The Emerging Enernet: Convergence of the Smart Grid with the Internet of Things

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***Abstract* -- Bob Metcalfe, inventor of the ethernet and well-known technology visionary, once said, "Over the past 63 years, we met world needs for cheap and clean information by building the Internet. Over the next 63 years, we will meet world needs for cheap and clean energy by building the Enernet." The Internet has resulted from revolutionary advances in electronics, telecommunications and information technologies, devices and applications. While it began as an Internet connecting people, by 2008 it connected more things than people. Its exponential growth has been primarily as an Internet of Things. Cisco has predicted that 50 billion new connections will be made in this Internet of Things (IoT) by 2020. The U.S. electric utility grid has until now been a patchwork of monolithic, weakly interconnected, synchronous AC grids powered by a few thousand or so very large power plants that are centrally monitored and controlled. For a variety of reasons this legacy grid approach is proving to be non-viable for the present and the future. It is being supplemented and may ultimately be supplanted by many, smaller networks with literally millions of distributed generation, storage, and energy management nodes. The grid is literally exploding into a network of things. Many consider it to be the largest example of an Internet of Things. The Enernet will be the inevitable convergence of the smart grid with the Internet of Things. Utilities, their customers and non-utility will find it necessary to plan, engineer and operate in the presence of orders of magnitude more devices and systems (e.g., smart nodes on the utility systems and, for consumers, smart thermostats, appliances, PHEVs/EVs, distributed generation / storage, premises monitoring, automation, and EMS, even transactive energy markets) ultimately leading to billions of new points that require monitoring, analysis and management. Meanwhile, the Internet of Things steadily grows more ubiquitous, powerful, economical and secure. It is an obviously attractive platform for the smart grid or, as Metcalfe has said, the control plane for the smart grid. The purpose of this paper is to discuss why and how the production and utilization of electric energy will become inseparable, even indistinguishable from the Internet of Things.**

***Index Terms*—Enernet, Internet of Things, Kurzweil's Law, Microgrid, Singularity, Smart Grid, Smart Node, Smart Meters.**

INTRODUCTION

The U.S. electric grid is approaching a singularity, a point beyond which it will be unrecognizable in terms of the physical, institutional and economic principles that apply today. The singularity concept originates in astrophysics for black holes but has been more recently applied by futurist visionaries including Vernor Vinge and Ray Kurzweil to the results of technological advancement. They predict that we are approaching a singularity, a point at which technological advances result in computers that individually and collectively have intelligence greater than that of the human brain. [7] They posit a world in which humans use technology to transcend these limitations of their biological bodies and brains to the point that there will be no distinction, between human and machine. Similarly, this paper will discuss new circumstances and accelerating advances in technology that are propelling the grid toward a singularity beyond which there is an entirely new kind of grid. Paraphrasing the above, we will transcend the limitations of the legacy grid to the point that there will be no distinction, post singularity, between customers and the grid. At the center of this transformation is the convergence of the grid with the Internet of Things.

THE LEGACY GRID ERODES

A. The Legacy Grid

The legacy North American electric grid has been a patchwork of several large, synchronous AC grids that are loosely interconnected with each other and within which:

- A few thousand large generating plants produce electric power and energy mostly from burning carbon and uranium based fuels.
- High voltage transmission lines carry electricity from the generating plants to remote load centers.
- Electrical distribution systems carry the power and energy at reduced voltage one-way to retail customers.

Each regional grid is centrally monitored and controlled to ensure that the generating plants will meet the aggregate needs of customers within the constraints of the transmission systems,

Almost all of the generation, transmission and distribution is owned by utility companies that operate as regulated monopolies. They provide all of their customers' electric energy and charge prices for electric energy designed to recover their costs plus a reasonable profit.

This grid performed exceptionally from its origins in the late 1870s into the 1970s because:

- Customer demand for energy grew exponentially.
- Persistent economies of scale resulted in declining costs and prices, both nominal and real.

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- Reliability and quality of service improved.
- Societal, economic, and environmental sustainability were not limiting concerns.
- There was little uncertainty about availability and price of fuel, equipment and labor.
- System security, public safety, customer privacy were not limiting issues.
- Customer satisfaction was high as their expectations were simple, to automatically get as much electric energy as required whenever desired at an affordable price.

B. Erosion of the Legacy Grid

These underpinnings of the grid began to erode as a result of a series of dramatic events beginning with the OPEC oil embargo in the early 1970s. This has caused essentially all of the positive trends of the first hundred years to be reversed. Economies of scale were eliminated by risk and rising costs of resources, construction and operations. The price of electricity began to increase. Load growth stalled. Grid reliability declined. Expansion and improvement of the grid slowed to the point that depreciation now exceeds new capital investment. Environmental impacts and resource sustainability became major issues. These changes in the foundations of the grid have accelerated over the past decade.

Furthermore, the grid began facing new challenges and complexities for which it was not designed. At the root of these new challenges is the emergence of alternatives to traditional exclusive monopoly utility electricity supply. Wholesale and retail competition has emerged, as have energy generation and management owned and operated by customers on their own side of the utility meter.

As a result of all of this, the national Energy Advisory Council concluded in its report to the United States Department of Energy (USDOE),

> " . . . *the current electric power delivery system infrastructure . . . will be unable to ensure a reliable, cost-effective, secure, and environmentally sustainable supply of electricity for the next two decades. . . . Much of the electricity supply and delivery infrastructure is nearing the end of its useful life.*" [1]

Some have suggested that the ultimate result will be a "death spiral" that will cause most utilities to cease to exist. Whether or not that is true is debatable. However, it is increasingly clear that the utility industry of the future will be dramatically, perhaps even unrecognizably different from the business model that prevailed for a century.

FACTORS LEADING TO CONVERGENCE

A. Beginnings of a Utility Facing Smart Grid

Deterioration of the foundations for the legacy grid model combined with the rise of difficult new demands and constraints have changed the industry's trajectory. And, in parallel, the development and deployment of new energy, electronics, telecommunications and information technologies are making it possible for a modern, intelligent grid, the "smart grid."

The USDOE has been investigating the concept of a smart grid as a part of its ongoing exploration of the imperative to revitalize America's electric infrastructure.

A USDOE report addresses how a smarter grid works as an enabling engine for our economy, our environment and our future, saying,

> "*. . . a Smart Grid uses digital technology to improve reliability, security, and efficiency of the electric system: from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources."* [2]

Utilities have, in fact, operated a smart generation and transmission grid for decades with centralized monitoring, analysis and control through sophisticated electronics, telecommunications and software applications. This has not been and is not yet the case for the distribution grid that serves the utility customers.

Utilities are increasingly trying intelligent electronic devices, systems and applications to better monitor, analyze and control the distribution grid. However, their approach has been, for the most part, to apply these technologies to try to maintain the legacy grid model that has prevailed for more than one hundred years. The predominant tactic has been to deploy smart meters and customer engagement programs to change energy usage patterns so as to reduce demands on the legacy grid. Most utilities continue their historic path of trying to build more bulk power production and transmission facilities. And they steadfastly resist the new constraints and demands on the grid.

Some utilities are trying out intelligent electronic devices deployed throughout the distribution grid for monitoring and analysis, and even autonomous automation. These are sometimes referred to as smart nodes. They will proliferate throughout the grid as time goes on, and can represent orders of magnitude more devices, data and applications than utilities use today

B. Beginnings of a Customer Facing Smart Grid

Meanwhile, utility customers are looking for and finding alternatives to the legacy grid for any or all of several reasons: economy, reliability, security, sustainability, independence, preference for renewable energy, carbon mitigation, nuclear waste avoidance, privacy, even novelty. In contrast to the legacy grid model, strong new developments propel the industry toward a new reality:

- Hundreds of thousands, eventually millions of small distributed generators (e.g., conventional engines and turbines, solar PV arrays, wind generators) and storage (e.g., electrical, thermal, mechanical) deployed at the distribution edges of the grid,
- Substantial changes in the nature of demand on the grid caused in part by increasing deployment of customer owned and controlled distributed generation that is not dispatchable by the utility and may actually be as intermittent as the sun and wind,

- A dramatic change in the nature of electric energy consumption as electronic device load had become the fastest growing component of electricity demand and entirely new kinds of consumption like electric vehicles and other batteries proliferate,

- A growing number of microgrids, deployed primarily by industrial and commercial customers who account for two-thirds of the power and energy supplies by the grid,

- Reduced consumption of energy resulting from conservation, energy efficiency, and distributed generation thereby eroding utilities revenues and complicating grid operations,

- Power flowing from customer owned distributed generation and storage into the distribution systems rather than just flowing one way to customers from the grid,

- More intermittent or even permanent "off the grid" operations and/or asynchronous connections to the grid by commercial and industrial customers,

- Non-utility providers of generation, storage, and management systems as well as demand response and energy efficiency services, and

- Competitive transactive energy markets in which retail customers participate directly in the purchase and sale of power and energy.

C. Disruptive Technologies

The technologies facilitating these trends benefit from the same phenomena that support Kurzweil's and Vinge's predictions of the human / machine singularity. Moore's Law has prevailed. The performance of integrated circuits (and other electronic devices) doubles every year or two while the cost remains the same. Conversely, every year or two comparable computational power can be had for half the cost. The result has been a revolution in electronics, information and telecommunications technologies and accompanying disruption and restructuring of the related industries, including the telecommunications utility industry as well as many other bricks and mortar retail businesses.

Moore's law is really just a special case of a more profound principle that applies to any technology, including energy technologies. Theodore Wright articulated this concept in 1936. His observation became known as Wright's Law or the Rule of Experience. [3] Ray Kurzweil more recently expanded and restated Wright's Law as the Law of Accelerating Returns. [4] Essentially, practice makes perfect and there are economies of production. The power and economics of new technologies in general, not just integrated circuits, improves exponentially both because we learn by doing how to make them better and the cost of any particular component declines as greater numbers are produced. In an ironic development, economies of scale in the electric utility industry have moved from fewer and bigger centralized power plants and transmission corridors to the mass manufacturing of distributed energy production, storage and management devices.

Factor in the exploding growth in global demand for electric power and energy. The developing economies, unencumbered by a legacy grid leapfrog directly to the distributed model, just as the moved directly to wireless telecommunications, skipping the landline systems in place in the developed economies. The rest of the world will use orders of magnitude more power and energy than is being used today which means that the acceleration increases by orders of magnitude! Just as this revolutionized the telecommunications industry, so it will revolutionize the electric utility industry.

CONVERGENCE

A. The Internet and the Smart Grid

The Internet is steadily more ubiquitous, powerful, secure, and is increasingly utilized by individuals and industries worldwide in almost every aspect of their existence.

The USDOE recognized the importance of the Internet for the smart grid in its Smart Grid System Report which states,

"*. . . the information networks that are transforming our economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning* ." [5]

Just making this legacy grid more observable, controlable and sustainable (i.e., "smart grid") means deploying many more monitoring, analysis and control devices throughout utility distribution systems, even on customers' premises. This already surpasses the capabilities of conventional electric utility monitoring, telecommunications, analysis and control systems as well as data processing, analysis and applications.

U.S. electric utilities serve about 145 million meters. Over half of these have been converted to smart meters. The "smart" is the ability to measure, record and report consumption data more often and in some cases measure, record and report other data (e.g., power on / off, voltage). This represents a tremendous increase in the amount and kinds of data that utilities, their customers and non-utility providers will be monitoring, analyzing and controlling. There is also a rapidly growing number of points on the customers' side of the utility meters: distributed generation, distributed energy storage, energy management systems, smart thermostats, equipment, appliances, lights,, EVs, transactive energy market purchases and sales, etc. This will ultimately result in hundreds of millions, even billions, of new endpoints on the grid and on the customers' side of their meters.

B. Why the Internet?

How can these billions of independent variables even be tracked, much less optimized for the most economical, reliable, efficient, secure and sustainable electric service? It will require distributed monitoring, analysis and control through ubiquitous, high speed, two-way digital communications. The sheer number and variability of these "things" will mean that distributed autonomous automation will be required at the edges of the grid. This is already being done in more and more of our lives and businesses through the Internet of Things (IoT).

The Internet is the result of a transformation of telecommunications and information made possible by persistent, exponential improvement in the performance versus price of electronics devices. In a sense, those three industries have already experienced a singularity and the other side is the Internet. It not only makes it possible to do many things better, it makes it possible to do things that have never been done before. As a result, the Internet is increasingly essential to every aspect of life and business.

C. The Internet of Things

The Internet began as the connection of people to people and people to things. However, by 2008, the number of things connected the Internet surpassed the number of people in the world. There are orders of magnitude more things that can benefit from this connection. As a result, Cisco predicts that some 50 billion new connections will be made to this Internet of Things (IoT) over the next decade.

The IoT is the network of physical objects connected to the Internet. These objects contain embedded technology to interact with their external environment and internal states. How does this turn reality inside out? When objects can sense, analyze, decide, and control, individually and in concert with other objects, through high-speed, two-way, digital communications, it changes how and where decisions are made, and who (or what) makes them. Sensing, analysis and automation become distributed and autonomous. This is the very definition of what the emerging grid needs. And it will make possible monitoring, analysis and automation beyond anything that we are doing or even contemplating now.

The Smart Grid is already considered to be one of the first and largest examples of the IoT. [6] Many more things use electricity than are connected to the Internet today, and essentially everything that uses electricity can be made more useful by connection to this network. Thus, the Smart Grid part of the IoT could be larger than the Internet is today. And, just as the Internet would not have been possible without the existing electric grid, a modern, intelligent grid will not be possible without the Internet.

The IoT will be the new reality of the grid. The electric grid will converge with the Internet. It will become an "Enernet" as expressed by Bob Metcalfe days after his 62nd birthday, "*Over the past 63 years, we met world needs for cheap and clean INFORMATION by building the INTERNET. Over the next 63 years, we will meet world needs for cheap and clean ENERGY by building the ENERNET*." [8]

Essentially all electricity customers rely on the Internet for an ever-growing part of their lives and businesses. They will expect to be able to do so with electric energy supply, management and utilization. Witness the explosive growth in the use of the Nest smart thermostat and other smart home / smart building devices and systems. Customers will not be content to be limited to the proprietary, closed-system data, communications and applications provided by electric utilities.

Making the Internet, a global standard for communications and applications the basis for the smart grid maximizes prospects for innovations by developers everywhere.

A severe constraint on the development of a Smart Grid is the lack of integration and interoperability of devices, data and applications. The common first step toward the IoT is converting networks on proprietary protocols to IP-based networks. What better way to accomplish new grid integration and interoperability to replace the complex mosaic of proprietary systems and multifarious industry standards that plague the smart grid? Think of a smart grid that benefits from the seamless integration and interoperability of so many different kinds of things via Wi-Fi.

Finally, in the long run, there will be no way that electric utilities, their customers or other market participants will be able to economically deploy, operate and maintain proprietary data communications with the capacity, speed, economy, ubiquity, security, and reliability of the IoT.

A modern, intelligent grid for the 21st century not only requires the capabilities offered only by the Internet of Things, but it will be so much more than we imagine because of it.

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