WHITEPAPER

Enhancing Combustion Turbine Capabilities for 21st Century Power Markets

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Abstract

Combustion turbines (CTs) have become the stars of most utility generation fleets. They are cleaner and faster to respond than their coal-fired counterparts and have been the technology of choice for new assets over the last 20 years.

However, the increase in generation from renewable assets has created additional opportunities for CTs. Renewable sources variable output can be nearly instantaneous, creating new demands for system operators. One reflection of this new need is the emergence of 5 minute dispatch in the energy markets.

This article presents a technology engineered to equip existing CTs with rapid response capability while reclaiming capacity currently unattainable due to the ambient operating temperatures or altitude of the CTs' site.

Renewable sources increase uncertainty in power supply

The push for higher percentages of renewable sources in the fuel mix has in-creased one attribute of the power supply system operators have worked diligently to eliminate: uncertainty. By their very nature, renewable energy sources are variable, with production output changing as weather conditions at the generation site change, variability is inherently uncertain. This variability means that grid operators cannot rely on the forecasted output of renewable sources in the same way they can rely on the forecasted output of fossil and nuclear-fueled sources.

Renewable variability can manifest itself in either over-producing or under-producing. Each have their challenges but when renewable assets under-produce versus their forecasted output, grid operators have a limited number of tools at their disposal to respond and make up for the shortfall. Spinning and other reserves can be dispatched. These are expensive and require a few minutes to come online.

FUEL SOURCE AS A PERCENTAGE OF TOTAL GENERATION

ALL FOSSIL FUELS
62.7%

NATURAL GAS
31.7%

COAL
30.1%

NUCLEAR
20%

ALL RENEWABLES
17.1 %

HYDROPOWER
7.5 %

WIND
6.3 %

BIOMASS
1.6 %

SOLAR
1.3 %

GEOTHERMAL
0.4 %

OTHER SOURCES
0.2 %

Demand Response (DR) programs can be dispatched. These can be faster to respond but their capacity is limited and overuse of this asset can result in custom-ers dropping out of the program, reducing the size of load curtailed.

Grid operators and generation providers are looking closely at ways to provide rapid response to renewable (and other) output variability. Energy storage in the form of batteries on a utility scale is the current "holy grail" and holds great promise for removing the variability of renewable sources. Efforts are underway to increase the use of these resources. And even as the cost hurdle continues to decline from steady technological and manufacturing advances, these assets have yet to be widely deployed. This leaves an unfilled need for generation assets that can be rapidly dispatched to meet renewable variation.

Improving the response and capacity of existing generation assets

Operating traditional coal fired plants in a fast response environment is not impossible but it is costly. This is one of many reasons why the majority of new generation facilities built in the last 20 years have been natural gas-fired. With the dramatic growth in domestic natural gas supplies, that fuel finally eclipsed coal as the largest percentage[1] of the national fuel mix in 2017 *(Figure 1)*. As the coal fleet ages out, this trend will continue.

The combustion turbine (CT – simple and combined) is a more flexible genera-tion asset, yet there are limits to how quickly, and efficiently, the CT can respond to demand variations. Like their coal-fired kindred, CTs are most efficient when operated in or near a base load level. Rapid cycling increases O&M costs, reduc-es efficiency, and results in a higher cost of power supply, costs that have to be recovered in rates.

Recovering previously inaccessible capacity for existing and new CTs

Two key factors impact the ability of a CT to achieve its rated output; ambient temperature and the altitude at which they are installed. In hot temperature or high altitude environments, CTs will produce less than their nameplate ratings, leaving a certain portion of the CT's capacity inaccessible.

The CT compresses air at a constant volume and the resulting power output is proportional to air mass flow through it. When ambient temperatures rise, less air is compressed and therefore the CT produces less power. A similar situation occurs at higher elevations.

[1]https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

5-10%

HIGHER GRID EFFICIENCY

The Turbophase solution can offset the capacity-robbing effects of ambient temperature and site altitude, allowing both existing and new CT assets to operate at rated output with 5-10% higher grid efficiency.

COURTESY: POWERPHASE

[2] A standard shipping container capable of flatbed delivery is 8' W x 40' L x 8.5' H.

Figure 2

Each Turbophase module is completely self-contained in an 8-ft. x 40-ft. x 10-ft sound attenuated enclosure. A common finished height, as shown here, is 18'. A gas-fired engine-compressor set produces compressed air that is added to the com-bustion turbine's compressor discharge section to reduce the effect of a high ambient temperature or altitude performance derate.

Additional mass flow of air at the appropriate temperature enables existing CTs to reach their design power output, usually up to the rating of the genera-tor, regardless of ambient temperature or site altitude. So long as the additional equipment is controlled to produce airflow proportional to the real time operating requirements of the CT, the power boost remains constant.

The Turbophase solution

Powerphase (Jupiter, FL-based) has commercialized a dry air injection system for existing or new simple or combined cycle CTs. The design concept is to take a combined cycle plant, typically the most efficient generation asset for any utility, and increase its efficiency, generation capacity, and its operational flexibility, espe-cially its rate of response to system operator calls for additional generation.

For owners of existing CT generation assets, Turbophase (the name given to this solution) increases the output and responsiveness of the units, imposing minimal demands on the site. The solution requires no water and a small incremental amount of power to operate, reducing demands on site infrastructure. Its small footprint and ability to be located as far as a kilometer from the CTs mean it can be sited for optimal space utilization. Since the Turbophase solution only injects compressed air, it can work with practically any make or model CT on the market.

Turbophase is able to add 10-20% more power to the grid by injecting high pressure and temperature dry air into the CT compressor discharge. The result is virtually instantaneous production of the fast response power the 21st century grid needs while at the same time increasing grid efficiency between 5 -10%, low-ering the cost of service to the ratepayers.

The Turbophase solution is sold in modules with each module consisting of a turbocharged, natural gas-fired reciprocating engine, gearbox, and multi-stage intercooled centrifugal compressor *(Figure 2)*. The module's components are housed in an 8' w x 40' l x 10' h, sound attenuated enclosure. This compact size lends itself well to onsite delivery via traditional flatbed equipment[2]. The module is connected to the CT via a single compressed air pipe and multiple modules can be connect-ed in parallel to a CT for maximum power production *(Figure 3)*. Where the site requires it, the modules can be located up to 1 km away from the CTs.

Turbophase injects higher temperature and pressure air, matched to the specific CT compressor discharge conditions, to regain the CT's lost power generation capability, irrespective of the ambient conditions (from 32F [-17C] to 122F [50C]) or altitude. The Turbophase compressor has a larger compressor pressure ratio margin than the CT compressors so CT compressor performance and surge margins are not a limiting factor.

The amount of air that can be added is determined by the manufacturer's rating of the CT. General Electric, for example, allows 5% mass flow injection into the compressor discharge plenum. Other OEMs have similar published standards.

The extent of performance gain depends on plant configuration (simple cycle CT or combined cycle) and the number of Turbophase modules specified. For example, on a 7FA.04 2x1 combined cycle, four Turbophase modules per CT (total of eight modules) can be used. For this example, the eight modules will drive an

Figure 3

Turbophase consists of four main components, from back to front: turbo-charged natural gas-fired reciprocating engine, gearbox, and multi-stage centrifugal compressor. The fourth component, the recuperator (located on the roof of the package), is shown in Figure 2.
SOURCE. POWERPHASE

incremental increase of ~54MW or about 6.8MW per module in combined cycle mode. H-Class CTs and aeroderivative engines have a greater pressure ratio so additional compression can be achieved by the Turbophase compressor to accom-modate the higher CT compressor discharge pressure, without a change to the standard module's 8' x 40' footprint *(Figure 4)*.

The limiting factor in determining the number of Turbophase modules that can be added is the CT generator design parameters. A quick estimate of the number of modules is possible by determining the incremental power output of the generator available at the highest expected site temperature. A typical 7FA can handle mean-ingful levels of additional power, assuming there are no other power augmentation or upgrades already present on the CT.

The economics of Turbophase compares very favorably with other technologies engineered to increase CT power output. For example, Turbophase compares fa-vorably to existing OEM upgrades keeping in mind that the actual results are site specific and the Turbophase solution has a service life of 30 years as compared to the shorter life of alternatives.

Rapid response upgrade

Wringing previously inaccessible power from existing CTs is an attractive proposi-tion in and of itself. When the technology retrofit also equips those same assets with a rapid response capability, the value proposition increases further. Properly configured and engineered, Turbophase can give CTs a response rate perfect for offsetting the rapid demand for power caused by renewable generation asset vari-ability, something of high value to system operators and power suppliers alike.

The response time of Turbophase is dependent on its operating mode. On an operating CT, Turbophase can ramp up to produce full air flow in approximately 60 seconds or less. If Turbophase is already running at idle then the ramp up from part load to full load can take place in 10 seconds or less *(Figure 5)*.

Because of the impact of renewable energy variability on system operation, system operators have moved to 5 minute dispatch. Some operators are engag-ing in 5 minute settlement as a next step. Since the cost of incremental power to compensate for under-producing renewable assets is highest in the first 3 – 7 min-utes, power suppliers who can ramp up and dispatch power within that time frame receive the highest compensation. With traditional settlement, the payment to the

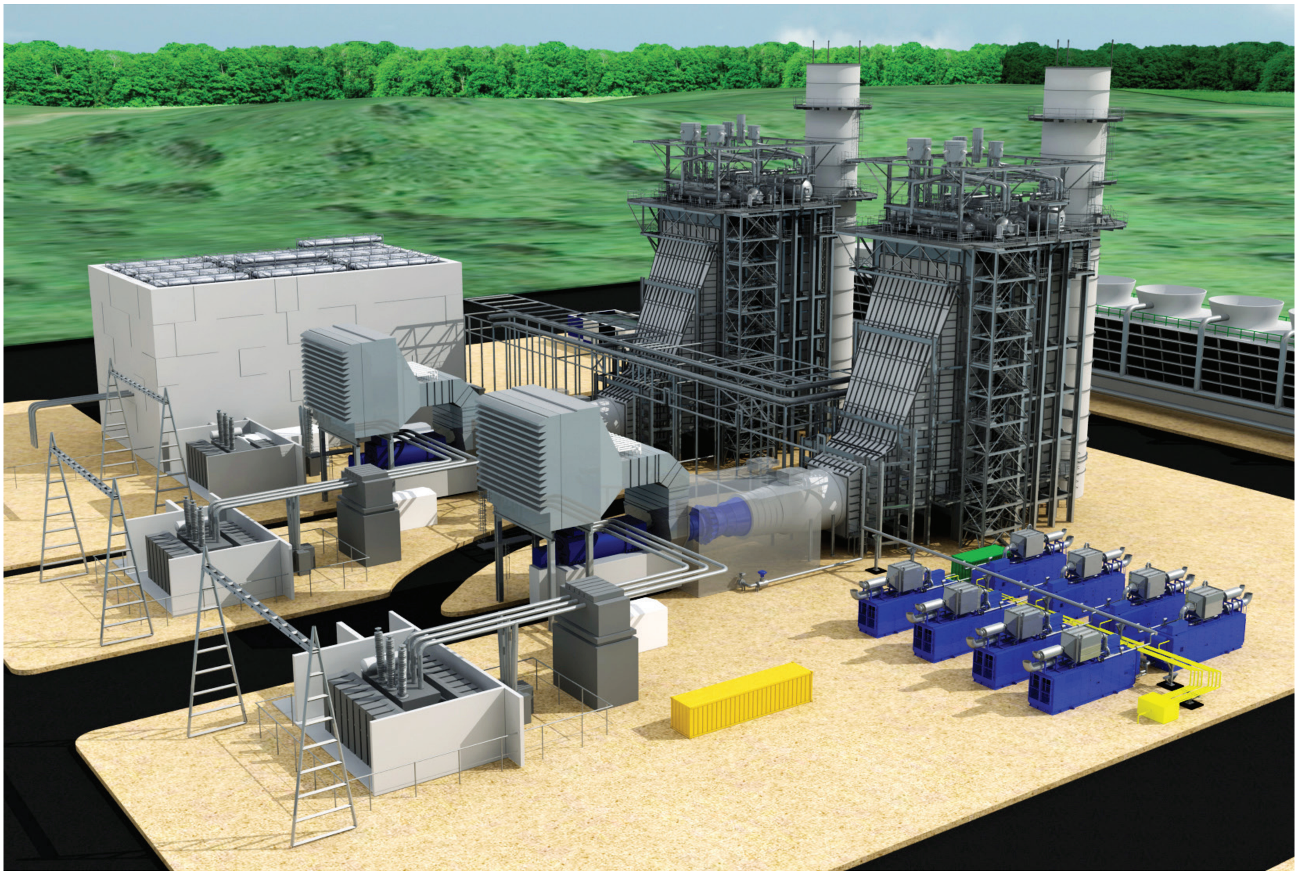


Figure 4

A typical 2 x 1 combined cycle plant is illustrated. This plant uses General Electric 7FA combustion turbines, which allows four or more Turbophase modules per turbine. The plant, outfitted with 8 Turbophase modules, will produce an addi-tional 54 MW. Source. Power-phase

generator is averaged over a 60 minute period, diluting the value of the first few minutes. With 5 minute settlement, that value is maximized.

Adding both increased output and rapid response capability to existing CT assets makes them attractive candidates for peaking power units, the value of which can be substantial. A recent study of the economic impact of adding Turbo-phase to the generating fleet of a Florida utility determined that the efficiency of the incremental power would displace generation from standard CT peakers and coal-fired units, saving about $100 million per year and reducing carbon dioxide emissions by over four million tonnes per year, the equivalent to removing 1 million cars from the road

Ancillary services opportunities

Turbophase has an important place in every utility integrated resource plan (IRP) for another reason: its contribution to grid ancillary services, such as synchronized reserve and fast grid regulation services.

Synchronized reserve

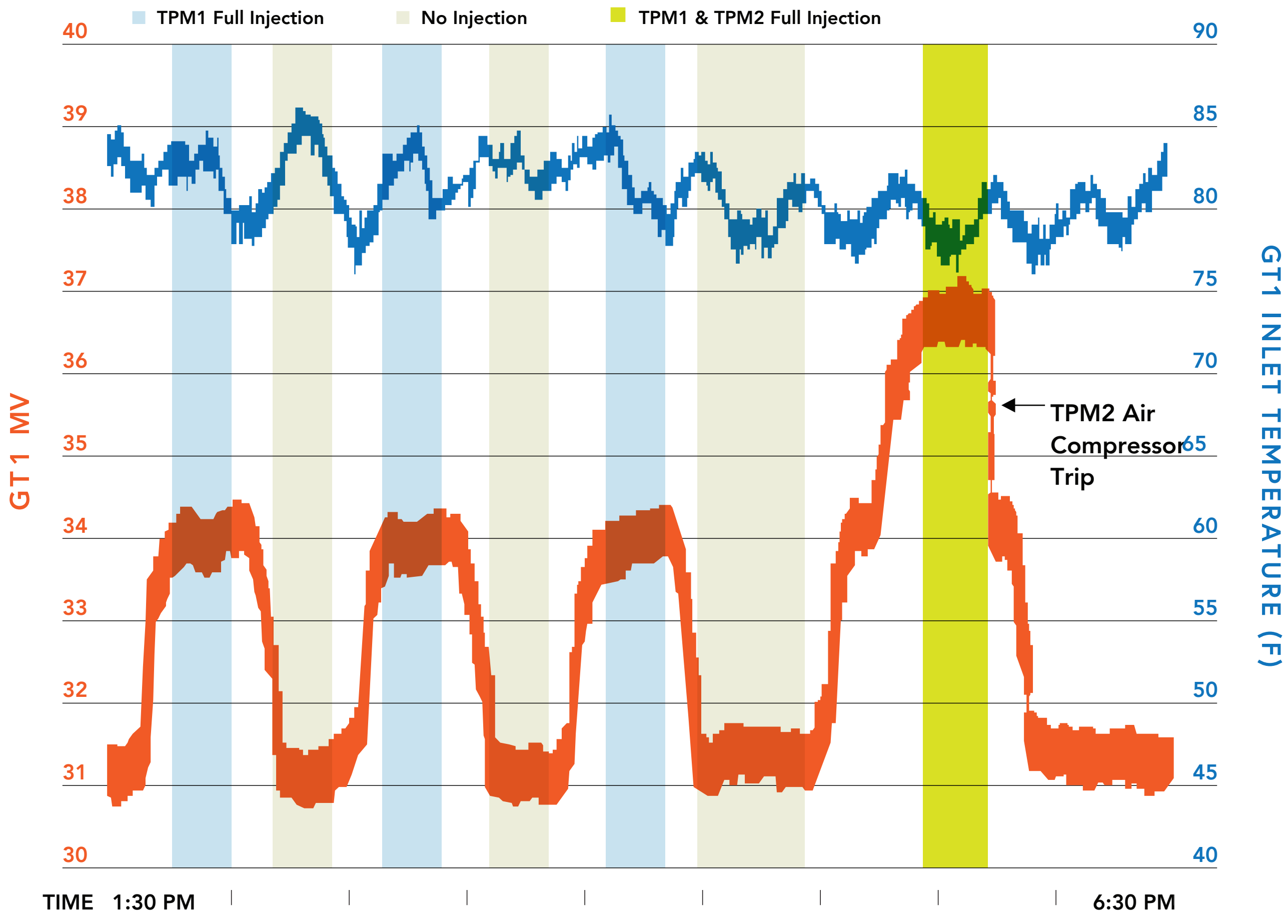
In the earlier example, a 7FA.04 2x1 combined cycle with eight Turbophase mod-ules can produce, at high ambient conditions, up to an additional 54 MW (~40 MW at ISO conditions), or about 6.8 MW per module. A small portion for the power increase, perhaps 10%, is produced by the steam turbine. That means that the Turbophase can quickly put about 36 MW (ISO) on the grid limited only by the CT ramp rate (for example, the GE 7FA ramp rate is 40 MW/minute) with the steam turbine power increase following several minutes later.

The competitive alternative would be a separate standby gas-fired engine sitting in "hot start" conditions that could be synchronized to the grid in about 60 seconds or less and but reaching full load in 90 to 180 seconds. The standby engine will also require a separate generator and switchgear. Turbophase responds faster than a standby engine generator with significant savings in initial and O&M costs.

Fast grid regulation

Turbophase responds to load demand fluctuations that occur within 60 seconds or less. Test data shows that an increase in CT output is measured within a minute with the steam turbine following in about 10 minutes. The standard PJM grid response requirement for grid regulation is within 10 minutes. That means Turbo-

TURBOPHASE TEST RESULTS



phase-equipped CT plant may qualify for increased ISO or RTO payments for grid regulation power, if offered in your area. It's important to note that the design of Turbophase will never be the limiting factor for plant ramp speed, even with aeroderivative engines, because its controls are tuned to follow the same ramp speed of the CT.

Figure 5

Two Turbophase modules were installed at Atlantic Power Corporation's Morris Cogene-ration Plant. The modules are connected to one of the plant's three gas-fired 177MW GE Frame 6B combustion turbines. The orange line shows the rapid response of the Turbophase when a single module is man-ually started and stopped. The final test, with both Turbophase units in service, illustrates the controlled response of the combustion turbine after an in-tentional trip of one Turbophase module.

SOURCE. POWERPHASE

Further increase CT flexibility with energy storage and capitalize on the new FERC[3] ruling

In addition to flexible generation, another highly desirable capability for power generators is energy storage. While energy storage has been discussed for many years as the "holy grail" of green energy, utility-scale projects have been slow to develop. As renewable penetration increases, even the addition of flexible genera-tion to the grid will likely be insufficient to compensate for the lost efficiency and

[3]https://www.ferc.gov/industries/electric/indus-act/rto/02-15-18-E-1-presentation.pdf https://www.greentechmedia.com/articles/read/ferc-energy-storage-wholesale-mar-kets#gs.BkzPH8Q

increased cost of cycling fossil fuel plants.

FERC has just taken a step to encourage serious deployment by issuing a rule on 02/15/2018 that opens the U.S. wholesale energy markets to energy storage on an equal footing with generators and other grid resources. The ruling expands market participation to areas beyond the fast-response frequency regulation that currently dominates the opportunity for storage assets. The challenge now becomes how to capture generation when it is produced and "save" it until the energy is required.

There are several competing technologies for storing energy for use at a future time, some of which are highlighted next. However, as will be illustrated, there is a technology that can equip CTs with a storage capability that further enhances the value and flexibility of these assets to their owners. This technology allows CTs to run at an optimum level, even if output exceeds demand, storing the excess for use later.

Developers have fielded several technologies to answer the problem of renew-able intermittency and matching demand and production. As already noted, bat-tery storage is one option. In February, AES Energy Storage placed what is touted as the world's largest lithium ion battery system online in Southern California. The plant is capable of delivering 30 MW for four hours before having to be recharged. The stated purpose of the plant is to facilitate integration of more renewable ener-gy with the grid. Not surprising, the cost of the system was not revealed although we do know that energy storage was mandated and incentivized by the California Public Utilities Commission.

Another option is compressed air energy storage (CAES). The 317-MW Bethel Energy Center, Anderson County, TX, represents the most modern CAES technology and is expected to enter commercial service in 2020. The $400 million CAES plant includes construction of a salt dome for compressed air storage.

A third option is pumped storage although the majority of plants in the U.S. were built over thirty years ago and there are only a hand full of projects in the FERC approval queue at the moment. Each of these energy storage options is limited in application, very expensive, or both. Data from the EIA show that this asset actually represents a -0.2% share of the fuel mix in their latest report because those facili-ties generally use more electricity than they produce[4].

Energy Storage Mode for Any Combustion Turbine

Powerphase has engineered an alternative that is utility-scale, available today, and effective. Instead of building an entirely new energy system, Powerphase has developed a simple method of adding energy storage to existing CTs. The solution, named, "FastLight", offers the benefits of energy storage which boosts both plant and grid efficiency, yielding fuel and ratepayer savings, while again, leveraging existing combined cycle infrastructure (Figure 6). The essence of FastLight is excess electrical energy available from the grid/the CTs during off-peak hours that is stored in the form of compressed air in cylinders.

On demand, typically during on-peak periods, the stored compressed air is

FASTLIGHT ADDS ENERGY STORAGE CAPABILITIES TO COMBINED CYCLE PLANTS

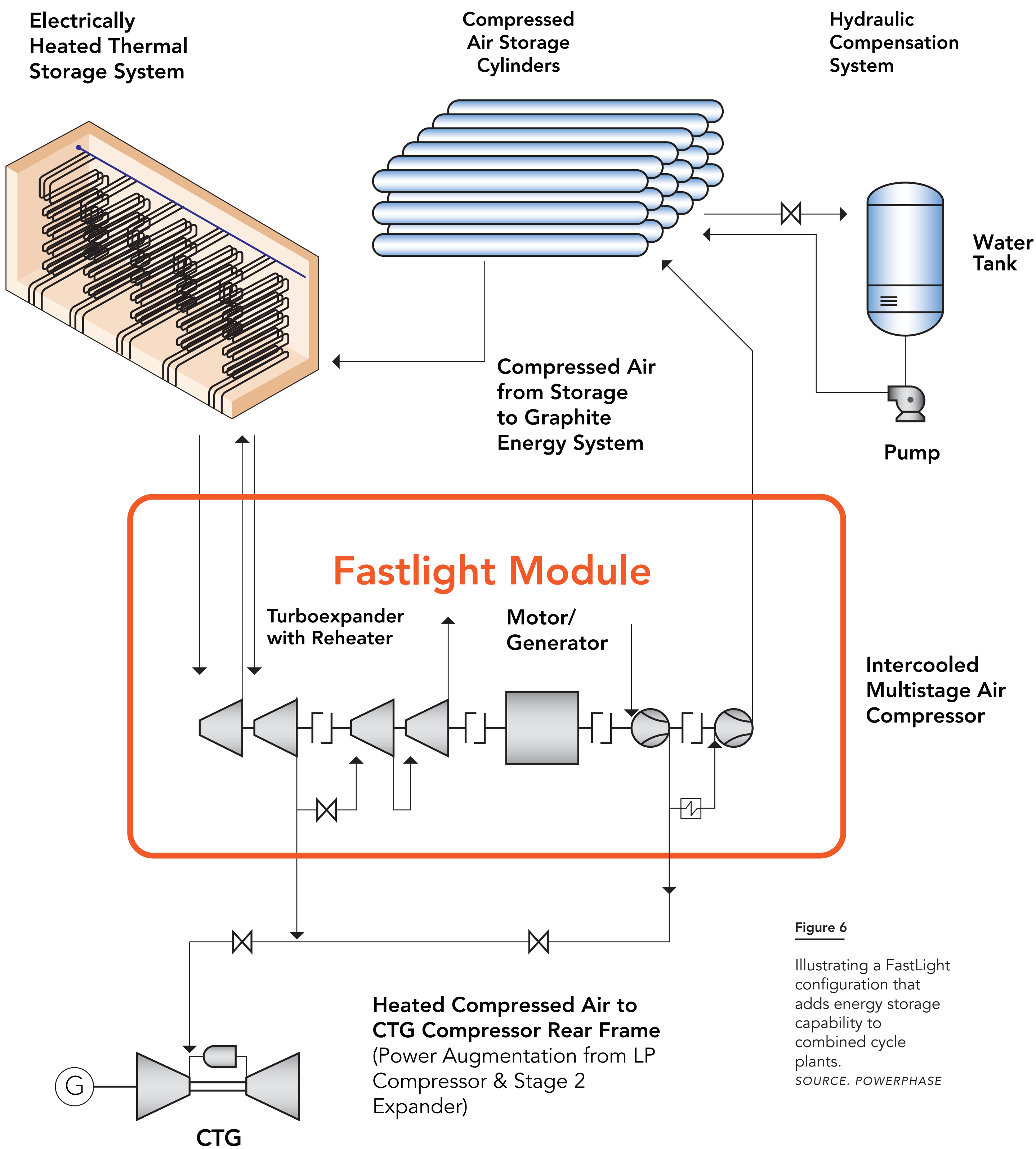


Figure 6

Illustrating a FastLight configuration that adds energy storage capability to combined cycle plants.
SOURCE. POWERPHASE

heated by passing it through the thermal storage blocks and then is used to produce power by air injection into the CT compressor discharge transition. Fast-Light is designed to charge and discharge twice per day, generating 15-20 MW per module for four hours, rivaling state-of-the-art battery-based energy storage systems. If deployed on several existing combined cycle plants in California, FastLight could deliver enough grid scale power to meet the entire California grid energy storage mandate, without a single battery. Also, FastLight systems have a 30-year useful life, further lowering life cycle costs and environmental impact compared to batteries that need to be replaced and disposed of every 7-10 years.

Put Powerphase solutions to work in your fleet

For an operator of a generation fleet that contains CTs, a close look at Power-phase offerings makes considerable financial and operational sense. The Turbo-phase solution can offset the capacity-robbing effects of ambient temperature and site altitude, allowing both existing and new CT assets to operate at rated output with 5-10% higher grid efficiency.

At the same time, the Turbophase solution can equip these same CT assets to function in a rapid response mode, adding additional revenue where the system

Put the Turbophase and FastLight solutions to work and equip your CTs for the 21st Century world of greater renewable penetration and rapid response generation demands.

operators compensate generators for this service. With the advent of 5 minute dispatch and settlement, such capability is of great value to generation providers.

Finally, with the addition of the FastLight solution, CTs can be run at a steady, base load level with the excess energy produced during off peak periods stored as compressed air for use during peak demand periods.

The power markets are moving away from a baseload, demand management model of large plants serving relatively stable loads to one characterized by increased volatility in supply driven by increasing penetration of renewable assets. This change requires lower baseload levels and faster incremental generation response. New or existing CT assets, outfitted with the Powerphase solutions, become the ideal, high performance asset the new power markets demand.

Put the Turbophase and FastLight solutions to work and equip your CTs for the 21st Century world of greater renewable penetration and rapid response generation demands.

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