bGen™
Brenmiller Energy

Combined Cycle Gas Turbine with Thermal Energy Storage

BRENMILLER ENERGY

The need

Over the last decade, there has been a dramatic change in the power production paradigm. The energy generated by centralized power plants has been progressively integrated with, and even replaced by, power generation from variable renewable sources. This change presents a new challenge for owners of combined cycle plants which are accustomed to baseload operation with regular maintenance intervals.

Today, Combined Cycle Gas Turbine (CCGT) plants require to operate in a flexible manner: they follow a double peak demand curve, resulting in increased number of ramp ups and daytime stops, as opposed to the traditional method of continuous operation, with stoppages mainly on weekends. As a result, these CCGT plants are experiencing up to 250 start/stops per year, much more than the 50 start/stops per year they were typically designed for as baseload plants.

In light of the foregoing, it has become vital for conventional power plants to change their operation mode and technical performance in order to increase their flexibility, yet at the same time ensure the reliability. The improved flexibility level offered to the ancillary service market is the main way to guarantee the competitiveness of thermal power plants. **Reduction of the minimum load, increase of the maximum power, reduction of the shutdown and start-up time, optimization of the ramp-up and ramp-down** phases, are all capabilities that are increasingly being demanded and whose value continues to increase.

Energy storage will play a pivotal role in providing the required flexibility and will offer balancing options to these thermal power plants. This is particularly true for Brenmiller Energy's thermal energy storage solution, which has unique features and can manage the variations in supply and demand at different scales, such as CCGT.

Brenmiller Energy's thermal storage system, called bGen™, allows CCGT to become more flexible and optimize market participation.

bGen™ allows CCGT power plants to offer better performance in the ancillary service market with respect to power capacity, spinning reserve, frequency regulation, voltage regulation, reactive power compensation and minimization of imbalance penalties.

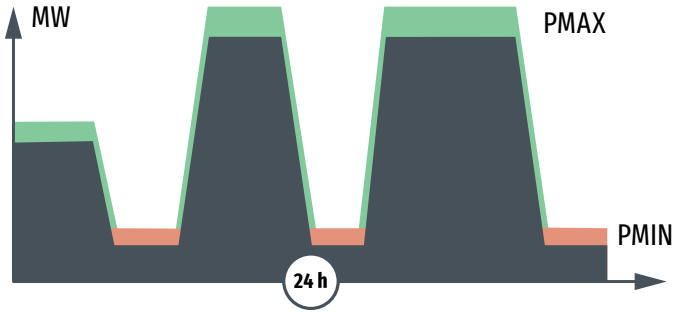
Key advantages gained by integration of bGen™ into CCGT:

- Increasing power plant flexibility
- Shifting production from off-peak to peak time
- Lowering the minimum electric load
- Increasing the maximum electric load
- Increasing the overall efficiency of the CCGT plant
- Reducing CO2 emissions
- Shorter start-up time
- Faster ramp up time
- Lowering O&M costs and extending the power plant's lifetime by reducing the HRSG thermal stresses

Services and Revenue Streams

Load shifting

charging at off-peak times and discharging at peak rates, to maximize revenues from energy arbitrage and from the sale of electricity.



Lowering the minimum electric load

bGen™ allows to operate the gas turbine without feeding the steam turbine, which reduces the minimum electric load. The resulting steam produced by the HRSG is not delivered directly to the steam turbine but is used to charge the thermal storage.

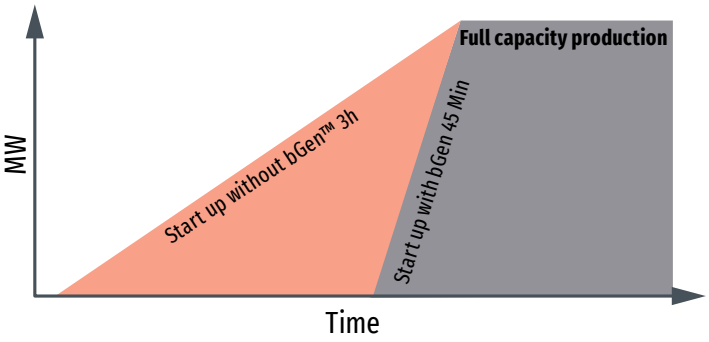
Increasing the maximum electric load

At peak demand the steam discharged from the bGen™ is added to the steam produced from the HRSG, providing additional thermal energy beyond the nominal capacity of the HRSG.

Reducing start-up time

Currently in CCGT power plants, both turbines operate in parallel, so in the start-up phase the rising gradient is driven by the slower steam turbine that receives the steam from the HRSG.

With the bGen™, the start-up time can simply follow the gas turbine ramp-up rate. The resulting steam from the HRSG would only be partially delivered to the steam turbine, respecting its gradient and thermal constraints. The excess steam would load the bGen™ and later be used for different needs (power production, HRSG ramp up).



Technology

bGen™ is a patented high-temperature thermal energy storage solution, incorporating three key elements: (1) Heat exchanger, (2) Thermal storage, using crushed rocks and (3) Steam generator.

The bGen™ is integrated in the HRSG and is charged with steam that is delivered from the final stages of the HRSG, to ensure minimal interruption to the plant's operation.

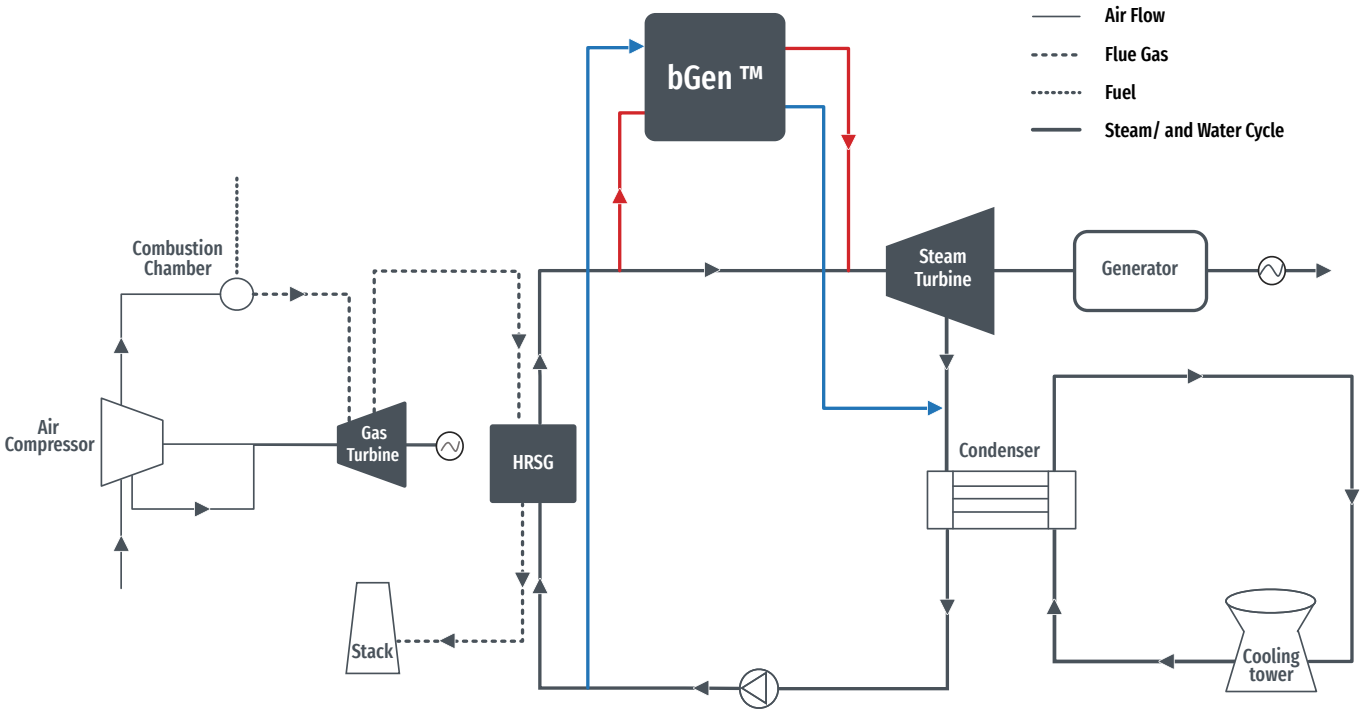
Heat is stored in modular sub-units, filled with crushed rocks. When the unit is charged, a controlled temperature profile is maintained, transforming the feed water flow into a steady and stabilized superheated steam. The system controls the pressure and temperature of the generated power, assuring steady steam conditions, regardless of the unit charging level.

Steam is discharged into the HRSG according to the power plant's needs and demand.

bGen™- Key Advantages

- The bGen™ system can work within a **wide range of temperatures** from 350°C (662°F) to 750°C (1,382°F), and **within a pressure range** of up to 120 bar for electricity production.
- bGen™ acts as a thermal battery and is u**naffected by any intermittent process.** Heat is captured whenever it is available, and is released in a **steady and continuous** manner, according to the demand.
- The storage media allows to conduct tens of **thousands of charge/discharge cycles,** with no degradation in performance.
- The bGen™ system can be installed on a **bypass** of the main steam path, to prevent even the smallest interference with the power plant's day-to-day operation. This will ensure continuous operation of the power plant.
- Different unit sizes can be built using the **modular elements**. System losses are minimized through the completely covered and insulated block. The modular structure enables simple shipment and short installation time.
- The storage thermal losses are less than 3% over a period of 24 hours
- The system's lifespan is **over 30 years** with no degradation in performance.
- The bGen™ system is considered a **'green engineering'** unit, as **no hazardous substances** and no chemicals are used in the storage media. Accordingly, there are **ZERO EMISSIONS** when using the bGen™.
- The bGen™ system **lowers the CO_2 emissions** by reducing the fuel consumption.

A process flow diagram of the bGen™ system in CCGT power plant:



Technical Details and Performance:

Key characteristics of the bGen™:
Thermal storage capacity of 200 MWht in a CCGT plant.
The modules are stacked and connected in a storage solution ranging from 5MWht and up to GWht scale.

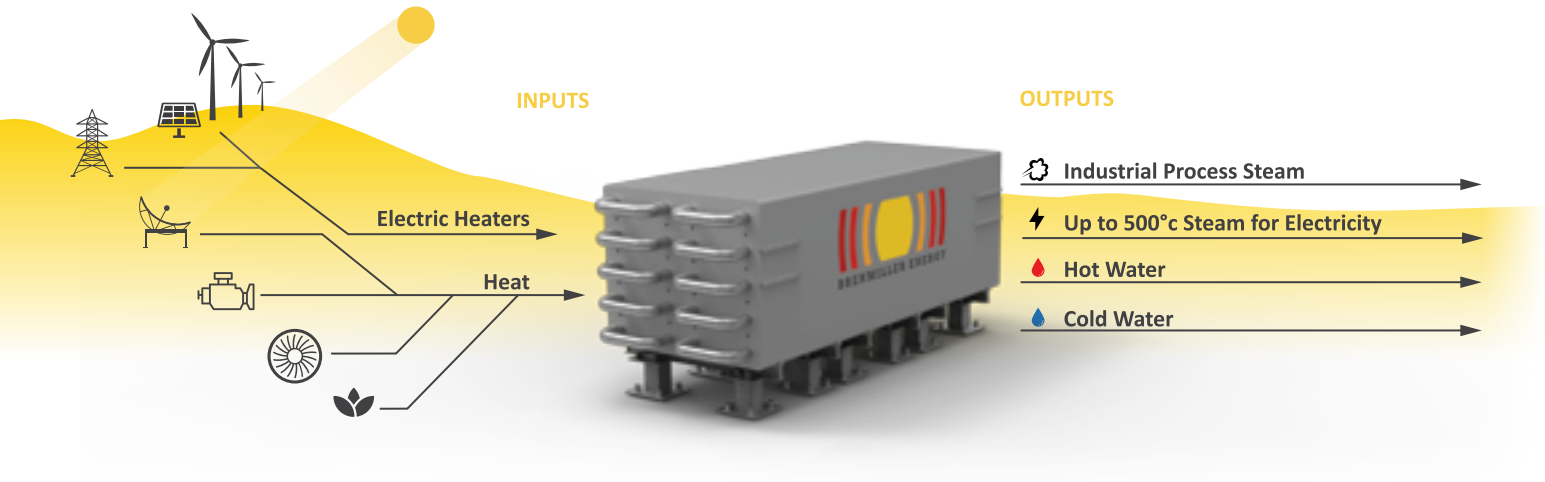
Storage capacity	200 MWht
Charging/discharging rate	40 MWht
Net size (W X L X H)	12 [m] X 12[m] X 16 [m] / 40[ft] X 40[ft] X 52[ft]
Storage medium	Crushed Rocks
Charging	Flue/exhaust gas, steam
Charge temperature, Max	750 [°c] / 1,382 [°f]
Steam output temperature	480 [°c] / 896 [°f]
Output pressure	90 [bar]
Steam hot start	< 5 [min]
Heat loss over 24h period	2.9 [%]
Charge/Discharge cycles	> 30,000
Design lifetime	More than 30 [years]

Company Profile

The Company was founded in 2012 by Avi Brenmiller, former CEO of Siemens CSP and Solel, and a team of experts in the field of renewable energy. Brenmiller Energy's knowledge and expertise are well-grounded and are based on years of field experience in designing, building and operating over 500MW of solar power plants in Spain and in the US. Recent accomplishments include being awarded a $1M grant for a joint project with the New York Power Authority, to supply electricity and heating to a building in a New York State University. The Company was also awarded a grant by the Ministry of Defence to supply a mobile-based CHP plus energy storage unit to the Israel Defence Forces.
The Company completed a successful IPO in August 2017 and is traded on the Tel Aviv Stock Exchange.

Company Projects:

- **Storage Based CCGT Project, Europe:** a cooperation between a European Utility and Brenmiller Energy. bGen™ will increase the flexibility of a standard combined cycle power plant, with a 200MWht storage capacity. This project is expected to be commissioned in the third quarter of 2020.
- **Rotem 1, Israel:** a hybrid power plant, using solar collectors and 90 MWht storage capacity, combined with natural gas, to generate clean energy throughout the day. This will enable baseload operation and continuous power generation and supply to the national grid, under a 20-years PPA. The project is guaranteed by the European Investment Bank and is planned to be grid connected in the second quarter of 2020.
- **Rotem 2, Israel**: a hybrid power plant of Solar PV with a 115 MWht storage capacity. The project is expected to be connected to the grid by the second quarter of 2021.
- **Storage Based CHP Project, NY:** a joint project of the New York Power Authority (NYPA) and Brenmiller Energy at Purchase College, State University of New York (SUNY). bGen™ will increase the efficiency of a standard combined heat and power (CHP) system, and will take the designed building off of the College's main central heating system. This project is expected to provide an annual energy saving of 10,000 MMBtu and an annual greenhouse gas reduction of 550 MTCO2e (metric tons of CO2 equivalent emissions). The project is expected to be commissioned in the fourth quarter of 2019.
- **Mobile Storage based CHP, IDF:** a mobile thermal storage unit integrated with a diesel generator to provide electricity and thermal energy to an IDF base.



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