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The Nanogrid Collective: a Means of Integrating Thousands of Individual Customers Into System Operations and Markets

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SUMMARY

The electric utility industry is struggling to incorporate large amounts of variable renewable energy sources, particularly wind and solar. This is especially challenging at the retail customer level. This paper describes a concept to resolve these problems called the "Nanogrid Collective" that will allow tens of thousands of dispersed retail customers to contribute to power system operation by reducing costs and saving money. The Nanogrid Collective resolves problems such as handling demand response in a timely manner; providing frequency and voltage control, communication speed and delays, and security.

A nanogrid is less than100 kw and is much smaller than a smart grid or microgrid. The 'grid' is the customer's internal wiring where each breaker protects an internal 'feeder'. Individual customers offer control of their devices through a Master Controller.

The Collective Provider/Operators coordinate the fleet of nanogrid participants. They will be the interface between the nanogrids and the system/market operators. They will maintain continuous contact with system/market operator and use the Master Controllers to control the customer's devices in response to changing market prices and operating needs. This arrangement allows the individual nanogrids to participate in the ancillary service and demand-response markets while divorcing the customers from the technicalities and details.

Widespread customer adoption will depend on great software user interfaces, functionality, attractive cost-sharing plans, and cachet. Full implementation will take some time while the existing fleet of major electric appliances is replaced over a decade, or so. But as the internet of things expands, so will the range of control available.

The Nanogrid Collective can provide frequency and voltage control in ancillary service markets as well as provide demand response. It is a realistic and achievable system. Market and system operators should start preparing.

KEYWORDS

Nanogrid, smart grid, microgrid, energy storage, distributed generation, renewable generation.

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The Nanogrid Collective

The electric utility industry is being challenged to incorporate large amounts of intermittent renewable energy sources, particularly wind and solar. They face both technical and business challenges. Among the technical challenges is the ability to incorporate renewable energy and smart-home capabilities at the residential customer level. This paper describes and discusses a concept to resolve these problems called the “Nanogrid Collective.”

The Nanogrid Collective will allow tens of thousands of dispersed residential customers to contribute to power system operation while reducing costs and saving money. While there would appear to be problems in coordinating that many participants, there are solutions. In addition, several well-known companies and new entrants are developing business models and systems to enable the Nanogrid Collective.

Today, small customer participation in utility markets in most of the US is limited to energy geeks and early adopters. Customer convenience and easy transactions are key attributes for consumer acceptance. So, a system that is easily used, that takes full advantage of the internet and smart phones, is backed by a well-known company, and with low initial costs would lead to widespread adoption of such systems.

This is not a utopian concept—there are some challenges—but, as discussed below, there are practical solutions and encouraging developments.

Nanogrid, not smart grid or microgrid

The nanogrid is not the smart grid or microgrid. These are concepts for much larger systems than the nanogrid. (Navigant Research, for one, has adopted a 100 kW maximum size for nanogrids.)

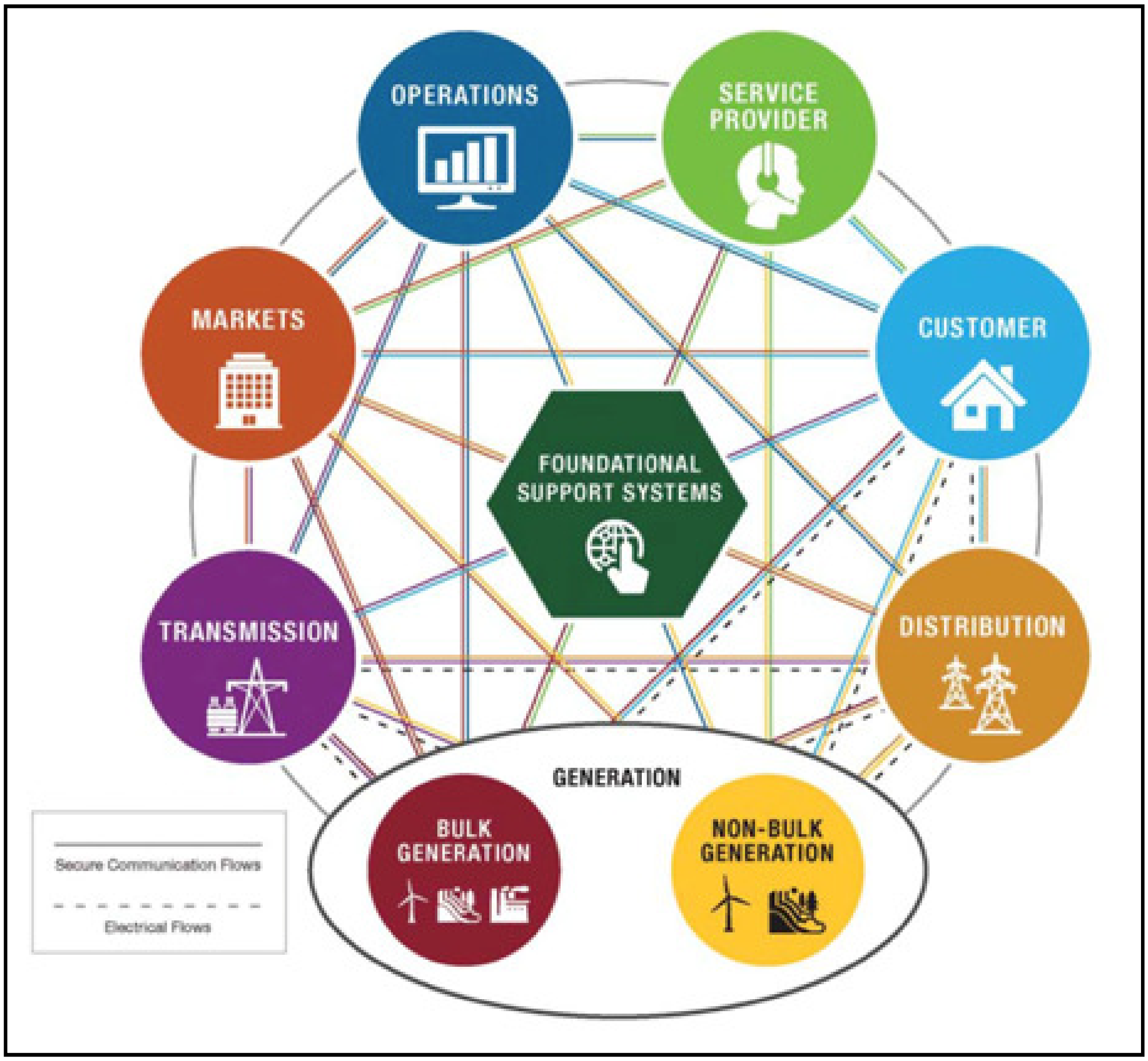
Smart grid

The term “smart grid has been widely used by both the technical press and mainstream media. It has come to refer to a wide range of options and capabilities. For simplicity, we will use the Wikipedia description of the smart grid:

> “… a modernized electrical grid that uses analog or digital information and communications technology to gather and act on information—such as information about the behaviors of suppliers and consumers–in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.
>
> “A common element to most definitions is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. Various capabilities result from the deeply integrated use of digital technology with power grids, and integration of the new grid information flows into utility processes and systems is one of the key issues in the design of smart grids.” (en.wikipedia.org/wiki/Smart_grid, 30 July 2015)

The just released *IEEE Smart Grid Newsletter Compendium 2015—Smart grid the Next Decade* further clarifies by describing eight smart-grid domains as shown in Figure 1, below. These domains and sub-domains are part of the smart grid framework 3.0 based on work with the National Institute of Standards and Technology (NIST).

Figure 1: IEEE smart grid domains



The two most important changes from the NIST 2.0 Framework, is splitting generation into bulk and non-bulk, and adding the Foundational Support Systems domains. This last domain includes non-energy processes such as cyber security and information technology—hardware and software.

Microgrids

A microgrid is a small electric 'grid' that it includes interconnected load, generation, transmission and switchgear. The generation is local, distributed, generation that allows the grid to operate independently from the larger interconnected system at times, and may include energy storage. This autonomy lets microgrids add to grid resilience and helps mitigate grid disturbances.

Microgrids are commonly low-voltage AC grids connected to the utility distribution system. While they may use a mixture of different distributed energy resources, they usually use some conventional generation such as diesel generators. Their size and local nature also allows integrating small renewable generation—especially photovoltaic.

They are well suited to university campuses, industrial parks or industrial customers. Microgrids are of a size and scale, however, that is well beyond that of individual residential customers. While a microgrid can include a group of nearby residential customers, as explained below, the Nanogrid Collective can include residential customers dispersed throughout a region.

There are significant socio-economic challenges to developing microgrids. Perhaps the biggest is cost. A microgrid is organized and operated differently than traditional utility distribution networks. Implementation requires changes to protection, control and communication equipment—all requiring significant investments. They will require updated or novel protection and sensing techniques, and customer education and acceptance. Microgrids may also require government involvement and subsidies.

The nanogrid

The nanogrid includes controllable devices within a residence, small business or building. The 'grid' is the internal building wiring. While they are not grids in the sense discussed above, they interconnect the building's devices and provide the means to control load and supply with the building. The building is like a very small ('nano') distribution network where each breaker protects an internal 'feeder'.

Many utilities now offer some limited form of residential load control of water heaters and air conditioners. Participating customers get a fixed monthly rebate by offering their controlled devices for limited interruptions during the annual peak-load season. The rebate is set as part of an approval process that usually pays customers based on estimated savings from the entire program. There is no flexibility that allows customers to adjust their participation depending on the actual utility needs or savings.

The current utility programs are top-down, offered by the utilities and controlled by them. This scheme largely removes the customer from the process. The Nanogrid Collective reverses this because it is a bottom-up approach to participation.

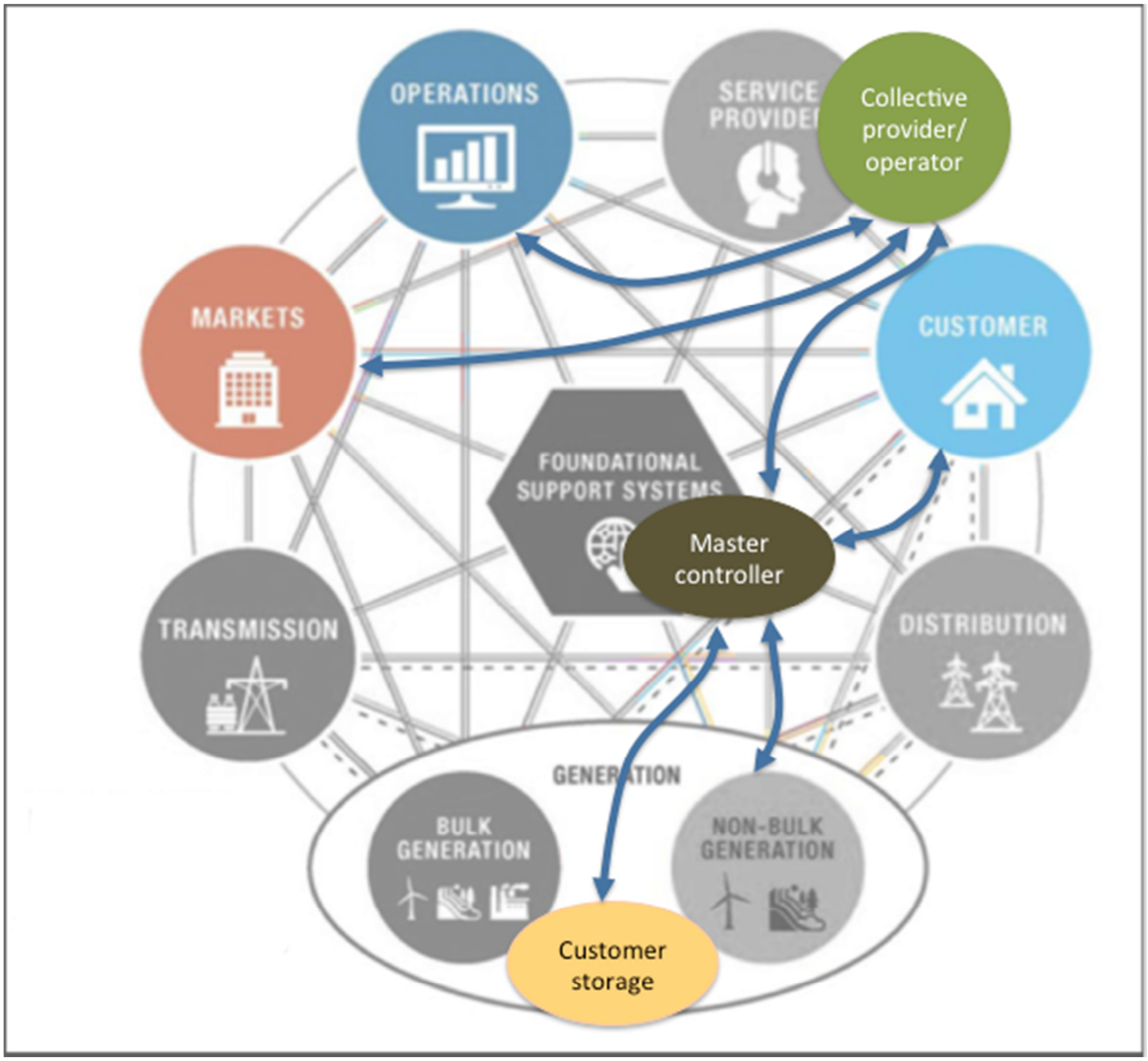
An overview of the Collective components is shown in Figure 2, below. The components are shown in relation to the NIST 3.0 Framework. Individual customers offer control of their appliances, devices, distributed generation, and storage through a Master Controller. The Collective Operator/Provider uses the Master Controller to control the customer's devices in response to changing market prices and operating needs.

User participation is key to successfully implementing the Nanogrid Collective. A process that, to the customer, looks a lot like another phone app will have great public appeal. The approach allows customers to participate as much as they wish. They get to select what devices are controlled and how much. They can change or override their choices easily. They are compensated based on their actual contributions to the needs of the overall system. However, for most customers the process will be invisible.

The controlled devices could include electric water heaters, air conditioning, refrigerators and freezers, pool pumps, etc. The customers would choose; controlled devices could be added or removed. And as smart appliances replace the existing stock, it will be easy.

Control will initially use network-controlled switches. As smart appliances and devices are added, they could be controlled using their internal capability. Firms such as *Carbon Track* are already moving forward with this approach. They offer current clamps to monitor actual usage and controlled switches to control individual devices.

Figure 2: The Nanogrid Collective as part of the smart-grid domains



As new devices are added, they too could be controlled. This would be especially applicable to storage, either as a stand-alone device or as an electric vehicle.

The key to all this is the Master Controller.

Nanogrid Master Controller

As should be obvious, the nanogrid Master Controller is the critical element linking the building devices and providing control. The Master Controller will use the internet to link the customers with the Collective Provider/Operators, and then with the utility/system operator, and the market operator.

The Master Controller will provide much more functionality. It will:

- Monitor all the devices under its control for actual usage;
- Use predictive techniques to anticipate individual device usage;
- Record actual usage of individual devices;

- Record actual energy reductions by device and by time and date;
- Respond to customer-programmed operations that reduce and/or shift energy use;
- Respond to system costs for additional savings;
- Respond to system condition to participate in ancillary service markets for frequency and voltage response;
- Provide specific detailed information on actual energy reductions; and
- Allow secure vendor software updates.

The Master Controller will provide users with full visibility now and show historical energy use. This enables smart customer choices. The Master Controller lets customers set timers for their appliances and equipment. And like today's smart thermostats optimize heating and cooling cycles in heating, air conditioning and water heaters.

The monitoring and user-programmed control functions are similar to those now offered by smart thermostats like those offered by Nest and others. These devices can be preprogrammed and controlled by the user from any internet-connected device.

What is new in the nanogrid are the functions that can respond to external system conditions. To participate in markets, the Master Controller must be able to monitor and respond to actual system and market conditions. It would maintain continuous contact with all the internal devices via the building network.

The Master Controller can readily respond to system frequency changes in real-time. Thus, the nanogrid can provide spinning reserve and regulating capability. The Master Controller can also respond to local voltages. And, the Master Controller would record usage by whatever time intervals the market required.

The fleet of Master Controllers will have regular, but not continuous, contact with the Collective Provider/Operators. The internet connection can easily provide 5 or 10-minute market pricing and other information to the Master Controllers.

The Master Controller will have a programmable randomness capability to ensure that that thousands of controllers do not all react identically.

Finally, the Master Controller will have a user-friendly interface. The device, settings and control will be accessible via the internet and mobile devices. This will be critical to wide customer acceptance. Examples can be seen in the interfaces from Nest and Carbon Track and others.

The Collective

The next stage is to coordinate what will be a fleet of tens of thousands of nanogrid participants. Firms, acting like today's load aggregators, will do this. These Collective Provider/Operators may be current load aggregators, but they will more likely be new entrants.

As with load aggregators, these Collective Provider/Operators will be the interface between the nanogrids and the system/market operators. They will maintain continuous contact with system/market operator and respond to changing load/generation conditions and energy and ancillary service prices.

The Collective Provider/Operators allow the individual nanogrids to participate in the ancillary and demand-response markets. The Collective Provider/Operators handle all these details. This approach divorces the individual customers from the technicalities and details of power system and market operations. It also relieves the utilities from tracking and handling the thousands customer records and details.

This is accomplished by communicating with the Master Controllers. The Collective Provider/Operators are at the top of the hierarchical structure of the Nanogrid Collective. The Collective Provider/Operators communicate with Master Controllers. The Master Controllers perform the actual control of devices and store detailed real-time information of the load controlled. The Collective operators aggregate this data for billing the market operator. The same data is also used to distribute the savings to individual nanogrid participants based on their actual contributions and market prices and their business arrangements with Collective Provider/Operators.

Because the Master Controllers can store detailed actual customer usage data, the Collective Provider/Operators can use it to improve predictions of ability of the Nanogrid Collective to respond in the future. This is often a concern regarding demand response—how much load is available that can be controlled? The Collective can track customer patterns to better predict future availability of demand response. The Collective will also have a record of the actual demand response when system or market conditions called for it. Together, this data will provide greater certainty for capacity planning.

There are no Collective Provider/Operators that now perform all the functions described above. There are a number that have implemented some of these functions. Nest, for example, has introduced several devices that allow customer control—in particular their thermostat. Carbon Track has a system that allows programming and remote control of multiple appliances such as electric hot water heaters, etc. Other industry players are also active such as Bosch, Eaton, and Johnson Controls along with cable and phone companies. No doubt, other major companies such as Google (who owns Nest), Apple, or Microsoft may enter the field.

The entire area is in its very early stages and is open to new entrants—and is ripe for innovation.

Benefits

There are many benefits from the Nanogrid Collective. The two biggest will likely come from the resulting demand and energy reductions. There will also be savings by providing ancillary services.

Keeping in mind that this entire concept is focused on the general public, a simple and clear user interface is critical. An easy interface along with easily understood savings would encourage greater participation. Greater participation will lead to increased overall savings.

Such an interface would first show customers their savings based on their monthly and annual participation. It would also make suggestions for further savings based on the customer's actual usage.

The system would also provide flexibility for the system operator. The Collective Provider/Operators could update availability every few minutes. These updates would provide actual usage and the amount of power and energy under control. The data would also be available with geographic information since the location of every nanogrid would be known and could be aggregated by any geographic regions set by the system operator.

The Master Controller software could be readily updated with new features and capabilities. Changes in market rules, ancillary services, or regulatory changes could be easily added through software updates. This would make the Nanogrid Collective highly flexible.

Another aspect of benefits is in the overall business model. The venture would likely come from outside the utility industry using private financing and investment. Nearly all the risk will be borne by these private investors. The process would be customer-driven as they see the benefits and adopt the systems with low financial risk to the utilities and customers. The breadth of customers would provide a wide range of diversity regarding the amount and type of equipment being controlled as well as geographically.

Overcoming problems

There are number of problems often raised regarding such a scheme of dispersed customer response in very large numbers. These include:

- Handling demand response in a timely manner;
- Providing frequency control;
- Providing voltage control;
- Dealing with communication speed and delays;
- Record keeping; and
- Security.

Each is discussed below.

Timely response

Demand response with the Nanogrid Collective could easily handle requirements for ten-minute (or longer) market intervals. The system and market operators would have a continuous high-speed connection with the Collective Provider/Operator who would determine the amount of demand response available. This amount would be based on actual operating information from the collective nanogrid and the pricing policies of the individual nanogrid customers. Day-ahead and hour-ahead participation could be determined based on estimates using the historical record of the Collective.

Frequency control

Frequency and voltage control could be done without communicating with the system operator using only the local frequency. During unusual conditions the system operator could inform the Collective Provider/Operators of anticipated critical conditions allowing adjustments to response settings for the Nanogrid Collective. Otherwise, there would be little need for direct communication for frequency control.

Frequency service would be accomplished using the local system frequency monitored by the thousands of Master Controllers. Each would respond as the frequency changed by starting or stopping devices as necessary and based on those that were operating at the time. The Master Controller could be programmed to act just like generator droop with an appropriate dead-band. The Nanogrid Collective could be a very effective frequency control resource.

Voltage control

Voltage service would be performed using the local voltage. This would be somewhat more complex than frequency control because it would have to be coordinated with the distribution system voltage regulation being done by the utility. With a proper dead band this too should be effective using only local control. Voltage support could be offered by controlling customer load, and, of course, with storage where it was available.

Communication speed

Communication speed and delays can become a significant problem when trying to deal with thousands of devices via the public internet. As discussed above frequency and voltage control can be accomplished with only local data. Demand response is generally given advanced notice of at least ten minutes, and usually longer. This is long enough for the Collective Provider/Operator to communicate with the Nanogrid Collective.

A serious potential problem could be a lack of diversity in the Nanogrid Collective—all the customers cannot respond in exactly the same way. The Nanogrid Collective could easily control hundreds of MWs, or more. Having them all simultaneously respond identically in most situations would cause serious operating problems. This can be overcome fairly easily by including a random element in the Master Controller systems. The Collective Provider/Operators could periodically revise the random response of the individual nanogrid Master Controllers. This instruction would adjust the response rate and dead band of the individual Master Controllers. In this way the Collective would incorporate diversity in responding to local frequency or voltage changes and to requests for demand response. Voltage control and distributed generation could also respond based on geographic needs.

Record keeping

The Collective Provider/Operator will handle record keeping. While this will be complex in combining the actual responses of the individual nanogrid participants with the real-time and day-ahead market prices, or tariff rates. This is merely a large database problem that will be handled by Collective Provider/Operator using data from the nanogrid Master Controllers.

The same sets of information would be used to determine the share of the savings for each nanogrid customer. All this would be handled by the Collective Provider/Operator and would be part of their overall marketing and business plan.

Security

Security is recognized today as a significant challenge for smart-grid and smart-home devices. It will require care in developing the Master Controller software, though this could be upgraded as necessary. It should also apply to the various controls and switches supplied by the Collective Provider/Operator. More challenging will be the third-party connected appliances—refrigerators, air conditioning, etc. These devices and all the others that will form the internet of things must also include security and be capable of being upgraded.

Remaining obstacles

Security must be incorporated from the earliest stages of the Nanogrid Collective's evolution. Security feature must be embedded in all the relevant equipment and software. There will be a tendency for each developer to develop unique and perhaps proprietary standards. This temptation may be greatest for vertically integrated manufacturers like Samsung or Black & Decker. Companies such as Apple and Microsoft also have a history of developing proprietary systems.

Common standards will be essential for large-scale adoption of the Nanogrid Collective. Customers will want be able to choose their own appliances and to switch Collective Provider/Operators. While the Master Controllers will have proprietary features that distinguish one supplier from another, changing providers should only require changing out the Master Controller.

Widespread customer adoption will depend on great software user interfaces, functionality, attractive cost-sharing plans, and cachet. Once the idea catches on with the public there will be appliance manufacturers and service providers ready to meet the need.

Some systems already control thermostats, and some providers now install switches to control hot water heaters and other devices. These are on-off switches and may not be suitable for devices like refrigerators. As appliance manufacturers deliver smart appliances, the range of control will expand. A refrigerator or freezer with a remotely adjustable thermostat will be much more appealing to users than simple on-off controls.

All of this will take some time while the existing fleet of major electric appliances is replaced over a decade, or so—refrigerators, freezers, hot water heaters, and air conditioners. As the internet of things expands, so will the range of control available. The "big kahuna" would be electric vehicles that would offer both significant supply and demand capabilities.

Economics will also become a challenge. Today, customers expect to have the savings based on retail prices. A large Nanogrid Collective will not be sustainable for utilities if savings are based on retail rates. Participation in ancillary markets also implies using market prices for determining savings. This may also shift retail customers to demand and energy pricing. If they do use demand pricing, where will the demand costs come from when nearly all of today's markets are based on energy costs?

Conclusion

The Nanogrid Collective is a realistic and achievable; system; and market and system operators should start preparing. The Nanogrid Collective will allow tens of thousands of retail customers to participate in market activities reducing costs and improving system performance.

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