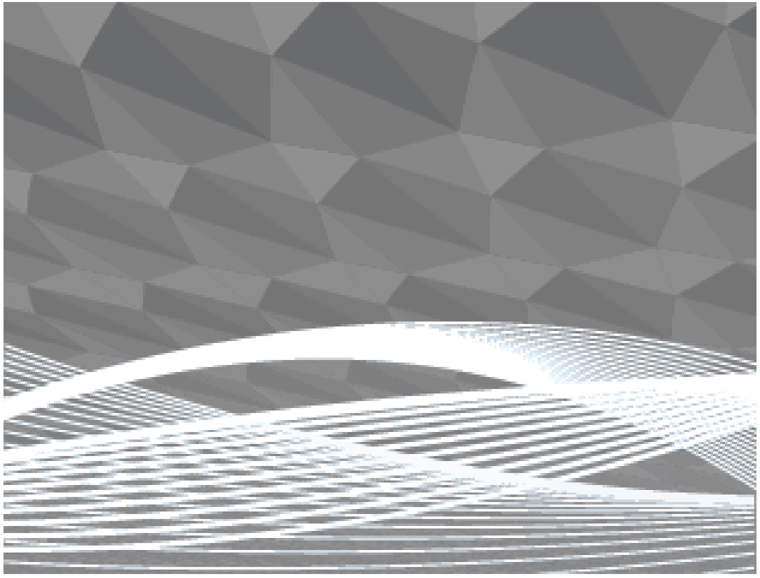

Value Creation Through Integrated Networks and Convergence

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1.0 Introduction

Customer adoption of distributed energy resources and public policies are driving changes in the uses of the distribution system. A system originally designed and built for one-way energy flows from central generating facilities to end-use customers is now experiencing injections of energy from customers anywhere on the grid and frequent reversals in the direction of energy flow. In response, regulators and utilities are re-thinking the design and operations of the grid to create more open and transactive electric networks. This evolution has the opportunity to unlock significant value for customers and utilities. Alternatively, failure to seize this potential may instead lead to an erosion of value if customers seek to defect and disconnect from the system.[1]

This paper will discuss how current grid modernization investments may be leveraged to create open networks that increase value through the interaction of intelligent devices on the grid and prosumerization of customers. Moreover, even greater value can be realized through the synergistic effects of convergence of multiple networks. This paper will highlight examples of the emerging nexus of non-electric networks with electricity.

2.0 Network Value

Traditional electric distribution systems that deliver energy one-way from central generation to customers have a linear value model. That is to say, the value of a traditional grid is the sum of the number of customers served. At the current forecasted[2] long-term average growth rate of under 1%, customer and societal value from the distribution system will not appreciably increase.

In contrast, an electric network that is based on a system of interconnected people and energy producing/consuming devices that are interactive can create significantly more value. These open and interactive networks have a unique property in that the greater number of points of interactive connectivity results in nonlinear value creation. The conceptual potential value as put forward by Bob Metcalfe[3] is that the potential value of a network is proportional to the square of the number of connected users of the system (n^2). This is known as Metcalfe's Law. A classic example is a telecom system in which a two-phone system has a fraction of the network value of a system with a million phones connected, as illustrated in Figure 1 below. This later became known as Metcalfe's Law.

A classic example is a telecom system in which a two phone system has a tiny fraction of the network value that a system with a million connected phones, as illustrated in Figure 2 below. The electric system is also undergoing a transformation in the use of the system by customers. Instead of the historical one-way flow involving customers consuming electricity, an increasing number are also producing. Beginning in the 1980s, customers began to install onsite co-generation plants that often provided services to system operators in addition to supplying a customer's energy needs. Today, the number of distributed resources has exploded into thousands of devices that can provide interactive services and multi-directional flows

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[1] J. Creyts, et al., *The Economics of Grid Defection*, Rocky Mountain Institute, CohnReznick Think Energy, and HOMER Energy, 2014

[2] U.S. Energy Information Administration's *Annual Energy Outlook 2014* (AEO2014)

[3] In 2007, Robert Metcalfe described this potential as the "EnerNet" building on his "Metcalfe's Law" that characterizes the exponential value effects of networks such as the Internet, social networking and business.

across the network. This changing use of the electric grid is increasing its network value – but only if it can support n-way power flows and multi-sided transactions. Otherwise, a closed distribution system will not create network value.

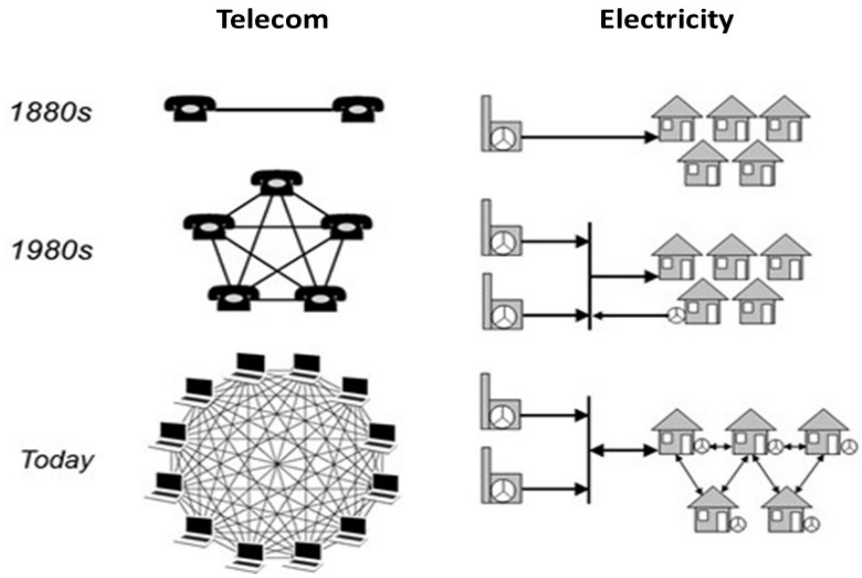

Figure 1. Evolution of Telecom & Electric Networks

2.1 Integration

An important architectural concept in development of a network is “integration”. Integration is an engineering task associated with adding more nodes on a network and realizing the economic value of that integration. This is often undertaken on a case-by-case basis until plug and play interoperability is achieved through standardization. Some examples of integration are an electric utility connecting a wind generation farm to its transmission grid or connecting a microgrid to its distribution system, or integrating distributed resources into distribution operations. This is a very important and foundational task that is currently underway in the electric industry, highlighted by California’s distributed resources planning proceeding and New York’s Reforming the Energy Vision proceeding. When integration reaches a standardized process it can have industry-wide effect and create value based on network effects. It enables optimization across a single network but does not, however, transform the related industries.

System integration is the connection of various components and subsystems so that the resulting overall system can deliver a specified set of capabilities and optimized value.

2.2 Platforms

A future with potentially 30% of the US installed resource capacity coming from distributed resources and customer participation requires a different physical distribution system than exists today. Consequently, the role of distribution system operations will expand to the management of thousands and potentially millions of distributed generators, and other energy resources. In short, as a more distributed future unfolds, the distribution utility will naturally become a critical hub between customers’ resources and bulk – and potentially even local – power markets. The key will be to create an open network that incorporates a platform designed to enable vast numbers of relatively small transactions. Such a network platform can build on the roughly $20 billion annual grid modernization efforts currently underway by U.S. investor-owned and major municipal utilities. A platform, by definition, is a set of common elements of form used in more than one product or system. In practice, platforms typically integrate a set of information technology, physical infrastructure and standardized business processes in an open manner to provide unique services. One type of platform, an open multi-sided transaction platform, is essential to enable network economic value to be realized.

Open multi-sided transaction platforms are designed to enable a variety of transactions among multiple buyers and sellers and to be able to scale in an efficient manner. These platforms usually add complementary revenue models beyond basic transaction services.[4] Examples include shopping and payment platforms, such as eBay and PayPal that last year enabled $20 billion in transactions.[5]

3.0 Convergent Value

Convergence of networks is a powerful transformative force that has strong implications for both business and technology. The opportunity to converge two or more networks arises from the potential to integrate various elements of the respective networks or systems in the context of resources sharing and common architecture. This integration of two or more networks into a unified system creates value that is intrinsically synergistic. Convergence leverages the respective exponential value property associated with each network. In simple terms, the combination creates more value than the sum of the discrete networks. Consider two networks of size N_1 and $N_{2,}$ respectively. The value of the combined network[6] is proportional to $(N_1 + N_2)^2$ which is greater than the simple sum of their values $N_1^2 + N_2^2$ by the amount $2N_1xN_2$. This last term represents the synergistic value from convergence.

Convergence is the transformation of two or more networks or systems to share resources and interact synergistically via a common and seamless architecture, thus enabling new value streams.

This concept is widely known in the telecommunications industry, which has experienced several convergences. For example, the integration of voice with data, and subsequently the addition of video, has ushered in tremendous innovation and value creation. Virtual medical care would not be possible without the convergence of voice, data and video in telecommunications. Consequently, convergence is not about one technology being displaced by another – typewriters did not converge with computers and horses did not converge with automobiles.

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[4] A. Hagiu, Multi-sided Platforms: From Microfoundations to Design and Expansion Strategies, Harvard Business School, 2006

[5] J. Donahoe, CEO eBay, Interview at Web 2.0 Summit, April 2012

[6] For illustration only, Metcalfe's Law is used to illustrate the conceptual potential. In practice this is unlikely to be achieved and other more complex models can be applied.

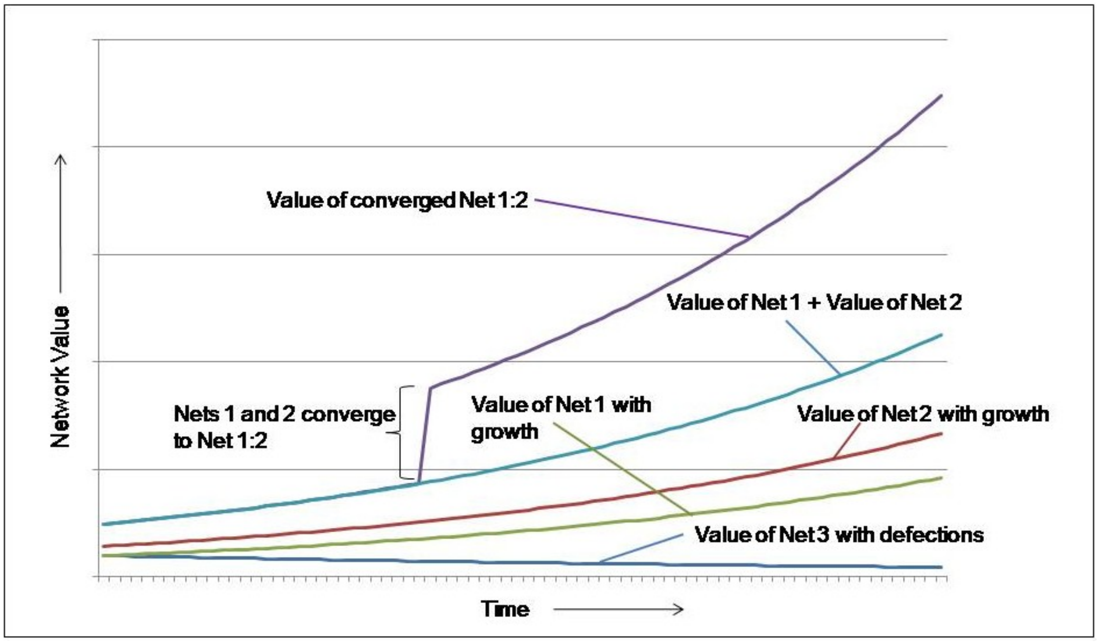

Figure 2. Scenarios of Network & Convergent Value

Various scenarios of network and convergent value over time are conceptually illustrated in Figure 2. The purple curve represents the converged value of two networks (Net 1:2). The underlying network value growth for each is represented by the red and green curves respectively for Net 2 and Net 1. If two networks are complementary, but do not provide synergistic benefits, the result is the sum of the two networks represented by the aqua color curve Net 1 + Net 2. Net 3 represents the erosion of network value from an increase in the number of network defections as may arise from customers becoming fully energy self-sufficient and going off grid. Of course, not all networks or combinations of networks realize Metcalfe's value potential due to aspects of human behavior that have led to newer models which account for the fact that interactions are not uniform but rather have a long tail distribution.[7] The non-linear nature of convergence will still lead to the same essential synergy effect, namely that the extra synergy component itself grows nonlinearly with the combined size of the converged network. However, an open transactive electric system has significant potential to realize the synergy suggested by Metcalfe's Law, since it is the largest physical network at the core of our modern economy.

Convergence most typically applies to whole industry segments, not just individual companies or customers, and results in significant changes in how products or service are delivered as well as how economic value is created. Convergence is a macro-process that comes about as a result of some imperative, which may be social, economic, political or regulatory. In fact, regulation is one of the larger drivers of convergence, though it may also be an inhibitor. Convergence arises from a recognition that increased value can be achieved through synergy if the two networks can be meshed so that each survives and prospers via the newly created value stream.

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[7] Bob Briscoe, Andrew Odlyzko, and Benjamin Tilly make the argument that a better model for actual value realization for communication networks is that value is proportional to n log(n); see "Metcalfe's Law is Wrong", IEEE Spectrum, July 2006, pp.34-39.

4.0 Value Evolution

The future of the electric system and its potential value is under discussion in several US states and internationally. These industry discussions have generally defined four potential futures for the distribution grid based on changes in the use of the electric system stemming from customer adoption and utility procurement of distributed energy resources.[8] The four end-states below should be viewed as being on a continuum in terms of the potential value of the grid.

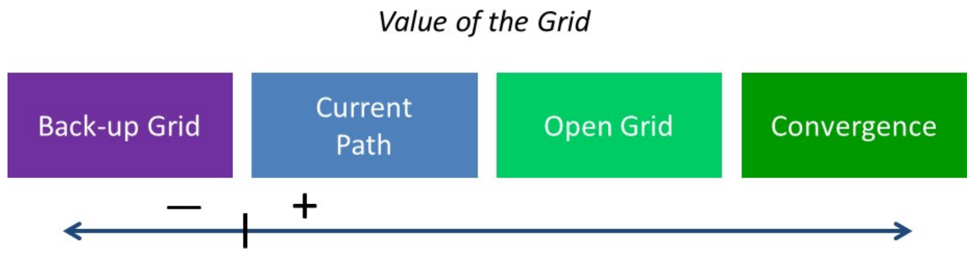

Figure 3. Value of the Grid Continuum

4.1 Current Path

This pathway is based on traditional unidirectional use of the distribution system by customers and others focused on investments to replace aging infrastructure, integration of advanced technologies to improve reliability, resiliency, safety and efficiency. The Current Path reflects the current grid modernization underway and establishes a value "baseline," but takes little or no account of the potential consequences of distributed energy resource proliferation.

4.2 Back-up Grid

This end-state envisions a smaller number of customers remaining wholly dependent on the integrated electric system and a growing number of former customers that have become totally self-sufficient and have disconnected. A Back-up Grid provides less societal value than the Current Path and may lead to further erosion through a "death spiral"[9] of increasing rates driven by fewer customers sharing the cost of the system, which then incentivizes more customers to become self-sufficient and defect.

4.3 Open Grid

This end-state builds on the current grid modernization investments along with an evolution of distribution system designs to create an open, plug-and-play grid to enable seamless integration of diverse distributed energy resources and independent microgrids into a unified multi-layered optimization structure. This enables the creation of substantial new network value.

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[8] De Martini, P., *More than Smart: A Framework to make the Distribution Grid More Open, Efficient and Resilient*, Caltech and Greentech Leadership Group, 2014

[9] Kind. P., *Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business*, Edison Electric Institute, 2013

Electric grid evolution as defined in California, Hawaii and New York involves transitioning from a closed single purpose system to a more open, flexible, efficient and resilient network that integrates distributed energy resources into the operation of the distribution and bulk power systems. Technology investments, as described by the Electric Power Research Institute[10], combined with an evolution of distribution engineering designs can create such an open-access distribution platform. A networked grid would involve "node-friendly" standardized, low cost physical and information interconnections.[11] This approach would also allow for the continued evolution into a multi-cellular structure comprised of microgrids as discussed in a 2014 California Public Utility Commission (CPUC) staff microgrid report[12]. These changes should be evaluated in the context of the potential to realize the value of open networks as demonstrated in other industries.

4.4 Electric Network Convergence

The value of the Open Grid achieves greater value through convergence of an integrated electric network with other networks such as water, natural gas and transportation systems to create more efficient and resilient infrastructure. This enables economic and environmental policy objectives for synergistic customer and societal benefits. The following discussion highlights several aspects of emerging convergence for the electric system.

4.4.1 Integrated Grid Convergence

The convergence of the electric network with cyber, social and economic networks has created what is has been called the smart grid and is becoming an energy Internet of Things (IoT). Each of these four classes of networks has been integrating with electric system for nearly 20 years. The difference is that a more transaction-oriented distribution system is beginning to emerge which allows the value of convergence to grow.

The convergence of the grid with information and communication networks has been underway for quite some time, and received a boost during the "smart grid" phase of grid evolution in the last decade. It continues with the focus on grid modernization and not only brings its own value streams, but also comprises a part of the platform for enabling other convergences.

Figure 4. Four Class Network Convergence

The creation of markets that began with the industry restructuring in the 1990s has continued, with markets and market-like mechanisms either implemented or proposed for ever deeper penetration into the grid. While not all parts of the US have access to bulk energy markets, there have been recent expansions

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[10] EPRI, *Needed: A Grid Operating System to Facilitate Grid Transformation*, 2011

[11] J. Raab, "Proposed Changes to the Uniform Standards for Interconnecting Distributed Generation", 2012

[12] C. Villareal, D. Erickson, M. Zafar, Microgrids: A Regulatory Perspective, CPUC Policy & Planning Division, 2014

of the markets to include various ancillary services and market mechanisms to foster integration of utility-scale renewable generation into the grid. Considerable work is now being done on how to monetize a variety of potential services at distribution level, including consideration of what could amount to distributed markets to support integration of large amounts of distributed generation, energy storage and demand response.

Capitalizing on networking and the Web, and since social networks have become ubiquitous, is not surprising that utilities would turn to them to provide new ways to interact with their customers. Some utilities have encouraged customers to interact with each other via social media to support and reinforce energy conservation practices. Perhaps most interestingly, there are indications of the spontaneous formation of informal "markets" trading in "comfort" (really building energy usage) in commercial office buildings and operating via social networks.

4.4.2 Natural Gas and Electric Convergence

The perception of natural gas as the less damaging fossil fuel for central and distributed generation is creating a convergence that has profound implications on the US electric system. Also known is the fact that gas production, processing and delivery to electric generation uses electricity at many points in the chain. Early stage convergence drives tighter coupling of networks (gas and electric in this case), so when activities like harmonization of markets and cross-observability implementation begin to occur, combined with the structural interconnection noted above, the convergence becomes a possibility. Ultimately, late stage convergence can result in the formation of new value streams, and while this does not appear to be happening yet, it is worth being aware of the possibility so that convergence is not unnecessarily hampered and innovation can occur. See Figure 5 below for an illustration.

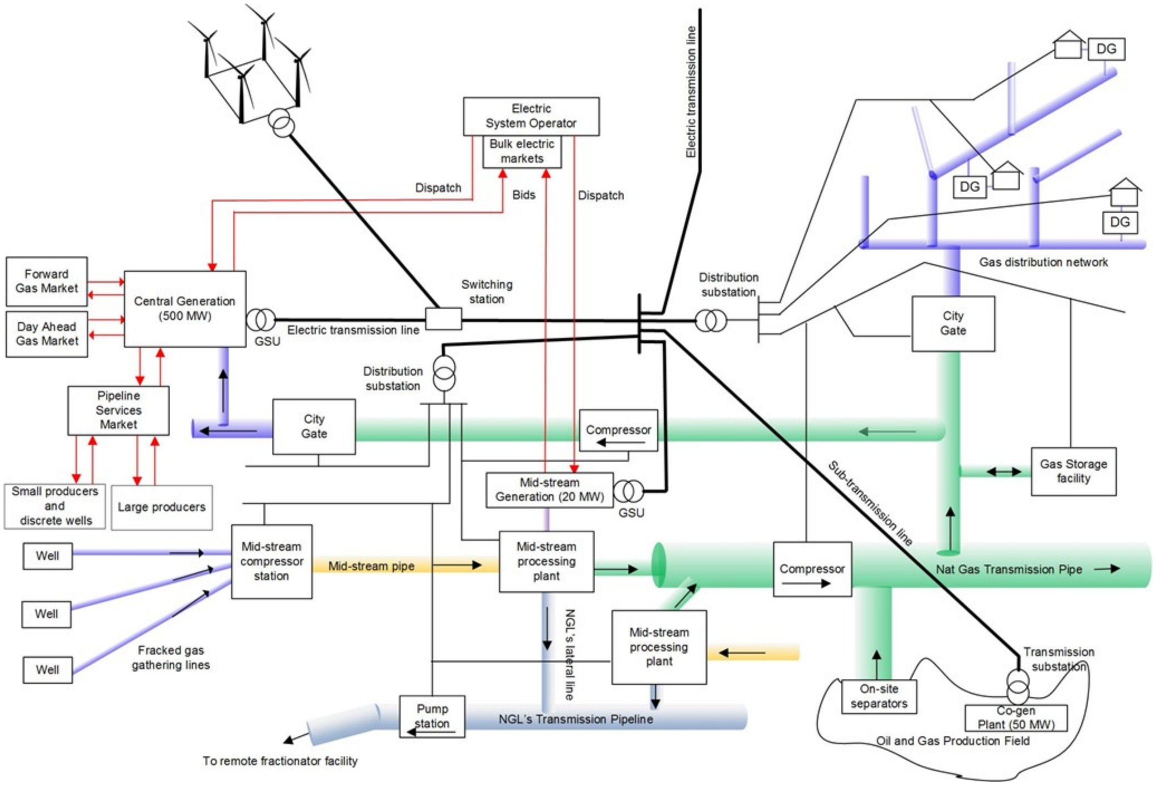

Figure 5. Natural Gas and Electric Systems Convergence

4.4.3 Water and Energy Nexus

Likewise the nexus of water and electrification of transportation represent another opportunity to create synergistic value. In particular, California's Water/Energy Nexus proceeding is focused on developing a partnership framework between investor owned energy utilities and the water sector to realize the value of convergence of water and electric networks. The energy embedded in water includes the amount of energy that is used to collect, convey, treat, and distribute water to end users. Also, this includes the amount of energy that is used to collect and transport wastewater for treatment prior to safe discharge of the effluent. The opportunity is significant as water represents 19% of energy consumption in California as identified in Figure 6.

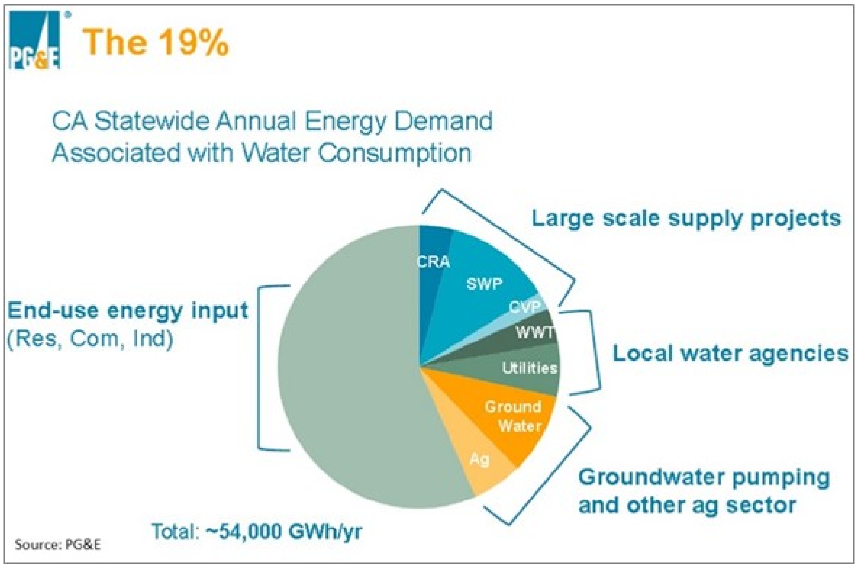

Figure 6. California Water System Energy Consumption

Persistent drought conditions also mean the need for conservation of water has become a critical issue. This presents the opportunity to explore the synergies to accomplish both a reduction in energy use and related greenhouse gas benefits, better optimization of electric grid assets and efficiency, and importantly the conservation of precious water. Water systems are “naturals” for converged operations because they have large aggregate demand over many sites, each with sizable discretionary loads. This creates opportunities for:

- Diverse efficiency measures
- Excellent Demand Response performance
- Leveraging onsite hydro, distributed generation and energy storage capabilities
- Utilizing existing water SCADA systems for integrated controls

Open, long-distance transport of water, as is common in California, offers an opportunity to reduce evaporative water losses by siting solar photovoltaic generation over major canals,[13] thus increasing the amount of large-scale solar on the grid without the adverse impacts of siting on pristine desert lands.

Additionally, as suggested by SolarCity[14], desalination of ocean water may prove to be a long-term drought-mitigation solution, and could also offer an effective use of excess energy from solar PV as identified in the CAISO’s “duck curve” analysis.[15]

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[13] The Canal Solar Power Project in Gujarat, India is an example.

[14] Public comments by Peter Rive, COO SolarCity at More Than Smart Conference, September 2014

[15] http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

4.5 Evolution of Electric Network Convergences

For the power grid, multiple convergences have occurred and continue to occur at differing paces and times. Information and Communications Technology (ICT) was an early convergence for transmission and then distribution, with aspects of this convergence still progressing, especially at the distribution level. Moving forward in time, we see additional convergences involving transmission, but significantly more for distribution, largely due to consumer interactions and the push toward greater use of distributed energy resources. Figure 7 illustrates a rough sequence of convergences, although it should be noted that convergence does not necessarily happen uniformly across the industry. Some convergences are long-tail processes, and the sequence of convergence going forward may be altered by legislation or regulation as well as market forces.

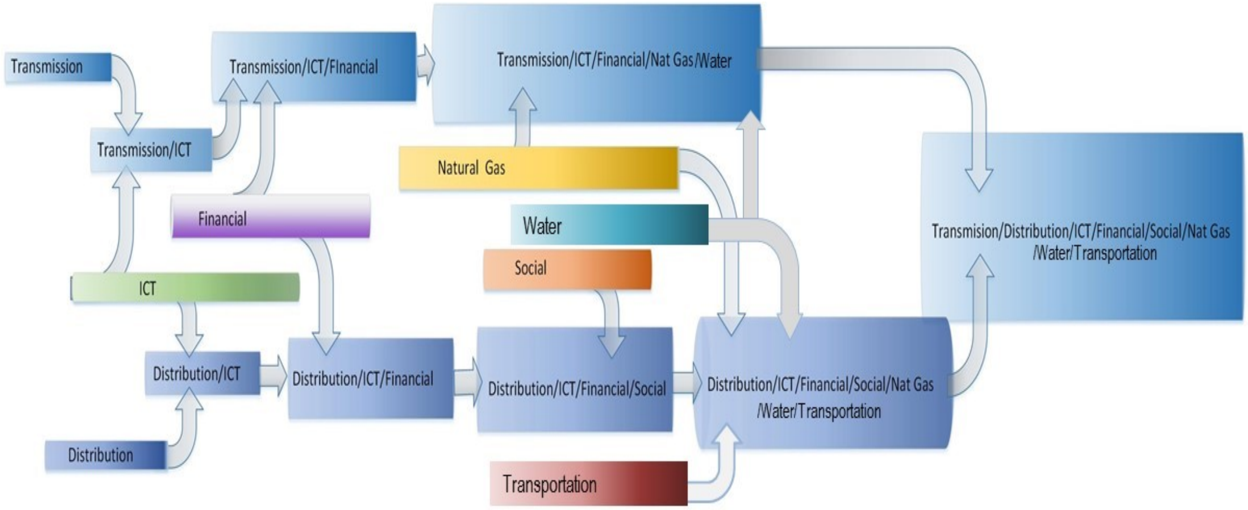

Figure 7. Evolution of Several Convergences with the Electric Grid

5.0 Architecture & Business Considerations

5.1 Architecture

Convergence of networks has tremendous value, but questions do arise as to whether it is possible to architect convergence and whether is it possible to recognize when convergence is beginning. To address these concerns it is necessary to apply system architectural methods. One of the functions of system architecture is to specify (allocate) the interfaces among system components. Doing so from a whole-system perspective rather than in a bottom-up fashion provides the context that assures proper interface design and later, standards specification. This approach also offers a better ability to manage emergent system behavior as well as to define platforms for convergence.
A system architectural approach considers the form and function as well as behavioral aspects of a system.

Form is a set of components and structure (relationships among components), where components are connected by interfaces; form is the thing that executes function.

Function is comprised of an operand[16] and a process.

As elements of form are bought together, new functions arise. Form aggregates in a sort of linear way, but function does not. Some of these system behaviors are deliberately sought as the product of methodical design activity. This is what gives systems their power: the system functionality can be greater than the sum of the parts' functionalities, due to the nonlinear combination effect.

Systems may also have unanticipated behaviors, commonly called emergent. Emergence is a phenomenon whereby unanticipated behavior arises from the interconnection of components into a form and where no subset of the components exhibits this behavior. Emergent behaviors may turn out to be desirable in retrospect, or they may be undesirable. When systems are designed "top down," emergent behavior may be planned to some extent, although it also may occur in unforeseen ways as well. This is especially true in ultra-large-scale systems like power grids. When systems are designed or just built "bottom-up," behavior emerges as the form is constructed and planning the emergent behavior is essentially impossible.

If convergence occurs in an ad hoc fashion, then the combinations of form and function are being created in a more or less bottom-up fashion and so emergence is essentially impossible to predict. A net result of this is that it may be difficult or impossible to recognize an opportunity and develop a suitable convergence platform until after the fact of the converged system's evolution.

Alternatively, if we wish to enable convergence platform formation as a means to facilitate or stimulate convergences with the power grid, and new value streams, we should recognize that the discipline of grid architecture (system architecture as applied to electric grids) can address these issues in a way that bottom-up component and system integration cannot. Specifically, a well thought out grid architecture can enhance the formation of convergence platforms by reducing structural impediments to secure information exchange and control coordination, enabling scalability of functions and interactions with new endpoints, and providing the means to manage complexity.

5.2 Convergent Integration

The implications of convergence include the need for physical and information integration, but they also extend further. Convergence with the electric system also requires integration at the control systems and business process levels. Control system integration is important because this is where the processes are operationalized; lack of control system integration prevents the value chain from operating properly, or at least impedes it significantly. Given the emerging trends in power grid operation it is clear that the existing controls were designed in ways that were right for the requirements of the time, but are now not adequate going forward.

Coupling of the networks involved in a convergence can also be a matter of degree. Given that coupling must occur on multiple levels, it can be the case that not all levels are so equally or deeply meshed. Consequently, we sometimes find convergences that have left some aspects of integration undone or only lightly done until additional developments in terms of markets or regulation drive further meshing. An example would be convergence of commercial buildings and electric networks. There is a

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[16] An operand is the part of a computer instruction that specifies data that is to be operating on or manipulated.

very minor degree of integration presently, but building and electric grid control systems are not well integrated, so there is no common control architecture.

Coupling of networks is not just a technical integration issue. Each network has an inherent "time clock" or pace at which certain processes execute. When these time clocks do not match well, then a certain amount of "mesh friction" occurs, and that impedes full realization of the expected synergies and thereby limits complete realization of the potential value stream. An example would be the natural gas/electric grid convergence, where the markets operate at different paces, as do the related transport mechanisms and control systems.

5.3 Value Chains versus Value Networks

Another consideration is value creation and value flows across a network. Conventionally, value flows "downstream", in a sense following the flow of a product or service delivery process. In a more distributed energy future, this view may not be sufficiently sophisticated for the network and convergence issues for the electric grid. Traditional linear value chains are giving way to nonlinear value networks and in the context of the modern grid, services in particular may flow at least bi-directionally (and may flow N-directionally), just as electric power and grid information may flow. Consequently, the question of what is downstream may need to be replaced with a more nuanced view of value creation and flow.

Business value creation in the emerging 21st century electric industry will be largely derived from two fundamental models:

- **Value Network:** Profit based on collective value of a partner ecosystem. Revenues from direct sale of services, and secondary and tertiary revenues including revenue sharing and after-sale services. This requires a dominant position in a value network. Examples: Cisco & Wal-Mart
- **Switchboard:** Intermediary based business enabling exchange (including delivery) of information, money, goods and services between multiple buyers and sellers in an open and massively scalable manner. Examples: Amazon, eBay/PayPal, and ICE

Businesses today depend on a set of relationships that include customers, technology and other suppliers and alliances/partnerships with firms that have complementary products/services. The resulting ecosystem of relationships is called a value network. These networks allow firms to expand their services and augment products in ways that increase customer value and the firm's profitability. The relationships need to be complementary to work – that is, mutually beneficial. This has been more challenging when viewed in the narrow confines of a single value chain, like sales of kilowatt hours of electricity, where the relationships operate in a zero-sum game. The opportunity today is to consider commercial relationships in emerging electric networks and related convergence.

Additionally, the creation of open electric network platforms as discussed in New York to "animate markets" is the same as creating a switchboard that enables market transactions among various parties. In a more distributed context this may involve managing the physical flows and financial transactions between millions of resources and parties.[17]

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[17] Kristov, L. and De Martini, P., *21st Century Electric Distribution System Operations*, CAISO and Caltech Resnick Institute, 2014

Benefit accrual in the utility industry is complex and value often accrues in places in a value network other than where investment is to be made[18]. Consider the potential interaction between commercial buildings and electric grids as an example. In the past, a grid operator (or a load serving entity or LSE) would view buildings as downstream “loads” and building operators would view the grid as providing a service (we even call it electric service). In a converged environment, grids and buildings would exchange energy-related services, so some value would flow to the buildings, but some value would flow from the buildings back to the LSEs and the grid, and potentially through them to other grid entities such as regional grid operators. In addition, buildings may be able to generate services for other buildings or loads in a Local Energy Network or microgrid environment, so that value streams may be rather complex, rendering the concept of “downstream” dependent on point of view, if not entirely irrelevant.

Every good business has at least one strategic control point. That is, a point where influence can be exerted over the use of a value network or between converged networks to gain competitive advantage and improve profitability. Identifying strategic control points is much less clear as customers have increasing influence over more complex and increasingly virtual value networks. For example, Google established a control point with online search to “control” valuable information for advertisers. Google extended its control with its Android smart phone operating system that reached 70.1% market share in Q4 2012 compared to Apple’s 20.1%, according to the International Data Corporation (IDC). Within 15 years, many utilities may lose control of their profitability in the context of the historical value chain to customers and others due to advancements in technology and distributed resources. This is why utilities need to reconsider the value of existing strategic control points and those that will emerge as electricity networks and convergence opportunities evolve.

In a growing number of states, the scale of DER adoption is creating significant pressure for fundamental changes in the design, operation, structure and regulation of the electric industry already reaching critical mass and policy action is underway. In particular, a grid is sought that provides safe, reliable and efficient electric services by integrating distributed energy resources to meet customers’ and society’s evolving needs while being aligned with the wholesale market and bulk power system. Central to these discussions is the evolution of the electric distribution system into an open network that may also converge with other critical infrastructure to enable customer value and public policy objectives.

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[18] De Martini, P. and von Prellwitz, L., Gridonomics™, Cisco, 2011