512 MW in 10 minutes – New York City peaking plant solution applicable for Europe

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Kurzfassung

Ein flexibles Spitzenkraftwerk für New York City mit Potenzial für Europa


Introduction

The New York City grid is highly volatile with daily load spreads of up to 3,500 MW – and sometimes even more. This is driven by the volatile power demand, which is strongly dependent on the weather and ambient temperatures. For example, the load increases substantially as air conditioning units are turned on or ramped up. Demand can abruptly drop when, for example, as a result of a rain shower ambient temperatures fall by just a few degrees. Peaking plants are therefore operated across the region to stabilize the grid load demands. One of the peaking plants in the region is Bayonne Energy Center (BEC) located in New Jersey, a natural gas-fired 512 MW peaking plant equipped with eight aero-derivative gas turbines. The BEC plant went into operation in 2012, making it one of the area’s most modern and youngest plants – most of the other peaking plants are up to 40 years old. The plant has exceeded expectations, as it is running more hours daily than originally planned. A 6.5-mile power line under the Upper New York Bay connects BEC with the volatile, high-demand grid of New York City (NYISO Zone J). At peak times, BEC can deliver sufficient power to supply electricity to over 500,000 households. During the planning phase of the project, the requirements for the plant were defined as follows:

– Maximum ten-minute start time (non-spinning reserve)
– Multiple starts and stops per day
– Low cost per start
– High full and part load efficiency
– Black start capability
– High availability and starting reliability
– High power density
– Automatic generation control
– Low operation and maintenance costs
– State of the art (SOTA) emission levels [1]
– Dual fuel capability

The following is a description of how the plant delivered to BEC is fulfilling these requirements. Many of the described characteristics are a result of the aero-derivative turbines installed in the plant. When possible, descriptions of BEC are supported with operational data. Comparisons to other technologies are drawn on occasion to illustrate differences and advantages.
Finally, the solution is presented as a possibility for peaking plants in Europe, where intermittent renewable energy sources are increasingly common.

The Bayonne Energy Center

At the heart of BEC are eight Industrial Trent aero-derivative gas turbines (Figure 1). These turbines feature a three-spool design derived from the Rolls-Royce RB211 and Trent aircraft engines, with a performance lineage founded e.g. in Boeing 777 (Trent 800) applications. In the meantime, the Industrial Trent has over 1.2 million fleet hours. As per a contract between Siemens and Rolls-Royce, Siemens profits from technology developments until 2039 – that means that innovations from the aero industry can also benefit the Industrial Trent 60.

The solution at BEC is distinguished by its cycling capability, quick start and high open cycle efficiency – characteristics that make it the optimum peaking plant. The BEC units are based on a modular package design, which by nature is optimized for operation and maintenance (O&M) and minimal installation time. The core exchange principle – which is described below in more detail – allows the core turbine to be serviced off site, allowing generation to continue. An added benefit of the design is that overhaul outages are reduced to less than two days of downtime.

512 MW in 10 minutes – repeatable throughout the day and with a high degree of load flexibility

BEC can provide 512 MW in less than ten minutes from non-spinning reserve, and it can realize load change rates of 168 MW/minute and more (21 MW/minute/turbine).

With cold start ability to 100% load in less than 10 minutes and power ramps of up to 39 MW/minute, the aero-derivative gas turbines offer an extremely fast power response time. In addition, due to their aero heritage design, the turbines are highly suitable for cyclic operation and multiple starts, as no penalties like Equivalent Operating Hours (EOH) are applied for high cycling or starts. This means that high stress operating cycle duty as shown below in Figure 2 does not affect the service intervals and costs. Furthermore, there are no lockout periods after shutdown.

In Figure 3, a typical start curve with a load ramp of 21 MW/minute is displayed. It is important to note that under certain circumstances the ramp rate can be increased – up to 39 MW/minute has been demonstrated, which meant that full load could be achieved in less than 8 minutes on gas and less than 9 minutes on liquid from a cold state. These figures compare very favorably with other technologies like reciprocating engines where OEM market-

![Figure 2](image)

**Figure 2. March 7, 2016: 33 total starts (six starts on unit 2) with no EOH penalty.**

![Figure 3](image)

**Figure 3. The standard eight-minute starting sequence of the Industrial Trent 60.**

ing material suggests 5 to 10 minutes to full load on hot or warm starts. However, it should be noted that the comparison applies to gas engines with power outputs of 20% to 40% of the aero-derivative turbines installed at BEC. Load change rates during operation can be as high as 2 MW/s ramp up and 4 MW/s ramp down, which is significantly higher than other technologies.

The short starting time of the aero-derivative gas turbines ensures that operation at less efficient part load is minimized, as full load is reached quickly. This helps to keep starting costs low: the cost per start per turbine at the BEC is reported to be between $40 and $60 [2].

Furthermore, the aero-derivative turbines can be started with a starting motor as small as 350 kW, thanks to the three-shaft turbine design, and they can commence power generation on gas pressures of 22 barg [3]. For starting, only the smallest shaft needs to be rotated by the starting motor; the other two follow as a result of aerodynamic coupling. In addition, the aero-derivative gas turbines have very low black start and standby power requirements.

High full and part load efficiency for the turbines and plant as a whole

BEC follows a modular approach with eight aero-derivative turbines. This enables plant efficiency to be optimized over the whole range – from less than 18 MW [4] (one turbine in part load) to up to 512 MW (all turbines at full load). The units can be switched on and off as needed. As such, it is possible to operate each individual gas turbine at loads that achieve the optimum efficiency. In this regard, maximum efficiency of the turbines is 42 percent, which is higher than most other New York City peaking facilities.

Furthermore, this modular approach enables the power plant to be operated efficiently over a much wider load range within the permitted emissions limits than a conventional CCGT can achieve. For example, if 180 MW are needed, then only three turbines are switched on – and they can be
operated at full load. Figure 4 provides an overview of plant efficiency over the MW range. The multiple-unit design also helps keep power plant availability and output high. At BEC, up to 448 MW is still available during maintenance. In contrast, in a plant with a single gas turbine, the entire power station has to be taken off line for maintenance. In a power plant of similar output but based on several turbines, as BEC, only a portion of power capacity is lost during gas turbine maintenance. Furthermore, the production loss is only 48 hours as a spare core can be installed (see A simplified maintenance concept below).

Although BEC was designed as a peaking plant, it has confirmed its suitability as a mid-merit and intermittent solution. This is due to its high overall efficiency, which allows it to be competitive in a market where, as mentioned above, most of the peaking stations are older – some up to 40 years old. On average, the turbines at the BEC are operated for six hours per day with an average of 1.4 starts per turbine per day.

In peaking applications or applications where frequent start/stop load cycling is expected, conventional economic models are not applicable. The key evaluation criteria are not $/kW or heat rate, but the Internal Rate of Return (IRR) on through life costs. Hence, while an open cycle aero-derivative gas turbine is less efficient than an optimized combined cycle plant utilizing heavy-duty gas turbines, the lower CAPEX and reduced O&M compared to a combined cycle plant costs outweigh the higher fuel consumption because of the limited number of operating hours. Furthermore, peaking plants with aero-derivative turbines offer a high power density (see A compact package design below).

**Up to 4,000 starts per year**

Availability and starting reliability are key for a successful operation. As mentioned above, the BEC performs multiple starts per day. In total, there are more than 4,000 starts per year, which corresponds to an average of 500 starts per turbine per year. In the eight months between January and August 2016, there were only 13 failed starts out of a total of 2,653 attempts. The average time of the failed starts was around 15 minutes, which is a very short recovery time. These figures speak for a very high starting reliability. (Table 1)

What’s more, the availability of BEC is clearly above industry standards. This is indicated by the IEEE Standard Equivalent Forced Outage Rate Demand (eFORD). The eFORD is a measure of the probability that a generating unit will not be available due to forced outages or forced derating when there is a demand on the unit to generate power. The average simple cycle eFORD is around 5.3%. For diesel power plants an eFORD of 9% and higher is not unheard of, and for coal power plants the figure hovers around 11% [5]. In contrast, the eFORD for the BEC during the eight-month period was 0.86%. (See Table 1.)

**A compact package design**

Land prices in the New York City area are at a premium, so BEC operators wanted the maximum power density on the parcel of land set aside for the generation facility. Each of the gas turbines is housed in a package with a footprint of around 220 m². Running at full capacity, the BEC solution has an output of 19 kW/m². Other approaches would come in at around 14.5 kW/m² for a total of approx. 400 MW. As such, the solution enables about 20% more power generation on the available plot of land.

Not only is power density significant with the solution delivered to the BEC, but also the short erection and commissioning times. The aero-derivative gas turbines are part of a pre-designed, pre-assembled standardized package. The advantage is that the turbines undergo significant levels of factory testing, and on site only a simple concrete foundation is required. Altogether, the approach reduces the amount of planning, engineering, site installation and construction work required. Furthermore, when compared to a conventional power plant, BEC could be brought online faster, while still maintaining a competitive first cost. Added benefits include a reduced risk of construction delays and associated contract penalties, which can lead to lost revenue.

**A simplified maintenance concept**

The aero-derivative turbines have a 25,000-hour overhaul regime and are capable of 5,500 cold starts between overhauls. Via a sliding mechanism the turbine cores can be easily removed from the package for single machines. During the maintenance period, Siemens can supply replacement gas turbines on a lease basis. For day-to-day operations, only two staff members are on site per shift for the eight hour on/8 hour off regime. Members of the team are on site per shift for the eight hour on/8 hour off regime. For day-to-day operations, only two staff members are on site per shift for the eight hour on/8 hour off regime.

**Fig. 4. Efficiency of the BEC tops in at 42% (schematic overview).**

**Tab. 1. The statistics for BEC from January to August 2016. eFORD = Equivalent Demand Forced Outage Rate.**

<table>
<thead>
<tr>
<th>Month (2016)</th>
<th>Attempted starts</th>
<th>Actual starts</th>
<th>Starting reliability</th>
<th>eFORD</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>207</td>
<td>206</td>
<td>99.5 %</td>
<td>0.40</td>
</tr>
<tr>
<td>February</td>
<td>263</td>
<td>261</td>
<td>99.2 %</td>
<td>0.73</td>
</tr>
<tr>
<td>March</td>
<td>512</td>
<td>511</td>
<td>99.8 %</td>
<td>1.76</td>
</tr>
<tr>
<td>April</td>
<td>423</td>
<td>422</td>
<td>99.8 %</td>
<td>0.29</td>
</tr>
<tr>
<td>May</td>
<td>328</td>
<td>325</td>
<td>99.1 %</td>
<td>0.03</td>
</tr>
<tr>
<td>June</td>
<td>275</td>
<td>273</td>
<td>99.3 %</td>
<td>0.14</td>
</tr>
<tr>
<td>July</td>
<td>311</td>
<td>311</td>
<td>100.0 %</td>
<td>0.59</td>
</tr>
<tr>
<td>August</td>
<td>334</td>
<td>331</td>
<td>99.1 %</td>
<td>1.30</td>
</tr>
<tr>
<td>Report totals</td>
<td>2,653</td>
<td>2,640</td>
<td>99.5 %</td>
<td>0.86</td>
</tr>
</tbody>
</table>
turbines. The plant itself can be controlled in auto mode, meaning that the units are turned on automatically via signals dispatched directly by the grid operator. In that case, the gas turbines are automatically started and controlled to achieve the desired MW set point. Alternatively, the grid operator sends start base point requests, and the staff on duty starts the units accordingly.

**State-of-the-art emission technologies**

Generally speaking, emissions control on the aero-derivative gas turbines can be supplied in various configurations, depending on the project needs. Both Dry Low Emissions (DLE) and Wet Low Emissions (WLE) are available for gas fuel. For liquid fuel, only WLE is available for emission control. The advantage of WLE over DLE is that it provides a power enhancement. The DLE has an advantage over other technologies in that it does not require seasonal tuning, which adds maintenance outage time.

The aero-derivative gas turbines delivered to the BEC feature WLE control with less than 25 ppm NOx on natural gas and 42 ppm NOx on liquid fuel before the SCR. After the SCR, the figures are 2.5 ppm NOx on natural gas and 5.0 ppm NOx on liquid fuel.

**Dual fuel capability**

The turbines delivered to BEC feature a dual fuel configuration, as they are able to operate on either 100% gas fuel or 100% liquid fuel. The turbines are capable of a rapid automatic changeover between the fuels, and there is no need to temporarily reduce load in the case of a fuel change. The liquid fuel for BEC – ultra-low-sulfur diesel – is delivered via pipeline from Buckeye Terminal, which is about 20 miles away from the BEC site. The capability to run on liquid fuel is not only important as a back-up in case of interruptions in the gas supply, but also allows BEC to benefit from price advantages in periods when gas prices are high. Using liquid fuel does not affect the engine life, nor does it count against engine life, nor does it count against fuel consumption.

As the experience with the solution at BEC shows, a power plant based on aero-derivative gas turbines can meet and exceed the challenges facing power generators and grid operators today.

In addition to their suitability for peaking stations, multiple unit concepts based on aero-derivative turbines are also an ideal solution for distributed power generation and grid support operations. A particularly attractive feature is the ability, as outlined above, to operate on a number of fuels. Furthermore, flexible combined cycle applications, in which the waste heat contained in the exhaust gas stream is used to generate additional electricity, can make sense. This is particularly of interest when the turbines are operated for a higher number of hours per day, for example in mid-merit and intermittent configurations. This configuration allows up to 53.6% electrical efficiency, but offers good flexibility. Another model is to use the waste heat in power in which the waste heat is used for process heat or cooling for industry or municipalities.
Summary

BEC with its eight aero-derivative turbines has proven its suitability as a peaking plant for New York City. The solution has proven to be the most economic compromise between CAPEX, operational flexibility, and fuel and part load efficiency. Highlights include start to full capacity in less than ten minutes, high efficiency at both full and partial load, and low operational and maintenance costs – despite multiple daily starts and stops. The operators of BEC are satisfied with the performance of the aero-derivative turbines – so much so that they have decided to add two additional Industrial Trent 60 turbines on a parcel of land adjacent to the site. The two new turbines are scheduled to go live before the end of 2017, adding an addition 132 MW capacity to BEC.

Service data from BEC reveals that the solution is a veritable alternative for peaking plants in Europe, where the incumbent technology is the more energy intensive reciprocating motors. In these cases, natural gas-operated aero-derivative turbines can be viewed as a bridge technology to zero-carbon power generation.

Literature

[2] Based on around 20 MMBTU gas required to accelerate to base load and $2 to $3 per MMBTU.
[3] 43 barg pressure is needed for full power.
[4] The Industrial Trent does not have a minimum operating power. But for operation under 18 MW, additional inspections are needed.
[5] See “Monthly Equivalent Forced Outage Rates” from US regional transmission organization PJM at http://www.pjm.com/markets-and-operations/energy/real-time/historical-bid-data/eford.aspx (accessed on Dec. 9, 2016). In the figures for 2016, the eFORd for a range of technologies is shown – coal, combined cycle, combustion turbine, diesel, gas, hydro and pumped hydro, nuclear, oil and other. The eFORd figures for coal range between 6.198% and 17.488%. For diesel the range is 6.348% and 9.238%.
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