How Does Smart Grid Impact the Natural Monopoly Paradigm of Electricity Supply? Part I

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Abstract

There is a lot of talk about how Smart Grid will change the electricity supply industry. There is no doubting the technological innovations that have been penetrating the industry in recent years, and providing utility engineers, managers and customers alike with hitherto unavailable views into electricity use and distribution system performance.

Technology today is moving faster than our ability to respond to it, yet for an industry widely regarded as a natural monopoly, what do these changes mean as Smart Grid deployments gather speed?

Technology has been evolving ever since the industry was born including such innovations as the rotary converter (1893), nuclear generation (1956), solid state relays, SCADA etc. and more recently phasor measurement units, but with the exception of the rotary converter, which arguably helped shape the industry as we know it today, these did not change the fundamental nature of the business. Or did they? So is Smart Grid just a new phase in technology evolution or is it something more?

1. INTRODUCTION

To answer this we need to look at some of the changes that the industry has witnessed over the last half century. In doing so our objective is to make people look at the evolution that has been going on in the industry and how Smart Grid is just the culmination of many changes that have been reshaping the nature of electricity supply.

This paper will try to answer the question posed by its title by exploring the characteristics of a natural monopoly and whether Smart Grid as a disruptive change has the potential to impact each of these characteristics. If Smart Grid is truly a transformational change then we should be able to see this reflected in changes to the fundamental nature of the industry itself by the effect on these characteristics as we move from a world where the regulator is the ultimate customer to a world where the customer is the ultimate regulator [1].

2. POLICY

In every country we find government involvement in the electricity supply industry to greater or lesser degrees due its natural monopoly features and also because of the key social needs. As what is, in the US, a government franchise for most utilities there is a level of responsibility that is not only expected but is also regulated for. For the purpose of this paper we have chosen to describe policy as “a way of managing a plan or course of action”. By this definition policy includes legislation, regulation, market rules as well as company and organizational rules, though the primary focus is on regulation.

The importance of policy was also recognized by the GridWise Architecture Council (GWAC) when it created its constitution. Unlike regulation, electricity does not recognize jurisdictional and organizational boundaries so neither should a maturity model such as the Smart Grid Interoperability Maturity Model currently being developed by GWAC. But policy has the ability to create unwanted (and unplanned) barriers to interoperability which is why it is an important topic for consideration throughout this paper. The physical flow of electricity can be controlled by technology to some degree but policy is abstracted from the physical exchange of energy yet still impacts it, so the importance of policy as an enabler and as an obstacle needs to be clearly recognized. Interestingly when GWAC was creating its constitution the one principal that received by far the most consensus was in the regulatory category and stated that “Interoperability strategies and issues must be communicated in a form to be understood by regulators and policy makers.” [2] As Smart Grid growth continues it is the nature and extent of related policy that will help us see its impact on the industry, for if the industry is truly transforming then the regulations should also change to reflect this, hopefully to facilitate this.

3. WHAT IS A NATURAL MONOPOLY?

A natural monopoly is said to occur when production and/or operations technology, usually involving high fixed costs, causes long-term average total costs to decline as output expands. In such industries, theories argue, a single producer/seller will eventually be able to produce goods and services at a lower cost than any two or more producers/sellers, thereby creating a "natural" monopoly. This is essentially looking at the total cost of ownership (TCO) for an entire industry or market where, in the case of a natural monopoly, this TCO is lowest when there is only one producer/seller.

However, even with one producer/seller the TCO depends on the time horizon and may include social costs which are difficult to quantify. This has been a challenge for many utilities when developing business cases for Smart Grid and AMI yet the annual cost of power disturbances to the U.S. economy is in the order of $100 billion according to EPRI and avoiding the productivity losses of poor quality power to commercial and industrial customers can restore billions of dollars of productivity to the economy. And from a residential customer perspective while each consumer’s contribution to improving efficiency is small, collectively it can result in significant societal benefits. With Smart Grid society will benefit from a stimulated economy, improved environmental conditions, improved national security, job creation, and a sustained downward pressure on future price increases for electricity. [3]

A good example of how cost variations are impacted by the time horizon is tree trimming. This is an activity which was cut back (tried to avoid the pun) by many utilities to reduce operating budgets and which may reduce costs in the short term depending on how successful the program has been in the past. But lower levels of trimming, if continued for several years, may lead to poor reliability, upset customers, claims for damages and performance based penalties. Then there is also the cost to fix the problem. Sometimes a lower short term cost may result in higher costs over a longer time.

3.1. Regional Markets

In some situations the nature of the market can create regional segregation into smaller markets where one or a few firms have lower costs within these areas. This is less evident today with globalization and corporate mergers but even now stores such as supermarkets still tend to be regional. Once you add the ability to store a product and ship it to other areas the size of a market can be increased and storage thus presents a growth strategy in many industries. Conveniently ignoring the storage piece of this example, and focusing instead on the ability to ship a product to other areas, this is exactly what the rotary converter did by converting DC power into AC power thereby enabling it to be transmitted over much greater distances. Interestingly High Voltage DC (HVDC) now provides better long distance transmission potential (again no pun intended) than AC but not without some associated complexity and availability issues.

Yet it is rare that an entire industry forms a natural monopoly. Much more common (such as the case with electricity supply) is that a series of local or regional monopolists exist in regional markets and thus create some diversity of approach. Natural monopoly is also generally a phenomenon where a high degree of distribution is involved which equates to the transmission and distribution portions of electricity supply. This is an interesting feature as we will see when we look at the impacts of deregulation/restructuring. We refer to this as restructuring in the rest of this paper since deregulation is misleading and what occurred in the industry was a change in the vertical structuring and the development of new regulations not the removal of regulation.

Refocusing on the topic of product storage; with today’s battery technology, including electric vehicles (EV)/plug in hybrid electric vehicles (PHEV), electricity can be stored and even moved to other areas. An EV clearly has the ability to move between different utility service territories, different control areas, and different countries. Should we regulate this? Can we regulate this? What are the ramifications of charging an EV in an area with e.g. coal generation but then using the stored electricity as input to the grid in an area that has environmental goals for renewable generation?

3.2. Monopoly or Natural Monopoly?

As we explore the nature of natural monopolies and electricity supply note that the term “natural monopoly” does not refer to the actual number of producers/sellers in a market. What it describes is the fundamental relationship between demand and supply in a specific market. Thus a firm that is the only producer/seller in a market is said to enjoy a monopoly whether or not the market itself is a natural monopoly. Conversely if the entire demand of a specific market can be satisfied at lowest cost by one firm then regardless of the actual number of producers/sellers the market itself is a natural monopoly.

One conclusion that can be made from this is that competition is not a viable regulatory mechanism under natural monopoly conditions since it will force costs up. In markets like Texas and the UK where competition exists, the transmission and distribution businesses offer the last vestiges of natural monopoly, and the generation and retail supply businesses have become competitive. An interesting and related question is that if prices increase under restructuring what does this imply? Does it mean that a natural monopoly really existed, or that the market is not truly competitive, or something else?

3.3. Supply and Demand

The relationship between supply and demand is an important factor in all markets but with Time of Use (TOU) rates exploring the boundaries of demand elasticity the point is made all the more relevant given the nature of many Smart Grid initiatives that seek to use technology in the form of intelligent devices and improved communications to modify and influence these relationships. From this simple perspective it is clear that Smart Grid is affecting the natural monopoly paradigm of electricity supply, since Smart Grid is being used to manipulate and control both supply and demand in order to meet lowest cost reliable supply within the limits of a transmission and distribution infrastructure that has arguably been under invested in for years. This is true even in markets where restructuring has not been introduced and where transmission congestion, limited generation, or other factors have prompted utilities to look at ways to use Smart Grid to shift demand.

In a natural monopoly higher prices result if more than one producer/seller supplies the market because each producer/seller operates below optimum size. This also relates to the argument that competition may cause consumer inconvenience because of the construction of duplicate facilities, e.g., digging up the streets to put in dual electric, gas or water lines, building multiple substations, multiple (smaller, inefficient) generating units etc. Typically, such is also the case with the electricity supply industry, a natural monopoly occurs in a market where the producer/seller has a service that is metered and which is not easily transferable.

However, natural monopolies are typically capital intensive and utilize durable, long lived, and immovable assets such as (in this industry) generators, breakers, transformers, T&D circuits etc. Other characteristics typical for a natural monopoly are that the price the producer/seller can charge after capital investment is limited so the incentive to invest depends on future pricing policy and who controls that policy.

Also, due to the large and durable nature of many assets the long lead time on construction may result in mismatches in supply (capacity additions) and demand relative to economic cycles although this is not so problematic where differences in regional economics can be offset by transmission (subject to available transmission capacity) that at least allows generators to sell into other markets. But then again we have already seen that generation does not necessarily form a natural monopoly (at least where sufficient transmission capacity exists) and not even the most enthusiastic meter manufacturer would claim that smart meters are durable, long lived and immovable.

This is an interesting point because historically the meter has not formed a part of the product or service being sold; it has just been a means to measure sales in order to generate bills. But now, with embedded intelligence and communications that enable companies and customers alike to manage more efficiently, the meter has become an important, even integral, piece of the products and services being sold.

3.4. Franchise Monopolies

The avoidance of inconveniences such as duplicate facilities and their associated higher costs is one reason offered for government franchise monopolies for industries with declining long-term average total costs such as electricity supply. During the late nineteenth century in the United States, when local governments were beginning to grant franchise monopolies, the general economic understanding was that "monopoly" was caused by government intervention (not by the free market) through franchises, protectionism, and other means. The implication of this of course is that the benefit-cost ratio of regulation was assumed to exceed one. [4] Perhaps it is time to once more assess the benefit-cost ratio of regulation since the role of regulation has also been changing as the industry has changed.

Starting in 1978 with PURPA and with unbundling and the evolution of merchant generation we now have a very different industry than just a few decades ago. But before we consider the role of regulation we need to remember that a natural monopoly is a market where the cost of provision is most efficiently served by a single firm but where multiple firms may still compete. In the absence of regulation markets like these might fail especially where strong competition forces the gap between average costs and price to the point where it becomes negative such as can occur when a company attempts to buy market share, sacrificing short term profits for (hopefully) long term gains.

3.5. Regulation of Natural Monopolies

Price cap regulation as employed in utility regulation is one mechanism that provides good incentives to reduce costs. But when increasing profits are realized, it ends up creating pressure to tighten price regulation, which then increases regulatory risk and raises the cost of investment. The major challenge in designing regulation for a restructured industry is to provide adequate assurances of investor protection, so that the necessary expansion will take place, while preserving the benefits of market competition. A good system of regulation does several things:

1. Provides an advocate for customers and a single voice of a powerful "customer"
2. Eliminates barriers to entry
3. Acts as consumer educator
4. Enables a utility to raise finance for investment at acceptable cost.
5. Provides incentives for efficiency in operation, pricing, investment, and innovation.

The fourth point above mentions "utility" but for the restructured areas of electricity supply the ability to raise finance for investment at an acceptable cost applies equally well and perhaps more so to the players in the competitive areas of the market where investors will want to see quicker returns yet face uncertain and changing policy requirements (PUC/PSC, FERC, NERC, ISOs, DOE, NIST, SGIP) that may impact their profitability. Also, will there be a need for the first point in the previous list when today's rate payer becomes tomorrow's customer?

So how should we view the large-scale production and economies of scale of an industry such as this: as a competitive virtue, or a monopolistic vice? [4] And of course how will this change in the future due to Smart Grid? This is a complex argument since it is not obvious whether technological changes such as we are experiencing today will weaken or strengthen monopoly forces that impact the industry and the resulting requirements for regulation. In many ways this will vary from market to market as each regulator and each utility takes its own approach to Smart Grid.

What will not change is that the heart of the regulatory process is, and will continue to be, the need to determine the revenue requirements that are necessary to cover the costs of regulated entities and that these same entities are becoming increasingly digital, have aging workforces, and need to invest in technologies that require business process management and data management to capture and automate many of today's manual and partially automated functions. And as we become increasingly interconnected with systems of increasing complexity it will be more and more important to ensure that the interoperability of these systems is front and center in our focus both in technology, business, and regulatory terms.

Beyond simply approving utility requests for related investments, regulators can accelerate progress by encouraging desired behavior. This can be done by offering incentive rates of return and by making it clear that there is a preferred direction to be considered ahead of more traditional approaches [5].

4. WHAT IS SMART GRID?

At a very high level we have described what a natural monopoly is but what is Smart Grid? If we are to examine the impact of one on the other we need to be clear what we are talking about. Everywhere you look today Smart Grid is in the news. Smart Grid means different things to different people and even within similar organizations it can mean different things depending on specific objectives etc. For the purpose of this paper we have chosen to view Smart Grid as broadly as possible.

4.1. Building a Smarter Grid

Defining Smart Grid is a tricky business and many definitions exist. One definition is "the electric delivery network from electrical generation to end-use customer, integrated with the latest advances in digital and information technology to improve electric-system reliability, security and efficiency." [6] A definition of "grid", or transmission system, is "the interconnected group of power lines and associated equipment for moving electric energy at high voltage between points of supply and points at which it is delivered to other electric systems or transformed to a lower voltage for delivery to customers." [7] Smart Grid is simply a smarter version of this latter definition, and we say smarter rather than smart because the grid already has many pockets of intelligence.

The important part of both of these definitions is that the Smart Grid is broad. It is not something that is just implemented by an individual utility, though each utility has a role to play. An individual utility can make its part of the grid smarter but the Smart Grid itself is bigger that any one utility or group of utilities.

We take the position that Smart Grid is the entire energy infrastructure from generation to consumption. It is a system that embeds intelligence and active control, management, and interaction capabilities into the existing grid with advanced metering, sensors, controls and an open, standards based, architecture for the integration of devices and services on the customer side of the meter. This includes everything from the points of generation to the points of consumption which extend beyond the meters at each end of this broad landscape. And of course all of this needs to happen reliably and in a secure way since the objective of making the grid smarter is to improve reliability, economics and security of the power system, while accommodating greater levels of demand response, distributed and intermittent generation, storage, and overall automation. To achieve all of this successfully will require interoperability across a wide spectrum of participants and systems.

4.2. A Suggested (and simple) Definition

Due to the human element in systems of systems this large, we need to focus on the human and organizational components as well as the hardware and software components. This is to say the Smart Grid is just more than the hardware and technology that we traditionally think of when defining system boundaries. The impact of this is that human behavior is a component of reliability and interoperability especially where operation and control depend on human coordination among multiple organizations; therefore the **Smart Grid is the entire infrastructure to provide energy and services from generation to consumption using distributed intelligence, including the people responsible for its operation and policy setting**. This in turn requires that any measure of maturity with respect to interoperability such as the Interoperability Maturity Model (IMM) being developed by GWAC must take these human elements into consideration at least to the extent that they constitute elements of some interfaces.

Looking at the distribution of ARRA funding by the DOE it is apparent that the federal government also considers Smart Grid to be a broad phenomena and one that is currently being catalyzed by the deployment of AMI. We do not take any positions in this paper that argue for or against the implementation of e.g. TOU rates but we recognize that the behavioral changes enabled by these and other Smart Grid initiatives will impact customers, utilities, regulators, generators, retailers, ISOs, and more.

4.3. Temporal Impacts of Smart Grid

Note that in the discussions in this paper we are not saying that these changes will happen overnight. Indeed many changes will take a significant amount of time to occur but the topics discussed in this paper will impact the industry even if some take a long time to get adopted. This is an important distinction to make since some technologies like electric vehicles have the potential to have a significant impact but will take a long time for large scale adoption. Yet despite the anticipated longer time for electric vehicle adoption, adoption cycles in general are happening faster for technology and environmental programs but the profile of the early adopter is changing.

The biggest change is that change itself is happening faster. The rate of change is increasing as technology advances continue and new solutions grow from them. At GridWeek 2010 Todd Rytting of Panasonic commented that “the technology we are selling to customers has far outstretched their ability to manage it.” Given that many consumers fail to program their video recording systems and thermostats, how likely is it that the average consumer will want to take the time to learn how to use energy management software that can monitor and optimize their energy usage especially if the customer has to do the analysis required to obtain benefits? The challenge for the providers of these systems will be to make it as simple as “set it and forget it” [3].

Smart Grid solutions need to be flexible and adaptable and the industry needs to be flexible to incorporate them as they appear, recognizing that there will be many advances that we have not yet considered and some that will surprise us.

The general impacts of social networking and consumer electronics may well be the catalysts for large changes but they will not happen overnight. The biggest increase in Facebook users is the over-60 group. How can we predict who the adopters of Smart Grid solutions will be when we don’t know what those solutions will be and who will offer them? Imagine an energy efficiency App on your smart phone: “Follow us on Facebook for the latest in energy efficiency” – just connect and provide some authentication details and let some of your in-home devices be remotely managed. Technology solutions offer more opportunities each day but interoperability and ease of use will be key factors in determining which succeed and which do not. We simply cannot predict the future in detail but must be prepared to accommodate it. We can do that by pushing for improved interoperability maturity and open standards adoption and supporting the efforts underway to make this happen.

In fact interoperability may be the most important part of Smart Grid from a consumer perspective. What is the value of an in-home display? Look at the astonishing array of applications for iPhone and Android devices. A handheld device bought to support a home energy management system may or may not cost justify itself but when it provides a platform for other applications the cost justification becomes easier and in some cases disappears since it merely provides an excuse to buy the latest technology. But whatever the justification for enrolling with a new service, the entities involved in making it work have to be seamlessly interoperable.

4.4. Benefits of Smart Grid

The benefits of a “smarter grid” are far reaching and go far beyond the scope of this paper where we are focusing on the fundamental nature of potential changes. Not only do these changes promise to empower customers to make more informed buying decisions, but they should also enable operators and policy leaders to do their jobs more effectively. These benefits should include [3]:

- Reduced losses to society from power outages and power quality issues
- Improved operating efficiencies of delivery companies and electricity suppliers
- Reduced O&M and capital costs
- Downward pressure on electricity prices for all consumers.
- Improved National Security
- Improved Environmental Conditions
- Improved Economic Growth
- Improved transparency
- Improved market monitoring (for market power)
- Improved asset management
- Better planning (better choices, increased options)
- Additional options for empowered customers

Collectively these changes need to reduce costs and help to bring a positive return for the customers, market participants and the economy.

4.5. Barriers to Smart Grid

While there are benefits to be realized from Smart Grid there are also barriers to its implementation. The barriers can be grouped into five categories:

- Cost
  Recovery from a global recession and determining who pays for Smart Grid have proven to be challenges for many utilities. With a recovering economy and ARRA funding from the DOE many utilities are moving ahead.
- Regulation
  Regulators will need to create new policies and regulations that remove economic and political barriers to integrated markets, while incentivizing capital investment [5].
- Proprietary Standards
  The many proprietary standards in use today need to be replaced by open standards. Open standards help to encourage multiple suppliers to innovate and compete with regards to features and performance. They also provide improved integration and interoperability for purchasers of equipment and also create more transferable skills while potentially reducing stranded investments in discontinued product lines
- Interoperability
  Smart Grid will be an ultra large scale system of systems where different systems need to exchange meaningful, actionable information, with common meaning and agreed types of responses to a degree that has not been seen in the industry before.
- Understanding and Acceptance
  The value of Smart Grid must be made clear to all stakeholders, especially to residential customers. Without this understanding and acceptance customers may become an obstacle to Smart Grid progress despite the huge social benefits.

4.6. A word of Caution

However, as well as providing opportunities to improve the relationships between utilities and their customers the deployment of Smart Grid also has the risk to adversely affect the relationship between utilities and their customers, cause friction with regulatory bodies, and negatively impact the market value for utilities' shareholders if it is not implemented well. Remembering that Smart Grid extends beyond any single utility this means that each and every utility faces potential regulatory scrutiny that may arise from failures beyond its control including by utilities or vendors in other jurisdictions.

5. CHARACTERISTICS OF A NATURAL MONOPOLY

We outlined earlier what circumstances/environments may lead to the evolution of a natural monopoly but in order to be able to examine if Smart Grid is causing the nature of the industry to change we need characteristics that can be assessed as evidence of these changes, and to do that we need to be able to define the characteristics of a natural monopoly. Fortunately (unlike Smart Grid) there has been over a century of research into natural monopolies and their regulation which we reference here in the following sections that describe the following characteristics [8] that define a natural monopoly.

- Capital intensity and minimum economic scale
- Non storability with fluctuating demand
- Locational specificity and location rents
- Necessary or essential for the community
- Involving direct connection to customers

5.1. Capital intensity and minimum economic scale

The large, vertically integrated firms that had become prevalent in many industries in the early twentieth century were characterized by capital intensity. This requirement for large investment tends to create barriers to entry in these markets. With businesses that are capital intense it is normal to see increased utilization of assets and reduced average cost occurring as scale of production increases. Businesses in these types of markets are thus highly capitalized. It is very expensive, for example, to build transmission networks therefore, regulation notwithstanding, it is unlikely that a potential competitor would be willing to make the capital investment needed to enter a market such as this.

A firm with high fixed costs also requires a large number of customers in order to have a meaningful return on investment. Adding one more customer may increase revenue and lower the average cost of providing service. So long as the average cost of serving customers is decreasing, larger firms will serve the customer base more efficiently.

So can Smart Grid provide products and/or services at a lower cost, especially via non-traditional vehicles?

5.2. Non storability with fluctuating demand

Commodities can be classified in many ways. One is to classify them as storable or non-storable. The length of time that a commodity may be stored can affect the price dynamics of the markets in which they are sold and traded. The storability of a commodity becomes increasingly important where the demand for it fluctuates since this can provide a buffer against supply chain fluctuations in response to supply and demand variations. Many retail stores have just-in-time supply chains that replace items as they are about to run out thus minimizing the investment in storage for both goods and facilities. Improvements in communications, information technology and asset tracking (bar codes, RFID) have enabled the creation of digitally integrated supply chains that operate across multiple businesses and permit large scale data mining that can move products to where they have more value.

Natural monopolies tend to have fluctuating demand and relative lack of storage which creates some serious challenges. Electricity is the ultimate in just-in-time supply chains where generation and demand have to be balanced in real time. But the product itself is evolving by differentiating it, making it no longer a pure commodity. For example, firms may gain customers who pay more by selling "green" power, or non-polluting power, or locally-produced power.

So can Smart Grid eliminate demand fluctuations or provide a means to store electricity?

5.3. Locational specificity and location rents

In general for most markets, the determining factor in determining location rent will be transportation costs. When transportation costs are low, the location rent will be high, and vice versa. This produces a sliding scale along which location rent decreases with distance from the market, eventually reaching zero. Commodities that lose mass during production can be transported less expensively from the production site to the market than from the raw material site to the production site. Production sites, therefore, will be located nearer the raw material sources.

Clearly there is not much in the way of mass to be transported when it comes to electricity thus (transmission capacity, regulation, and suitable sites permitting) generation may be sited at large distances from end consumers of power and that is often a preference of customers. With electricity, losses occur during transmission and distribution and there are design decisions that need to be made so as to balance cost and reliability. This creates requirements for placement of some types of equipment and installations at certain locations and thus places a premium on those locations. Moving these installations and equipment can be very expensive due to the capital intensive nature of the industry. This can also make it easier (and cheaper) to provide new service in some areas than in others. This is the case in areas where a utility already has adequate supply and infrastructure as opposed to new developments being built in geographic areas where the utility has little infrastructure.

So can Smart Grid provide a means to site equipment such that the associated location costs are minimized?

5.4. Necessary or essential for the community

Natural monopolies are usually associated with the provision of products that are considered necessities and which are considered essential for the community. Clearly electricity falls into this category. Modern lifestyles and the information technology that supports it depend on not only on a reliable supply of electricity but also on increasingly higher and higher power quality requirements.

So does Smart Grid make electricity less of a necessity or less essential to the community? Or a better question might be does Smart Grid reduce the necessity of products and services currently provided by natural monopolists?

5.5. Involving direct connection to customers

This is somewhat self-explanatory but the final characteristic of a natural monopoly is that the producer/seller requires a direct connection to its customers. This also relates back to minimum economic scale and capital intensity since for two distribution companies to compete would require that both companies have direct connections to the same customers. More interestingly this also implies a level of immobility on behalf of the customer and the supply to them. This means that the customer has little or no choice (usually none) for who may provide the specified goods or services to them. Restructuring has already changed some aspects of this for electricity supply. The erosion of the requirement for a direct connection to the service provider has already brought about tremendous changes in the telecommunications industry as long distance service was opened up for competition and then wireless carriers changed the whole nature of the industry and created new opportunities for consumer electronics companies.

So can Smart Grid provide the ability to purchase electricity and services from producers/sellers in multiple locations?

5.6. Impacts on Interoperability

When considering the questions posed after each natural monopoly characteristic, the authors urge the reader to also consider the requirements that any conditions that might cause us to answer "yes" would place on interoperability for there can be little doubt that interoperability is a critical characteristic that is required to enable Smart Grid.

5.7. Regulation and Investment

This combination of necessity and direct connection to customers creates the potential for exploitation in a natural monopoly and thus creates a need for regulation. Investors in the electricity industry must therefore expect limits on the prices they can charge and sometimes onerous but necessary obligations relating to safety, supply, and stability. In exchange investors need reassurance that future prices will be set high enough to justify their investment. Investors, in turn, must coordinate investment in transmission and generation to find least-cost ways to expand the system and to prevent system failures, fuel shortages, and price shocks. And because electricity is vital to production in all major industries, they need to reassure governments that supplies will be available at all times. How to satisfy this set of objectives constitutes a challenging regulatory problem.

Looking at the characteristics of a natural monopoly it is not surprising that we see both political and social demand for some sort of control of an industry like electricity supply.

5.8. The Need to Innovate

The electricity supply industry has seen a lot of change and (increasingly) innovation in recent years; a trend that is expected to continue. With margins that are capped through regulation it has been argued by others that a T&D business has little incentive to innovate yet with the changing role that the customer will take through Smart Grid, innovation is exactly what some utilities are doing, and in fact there is a strong theoretical incentive for the natural monopolist to innovate. However in practice there is little motivation for innovation unless rate recovery for the innovation can be guaranteed.

W. Edwards Deming [9] said that "Innovation comes from the producer - not from the customer." Ideas may come from customers but they are not the innovators. The regulatory model for electricity supply does not incent utilities to innovate and one reason for the current regulatory role as a single large customer is because utilities have not historically been good at listening to the customer. Producers are far more likely to innovate when the customer has a choice and where innovation and product evolution play a part in acquiring and retaining customers. This was the distinction made earlier about the differentiation between real customers who have choice and ratepayers who have no options. Now is the time for this industry to get serious about listening to the people who pay the bills.

The fact that an industry is a natural monopoly or consists of regional monopolies also does not mean that only one firm is pursuing R&D in technologies associated with those markets and the various manufacturers of the equipment used by natural monopolists are an additional and very important source of diversity. However technological innovation creates the risk in some situations that the monopolist could be supplanted especially where disruptive technologies may change the very nature of the market itself.

Indeed many components of Smart Grid provide this disruptive capability. The impact of distributed generation and micro-grids present interesting potential here, yet the need to innovate is ever present and the fact that the energy supply business has not traditionally been a great innovator could make utilities and regulators alike take a long look at opportunities for innovation while new participants are perhaps more willing to be innovative in their uses of technology in their attempts to generate new market opportunities. Perhaps a regulatory tool to stimulate innovation is required such as a tiered recovery mechanism based on levels of customer participation and/or customer satisfaction?

Innovation can create new services that are valuable to customers. In other industries early adopters of new products and services have seen that increasing market adoption increases market awareness and acceptance of new ideas and drives down the cost of such services. Who will make the investments for new services in the electricity supply industry, what they will be, and who will ultimately gain from these remains to be seen, but Smart Grid presents a wonderful opportunity to bring together and align the myriad changes that we have witnessed since PURPA was passed. The challenge is to do this in a way that the value of all these pieces together exceeds the sum of the parts. What is needed is new capital to make these changes. There simply isn't enough capital available from captive ratepayers to support the required changes, which should be a key determinant in attracting new innovators. We use the term ratepayer here since that is exactly what consumers of electricity are today. Smart Grid will facilitate the evolution of rate payers into true customers.

5.9. Research and Development

How does electricity supply rate as an industry in terms of the percentage investment in research and development versus other industries? The makers of pet food spend more money researching dog food than our industry spends researching electricity. [10] What does this say about the incentive to innovate, assuming that innovation is strongly correlated to research and development? Research shows [11] the existence of true dependence both in the decision of R&D investment and in the production of innovations. If innovation is an indicator of market success and if research and development is related to innovation then this is not a good sign for incumbent providers in this industry in areas that are likely to attract new entrants.

5.10. Wires and Wireless

With Smart Grid there is a parallel to the changes that occurred in the telecommunications industry in the USA. Traditional land-line phones, once the connection between the seller/provider and the customer, have increasingly been supplanted with wireless or voice over internet phones. The separation of local and long distance service providers was the starting point for competition between long distance carriers much like the energy service providers in the electricity supply industry who use the local utilities' distribution systems to actually deliver the power to the customer.

But the next big catalyst in the telecommunications industry was wireless. Wireless phone adoption around the globe has grown rapidly over the last decade and the appetite for wireless devices now extends well beyond mobile phones and includes webcams, gaming systems, computer networks and of course advanced metering infrastructure and the array of applications designed for these platforms is vast. The impact of this was that it has circumvented the natural monopoly characteristic requiring a direct connection between the producer/seller and the customer and once that happened people were free to purchase phone agreements from a variety of competitive suppliers. This freedom extended to being able to keep your phone number and transfer it between suppliers as customers switched from one provider to another. Once this natural monopoly characteristic was changed the number of land-lines started to reduce since customers were not dependent on that direct connection for access to services and products.

Now unless you believe the stories about the wireless transmission of electricity for Tesla's fabled car, stories that have been proven to be false, there is no way to circumvent the supply of electricity to homes without using the utility wires (ignoring on-site distributed generation). But, and this is a big "but", there are ways to circumvent both the utility's wires and the utility's communications systems in order to establish a communication path between producers/sellers and customers in order to offer new products and services.

Why should we expect utility customers to be any different in their desire for mobile access to products and services; to want wireless access and to be able to access those products and services from devices that are not solely dedicated to a single purpose? After all they are the same customers that have already voted with their wallets to switch to wireless devices in many other areas. Big carriers such as AT&T and Verizon still have to spend billions of dollars each year to maintain their land-line networks even though there are less and less people using them.

A similar situation now looms for distribution companies. There will always be a need for distribution companies but the future scope and extent of their businesses may rely on how well they engage with their customers and educate the public about the societal benefits of Smart Grid and how customers can use new information to manage their lives.

We expect to see more private investment in the electricity supply industry just as private investment followed the restructuring of the telecommunications industry where the introduction of multiple providers was accompanied by new pricing schemes and rapid advancement of technology and user interfaces. The impact in electricity supply will be different since the replacement of land-lines by wireless platforms affected the delivery of information to the traditional natural monopolists but with Smart Grid there will still be interval data available to the distribution companies.

6. SUPPLY AND DEMAND

If a product can be improved and the demand curve subsequently shifted (to the right) then the value of the product may be perceived as increased by the customer. In the case of electricity the "change" in the product relates to pricing models and the provision of more information and more choices to customers that allows us to be more proactive in the control of our costs. Thus, customers who see improved services and/or reduced costs are more likely to be happy. Also customers who believe they have control also feel more positive. These reasons themselves ought to be incentive for us as an industry to innovate, and happy customers create better long term viability for a producer/seller whether they are a monopoly or not.

The interesting point here that should not be overlooked is that the meter has now become a key enabler of the products and services rather than just a way of measuring them. In fact more even than an enabler, the smart meter has now become an intrinsic part of the product for the end customer. Now electricity (as a product) can be separated from a commercial perspective from transmission and distribution which become services for distribution. At a transmission and distribution operations level we saw the same type of evolution as SCADA penetrated the industry but in this case the customers for the information were the dispatchers, generators and ISOs.

6.1. Demand Elasticity

A monopolist typically cannot bargain with or determine the demand elasticity of each customer for each individual unit of product. If possible this might be viewed with suspicion in a natural monopoly because of its potentially extortionate nature considering that the market for the product is a necessity. However, electricity supply does have flexibility to shift the demand curve because the product is both a necessity and a luxury and therefore the consumer does have some affinity for adjusting levels of consumption based on cost especially where the use is not necessary and where behavioral adjustments yield benefits for the customer. It is this "luxury" use of electricity that has been targeted by early DSM programs and which TOU also seeks to exploit. Yet this determination of elasticity and shifting of demand curves is what Smart Grid can make possible and which has caused several protests from groups focused on privacy concerns. Not everyone wants their utility to have detailed information on their energy usage patterns, which can also reveal a great deal about their overall lifestyle [3].

7. THE EVOLUTION OF SMART GRID

In the late 19th century the rotary converter enabled the conversion of DC to AC allowing for the interconnection over greater distances of multiple metropolitan distribution systems. Although these systems were regional in nature this was a catalyst that started the transformation of the nature of electricity supply into a more interconnected system of systems allowing for economies of scale and improved reliability through shared generation etc. on both local and regional scales. Robust interconnections between these systems did not really occur until the 1960s at which point the "grid" started to resemble what we see today.

7.1. The Dawn of EMS

Of course this greater interconnection also led to the possibility for more widespread outages as seen in 1965 and 2003. With opportunity comes risks and rewards. With careful identification of risk and the development of mitigating strategies the balance between reward and risk can be tipped in favor of reward but we must not forget that those risks still exist. And there lies a problem that is easy to forget: a risk that has been successfully mitigated for a long period of time should be ignored at our peril.

The 1965 blackout in the Northeast region of North America was a truly game-changing event. It led to the formation of EPRI, significant investment in the methodologies used in "advanced applications" for network monitoring and control as well as generation scheduling, and a willingness on the industry's part to invest in new control center technologies and systems. In many ways the period 1965 – 1980 was a kind of golden age of EMS development, planning software development, and was also a period when large systems software development and systems integration become core competencies for industry vendors. [12]

The advent of the microprocessor based relay in the 90s led to the use of digital computers in the substation and Substation Automation was launched as the ultimate replacement for the SCADA RTU in a new paradigm that lead in part to Smart Grid.

7.2. Economic Reform

From this point in time we started to see changes that were driven both by reliability and economics with a trend towards more economic driven industry reform. The Public Utility Regulatory Policies Act (PURPA), passed in 1978 by the United States Congress as part of the National Energy Act was meant to promote greater use of renewable energy. The biggest result of PURPA was the prevalence of cogeneration plants, but it also became the basic legislation that enabled renewable energy providers to gain a beach head in the market. The Energy Policy Act of 1992 (EPAct) subsequently laid the initial foundation for the eventual restructuring of North American electricity markets. This Act called for utility companies to allow external entities fair access to the electric transmission systems in North America. For “fair access” read: “competitive”. This relates to the previous discussion on location rents and transportation costs. The act's intent was to allow large customers (and in theory, every customer) to choose their electricity supplier and subsequently pay for the transmission to deliver it from its source of generation to serve their load.

To protect and promote generation competition and also enforce fair treatment of external users of the transmission system, FERC issued Order 888 and Order 889 on April 24, 1996. Although the EPAct of 1992 was the beginning of electric restructuring in North America, orders 888 and 889 marked the point where the trading of electricity gained a firm foothold. And with the advent of both SCADA and electricity trading came community scale need for interoperability. It is this community level interoperability of interfaces that is the focus of the Smart Grid Interoperability Maturity Model (SGIMM) being developed by GWAC.

7.3. Vertical Decoupling

One fairly immediate result of this order was the functional separation and isolation of the power schedulers and power marketers within vertically integrated utilities from their company’s area of transmission operations. Affiliated power marketers could no longer work alongside the transmission operators who were charged with treating them and external parties equally. At the same time affiliated power marketers would no longer have any “inside information” on the availability of the transmission system nor the transactions being scheduled on it.

So even 14 years ago we were at the point (in some markets) where there was competitive generation and retail services, interconnected systems of systems with real time control systems based on data from intelligent devices, sharing of networks, and programs (air-conditioning, pool pump control etc.) designed to shift demand and control market prices, with all of the associated regulation, legislation, market rules and interoperability to enable this.

This led to new arrangements where utilities entered into long-term power purchase agreements with neighboring utilities, or located new generation facilities outside of their service territories and entered into long-term agreements for transmission rights to deliver that energy to their own systems. In day-to-day operations, companies would agree to day ahead and same day transactions with adjacent companies to supplement their own generation capabilities and balance supply and demand.

7.4. The Need for Regional Authority

Once power marketers started to move their electricity purchases across multiple transmission systems, many transmission systems became loaded to much higher levels. Transmission services are generally contracted “point-to-point” but physical power flows divide among numerous paths according to the properties of electricity. As mentioned earlier this creates a situation where policy and physics are not aligned and as a result of many long distance electricity transactions being scheduled "loop flows" caused by energy flowing on alternate paths led to stress on the system and the only way to reduce the stress was to curtail transmission sales.

The North American Reliability Council (NERC) stepped in to address this problem by introducing the NERC Tagging application which captured information about entire transactions from beginning to end. This has parallels to the business transformation and business process management activities being performed by many utilities as a result of AMI and/or MDM deployments where the need to model end-to-end processes is paramount to achieving benefits.

Then what occurred was the beginning of a transition from a reliability centric focus to more of an economic centric focus, as reliability was taken more and more for granted. SCADA systems were well established and ISOs appeared in markets to balance loads and manage wholesale markets on a regional scale. We also started to see a challenge to the natural monopoly paradigm as deregulation/restructuring appeared in the UK and spread elsewhere. This model of the industry had competitive generation and competitive retail services as the traditional energy supply chain became unbundled, leaving the transmission and distribution pieces still essentially as regulated monopolies within set franchise areas and competitive generation became more common. We also saw “competition” between transmission and distribution utilities as they increased revenues and lowered costs by a series of mergers and acquisitions that also meant (to some degree) that smaller proportionate reserve margins were required.

8. MAKING IT ALL WORK TOGETHER

So what parts are we talking about here when we say that the value of all the pieces together must exceed the sum of the parts? As a natural monopoly there are issues that all utilities face, and which force a superficial similarity upon them. These similarities start to become less clear as we look into them in more detail, even for two apparently similar utilities.

Most utilities are the same in as much as they share many common goals, challenges and drivers and share much similar accountability but while utilities are fundamentally similar in many ways the history, goals, drivers, demographics, and regulatory requirements also make each utility unique [13]. And just as utilities are unique, requiring utilities to conform to a single definition of Smart Grid would impose false targets and imprudent requirements in some cases which is why every utility needs to understand what Smart Grid means to them and to take the steps to meet those objectives with their regulators.

The definition of Smart Grid previously offered is deliberately holistic and broad. Its intent was to make the point that Smart Grid is an Ultra Large Scale System of Systems. But for each utility it means something more specific, more "personal", and includes a vision, goals, objectives, strategy to bring the pieces together, and a roadmap to coordinate the implementation.

8.1. The Nature of Interoperability

Once you start to break down these specific goals into more detailed objectives, the evolution of Smart Grid at each utility starts to change to reflect the nature of these utility specific components. For this reason it will not be easy to eliminate gaps between different organizations, or between utilities that have been subject to different drivers and challenges. By aligning strategy across old operating boundaries, the gaps can begin to be closed but issues such as performance based rates, geography, customer demographics, regulation, rate cases, and the multitude of existing systems will mean that while it will be possible to build the system of systems that is Smart Grid, achieving interoperability will take longer in some areas than in others. Thus the ability to measure and improve the maturity of interoperability is key to making the transition to Smart Grid as painless as possible.

Many (perhaps all) utilities have been introducing intelligent devices into their transmission and distribution systems over the last two or more decades. Some of this has been through the replacement of electro-mechanical relays with functionally equivalent smart relays, or with substation data collectors, or one-way or two-way metering projects etc. but the fact is that there is already much intelligence embedded in today's electrical networks, and this embedding of intelligence is one of several factors that have been steadily reshaping the industry.

In the 1990s Serious industry efforts at developing interoperability standards, sponsored in part by EPRI, began with the Common Information Model (CIM) and DNP as a standard RTU protocol. These ultimately valuable and successful efforts continue to grow and yield benefits globally today. [12]

Today there is a lot of investment being made in interoperability which reflects its importance in making Smart Grid a reality. Much of this focuses on the development of standards and includes the work being done by NIST, SGIP, UCA, IEC, GWAC, SEI and others. But just as we questioned the cost benefit ratio of regulation we also have to ask ourselves what is the cost benefit ratio of interoperability and what is the ROI of moving to a more mature level of interoperability? This is an area of focus that needs to be incorporated into the GWAC SGIMM. [14]

In many ways data is arguably the ultimate change agent. Turning data into actionable knowledge is the real promise of Smart Grid. The revelation will be discovering what data becomes actionable, by whom, and what for. Of course this includes good decisions, bad decisions, informed decisions and uninformed decisions. Our job is to make the correlation between informed decisions and good decisions as strong as possible. Bad decisions occur when subjectivity is involved, where data is incomplete and/or where the data is incorrect or misunderstood. By eliminating the causes of bad and/or uninformed decisions we increase the likelihood of making good decisions.

But there are steps that can be taken to reduce the likelihood of bad and uninformed decisions and the GWAC IMM will hopefully address many of these by helping to identify and reduce immaturity in interfaces at both inter-personnel and inter-system levels. In both contexts (systems and people) one important area that has to be mature is that of semantic modeling. Two big benefits of Smart Grid are the ability to share information both within organizations and between them. Yet there is also risk here (unrelated to any cyber security issues that are separate from this) that data may be shared without consistent shared semantic understanding of what the data represents.

Check for yourself: see how many different definitions you can find for the word "load" within your organization. Now stop to consider what might happen if your organization's back office and operational systems were suddenly and seamlessly integrated with a service oriented architecture and data was made available to any suitable qualified and authorized staff. If the semantics were not fully and completely defined think what could happen.

So improving the maturity of shared semantic definitions is one of the important goals of the GWAC IMM and is the area that will be built out first as the tool is developed. This is an area of the GWAC Stack that, if you look closely, affects both the context setting framework issues and the cross cutting issues. Layer 4 of the context setting framework issues is “semantic understanding”. It is one of the two issues in the informational category and sits directly between the technical issues and the organizational issues in the GWAC Stack. The other informational issue is “business context”. If you look at the cross cutting issues, the first one is “shared meaning of context”. As with any hierarchical stack model the context of any entity has to remain consistent as it is managed within different layers. This understanding has to be not only consistent vertically within this stack but must also be consistent internally across business boundaries and also within communities of organizations where the data is used. Without this the risks to interoperability are significant to say the least.

9. MAJOR SMART GRID INITIATIVES, THEIR RELATION TO NATURAL MONOPOLY CHARACTERISTICS, AND IMPACTS ON INTEROPERABILITY

9.1. Demand Response, Distributed Generation & Renewables

9.1.1. Distributed Generation

The concept of distributed generation (DG) has been around for many years. Initially, the technologies focused on traditional, fossil-fueled devices such as diesel and natural gas generators. These technologies were utilized for Combined Heat & Power systems (CHP)) and backup power systems for commercial and industrial companies, but emissions requirements limited the use of these devices. When micro turbines and fuel cells appeared on the market during the late 90’s, the prospect of “ultra-low” emission factors lead to the expansion of the concept of distributed generation. Now, having escaped the emission limitations, and coupled with restructured energy markets, concepts have been devised to greatly expand the role of DG and use the concept as an economic and reliability tool. Applications such as peak shaving, facility demand management, and load leveling were developed in anticipation of the new technologies. Unfortunately these advanced DG systems were not able to meet their full promise of providing low emission generation, and the cost of the devices never lowered to the point of mass deployment.

9.1.2. Renewables

Today, the market is changing again. New, smart energy technologies mean new opportunities for the utility, customers and third-parties. The importance of integrating these technologies grows as carbon control and environmental policies and standards come increasingly into play.

Consequently many of the concepts are again being evaluated but this time distributed generation is becoming synonymous with renewable energy technologies such as solar and small wind. Like the previous scenario the belief that these technologies will meet the cost requirements are ensuring that renewable DG technologies are poised for substantial growth as Smart Grid technologies and innovations in energy storage take hold.

9.1.3. Demand Response

Among the many benefits claimed for advanced metering infrastructure (AMI) is an expansion of demand response programs and practices. Demand response consists of changes in patterns of end-use electricity consumption triggered by changes in the price of electricity over time or incentive payments and which leverages the “luxury” component of consumption. This is distinct from energy efficiency, which involves efforts to increase the level of service output for a given level of consumption, or to put that in more familiar terms to reduce the amount of energy consumption for the same level of service. The primary goal of demand response programs is to reduce load during periods of peak demand and shift it to other times, thereby enhancing system reliability, reducing congestion, reducing hourly market prices, and delaying the need to construct additional generating capacity.

Demand response programs such as time of use, critical peak pricing, and critical peak rebates have existed for many years, but implementation has mainly been effected through large commercial and industrial customers. In competitive markets, these programs are often administered by market operators, since they are responsible for planning and dispatching the regions’ generation capacity and can use demand response resources to reduce the need to run higher-priced peaking facilities and help cover capacity shortfalls. [15]

The relatively high costs required to facilitate demand response in the past has led programs to direct their efforts toward commercial and industrial customers, and in many cases met with limited but useful participation. Today smart meters and AMI systems are widely viewed as enabling technologies for demand response that will permit greater and more effective use of these strategies.

Two-way communications, intelligent networks, and smart meter technologies will allow for demand response programs that are both more extensive and more efficient. Demand response programs built on AMI will foster the integration of residential customers into demand response programs yet should also promote increased participation by commercial and industrial customers.

Load shifting or peak shaving programs typically involve customer curtailment of load at specific times of the day, either by request of that customer's retail power supplier or in response to real-time price signals. For smaller commercial and residential customers, such programs provide either for remote load control and interruption of customers' air-conditioning equipment by retail providers or customer-initiated shifting in response to differences in rates for on- and off-peak usage.

By shifting usage from peak to off-peak periods, TOU program participants reduce their power-supply costs in two ways. First, they reduce their energy costs by shifting usage from the high-priced peak period to the lower-cost off-peak period. Secondly (for large commercial and industrial customers), they reduce the cost of procuring reserve capacity associated with their total energy usage by reducing that same usage during the hour of system peak. For large customers, their reserve-capacity obligation is often determined on the basis of their contribution to system peak, and since program participation is designed to shift usage away from hours of system peak, load-shifting reduces capacity obligation and thus the associated cost of procuring capacity to meet that obligation. Similarly reductions in system-peak load in response to TOU rates also provide benefits in the form of avoided investments in additional transmission and distribution capacity.

Load curtailment programs offered by utilities provide commercial and industrial building owners with reduced electrical rates in exchange for an agreement to curtail energy use at the request of the utility. Typically, these requests come during periods of high load such as hot summer afternoons for summer peaking utilities. Commercial facilities that can respond to these requests by turning off equipment or using alternative sources of energy for short periods of time can realize significant savings under these programs.

It is often more cost effective to pay customers to curtail loads than to call on additional generation which is often provided by inefficient (and expensive) generators. If enough load can be reduced, the utility does not have to add generation (or make purchases on the spot market). The compensation for participants in these programs can take several forms, but is generally in the form of lower overall rate schedules and/or rebates.

Although not a new concept but a part of recent industry evolution, demand response and distributed generation clearly impact the natural monopoly paradigm of electricity supply. These programs will continue to challenge the natural monopoly paradigm of electricity supply.

9.2. Phasor Measurement

A phasor measurement unit (PMU), commonly referred to as a synchrophasor, measures the magnitude and phase angle of the electrical waves on an electricity grid to determine the health of the system. They are a part of many Smart Grid programs and are considered an important part of the future of power systems. Synchrophasor technology provides a tool for system operators and planners to measure the state (and thus the "health") of the electrical system and manage power quality by taking measurements from different locations in the power system that have been synchronized to a common time source such as GPS radio clock. Because these phasors are truly synchronized, the comparison of two remote quantities is possible in real time. These comparisons can be used by system operators to assess system conditions.

This is not a technology that today challenges the natural monopoly paradigm. Whether that also applies to operating decisions that are made based on analysis of PMU data is unclear but clearly this is a technology with a lot of potential to help improve reliability.

9.3. Voltage Reduction

A key driver of voltage reduction is to reduce the voltage on specified feeders in order to lower electrical power demand by monitoring voltage readings from smart meters. An important consideration in doing this is to maintain acceptable voltages at the end of the feeder when the voltage is reduced at the substation. The use of switched capacitor banks along the feeder facilitates the potential (no pun intended) to have the voltage profile flattened along the feeder before any voltage reduction activity is started. Since flattening the profile will require avoiding large steps in voltage along the line there will normally be a requirement for more, smaller capacity, capacitor banks to be installed.

The implementation of distributed generation will also impact the voltage profile of the feeder and that will subsequently affect the adequacy of any capacitor switching schemes that are developed so it is important also to develop requirements related to the ability to assess the likelihood of DG installations on the feeder and the impact that they might have due to the different reactive power characteristics of different devices and their ability to absorb or generate reactive power.

By itself the use of voltage reduction does not impact the natural monopoly paradigm but by flattening the voltage profile and preparing the distribution system for distributed generation the barriers to entry from capital intensity and the values of location rents are diminished for new entrants.

9.4. Electric Vehicles

PHEVs/EVs are a hugely disruptive technology. A PHEV/EV on rapid charge draws a load equivalent to approximately four typical households which places a great demand on transformer load management and phase balancing, however these are not new challenges in themselves. A PHEV does not require large investments by the owners, it has the ability to moderate demand fluctuations (and also cause them) through its ability to function as a storage facility, a load, and a generator. By varying charge rates it can even be used to help with voltage/frequency regulation. It also challenges locational rents and opens up a whole new interpretation of this topic through "demand roaming". Finally the authors argue that it also challenges the characteristic of a direct connection which traditionally implies immobility. The PHEV is anything but immobile and brings with it many technological, informational and regulatory challenges.

It is important to note that there is a lot of speculation about how fast electric vehicles will be adopted, when and where people will charge electric vehicles, and who will control this but the fact is that today we don't know. We can make educated guesses bases on early adopter experiences but on any given day the state of charge for any vehicle will not be predictable until sufficient data has been accumulated and thus the knowledge about the amount of storage and generation available for participation will vary. As with demand response, the use of aggregation across a large number of vehicles, such as in a fleet or a concentration of Electric Vehicles (EVs)/plug-in hybrid electric vehicles (PHEVs) in an organization could help to develop a more predictable resource.

Plug-in Hybrid Electric vehicles (PHEVs) represent a disruptive technology that has a significant level of complexity. While conceptually, the PHEV could be charged when supply is more readily available and low cost the mass adoption of such an algorithm would cause a new peak that needed to be managed so the gradual adoption of plug in vehicles may be a good thing. There are many logistics that will need to be resolved in terms of the communications between the PHEV and the grid and the robustness of data models to handle the management of associated data and which could provide some interesting interoperability challenges.

Unlike PHEVs, EVs rely entirely on electricity to charge their batteries and as such, the grid must be capable of delivering the power to recharge EVs even on the busiest days.

Despite the clear evidence that more power generation plants are needed, two primary concerns are hindering efforts to build them: an unsettled regulatory environment and a 'not in my backyard' mentality. While PHEVs/EVs may provide ways to help integrate renewable generation into the grid and provide the ability to manage frequency there is also a valid concern about the U.S. electric grid's ability to absorb electric vehicles into its already-stressed system. Despite the benefits offered by these vehicles, high adoption rates have the potential to increase peak loading of the grid, further exacerbating the lack of generation capacity.

Nonetheless the momentum for EV and PHEV adoption has reached a tipping point and these vehicles are very much a focus of future development for the major auto manufacturers. With or without without EVs, the U.S. will need to add generation capacity to replace aging units and meet demand increases due to a growing population and a world that is becoming more dependent on electronics by the day.

9.5. Energy Storage

Battery technology has been evolving at a rapid pace in recent years but is only now starting to offer real opportunities for integration into the electric grid. Yet storage has been around as an operational and economic tool for many years in the form of pumped storage hydroelectricity used for load balancing.

This approach stores energy in the form of water, moved between two reservoirs at different elevations. Using lower-cost off-peak electric power to run the pumps the water is pumped from one reservoir to another reservoir at a higher elevation. Then during periods of high electrical demand, the stored water is released through turbines where it flows back to the lower reservoir. This technique is currently the most cost-effective means of storing large amounts of electrical energy from an operating perspective, but capital costs involved in building these facilities and the location of appropriate geography both from a reservoir and construction perspective and also a grid perspective create factors that limit the use of these systems. The relatively low energy density of pumped storage systems (kWh generated per ton of water) requires either a very large body of water or a large variation in height.

It is also important to note that unlike battery storage pumped storage is an economic tool. This is because more energy is consumed in pumping the water to the higher reservoir than is generated when it flows back through the generator turbines. Losses occur due to several factors such as water evaporation, electric turbine/pump inefficiency, and friction due to the water flow. Yet although the losses of the overall process makes the plant a net consumer of energy, these systems are a useful economic tool that can increase generator revenue by selling more electricity during periods of peak demand, when electricity prices are highest, and are a useful operational tool that can be used to supplement generating capacity in times of unanticipated problems.

So where can battery storage make an impact? There are increasing numbers of large-scale centralized renewable generation as well as small-scale distributed generation facilities being developed especially wind and solar. With an emerging renewable and distributed generation infrastructure that will need to be integrated and supported, there is a general recognition that these variable generation resources may also increase grid volatility, requiring increased ancillary services to help maintain grid operations.

Storage technologies can perform these roles and can be used to mitigate ramping issues so emerging energy storage technologies offer a viable solution for renewable and distributed generation grid integration. Advanced technologies, with the ability to provide fast-acting energy storage for regulation services, also show promising potential for enhancing grid reliability.

9.1. Virtual Power Plants

A virtual power plant (VPP) is a collection of distributed generation installations (such as micro-CHP, wind-turbines, small hydro) which are collectively run in a coordinated manner by a central control entity. This is done such that they essentially operate as a single power plant with a multitude of different characteristics that can be leveraged to provide a flexible generator without the limitations of some or all of its individual constituent units. A well-chosen mix of generator types can thus offset the unreliability inherent in some generators to make a virtual plant that is able to operate much the same as a conventional generator.

As VPPs have grown there have been at least two important advances in the development of the VPP. The first is the development of a conceptual framework that matches demand-side resources to electricity supply products, such as capacity, energy, and regulation. The second is the experience gained from operating these coordinated systems that provides insight into customer segmentation and the provision of appropriate value propositions for each segment.

9.2. Microgrids

Power systems have undergone considerable change in operating requirements as a result of restructuring as previously discussed but operating requirements vary continuously and will continue to do so due to increasing amounts of distributed energy resources (DER). These requirements vary depending on the amount of local load and generation, and also on the need to manage reactive power. In many cases small scale generators using DER that includes different technologies can take advantage of renewable energy resources such as solar, wind or hydro energy. Having micro-sources such as these close to the load has the advantage of reducing transmission losses as well as preventing transmission congestion.

Power islands naturally occur in some areas of the grid where there is a good local balance between generation and load, and it was power islands that helped the initial recovery from the 2003 Northeast blackout. Low voltage generation and power islands reduce the chances of having a power supply interruption for end-customers since local micro-sources, controllable loads and energy storage systems can operate in the islanded mode in case of severe system disturbances to the extent that they can operate fully independently of the main grid if required.

These small low voltage power islands, known today as micro-grids, typically have the same size as a low voltage distribution feeder and will rarely exceed a capacity of 1 MVA and a geographical span of 0.5 to 1 miles.

Micro-grids can often provide both electricity and heat to consumers by means of combined heat and power plants (CHP), gas turbines, fuel cells, photovoltaic (PV) systems, wind turbines, etc. The energy storage systems usually include batteries and flywheels as storage is used to help integrate DER as previously discussed.

One of the major challenges for micro-grids is establishing is a protection system which must respond to both main grid and micro-grid faults. In the first case the protection system should isolate the micro-grid from the main grid as rapidly as necessary to protect the micro-grid loads and generators. In the second case the protection system should isolate the smallest possible part of the micro-grid when it clears the fault. Clearly there are also safety issues that have to be carefully managed when there are line workers working on de-energized sections of the main grid close to energized portions supported by micro-sources.

9.3. Self-Healing

Using real-time information gathered from sensors and automated controls in the electrical network to detect, respond to, and ultimately anticipate (and thus avert) system problems, the Smart Grid can automatically avoid or mitigate a number of problems such as power outages, power quality problems, and service disruptions.

To have a Smart Grid means having a flexible electrical network architecture and an open communications architecture. The data on which to base decisions has to be collected and made available. The data must be analyzed and decisions made. And finally the software and equipment must be able to respond to these decisions rapidly and in an interoperable manner. Even then, the nature of the electrical system network will limit its ability to “self-heal”.

For many rural distribution networks, there can be no such thing as a "self healing" network. If there is a failure of an overhead power line in a rural area, given that these tend to operate on a radial basis (for the most part), there will be an inevitable loss of power. In the case of urban/city networks that for the most part are fed using combinations of overhead lines and underground cables, networks are designed to be much more networked such that failure of one part of the network will result in no loss of supply to end users.

9.4. Customer Education and Outreach

In a nation with the largest disposable income on earth, where the bestselling vehicle is a full sized truck, and where technologies like compact fluorescent lights (CFLs) that have a ROI of mere months sit on shelves in retail stores while many people still use incandescent light bulbs, what makes us as an industry think information slips sent out with bills in the mail will change customer behavior and motivate them to save $10 per month? Residential consumers, remain reluctant because their perceived value proposition is not viewed by them as compelling [3] and indeed many of the benefits for residential customers are non-financial though the financial case is still positive.

Smart Grid offers the promise of many operational benefits but from a customer perspective there has to be much more in terms of benefits than simply saving a few dollars. Helping customers to understand what Smart Grid is and what these new products and services are will require large investments in education. These programs should address both financial and non-financial concerns.

So while customer outreach is not any kind of technology initiative, it forms a critical component of many Smart Grid programs and is worthy of inclusion here.

Customers do not speak the same language that utilities speak. Consumer electronics companies however talk the language that customers understand but how many of these companies have been engaged in Smart Grid customer outreach programs? The value proposition projected for society as a whole is expected to be great and it may be that consumer electronics companies have a valuable part to play in achieving a compelling value proposition is for customers.

When intelligence is ubiquitous and Smart Grid is a reality who is it that will manufacture the products that customers want, and who will provide the services that they will use? Who has an App for that?

But customer outreach is a critical and necessary element that is required to build the Smart Grid when viewed in context of the definition offered earlier. Will customer outreach affect the natural monopoly paradigm of energy supply? Absolutely it will. Early Smart Grid projects talk about the hidden cost of IT and unanticipated interoperability challenges. While this is a problem to be overcome for utility projects, there are people and resources available (to varying degrees) to throw at the problems to solve them and learn from them.

What kind of intellectual and financial investment will customers be prepared to invest to make things work? If we expect residential customers to invest a lot of time and effort into making these consumer systems work we have two chances for success: (1) fat, and (2) slim. It has to be plug and play. Interoperability needs to be guaranteed.

9.5. Smart Grid Impacts on Natural Monopoly

The following table provides a preliminary assessment of which Smart Grid initiatives are impacting the natural monopoly paradigm of electricity supply and in which areas. This was in truth a very high level activity since it provoked much discussion and argument, is very subjective, and will probably vary in interpretation from reader to reader. Our goal here was not to try to be 100% accurate but to stimulate thought in the industry about how Smart Grid is an evolution of many changes that have been underway for years.

	Capital Intensity & Min Economic Scale	Non -storability with Fluctuating Demand	Locational Specificity & Location Rents	Necessary or Essential for the Community	Direct Connection to Customers
DR, DG, & Renewables	×	×	×	×	×
Load curtailment suppliers			×	×	×
Phasor measurement					
Voltage reduction	×	×	×	×	
Electric vehicles	×	×	×		×
Energy storage		×			×
Microgrids	×	×	×		×
Virtual Power Plants	×	×	×		
Self healing					
Customer Education and Outreach	×	×	×	×	×

10. CONCLUSIONS

Smart Grid won't happen overnight yet the grid gets smarter each day that passes. Undoubtedly Smart Grid has been over-hyped but the promise is real and it is here to stay. The industry has been evolving over many years and Smart Grid is not a new concept so much as it is a catalyst to bring together an integrate the myriad of changes that have happened already and provide a springboard for even more evolution.

10.1. The Near Term Future

As Smart Grid deployments continue we will see more and more standardization and innovation. There will be successes and failures but both will provide valuable lessons learned that will contribute to the continuing development of best practices.

In any ultra large scale system of systems such as the Smart Grid some degree of system failures will be intrinsic just as they are today. Complexities are introduced due to the fact that FERC regulates interstate / inter-regional power markets but individual states regulate utilities within their jurisdiction. Municipalities and coops further fragment the market for interoperable products yet interoperability is the key to making Smart Grid successful. The GridWise Architecture Council's Context Setting Interoperability Framework [17] recognizes this and Technical interoperability is only one of three interoperability categories, with Informational and Organizational being the other two.

High levels of Distributed Generation will cause major changes in distribution engineering and operations and renewables, especially distributed renewables, have to be integrated with grid operations and markets with all the communications and information handling that that implies. Electricity Storage will also become a reality and will be applied throughout at all levels from generation to consumer.

But these things have been stated many times already. Our intention when writing this paper was not to predict the future of Smart Grid or to discuss which technologies would help advance Smart Grid. Instead we wanted to examine the evolutionary nature of the industry and to see how Smart Grid and other changes have impacted the natural monopoly paradigm of electricity supply by examining the characteristics of a natural monopoly. And what is obvious is that the nature of electricity is changing and has been changing for many years. Once the hype around Smart Grid dies down and we are left to get on with implementing it, doors to new changes will be opened and these will require a strong focus on standards and interoperability.

10.2. Natural Monopoly Characteristics Questions

Earlier we posed a number of questions at the end of the description of each natural monopoly characteristic. These questions were intentionally left unanswered so that the reader could form their own opinion but the following sections provide brief answers to each of these questions according to our perspective.

10.2.1. Can Smart Grid provide products and/or services at a lower cost?

If the answer to this question is "no" there are a lot of business cases and ARRA grants that need to be put back under the microscope. There is no doubt in our minds that the answer is "yes" though the degree of confidence will vary depending on the success of individual implementations and just as sure as the sun rises in the East there will be some failures and everybody will share the pain of these to some degree. But more than simply providing lower costs through demand response and time of use rates, or through improved productivity due to better power quality and improved reliability, Smart Grid promises to improve interoperability of an industry with many silos and to provide opportunities for new market entrants. This may not be good news for all of the incumbent participants but it should be good for the industry overall.

Providing goods and services at lower costs will involve reducing operational costs for utilities, improving commercial and industrial customer productivity through improved reliability and reducing customer costs through new pricing models. Realizing these benefits will place many requirements on interoperability:

- within each utility in terms of operational systems coordination,
- within communities of organizations as DR and DER are more fully integrated into electricity markets, and
- between customers and their service providers associated with delivering benefits associated with data management of customer data.

10.2.2. Can Smart Grid eliminate demand fluctuations or provide a means to store electricity?

The answer to this question is a firm “yes”. Demand fluctuations are already being influenced in many programs through direct load management and load curtailment programs. Smart Grid offers new and improved mechanisms to provide wider access to more of these programs. New storage technologies provide methods to store electricity and the increasing deployment of electric vehicles will open up many opportunities in this area in the future once charging schedules and driving habits become aligned based on growing experiences in the next few years.

While the answer to the question is positive, there are a lot of interoperability impacts. Pricing schemes for residential customers will need to be easy to use whether through the use of interactive controls (PCT, mobile phones etc.) or through the use of intelligent appliances. The mechanisms for communicating with customers may not be utility centric and thus will need to work with customers in different service territories with different devices. For the integration of storage there will need to be control and monitoring systems developed that in many cases may be part of a VPP where interoperability across multiple different unit types will be required.

10.2.3. Can Smart Grid provide a means to site equipment such that the associated location costs are minimized?

Again the answer to this question is “yes”. Smart Grid will open up opportunities for small scale distributed generation with limited capital intensity and with the ability to site equipment in smaller sites and in residential areas. The need for high location rent sites will be diminished slightly but will not disappear. We will still need substations and there will be additional equipment that will need to be deployed on both transmission and distribution circuits. We will still need new large generators and new substations which will all command location rents appropriate to their required use. Smart Grid is not a magic bullet that will fix all of our problems but it does help us to make better use of the resources that we have and to have more flexibility over equipment siting.

But we can only have flexibility over equipment siting if we have a flexible communications infrastructure that can support the establishment and movement of device locations and which can support many different device types on one network. This can only happen with standard protocols based on open standards so even the issue of location rents has an impact on interoperability if we are to make Smart Grid effective.

10.2.4. Does Smart Grid make electricity less of a necessity or less essential to the community?

A better question might be does Smart Grid reduce the necessity of products and services currently provided by natural monopolists? Smart Grid will not make electricity less vital to our civilization but it can help us to look at how and why we use electricity and to separate the necessary use from the luxury use and to examine the opportunity cost of the next kWh or of running the pool pump for an extra hour or of leaving outside lights on all night. So from a perspective of luxury use the answer to this question is “yes” but one reason that we need Smart Grid is because electricity is a necessity and it is becoming a scarce resource as our demand increases and our infrastructure gets ever older.

This is another area that comes back to making the customer interface to new products and services seamless. It requires education, outreach, and innovation that can be applied to interoperable consumer devices that are easy to use.

10.2.5. Can Smart Grid provide the ability to purchase electricity and services from producers/sellers in multiple locations?

There are two potential interpretations to this question. Luckily the answer to both of them is “yes”. Yes, Smart

Grid will open up opportunities to purchase electricity and other services not only from the incumbent utilities who own the wires to the house but also from service providers in other locations. Yes, Smart Grid will let you purchase power from different utilities as you move from one service territory to another, or within the same service territory at different locations. These latter changes will take some time to occur but the ability to purchase electricity from different retail sellers already exists. Smart Grid will just open up new opportunities and vehicles (another unintended pun) to facilitate this but only if the mechanisms to support this are seamlessly interoperable.

Other than the consumer devices already discussed the other key area of interoperability required to support this is the development of standards around how to treat electric vehicles in terms of regulations, charging schemes, access to stored power to supplement scheduled generation, “roaming” agreements for how to identify a vehicle and reconcile it’s power consumption and generation across multiple service territories and/or jurisdictions, and the data modeling and services required to make this work.

10.3. Key Regulatory Questions [18]

10.3.1. Who will “own” and oversee DG interconnection and IT integration issues?

Whatever business model is adopted for ownership/operation of DG assets, avoiding customer dissatisfaction over integration issues, not to mention real reliability and safety problems, is key to maintaining customer and political support. Also, many third-party entrants will lack the technical competence to deal with complex integration issues, or may not wish to fully recognize the costs involved. We will see a change in business models as we always do when technology spurs changes and we need standards set by an independent processes. Under the Energy Independence and Security Act (EISA) of 2007, the National Institute of Standards and Technology (NIST) has "primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems…".

10.3.2. What level of T&D Utility of the Future investment, will the various state PUCs support and what quid pro quo will be required?

We have argued that “Smart Grid” is the only tenable strategic path in the T&D space. This will require significant increases in T&D investment levels and a corresponding increase in rates. It is possible that kilowatts per hour (kWh) demand could increase, decrease, or stay about the same on a per circuit basis given the uncertainties about the pace of energy efficiency, fuel switching, and DG adoption. Therefore, utilities must obtain regulatory approval for Smart Grid investment including recovery mechanisms that do not expose them unduly to fluctuations in utilization – except where they have made commitments to demand reduction and are in a position to affect the result. Historically, utilities have been reluctant to trade performance (reliability, OpEx cost) incentives for cost recovery of additional spending, but this may be a necessary consideration.

10.3.3. How will business models be shaped for ownership and operation of DG?

Politicians will be under tremendous pressure from non-utility players to allow their participation in this wave of spending – from plumbing/heating contractors to large retail chains. Business models that allocate a share of new activity to local small business are always politically irresistible – and coupled with subsidies for energy efficiency, will be a major focus of political debate. For utilities that are pursuing regulated ROI models for DG and other renewable development, the debate will also be charged with typical regulated consumer issues around risk sharing and fairness. Making the political case for better consumer value in the face of increasing costs and more predictable/sustainable results will be difficult and may require some creative partnering with regulators to establish win-win scenarios.

10.4. In Summary

There is no doubt that Smart Grid is a disruptive change that impacts the natural monopoly paradigm of electricity supply. The nature and full extent of those changes will unfold over time but the authors do not offer any “crystal ball” vision of the future here. Some areas of the industry both geographically and vertically (in terms of the value chain) are likely to be affected to varying degrees but changes will continue to occur as indeed they have been for many years now, but the tipping point for how the industry looks may be very close now.

An energy future built on yesterday’s technology, yesterday’s regulatory model, and yesterday’s financial model, is not sustainable. New business models are required and new regulatory models are required. Progressively difficult challenges to traditional utility regulation will appear that will require a new mind set and bold action. Those regulators who recognize the resultant full set of benefits to all of society (not just to the utility) will be most willing to take these steps [5].

Smart Grid is a disruptive catalyst for change that brings together many other previous initiatives and will enable new market entrants to enter the electricity supply market since we expect even the natural monopoly character of distribution will be challenged in the future.

We don't know what we don't know but it is safe to predict that the end state is nowhere near yet.

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Biography

Mark Knight is Director of Grid Applications at KEMA. Mark's background, spanning 24 years, has included a mix of information technology work and business process work both as a consultant and as a utility employee in the UK and the US and has spanned several areas including distribution, transmission, metering, systems integration, and restructuring. In his role at KEMA he is responsible for developing vision and requirements for Meter Data Management and other applications that can mine the data from smart meters and other intelligent devices. He is focused on the integration with and impact on utility processes and applications required to support information sharing for enterprise users' needs and to prioritize areas that will benefit directly from this data in order to define the value propositions for the new uses of data and to enhance interoperability.

Nora Brownell is co-founder of ESPY Energy Solutions. She was nominated to be a Commissioner to the Federal Energy Regulatory Commission (FERC) on April 30, 2001 by President George W. Bush. She was confirmed by the United States Senate on May 25, 2001, for a term that expired June 30, 2006. Brownell's tenure at the FERC reflects her longstanding and unwavering commitment to fostering competitive markets to serve the public interest. She championed the development of independent transmission organizations for wholesale power, which now represent the electricity market structure serving two-thirds of the U.S. $10 trillion economy. As a leading advocate of responsive and effective independent board governance at RTOs and corporations, Brownell is a strong proponent of FERC policies that promote investment in national energy infrastructure development. Prior to FERC, Ms. Brownell served as a member of the Pennsylvania Public Utility Commission (PUC) from 1997 to 2001. During her time at the PUC, Ms. Brownell took an active role in the rollout of electric choice in Pennsylvania.

