Spreading the net

Distributed power generation and creating a 'virtual utility' to manage it

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The way electricity is generated and distributed is about to undergo a change with the potential to transform its societal and environmental impact. Developing countries, in particular, but also numerous niche markets, are set to benefit from the 'virtual utility', in which clusters of dispersed power generators – often making use of alternative energy sources – are connected together in an intelligent and optimized network controlled by Web-enabled systems. As they are small, distributed generation systems can be built up incrementally, avoiding high first-time costs and allowing fast payback.

In the future, large centralized power plants may be replaced by distributed generators utilizing a variety of power sources, such as wind, sun, gas or biomass.

An analogy: In the 1960s, computing was done on large, central powerful computers connected to remote terminals. These 'mainframes' were eventually superseded by the ubiquitous desktop personal computer, which is itself now being replaced by networked computers and Web-based information systems.

Electrical power is produced today within a structure not unlike that used for computing back in the 'sixties; large, centralized stations generate the electricity, which is sent out over high-voltage transmission lines. The voltage is then stepped down in several stages and delivered to the customer. Similar to the way in which computing power evolved, the electrical power distribution structure is now being transformed into a network of distributed power generation facilities. Electronically controlled, this 'smart' electricity network is able to handle the increasingly complex issues of scale, transactional complexity and power quality. Thus, distributed power generation has the potential to completely reshape the production and delivery of electricity.

A completely new power utility concept

Distributed power generation will provide an alternative to the way utilities and consumers supply electricity, while also enabling them to minimize investment, improve reliability and lower costs.

Electric power costs less if bought from a system closer to the generating plant. Prices shown are per kWh, paid by a user of electricity at the site shown.

It could also change significantly how power generation and distribution systems are planned in the future. Distributed power generation is ultimately about *putting the energy generation and storage as close to the point of consumption* as possible, and doing so with higher conversion efficiency and minimal environmental impact. With the help of modern communications and control technology, such dispersed systems can be operated as individual power plants. This offers numerous advantages to both the end-user of electricity and to the grid operator.

Distributed generation – 'three sizes fit all'

There are three main types of unit in ABB's distributed generation concept:

- *Dispersed generators*, which are 'customer sized', usually in the service transformer size range (5 kW to 500 kW), and are connected at low voltage to the network.
- *Larger distributed generators*, which are roughly the size of primary distribution equipment, such as feeders or substation transformers (2 MW up to 10 MW). These are connected at MV levels to the distribution network.
- *Thermal generator*, for applications in which heat is the primary energy requirement.

In locations where there is no energy infrastructure, any source of power generation is, of course, of significant value to end-users, to the regional government, and to the prospective energy service company. Consequently, distributed generation is regarded as a solution for providing power in developing countries. However, from the traditional utility perspective, distributed generation is also attractive because it

Table 1: Why distributed is better than conventional for the supplier

- Generator can be sited close to the end-user for lower T&D costs and electrical losses.
- Sites for small generators are easier to find.
- Distributed generators are more quickly planned and installed.
- Energy can be ‘stored’ as fuel (eg, gas) and easily ’released’ at peak times.
- The network can ‘close ranks’ if one generator is taken off-line, resulting in higher reliability.
- Newer technologies are environmentally clean and not noisy.
- Newer distributed generators can run on multiple types of fuels, even biogas, thus increasing flexibility and reducing fuel transportation costs.

Table 2: Why distributed is better than conventional for the end-user

- Power is readily available and offers better quality and reliability.
- Depending on the fuel used, electricity prices are often lower.
- Since the generators can be operated on command, peak shaving is possible, which reduces demand charges.
- Cogeneration of heat and electricity improves the overall energy efficiency of the installation.

offers the option of tailoring the energy solution to the location (*Table 1*). From the end-user perspective, distributed generation is attractive for several other reasons (*Table 2*).

The technology behind the concept

Distributed power generation technologies include new reciprocating engines, microturbines, wind turbines, solar modules and fuel cells. These small (5 to 500 kW) generators are now at the early commercial or field prototype stage. Although originally developed for defense and non-polluting transportation applications, the stationary power market appears to be the first large-scale commercial opportunity for these devices.

Within ABB, there are several business units designing and marketing wind power and cogeneration plants. Novel heat- and electricity-producing microturbines are also being developed by ABB to meet environmental and consumer demands for cleaner, lower-cost electricity and heat. Primary applications for these units are apartment buildings, spas, greenhouses and small industrial facilities. Fuel cell development activities within ABB are aiming at even smaller, more efficient units for telecommunications or residential use.

The value of these technologies can be greatly increased when they are connected together in an intelligent fashion.

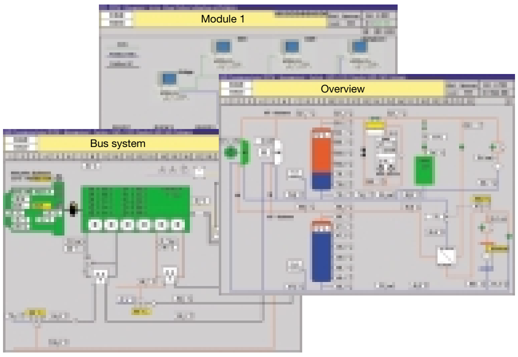
Linking the technology together in a virtual utility

ABB is developing a ‘virtual utility’ to connect multiple, broadly dispersed distributed generation clusters into an intelligent optimized system. A cluster could be several distributed generators located at a specific site. Such generation clusters can either be connected to the main grid or operate as stand-alone (islanded) systems. The virtual utilities’ aggregated load can be considered as a single power plant.

The virtual utility offers a value that is greater than the sum of the individual distributed generation units. It is ‘technology-neutral’ with regard to the generation or storage components, and is being designed to provide the optimal solution for the application regardless of any specific technology. This technology-neutral strategy gives ABB the opportunity to make use of advanced and developing generators and technologies both within and outside of ABB.

The virtual utility is fully automated

It is not enough to develop distributed generation that only produces electric power or thermal energy. A fully automated control system that requires

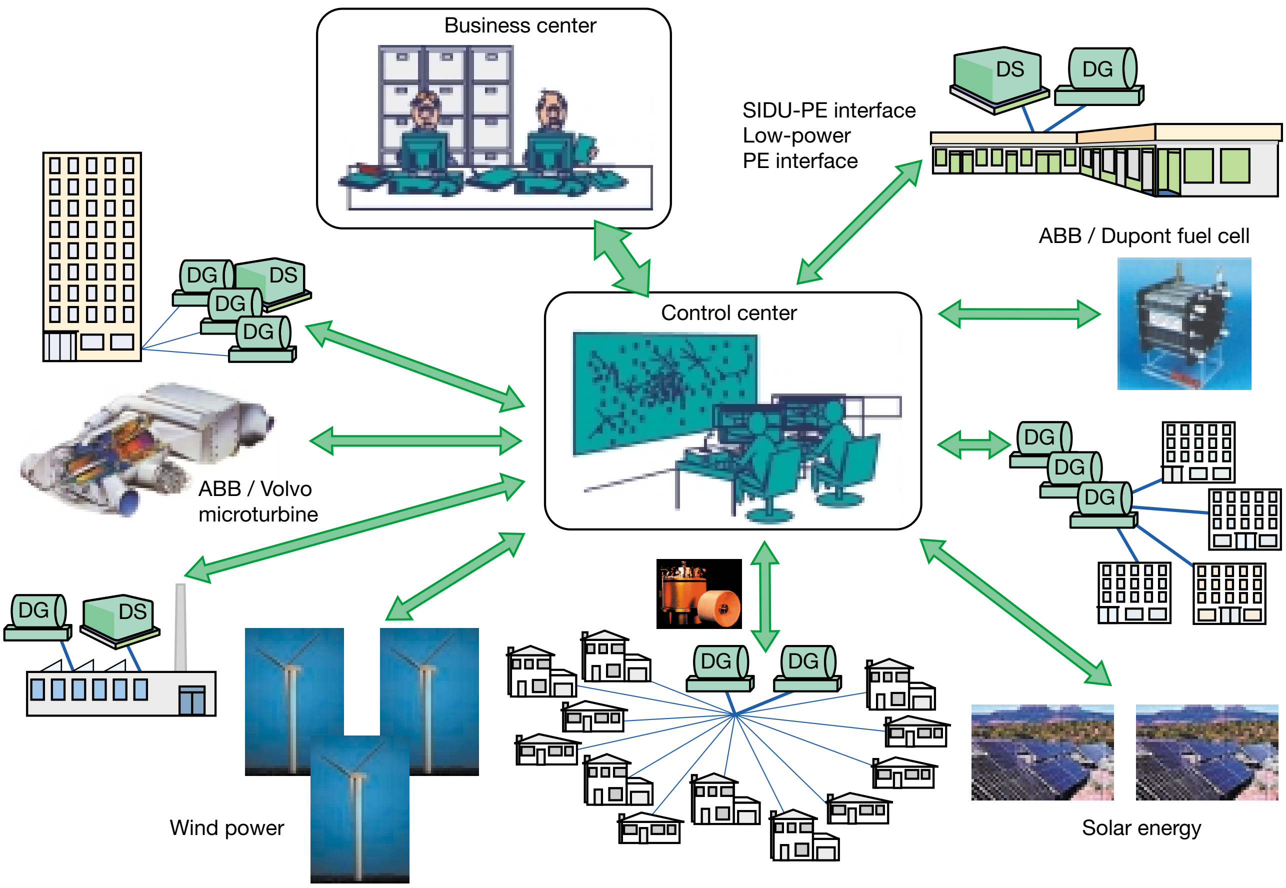


Since it is fully automated, the virtual utility requires little or no human intervention. ABB technologies are available for the necessary control, automation and optimization of facilities.

little or no human intervention is desirable in order to optimize the energy distribution for a consumer or utility. ABB has technologies which are able to provide, as part of its virtual utility concept, the control, automation and optimization capability needed to aggregate distributed generators or clusters.

Skillful integration of distributed assets with targeted performance and load management can have benefits for utilities and consumers alike. A virtual utility will provide a scalable energy resource that can assist utilities in short/medium-term energy planning.

As an example, think of a hypothetical energy service company, World Electric Service Co (WESCo), which owns 500 100-kW distributed generation units installed at customer sites all over a given geographical area. Connected by a communications system that allows a single control center to monitor and dispatch all 500



SIDU *Smart integrated distributed unit*
PE *Power electronics*

The virtual utility brings together widely dispersed distributed generation (DG) and distributed storage (DS) systems, serving many customers at multiple locations, as if in one centralized system.

In the virtual utility, simplicity of operation is paramount.

units, this group could be operated as a single body of generation. The owners could schedule their output to any required level from zero megawatts (during times when the going price for power is very low) to 50 MW (when the spot price is high), simply by turning on and ramping up various combinations of units from the control center. The owner could also operate these units to maximize the power quality and availability that might be demanded by certain customers.

A virtual utility owner focuses on running distributed generation units to ensure quality of supply and profitability of operation by injecting power intelligently into the microgrid. The grid owner can use this combination of assets to allow optimal leverage of the system in different ways. Many other benefits will be realized as a result of adopting the virtual utility concept. Some regulatory influences will tend to restrict the benefits, and 'cutting the wires' may be an attractive solution for certain consumers.

Electrons on Line

To support implementation of the virtual utility, ABB has come up with the idea of offering a bureau service to customers rather than just sell them hardware and software. Called 'Electrons on Line'(EOL), it is based on selling the service of controlling and monitoring distributed generation. EOL is an automated service bureau that allows clients to monitor and control various resources related to distributed power generation. These sources include but are not limited to distributed generation, storage, curtailable loads, etc. The service bureau maintains the database, specifies the communications protocol and interconnection devices, and provides and maintains control, monitoring and applications software for the clients to use. The clients are charged a fee based either on elapsed time, connect time, or data points, etc. All communications are done through the worldwide web and the database is maintained on the EOL web server.

More than just a virtual utility

The realization of the virtual utility is not just an exercise in the use of software. In order to enter this new market and provide differentiation and sustainable advantage, ABB will rely on the following experience and strengths:

- In-depth understanding of the power distribution system (including analytical modeling capability)
- Ability to effectively integrate equipment into the power system as well as provide service and systems management
- Understanding of the business objectives of our customers in order to plan and construct systems that meet them in the most effective way
- Breadth of products in the power distribution area

In short, ABB is well-positioned to enter the virtual utility market.

Distributed versus conventional – small versus big

The bulk of today's electric power comes from central power plants, most of which use large, fossil-fired combination or nuclear boilers to produce steam that drives steam turbine generators. Most of these plants have outputs of more than 100 MW, making them not only physically large but also complex in

Cogeneration of heat and power improves the overall energy efficiency even further.

terms of the facilities they require. Site selection and procurement are often a real challenge because of this.

Efficiency is higher

For new installations, the most direct comparison between distributed generation and central generation is by efficiency. The plant efficiency of existing large central generation units could be in the 28–35% range, depending on the age of the plant. This means that they convert between 28–35% of the energy in their fuel into useful electric power. Typical large central plants must be over-designed to allow for future capacity, and consequently they run for most of their life in a very inefficient manner. Small distributed generation systems that can be added as modules reduce the financial risk of the grid owner.

By contrast, efficiencies of 40 to 50% are attributed to small fuel cells and to various new gas turbines and combined cycle units suitable for distributed generation applications. For certain novel technologies, such as a fuel cell/gas turbine hybrid, electrical efficiencies of about 70% are claimed. Cogeneration, providing both heat and electricity, improves the overall energy efficiency of the installation even further.

Construction time is short

Perhaps one of the most important advantages distributed generation offers is the comparatively short time in which a system can be installed – significantly less than that needed for coal and gas plants.

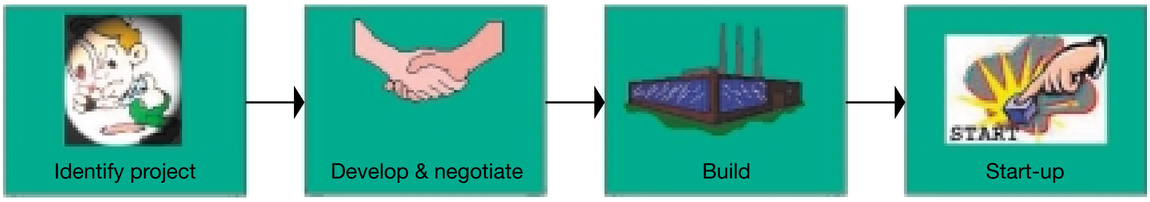
Lower infrastructure costs

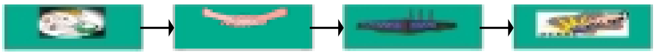
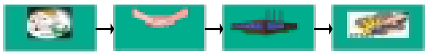
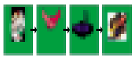
A distributed generation unit does not carry a high T&D cost burden because it is already sited there where the electricity is used. The effect of the T&D infrastructure on the price electricity users along the system pay is shown on page 14. Electricity costs less the nearer you are to the source of generation, and with distributed generation the electricity user is at the source of generation, so there are no transmission losses. An added bonus is that the T&D infrastructure itself is often the cause of many service reliability problems. This is especially true in regions that have allowed the T&D infrastructure to deteriorate as a result of cost pressures, deregulation, etc. By avoiding these problems, distributed generation can provide better service at lower cost for many applications.

Easily upgradable

One of the fundamental factors dominating the design of conventional T&D systems is that it costs more to upgrade most facilities to a higher capacity than it does to build that capacity into the original construction. This leads to the infrastructure being built with considerable margin to allow for growth. The very high cost per kW of upgrading a T&D system (*Table 3*) creates one of

Distributed power generation units can be brought on line in a much shorter time than large, centralized power plants.



Coal		5-7 years
Large gas IPP		3-5 years
Distributed generation		6-18 months

the best-perceived opportunities for distributed generation applications. Thus, distributed generation planners look first at areas of the system where slow, continuing growth has increased the load to the point that local delivery facilities are under strain.

Technologies for distributed power generation

Newly developed distributed generators typically range from 5 kW to 500 kW, have a footprint of between 0.01 and 59 kW/square meter, and involve capital costs ranging from US$200 to US$6000/kW. They are capable of producing electricity in the 3–20¢/kWh range. These characteristics are ideal for distributed power systems. *Table 4* provides important characteristics of distributed generation technologies now commercially available.

Table 3: The high cost of expanding T&D peak load incrementally (US$/kW)

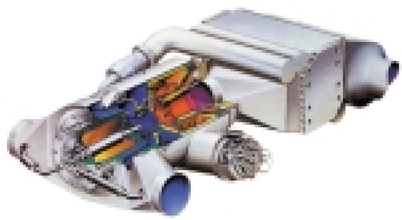
Utility	*Low*	*High*
United States – Northeast	166	925
United States – Southeast	45	729
United States – Central Plains	82	336
United States – West Coast	64	610
Central America – urban system	51	300
Central America – rural system	51	920
South America – urban system	129	438
Caribbean	65	518
Europe – North Central urban system	290	846
Southeast Asia – urban system	29	400
Southeast Asia – rural system	40	2000

Microturbines

Microturbines operate on the same principles as traditional gas turbines. However, the compressor and generator are typically driven at high speeds, such as 70,000 to 120,000 rev/min.

The generator thus produces high-frequency AC power that is converted to 50/60Hz by power electronics. Typical power ratings range from 25 to 500 kW. Utilizing the exhaust heat for thermal loads can improve the overall efficiency up to 80%. Typically, microturbines use natural gas as fuel, but other fuels, such as diesel, propane, and kerosene are possible. Flare gas from well heads has even been used, and biomass converted fuels are being investigated.

ABB is currently developing a 100-kW microturbine through a joint venture with Volvo. The MT100 CHP is available in a combined heat and power (CHP) unit;



Microturbine

uses for this unit range from the production of hot water and electricity to chilling. The CHP unit covers the various needs of energy users in the residential, commercial, and industrial sectors. Besides exhibiting a relatively high efficiency even at half-load, its NO_x and CO emissions are less than 15 ppm, so there is no need for a catalytic system.

Fuel cells

Fuel cells are able to convert hydrogen and oxygen into electricity, heat and water. They are similar to batteries in that they also use an electrochemical process to produce a DC current. Unlike batteries, fuel cells electrochemically convert the energy in a hydrogen-rich fuel directly into electricity and operate as long as the fuel stream lasts. Fuel cells are characterized by the type of electrolyte used, for example alkaline, proton exchange membrane, phosphoric acid, molten carbonate or solid oxide. Depending on the electrolyte, the fuel cell operates between 80 and 1000°C. Ignoring this produced heat, fuel cell efficiency can range between 35–65%. Utilizing the produced heat can raise the efficiency to over 80%.

ABB has recently begun development of an advanced fuel cell that promises low costs and high efficiencies at the low end of the power scale. These units will be designed so that they are fueled directly, thus avoiding the high costs and technical issues involving hydrogen reformers. The entry markets for this product will be industrial and residential customers requiring base loads of less than 5 kW.

Wind power

Wind turbine generators (WTGs) convert wind power to electrical power. Typical systems range from 30 kW for individual units to 1.5 MW for wind farms with multiple units. Hub heights are around 80 meters, rotor diameters 65 meters. The rotor construction is either variable blade angle (pitch regulation) or non-variable. Either synchronous or induction generators are used to convert the mechanical energy to electrical energy. WTGs are often installed in clusters, or wind farms, and are seldom used in isolation. ABB's HVDC technology makes it easy to connect wind farms to transmission grids.

Helped by a favorable political situation and decreasing costs, the market for wind power is growing by 40% annually. Today, Europe dominates the wind energy market, but pilot industrial and even residential systems are in the process of being developed for world markets. ABB is a project developer in the wind energy market. This activity builds on ABB's strengths as a turnkey supplier, project manager and component manufacturer.

Solar power

Conversion of solar energy to electrical energy has been technically possible since the late 1930s. The main difficulty is the high cost of photovoltaic systems, US$ 6000/kW being a typical figure. Additionally, the power output is directly proportional to the surface area of the cells, and footprint sizes are hence relatively large (0.02 kW/m^2).

Typical applications of photovoltaic cells include small installations of < 10 kW on building rooftops or remote power systems that cannot be connected to the electricity grid. Energy storage is usually required for wind and solar power during periods when there is no wind or sunlight. The cost of the energy storage component could be significant.

Reciprocating engines

Use of diesel and petrol engines to provide standby power for commercial

Fuel cell

Wind turbine

Solar energy

Table 4: Distributed generation technology options

	Engine generator	*Gas turbine generator*	*Microturbine generator*	*Photovoltaics*	*Wind turbine*	*Fuel cells*
Fuel	Diesel or gas	Gas	Multiple gas or liquids	Sun	Wind	Gas
Efficiency, % [1]	35	29-42	27-32	6-19	25	40-57
Energy density, kW/m^2	50	59	59	0.02	0.01	1 – 3
Capital cost, $/kW	200-350	450-870	500-1000 (500 in 2001)	6600	1000	3000 (1000 expected when fully commercialized)
O&M cost, $/kWh [2]	0.01	0.005-0.0065	0.005-0.0065	0.001-0.004	0.01	0.0017
Electrical energy cost, $/kWh [3]	0.07-0.09	0.06-0.08	0.06-0.08	0.18-0.20	0.03-0.04	0.06-0.08
Energy storage required	No	No	No	Yes	Yes	No
NO_x (lb/BTU)						
Natural gas	0.3	0.01	0.01	n. a.	n. a.	0.003-0.02
Oil	3.7	0.17	0.17	n. a.	n. a.	–
Heat rate, millions BTU/kWh	10-15	5-10	5-10	n. a.	n. a.	5-10
Expected operating life, hrs	40,000	40,000	40,000	–	–	10,000-40,000
Technology status	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial in 2001

1. Efficiencies of renewable energy technologies should not be compared directly with those of fossil fuel technologies since the latter fuel is limited.
2. O&M costs exclude cost of fuel. There are no fuel costs for wind systems or photovoltaics.
3. Natural gas fuel is used for calculating energy costs except for wind and solar power.
n. a. = not applicable

and small industrial customers is not new. Engines operating on natural gas have recently been developed. Typical capacities are 50 kW to 6 MW, and footprints are in the order of 50 kW/m^2. Disadvantages of combustion engines are pollution (both emissions and noise) and relatively high maintenance and operating costs.

Previously, these systems were connected to the electricity grid for standby power only. Studies show that peak-shaving or base-load operation may require new generator designs and power conversion systems. These newer systems are now coming onto the market from several suppliers.

Managing the distributed power generation network

Distributed power generation provides new ways for customers to supply electricity, while enabling them to minimize investment, improve reliability and quality, and lower costs. By putting energy generation and storage as close to the point of consumption as possible, and by doing so ensuring high conversion efficiency and minimal environmental impact, it has the potential to reshape the future structure of electricity production and delivery.

The virtual utility provides a coherent structure within which a distributed power generation system can operate. It will link and intelligently control and manage widely distributed generation assets. The virtual utility builds on the many ABB technologies which are suitable for distributed power generation and can take full advantage of ABB experience and products in control and distribution.

Although the virtual utility is technology neutral, ABB already offers compatible distributed power generators.

With data now being transmitted over power lines, the two worlds of computing and power networking may be thought of as being convergent; it is intriguing to think that the very data exchanged by automatic energy trading computers may accompany that energy over the same power lines!

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