Dream Machine

BY DAVID ENGLE

An inverter connection to the grid lets CHP stay on when the lights go out.

Just a few years ago, Bob Panora was a sort of DE poster child, embodying a whole segment of power-project developers shut out of markets, at least in part due to contrived utility obstacles.

In testimony presented to the California Energy Commission at that time, Panora, president and chief operating officer of Massachusetts-based Tecogen Inc., told commissioners of being made to run a gauntlet of technical hurdles time and again to get his company's 75-kW combined heat and power (CHP) engines grid-connected—only to be shot down in the end on one pretext or another.

Partly as a result of Panora's accounts, things soon began improving for DE developers. Changes to California's Rule 21 on interconnections were implemented in 2006, forcing utilities to lower some barriers.

After stating his testimony, Panora eventually went back to Massachusetts, rolled up his sleeves, and began thinking of approaching the basic technical interconnection problem in a whole new way. Now—thanks to potentially revolutionary breakthroughs that are just coming into view—the relationship between DE, utility companies, and grids may be heading for a momentous improvement. The day is now imaginable when, instead of raising barriers, utilities will embrace DE for the benefits it can offer and for its real assets. Until now, these were rather offset by certain negatives for the utility.

Benefiting, too, will be power customers. For the first time, they'll be able to install affordable multiple reciprocating CHP engines in the sub-megawatt range—which are able to stay operating during grid outages—without the prohibitively expensive and challenging controls that were needed before.

Such an ideal has long represented a kind of dream machine for the industry: a very desirable, versatile product, oftenrequested by customers but, until now, not attainable.

The idea of 70- to 100-kW CHP generators serving for backup, as well as primary or peak-shaving power, seems, to a novice energy customer, a perfectly sensible one. This expectation, as Panora notes, comes up constantly in the marketplace. Of his thousand-plus adopters of Tecogen's 75-kW system over the years, he notes that the question they ask is always the same: Can it make power when the lights go out?

And, in all that time, he and other cogen developers who were selling in this size range have had to concede: "Uh ... er ... unfortunately, no."

Then follows a rote explanation of all the cost hurdles and safety hazards that prevent small (or medium-to-large) generators from doing any kind of interconnection which can support autonomy when grids fail.

The "No-Fault" Connection

At about the same time Panora was butting heads with West Coast utilities, he hit upon the theoretical solution that he's now poised to introduce: Why not simply insert a power-inverter between his small generator and the grid? This would neatly rectify the electricity instantaneously, smoothly, and reliably. It would also create an effective safety buffer against the things that can go wrong with a direct interconnection. "Inverters," he explains, "are 'fail safe,' that way, which makes them utility-friendly so that [generation] can be installed."

This and a host of other advantages are gained.

Using inverters is, of course, hardly a novelty in power generation, and in fact is an eminently logical starting point, given that inverter electronics are found on microturbines, fuel cells, and solar photovoltaic arrays. It is even more sensible, then, that inverters should be married to synchronous or induction engines. These make up about 60% of distributed generation.

But the additional cost of integrating inverters, along with other technical reasons, has rendered this option not very viable in spite of the logic.

Dana Levy, the program manager who oversees CHP projects for the New York State Energy Research and Development Authority (NYSERDA), explains why. Generators, he notes, consist of two types: induction and synchronous. The former need an electrical signal from the power grid, he says, "in order to stabilize their frequency." Hence, when the grid shuts down, the signal is lost, "and induction engines do what they're supposed to do: They shut down and protect themselves."

Thus, they're of relatively little use for grid-connected backup power.

On the other hand, synchronous engines are able to run either with or without the grid and are thus suitable for the standalone or independent capability that customers seek. However, as Levy elaborates, "the electric utilities tend to have difficulty with interconnection of synchronous generators in certain locations ... where the network protectors—essentially, the industrial-strength circuit-breakers that protect the grid from overloading—are at their rated capacity for fault duty." This means they cannot accept additional current "or anything else that would seem like a short-circuit without tripping," he says.

Moreover, synchronous generators produce potentially huge amounts of fault current, and hence they too are inappropriate for double-duty as both primary and backup power.

The maxed-out circuit-breakers that Levy describes are especially common in New York City and dense urban areas. Additional generators would be most desirable there, and hence NYSERDA's keen interest in facilitating power, overcoming interconnection barriers, and supporting promising technologies.

With the advent of Panora's inverter-based generator, says Levy, the DE world effectively gets a third generation option. "Inverter generators do not contribute as much fault current [as synchronous ones]," he says, "but they can run without the grid [unlike induction generators], and therefore they might serve as the ideal scenario for providing the best of both worlds."

Control-Free Interaction

"Another really interesting aspect that caught our attention with this project," Levy continues, "is the fact that its inverter base means that the engine can run at varying speeds, and the inverter ... electronics package can still produce a 60-hertz [i.e., 60-cycles-per-second frequency] sine wave." This amounts to, he says, a kind of electronic transmission system in which the engine either revs faster or throttles down, and yet the inverter output in cycles stays the same—a powertrain relationship not unlike that of, say, an all-terrain vehicle.

At any rate, the key advantage here is the ability to do more precise heat and electrical load following, as engines can run at optimized efficiency, varying rpm as required.

For example, notes Panora, during times of peak electricity rates, it would often make sense economically for the engine operator to send the kilowatt output into overdrive (about 3,000 rpm), "to make 125 kilowatts for a few hours and get special demand-reduction credits from the utility."

Without the presence of an inverter, his particular engine would need to run at a steady 1,800 rpm all the time, to output a consistent 60 Hz.

That variable-speed patent was an important breakthrough, but another innovation—just as significant and potentially far-reaching, too—arrived rather serendipitously from elsewhere: An integrated power-balancing algorithm developed at the University of Wisconsin. Equipped with this formula, Panora's inverter-based engines (or other energy resources, for that matter) can align seamlessly and effortlessly with each other on a common subcircuit. Generators can run together, even islanded from a main grid—all in sync.

All this is accomplished with no complex controls, no master-slave configuration, and no battery banks needed to handle surges.

In fostering both technologies and their interoperation, Panora is quick to credit the California Energy Commission and Sempra Utilities for their financial backing, all the way from proof-of-concept through field demonstration.

From a customer perspective, the result is indeed a "dream machine." It's an elegantly simple, inexpensive circuit of engines which A) can be positioned around a site for optimal CHP efficiency that will save money and B) will keep running robustly and automatically, powering critical services, regardless of what the grid does or doesn't deliver.

The MOBOCES campus keenly wanted, he says, "a machine that—when the lights went out—they can count on it to run."

To understand the impact of inverter electronics more specifically, here's the scenario of how it works in an outage.

Under a conventional electrical design, whenever a grid indicates a fault or shuts down, the main breaker on a DE resource connection opens. This isolates it and prevents dangerous current flowing out from a synchronous generator.

Induction generators also must shut down, as Levy noted, because they lack the grid's signal for alignment.

Now, under the cutting-edge microgrid mode, the main breaker on the MOBOCES campus will open to isolate the circuit, but the six inverter-based Tecogen units will keep running. At this point, though, campus loads must likely be selectively reduced to compensate for the loss of outside power. So, the six

The MOBOCES campus houses a regional information center serving dozens of schools.

A School Resource Center

"And that's really the thing," continues Panora, "that sold this [first] project," referring to his winning bid for a circuit of six inverter-equipped Premium Power Modules installed in 2007 at the Madison-Oneida Board of Cooperative Educational Services (MOBOCES) in Verona, NY. This five-building regional educational campus serves 10 school districts as a hive of student activities from 7 a.m. to 10 p.m. all year round. The MOBOCES campus houses a regional information center serving dozens of schools.

generators will be taken offline for at most 30 minutes (although still running) while the preplanned load-shedding drill occurs. Engines can then be powered back full-throttle. The interruption to educational services is negligible—regardless of how long the external outage may last. Of some technical interest here, too, notes Panora, is the fact that the machines will actually switch between two distinct modes of operation: first, as conventional grid-parallel power resources compliant under the UL 1547 certification; then, after the breaker opens, each interacts in this algorithmically determined microgrid mode mentioned above.

The latter element—the result of several years of research done primarily by Robert Lasseter, a professor emeritus at the University of Wisconsin—is the breakthrough which may well revolutionize DE. Tecogen currently licenses this technology from the university's IP office. On this, Lasseter worked closely with the Consortium for Electric Reliability Technology Solutions (CERTS). At a grid-based demonstration of the concept that took place in 2006 at Columbus, OH–based utility American Electric Power, Lasseter's algorithms proved the automated balancing concept flawlessly.

Under the CERTS electronics protocols, all six units can parallel each other without supervisory controls. "One unit doesn't even know the other unit is there," notes Panora. "They naturally fall into equilibrium, with reactive power voltage frequencies matched. Everything is synchronized. It's like magic."

New Interactivity

Appearances to the contrary, the MOBOCES campus is not really a cogen guinea-pig here either. Rather, this site was already a longstanding CHP success showcase, having used four earlier-generation 75-kW units in a second-floor utility room at the campus, "primarily for load-shedding," reports Gary Myers, supervisor of buildings and grounds for the MOBOCES campus during that period. "We had great luck with them," he adds, recovering heat for 13 years prior to decommissioning in 2006 to make way for an expansion.

All four units generally ran at full output for peak shaving day after day, Myers recalls. "We had tremendous success doing that," he says. "Our load profile was such that our electrical demand increased by midmorning and continued throughout the day into the late p.m. ... We purposely ran that output as high as we could throughout that period of the day," to reduce not only power consumption but demand.

Four units shaved 300 kW off the campus' monthly demand charge. "At $15 per kilowatt, that was significant in itself," he says.

But the real savings came, again, with heat utilization.

"To produce power for the sake of power alone is foolish," says Myers, "because National Grid can do this much cheaper." But the year-round heat benefit added up to real money. "At full output we were able to satisfy about 75% of the campus' total heating need ... in the dead of winter, in central New York. We're talking about 10-below and 30-above the next day."

Water—heated by the exhaust from four engines—circulated in underground piping to the campuses three buildings at that time, totaling about 160,000 square feet. Supplemental boilers supplied the small remaining balance.

In summer, he adds, "The heat that was scavenged was cycled through a 200-ton absorption chiller" to supply all cooling for a 40,000 square-foot alternative-education building.

Madison-Oneida Deputy District Superintendent Paul Seversky quantifies the cumulative savings during that period at "well over $1.75 million, in 1993 dollars." This works out to more than double that sum in present value compared with what the local utility (National Grid) would have charged, he estimates. "We received plenty of heat, domestic hot water, and air conditioning" over the years, he says.

Load following and automated plant management were accomplished with Allerton's building energy management system. A specially developed protocol integrated the engines' operation with environmental controls; in response to loads, rpm could be ramped up or down in 5-kW increments.

All in all, says Myers, the system proved remarkably capable of juggling many cycles and functions, ranging from the four Tecogens and their heat to lighting and HVAC ducts. Daily performance was automatically logged, and the data were applied to tweak parameters—thereby producing a constant improvement feedback. "It practically borders on artificial intelligence," notes Myers.

Although located in a second-floor room right above an educational space, the four engines ran "very quietly," Myers continues.

Overall, uptime reliability over the 13 years of the first-generation Tecogen units, he notes, "was amazing." At times, two of the units would run continuously for full months at a time without shutoff. "It was very impressive," he says. "The motors were the strongest component of the system. It was just a great experience."

An End to the Darkness

But eventually, educational services outgrew the campus, and so MOBOCES has recently added a 100,000-square-foot expansion, raising the number of buildings to five and making it a good time to start thinking about a plant upgrade.

Local engineer Rae Butler of Building Energy Solutions had long experience with CHP and with the previous Tecogen project. She was asked do a feasibility study, this time putting the priority squarely on backup capability, even more than on saving money.

In upstate New York, as in a great many locales, grid outages are not at all uncommon, Butler notes, and can be disruptive when they hit. Just in the past year, for instance, a few have occurred that lasted a matter of hours rather than minutes—even lasting, in one or two cases, for days. In previous years, pelting ice knocked out power for nearly a week; the same happened again after a Labor Day storm. The sudden inconvenience is especially acute because MOBOCES students must then be packed on buses and sent home.

The campus houses a regional information center serving dozens of schools. Though outfitted with a $150,000, supposedly 24-hour uninterruptible power supply (UPS), as Seversky notes, even this has performed far below rated expectations.

In short, power reliability on the MOBOCES campus—or rather, lack thereof—affects everyone, says Butler, and this issue was the prime mover in doing her new design.

Emergency standby generators are the typical remedy, of course, but, as Butler and others reason: "With all this onsite power sitting around, it just seems logical that someone should be able to make it work as a backup."

And there is still another big item on the wish list.

Because the MOBOCES campus is loaded with vocational training facilities—welding shops, auto repair bays, kitchens, and a nursing center—and it sits next to the New York Thruway, this site has been eyed for years as a potentially ideal emergency center and shelter—"If only," says Butler, "it had reliable backup power."

Thus in 2003 she began looking into potential replacement engines, thinking not about Tecogen units but of larger-output engines, when, by a convenient coincidence, Panora happened to inform her that his company was on the verge of introducing this first-of-its-kind CERTS-enabled backup autonomy and flexibility.

Almost instantly she realized this was the answer. Today, after some light remodeling of the second-floor engine room, six 100-kW Premium Power Modules now reside next to a new absorption chiller, where four earlier-generation units had supplied CHP since 1993.

Butler points out, too, that one of the very good reasons for owning six 100-kW engines, rather than one or two bigger ones, is the benefit of getting "plenty of redundancy, so that even if one or two units are down and grid power fails, the base and critical loads will still be carried."

In this array, power output feeds from each into a common panel tied to the bus on the main electrical service intake.

A relay prevents any export to the utility.

Peak summer demand runs about 920 kW, she says. So the six Tecogen units, yielding 600 kW, will handle two-thirds of it. In winter the peak hits about 650 kW, of which 95% will be supplied onsite, she estimates.

Thermally, the sizing at 600 kW again maximizes the all-important exhaust heat utilization. Dumping unneeded thermal energy of this kind, she observers, "means you're losing money." So, on nice days when no heating or cooling is needed, engines will actually be turned down to minimal output—assuming National Grid's peak rates aren't in effect.

Five campus buildings (totaling 300,000–350,000 square feet) are thus tied to a common exhaust loop. They'll get nearly all their heat from this one source, except on the coldest winter days when boilers will fire.

In the summertime, absorption chillers in two of the five structures will use much of the loop's heat for energizing as well.

As for automated controls, the new plant and system, commissioned in mid-2007, are upgraded with Modbus, enabling even tighter integration. Myers will enjoy easy remote monitoring and control from his notebook computer.

Significantly Lowering Costs

Besides the impressive technological breakthroughs noted earlier, major economizing is achieved by Tecogen's unusual production source: As the basis for his power plants, Panora buys standard engine blocks from a General Motors foundry and converts them to run on natural gas. His costs are thus an almost unheard of $100–$125 per kilowatt.

With the inverter, generator, heat recovery, emissions control, packaging, enclosure and margin for engineering, and warranty support, the selling price to customers comes out to about $1,000 per kilowatt, depending on options—a bargain for them, he says, and "a very good business model for us."

Factory assembly and skid-mounting in Massachusetts further shave installed costs.

At its price, and with the 100 kW–125 kW CHP output rating, a building-block approach to sizing works quite well, says Panora. A site can combine "two, three, five, six—however many you may need," rather than putting all the investment in one or two big engines. Customers gain additional flexibility to disperse the power to optimize heat utilization and match the loads. There's also enhanced reliability from the redun dancy, as Butler noted.

Economics and payback on this particular project are somewhat indeterminate now, says Butler, because the plant upgrade brought about a change in tariffs; new comparative peak rates with National Grid are a question mark. However, in order to simplify the savings equation, she derived an aggregate annual projected cost reduction figure based on per-hour run time, at $5.90 per unit.

Two or three engines will likely run all the time; the others, about 70%.

Adding all of these hours up and multiplying the sum by $5.90 yields a gross annual cost avoidance estimated at about $215,000. She considers this conservative. Subtract from this, though, maintenance (to be done by Tecogen for the first two years) at $1.50 per hour per engine for a net of $4.50 per hour in savings. Payback would thus arrive in eight or nine years.

However, in this particular case, making the numbers come out even better is a supportive incentive, worth about $650,000, from NYSERDA. About one-third of the total initial investment is thus being covered, notes NYSERDA's Levy.

Then, too, as he explains, there's also an unusual opportunity for the MOBOCES campus to parlay its power into an income opportunity.

Tecogen's engine comes with a kind of overdrive gear that an operator can punch in on demand. This will activate a 25% surge beyond the rated 100 kW (i.e., boosting it to 125 kW). Panora calls it his "sprint mode" and notes the engine can safely sustain this for use during at least some peak demand periods (which are typically six to eight hours per day in the summer months) or during outage periods for as long as a day or more.

By "sprinting" its engines, as Levy explains, the Madison-Oneida schools "are thus going to be able to ramp all the way to 750 kilowatts—and that extra 150 kilowatts can be sold to the New York ISO [the regional grid operators] as a 'spinning reserve.'"

Based on this, MOBOCES is expected to sign auxiliary power-supply contracts with the ISO. In return, the school facility will be paid, he says, "first, for enrolling in the program, and then, if they ever get pressed into Service, they'll get paid again for the power generation"—not unlike joining the Army reserves.

This energy-reserve element, Levy adds, "is actually a very important feature that we're going to be watching closely." Built-in booster capacity on an engine like this is a rarity. Potentially, it could dovetail nicely with certain energy markets which urgently need brief peak-power burst, such as, again, New York City.

Realizing the broader implications of this pilot site, both MOBOCES and NYSERDA are planning to share the system's performance data, some in real time, under a NYSERDA program. Heat efficiency numbers and an array of datalogging output will be Web-accessible at chp.nyserda.org, beginning around October 2007.

MOBOCES also anticipates arranging public tours of its new, cutting-edge CHP plant, to promote energy efficiency and innovation. The school district's Web site, too, will post the engines' "report cards." Notes Seversky: "Once that data gets out there, I think you'll see more and more schools and public-sector buildings looking at this [CHP] option. It's affordable, and the configuration is very feasible—well within the means of a public agency."

Butler suggests, too, that if the backup role actually proves itself during outages, markets will indeed take note. She comments: "I've [studied the feasibility of] a lot of cogen plants where they didn't have the emergency backup. And people would say, 'Well, you know, if we're not going to get emergency power out of it, it's not worth it for us.'"

Even if the money works out well, she says, reliability is what clients want and expect most. This MOBOCES site thus becomes, she adds, "a big test ... really, the first real, 'live' site" using Lasseter's and CERTS' technology.

Ever since the project's inception, it has continued to evolve in dramatic ways, as when the premium power module became available serendipitously and changed all the working assumptions, in interesting ways. "It ended up being a perfect fit for what we're doing here," she says, "and it's been great being a part of it." **DE**

La Mesa, CA-based writer **DAVID ENGLE** *specializes in construction-related topics.*