Power When and Where You Need It Clean and Simple

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Microturbines are an enabling technology for the full potential of DG.

In his book, *Building Wealth: The New Rules for Individuals, Companies, and Nations in a Knowledge-Based Economy*, noted MIT economist Lester Thurow identifies engineering-driven product development of the German chemical industry and the mass introduction of electricity as the two most important elements in the second industrial revolution. This revolution gave birth to the fantastic economic development of the twentieth century.

For the last 100 years, the electric industry has delivered power to virtually everybody in the industrialized world and most parts of the developing world. Overall it has been such a success story that at least in the industrialized world, we had begun to take reliable and relatively inexpensive power for granted, almost as a right.

In most countries, utilities were given a geographic monopoly in exchange for an obligation to serve. The monopoly allowed the utility to do very long term planning, including undertaking and financing large-scale power generation as well as transmission projects.

Conservation and Environmental Concerns

The 1973 and 1977 energy (oil) crises triggered a number of initiatives to conserve energy, e.g., more energy-efficient homes, energy-efficient industrial processes, energy-efficient appliances and so on. All factors combined to reduce net load growth in most parts of the industrialized world to 1-2 percent per year.

About the same time, environmental concerns started to become part of the global consciousness. It started with concerns over sour rain. During the 1980s and 1990s, concern expanded to include nuclear safety and long-term nuclear waste disposal, large-scale hydro and global warming. Environmental concerns are now an integral part of the energy agenda. It is probably correct to say that electric power is presently generated in a more environmentally friendly manner than ever before. It is also fair to say that much more needs to be done to realize the stated visions of "sustainable growth" and "zero emissions."

In an effort to stimulate more energy-efficient power generation, the PURPA Act of 1978 introduced a new set of players on the electricity market, the Independent Power Producers (IPP), along with large-scale acceptance of a new technology, natural gas-fired combined cycle gas turbines (CCGT). The IPPs could build and operate CCGT power plants and sell power at attractive rates. Utilities were required to purchase this power at prices equal to their avoided cost of production. This was thought to be beneficial to both parties, allowing the utilities to avoid construction of new generating assets while providing a strong incentive to the IPPs to put their capital at risk. In retrospect, this did not always turn out to be as beneficial for the utility as first expected; in the deregulation process, some of these contracts have become part of the utilities' stranded investments.

By and large, the electric infrastructure remained the same, i.e., large centralized power plants and a transmission and distribution system bringing power to the consumption, the "load." An increasingly sophisticated electric grid to transmit and distribute power was built. On average, the electric grid delivers 99.9 percent reliable power and in urban areas, 99.99 percent. This is commonly referred to as three and four nines, equivalent to 8 hours and 45 minutes, respectively, of accumulated outages per year.

Investments in the electric grid are significant, estimated to cost $400-$500 per kW. That number may be misleadingly low. To replace or expand this aging infrastructure today, actual costs are realistically closer to $800 per kW.

Fundamentally, the supply side of electric power was in good shape, but during the 1980s voices claiming electricity to be too expensive began to be heard, not least from large industrial consumers like the big three automotive companies.

A Deregulated Electric Industry

In light of this situation and the successful deregulation of many other industries such as the gas industry and the telecom industry, it was considered that a deregulated electric industry would be operationally more efficient and likely to reduce costs. The electric deregulation process started around world in the 1990s, beginning with privatization of the state-owned power industry in the UK. Once privatized, it was not a giant step to deregulate the industry. As a state-owned industry, it had not required many regulations!

In sharp contrast, the United States, with 50 state governments and 200 heavily regulated Investor Owned Utilities, began the deregulation process in 1996 initiated by the Federal Energy Regulatory Commission (FERC) through orders 888 and 889 which were far more complex. Expected to take 10 years to implement, it may in reality require an additional five to 10 years to complete. Uncertainty about rules and imperfections in the regulatory framework did little to stimulate investments in power generation and even less interest in the electric grid. If everybody should have access to the grid at the same cost as the one who owns it, why invest?

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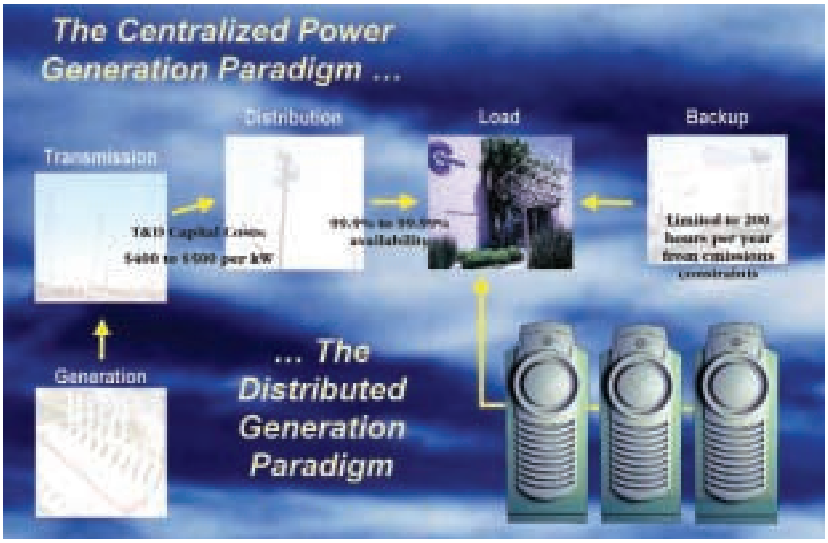
The Demand for Premium Power

Concurrently, a potentially more dramatic but much more silent change started to have a transformational effect in the late 1990s. The emergence of the digital economy foretold microprocessors being used almost "everywhere," identified first by Peter Huber and Mark Mills. With rapid and simultaneous growth of the Internet and the telecom infrastructure, demand for power started to grow exponentially. More important, demand for higher levels of reliability began to emerge. Instead of "three and four nines," demand for "five to seven nines," or premium power, became more frequent, requested not only by data centers but also by a broad swath of businesses requiring reliable and quality power. Even the "shortest" of interruptions will cause major problems and costs.

Since most interruptions occur in the electric distribution systems, the first approach for uninterruptible power has traditionally been in the form of on-site back-up power utilizing lead acid batteries and, as a last line of defense, diesel generators. However, batteries have serious limitations in the amount of storable energy, maintenance demands and still limited operating life. Diesel gensets are generally reserved for emergency use, and their downside is



DG represents a paradigm shift in the approach to power generation.

emissions and maintenance. In most parts of the U.S., diesel gensets, for air quality reasons, are not allowed to operate more than 200 hours.

Distributed Generation

Distributed generation (DG) represents a paradigm shift in the approach to power generation. By generating power at or very close to the load, it eliminates or at least reduces much of the requirement of the electric grid infrastructure and related costs.

The tenets of DG are simple:

- DG is another way to distribute power, not just another way to generate power!
- DG achieves economy of scale by virtue of quantity, rather than achieving economy of scale by size. A centralized power plant costs about $500 per kW for a CCGT, while an automotive engine costs less than $50 per kW thanks to the economies of scale realized by mass production. Reciprocating engines used for power generation have benefited from their automotive roots and are comparable in costs with a CCGT. The challenge for any new DG technology is to find a path to the mass volume quantities.

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- DG can be deployed very quickly. Generally it is a matter of weeks or months rather than a matter of years. In this respect, this faster speed of deployment equates to more flexibility and less risk.

More often than not, initial cost is a key driver in determining whether certain technology gets deployed or not. Yet in evaluating alternatives, many more aspects beyond initial cost should be considered. Operating costs, including fuel and maintenance expense, are distributed over the life of the equipment and, in most cases, constitute the most important costs. Also, environmental and reliability aspects must be brought into the equation.

Low initial costs are dependent on mass volume through efficient production processes. However, it is not easy to get to the mass volumes and the low costs. For example, photovoltaics were introduced about 30 years ago at a cost of roughly $30,000 per kW, and despite constantly growing production volumes and reduced costs, the cost is still not below $4,000 per kW.

Fuel cells face possibly an even bigger challenge. Today, the lowest cost for a commercially available fuel cell is $4,300 per kW. In the case of hydrogen-based fuel cells, the need to establish a hydrogen infrastructure, while technically possible, would create yet another dimension of cost and challenge.

Comparatively, microturbines hold a lot of promise. With first cost of roughly $1,000 per kW, in a relatively short time microturbine costs have started to fall towards $800 per kW and less. Still, costs have to come further down to gain additional economies of scale and widespread adoption.

It can be done.

Lowering Costs Through Additional Applications

Clayton Christensen described in his book, *The Innovator's Dilemma*, how disruptive technologies find their first use in applications where the new technology adds value by new features. Over time, more applications mean more volume, which ultimately leads to lower costs. Eventually the new technology becomes more cost efficient and can actually surpass traditional technology in its mainstream applications.

Applying this model to Capstone, we have identified five primary applications where our microturbine systems offer great value. These applications are hybrid electric vehicles (HEV), resource recovery, micro-cogeneration, power quality and reliability, and peak shaving.

For HEV applications, the microturbine serves as an on-board generating device working in concert with a primary source battery array to enhance the performance of hybrid electric transit vehicles and other heavy-duty vehicles. Partnering clean power generation with electricity storage dramatically lowers NOx and other emissions, cuts O&M costs while maximizing in-service availability, and enables a combination of vehicle size, payload and operating range capabilities previously unattainable with electric-only vehicles.

In resource recovery applications, the microturbine enables conversion of oilfield and biomass waste gases into electricity, using fuel that is otherwise wasted and essentially "free." It can be flared or vented gas at oil and gas production sites. It can be methane gas from landfills, wastewater treatment plants and agricultural operations.

The Capstone microturbine can operate on gas with a high amount of sour gas (up to 7 percent H_2S) and/or gas with a low or variable Btu content. It can operate without the need for costly intermediary equipment, with near-zero maintenance requirements and with ultra-low NOx emissions. This makes it possible to deploy the microturbine directly at the exploration site, use the gas at wellhead and generate power for the requirements of the site. The need for building distribution lines is eliminated. Alternatively, the need for trucking fuel to a diesel generator is eliminated, provided it could be permitted in accordance with air quality regulations in the first place.

Cogeneration seeks to use both electric energy produced in the generation process and the exhaust heat for heating and or cooling. The total energy efficiency then exceeds 70 percent and can in certain applications be as high as 90 percent. Large-scale cogeneration, e.g. district heating, has been deployed to a high degree in Europe and Japan. The challenge has been to find cost-efficient solutions to capture small-scale cogeneration opportunities.

Microturbines open up the opportunity to capture small, less than 100 kW, on-site power and heating requirements. Soon it will also be possible to offer solutions for on-site power and cooling using dedicated absorption chillers in combination with the microturbines.

From a global perspective, the ability to use a local fuel of choice – for example, natural gas, methane "waste" gases, kerosene, diesel or propane – means countries can use available fuel source infrastructures more efficiently.

Power quality and reliability can be demonstrably improved by on-site generation. Studies show that power outages in financial services, continuous-process manufacturing and food processing facilities are extremely costly. For digital economy companies, a power dip of less than one second can cost millions in lost production and related costs. The microturbine solution gives end-users a suite of solutions, including uninterruptible power systems (UPS) powered by microturbines, and a small- or no-battery solution instead of a large battery and a diesel

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W.J. Findon & Son greenhouse located in Stratford-upon-Avon, UK, takes advantage of the very clean exhaust and CO_2.

generator. In larger systems utilizing multiple microturbines, n + x redundant designs further increase system reliability.

Lastly, in a more open and more sophisticated electric power market, peak shaving with microturbines can be a very attractive proposition. Microturbine-generated on-site power can protect end-users against price spikes and may eventually offer opportunities to sell power back into the local power pool at a profit. Another example of new opportunities: combining interruptible rates for inexpensive grid power with microturbines for powering prioritized loads during the interruptions can be a minimum-cost solution.

This is the route Capstone has chosen to achieve larger volumes, lower cost and wider adoption of microturbines as an enabler for the full potential of distributed generation. We are well underway.

As time goes on, progress also continues to be made in other emerging DG technologies like photovoltaics, which can now be used as building elements for roof and exterior walls. This offers the possibility of a longer depreciation of the capital cost and thus a reduced barrier against the relatively high first cost. A steady growth in demand will also help reduce the costs. Fuel cells may have a longer way to go before full-scale commercialization, but there is no doubt about steady progress here as well.

Technology will go far toward realizing clean, efficient and inexpensive DG, but for large-scale introduction of DG, we will also need a more perfect electric market.

Economic growth depends on reliable access to inexpensive electricity. DG is an increasingly important supplement to the traditional ways of generating, transmitting and distributing power. Widespread acceptance of DG requires no compromises of environmental aspects. Emissions have to be as low or lower than the centralized power plants. In fact, one of the major advantages of microturbines and fuel cells is the very low emissions footprint. Photovoltaics, with no emissions, are as "green" as it gets.

A More Perfect Electric Market

Technology will go far toward realizing clean, efficient and inexpensive DG, but for large-scale introduction of DG, we will also need a more perfect electric market.

Unless customers have a choice, there is no market. A price mechanism acknowledging differentiations in demand as well as in supply, by definition, is a prerequisite for any market. Unfortunately in the electric market, the end-user has been, and to a large extent still is, "protected" and isolated from the true market prices. A customer demanding highly reliable power, e.g. seven nines, must be prepared to pay more than a

Microturbines offer great value in (clockwise from top left) HEV, biomass waste recovery, coalbed methane recovery, and micro-cogeneration applications.

customer accepting interrupted power. Customers demanding "green power" have demonstrated that they are prepared to pay a premium. In that case, price elasticity occurs: the lower the premium price, the more customers and the higher the premium price, the fewer the customers.

Customers shaving expensive power peaks, either by turning off load or by starting their own generators, must see their electric bills come down in order to have an incentive to do so. The more elaborate we can make the price mechanism, the better the market will function.

In terms of the electric infrastructure, the ones using it should pay for it. The more remote the power generation source, the more it should cost to use the grid. In the UK, certain DG users do not have to pay for the transmission part of the infrastructure. In the United States, FERC Order 2000 introduces the concept of node costs. It makes sound economic sense.

On the contrary, it does not make sense that the electric utility, the "wireco," is not allowed to use DG. Using DG up to about 2 MW would help them optimize power distribution systems.

Open and hidden barriers (against DG) in terms of interconnection and stand-by charges must be removed. Interconnection must and can be done in a safe manner. Interconnection requirements must be standardized at least on the state level. One of the attractive aspects of DG is that it does not require a centralized control. It can be done in an automated way, so in the future, real-time price data may trigger the DG device to be activated or turned off. DG will rather help maintain grid stability. Instead of asking "rate payers" to turn off the load, when what they really need is more power, it makes more sense to give customers a choice as to when to turn on DG and have the power!

Microturbines are easily deployed in remote oilfields from Alberta to Nigeria.

In fact, DG should be seen as an excellent supplement to the centralized power plants and the electric grid, and not a substitute for it.

Power when and where you need it.
Clean and simple.
Now. ■

Dr. Åke Almgren is president and CEO of Capstone Turbine Corporation, a newly public American company focused exclusively on the commercialization of microturbine power generation technology. Founded in 1988, Capstone is the world's premier developer, designer and assembler of microturbine systems for on-site power production and for use in hybrid electric vehicles. After accumulating more than 160,000 test hours, Capstone introduced its third-generation microturbine, the Model 330, in December 1998. The company's Capstone 60 kW family of products was introduced in 2000. Prior to Capstone, Dr. Almgren spent an accomplished 26-year career at ASEA Brown Boveri (ABB) Limited, a worldwide power solutions company. While there he served as president of various divisions, managed the operation of 36 plants in 28 countries, and led turnkey projects in the U.S., Canada, Brazil and India. Before relocating to the U.S. in 1991, Dr. Almgren was president of Autoliv, based in Stockholm, Sweden. Under his leadership, the automotive restraint company established a North American presence and expanded into the development of airbags.

Dr. Almgren holds a Ph.D. in engineering from Sweden's Linköpings Tekniska Hogskola and a master's degree in mechanical engineering from Sweden's Royal Institute of Technology.

He is an early advocate of distributed generation and believes microturbines and other emerging technologies will increasingly supplement more conventional technologies for generating and distributing electric power.