

Distributed Energy Resources: New Markets and New Products

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Abstract

The rapid introduction of Distributed Energy Resources (DER) into the retail/distribution sector of the electric power system has raised questions concerning both the economics and control of the power system. This paper presents one market paradigm that builds upon extension of the logic of Locational Marginal Pricing into the distribution level arguing that this extension is necessary if there are to be competitive forces that bring new technologies to market while at the same time assuring the reliability of service. We introduce three concepts: first that there are only three core products (real power, reactive power and reserves) and that all other products are combinations of these; second that it is necessary to calculate Distributed Locational Marginal Prices (DLMP) in order to value any DER; and third that for there to be a market for DER it should be structured as an economic platform.

1. Introduction

Widespread incorporation of Distributed Energy Resources (DER) arguably poses the most significant challenge to the electric utility industry since the advent of wholesale market restructuring that began in the 1990's. DER such as distributed generation, distributed storage and responsive demand, made possible because of advances in information and communication technology, have the potential to dramatically change the direction of the flow of kWh on the physical assets (substations, wires, etc.) of incumbent distribution utilities. This change in energy flow will initially increase rates and ultimately would prevent those

incumbents from collecting sufficient revenue to cover their fixed costs if policy makers do not approve changes in the basic structure of distribution tariffs to reflect the critical value of the distribution assets (connectivity) in providing reliability in supply of energy.

While the concern for the possible negative revenue impacts of DER has gained the greatest attention, the states of New York and California have approached DER as a positive and economically efficient force in the delivery of electricity to consumers. ERCOT has developed an innovative pricing structure and much of Europe is struggling with the impact of DER and more generally the advent of massive infusion of renewable technologies into the power system. Australia is in the midst of evaluating economically efficient means of incorporating DER into their energy-only market.

New York and California have proceeded quite differently in their approach to adoption of a pro DER position. New York has created a proceeding within the state entitled Reforming the Energy Vision (REV) with a focus on creating one or more markets for the products of DER. California has focused more on legislative and administrative mandates in an effort to require the distribution utilities to incorporate greater quantities of DER in their distribution systems.

The objective of this paper is to present one market paradigm that builds upon the logic of Locational Marginal Pricing (LMP) suggesting that extending the logic of marginal cost pricing / valuing into the distribution sector is not only feasible but necessary if there are to be

competitive forces that bring new DER technologies to market while at the same time assuring the reliability of service. [1]

We introduce three critical concepts in development of a competitive market at the retail level and relate these to both the wholesale market experience and to the underlying physics of the power system. The first concept is that there are three core products (real power, reactive power and reserves); all other products in the market are combinations of these three in function, space and time. The second concept is that it is both necessary and possible to calculate Distributed Locational Marginal Costs (DLMPs) and that without this ability it is not possible to accurately value any given DER. The third concept is that for there to be a market for DER that can be interactive with the wholesale market there should be an economic platform on which the DER products can be traded. These three concepts are developed within the paper and numeric examples are provided of the economic value of “getting the prices right” at the distribution level.

2. Regulatory Initiatives: Overview

The New York Public Service Commission initiated the Reforming the Energy Vision (REV) proceeding in April 2014. The February 26, 2015 Order in the REV proceeding states that the general goal of REV is to move the electric industry and ratemaking paradigm toward a “...consumer-centered approach that harnesses technology and markets.”[2] The Feb. 26 Order introduces the concept of a Distributed System Platform (DSP) provider, an entity responsible for three major functions at the distribution level: integrated system planning, grid operations, and market operations. The Order assigns the role of DSP to the state’s distribution utilities. The Framework Order places particular emphasis on improving and increasing the integration of distributed energy resources (DER) into the planning and operation of the state’s electric distribution systems. It expects that better integration will lead to “...optimal system efficiencies, secure universal, affordable service, and enable the development of a resilient, climate-friendly energy system.”

Juxtaposed against the platform-based proposed market structure for New York is a more centrally driven structure in California. The California approach focuses on requiring aggregators to acquire and package DER products (e.g., real energy, reactive power, capacity) and to offer those products in the CAISO markets. [3] The focus in California continues to be on the increased penetration of specific DER such as solar and storage.

3. The Core Products

This paper distinguishes three categories of core electric products that are central to the operation of power systems: real energy, reactive power, and reserves.

- Real energy, measured in kWh, is the fundamental physical electric commodity underlying the electric products required by utilities, ESCOs and customers. This fact is particularly relevant to the formation of prices for the other core electric products.
- Reactive power or VAR (Volt Ampere Reactive), measured in kVAR, sustains the electrical field in alternating-current systems while maintaining voltage within specific limits required by regulation,
- Reserves, measured in KW, represent the potential to deliver real energy (kWh) at a point in the future.

The other electric products discussed are all derivatives of, or combinations of, these three core products.

Reactive power and reserves are critical to the reliable operation of distribution systems. Utilities maintain voltage within specified limits and have traditionally done so through the design of distribution circuits and investments in capacitors. Reactive power from DER represents a supplemental if not alternative source. Significant PV penetration can lead to violations of voltage standards that protect customer equipment and cause capacitors to exceed their design daily duty cycles and quickly “wear out,” suggesting that services for voltage control will become increasingly valuable at locations where utilities are integrating greater quantities of PV.

Operating reserves from DER that can ramp their output up and down quickly may be particularly valuable at specific locations on distribution systems where the Distribution Utility would otherwise have to make a traditional infrastructure investment. DER are widely recognized to have the potential to provide core electric products that can serve as alternatives to capital investments in distribution system infrastructure and/or to procurement of electric products from wholesale markets. [4] PV can provide real energy and reactive power, EV and Electric Energy Storage can provide all three core products and DR can provide real energy and reserves.

One of the economic factors that will affect the quantity of each core product a specific DER will choose to provide during any given time interval is the fact that any unit (kW, for instance) of a specific resource can provide only one of the three products during that time interval, i.e., either real energy, or reactive power or reserves. [5] As a result, the party controlling operation of a DER must choose which product to provide during a given time interval. The prices of those products not chosen represent the party's "opportunity cost" of not being able to use its DER to provide those products during that time interval. Since real energy is the dominant core product the prices for reactive power and for reserves tend to be heavily affected by the opportunity cost of not producing real energy.

The contractual and operational attributes of these core products will also affect their value including:

- *Product Location.* Where the product may be bought or sold and for which product prices are set. It identifies the geographic granularity of the product market. Locations may be region-, zone- or utility-wide; at an aggregated pricing node or trading hub; or at a location as specific as the meter for a customer or resource.
- *Product Period:* The time period for which the product may be transacted and prices are determined. It identifies the time granularity of the product market. For energy products, this might be a five-minute interval. However, forward capacity products can be traded on a

monthly, seasonal, or annual basis.

- *Financially Binding Forward Commitment and Associated Financial Penalty For Non-Performance.* An agreement to provide a quantity of a specific product, in a specified period, when specified conditions are realized, and a dispatch signal or notice is issued or to purchase or use a quantity of a specific product in a specified period. Forward commitments may be physical with penalties for a failure to perform or financial when the obligation may be settled financially or covered by an offsetting transaction in a market that clears at a future point in time.
- *Resource Qualifications.* To make a forward commitment to physically perform, a resource may have to meet and maintain specified physical, deliverability, measurement, testing, or other qualifications. Forward commitments also may require additional credit qualifications.
- *Response or Ramp Rate (Rate of Change in Output or Usage):* Reserves (including Frequency Response, Regulation, and Operating Reserves) are dynamic in that the resources are required to change their output or usage at a specific rate commonly specified the movement of output or demand per second over a specified period. The required change in output or demand may be specified as a percentage of the called upon Reserve quantity.

4. Distributed Locational Marginal Prices (DLMP)

The value of electricity varies by time interval and location within any utility distribution system. With continuing advancements in information, communications, and control technology, it is feasible to extend time- and location-specific markets to reflect these differences. Establishing distribution level markets for DER products at more granular pricing would accomplish this. We argue that understanding of and ability to calculate DLMPs is the critical step in the economic integration of DER into the power system and also provides the signals necessary for efficient physical operation of the system in much

the same manner as LMPs provide those signals at the wholesale level.

Implementation of more granular pricing for core electric products at the distribution level provides the economic logic of the proposed Platform Market. The paper acknowledges that DLMP is only one of various possible approaches to calculation of the value of DER. However, an analysis of the DLMP approach is fundamental to understanding the gains in economic efficiency from moving the pricing point for electric product production and consumption deeper into the distribution system.

The mathematical structure for the calculation of DLMP is analogous to, and needs to be coordinated with the calculation of LMPs. DLMP measures the locational value of real energy and reactive power at specific nodes within the distribution system, and therefore can measure the value of core electric products from DER. [5,6] The calculation of DLMP is distinct from and more complex than that for LMP but arrives at the same conceptual point from an economic perspective – it defines the precise marginal value of electric products and services at any point in time at any location within the distribution system.

A key point to note with respect to the establishment of the distribution markets is the importance of the price of real energy in the wholesale or bulk market. The price of real energy is the key driver of all the electric products against which DER products are competing. The same kW of capacity can only provide one core product during any given time period, e.g. real energy, reactive power, or reserves. Any given asset can deliver a mix of core products but cannot do so beyond the maximum capacity of the unit. Thus, when deciding which and what mix of core products to produce the resource owner has to decide which product or products will yield the greatest compensation. The price of real energy is the most common reference point for those decisions.

5. Platform-based market for DER

The challenge being presented by the advent of DER is to design a new, distribution level

market for energy and related electric products from DER that can animate and facilitate the financial transactions for these DER products. We propose a market paradigm that builds upon the rapidly expanding development of and academic understanding of economic platform markets. [1]

As defined by Parker and Van Alstyne and others:

A platform is business ecosystem that matches producers with consumers, who transact directly with each other using resources provided by the ecosystem itself. The platform ecosystem provides outside parties with easy access to useful products or services through an infrastructure and a set of rules designed to facilitate interactions among users. A platform's overarching purpose is to consummate matches among users and to facilitate the exchange of goods and services, thereby enabling value creation for all participants.[7,8,9]

A platform functions because of significant buyers and sellers that use it for transactions of goods and services. These participants on the platform provide the economic incentive for the development of third party products – network externalities – that can exist only because of the existence of the platform itself. Platforms like Amazon, Uber, and AirBnB spawn these additional applications in products and services that range from technology to forecasting to name but two.

The critical question for extending markets into the distribution sector through the establishment of platforms is how to create a highly liquid core product market that can provide a “level playing field” for DER, improve system efficiency and reliability, and provide benefits to customers. This platform paradigm considers opportunities to:

- Promote fair and open competition and reduce barriers to the development and use of DER;
- Identify, quantify, and reflect in market design the temporal and spatial value of DER within the larger utility system; and
- Capture the economic benefits of digital

platforms to support market operations, for example as a mechanism for price discovery and a means of integrating electric products with digitally based services.

The design of this new market has drawn upon the well documented and extensive experience with electric market design at the wholesale level. The key lesson from that experience is the importance of “getting the prices right.” Prices in this new market need to reflect the value of core electric products from DER as a function of the time at which DER produces those products and the location at which DER produces them. Getting the prices right – more granular – for transactions within the distribution system requires that price formation take place deeper in the system. This more granular pricing will identify where, when and how DER can provide significant value through reduction in system operating cost or where the ability of DER to respond to these granular price signals can reduce the need for additional capital investment.

Under the proposed market structure distribution utilities would continue to provide two services: delivery service and, where required by the market structure, default supply service. However, distribution utilities would specifically be responsible for integrating DER into their provision of delivery service in their respective service territories and assuming that the market structure included a shift to DLMP, they would have a financial incentive to do so. One component of that financial incentive would be net revenue that distribution utilities would receive due to the difference between charging for losses at the marginal cost of power and their actual cost of supplying those losses. Additional incentives would derive from increased transactions on the platform and from any creative, new long term regulatory recovery mechanisms that might be introduced.

A Platform Market for DER would combine the benefits of a digital platform with the economic efficiency of more granular pricing that reflects their location- and time-specific value.

Establishing a Platform Market would create additional value for DER owners and consumers by:

- **Expanding market access for DER.**

Demand Response (DR) programs typically provide the only available paths for active DER participation in the existing wholesale power markets, and there are significant gaps in DER participation in those markets. A Platform Market would expand DER access to markets for electric products and services by creating a new market and by reducing the transaction costs of accessing existing wholesale markets. The Platform Market would enable DER to provide real energy, reactive power, and reserves to Distribution Utilities, default suppliers, energy service companies (“ESCOs”), aggregators who would bundle and market DER resources, and even directly to other consumers. Additionally, distribution utilities initially can use the Platform to obtain option contracts or firm commitments from DER, and ultimately to rely on increasingly more granular distribution level pricing to promote the development of DER, in quantities and locations where DER can avoid investment in new substations and other major distribution investments.

- **Supporting new combinations of products and services.**

By creating a market with a significant number of buyers and sellers with varying needs, and by enabling those buyers and sellers to find and execute transactions electronically, the Platform will support transactions for new, innovative combinations of products and services from DER and third parties at low transaction cost. In addition, The Platform, by supporting the provision of price forecasts, data analytics, and other smart technology services would enable price responsive flexible demand, more efficient electric vehicle charging, and bring to market other distributed resources to consume or supply power when it is economical to do so consistent given customer preferences. (Price responsive demand is a method by which customers, such as space conditioning in commercial buildings and charging of electric vehicles, can reduce their energy costs by scheduling the flexible portion of their load according to the forecast price of electricity in each hour.)

A number of studies have identified the technical potential for responsive demand to

reduce system peak to be as much as 25%.[10] More granular pricing could ensure that these changes in demand and distributed supply occur where they can provide the greatest value to the system as a whole.

- **Improving distribution system efficiency.** Distribution Utilities traditionally manage voltage through investments in capacitor banks, line voltage regulators and load tap changers located on the primary, higher voltage elements of the distribution system. The implementation of new technologies like smart inverters on rooftop solar, distributed storage and electric vehicle systems or autonomous fast-acting distributed Var control (a current technology that enables up to 5% or greater energy and demand savings) may well provide a local source of Volt VAR control at a lower cost and at higher efficiency than traditional utility investments. [11]

Our proposed structure is comprised of a forward (*ex ante*) market for electric products and a separate (*ex post*) clearing market, both markets operating by and on the Platform. The forward market provides the structure through which the platform provider can bilaterally match location and time-based bids and continuous price formation can occur. Bids and offers are visible on the Platform to all market participants but the Platform does not identify the entities making the bids or offers. This market is continuous in that market participants can transact trades days ahead, at the time of the wholesale Day Ahead market or at any time up to the point of market closure (production and consumption). The platform is the mechanism for bilateral distribution system level transactions in the forward market in much the same manner as other bilateral trading markets such as ICE and NYMEX operate for energy and other commodities where it provides transparency for bids and offers by product and location.

We have proposed a separate clearing market to resolve the imbalances between scheduled supply and actual consumption that will occur under this market structure. Imbalances will occur because demand forecasting is not and cannot be perfect, and because electricity is produced and consumed simultaneously. As a result, *ex post*, the platform financially clears all positions from

the forward market. (In the wholesale market, the ISO accomplishes this through calculation of real time Locational Marginal Prices (LMP). In the platform market distribution utilities will provide to the platform the information it needs to calculate imbalances, i.e., metered quantities of real energy and reactive power actually consumed and the measured flows on the system. The Platform will run a mathematical load flow calculation, with, in the organized markets, the substation LMP as the reference price, to determine a clearing price at each of the traded distribution nodes. This is conceptually comparable to the real-time LMPs the ISOs currently calculate. While the complexity of the calculations will increase with greater levels of granularity and the need to recognize the value of reactive as well as real power, the logic of the calculation is independent of the level of granularity of the nodal system and therefore is easily extended as the market expands.

The establishment and operation of a platform requires a breadth and depth of participants along with the platform sponsor and a platform provider. The size of the potential participant pool on both the buy and sell side is critical to the acceptance and the success of the platform.

To further describe the operation for DER products, appendix A provides an example of the transactional steps in “A day in the life of the Platform” under a DLMP Market.

6. The Benefits of DLMP over Business as Usual and only LMP: Example

The authors have developed a quantitative assessment of the value of moving to more granular locational prices under a platform market by using the DistCostMin (DCM) model, an optimization modeling system developed by Boston University for analysis of the economic value of provision of and response to increasingly granular pricing of core electricity prices in the distribution system.[4] The DCM model was used to compare the marginal cost of real and reactive power supply to a simulated 800 bus radial feeder with both commercial and residential demand incorporating supply (solar) and storage (electric vehicle) loads along with space conditioning located in the Capital Region of New

York State.

DCM considers full AC load flow constraints. As per [12], a radial network with voltage magnitude constraints and non-convex full AC load flow constraints, can be seen to have a unique optimal solution. This means that the dual solution, i.e. the nodal prices, will be unique [6] and applies KKT conditions to find the building blocks that comprise the nodal prices. In particular, DCM uses the reduced branch flow model developed by [13] and furthered by [14]. In most radial distribution networks, and in the one examined here, we can verify through simulations that the relaxation is tight. The authors would like to point out the possible multiplicity of solutions in the case of meshed networks with AC load flow considerations as an interesting future research direction.

The modeling results illustrate the criticality of location within the distribution feeder and thus of the relative value (positive and negative) of energy within the system. DCM valued real energy plus reactive power at each node, i.e., at commercial customer meters and at residential pole transformers, for a peak summer day and a peak winter day for each market structure under low and high levels of DER penetration. Figure 1 provides a graphic summary of the results of the DLMP (dollar value) for real energy and reactive power indicating the maximum and minimum values that occurred at any point within the system for each hour and the LMP nodal value (the nearest point to the bulk power market). As can be seen at 2pm on the test day the value of real power ranges from a low of \$0.033 to a high of \$0.112 per kWh while reactive power for the same time period ranges from a low of zero to a high \$0.038 per kVarh.

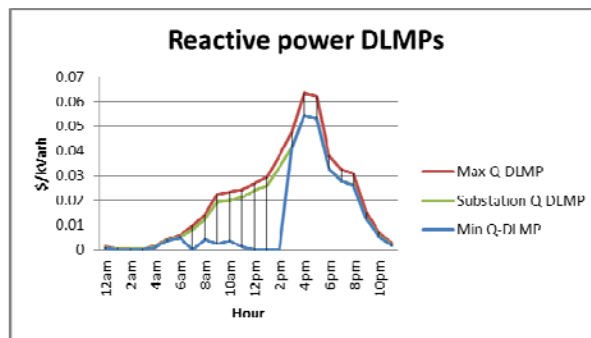
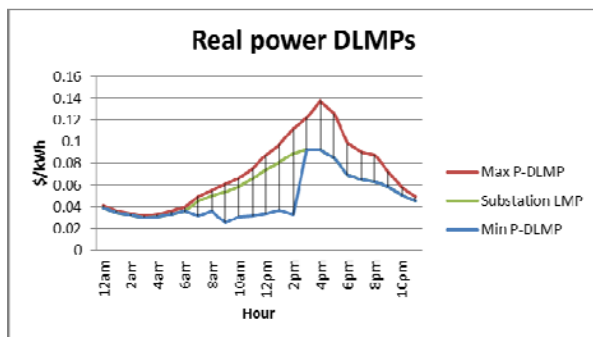


Figure 1: DLMPs Summer Peak Day

7. Conclusion

The paper has introduced three critical concepts in development of a competitive market at the retail level that allows the market for DER to function coordinated with the wholesale market and respect the underlying physics of the power system. The first concept is that there are three core products (real power, reactive power and reserves); all other products in the market are combinations of these three in space and time. The second concept is that it is both necessary and possible to calculate Distributed Locational Marginal Costs (DLMP) and that without this ability it is not possible to value any DER. The third concept is that for there to be a market for DER that can be interactive with the wholesale market there should be an economic platform on which these product can be traded. These three concepts are developed within the paper and numeric examples are provided of the economic value of “getting the prices right” at the distribution level.

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9. Appendix: A Day in the Life of a Platform: DLMP

Assumptions underlying this chronology

- For any given electrical region (state, Province, etc.) there is only one financial Platform, and it interacts and exchanges critical information and data with each Distribution System Operator (DSO) or functional equivalent that oversee the physical distribution system (see next bullet).
- DSOs will monitor, operate and maintain the physical distribution system (e.g., wires, transformers, switches, capacitor banks.) This discussion assumes each DSO has a system-monitoring and distribution level state-estimation process, enabling it to provide the Platform, in near-real-time, descriptions of what the distribution system's actual topology has been on an interval-by-interval basis, and what the physical flow on the distribution system has been on an interval-by-interval basis.
- The Distribution System Operator, is assumed to provide the Platform:
 - specifications for any local distribution system reactive power management capabilities that it wishes to procure from DERs;
 - specifications for any location-specific reserves that it wishes to procure from DERs to address local constraints within its distribution system; and
 - information on its dispatch of DERs for reactive power management, on its location-specific reserves for settlements, and on the performance of DERs it dispatched.
- Energy Service Companies (ESCOs) are market participants that provide energy or offerings that include energy and other products and services to end-use consumers. They are financially responsible parties for the acquisition and settlement of energy and other products and services transacted over the Platform.

- ESCOs may aggregate the requirements and resources of small consumers and prosumers (generation and load response) into packages they can then trade in standard units on the Platform.
- ESCOs will combine energy with other potentially high-value products and services available on the Platform to provide offers tailored to the preferences and requirements of specific customers, including both large and small consumers and prosumers.
- Distribution Utilities, should they also be default suppliers, function similar to the ESCO as a regulatory requirement. They would be subject to regulatory oversight and potentially performance-based incentives.
- DSOs purchase distribution-reactive power management capabilities and location - specific reserves from DERs.
- Distribution Utilities, as distribution system operators, will monitor activity and forward market liquidity in the Platform's DLMP markets, paying particular attention to areas in their distribution systems that rely on DER for service reliability, and, if needed, will contract for and hold in reserve the output of DER assets that may be required to address future local constraints.
- Market participants are ESCOs, Distribution Utilities, aggregators, third-party product and service providers, financial participants, end - use customers participating on their own account, and DERs and prosumers.
- Aggregators (when and where economically relevant) are market participants that purchase and bundle the capabilities of smaller customers for resale to ESCOs, default suppliers, and NYISO.

Initial Conditions on the Platform

- Because the market on the Platform will be continuous, some market participants will have standing positions (bids to buy, offers to sell) for standard products for extended time blocks, i.e., similar to the standard transactions traded in today's wholesale market that focus on peak and off-peak hourly

blocks. Bids to buy and offers to sell include a pricing provision.

- The Platform will provide a continuous matching of bids and offers (the market-making function) that, as part of the Platform functionality, will include standard contract terms and conditions (market operation rules) for transactions, as well as the mechanisms for market settlement.
- The Platform will have, at all times, multiple forecasts from the DSO and third parties of locational prices. These forecasts will be dynamic, changing as conditions change and as the clock moves forward.

Prior to the Day Ahead wholesale (ISO) energy market

- Retail suppliers (ESCOs, Distribution Utilities and others) will forecast their hourly needs for the next day and, if they elect to do so, bid into, the ISO market for supplies, as is the case today.
- Distribution Utilities providing default supply service to customers will purchase the supply for those customers from the ISO's Day Ahead Market. However, prior to making those purchases, Distribution Utilities would provide customers the option to accept or modify their respective supply requirements for the delivery day.

After the close of the Day Ahead bulk power (ISO) energy market and before the close of each real time (hourly¹) market on the Platform

- All market participants now have the information reported by the Platform as to the (hourly) expected value of nodal LMP, and the value for Real Energy and reserves (as well as any other day-ahead ancillary services) that have cleared the day-ahead market.
- Additional bids and offers are entered onto the Platform by market participants wanting to create a position in the Platform's real-time

¹ "Hourly" is used only to indicate an agreed time step. Sub-hourly time steps are equally likely.

market (for instance DERs and prosumers) or improve their market position (such as ESCOs or Distribution Utilities).

- The Platform will continuously match bilateral bids and offers providing for continuous price discovery.
- The Platform will collect a transaction fee from the sellers (least-elastic entity) as a percentage of each buy/sell transaction logged on the Platform.

At the time of closure of the Platform electric product markets

- The Platform will continue to match bids and offers until a time certain before the close of the time period in which the electric product will be finally “delivered.” **“Delivery” in this context is purely financial** i.e., the market participant that has contracted to supply or buy energy is financially obligated to supply or consume against the terms of the standard contract. The Platform will settle any imbalance between market positions for real energy at market close and actual delivery or consumption at interval marginal prices based on actual distribution system topology and power flows, as discussed below.
- The Platform will collect a transaction fee as a percentage of each buy/sell transaction logged on the Platform.

After the closure of the Platform electric product market

- The Platform will query and receive from the DSO a record of energy produced and consumed by location within the distribution system and system information needed to calculate imbalance prices.
- Based on the contracted values of the closed market and DSO record of energy produced and consumed (by specific location), the market clearing function of the Platform will calculate *ex post* clearing prices for energy and reactive power by location.
- The clearing calculation will take place as a function of *ex post* actual real and reactive energy consumed and delivered, forward real

and reactive power obligations ~~requirements~~, operating resources, power flows, marginal losses, and any constraints within the distribution system (network) during each interval (integrated over the Platform trading period) as well as any marginal deterioration in the lifetime of capital assets such as transformers.

- If during the interval there are no distribution system constraints affecting the portion of the monitored distribution network that includes the relevant DLMP pricing point, the interval DLMP energy clearing price will be calculated algorithmically, based on the applicable *ex post* nodal (wholesale) DLMP based on the distribution network power flows for each interval.
- In this case, the DLMP reactive power clearing price for resources enrolled and operated within the DSO’s Volt VAR Control (VVC) program will be equal to the resources net DLMP lost opportunity cost from being limited in its ability to provide Real Energy. The DSO may pay resources participating in VVC programs an option price that allows the utility to call upon the resource to provide VAR support and voltage control.
- The Platform will provide all financial clearing information to market participants. The Platform is the bookkeeping entity of the market.