A STATIONARY BATTERY IN EVERY HOME?
PREDICTING THE FUTURE FOR RESIDENTIAL ENERGY STORAGE

Jim McDowall
Business Development Manager
Saft America Inc.
North Haven, CT 06473

ABSTRACT

"Transmission reliability, distributed resources and energy storage… will contribute to the development of the dynamic power grid of the future, characterized by distributed intelligence, distributed generation, and distributed storage." This is a quote from Imre Gyuk, Energy Storage Systems Program Manager at the US Department of Energy and a notable speaker at past Battcon conferences. It is interesting to think about what that dynamic grid might look like, and what the role of energy storage will be.

Almost certainly this grid will have microgrids as a prominent feature – relatively small parts of the distribution system, normally connected to the main grid but able to disconnect themselves and function autonomously. Equally probable will be the use of Combined Heat and Power (CHP) generation systems, in which electricity is produced and excess heat from the generation process is captured and used for other purposes, such as water heating. In fact, so-called micro-CHP systems are likely to be deployed in individual homes.

The case for microgrids and CHP systems is compelling. Not only will they improve energy security but they will also provide dramatically improved efficiency. The efficiency increases result from the 'dual-use' nature of their heat and power output and also from the fact that much of the approximately 9% energy losses in the transmission and distribution network are avoided.

It is generally accepted that microgrids will not be able to function without electrical energy storage systems. Various devices have been promoted for the storage function, including batteries, supercapacitors and flywheels. With some form of generation possibly being installed in or very near every home, the widespread use of residential energy storage becomes increasingly likely.

This paper discusses the interaction of micro-CHP generators and energy storage and how such systems are likely to be deployed. The role of battery storage, particularly lithium ion technology, in microgrids will be explored. Also included is some speculation on the possible impact of Plug-in Hybrid Electric Vehicles (PHEVs) as a distributed energy resource.

SHORT-TERM OUTLOOK FOR RESIDENTIAL STORAGE

Imagine the frustration of some California homeowners. It is a hot summer day and the sun is shining brightly on their rooftop photovoltaic (PV) arrays, purchased with the aid of generous rebates under the state's Million Solar Roofs plan. Their net meters are running backwards, despite the fact that their air conditioners are laboring against the heat. Then – click – everything goes dead as a rolling blackout hits the area. The solar panels become useless, because interconnection standards require that grid-connected local generation be disconnected when the grid goes down.

To allow such a PV system to continue operation during a blackout requires a considerable—and costly—leap forward in technological sophistication. A PV controller, battery and transfer switch must be added to make a standalone system. This is certainly feasible, as past Battcon papers[1, 2] have shown. However, as those papers describe it, the effort required for battery maintenance and vigilance against energy waste is probably beyond the motivation of the average homeowner.

Even those industrious individuals who succeed in making their homes self-sufficient in energy would probably want to maintain their link to the grid, in which case they would find that their local utility would still levy a connection charge even when no energy is flowing to or from the grid. This would likely make it impossible to recoup the cost of the added investment. With this in mind, the outlook for electrical energy storage at the residential level is rather bleak, at least until microgrids become viable—but more of that later.

TRENDS AND DRIVERS IN GRID DEVELOPMENT

Looking at some of the trends at work in today's electricity grid, and the drivers for future development, it is apparent that the future grid will be quite different in a number of respects. Some of those trends and drivers are described below.

Energy Security

The Northeast blackout of 2003 and Hurricane Katrina in 2005, among many other events, have shown that today's grid is vulnerable to system instability and natural disasters. There is also a desire to make the system more resistant to terrorist attack. In addition to these supply-side issues there is a need for better power quality and reliability on the demand side, particularly with the increase in digital loads that are intolerant of the smallest deviations in the power supply. Many experts believe that these needs for improved energy security can be met with distributed energy resources such as distributed generation and distributed storage.

Transmission Capacity – NIMBY, NOTE and BANANA

The US transmission system was originally built by utilities to move power from their generating stations to their customers via the shortest route. More recently this system has been pressed into service to move power over much longer distances to customers in competitive markets, and this is a role for which the grid was never intended. To make matters worse, a report prepared for the Edison Electric Institute and US Department of Energy[3] states that historic transmission capacity growth has consistently lagged behind growth in peak demand, and will continue to do so through at least 2012. The result is a severely congested transmission system that is frequently incapable of delivering the necessary amounts of power where it is needed, leading to problems such as the rolling blackouts that periodically affect California.

This situation is unlikely to change soon. Residents in the vicinity of projects for new or upgraded transmission capacity typically fight protracted legal battles against those lines. To the well-known NIMBY (Not In My Back Yard) effect has been added NOTE (Not Over There Either) and BANANA (Build Absolutely Nothing Anywhere Near Anyone).

With this in mind there is little point in building a new central generating station (with its own burden of NIMBYism) if its power cannot be moved to the intended customers. While new large generating plants will certainly continue to be built, ongoing transmission congestion clearly favors the development of distributed generation much closer to the end user.

Energy Efficiency and Carbon Emissions

The Energy Information Administration[4] reports that the efficiency of central generating plant varies quite widely but an average of 33% of the energy content in the fuel is actually converted into electricity and fed into the grid. A surprisingly high amount of that electricity—9 percent—is lost in the transmission and distribution grid. Fossil fuels represent 70 percent of the energy consumed to generate electricity in the USA and this consumption obviously results in emissions of carbon dioxide and contributes to global warming.

Increased generation from renewable sources such as wind and solar energy provides a way to reduce carbon emissions, but there are limits to what can be achieved. It is generally accepted that generation from highly variable sources such as wind can only increase to about 20% of total generation before destabilizing the electricity network. Furthermore, the best sites for wind generation are often far removed from population centers, so wind energy competes for the same strained transmission resources as central generation.

Another way to reduce carbon emissions is to improve the efficiency of fossil-fuel use. If excess heat from generation can be captured and used, rather than wasted, the overall energy efficiency can be increased to 70 percent or more. The problem is that thermal energy cannot be efficiently transported, so there is little hope for improving the efficiency of central generating plant. Local generation, however, lends itself very well to so-called Combined Heat and Power (CHP) applications, in which the thermal energy is used for industrial processes or district heating and cooling for residences.

In addition to being two to three times as efficient as central power plants, CHP has the additional benefit that, being closer to the end user, transmission congestion and losses are avoided. The number of CHP installations is increasing strongly, and US CHP capacity reached 82 GW in 2005[5]. The bulk of this capacity is of course in industrial plants where process heat is required, but there are more and more developers applying CHP systems to apartment complexes, for example.

Denmark is the unquestioned world leader in CHP; as long ago as 1996, CHP plants supplied 48 percent of domestic electricity needs and 38 percent of the domestic heat demand[6]. As much as 50 percent of residential energy consumption is for heating and cooling, so it seems logical to extend the concept of CHP to individual dwellings – so-called micro-CHP. Indeed, there are many companies developing such systems, using technologies such as PEM and solid-oxide fuel cells, pico-turbines, Rankine steam generators, Stirling engines and internal combustion (IC) engines. The Japanese have become early adopters of micro-CHP systems, with more than 30,000 IC units installed[7].

Restructuring and Utility Resistance to Change

Whether the above trends towards, and drivers for, distributed generation succeed in the short term depend largely on utilities and their business models. Traditional vertically-integrated utilities have no incentive to promote or allow customer-owned generation since it would complicate their activities while reducing their sales. This could change if those utilities were constrained in transmission or distribution capacity and sufficiently forward-looking to promote utility-owned customer-based CHP systems.

The picture is somewhat bleaker for the “deregulated” utilities (“restructured” is a more accurate term). Restructured distribution utilities, or “wires” companies, that deliver power to the end user are forbidden to own generation. Moreover, their income depends on the fair returns they are allowed to make on “prudent investments” in expanded capacity. If they were to allow customer-owned generation they would have little need to invest in expanded capacity and therefore would have no way to increase their profits.

In order to avoid a patchwork of CHP implementation and regulatory barriers it is important for enabling policies to be established at the national level, at least in the form of models that the states can be encouraged to adopt. Such policies should include a carbon cap and trade system, should promote net metering and time-of-use tariffs, and should encourage or at least allow microgrids to be established.

MICROGRIDS

The microgrid concept is one in which a group of loads—for example, an industrial facility or residential neighborhood—are connected to the grid through a single connection point (known as the point of common coupling). A microgrid would normally be connected to the main grid but would be able to function autonomously in the event of a disturbance on the grid. One of the principal groups working on microgrids is the Consortium for Electric Reliability Technology Solutions (CERTS) and their concept is illustrated in Figure 1.

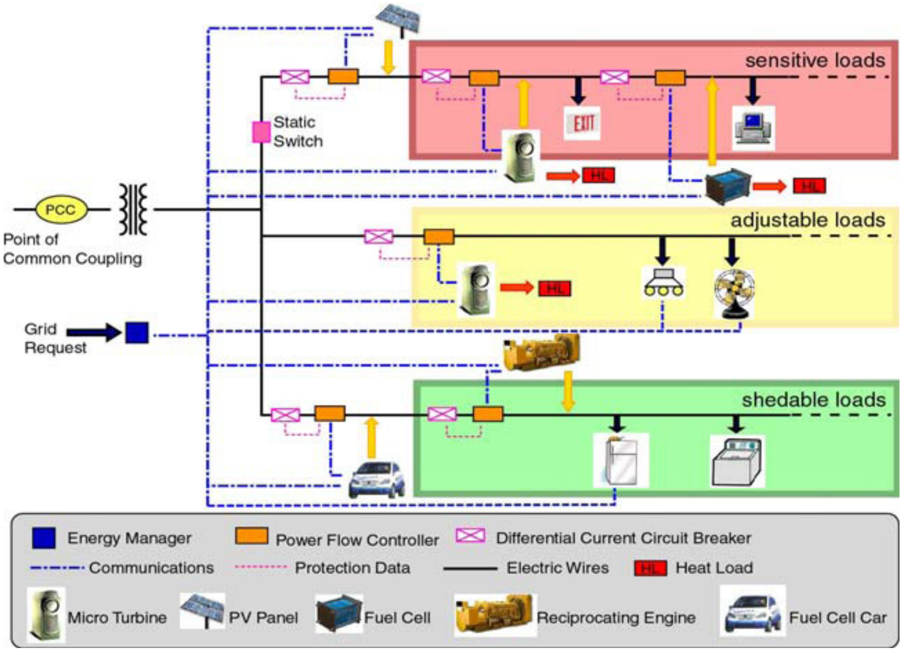

Figure 1. CERTS microgrid concept (from http://certs.lbl.gov/certs-der-micro.html)

The CERTS group prepared a report on this concept for the California Energy Commission[6]. One of the interesting quotes from that report is, “Microgrids will not be competing with the centralized power system of today but with the erratic growth of that system in an environment hostile to its expansion.” This is an eloquent summary of the transmission capacity issues discussed previously.

The CERTS report says that microgrids must behave as “good citizens” by complying with existing grid rules and behaving in a way that would be acceptable in an existing customer (bearing in mind that existing customers may have CHP units on-site). Moreover, microgrids could act as “model citizens” by providing ancillary services such as local voltage support and by acting as interruptible load that the utility can disconnect when the system comes under stress.

To operate autonomously a microgrid must have embedded generation. On the scale of tens to hundreds of kilowatts generally envisaged for microgrids, this generation would be based on power electronics rather than synchronized spinning machinery. This “inertia-less” generation is often coupled with slow response times and can give rise to problems in the response to non-coincident loads.

Non-Coincident Loads

An excellent discussion of the topic of load coincidence is provided in the book “*Distributed Power Generation: Planning and Evaluation*”[8]. For a large group of residences a central generator would see the coincident load curve represented by the lower diagram of Figure 2. For the same time period the loads of a single household are shown in the upper diagram, characterized by rapid variations and load spikes.

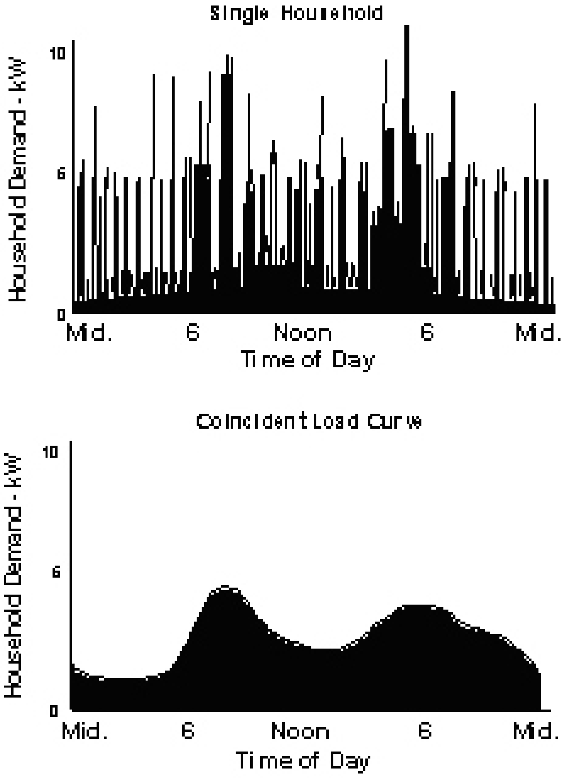

Figure 2. Coincident and non-coincident load diagrams

A large central generator supplying many homes of this type needs only about 4 kW of capacity per household, while one supplying a single household would need close to 12 kW. The slow response time and lack of inertia from the smaller generator would cause significant problems and at a minimum would lead to very inefficient operation. The answer, of course, is to use fast-acting energy storage in conjunction with a generator sized for the average load. An analysis of this particular load diagram shows that a battery capable of supplying 10 kW for 20 minutes can stabilize the output of such a generator.

Location and Type of Storage

CHP systems are expected to be a central feature of microgrids, as indicated in Figure 1. One of the control issues that must be addressed is the dispatching of those systems. Existing CHP systems are normally dispatched when thermal energy is needed, with the co-generated electricity supplying local loads or being fed into the grid. When a microgrid is operating in isolation from the grid, however, any excess energy must be either stored or wasted.

If a microgrid-based CHP unit is dispatched when heat is needed then excess electricity would be stored in a battery system. On the other hand, if the CHP unit is dispatched when electricity is needed then excess heat would be stored, most likely as hot water. A plausible scenario is that a residential micro-CHP system would be supported by thermal storage within that home, while electricity storage would be deployed at the neighborhood level to achieve at least some benefits from load coincidence.

ELECTRICITY STORAGE TECHNOLOGIES

The storage technology of choice for the majority of today's off-grid PV homes is unquestionably lead-acid batteries, typically golf-cart or deep-cycle marine types[1, 2]. As mentioned previously, however, such batteries require a certain amount of care and attention that the average homeowner would not be willing to provide. Furthermore, while they are well-suited to supporting residential loads for days at a time, they would not be practical for leveling out momentary peaks in conjunction with micro-CHP systems. Although they have a low initial cost, these batteries could not provide a low life-cycle cost in unattended high-power, short-duration cycling operation.

A number of technologies have been proposed for this type of application. For pure power cycling with seconds of discharge it is difficult to beat the capabilities of supercapacitors or flywheels. However, these technologies typically lack the energy content for minutes of discharge and would quickly become uneconomical for the 20 minutes or so needed to stabilize household loads. Battery energy storage is the most promising solution for this application, with technologies such as nickel-metal hydride (Ni-MH) and lithium ion being possible candidates. Although lithium ion batteries are not yet widespread beyond the portable battery market, their energy efficiency and excellent cycling capabilities will make them an excellent choice for electricity storage systems of this scale.

The Influence of Hybrids

Hybrid Electric Vehicles (HEVs) are becoming increasingly popular on US roads. Considering their electrical configuration they are not unlike the residential systems we have discussed, with an engine-generator providing baseload energy and a battery providing peak power for acceleration. Without exception, today's production hybrids use Ni-MH batteries and have achieved quite respectable fuel consumption (although the published gas mileage figures will take a hit under the new EPA calculation rules). While Ni-MH technology is likely to see continued use in certain niche applications, particularly for large vehicles such as trams, all eyes are on lithium ion for the future of hybrid automobiles. Indeed, Toyota has already announced that the next Prius design will feature lithium ion batteries and the aim is to achieve 94 miles per gallon (40 km per liter).

Such a leap forward in fuel mileage is unlikely to be achieved without some help, and that help is likely to come from the electricity grid. Much of the buzz in electric-vehicle circles today is being generated by so-called Plug-in Hybrid Electric Vehicles (PHEVs). Such vehicles will be capable of operating for perhaps 20-30 miles in battery-only mode, following which they would revert to the standard engine-battery mode of today's hybrids.

An approximate rule-of-thumb for electric mileage is that a Prius-sized vehicle can travel approximately 3 miles on a kilowatt-hour of battery energy. Very broad approximations of \$3.00 per gallon of gasoline and \$0.10 per kWh of electricity work out to around 100 miles per gallon of "electric-equivalent" gasoline. Perhaps it will be judged that Toyota is cheating a little with its numbers, but there is no doubt that PHEVs represent a leap forward in automotive capability.

PHEVs and the Grid

Even with a standard 120-volt grid connection for charging, PHEVs represent an opportunity for grid optimization. The charger can be treated as an adjustable load that, with existing control technologies, could be "dispatched" by the grid operator. If PHEVs become ubiquitous their charging could help to optimize baseload operation of the grid at night, eliminating the need to cycle generating stations up and down in response to system loads.

Going one step further brings us to V2G (Vehicle-to-Grid) technology. V2G, already well established in concept[9], would provide a grid connection capable of bi-directional power flows of about 10 kW. Such a connection could assist with momentary load spikes at night; more interestingly, it could be used during the daytime for reserve capacity and the vehicle operator could be paid for this service. (Primary system reserves are normally provided by unused capacity on spinning generators; utilities pay for such reserves even though they are not routinely called upon. Using PHEV batteries for primary reserves would free up this spare capacity and improve generation efficiency, while causing little additional aging effect on the batteries.)

V2G-type services will not become significant for the main grid until a certain critical mass of these vehicles is reached. However, even a single PHEV connected into a microgrid can contribute to smooth functioning, particularly when the microgrid is isolated from the main grid.

SUMMARY

The subject of this paper, residential electricity storage, is certainly not commercially viable today. Such storage is, however, an essential component of the microgrids of the future. Microgrids offer the promise of vastly improved generation efficiency through combined heat and power systems, with corresponding reductions in carbon emissions, and significantly improved energy security.

Lithium ion battery technology will feature prominently in microgrids and also in plug-in hybrid vehicles, and it will be interesting to observe whether there will be any convergence of these functions.

REFERENCES

1. Hammond, R L and S Everingham, "*Fundamentals of PV systems: Tutorial*," Proceedings of Battcon 2002.
2. Hammond, R L and S Everingham, "*Stationary batteries in cycling photovoltaic applications*," Proceedings of Battcon 2003.
3. Hirst, E, "US *Transmission Capacity: Present Status and Future Prospects*," prepared for Edison Electric Institute and Office of Electric Transmission and Distribution, US Department of Energy, August 2004.
4. "*Annual Energy Review 2005*," US Department of Energy, Energy Information Administration, Diagram 5, Energy Flow 2005.
5. "*World Survey of Decentralized Energy 2006*," World Alliance for Decentralized Energy, May 2006, www.localpower.org.
6. "*Integration of Distributed Energy Resources – The CERTS MicroGrid Concept*," prepared by the Consortium for Electric Reliability Technology Solutions for the California Energy Commission, April 2002 (http://certs.lbl.gov).
7. Clayton, M, "*It heats. It powers. Is it the future of home energy?*" Christian Science Monitor, Nov. 14, 2006
8. Willis, H L, and W G Scott, "*Distributed Power Generation: Planning and Evaluation*," pps.397-407, Marcel Dekker, Inc., New York, 2000.
9. University of Delaware, www.udel.edu/V2G/