoFLow runs as requested. Please Contact Us to discuss your specific requirements & we will connect you with our engineering team to analyze your Power Plant's conditions.

Also, we have made available a simple & convenient online tool:

The Turbophase Calculator provides incremental plant output & heat rates at various ambient temperatures & altitudes for various numbers of Turbophase modules added onto the Power Plant.

Turbine Cooling

Will the Turbine cooling be negatively impacted and cause reduced turbine part life and/or part durability?

Current General Electric Gas Turbine performance characteristics, GER 3567-H (google this to find it on web), on page 14 describes the effects of steam injection on the gas turbine and says " GE gas turbines are designed to allow up to 5% of the compressor air flow for steam injection to the combustor and compressor discharge". From a cooling pressure potential, there is practically no difference in the pressure changes throughout the combustor, compressor, and turbine of injection of 5% steam or injecting 5% air (Turbophase). In other words, GE's gas turbines are designed with 5% injection in mind, therefore, there are no unallowable effects on the Turbine Components. This stands to reason because as the air injection is ramped to 5%, the pressure in the compressor discharge case goes up approximately 16psi, or about 7.4%.

Since the ambient pressure at the inlet of the gas turbine is unchanged, both the compressor and turbine pressure ratio go up by 7.4% Since the flow from the compressor and through the turbine are controlled by a fixed flow areas in various parts of the gas turbine, the incremental cooling flow rate and pressure go up similarly and balance each other.

Turbine Inlet Chilling

How does Turbophase compare to Turbine Inlet Chilling in terms of cost, benefits & impact to the gas turbine?

Turbophase compares favorably to chillers. Typically if the choice for more power is Turbophase or Chillers, Turbophase is a better option:

- Full power boost from 40 Degrees F – 120 Degrees F
- 10-15% of footprint requirement compared to Chillers
- No efficiency penalty to Gas Turbine when Turbophase is not running (compared to an efficiency penalty for Chillers)
- More efficient than Turbine Inlet Chilling when running, much simpler & quicker installation.
- Continuous operation capability
- Flexible operation – Turbophase starts & ramps in less than 1 minute
- Mobile – Turbophase can be moved to any Gas Turbine at any plant in your fleet quickly & easily as market conditions or seasons change. Chillers are fixed & cannot easily be moved.

Turbine Trips

How do you know if the Turbine trips?

Turbophase operates during any load condition. If the Gas Turbine trips, Turbophase is sent a signal by the control logic to go offline. The compressor uses the backpressure from the gas turbine to determine flow & load. The system also has sensors that in the event of backflow, the system goes into shutdown mode.

Turbophase Modules per Gas Turbine

How can we determine how many Turbophase Modules can be added to a particular power plant?

Powerphase has evaluated many power plants and typically the limiting factor is generator capacity. If this is the case at the plant in question, then simply look at the incremental power output capacity of the gas turbine generator at the most severe conditions, typically a very hot day. Gas Turbine generator capacity typically shows how much incremental power the Turbophase system can add. Then use The Turbophase Calculator and select your gas turbine & site conditions to determine the number of modules needed for the incremental capacity that you wish to add. A typical 7FA Gas Turbine can handle approximately 25MW additional power. Some of this capacity may be taken up with other power augmentation or gas turbine upgrades. This does not preclude Turbophase from still being added to the Power Plant. For example, if you have 25MW of generator capacity and want to add 7MW of fogging, then you can add 18 MW of Turbophase.

Unexpected Stoppage

What happens if the Boost Air turns off unintentionally on a 7FA?

Similar risk exists for steam injection both from a lean blow out caused by a sudden loss of steam due to a steam supply valve closing inadvertently and from a rich flame blow out, which is less likely than a lean blow out. Based on Powerphase team's experience, steam valve failures have happened several times and there was not a GT trip. The Turbophase air is being proposed to be injected into the inlet bleed heat manifold to promote better mixing and provide additional cooling. When the air is injected in the steam injection ports, there is only a short distance and no significant orifices for the air to go through, so pressure perturbations caused by sudden loss or injection of air are amplified compared to injection into the CDC wrapper through the IBH system. Also, most GT's have the IBH manifold, so it is easy to install. When the IBH system is used for injection, the increased air flow from injection has to go through the transition piece holes and the flow sleeve holes and travel approximately 3 feet through the annulus between the TP/Liner before it gets to the head end of the combustor. This extra length promotes pressure damping and mixing, and therefore is a superior injection location.

The OEM's IBH manifold is designed for 5% air extraction and therefore works very well for air injection.

Valve Failure

What happens if the Turbophase control valve fails open?

If the Turbophase air injection valve at the gas turbine inadvertently opens while the Turbophase units are not on line, the individual stop valves at each Turbophase unit will be closed so there will be no airflow. If for some reason, the stop valves at each Turbophase unit are open, there is a check valve at the Turbophase compressor, so there will be no flow. Effectively, there is a triple redundancy of this happening. If the Turbophase injection valve fails open while the units are operating, meaning they won't close, then, for the reasons above there is double redundancy of flowing air inadvertently in any direction. If for some reason the triple redundancy does not catch this event, there should not be any adverse effects on combustion flame out. Furthermore, all of the control valves on the system will be orficed to maintain a minimum slew rate. If a valve does fail in either direction, the control system at the GT controller will be notified immediately.