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Nanogrids
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Abstract

A nanogrid is a very small electricity domain that is distinct from any other grid it is connected to in voltage, reliability, quality, or price. Nanogrids could form the basis of a future electricity system built on a bottom-up, decentralized, and distributed network model rather than the top-down centralized grid we have today in most parts of the world. This document introduces the idea of a nanogrid to the IETF community for two purposes -- to inform the work on energy management presently underway in the EMAN working group, and to describe how future communications within and between grids could be accomplished with protocols that are the product of the IETF. There appears to be no fundamental conflict between the nanogrid concept and the current drafts in the EMAN working group.

1. Overview

A nanogrid is a very small electricity domain that is distinct from any other grid it is connected to in voltage, reliability, quality, or price [CIGRE] (also [NG-2009]). Nanogrids could form the basis of a future electricity system built on a bottom-up, decentralized, and distributed network model rather than the top-down centralized grid we have today in most parts of the world. Central to nanogrids is the ability to communicate electricity price and availability to enable matching demand with varying supply of electricity. For the remainder of this document, we use "nanogrid" to refer to those which use price to manage supply and demand. Nanogrids bring an Internet approach and architecture to our electricity system.

2. How Nanogrids Work

A nanogrid must have at least one load or sink of power (which could be electricity storage) and at least one gateway to the outside. Electricity storage may or may not be present. Electricity sources are not part of the nanogrid, but often a source will be connected only to a single nanogrid. Interfaces to other power entities are through gateways within the nanogrid controller. Nanogrids implement power distribution only and not any functional aspects of the devices (or loads) that connect to the nanogrid. Thus, the components of a nanogrid are a controller, loads, storage (optional), and gateways. Figure 1 is a schematic of a nanogrid. A nanogrid manages the power distributed to its loads. All power flows are accompanied by communications and all communications are bi-directional. Communication - either wired or wireless - is used to mediate local electricity supply and demand using price, both within the nanogrid and in exchanges across the gateways. The nanogrid controller receives requests for power, grants or revokes them, measures or estimates power, and sets the local price. Loads take the price into account in deciding how to operate. Controllers negotiate with each other across gateways to buy or sell power. Battery storage is optional - batteries can increase the reliability and stability of a nanogrid.

```
                Grid or local renewable power
                       |
                       |         +---------------
                       |         |       More connections
         +-------------+---------+----+  to other grids
         |      Nanogrid Controller      +
         +---+----------+---------+----+
             |          |         |
             |          |    +----+----+  All connections
             |          |    | Battery |  include power and
             |          |    +---------+  communications to
             |          |    (optional)   mediate power supply
         +---+---+  +---+---+             to demand
         | Load  |  | Load  |
         +-------+  +-------+
```

Figure 1: Conceptual diagram of a nanogrid

Controllers may resemble existing Power over Ethernet (PoE) switches, however unlike PoE they need not be limited to one device per port. To set the local price, the controller takes into account the price of any utility grid electricity it has access to, as well as the quantity and price of any local power sources. A nanogrid can exchange power with other nanogrids or with microgrids whenever mutually beneficial (as indicated by relative price). This enables optimal allocation of scarce and/or expensive power among loads and among local grids. A price will typically be a current price and non-binding forecast of future prices, up to one day in advance.

Devices that connect to a nanogrid will ship with default price preference functions that make sense given typical grid prices. When a nanogrid is connected to the grid, the grid price will be a strong influence on the local price, though local generation and storage can dramatically change that dependency. When not grid-connected, the local price will reflect the local supply/demand condition, the estimated replacement cost for battery power (which may be future grid power), and an assessment of battery capacity. Nanogrid policies establish the local price and load policies establish the price a given load is willing to pay.

A core principle is to separate power distribution technologies from functional control technology. Power distribution is envisioned to have three layers: layer 1 is power; layer 2 is power coordination; and layer 3 is device functionality. Nanogrids implement layer 2 to improve the efficiency and flexibility of power distribution and use (layer 1), and isolate power distribution from device functionality (layer 3). Separating power coordination from functionality has several purposes. In future usage, devices that are in the same room or otherwise need to coordinate functionally will often be powered differently, and devices that share a power infrastructure may not have functional relationships. Separating power distribution into different functional layers allows each function to evolve separately, greatly easing and simplifying the development of new technologies and deploying them alongside existing products.

To develop useful nanogrid technology we need standards for communication internal to nanogrids, and for communication between them via gateways.

Nanogrids use price to mediate their internal supply and demand with attached loads, and to determine how power is acquired from external grids and exchanged between nanogrids. They require energy price information, common communications protocols and interfaces, and standardized semantics.

3. Benefits

Nanogrids could offer many benefits, broadly including:

- o Local Renewables
- o Storage and Reliability
- o Security, Privacy, and Reliability
- o System Reliability
- o Demand Response
- o Smart Grid
- o New Electricity Users
- o Disaster Relief
- o Military Applications
- o Reduced Capital Costs
- o Reduced Energy Use
- o Mobile and Off-Grid

Nanogrids could provide smart grid benefits at the small (local) scale, a capability we lack today; smart grid efforts only address grid connected and large scale contexts. Nascent nanogrids are common today in digitally managed forms (technologies including USB and Power over Ethernet (PoE)), and unmanaged ones (vehicles, emergency circuits, etc.). However, they all lack the ability to use price as the core prioritization mechanism and lack the ability to exchange power with each other; a fully functioning "managed" nanogrid can do both. Such future nanogrids could be connected in arbitrary and dynamic networks to each other, to microgrids, and to the utility grid.

Nanogrids are a new mechanism for managing power at the local level, useful in a wide variety of applications. They particularly enable more and better use of local generation (including intermittent renewables) and local storage, as well as facilitate "Direct DC" - powering loads with local renewable power without converting to and from AC. Recent studies have estimated 5-13% electricity savings from Direct DC in residences [DIRECTDC], and local renewables also avoid transmission system losses. Many people value local renewable energy more than grid power and value the reliability and certainty of local storage and off-grid capability.

Nanogrids offer the possibility of moving to a less reliable large-scale grid, providing increased quality and reliability locally, and saving capital and energy in a distributed, bottom-up manner. While the smart grid will better match supply and demand at the large scale, we lack mechanisms to do this at small scales. Nanogrids fill this gap. Microgrids are important and necessary, but lack near-term potential for dramatic scale-up of deployment, lack standards-based plug-and-play technologies, lack comprehensive visibility into individual loads, and lack pervasive use of price. Nanogrids build on standard semiconductor and communications technologies already produced at mass-scale, and can be deployed incrementally and at low capital and installation cost. This will enable them to spread rapidly and quickly become a standard fixture in buildings.

While existing nanogrid technologies enable only relatively small loads, there is no power limit to nanogrid loads or controllers. While nanogrids work best with communicating loads, for legacy devices, with one device per port, the controller can implement the load control function itself for on/off loads, as well as variable loads like lights and motors.

By being directly and correctly responsive to the most local conditions of energy supply, storage, and demand, nanogrids can provide price and other control abilities not possible with other technologies which treat electricity distribution at a more aggregated and abstracted level. Nanogrids are also inherently more flexible and should be less capital-intensive than alternatives, and provide a more nimble infrastructure for local generation and storage.

4. Implications for EMAN

The concept of power interface in the current EMAN drafts is consistent with the interfaces that nanogrids have, both those from controllers to loads, and those at gateways between nanogrids. A load could report via EMAN protocols directly, or a controller could report information about loads on their behalf; these are both basic EMAN functions. The role that batteries play in nanogrids is consistent with EMAN's treatment of them.

Nanogrids enable bi-directional exchange of power between grids; recent versions of EMAN documents acknowledge this as a possibility and support it (of course, the power flows in only one direction at any given time). Two existing power distribution technologies, UPAMD and HDBaseT, support bi-directional power flows.

Nanogrids have two characteristics that could be challenging for EMAN to handle and deserve further consideration. The first is that grids can be arranged in any topology and may lack a single "root" as the utility grid generally provides. The second is that connections among grids and connections to loads may be intermittent and dynamic. Accommodating these does not seem contrary to the goals of EMAN, but EMAN semantics could be defined in a way which makes doing so difficult or impossible.

5. Other Implications

Communication internal to a nanogrid will be specific to the particular physical layer technology. USB, for example, could add nanogrid capability by simply extending the existing protocols it provides for coordinating power distribution on USB links. For PoE, it would be possible to do this with LLDP, or with some higher-layer protocol. Communication between nanogrids will require standards for gateways between them that cover both electrical and communications aspects. IEEE is a likely choice for at least most of this. Some of these may benefit from using IETF protocols, though core to the concept of local power distribution is that it only requires communication between immediately adjacent (electrically-connected) grids - just one hop.

Whether or not the IETF is involved in power distribution protocols, most of the devices in future that are on nanogrids, and the controllers themselves, will likely also implement IETF protocols, so that semantic consistency between the two domains would be extremely beneficial. Just as EMAN provides visibility into device power (measurement and control) at the network level, the IETF may want to in future support management protocols for small (microgrid or smaller) grids (that is, not intruding into the utility grid space where other standards organizations are active).

6. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

7. Security Considerations

This mechanism introduces no information security vulnerabilities. A security advantage of nanogrids is that they only need to communicate with other grids (or power sources) to which they are directly electrically connected. This requirement for physical connection greatly reduces their vulnerability, and is in sharp contrast to many grid architectures which require communication across many network links.

8. Privacy Considerations

Nanogrid gateways need only communicate information about the price and quantity of electricity, not about their internal structure or electricity-consuming loads. This makes them exceptionally protective of privacy.

9. References

9.1. Normative References

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9.2. Informative References

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