Micro-Grids

A discussion about the opportunities and issues involved with micro-grids

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Overview

The problem

Today's buildings operate as islands of consumption on the electricity grid. There are few restraints on when and how much energy is consumed. The most common restraint is in the form of published utility tariffs, which provide a combination of price adjustments based on consumption (kWh) and demand (kW). Very few buildings are managed to respond to their respective tariff. Demand limiting (kW) is seldom implemented. Energy conservation (kWh) is usually weakly implemented as part of general conservation program. As alternative energy sources have moved up the priority list very few building owners are prepared to deal with these energy alternatives. Simply put they have neither the technical expertise nor the budget to manage this type of initiative.

The problem is even more complicated where a single building doesn't offer an opportunity to effectively leverage a solar installation or sizable generation capacity, regardless that it uses natural gas, landfill gas, or even pyrolysis gas. Clearly multiple buildings need to be linked into a cohesive operating arrangement with an electrical connection capable of sharing distributed renewable resources.

The opportunity

Micro-grids provide the ability to link buildings into a working arrangement that leverages load management as well as energy sources. It's not enough to mount a solar array on the roof of a building and proclaim this building as "energy efficient because it uses renewable energy". It's equally important that buildings (loads) and generation (sources) be combined into an optimized "source-load management" system. Further, renewable energy source connections cannot be casually installed without significant attention to utility details that mandate certain operating provisions for personnel safety and grid reliability. What's needed is a micro-grid of inter-connected buildings operating as a single entity. It must be capable of managing internal building loads in such a manner that building environmental conditions are reasonably preserved. At the same time it must incrementally provide for load reduction in response to both on-site generation as well as grid generation. It needs to actively involve building participants who can contribute to load management within their personal space while understanding building energy usage needs in the context of available sources. This is not the equivalent of watching a power meter as daily energy usage changes. The most successful installations will keep participants informed but work within an "energy policy" that automatically manages sources and loads. The switch to renewable generation sources requires an approach that leverages technology, people, and creative methods to handle building energy requirements in the future.

Quick Summary

A quick look at the important features of a successful micro-grid involves geography, energy costs, building aggregation and system security.

Geography

Buildings may be located within a relatively close proximity or otherwise within a geographical area that inter-connects within the common utility energy distribution. In some instances several buildings within small regions, each drawing from 500 to 3,000 kW, could be linked together into a single micro-grid. Depending on building sites, alternative generation can be added at one or several buildings.

With buildings already connected to the primary grid, either a separate connection between the buildings is needed or the utility must be able to separate the buildings within the existing grid layout. To avoid service disruption, installation of suitable high voltage connections between nearby buildings may work better.

For micro-grids located in a larger geographical area, the primary grid is needed for local inter-building connections. Distributed energy sources can feed their respective buildings. Micro-grid management involves inter-building coordination in combination with the primary grid operator.

Security

Communications between distributed energy sources, building loads, and each building can be managed using secure Internet communications. Data packets are encoded as AES 256 protocol. Data traffic is socket-to-socket using IP Version 6.

In-building communications uses IP version 6 where available (i.e. wireless 6LoWPAN) or IP version4 to connect with building automation systems. Existing building IT systems may currently offer a VLAN for data isolation between standard communications and dedicated building micro-grid and load management communications. Metering devices can either be connected through the existing building automation system or separately to a dedicated network - wireless or wired.

Outside attack prevention uses a combination of VLANs, encrypted Internet communications, and suitable firewall protection with all web servers. Access to the local network within a building needs to be managed through physical means, such as a combination of RFID wireless devices along with appropriate login and password.

Electrical Costs

Alternative energy sources provide a more effective method for managing off-peak and on-peak energy sources. On-peak conditions typically require all available energy sources whether the tariff includes energy (kWh) price adjustments by time-of-day, dynamic pricing on 5 minute intervals, or uses separate demand (kW) charges. Peak loads for buildings are set by the demand for cooling in the form of extended compressor runtime or full output performance for chillers. Managing peak energy cost requires a combination of operating all energy sources while restricting air conditioning to the building for limited times or in accordance with pre-set environmental conditions (i.e. temperature, humidity, air flow, etc.) Environmental feedback is important to limiting restricted HVAC operations.

Base load energy usage contributes to both peak load and off-peak energy usage. Today's buildings are experiencing significant increases in plug load that often ranges from 30 to 50 percent of total building consumption. In many cases it's not possible to reduce plug loads much during building occupied hours. However, plug load energy management represents an important method for reducing CO_2 from power plant emissions over the long term. Further, reducing unoccupied energy consumption also allows alternative energy sources to be shutdown while power is taken from the primary grid, especially during non-peak periods.

Air conditioning loads can be managed appropriately to minimize peak demand and the need for alternative energy sources. In many buildings it is possible to defer cooling during the 2 to 4 hour peak cooling demand such that building temperatures are not significantly impacted. Most chillers can be demand limited using a 4-20 ma signal. Air handler variable frequency drives also offer an important reduction opportunity. A 10% reduction in supply air reduces motor horsepower by approximately 25%.

Aggregating

In a simple micro-grid installation multiple buildings can be linked via the Internet to reduce loads with or without the use of alternative energy sources. This form of aggregating offers an opportunity to share loads as a function of outside air temperatures, internal building loads, and Demand Response signals.

Micro-grids equipped with alternative energy sources offer a better opportunity to manage energy through the appropriate sharing of energy sources. In some cases, such as linking large schools with commercial office buildings, significant reductions are possible with the installation of only a few shared alternative energy sources.

Major Features

Managing connections to distributed power sources

Effective micro-grid technology provides for distributed/alternative energy sources to connect automatically to the micro-grid. This requires a combination of Phasor measurements (current and voltage) on both sides of the connection along with provisions to automatically sync sources to the existing micro-grid. Alternative energy sources may be distributed over a region requiring communications that can work successfully over the Internet.

Managing the primary grid connection

Each micro-grid connection to the primary grid can be automatically managed along with alternative energy sources. Primary grid management ranges from a complete disconnect from the grid (requiring appropriate hardware) to sharing of primary grid power within the micro-grid itself. The relationships between energy sources, micro-grid loads and primary grid availability is managed using software designed for high performance and high availability.

Managing loads within buildings

Load management within buildings has traditionally been handled by building automation systems. Most BAS installations require hard wiring from sensors to controllers. Regardless of advertised features, programming specialists are required to install, program and assist in load management. Better alternatives use a combination of wireless communications connected to the building communications network or bypass the building Internet connection and connect directly to the Internet using cellular data packet communications.

Optimize sources

Sources can be optimized to use the least costly alternatives. An obvious method to minimize energy cost is to use solar whenever available. The optimization process uses an algorithm that reads building energy, from across the micro-grid, while understanding which energy sources are available and at what internal cost.

Choosing different energy sources by fuel also provides a method of reducing overall energy costs. In practice the choice of fuel source may have more to do with availability (i.e. down for maintenance or other failure) than internal cost of operation.

Rotating energy sources (i.e. engine generators) offer an opportunity to adjust engine speed to more closely match load requirements. This optimization method requires control over the engine speed adjustment – a feature that is not available to all engines.

Building energy sources must operate using an auto switching algorithm designed to handle synchronization and connection. The method varies depending on the source.

Continuous building commissioning

Building internal HVAC operation must be re-evaluated every 15 to 60 minutes for several conditions including:

- Where electrical demand exceeds a known boundary of predicted levels. Boundary levels can be found from analyzing current building interval data and comparing it to outside air temperatures. This type of analysis builds a known history of demand as a function of outside influences, of which outside air drybulb temperature is the most important, as well internal plug loads. Unoccupied plug loads need to be factored separately into the overall building demand such that gradual reductions in plug load can be normalized with historical energy usage through each day.
- Building meter interval analysis provides only a high-level understanding of building load usage. Better decision making is available by using several sub-metering devices throughout a building. This type of sub-metering does not need to be revenue grade which minimizes installation cost.
- All buildings have only a few key HVAC variables that need to be measured to evaluate equipment operating efficiency. Depending on the type of air terminal system installed, air handler discharge air temperature may be the single most important variable. Mixed air temperature also offers important benefits along with a combination of outside air temperature and selected return air temperatures. Chiller supply and return water temperature measurements offer an important opportunity for tracking chiller performance. Several key boiler temperatures/pressures can be used to measure both output capacity as well as overall boiler efficiency. Finding and measuring key building operating variables offers the best opportunity for continuous monitoring and re-commissioning of the building. Every building that promises sustainability needs this type of on-going analysis.

Getting the job done

Cloud-based web services

Ubiquitous connections to the Internet allow the use of Cloud-based web services to support, manage, and provide high-level optimization for micro-grids. Cloud service providers allow for adding more computing services quickly while providing a very high level of service availability.

The use of Cloud services requires splitting access functionality between in-building web servers and Cloud-based services. Specifically, Cloud services are provided for high-level data analysis such as for multiple interval meters and intra-building operating conditions. Data presentation can include complex graphical and tabular analysis.

In-building web services usually delivers sample operating data in the form of tables and simple charts. These services work with locally-connected equipment such as sub-meters and temperature sensors. In-building web servers work with direct connected devices to provide immediate sampling and quick analysis of impending problems. Collected data is made available to Cloud servers for extended analysis.

Packet-based

Data collected within the building is delivered to the Cloud servers as small encrypted packets. Packets are kept small to permit many in-building servers to supply data in as close to real-time as possible. Packet data transport uses Erlang Open Source software developed by Ericsson for telephony switches. It typically operates with 9-9s of uptime. Various libraries, such as RabbitMQ, built on Erlang, simplify coding while leveraging Erlang features. Applications built on Erlang offer the ability to hot-swap code without shutting down the task.

Micro-grid application programming

Coding in traditional languages often inhibits software development because of the skill levels needed and programming environment requirements. A better way to handle application code is to use a very high speed interpreted language such as Lua. Lua is an Open Source interpreted language widely regarded as one of the fastest languages of its type. Working in Lua offers simplicity without compromising speed.

Source and load synchronization

Synchronization between sources and loads needs a method of continuous updating of each source and load capability. One method is to use a single processor to gather data continuously from each machine, run the management and optimization algorithms, then return appropriate variable values to each for local processing. A better way is to use the Mnesia database included with Erlang. Mnesia has the unique characteristic that it is capable of auto-synchronizing tables between multiple Erlang instances. Typically a Mnesia table resides in the controller for each energy source or group of loads. By synchronizing data, including Demand Response requirements and dynamic pricing, local load management algorithms can function equivalent to a single high level processor but in a distributed manner.

Individual load management

Accessing building real-time data

Reading and writing building real-time data requires one or more methods of accessing this data. Buildings equipped with an automation system can usually provide the needed data via an access point such as central controller or web server. In most cases the connection can be made using BACnet. In LonWorks installations it may be necessary to install a separate PC equipped with a LonWorks card or USB device capable of joining the building network. For buildings without an automation system, a separate means is needed to retrieve real-time data.

Automation systems

Leveraging building automation systems is often the easiest method of acquiring real-time data. The exception is that in virtually all cases the automation contractor may be required to either upgrade the hardware or provide on-going support for the installed system.

Building automation systems can be used for additional sub-metering. The offset to leveraging BAS installations is that the available meter monitoring equipment is expensive and may be limited to restricted periodic variable updates because of network limitations. Virtually all building automation systems use RS-485 for internal controller to sensor communications. The practical speed operating limit is usually around 56K – not much faster than dialup modems.

6LoWPAN

A better way to deal with in-building communications, where sub-metering and selected sensors are needed, is to install 6LoWPAN wireless communications. This technology uses IEEE 802.15.4 wireless communications standard, the same as Zigbee. 6LoWPAN is based on IP Version 6, which provides millions of IP addresses beyond the traditional IP 4 address space and uses the same 802.15.4 wireless standard.

Override only

In most cases the best way to deal with load management is to override existing temperature controls. Instead of resetting chiller leaving water temperature from 45 to 50 degrees, it's better to override chiller output using an external signal applied to the demand limiter without regard to the leaving water temperature. Space environmental conditions serve as feedback for regulating demand limiting.

Air handler VFDs offer another way to reduce building loads by forcing a reduction in fan speed. Usually this is handled as an override signal directly to the variable frequency drive rather than through the building temperature control system.

Individual room VAV air supply units usually offer a separate controller pin which can be used to force a box into the minimum position air supply depending how it programmed.

Local Optimization

Building occupancy can provide additional feedback about expected building loads. In many cases air handlers are programmed to run during certain hours regardless of occupancy in the space served. One example is to use occupancy sensors to close off VAV boxes for unoccupied rooms. Usually this feature operates as an override to existing box controls. Another consideration is to limit chiller demand as a function of outside air temperature as well as internal building occupancy. This control method can be used to limit building demand significantly during both occupied and unoccupied hours.

Individual space temperature sensors may be needed to supplement building automation sensing. 6LoWPAN wireless sensors are especially useful for monitoring temperature conditions where it would otherwise be difficult to the use the installed temperature control system.

In buildings with intense occupancy levels, CO2 sensing is an important tool in limiting outside air introduction and conditioning. Classic building outside air intakes open to minimum position when the air handler runs. By regulating outside air introduction for both heating and cooling, energy requirements can be lowered during both peak and non-peak operating periods.

Building-wide optimization

Building-wide optimization requires lots of data. Synthesizing data points from throughout a building is the only way to understand and adjust primary heating and cooling equipment. The type of analysis required for this type of optimization to succeed is usually operated as a separate application on the Cloud server.

Expected building energy usage may well be handled best through building simulation where a family of curves (i.e. neural net or other method) is populated with expected operating conditions. Simulated building operating results offers a good way to check building performance from interval data. This includes both interval data from heating sources (gas meters) as well as electricity.

For predicted daily weather it is possible to estimate daily energy usage. This type of prediction can be used to anticipate which alternative energy equipment is expected to run that day. This ability to sync to energy sources by predicted loads can help queue energy sources for that day.

Supplemental

Awareness

Building occupants need to be aware of building energy consumption on any given day. By making expected building energy usage and demand levels available to occupants, the system can build a higher level of participation in daily building energy management. Awareness information is best delivered by a high-level application running on the Cloud server. It needs to query building real-time information, weather bureau predictions (NOAA), as well as expected occupancy conditions. Properly done it is possible to provide a simple graphic of expected energy usage, actual energy usage, and contributions to conservation by occupants – preferably by location in the building.

Interactive participation

Simple energy information presentations offer a first-level opportunity to describe building energy operating information. To enhance the experience, the ability to drill down into building operations can be added to the awareness program. Drill-down features normally appeal to only a sub-set of occupants. Still, those individuals taking the time to understand more about the building energy usage, especially as it changes throughout the day, can offer their experience to others as their own contribution to energy conservation leadership. Drill-down features are also provided for building management where specific equipment operating characteristics can be provided using graphical and tabular data. In some cases it may be important to use a high-level awareness presentation as the means for individual occupants to adjust their local space temperature setpoints.

Personal Energy Rating

Another interesting opportunity is to create a Personal Energy Rating (PER) score for occupants. This type of rating requires additional data be collected from individual work areas. Wireless collection methods offer the best technology for collecting this type of data. Nevertheless, the more information each occupant has about their personal energy usage, the more active that individual can be in contributing to overall building energy conservation.

Social sharing

Today's interactive social websites provide the ability to share common experiences. This suggests that the awareness application also include a sharing opportunity. A simple informational forum may work at one level as a source of collective building operating knowledge. Twitter accounts may work best where property management staff is making changes to equipment operation or especially where the ability to convey current building energy information is important. One example is where occupants are delivered current building Demand Response levels or outside air temperatures are high enough to require chiller demand limiting. Making this information available on a continuing basis provides an effective way to keep occupants in the building energy information loop.

BIM – Building Information Modeling

BIM offers an important method of navigating and documenting building construction and operating information. BIM is most commonly used during new construction and remodel. But BIM also offers an interesting opportunity to interactively view building operations in 3D. BIM modeling software is now available running from Cloud servers capable of accepting and displaying real-time building information. BIM derived buildings can float on Google Earth to provide a quick navigational method for viewing and changing building operating information. (See http://www.youtube.com/watch?v=nbsnBLg8Yfg)

OpenLynx

Most building automation system vendors provide a way to generate 2.5D renderings of HVAC equipment. Each rendering can display multiple real-time data points as well as allow the user, with suitable permissions, to change key operating variables. Building these renderings, in most cases, requires custom software with appropriate licensing. One way to provide equivalent functionality is to use Open Source software such as OpenLynx. This approach uses non-proprietary methods that allow contributors from around the world to build 2D representations of HVAC equipment.

Sub-metering

Building internal sub-metering offers the opportunity to localize energy usage to a tenant or operating group within a building. Green leases, for example, need tenant energy usage feedback to measure energy performance. Sub-metering also offers a the ability to locate unusual energy usage patterns within the building.

Coding

Requirements / speed / distributing processing / data sharing

For the most part the type of coding required for micro-grid management needs to be fast, predictable and capable of running in a small memory footprint. It needs characteristics much like programmable ladder logic but with the flexibility of being able to swap out an application in real-time without shutting down the process. It needs to leverage the Internet using socket-to-socket communications while hiding some of the details from programmers, such as that offered by Erlang/RabbitMQ.

Speed requires quick data transfers such that moving data within a micro-grid needs to avoid the verbose syntax of typical XML communications. By contrast, XML offers the best way of sharing data between Cloud applications, especially where multiple software vendors are providing various apps.

Data sharing, even within a single microprocessor, usually uses socket communications as a common method for moving data between tasks. Shared data methods, where memory can become corrupted by an accidental overwrite, should be avoided. Shared memory and semaphores, for example, offers some interesting performance options but only at the expense of blocking a task while it waits for data to arrive. Better methods use non-blocking socket communications where a task can continue on with other work while it waits for data to arrive. Any method that causes a machine to block or potentially lockup is not acceptable at the real-time level on the micro-grid.

Open Source

All coding should be built on Open Source libraries and methods. Previously mentioned Erlang, RabbitMQ, and Lua provide the type of world-wide support for what are effectively premium performance coding methods.

Real-time processors for the micro-grid should run on Linux. Selected tasks can be given higher runtime priorities. Computational work can be divided into multiple tasks, each optimized for performance. Inter-task communications is best handled through socket data exchanges to prevent lockup conditions while keeping performance at highest levels.

Separable operation

Each task should be separable from the others without causing the system to crash. While a given task may need data from another to properly execute its algorithm, it nevertheless should be able to handle other functionality regardless of the failure of a other tasks within the system.

Easy to add sources and loads (auto-discovery)

Sources and loads must use auto-discovery methods, such as Avahi, to provide a seamless control method for the micro-grid. IP version 6 provides for auto IP generation based on MAC addresses as well as auto IP changing if a conflict is discovered with other devices on the Internet. Avahi facilitates service discovery on a local network where Erlang tasks are registered as a discoverable service.

Remote management / distributed loads / web browser access

The micro-grid must be capable of remote management. This suggests that access methods and operating permissions need to be supplied such that users from outside the micro-grid network can view and change operating parameters. Access, for the most users, needs to be via web browser. Certain features may require a Windows application but for most (if not all functionality) micro-grid management needs to be handled through a browser application running from either the Cloud or from in-building edge routers.

MMI / features / use

Basic man-machine interface needs to be simple to view and use. The most basic MMI depicts micro-grid operating parameters within one or more tables. Content can be updated continually using poll methods or a Flash application might offer a more comprehensive view of micro-grid operations.

Default operation / watchdog timer

Each real-time microprocessor needs to have a built-in hardware watchdog timer capable of resetting the machine if the software halts. The reboot calls typical Linux OS files to properly restart all processes and initialize appropriate variables.

Data security /AES 256 / firewalls

All data transfers between microprocessors should use AES 256 encryption. Individual building web servers, where used, should incorporate a suitable firewall to prevent casual machine access both remotely and on-site.

Load Management

Conventional T-stats

Buildings equipped with classic pneumatic control systems or standalone electric thermostats require a separate method for control and monitoring. Pneumatic control override may need a digital-to-pneumatic controller to override damper position or discharge air temperatures.

Temperature, CO_2 and sub-metering are needed to provide feedback to the micro-grid. Two alternatives are available: wired and wireless. Unless there is some compelling reason to use wire, wireless 6LoWPAN devices offer the best alternative.

BAS installations

For buildings equipped with an automation system it may be easy to leverage it to read and write variables to building HVAC equipment. The downside to using an automation system is that using it can significantly complicate the installation and increase system cost.

6LoWPAN

Wireless communications offers a relatively low cost and effective way of reading real-time data from the building. The tradeoff, however, is that installation methods are not widely understood. Some considerations include:

- Conflict with local WiFi units where the 6LoWPAN units are operating on the same or nearby frequency. Provision is included with 6LoWPAN devices to change the frequencies when necessary. Signal throughput measuring devices look for retransmissions on errors, for example, as one indication of a problem.

Summary

Micro-grids may offer the best alternative to managing multiple types of energy sources a collection of buildings. Packaging hardware and software as a plug-and-play solution offers an interesting market-delivery method that contains costs while exploiting various forms of energy sources.