ELECTRICITY SPIKES and the **Power of Collaboration**

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LIKE MANY DEPARTMENT OF NAVY INSTALLATIONS, NAVAL SUPPORT ACTIVITY MONTEREY (NSAM) faces power bills that can change dramatically due to short spikes in electricity demand. Unlike most Navy installations, NSAM hosts an academic institution—the Naval Postgraduate School (NPS), where students and faculty can work closely with Naval Facilities Engineering Command (NAVFAC). At NPS and NSAM, the connections built over years of collaborations formed through the Energy Systems and Technology Evaluation Program (ESTEP) researchhelped save 25 percent on power bills for one of the NPS labs.

Air-Compressor Billing Spike

Non-residential customers often pay not just for power consumed in kilowatt-hours (kWh), but also charges associated with short-duration demand spikes—kilowatts (kW) experienced in 15-minute periods. At NSAM, the Pacific Gas and Electric Company (PG&E) monthly bill includes a demand charge of $20.22 per kW for the highest 15-minute electricity

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demand during the billing period if it occurs in the morning during summer, and up to $35.35 per kW if it occurs later in the day. Rates vary by time of day and season, and change occasionally.

When peak demand at the TurboLab increased from about 200 kWh in July to more than 1600 kWh in August 2017, NSAM Energy Manager Douglass Taber took notice.

At the Vavra Turbopropulsion Laboratory, affectionately known as the "TurboLab" by the faculty, students and faculty design and test gas turbines. The Navy has more than 400 gas turbines in its ships and a similar number in its planes. The greater the turbines' efficiency, the more capable is the fleet—and they must be extremely reliable to avoid accidents like the April fan blade failure on a Southwest Airlines jet that killed one passenger and nearly brought down the plane. TurboLab's in-class demonstrations and experiments run gas turbines at supersonic speeds—the blade tips may be moving at over 900 miles per hour. Without this high-speed ability, tests would not be relevant to modern jet engines.

These tests require a huge volume of compressed air—10,000 cubic feet per minute (cfm) at 3 atmospheres pressure (atm), which is provided by a transonic compressor test rig, powered by a 1000-kW compressor. The system is very effective and reliable—it provides the large volumes of air required. But it is not efficient as it dates from the late 1960s, when power electronics required to regulate the speed simply were not available, and the compressor runs at a single speed. Excess air is simply bled off to the atmosphere, wasting the power used to compress it.

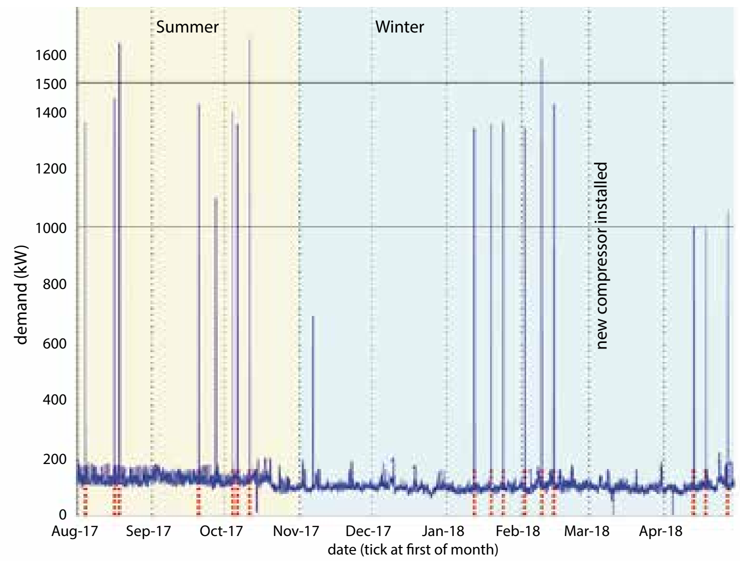
The 1000-kWh capacity is required for top-speed runs. However, top-speed runs are only a small portion of a typical test run program, which requires runs at speeds at 50 percent, 60 percent and so on up to 100 percent of capacity. In addition, lower-speed runs often are used to set up new instrumentation and rotors because the 100 percent speed runs have much higher chances of catastrophic rotor failure. The large majority of runs in a typical test use much more power than would be required if the compressor could be operated at lower speeds. Since the power requirement is proportional to the square of the test turbine speed, with a variable-speed compressor, a 50 percent speed run requires only 250 kW.

The test rig also includes a 500-kW compressor that provides secondary air at up to 10 atm to balance the rotor load and provide air to bearing cooling systems. It also drives TurboLab's supersonic wind-tunnel and the spin-pit test rig. This compressor was purchased in the 1980s and operates at only one speed, with excess air being bled off. Figure 1 shows the recent electricity demand at TurboLab—demand spikes on test dates.

TurboLab has been conducting its tests early in the day in order not to incur peak time-of-use charges, but Taber's call regarding the $44,000 bill in August—which would have been $16,000 without the three tests—led Associate Professor Anthony Gannon to revisit the system requirements. His experience designing and building a small-scale compressed-air energy storage system for an ESTEP-funded compressed-air energy storage project gave him the technical knowledge to size and specify a more suitable compressor. Recent improvements to the test rig reduced the secondary air requirement, and a 55-kW variable-speed compressor was specified, and in March it replaced the 500-kW compressor. Both are shown in the photograph.

Since the installation of the smaller compressor for secondary air needs in March 2018, the system has performed flawlessly and its use is beginning in various other thesis projects in developing small air-driven turbines for backup power. As an added bonus, the operation of the new compressor is far simpler than the previous one and the time to start up to gather data is reduced by around 30 minutes per test. Figure 2 expands the power demand plot for two

Figure 1. TurboLab's PG&E Power Demand



Note: The test rig was used on the dates shown with red lines. After the 500-kilowatt (kW) compressor was replaced with the 55-kW unit, peak demand during tests dropped about 500 kW.

Photos and figures by Naval Support Activity Monterey.

The old 500 kW compressor (left) was replaced with a 55-kW compressor (right).

tests, one (blue) that peaks at 1585 kW dates from before the installation of the new compressor. The second test date (orange) shows the change after the new compressor was installed, and peaks at 1058 kW.

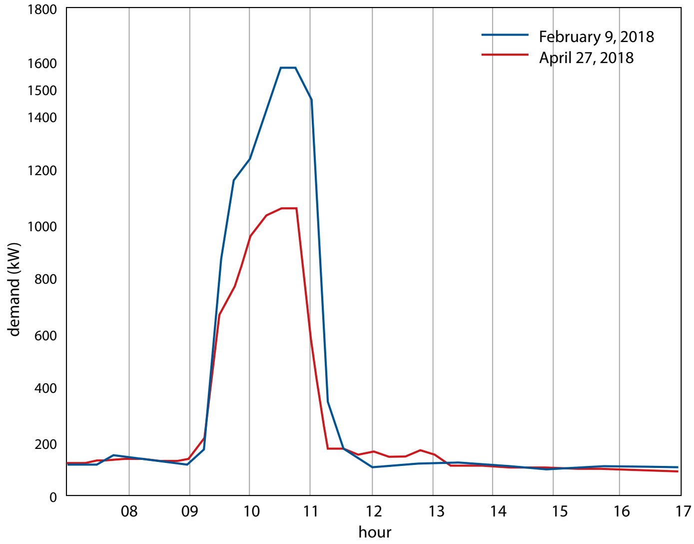
It was through experience with the ESTEP research and a compressed air energy storage project that Gannon's team had the technical knowledge to make the procurement of the smaller compressor so successful. Planning for the upgrading of the larger 1000-kW system is ongoing.

Costs and Savings

Meanwhile, a second ESTEP team from the NPS Graduate School of Business and Public Policy had been studying utility rate structures and how the time-profiles of power demand can drive up power bills. Figure 3 shows their analysis of the attribution of utility costs to supersonic tests.

The costs of 13 tests between August 2017 and February 2018 are estimated at between $105,000 and $113,000

Figure 2. Demand in 15-Minute Periods



Note: Figure shows tests before (blue) and after (orange) replacing the 500-kW compressor.

from demand charges, and only about $2,000 from the actual power consumption (kWh). The costs were calculated relative to a baseline demand profile in which TurboLab used the average demand for the same month, day of week and hour, instead of the observed demand. During PG&E's summer billing months, a single test spiking to 1600 kW would cost more than $28,000, relative to a baseline maximum demand of 200 kW, which we see for August and October 2017. In the winter, the same spike would cost more than $21,000, which we see for the February tests. With the new test rig in April, the spikes decreased to about 1,000 kW, and the demand charge from the tests decreased to $12,700, a savings of $6,800.

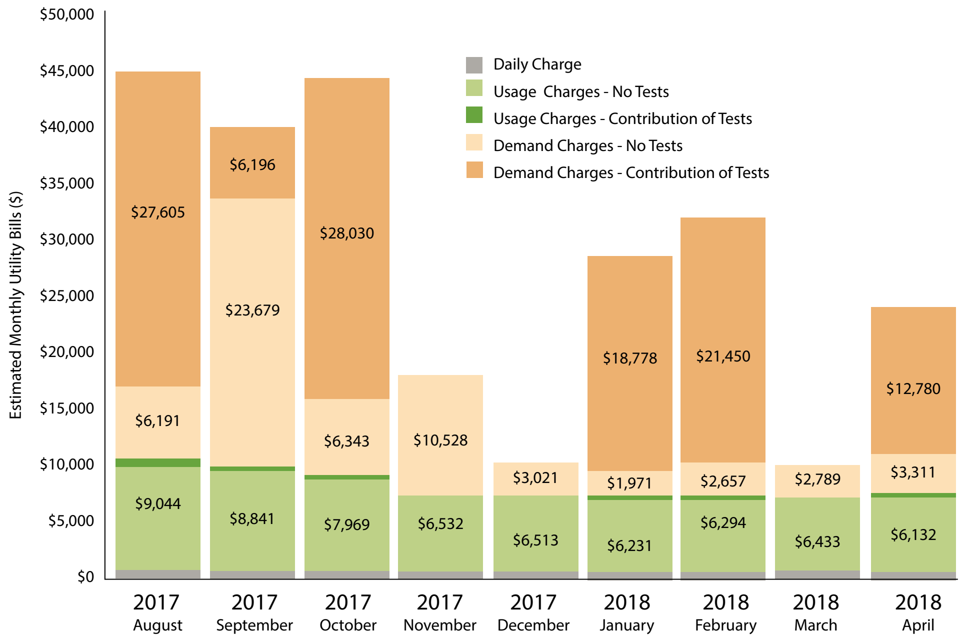
Figure 1 shows that the peaks in Figure 3 are typical. Tests in April have power spikes to 1000 kW from the primary compressor, rather than to 1500 kW above the baseline power demand of about 150 kW. The cost per test is difficult to attribute since the first test in a month triggers a big demand charge. Once that big peak demand charge is incurred, additional tests in the same billing period have a much smaller marginal cost. However, reducing the peak demand by 500 kW saves more than $10,000 in a summer billing month and $7,600 in a winter billing month. The new equipment would recoup its $72,000 cost in about 2 years with a similar test schedule.

Other benefits are excluded from the calculations above. The new compressor is easier to operate, and tests are shorter (as illustrated by the shorter orange spike Figure 3), saving labor hours. Using the smaller compressor also puts far less mechanical stress on the system, and reduces the frequency of other ancillary maintenance.

The S&T-NAVFAC Connection

Gannon knew of the high energy demands of the TurboLab, but, like most research tenants, is constrained by limited research money for changing the laboratory equipment. All tests are always completed before 12:00 noon, as there is an increase in the tariffs afterward, but this means that test programs are not carried out at the optimal hour of day for the educational and research program. The purchase of the smaller compressor to supply secondary air was a fairly straightforward decision, but the 1000-kW system requires significant investment in money and time to ensure that the new equipment will provide the capabilities of the existing system.

Figure 3. Estimated Bills for TurboLab by Month, Breaking Out Contributions Due to Test Runs



Note: Because rates and start and end dates of billing cycle change, these are estimated based on recent rates and first-of-month start dates for the billing cycle. The daily charge (shown in gray) is unaffected by tests. The dark green shows consumption charges due to tests—their contribution is very small. The dark orange shows the demand charges attributable to test runs. In September, there was one test run, but there was a spike that was not due to gas turbine tests, so the contribution of the test runs is smaller.

The close relationship between NAVFAC, the business school and TurboLab largely is due to a research program funded by the Office of Naval Research that specifically emphasizes developing professional expertise within the Navy while simultaneously demonstrating promising new technologies on Navy installations. ESTEP aims to identify promising technologies, and speed their operational adoption. It funds demonstrations of promising technology at Navy installations, emphasizing use of the Navy's organic science and technology (S&T) workforce, so that the knowledge endures beyond the project and keeps on giving in the form of a more capable S&T workforce.

The ESTEP approach also forges connections across Navy communities, in particular between S&T personnel and NAVFAC personnel that create follow-on benefits in a couple of ways:

- First, by demonstrating technologies on an installation, the S&T personnel learn more about the operational and organizational requirements of NAVFAC. The utility rate structure is an example of a NAVFAC consideration of which most S&T personnel might be unaware. Other examples include contracting rules and technical approvals that do not always apply to research projects but are very important in NAVFAC's operations.

- Second, developing professional working relationships between operational NAVFAC engineers and S&T engineers expands opportunities for effective collaboration. NSAM NAVFAC is very open to experimental projects on the installations, and supports and develops relationships with the students and faculty. For example, as described in this article, NSAM worked closely with Gannon as he installed and tested many innovative technologies at TurboLab for the ESTEP, including renewably powered thermal storage for both heating and cooling applications, microgrids based on super-capacitors rather than batteries, and most recently a building-scale compressed-air energy storage system.

The cost-benefit analysis portion of ESTEP in the business school helps S&T engineers identify and quantify the benefits and costs of the technologies, and facilitate their wider adoption. In addition to the ongoing thesis on the effect of demand management on utility bills, Taber has supported many NPS student theses, including two on the benefits of energy management systems and another studying barriers to technology adoption at Navy installations.

Although Taber is retiring, the NPS faculty and the ESTEP program in particular will continue to benefit from the years of productive collaboration and mutual learning.

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