# Think Globally, Distribute Power Locally: The Promise of Nanogrids

**Bruce Nordman,** *Lawrence Berkeley National Laboratory*
**Ken Christensen,** *University of South Florida*
**Alan Meier,** *Lawrence Berkeley National Laboratory*

**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

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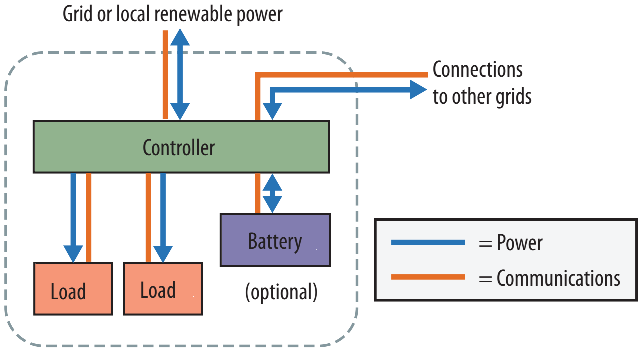

**Figure 1.** Conceptual diagram of a nanogrid.

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 developing IEEE Universal Power Adapter for Mobile Devices standard (P1823) incorporates some nanogrid principles, such as peer-to-peer power exchange, bidirectional power flow, managed distribution to loads, and enabling integral storage.

To set the local price, the controller takes into account the quantity and price of any external electricity it has access to, along with internal demands and storage, the estimated replacement cost for battery power, which could be future grid power, and an assessment of battery capacity. The price then correctly reflects local scarcity and cost, which enables optimal allocation of power among loads and local grids.

The controller will set a current price and also typically publish a nonbinding forecast of future prices, up to one day in advance. When a nanogrid is connected to the utility grid, the grid price will be a strong influence on the local price; however, local generation and storage can dramatically change that dependency.

Devices that connect to a nanogrid will ship with default price preference functions that make sense with typical grid prices.

## GRID ARCHITECTURE

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 adjacent houses and other structures—for example, to a school, medical clinic, or mobile phone base station. When the school has days off, its excess locally generated power could be sold to its neighbors; on school days, the reverse could occur.

A medical clinic could have devices that need high power continuity to provide critical life services or to refrigerate vaccines and antibiotics. The electrical supply to such devices should be prioritized over other loads. The price-based mediation of nanogrids enables this prioritization both within buildings and between them.

A network of nanogrids could manage a village's power distribution. Power sources might include the utility grid, local renewable power, and batteries.

At any given time, there would be a net flow across many "links" in the power distribution network, with many nanogrids buying and selling power on different ports. The power distribution network topology can change at any time.

This raises the problem of how to determine the amount of power exchanged among the connected nanogrids. A central controller solution would impose costs, communication needs, and administrative burdens, and create a potential single point of failure for the entire system.

A better approach utilizes a fully distributed system, with each nanogrid periodically reconsidering its selling and buying options based on its own needs, quantities available or desired, and prices. This makes the grid scalable from a single isolated nanogrid to large networks of grids of different sizes, all interoperable via a single architecture.

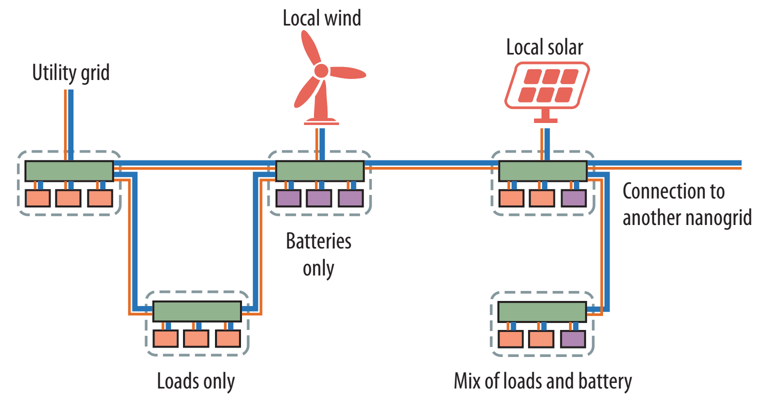

**Figure 2.** An example nanogrid network for a utility customer.

## BENEFITS

The telecommunications infrastructure in some developing nations has leapfrogged from being almost nonexistent to supporting modern mobile technology, offering more 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.

Nanogrids are inherently secure because communications for power distribution are only between entities with a direct power connection. Nanogrids enable privacy because other grids don't need to know details 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. **C**

***Bruce Nordman*** *is a research scientist in the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory. Contact him at bnordman@lbl.gov.*

***Ken Christensen*** *is a professor in the Department of Computer Science and Engineering at the University of South Florida. Contact him at christen@csee.usf.edu.*

***Alan Meier*** *is a senior scientist in the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory. Contact him at akmeier@lbl.gov.*

**Editor: Kirk W. Cameron, Dept. of Computer Science, Virginia Tech; greenit@computer.org**