Think Globally, Distribute Power Locally: The Promise of Nanogrids

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Nanogrids use price to mediate local electricity supply and demand, improving electricity allocation at the local level, facilitating integration of local storage and generation, and achieving more efficient use of low-voltage DC from local sources.

Matching electricity demand with supply is central to emerging smart grid designs. In addition to more efficiently managing variations in demand, these systems must take into account fluctuating supply from renewable energy sources and fine-grained changes in prices.

Buildings will increasingly consume—and supply—multiple types of power, both alternating current (AC) and direct current (DC), with some backed up by local battery storage. Each power source has different levels of reliability and cost, which can continually change. For example, a facility could have DC power, coming directly from solar cells on its roof, which is highly intermittent but has a low marginal cost; AC power that comes from the grid, which has predictable reliability but also has a higher and increasingly variable cost; and a finite amount of battery power for which it’s possible to estimate the replacement cost.

With this increasing complexity at the “edge” of the grid, total central control becomes infeasible, making new system designs a necessity. In addition, many usage contexts lack grid connectivity, sometimes or always, but have the same, if not greater, need to match supply and demand.

Energy price—and the ability to communicate this price among supply and demand units at all scales—is central to making intelligent choices regarding the timing and amount of energy used.

Nanogrids can provide local operational management with lower costs and reduced energy use. Applying digital control to power distribution is a foundational example of green IT.

WHAT IS A NANOGRID?

A nanogrid is a single domain for voltage, quality, reliability, price, and administration (http://nordman.lbl.gov/docs/nano.pdf). It must have at least one load or sink of power—which could be electricity storage—and at least one gateway to the outside. Electricity sources aren’t part of the nanogrid, but a source often will be connected only to a single nanogrid.

Figure 1 illustrates a simple nanogrid structure. All power flows are accompanied by communications—either wired or wireless. Interfaces to other power entities are through gateways within the nanogrid controller. Each nanogrid manages the power distributed to its loads.

The controller uses price to mediate local electricity supply and demand, both within the nanogrid and in exchanges across gateways. The nanogrid controller receives requests for power, grants or revokes such requests, measures or estimates power, and sets the local price. Nanogrids implement power distribution only—they perform no functional
control of the devices that connect to them. Nanogrids are already quite common—a notebook computer includes all of these elements: it can provide power to attached USB devices, has an internal battery, and can operate either connected to grid power or off-grid.

Nanogrid loads take the local electricity price into account in deciding how to operate, along with functional considerations. High prices will tend to reduce or delay energy services; low prices increase or advance them over time. Controllers negotiate with each other across gateways to buy or sell power. Battery storage is optional, but it can increase reliability and stability.

Figure 2 shows a schematic of a small network of nanogrids. Connections can be made or broken at will, and there need not be a utility grid connection. Connections can be to other administrative domains—for example, directly to other utility customers, bypassing the grid.

Nanogrids are a bottom-up means of evolving the power distribution system, bringing grid benefits to the local area. Analogous to the Internet paradigm, the smart grid is the core backbone network and nanogrids are the LANs that provide connections to and full use of the entire system.

Nanogrids enable the most effective integration of local renewable generation and storage, and are the only way to provide price signals to devices that correctly reflect local conditions, whether connected to a grid or not.

Nanogrid controllers can resemble Power over Ethernet (PoE) switches or USB hubs; however, unlike with PoE, more than one device can be attached to each port. A nanogrid can exchange power with other nanogrids or microgrids whenever it’s mutually beneficial as indicated by relative price. The controller will set a current price and also typically publish a nonbinding forecast of future prices, up to one day in advance. The price then correctly reflects local scarcity and cost, which enables optimal allocation of power among loads and local grids.

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A core principle of the nanogrid is to separate power distribution from functional control. Future device networks would have three layers—layer 1 is power itself, layer 2 is power coordination, and layer 3 is device functionality. Nanogrids implement layer 2.

Devices connected to a nanogrid make functional decisions about operation, which can be coordinated with other devices at layer 3.

The Internet Protocol suite has a well-known “narrow waist” at the IP layer. There are many protocols both above and below the IP layer. The narrow waist minimizes complexity between higher and lower layers. In a similar fashion, there is a narrow waist between layers 2 and 3, in which only electricity, quantity, and price need to be communicated; this occurs within devices, not within a protocol layer.

Separating power coordination from functionality has several advantages. In future applications, devices that need to coordinate functionally, such as those in the same room, will often be powered differently, and devices that share a power infrastructure might not have functional relationships. Separating these functions into different layers lets each function evolve separately, greatly simplifying the development of new technologies and their deployment alongside existing products.

**VILLAGE EXAMPLE**

Consider an off-grid household in a developing country. It has a car battery, a solar panel, and several devices with varying priorities, such as lighting, refrigeration, and communications. This household can operate in isolation or it could connect to adjac-
and better services than traditional landline services can provide, all at a much lower total cost.

Nanogrids offer the same potential for power distribution. Rather than investing large amounts of money in traditional central-station generation facilities and high-capacity transmission and distribution systems, developing nations could rely mostly on distributed generation and low-capacity electricity exchange lines. Traditional utility grid technologies would still be needed, but could be much smaller, and less reliable, since reliability can be provided at the edge of the grid.

The premise of local power distribution technology is that it’s universally useful, like USB. It offers advantages for devices needing power with higher or lower reliability, various types of vehicles (land, air, and water), and any building type. The basic principle is that any electricity load can be connected to a nanogrid much like any IT device can be connected to the Internet.

**BENEFITS**

The telecommunications infrastructure in some developing nations has leapfrogged from being almost nonexistent to supporting modern mobile technology, offering more of the devices or their use within the nanogrid. Nanogrids also facilitate using local renewable power directly in DC devices—saving about 10 percent of electricity over the common conversion to and from AC power. They increase the value of batteries because they allow storage to be added locally, where it’s most needed.

Without nanogrids, the smart grid won’t be brought to its full potential. The next step toward such fulfillment is to build a nanogrid hardware prototype and simulation model. This proof-of-concept could attract the attention of industry, which is critical to creating this new technology.

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