Microgrids, Virtual Power Plants and Our Distributed Energy Future

Opportunities for VPPs and microgrids will only increase dramatically with time, as the traditional system of building larger and larger centralized and polluting power plants by utilities charging a regulated rate of return fades. The key questions are: how soon will these new business models thrive – and who will be in the driver's seat?

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I. Introduction

Microgrids may be a hot topic among those forecasting key future trends shaping the world's energy infrastructure, but few significant state-of-the-art commercial microgrids are actually up and running in North America, the world's leading market for microgrids. One leading domestic developer goes so far as to claim that not a single advanced microgrid is providing energy services today in the U.S. (although the firm uses a very narrow definition of what a microgrid is.)

At present, regulations governing energy have not kept pace with emerging microgrid ''islanding'' technology (definition below), frustrating immediate progress. Most of the public and private investment dollars pouring into modernization of the globe's electric grid have been soaked up by utility Smart Grid deployments, with very little funding filtering down to the microgrid level of design and

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deployment. *Of the $4.5 billion allocated from federal American Recovery and Reinvestment Act (ARRA) stimulus spending on Smart Grid-related spending, only $55 million – 1.2 percent – flowed to projects that advanced microgrid technologies.*[1]

Academics from the University of Wisconsin-Madison – an institution often credited with the birthing of the microgrid concept (at least in engineering terms) – predict it could take 30 years for the microgrid to become ubiquitous.[2] Yet current trends appear to make microgrids an inevitable augmentation of today's centralized grid infrastructure. Aggregation platforms for distributed energy, storage, and multiple customer loads similar to microgrids will be absolutely necessary if our energy infrastructure follows in the footsteps of telecom and the evolution of today's Internet. No doubt the existing radial transmission grid will still provide the majority of power supplies to the industrialized world. But renewable distributed energy generation (RDEG) will also play a larger role in providing energy supply, reliability, security, and emergency care services.

Given consumer pushback on smart meters – the very underpinning of the utility-dominated ''Smart Grid'' – in California, Texas, Colorado, and elsewhere, the microgrid represents an alternative business model for boosting the quality of grid services, particularly for end users. It is becoming self-evident that the hype behind the Obama administration's stimulus spending on Smart Grid upgrades raised expectations to unrealistic heights. Furthermore, utilities focused too much on the benefits meter data might bring to their own operations – and forgot to connect the dots with consumers, many of whom saw only higher bills, and no coordinated programs to respond to real-time price signals with tools that boost efficiency. And then there were the concerns about data security.

Perhaps the most compelling feature of a microgrid is the ability to separate and isolate itself from the utility's distribution system during brownouts or blackouts.

The microgrid is one choice to aggregate, manage, and deploy distributed energy resources, particularly during a grid outage. Another aggregation option that is actually dependent upon Smart Grid upgrades is the concept of a ''virtual power plant'' (VPP). Both of these aggregation platforms are emerging as viable options to boost reliability, shrink capital costs related to peaking generation plants, and tapping demand response (DR) resources that can help mitigate impacts of an increasing reliance upon variable renewable resources such as solar and wind power.

II. Definitions: Microgrid

Microgrids have a long history. In fact, Thomas Edison's first power plant constructed in 1882 – the Manhattan Pearl Street Station – was essentially a microgrid, since a centralized grid had not yet been established. By 1886, Edison's firm had installed 58 direct current (DC) microgrids. However, shortly thereafter, the evolution of the electric services industry evolved to a state-regulated monopoly market, thus removing incentives for microgrid development.

The fundamental concept of a microgrid can be summed up as follows: an integrated energy system consisting of distributed energy resources and multiple electrical loads operating as a single, autonomous grid either in parallel to or ''islanded'' from the existing utility power grid (**Figure 1**). In the most common configuration, distributed energy resources are tied together on their own feeder, which is then linked to the larger grid at a single point of common coupling.

Perhaps the most compelling feature of a microgrid is the ability to separate and isolate itself – known as ''islanding'' – from the utility's distribution system during brownouts or blackouts. Under today's grid protocols, all

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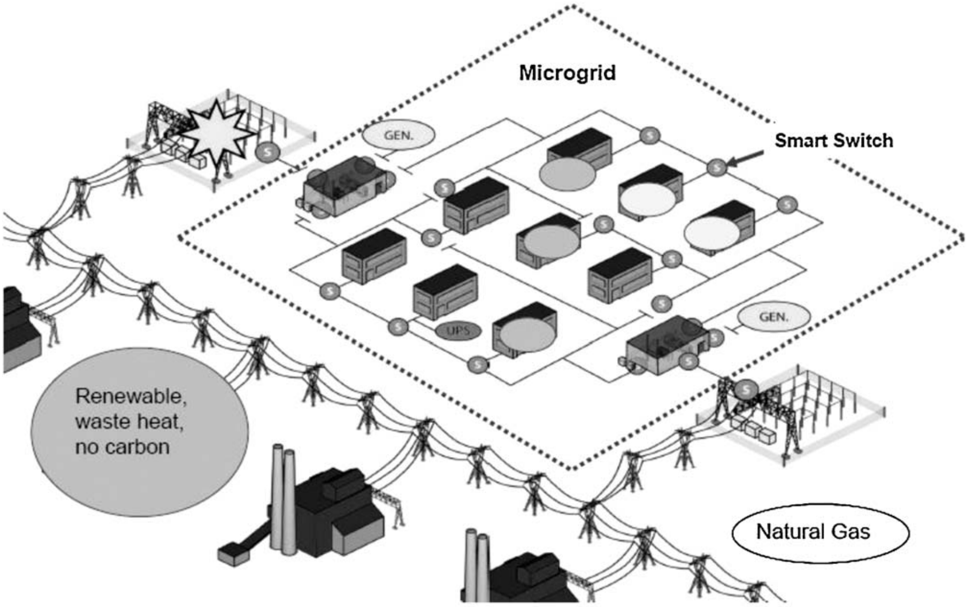


Source: Galvin Electricity Initiative

Figure 1: The Microgrid Paradigm

distributed generation, whether renewable or fossil-fueled, must shut down during times of power outages, unless it can control voltage and not feed power back to the larger utility grid. This fact exasperates microgrid advocates, who argue that this is precisely when these on-site sources could offer the greatest value to both generation asset owners and society. Such sources could provide power services when the larger grid system has failed consumers. With additional technological advances and engineering and government standards, these microgrids could also provide ancillary services that would help their host distribution utilities maintain reliability at a lower overall cost.

Recent advances in inverters, necessary for solar PV and small wind turbines to convert DC generation into alternating current (AC) at a 60 hertz voltage level to synchronize with the utility grid, are setting the stage for a viable microgrid market to evolve. New inverters allow for safe ''islanding''; they enable these RDEG renewable to continue to operate when the larger grid goes down, thus avoiding the feeder fault concerns associated with synchronous generators, which may take 2, 5 or even 10 seconds to respond to a grid outage.

Utility engineers have historically opposed the concept of ''islanding'' on the basis of safety and lack of control of the distribution grid. The Institute of Electrical and Electronics Engineers' standard P1547 requires an automatic and rapid disconnection of all DEG during grid outages. For well over five years, the IEEE has been working on developing a ''guide'' on islanding. This guide – P1547.4 – received a 90 percent approval in voting in late 2009.[3] This standard will finally be published by spring 2011. This vote is a major step forward, as not only does it spell out safe utility protocols for islanding, but puts into place standards for reactive power, which will allow microgrids to sell ancillary services to distribution utilities much in the same way as DR providers currently do in well-developed markets such as the Pennsylvania-New Jersey-Maryland (PJM) transmission grid control area. Though P1547.4 may not become a binding standard for utility operators for another five to 10 years, it is a major milestone for this emerging industry.

Inverters are not limited to renewable energy sources. In fact, the Tecogen technology that has been commercialized thanks to the R&D efforts by CERTS is a 100 kW combined heat and power (CHP) generation technology that can not only deliver both electricity and heat from a single fuel, but safely island a microgrid via its inverter. ''Smart'' inverters are also being conceived that could allow microgrids to access smart meters and tap peak power pricing programs to help deliver ancillary services to the distribution grid, too.

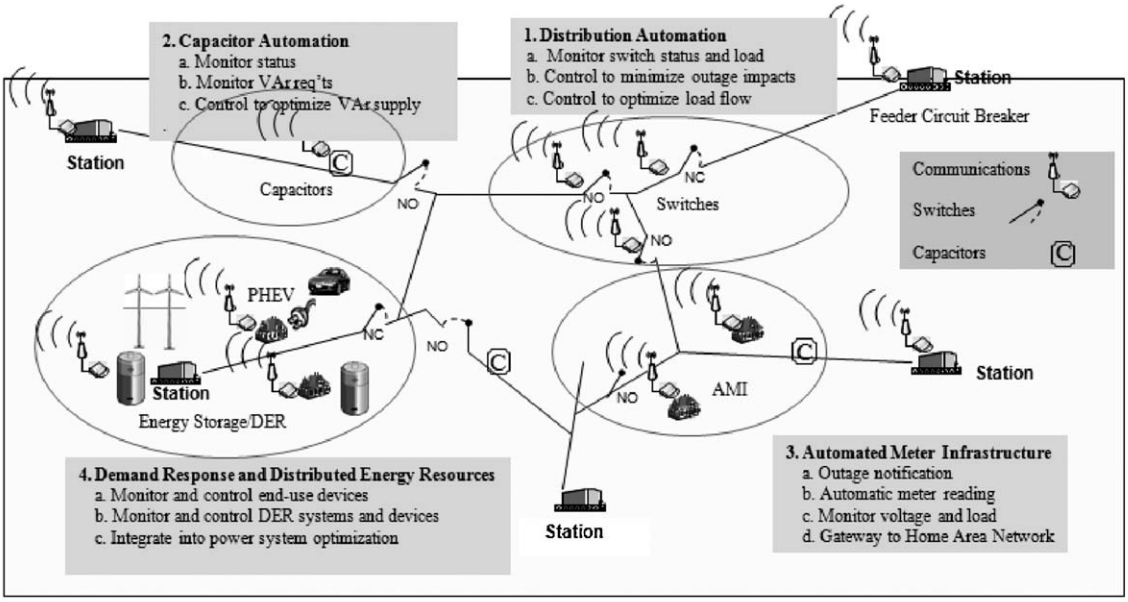
III. Definition: Virtual Power Plant

Virtual power plants – a term frequently used interchangeably with ''microgrids'' – rely upon software systems to remotely and automatically dispatch and optimize generation or demand-side or storage resources in a single, secure Web-connected system. In short, VPPs represent an ''Internet of energy,'' tapping existing grid networks to tailor electricity supply and demand services for a customer, maximizing value for both end-user and distribution utility through software innovations (**Figure 2**).

In Europe, a VPP typically refers to aggregating supply side resources, most often a diverse pool of RDEG and/or wholesale renewable energy sources. One such research and development project in Germany – which has also been deemed a ''regenerative combined power plant'' – was awarded the German Climate Protection Prize for 2009.[4] But the term VPP can also refer to the ability of commercial consumers in countries such as Denmark to purchase capacity at the wholesale level via an auction from baseload fossil fuel facilities for short periods of time.

In the U.S., a VPP may not involve generation sources at all. Instead, these VPPs tap utility demand response (DR) and critical peak pricing (CPP) programs as resources that, when aggregated, can mimic characteristics of a traditional power plant delivering peak capacity, energy or grid reliability regulation services when called upon by a utility or independent system operator (ISO).

Without any large-scale fundamental infrastructure upgrades, VPPs can stretch supplies from existing generators and utility demand reduction programs, delivering greater value to the customer (lower costs, new revenue streams) while also creating benefits to the host distribution utility (avoidance of capital investments in grid infrastructure or low-capacity



Source: American Electric Power

Figure 2: Diagram Displaying VPP Versatility

peak power plants) as well as the transmission grid operator (regulation services such as spinning reserves). When compared to the fossil central station power plants that dominate electricity markets worldwide, one of the primary advantages of VPPs is they can react quickly to changing customer load conditions, are dynamic, and deliver value in real time.

The beauty of the VPP is that it can optimize the entire system, and deliver much greater value, without the need for large capital investments in infrastructure and corresponding long lead times for implementation. Customer-owned generation sources, utility designed DR and CPP – and even plug-in electric vehicles (PHEV) – all become eligible candidates to help utilities solve grid balancing challenges. It seems likely that the best way to deal with this increasing complexity evolving at the distribution level of service today is a VPP or microgrid topology – or perhaps both layered on top of each other.

The VPP, in short, meshes the unique characteristics of all of these potential resources into a ''virtual'' facility that can be organized by program type, supply-side resource category, or location on the distribution network. VPPs are really geared to helping utilities cope with the Smart Grid by aggregating a meaningful number of RDEG and/or DR customers to reap the rewards of economies of scale in a whole new way. Instead of building bigger and bigger physical power plants, software and other controls enable utilities to aggregate resources on a short-term basis according to proximity, cost, environmental performance, and/or other criteria. Like the microgrid model, VPPs are inherently flexible and modular. Since IT systems and corresponding software is the ''glue'' holding the VPP together, resources can easily be swapped in and out, depending on the ever changing requirements to keep grids in balance or to lower customer costs or displace dirty fossil generation during peak periods of demand.

The beauty of the VPP is that it can optimize the entire system without the need for large capital investments in infrastructure.

A key distinction between a microgrid and a VPP is that the latter is not limited by geography and a static set of resources (as is the typical microgrid.) With its emphasis on smart meters, real-time pricing and DR, the Smart Grid is actually a necessary prerequisite for VPPs. *What distinguishes a VPP from the smart grid is that most VPPs (at least in the U.S.) attempt to create a mini-ISO on the customer side of the meter to optimize energy resource aggregation.* VPPs are likely a natural evolution of the smart grid and are highly synergistic with the more sophisticated billing systems that are emerging as hallmarks of ''backroom operations'' supporting the rollout of the smart grid.

IV. Microgrids Versus VPPs

VPPs and microgrids share some critical features, such as the ability to aggregate DR, RDEG, and storage at the distribution level. *Some market participants estimate an 80% commonality between these two business platforms, yet there are some (usually) defining differentiators*:

- Microgrids can be grid-tied or off-grid remote systems (VPPs are always grid-tied);
- Microgrids can ''island'' themselves from the larger utility grid (VPPs do not offer this contingency);
- Microgrids typically require some level of storage (whereas VPPs may or may not feature storage);
- Microgrids are dependent upon hardware innovations such as inverters and smart switches (whereas VPPs are heavily dependent upon smart meters and IT);
- Microgrids encompass a static set of resources in a confined geography (whereas

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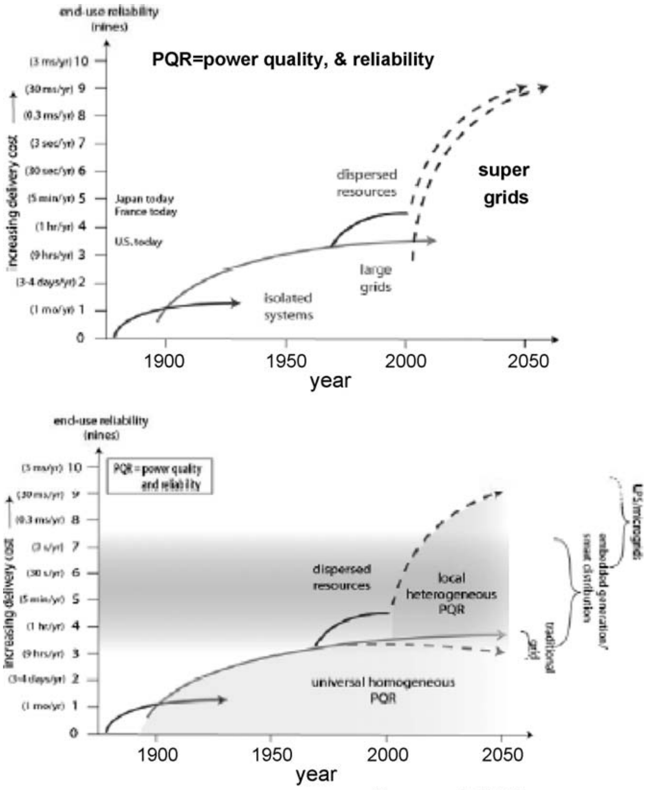
VPPs can mix and match among a diversity of resources over large geographic regions);

- Microgrids typically only tap DER at the retail distribution level (whereas VPPs can also create a bridge to wholesale markets); and
- Microgrids still face regulatory and political hurdles (whereas VPPs can, more often than not, be implemented under current regulatory structures and tariffs).

Due to the lack of current standards, a variety of microgrid models are proliferating. Some are focused on reliability just within the microgrid itself, whereas others are focused on maximizing economic opportunity by selling excess energy services to the larger grid. Some models that cross-over to the VPP category would operate on the transmission side of the substation – aggregating, optimizing and then dispatching – though the vast majority would function below on the distribution side. For the military, the value proposition is security, cyber and physical, since the term ''emergency'' is a 24/7 matter. (With mobile applications deployed during combat missions, microgrids can literally be a matter of life and death when it comes to minimizing reliance on liquid fossil fuels.) Still other microgrids never interact with any larger grid, and are focused on reducing diesel fuel consumption and optimizing the relationships between otherwise disparate generation or customer loads.



Source: LBNL

Figure 3: Super Smart Grids Versus Microgrids

V. Smart ''Supergrids'' Versus ''Dumb'' Microgrids

The goals of the Smart Grid, VPPs, and the microgrid are the same: to maximize services provided by generation and storage assets through embedded intelligence while dramatically boosting efficiencies, thereby minimizing costs. However, the Smart Grid and microgrid appear to offer two potentially different paths forward, as depicted in **Figure 3**, from Lawrence Berkeley National Laboratory.[5]

The ''supergrid'' vision (focused on transmission upgrades rather than distribution line optimization) is still heavily dependent upon centralized power plants, subject to the whims of volatile bulk power markets, and is therefore inherently insecure. In contrast, the microgrid paradigm is all about boosting efficiency at the local level for electricity and heat recovery (through small CHP plants), the provision of heterogeneous power quality based on end-user customer needs, and minimizing investments in the bulk power transmission level infrastructure. The VPP attempts, in essence, to straddle these two worlds, focused on innovation at the distribution level, but rather than focused on precise needs of individual end users, attempts to optimize a wide and ever-changing mix of distributed resources to serve the larger grid at both distribution and transmission levels of service.

Today's distribution grid network is clearly inadequate to support the type of innovation now occurring with distributed resources, including devices such as plug-in hybrid electric vehicles (PHEV) serving as distributed storage batteries. The question is: Do we need bottom-up or top-down innovation?

Microgrids installed in developing nations or rural regions of the United States may be quite simple, even ''dumb,'' if compared to the hyperbole often attached to descriptions of the Smart Grid. The Consortium for Electric Reliability Solutions' (CERTS) demonstration projects involving the University of Wisconsin, American Electric Power, federal Department of Energy, and California Energy Commission show that microgrids do not necessarily need to rely on all of the sensors and fast, real-time communication protocols that are hallmarks of the smart grid.

VI. Microgrid Control Systems: Purists and Pragmatics

Among the current microgrid control options are centralized management systems requiring high-bandwidth links between the inverters and central controller. Other prototype microgrids rely upon distributed on-board control that reduces the bandwidth needed – but at the cost of synchronization difficulties. More recent work has investigated a hybrid control scheme where proximate inverters operate in a master/slave arrangement. Still others are focused on remote or smaller microgrids sticking with common frequency droop method, commercialized through the CERTS work, which greatly reduces the need for any high-bandwidth communications over large distances.[6]

Control systems fall into two major camps. The *purists* – epitomized by the CERTS software – believe that microgrids should operate without any central command and control system, with generators and loads harmonizing autonomously based on local information. This is the view espoused by leading academics and localization advocates and the rationale is compelling. This system will work for the majority of smaller microgrids with a single owner and whose top priority is reliability and sustainability during emergencies. These are the ''dumb'' microgrids, if you will.

In the other camp are what you might call the *pragmatists*. They lean toward systems that can be described as ''master/slave,'' (whereas the CERTS approach has been described as being ''like a commune.'') These operating systems are much more focused on optimization of services outside the microgrid. The benefits of reliability may come second to generating new revenue streams from excess generation (or even demand reductions.)

There are also those systems that can straddle these two views. There are few clear cut direct competitors in the space since no standards exist and microgrids are so modular, diverse, and optimize such a broad array of energy-related services. It is these control systems – still literally being defined – where the fiercest competition may reign within the microgrid space. This is the guts of the microgrid, if you will, and the focus of current software innovation. Companies such as Viridity Energy, General Electric, EDSA, and Power Secure are all competing with their respective software/hardware systems, with no clear winner in sight. Since microgrids are so modular and can be optimized for such a variety of goals, it is likely that there will always be a mix of control approaches.

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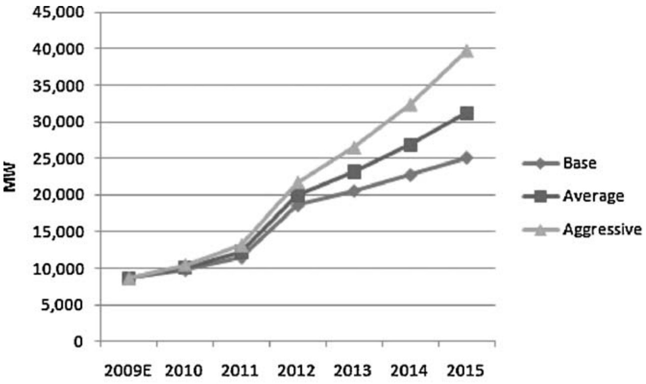
VII. VPPs: Market Forecasts

Unlike microgrids, utilities will have to play a major role in the evolution of the VPP market. With its emphasis on smart meters, real-time pricing, and demand response, the Smart Grid is actually a necessary prerequisite for VPPs. *What distinguishes a VPP from the Smart Grid is that most VPPs (at least in the U.S.) attempt to create a mini-ISO on the customer side of the meter to optimize energy resource aggregation.* VPPs are likely a natural evolution of the Smart Grid and are highly synergistic with the more sophisticated billing systems that are emerging as hallmarks of ''backroom operations'' supporting the rollout of the Smart Grid.

Developing market forecasts for a nebulous technology category of ''virtual power plants'' is a daunting task. Competing definitions, temporary aggregations of highly divergent technologies, and resources that may only be tapped for minutes (or even seconds) at a time, all add up to complexity and uncertainty. A market forecast, published in fall 2010 by Pike Research,[7] divides up the VPP universe into four distinct segments:

- ***DR-based VPPs***: This is the largest commercial segment in the U.S., since the U.S. has the most mature DR market in the world (**Figure 4**).
- ***Supply-side VPPs***: Europe, particularly Germany, has led the world in this category, though most of the projects have been R&D pilots, with only a handful of VPPs in commercial operation.



Source: Pike Research

Figure 4: DR-VPP Capacity Worldwide, Base, Average and Aggressive Scenarios, 2009–2015

- ***Mixed-asset VPPs***: This is the ultimate goal of the VPP, bringing distributed generation and DR together, to provide a synergistic sharing of grid resources to squeeze out more value, thereby reducing capital costs. Few of these projects are in commercial operation today.
- ***Wholesale auction VPPs***: Unique to Europe, VPP auctions have been used in Europe as a condition of mergers, requiring asset owners to auction off base-load and peaking capacity to bidders under short- and long-term contracts. Unlike the category of supply-side VPP segments, these resources are typically traditional centralized power plants burning fossil fuels.

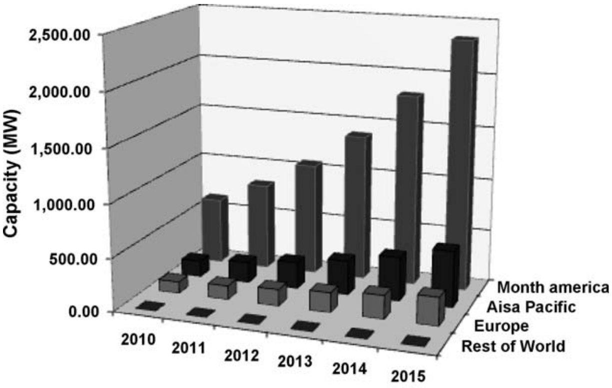
Pike Research has developed market forecasts for each of these four segments. All told, the total current VPP capacity worldwide is 19,428 MW. The largest segment is wholesale auctions exclusively in Europe, but which represents 51 percent of the total VPP market. The next-largest segment is the DR-based VPPs which dominate the U.S. market, with 44 percent of the total global capacity. The supply and mixed-asset segments split the remaining 5 percent of the VPP market virtually equally. The total revenue from VPPs worldwide is almost $5 billion, with the vast majority (90 percent) of that revenue stream captured by the wholesale auction VPP segment.

Over time, it is expected that many supply-side VPPs will morph into mixed-asset VPPs, as more cost-competitive storage enters the market and as DR resources continue to grow in terms of capacity and sophistication. Ultimately, the market for VPPs will likely undergo an evolution where the lines between the first three segments profiled will blur further.

The last category of VPPs – wholesale auctions – is, at present, a uniquely European phenomenon, yet it dominates the revenue side of this broad business category. It is possible that this regulatory approach to offsetting market power potentially created by mergers could spread to Asia or other regions of the world, but there are no current data or trends that can support a valid market forecast.

VIII. Microgrids: Market Forecasts

Perhaps guilty of getting caught up in the Smart Grid (and microgrid) hype, the 2009 market forecast was fairly robust, showing over 3 GW of accumulative global capacity by 2015 (**Figure 5**).[8] It attempted tried to bridge the gap between what the Galvin Electricity Initiative (GEI) so exuberantly proclaimed would be achieved in 2010 (with 300 microgrids up and running in the U.S. alone) and microgrid forecast developed by Navigant Consulting issued in 2006, which offered an accumulative range between 1 and 13 GW of microgrids globally by 2020.



Source: Pike Research

Figure 5: 2009 Microgrid Forecast: 2010–2015

Among the key assumptions underlying the 2009 forecast that are being adjusted for a 2010 update are the following:

- The U.S. still has not implemented a meaningful carbon regulation regime, which the 2009 Pike Research market forecast assumed would have been enacted by now given the political dynamics of last summer. The failures at Copenhagen in 2009 and the U.S. Congress in 2010 have slowed down the rush to implement energy projects that cut carbon emissions – including microgrids that aggregate RDEG.
- The lack of a clear market for carbon-free energy hindered the evolution of the green technology/green jobs sector, further dissipating momentum in green power and distributed energy markets, reducing the need for near-term microgrids.
- The stimulus funds deployed on behalf of the Smart Grid have, in some cases, been frittered away on poorly designed rollouts of smart meters and automated meter infrastructure and have underwritten utility overhead charges instead of creating new jobs linked to thoughtful and effective grid upgrades (including microgrids).
- The regulatory support for microgrid developments have yet to coalesce in the U.S. and throughout global markets, though there is some legislative activity in regard to military applications – one of the most promising near-term market opportunities – and within engineering circles at the IEEE.

Since the 2009 report, several new microgrid projects have popped up, especially in the military sector. One of the largest microgrids in the world – 48 MW – may be up and operating as you read this article at the University of California-San Diego.[9] Dozens of projects are on the drawing board, yet the lingering economic recession and lack of any single policy framework to accommodate microgrids will still limit opportunity over the next five years. Navigant has decided not to update its 2006 forecast since little progress has been made in the U.S., or globally, to specifically promote microgrids.[10]

At present, there is no agreed policy in any major market as to how microgrids will behave under different operating conditions, distinguishing, for example, between periods of light or heavy demand, with or without connection of loads to the larger grid or after communication failures. Also problematic is the potential for generators and loads and other components in a microgrid to be owned by different entities, perhaps with conflicting interests. In the long run, public policies will be needed to address how to apportion investment and maintenance costs between multiple owners, what loads are disconnected in the event of faults and what compensation (if any) should be applied in the event of power loss. In short, what may be needed is the equivalent of ''integrated resource planning'' at the distribution level of service.

It is one thing for the owner of the microgrid to take care of its energy supply and security needs within the walls of its system. What about grid operators such as an ISO? In order for microgrids to serve the needs of the larger grid, resource management systems may be necessary so that microgrid resources can be scheduled or called upon in the same way as DR resources.

IX. Conclusion: New Utility Business Models Are Inevitable

Both microgrids and VPPs represent a vision of the future in which traditional utilities face unprecedented challenges and changes, according to Peter Fox-Penner, a principal with the Brattle Group consulting

Fox-Penner sees two futures for utilities.

firm and author of a new book about the future of ''smart'' utilities.[11]

''Today, the electric power industry faces challenges far larger than any in its history. A system of nearly 1 million megawatts, operating mainly on fossil fuels, will require a trillion-dollar retooling in the span of the next several decades, ''writes Fox-Penner. Not only must old, polluting, and centralized power plants be swapped for new ones on a massive scale, but new regulatory schemes and industry structures must be worked out, while the lights stay on and industrial motors keep humming along. ''It is like rebuilding our entire airplane fleet, along with our runways and air traffic system, while the planes are all up in the air filled with passengers,'' he writes.

Fox-Penner sees two futures for utilities.

In his first scenario, regulated utilities turn into *''smart energy integrators''* that operate an energy delivery and information network *but no longer own power plants or even sell power into the grid*. These new utilities keep supply and demand in balance and run Smart Grid programs enabling customers to shift their electricity usage as prices change during the day, or swap power in and out of the larger utility grid from hybrid vehicles. Customers choose their own private or public power providers as well as energy efficiency service contractors.

Utilities operate under an *''energy services utility''* in his second scenario. Under this model, utilities still deal directly with customers – unlike the energy integrator – and they continue to operate the grid, and may or may not own power plants. Instead of just selling electricity, however, the services utility may also sell heat, cooling, or lighting (just as Thomas Edison did in the late 19th century), exploiting new technologies to achieve efficiency and thereby boost profits.

Under either one of these provocative newly envisioned utility business models, opportunities for VPPs and microgrids will only increase dramatically with time. I believe other potential new business models are quite possible. But under virtually every conceivable scenario, the traditional system of building larger and larger centralized and polluting power plants by utilities charging a regulated rate of return is dead after more than a century of dominance. *The key questions are: how soon will these new business models thrive – and who will be in the driver's seat?* ■

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