Issues to Consider When Designing Rules for Transactive Energy Markets and New Distributed Energy Resources (DERs) Policy

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White papers highlight issues related to energy system architecture, business model design including measuring economic value, and new energy policy

Introduction:

Three white papers can help policy designers and energy planners understand the critical issues to achieve a thoughtful, planned, evolutionary path to address the growth of distributed energy resources (DERs) into the energy system. A convergence of architectural changes and potential energy marketplace changes must integrate with policy and regulatory measures to guide the transition and have robust transactive energy (TE) markets. The three white papers are:

- Electric Power Research Institute (EPRI), written under the general title of "The Integrated Grid" -- has issued two important reports, *The Integrated Grid – Realizing the Full Value of Central and Distributed Resources* and a second in the series, *The Integrated Grid – A Benefit-Cost Framework*, to establish a framework for the discussion about evolving the power system.
- Jeff Taft and Angela Becker-Dippman, the *Grid Architecture* from the Pacific Northwest National Laboratory (PNNL)
- Paul De Martini and Lorenzo Kristov, *"Distribution Systems in a High Distributed Energy Resources Future,"* under the Future Electric Utility Regulation series from Lawrence Berkeley National Laboratory (LBNL).

In consideration of current federal and state policy actions in the U.S. energy market, this overview of the white papers will help identify potential structural constraints to grid modernization efforts, optimal architectures and design issues, and a broader range of barriers and opportunities needing to be addressed. Tools and dimensions of consideration in this evolution of the grid and electric energy business models will include cost and benefit analysis, grid planning and operation pathways, and principles of system architecture.

This essay will be organized into four sections to consider how these three white papers separately raise important questions and issues about our changing U.S. electrical energy system and collective provide a plan for evolving integration of DERs and growth of transactive energy markets.

I. **Challenges:** The first section will address the challenges of DER growth in the legacy energy system.
II. **Discussion of the three papers:** The second section will be a discussion of each of the papers.
III. **Evolutionary Paths for DERs:** The third section will discuss how the three papers show potential evolutionary pathways for grid modernization and transactive energy markets.

IV. **Conclusion:** The fourth section will discuss other evaluation matters and some conclusions to consider moving forward with DER growth in the energy sector.

Together, these papers combined offer a “roadmap” of sorts or at least key insights for building transactive energy markets. The three white papers provide insights into unique areas such as: (a) Smart grid architecture based on a systems planning and design approach guided by stated principles for such design (see Taft & Becker-Dippman); (b) Standardized, verifiable and consistent methodology for evaluating the costs and benefits of DER to create an “Integrated Grid” in which utilities can determine the cost-effectiveness of DER versus traditional investments within their planning, operations and trading (see EPRI); and (c) Regulatory, institutional changes that will be needed with higher penetrations of DER – the distribution systems level becoming increasingly like a transmission resource, calling for more proactive planning and management by utility distribution companies and potentially evolving into what some have termed, “Distribution System Operators” or “Independent Distribution System Operators” (see DeMartini and Kristov).

I. Challenges:

Today we are in the early stages of re-engineering the electrical grid system primarily to integrate new technologies called distributed energy resources (DERs). Further, this work is preparing to address a potentially much more diverse network of energy suppliers including what has been termed prosumers who may be both buying and seller energy from a home or business location. Understanding grid architecture and the interactions of power systems, markets, and grid control systems can assist in understanding the challenges and potential solutions as this re-engineering process moves to more advanced stages. Yet, there are additional challenges to considered including:

The 20th Century grid was designed as a one-way transmission and communication pathway from primarily a large centralized energy generation source and the end user had little to no choice in wholesale or retail transaction relationships. Therefore, a widening gap of issues may occur as the integration of DER technology is already occurring before systems are in place to manage and operate a 21st Century grid with the reliability and safety, and relative low energy costs society has become accustomed to having on a day-to-day basis. Additional, growing structural or physical network issues are convergence with fuel, transportation, social, environmental networks interfacing with the electric grid. This additional network interaction has not been tested with a new economic network such as proposed in an advanced transactive energy (TE) market to fully understand the net value improvements and whether the entire systems will work in synergistic ways.

The three papers each provide some foundation to address these challenges. All three papers point out the importance of addressing issues at the transmission and distribution system interface. The EPRI paper points that new approaches to energy planning will be needed as DERs means two-way power flows and communication channels. The Taft and Becker-Dippmann paper focuses on the importance of linking architecture issues and potential policy solutions. Further, Taft and Becker-Dippmann note that because DERs vastly increase complexity in an already complex energy system that understanding upfront the interdependencies of fuel, transportation, and other networks will require coordinating bodies. Similarly, in De Martini and Kristov's analysis they make the case that grid investments need to be planned ahead with understanding that as DER penetration grows grid management and operations will have to change and adapt through regulation modifications.

II. Discussion of the three papers:

A. EPRI: This report makes an important distinction that many early adoptions of DER technology and services are connected to the grid, but not integrated into grid operations. To facilitate integration of DERs into the grid operations, EPRI calls for consistent, uniform and verifiable methods for characterizing, assessing and quantify net benefits of DERs. This type of work will include interconnection rules, grid interfaces, managing variable and uncertain outputs, environmental factors, and common data and agreed upon methods to determine cost and benefits. Some of this work is now occurring through EPRI collaborations with utilities and other business parties in demonstration projects and research. Related work by entities that establish standards, such as NIST, and regulatory agencies is taking place today. Advancing this work and related research will help open the door for accepting and building transactive energy markets.

Another clear takeaway from the EPRI paper is the importance of understanding the basic functions and the laws of physics that govern our electrical system (and the other connected fuel, water, and information systems), in order to redesign the electric and power system to accommodate greater numbers of distributed energy resources**.** The EPRI reports, *The Integrated Grid – Realizing the Full Value of Central and Distributed Resources* and a second in the series, *The Integrated Grid – A Benefit-Cost Framework*, establish a framework for the discussion about evolving the power system. The papers make it clear that a new commercial and business model will be necessary to continue to meet the physical requirements of the electricity system and adapt it to changing customer needs and demands as new technologies drive change. The Integrated Grid papers provide this critical engineering and architecture discussion to assist in redefining what the distribution system needs to look like in the future to make the best use of DERs. The core concept starts with building into the planning and operation of the grid the integration of DERs to minimize potential problems and maximize many coming benefits of new technologies.

"Because of the interconnected nature of the transmission and distribution systems and the increasing potential for distributed energy and ancillary services to be provided from the distribution system, the overarching T&D network will increasingly need to be planned and operated in a much more coordinated manner. Increasing DER levels will drive the need for integrated T&D models and for exchange of information that can be used to simulate and evaluate the aggregate systems reliability, sustainability, and safety implications of various developments, investments, and technology choices," the EPRI report states. [1] According to the EPRI report, the major DER characteristics that impact existing utility grid operations and planning are:

1. Point of interconnection Impacts.
2. Inverter interface
3. Variability and uncertainty of output
4. Environmental compatibility. [2]

The EPRI study points out that locating DERs at the distribution service level means that the interconnect is at medium-voltage or low-voltage points. The proximity of DERs to the load has potential for both positive and negative impacts. Today, we have a distribution system that is primarily radial, where power flows from single generation source to its end-use load. The proliferation of DERs means it will be a two-way power flow. The location of DERs also creates challenges with protection and voltage regulation and operational reliability risks. With more of what are called behind the meter DER deployments there are situations that can develops where a lack of visibility and controllability of these customer-owned resources can cause additional reliability issues.

With an increase in DER technology combinations such as solar PV, battery storage, and plug-in electric vehicle charging, they use inverters to interface electrically with the electric grid. These types of energy resources do not respond to the power system same way as traditional synchronous machines. The inverter can decouple the DER from electrical system frequency and the DER inverter connection does not provide the same levels of inertial response to correct frequency excursions. In further contrast to synchronous generators, the inverter-based resources do not necessarily have the same type of frequency controls and voltage controls. Still, as inverter technology improves there are multiple opportunities to address these current problems with growing numbers of DERs and the existing electric grid interface issues.

The issues with variability and uncertainty of output, especially solar PV that depends on sun light availability and wind generation intermittency, are a major

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[1] Forsten, K. project manager, Electric Power Research Institute (EPRI). (2015) The Integrated Grid. A Benefit-Cost Framework. Final Report, February 2015.

[2] Forsten, K. project manager, Electric Power Research Institute (EPRI). (2015) The Integrated Grid. A Benefit-Cost Framework. Final Report, February 2015.

concern for electric utilities and regulators. The concern increases during peak energy demand times where additional higher cost energy supply and delivery assets may need to be deployed. Likewise, for planning purposes the output uncertainty impacts the need for alternatives or reserve generation sources. Distribution utilities will need new approaches for system operation, grid planning, interconnection procedures, and coordination with transmission and wholesale markets. There is a traditional hierarchical responsibility for reliability management in the existing generation-transmission-distribution system.

B. Taft and Becker-Dippman: Among the many insights of this paper is the inter-relationship of power electronics, converging information and communications networks with the power networks, and the broad need to understand system architecture. Too many assumptions have been made about devices and markets being integrated into the current grid structure with a full understanding of how all the parts interact and may not cooperate with the addition of greater complexity. The paper, "Grid Architecture," raises 17 important architecture insights for consideration and 6 policy insights for addressing a future grid (see appendix 1). The purpose of their paper includes addressing possible constraints to grid modernization when looking across relevant dimensions of the U.S. electric transmission, storage and distribution infrastructure. Their work starts with the principles of system architecture and then does a deeper dive into specific sub-system issues. In this paper it is candidly stated that there is a linkage between creating a new architecture and refashioning current energy regulatory policy. This system evolution and new policy design requires a number of inherent decisions on tradeoffs given the current limits of the 20th Century grid and long-term need for a modernized 21st Century grid.

Planning for Change: Addressing the challenges in the transition from the current electrical grid to the future grid architecture

The Taft and Becker-Dippman "Grid Architecture" paper and EPRI "Intregrated Grid" paper provide a very good framework for defining the functions of the existing grid and potential issues that can occur with greater DER integration. As we move forward with the energy transition with greater DER market penetration core issues include: safety, robustness (reliability and resilience), security, affordability, minimum environmental footprint, flexibility (extensibility and operationality), financeability (utility and non-utility assets). Then, specifically dialing into the interconnected nature of the transmission and distribution system allows for research into potential problems and challenges and how to find solutions. The key again for the policy and regulatory world is planning for change.

Taft and Becker-Dippman point out that this layered regional oversight has architecture and policy implications with reliability coordination. [3] In a world of rising merchant DER and individual prosumers participating in energy market there would be a need for governing aspects of scheduling and control of physical exchanges of electricity. Like any challenge this might also be an opportunity to improve the managing of assets across jurisdictional lines with the inclusion of greater input from consumers. Still, reliability and associated operational procedures are important issues that in this space will require new regulatory approaches and changes in state and local laws to achieve a consensus around agreed upon protocols for communication and interoperability.

Here are some of the architectural and structural driven policy issues needing to be addressed, according to the Taft and Becker-Dippmann report:

1. As DER installations increase there will be a need to examine new regulatory approaches for scheduling and control of the physical exchanges of electricity.

2. Issues surrounding reliability and resiliency must be addressed by some oversight organization, especially the potential conflicts with federal wholesale activity regulations versus state or local authority over most distribution level matters. Specific concerns are raised with merchant DERs and consumers who may bypass distribution utilities.

3. As two-way energy flows proliferate new policy and regulation may be needed to make explicit shared responsibility for system reliability between load producers and distribution system operators.

4. As two-way energy flows proliferate there may be a need for new charges or fees at the existing utility level to unblock the potential for certain building-to-grid energy/power services.

5. New planning tools could assist with either additional research and development or at least better understanding of emerging infrastructure interdependencies (such as the electricity network and gas network). Similarly, novel configurations of assets at the distribution level (including energy storage) may require new thinking on allocation of cost and benefits and related regulatory changes.

6. Potential oversight changes with a concept such as Distribution System Operator (DSO) create an opportunity to carefully rethink or realign responsibilities among the legacy bulk system or distribution system or role of the unregulated prosumer or third party providers. [4]

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[3] Taft, J.D. and Becker-Dippmann, A. (2015) Grid Architecture. Pacific Northwest National Laboratory (PNNL-24044). Final January, 2015.

[4] Taft, J.D. and Becker-Dippmann, A. (2015) Grid Architecture. Pacific Northwest National Laboratory (PNNL-24044). Final January, 2015.

C. DeMartini and Kristov: Their work details a three-stage evolutionary structure defined by the volume and diversity of DER penetration in a given jurisdiction (whether it is local, state or regional) and contains critical adaptive steps at each stage in the design. The focus is on the transmission and distribution system interface (T&D interface) and yet still recognizes that all parts of electric energy system must work together. Their framework is mainly driven by local needs so they recommend using a bottom-up approach versus top-down architectural design. While acknowledging there will likely be several different business models advanced in the electric utility evolution, these authors suggest it is important to offer end-use customers incentives to remain connected to the grid rather than defect. They also create what they call as local distribution area (LDA) that will function as a separate operational sub-system and at the final stage of high DER adoption will include multi-sided "many-to-many" and "peer-to-peer" transactions in regulated marketplace. In the evolution to a new operational distribution market place the DER will provide services of capacity deferral, steady-state voltage management, transient power quality, reliability and resiliency and distribution line loss. [5]

The Three Stages, according to Kristov and De Martini, are listed below:

1. "Grid Modernization"

- Low DER adoption – can be accommodated by existing system without enhancing infrastructure, operations or planning
- Some new planning studies and review of interconnection rules and processes useful if greater DER expansion is anticipated

2. "DER Integration"

- DER adoption level requires new operational capabilities – multi-directional flows, more variable grid conditions
- DERs can provide system benefits => real-time operational services & infrastructure deferment for the distribution utility

3. "Distributed Markets"

- "Peer-to-peer" transactions between DERs & customers
- Requires distribution-level market structure, market services, & new regulatory framework; may be state regulated. [6]

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[5] De Martini, P. and Kristov, L. (2015) Lawrence Berkeley National Laboratory. Future Electric Utility Regulation, Report No. 2, October, 2015.

[6] De Martini, P. and Kristov, L. (2015)

A logical sequence for an evolution of the U.S. distribution system

There is a logical sequence for an evolution of the US electricity distribution system, according to authors Kristov and De Martini. The process of change or evolution should start with very clear statements of policy objectives for a new distribution system including desired system qualities and functional capabilities. Yet, the authors believe the process really starts rather simply with making sure the electric grid operates safely and reliably. In the medical science this is called "do no harm" to the patient when considering treatment options. The key to this simple goal of safety and reliability comes from understanding the electric grid architecture, specifically its limits, capabilities, along with the challenges and opportunities associated with integrating a greater number of distributed energy resources into the system. In a somewhat similar manner the authors Taft and Becker-Dippmann highlight seventeen "architectural insights" that must be consider for the grid and energy system of the future, and further what are the policy implications of these lessons about the architecture. Using slightly different terminology, the EPRI paper on the integrated grid provides more of an architectural engineers perspective that existing designs and features may need to be preserved even as the grid changes or evolves. "An Integrated Grid should make it possible for stakeholders to identify optimal architectures and the most promising configurations, recognizing that solutions vary with local circumstances, goals, and interconnections," the EPRI authors state. [7]

Markets are Tools

A significant observation for the discussion of (TE) is that a market should be viewed as a tool – in fact one of several tools – that should be designed to fully realize DER value, according to Kristov and De Martini. This portfolio of tools includes communication and control systems, markets, rates, programs, compensation, and others. It is important to understand that the growth of DER is largely driven by customer choice enabled by these new technology developments. So as policy is created to advance the evolution of the electric energy architecture and marketplace that the focus should stay on goals of reducing transmission and distribution system operating costs, creating net benefits for all customers, and enabling robust customer choice. Finally, it will take specific market and regulatory framework to integrate and reliably utilize DERs to meet grid needs as well as customers needs.

In their paper, De Martini and Kristov, discuss a method for planning, market design, operation and oversight at the equivalent of either a state level or in-conjunction with an ISO/DSO regulatory system. The paper is written to address the question and issues in a manageable, logical sequence, according to the authors. Their work focuses on the transmission and distribution interface (T&D interface) and advances a system approach to the issues. The reader is walked

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[7] Forsten, K. project manager, Electric Power Research Institute (EPRI). (2015) The Integrated Grid. A Benefit-Cost Framework. Final Report, February 2015.

through the necessary issues and plans steps for a three-staged evolutionary process that anticipates future DER growth in a given jurisdiction.

In stage one it is recommended that the distribution region (possibly planning done at a state or local government level) develop some scenario-based probabilistic planning studies looking at a range of possible DER growth over time and a second set of models on DER behavior impacts. Further research and studies would consider enhance interconnection needs for DER growth in this distribution region. In order to assure reliability and safe grid operation work would need to be done in hosting capacity for the potential maximum DER growth over time. At this stage consideration must be given to how generation variability will be managed (exp. controllers at sub-station level or elsewhere at T&D interface). A robust set of analysis would also be needed at this stage on the trade off with benefits and costs from DER (a locational net value) with all the work described here analyzed further as a part of an integrated transmission and distribution planning process.

It will be necessary to build off the modeling and planning work described in stage one during stage two and three. More specifically, once a distribution region has reached a higher stage of DER penetration then more specific decision-making will be necessary on the design-build and ownership of the distribution grid. Now important protocols and procedures will be necessary for the DER schedules and coordination with more complex switching, outage restoration, and grid maintenance to assure reliability. Decision-making will be necessary for coordination with transmission and wholesale market sales at the T&D interface. Operations at the local level will need to be very robust as decisions will need to be made on the pros and cons of managing DER variability at the local level (local real-time balancing) versus exporting to the transmission grid.

By stage three the distribution system of the future will require an advanced DER operating structure and management locally. Critical questions needing answers include whether contracts will spell out performance requirements on real-time reliability management and other supportive services. Others questions needing answer will include who can serve as an aggregator of DER wholesale market participation (exp. load serving entities, independent aggregators, distribution operator) and all activities will be in real-time. There will be a need for operational rules of a marketplace for example the clearing and settlements of inter-DER transactions in this new distribution system. At this stage a critical element of evaluation centers on the optimal degree of temporal and locational price granularity. A trade-off or balance will need to be evaluated on this issue of granularity versus the “diminishing return to complexity.” Finally, decisions will need to be made on market facilitation services such as bilateral markets and whether to provide park & loan energy services, according to the Kristov and De Martini paper. [8]

Local needs will drive DER adoption and policy must rely on research and planning for success

High level, clearly stated, public policy objectives will shape this whole system architecture and market framework at the transmission and distribution interface. The DER adoption will be mainly driven by local needs and decisions and through the evolution structures and rules may need to be adaptable to facility change. While developing this ever-increasing local DER penetration three-phased evolution, the authors recommend focusing on using engineering studies, infrastructure planning, and interconnection rules and procedures. This is consistent with the recommends from the EPRI Integrated Grid studies that include detailed benefit and cost analysis methodology, operations and planning dimensions, scenario analysis and pilot studies.

There are differences between the recommendations of Kristov and De Martini and those in the EPRI study. “They (current electric utility stakeholders) tend to think of managing the evolutionary process through incremental changes to the current structural elements and processes, rather than recognizing a need for entirely new approaches to operations, planning, markets and regulatory frameworks,” Kristov and De Martini state.[9] This can be seen under close examination of assumptions from the recommend analysis steps from the EPRI study, for example, in calling for “hosting capacity studies” or existing electric utilities frameworks. In their bifurcation that examiens impacts on the bulk power system, transmission system, and distribution system, they do not discussion how this skews analysis of benefits and costs. The EPRI report authors state, “The bulk power system’s focus begins with resource adequacy, making sure that sufficient resources are available to meet electric demand.”

While all three studies make a strong case for recognizing the importance of architectures and their design, the planning and analysis that begins today must accept some critical paradigm shifts necessary for a (TE) marketplace. Kristov and De Martini address this in their analysis of distribution markets and evolving three developmental-phases of DER integration by discussing “structured versus unstructured” system evolution. A structured evolution will follow gradual change guided by policy, regulation, and adaptation on the part of the existing system structure. In contrast, dramatic change driven by customers and external forces such as technology and business innovation disrupts the existing structural elements and their relationships. The authors correctly note that: “In the electricity industry context, these two different models have different implications

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[8] De Martini, P. and Kristov, L. (2015) Lawrence Berkeley National Laboratory. Future Electric Utility Regulation, Report No. 2, October, 2015.

[9] De Martini, P. and Kristov, L. (2015).

for operations, planning and markets, and how for regulators think about the reforms needed to their regulatory framework." [10]

All three papers make a case for further research. In a detailed diagram from the EPRI report they explain that five major grid and utility activities merit analysis. These are a) characterization of distribution feeders and distributed energy resources, b) hosting capacity analysis, c) energy analysis, d) thermal capacity analysis, and e) reliability analysis. The details of this analysis are explained in pages 5-12 through 5-24 of the EPRI report. [11] The key is that research and analysis begin now to determine architectural and operational needs for integrating DERs into a specific location.

III. Section Three: How to consider the evolutionary pathway for grid modernization and the organizing principles linking architecture and markets under Transactive Energy?

In designing a new architecture that will best accommodate an evolving electrical energy business model and marketplace for (TE) it is critically important to understand the larger societal end goal. DERs and clean energy technology is the foundation for the future electrical energy system, but we must also consider the principles behind this new system. The GridWise Architecture Council has advanced six (TE) principles so far in their discussions about a future system. These principles are what they call the high level requirements for a (TE) system:

- Highly automated coordinated self-optimization.
- Transactive systems should be observable and auditable at interfaces.
- Transacting parties are accountable for standards of performance.
- Maintain system reliability and control while enabling optimal integration of renewable and distributed energy resources.
- Transactive energy should provide for non-discriminatory participation by qualified participants.
- Transactive energy systems should be scalable, adaptable and extensible across a number of devices, participants and geographic extent. [12]

This final principle is subject to some further debate when considering the design of the electric energy system today, what is needed in a transition to the future, and how a system architecture and marketplace might be designed. Keep in mind the current U.S. electric grid delivers power to 140 million customers through some 3,000 electric utilities. The infrastructure today is an immense 300,000 miles of transmission and distribution lines and 7,000 power plants. The bulk of regulatory requirements are tailored to 50 different state needs. So

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[10] De Martini, P. and Kristov, L. (2015) Lawrence Berkeley National Laboratory. Future Electric Utility Regulation, Report No. 2, October, 2015.

[11] Forsten, K. project manager, Electric Power Research Institute (EPRI). (2015) The Integrated Grid. A Benefit-Cost Framework. Final Report, February 2015.

[12] GridWise Architecture Council. (2015). GridWise Transactive Energy Framework Version 1.0.

certainly a case can be made that solutions may need to reflect the scale, complexity, and individualized goals of each state. While this complexity and overall grid interconnection issue arguable calls for some over-arching federal government policy and regulation in this space, that topic will be set aside for a later discussion in this paper. The complexity of current electricity energy delivery requires systems-thinking and elegant models to seek clarity for future scenarios and architecture designs.

This is more than a bureaucratic barrier because each interconnection is a synchronous machine and the existing three interconnections in contiguous states are under separate control with protocols for power exchanges (Western Interconnection, Eastern Interconnection, Texas Interconnection). There are reliability coordinators within the regions who continuously monitor the grid and provide critical communications on any issues. There is a separate breakdown into Balance Authority Areas with about 75 total and more than 30 in the Western Interconnection. Each area is given balance authority and is affiliated under NERC. Further complexity and breakdown occurs in the restructure markets of Texas alone. The next layer is a regional wholesale market including the independent system operators (ISO) and distribution system operators (DSO) with current oversight primarily from the Federal Energy Regulatory Commission (FERC).

Stages for change

Again, using the three stages of evolution spelled out in the De Martini and Kristov paper helps to understand how policy and regulatory changes must adapt with higher levels of DER penetration. The likely evolution of the electricity industry under a planned set of steps for change in the sector can be “structured” or measured by policy and regulatory changes that affect the pace of DER adoption. This would be true for Stage 1 evolution as they describe and partially true for Stage 2 with greater DER market penetration. During the first two stages of the evolution the predominance of central station generation, one-way energy delivery and clear delineation between wholesale markets (for energy and capacity at the transmission level) versus retail markets (for electricity supply to end-use customers) may not be substantially altered. This will be a marked contrast in Stage 3 which is high DER penetration, more decentralized system with peer-to-peer energy trading across the distribution system. This stage 3 phase is an unstructured system and creates what some states (NYREV, Hawaii, and CA) are wrestling with for the role of Distribution System Operator and new market relationships. “These new market functions should be designed from a whole-system architecture perspective—as an explicit paradigm shift—rather than allowing them to develop through a process of gradual accretion of new activities,” Kristov and De Martini state. For example, a stage 3 or advanced state with the unstructured system such as California already has a large penetration of renewable energy including high numbers of rooftop PV, smart inverters, aggregators of DER services, integrated capacity analysis (DER hosting results) and a large existing energy efficiency infrastructure. Why this distinction between structured and unstructured industry evolution is important and has a lot to do with the planning process beginning today if the end goal is creating robust transactive energy markets. It is likely in the early stages great variation may occur in states with traditional monopoly utility regulations and markets that have been competitive for a long-time.

Again, the Kristov and De Martini paper points to a logical sequence in developing the design for a future high-DER system built on systems engineering and grid architecture principles similar to what is spelled out as well in the Taft and Becker-Dippmann paper. Kristov and De Martini suggest using a building block approach, what the authors call the local distribution area, and from the distribution facility at each transmission-distribution interface point. The sequencing begins with a set of high-level public policy objectives that the electric city should achieve, then develop a set of qualities the electric system should have to achieve those objectives including observable outcomes, then the operational and planning functional requirements and their interrelationship to achieve the objectives is designed, and finally determining who does what in organization roles and structures. This final point is where the discussion about whether an independent distribution system operator or utility distribution system operator should be utilized occurs.

Another point of view is driven by where early adoption of these changes may occur. First and foremost, the location must have a high market penetration of DERs. Another area where early adoption may occur is local government jurisdictions seeking physical and economic resilience and opportunities to take advantage of synergies between electric service and municipal functions including public safety, water supply, wastewater treatment and local transportation. This again calls for bottom-up solutions versus top-down in designing architectures, functions and organizations, and eventually markets. The report suggests that states develop locational value assessments to identify areas where additional DERs could provide real time services and defer infrastructure investment.

Section Four: Conclusion and other evaluation issues:

These three reports provide some cross cutting ideas and steps to assist in the evolutionary process of greater DERs products and service penetration and transactive energy markets including:

- systems planning and analysis;
- valuation and comparison of net benefits of resources;
- integrated distribution resources planning;
- regulatory and institutional reform to change incentives and align utility financial interests with long-term customer value;
- and developing the distribution systems level into a transmission resource

to manage distributed resources.

Two-way power flows within the distribution systems will require a greater emphasis on making explicit shared responsibilities for reliability management, including necessary investments, between operators and loads or producers of power within the distribution system. These will often be new relationships with the growing complexity added by the growth of more DERs in the energy market, especially those behind-the-meter, and if prosumer participation proliferates. Today, we may not know the best way to address this need for distribution control and coordination. The States of New York and California have regulatory proceedings looking at these issues and New York has advanced the concept of the Distribution System Operator (DSO) model. States have traditionally required utility planning and that may require expanding participation of new DER market participants. These new relationships may include dimensions of contract law provisions and incentives and penalty structures for market participants.

Technology advancement coupled with customer choice can change the policy and regulatory environment latitude in managing the evolutionary process with structured steps. The example provided by Kristov and DeMartini is being somewhat played out today with increasing efficiency and lower cost of solar panels and significant gains in cost-effectiveness of energy storage. What the economic market tipping point is not known today with these new technologies, much less if even more disruptive technologies emerge. To the extent that some policy decisions are being made today in some states the definition of guiding principles become even more important. True customer choice will require nondiscriminatory marketplace policy and operations, transparency and oversight of the marketplace, addressing other issues with market power and rules of the game in operations. Approaching this evolution of the grid, business structures and marketplace can find this balance with structure and unstructured evolution by smart steps today. Kristov and De Martini state, "This should make it attractive for regulators and distribution utilities to accelerate DER deployment in the near term where net benefits can be achieved while leveraging the existing distribution grid." [13]

Well-established business sectors such as the existing U.S. electric utility, especially the regulated monopoly utilities, historically have not been the leaders in research and development (R&D) necessary for continuous innovation. In fact, utility spending on R&D averages 0.1 percent of revenues compared to average of 3.5 percent of revenues for other U.S. industries. To make matters worse, utility R&D spending has declined in absolute terms since the mid-1990s. Research by the National Science Foundation found that the average U.S. firm had 63 R&D engineers and scientists per 1,000 employees and that utilities only employed 5 per 1,000 employees, as cited by the American Energy Innovation

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[13] De Martini, P. and Kristov, L. (2015) Lawrence Berkeley National Laboratory. Future Electric Utility Regulation, Report No. 2, October, 2015..

Council.[14] It is worth noting that in recent years utilities have worked more with the Electric Power Research Institute, the Edison Institute, and other organizations on energy technology innovation. Still, the future configurations of our energy architecture and the new utility business models must be designed to find a way that allows for greater R&D and a continuous cycle of energy technology innovation.

Networks are the engine of innovation.

Energy technology innovation going forward increasingly relies on network services and cloud-based applications. New energy companies will need to leverage these networks, develop service platforms, take the most robust, timely data available, take the best and latest technology available to remove barriers from efficient market participation. Energy companies are going to need to match services to their customers by using data analytics, intelligent devices, and an integrated network perspective. Successful transactive energy service companies will operate efficiently at the nexus of the electric, gas, telecommunications, transportation, financial and environmental networks. In summary, the new energy business model will involve using the best of the digital age (intelligence), linking physical, digital, and social networks creating platforms for future models that leverage all the networks and the overall systems intelligence.[15]

Architecture drives design of networks, business models, policy and the determination of value

In summary, when thinking about the next business model to optimize electricity delivery it will be critical to consider what produces the optimal network. To achieve this will take building an architecture that will make both the operational and financial components, such as transactive energy, work together. Because energy requires functioning within the laws of physics the architecture to achieve the optimal network will not look the same as in communications or information technology networks. The complexity of management and control of hundreds of thousands of distributed energy resources will take stability across these large numbers of independent sources. Further, it will require optimality of these highly diverse networks. Finally, it will take an agreed upon methods and metrics to evaluate the life cycle of value of the new architecture and the technologies in the operations. The determination of value will shape the new energy marketplace and the market is only a tool in the architecture. Once the architecture is understood, then policy can determine the rules of the market.

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[14] American Energy Innovation Council. (2011) Catalyzing American Ingenuity: The Role of Government in Energy Innovation. www.americanenergyinnovation.org.

[15] De Martini, P. and Taft, J. (2015) Value Creation Through Integrated Networks and Convergence. Caltech, Resnick Institute and Pacific Northwest National Laboratory.

Final Thoughts:

The growing customer adoption of DERs represents disruptive technologies for the traditional energy system. Further, adjacent technologies such as microgrids, smart inverters, silicon carbide power switches, synchrophasors, and advanced controllers contribute to the management of intermittent solar and wind, making the higher state mandated proportion of renewable integration more manageable. Transactive energy (TE) represents the methods to enable all wholesale and retail sellers and buyers of energy services to transact with each other. The advanced stages of greater DER penetration and implementation of market rules for transactive energy means greater potential for robust peer-to-peer retail transactions across the energy distribution system. The design of innovative regulatory policies needs to start today to enable these distribution market changes to accelerate the evolution toward the new utility business models that are urgently needed. The lessons learned from early adopter states, must be evaluated and shared, and regulators may need to learn flexibility not common today.

Appendix 1:

The 17 Architectural Insights from Taft and Becker-Dippmann Paper and some of the policy insights

“Architectural Insights:

1. Grid architecture provides the discipline to manage the complexity and the risk associated with changing the grid in a manner that significantly reduces the likelihood of unintended consequences. P. 3.4

2. The Balancing Authority Areas would contribute to better integration of bulk wind and solar with Distributed Energy Resources (DERs) by improving fast coordination of more widely aggregated assets.

3. The geographic-based structures of the electric energy system (see page 4.4) are artifacts of the evolution of the electric power industry over the past century. Customers and their assets do not have to follow any such geographic encapsulation, even for distribution. This can become important as more non-utility assets interact with the grid, raising questions about both reliability coordination and grid control in merchant DER and prosumer environment.

   (see policy implication 1 – If customers and the assets they control reside in the distinct physical parts of a single region or within distinct geographic encapsulations, and there are physical exchanges (or coordination in the production of and consumption of) electricity among them, or with other parties, regulatory issues must be addressed governing aspects of the scheduling and control of the physical exchanges/coordinated actions. An improved approach may include managing assets across jurisdictional lines and include consumers. This will require new regulatory approaches, changes in state and local laws and agreed protocols for communication and interoperability.) p.4.5

4. When looking at Figure 4.7 on Page 4.10 about the Cooperative, Public Utility District, Municipal Joint Structure Model it is worth noting that the red lines in the industry structure diagrams show the relationships involved in various aspects of system control, and have direct relationships to reliability roles and responsibilities. Instances exist in the ISO and PUD/Muni/Cooperative cases in particular where bypassing distribution utilities, instead of working through them in a coordinated fashion occurs.

   (See policy implication 2 – The majority of ISO/RTO and some other industry activities at the wholesale level are regulated by the Federal Energy Regulatory Commission (FERC) and industry oversight bodies such as the North American Electric Reliability Corporation (NERC). Investor-owned utility (IOU) and public power/cooperative activities at the distribution level are regulated by state public utility commissions, elected or appointed local boards. Physical and financial exchanges between these separately regulated entities may involve potentially conflicting interactions and/or priorities on the part of Federal and local or state authorities. Moreover, local distribution companies retain the responsibility for maintaining reliability and quality of service at the retail level. However, increasing number of direct interactions with merchant DERs and consumers, while bypassing distribution utilities, adds complexity to the reliability and resilience-related challenges.) p. 4.11

5. To build value stream models, start with the industry structure diagram (figure 4.6 on p. 4.9), then add the relevant external entities that may participate in the business ecosystem. The resultant flow models can be recursively detailed, and the placement of any investment or new value stream in the architectural model can be analyzed in context to determine such issues a where value accrues, what value stream share may be available, and how a value stream supplier should be coupled to its ecosystem partners.

6. It is practical to partition value stream sources (e.g. products and services) into those with high growth and value production potential, and those with limited potential. With the exception of the customer/prosumer, any box that touches a commodity stream (blue arrows in Figure 4.8 to 4.11 on pages 4.13 to 4.16) should be considered within the limited potential category, because optimization of the energy stream is essentially a zero-sum proposition. This means that value shifting can occur between entities, but opportunities for new value creation are limited, at best. In fact, some new devices providers (such as solar PV leasing entities) prefer to be classified as offering “net load” rather than as energy producers, in order to stay on the non-regulated side, away from the commodity streams. The main reason is that state regulatory interconnection rules usually pass interconnection costs for customer side connections to all customers – where as merchant DER has to pay for the interconnection costs solely. In addition, the merchant DER providers wish to minimize the amount of regulation they encounter.

7. In the chaos theory view of grid stability, the seeds of wide area blackouts and other manifestations of instability are inherent in basic grid structure. This viewpoint, which is not universally accepted, arose even before the recognition of stochastic generation and reduction of grid inertia as destabilizing influences. However, time and again, the structure of the grid determines important system properties and basic limits.

   (Policy Implication 3 – Responsibilities for reliability management have historically been established hierarchically, starting with wholesale generation & transmission treated in a semi-integrated fashion, but then separately at a lower level within distribution—where reliability requirements have historically been assigned to single regulated entities. As previously noted, two-way flows within distribution systems will require greater focus on making more explicit shared responsibilities for reliability management (and supporting investments) between distribution system operators and loads/producers within that distribution system. See p.22).

8. The structure of the dense urban mesh limits any services that buildings might supply to grids except for those that reduce net load and thus do not attempt to put power back into the grid. In these contexts, DG and storage cannot push power back into the mesh primary feeders, and thus cannot push power to the grid. Furthermore, tripping of multiple network protectors can cause a portion of the secondary mesh to island (separate from the rest of the grid). Since the network protectors are not coordinated, the extent of the island is unpredictable.

Where fuses are used in the secondary, some of these may blow, requiring truck rolls to replace before normal operation can be restored.

(Policy Implication 4 – The enablement of two-way flows within distribution systems in the face of structural limitations such as described above can have costs that go beyond those related to new premise equipment and software. Some amount of change at the utility level may be needed just to unblock the potential for certain building-to-grid energy/power services. P. 4.28)

9. While basic coupling occurs electrically at multiple levels in the grid, coupling can and does occur in other ways, some of which can be quite subtle. Coupling can occur through controls, markets, communication networks, fuel systems, loads, and social interactions of customers/prosumers. Unsuspected coupling is a hazard of increasing grid complexity.

   Even basic electric coupling can have subtle consequences. DG with reverse power flow on a radial feeder can cause false circuit breaker trips on that feeder due to a fault on a different feeder connected to the same substation bus. DG can also interfere with breaker/fuse coordination. On dense urban meshes, DG can cause unintentional islanding due to tripping of network protectors (islanding is not just for microgrids – DG can cause or support islanding in a variety of ways). The list of interaction is growing as the penetration of new devices and functionality increases.

10. System inertia and coupling (interaction) of generators with droop control through the transmission system are crucial to proper present-day grid operation. Other methods are possible but the majority of existing generators use this method. The gradual reduction in system inertia caused by replacing traditional generation with wind and solar will cause gradual degradation system stability.

    System inertia is not just a single value of a whole interconnection. For example, in the Western Interconnection, loose coupling means that the effective inertia in one area as seen by the generators there is different from that seen in another area of the same Interconnection. The Western Interconnection is also the one where most of the system inertia reduction trends shift to wind and solar generation are presently evolving. Measurement of system inertia to track changes must done in multiple locations in the Western Interconnection in order to understand the implications of changing the generation mix.

    Other emerging causes of instability include “hiding” of bulk system reserve requirements due to the existence of DER that can change rapidly, and lack of coordination between DER operations and bulk system operations.

    Policy Implications 5 – Exploring methods for measuring – and potentially predicting – system inertia associated with existing operations as well as in the context of a changing generation mix may provide key insights for policymakers and regulators concerned with system reliability. At present, this may require additional R&D efforts. In addition, such methods would be useful in the development of joint planning tools, which likewise do not yet exist for purposes of enhancing industry and policymakers’ understanding of emerging infrastructure interdependencies (such as electricity and natural gas). Meanwhile, efforts underway in ERCOT to consider inertia-related grid service merit careful attention. As discussed more fully below (p.4.33), novel configurations of assets at the distribution level (including storage) may ultimately be leveraged to help provide such services – but once again, regulatory friction associated with determining which entities are eligible to provide such services, and allocation of cost and benefits, may arise under current law.

11. The inclusion of real time power markets inside closed loop grid controls means that these markets could contribute to control instability. The problem will worsen with additional entities in the loop and the presence of faster dynamics and diverse sources of net load volatility.

12. Consider the fact that distribution control and coordination is presently not well coordinated with the rest of the grid in the light of regulatory structure, namely the Federal regulation of the bulk power system, vs. State regulation of distribution grids. Note that regulatory structure, industry structure and control/coordination structure are aligned—but this alignment if with control structures that are increasingly problematic as the grid changes due to emerging trends. Bifuraction of generation (across the transmission and distribution levels), responsive loads, dynamics association with managing net loads vs. gross loads and the increasing impact of distribution on transmission operations suggest that new models for how reliability responsibility is allocated are needed. Such models are starting to emerge at the State level, and they may imply structural changes to reliability oversight and to markets for distributed energy resources. In addition the recent 3rd Circuit Court of Appeals ruling regarding jurisdiction over DER, and the subsequent view published by PJM conceding that DER and bulk system generation regulation should be separated add to the architectural argument for changing structure.

    Policy Implications 6 – The changing nature of system dynamics, implications of DER deployment at increasing scale, new technologies, and models of consumer engagement are putting pressure on regulatory boundaries that have evolved in the past century. Current academic and industry literature suggests consideration of a new, Distribution System Operator (DSO) model, though this thinking is very new and includes a highly varied set of topics. The States of New York and California are currently engaged in regulatory proceedings that may define and establish responsibilities for what may ultimately be termed a DSO—though outcomes remain uncertain at this early juncture. A careful consideration and/or rationalization of these responsibilities might better align with system structure (bulk system vs. distribution vs. unregulated prosumer/third parties) p. 4.39)

13. The ability to quantitatively analyze and optimize architectures is crucial due to the complexity of modern grids. The development and validation of the mappings is a critical early phase step in the architecture development process.

14. In addition to the lack of interconnection standards, building to grid integration is hindered in some places by certain electrical structure limitations and more importantly lack of a coordination mechanism on the grid side that extends across the grid/building boundary.

15. The key principle for a mix of centralized and distributed control that provides properties such as boundary deference, control federation and disaggregation, and scalability is: Local Optimization Inside Global Coordination: Note that coordination is not control, although goal decomposition coordination mechanisms can be used to solve control problems if desired.

16. Note that the DSO-based industry structure, while motivated by the need to clarify and simplify responsibility for distributed reliability, arrives at a result entirely consonant with the laminar coordination structure. Since the laminar structure was motivated by the need for whole grid coordination with a rigorous basis for predicting properties such as scalability, it is reasonable to expect that the DSO model can share those properties that derive from such.

17. Key limiting issues on distribution are lack of adequate observability, lack of advanced protection systems to address multi-directional power flow, and lack of distributed control and coordination systems.

    Distributed grids suffer from poor observability (lack of sensing) and very little effort has gone into developing observability strategies and tools for design of distribution grid sensor networks. Advanced distribution grids must have excellent observability, so these issues must be addressed.

    As DER penetration increases, adjustable flow control can be used to provide flexibility in electric circuit operation. It can also be used to cut or limit the effect of some kinds of constraints that exist in present circuits, such as unwanted cross feeder flows or unscheduled flows to the transmission system.

    Partial meshing provides more paths for power flow (with flow controllers directing the “traffic”) so that it becomes possible to make more effective use of DER, meaning that the cost effectiveness of such assets is enhanced two ways: better sharing of the assets, and enablement of new value streams and innovations.”[16]

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[16] Taft, J.D. and Becker-Dippmann, A. (2015) Grid Architecture. Pacific Northwest National Laboratory (PNNL-24044). Final January, 2015.