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Integrated Distributed Energy Resource Pricing and Control

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SUMMARY

U.S. policy is to allow owners of distributed resources to effectively and reliably provide their services at scale, and operate harmoniously on an interconnected distribution and transmission grid. Accordingly, regulation, new business models and technology advances over the past decade have led to significant growth rates in distributed energy resources including generation, responsive demand, energy conservation and customer adoption of industrial, commercial and residential energy management systems. The result is that several regions are reaching proposed capacity levels for distributed generation that exceed traditional operating and engineering practices for distribution systems. At the same time, policies advocating wholesale spot prices to customer devices ("prices to devices") have not adequately considered distribution system reliability impacts or relationship to distributed generation. As such, it is also not clear that current market models or regulations are entirely adequate or appropriate for the several emerging hybrid regional markets, such as California, with millions of distributed energy resources envision by the year 2020.

As the market adoption of distributed energy resources (DER) reaches regional scale it will create significant issues in the management of the distribution system related to existing protection and control systems. This is likely to lead to issues for power quality and reliability because of three issues: (1) current wholesale pricing models for distributed resources do not reflect distribution level information related to location, reliability or power quality considerations; (2) pricing schemes involving real-time spot market prices, like Locational Marginal Pricing, are likely to create significant volatility for customer DER that is not desirable from either from operational or commercial perspective; and (3) integrating distributed resources into wholesale markets without aligning distribution control schemes may create unacceptable consequences.

In this paper, we describe a framework for the development of a class of pricing mechanisms that both induce deep customer participation and enable efficient management of their end-use devices to provide both distribution and transmission side support. The basic challenge resides in reliably extracting the desired response from customers on short time-scales. These new pricing mechanisms are needed to create effective closed loop systems that are tightly coupled with distribution control systems to ensure reliability and power quality.

KEYWORDS

Distributed Resources, Distribution, Controls, Markets, Pricing, Reliability, Stability, Power Quality

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Introduction

U.S. public policy has set clear objectives to enable broad market participation by customers' distributed energy resources. Over the past decade regulatory rules and market changes have increasingly reduced barriers to participation. Toward that end, a current policy objective is to provide economic signals to dynamically connect wholesale and retail markets, by enabling end-use consumer devices to respond to system conditions and thus provide both grid and consumer benefits. However, consumers view reliability as a public good – they expect that whether they turn on their appliances will have no influence on the quality of power delivered to their neighbors, and no consumer is prevented from using an appliance at any time. As customer adoption of DER increases, it is becoming clearer that price responsive DER will have a material effect on distribution networks reliability/power quality. As such, distribution management will evolve from a passive to an active interaction with distributed resources. In this context, it becomes critical to consider the effects of the current pricing policies and control schemas.

This paper describes the relationship between pricing schemes and grid control systems as it relates to distributed energy resources to ensure market structures, power systems and participation rules maintain a highly reliable system. Three basic issues should be addressed in this evolution: (1) the lack of effective grid services and related market based pricing schemes aligned with the temporal attributes of the use and response characteristics of customer devices/resources; (2) the lack of adequate pricing components that reflect distribution system operational considerations for the respective time periods; (3) new market structures based on hierarchical controls and appropriate feedback methods to ensure that the collection of independent agents will adapt, in real time, to changing conditions so as to ensure power quality and grid stability.

Integration of Distributed Resources into Grid Operations

Ideally, the ability to inform consumers and devices of market and grid conditions will allow the devices to proactively and independently become a beneficial part of grid management, while remaining under customer control. In order to incentivize desired consumer response, it is essential that any pricing schema for customer device response include distribution system operational factors, not just wholesale markets or transmission considerations [1]. This is because, price signals can have an instantaneous effect on a number of independent agents, and thus the actions of one agent significantly influence the quality of power delivered to others. The risk is that significant variability is being introduced that does not follow the traditional control system and operating paradigms. As such, the use of open loop real time prices (e.g., "prices to devices") will create a problem. Instead, a closed loop system of price signals aligned with market and operational factors is needed and can be effective.

If, for example, most buildings on a distribution circuit have an energy management system that turns off HVAC systems when electricity prices rise above a threshold, then the distribution circuit, and indeed the entire grid, can be destabilized. Several potential negative effects can occur under this scenario. First, the immediate drop of load may simultaneously create an unacceptable phase unbalance on the distribution circuit since many loads are connected to only one or two phases. Second, if a material amount of DG was interconnected at the time of load response, power flow on the distribution circuit may change direction and voltage would rise. This could cause protection scheme issues and unacceptable voltage levels. Third, in a worst case, this load curtailment could inadvertently trigger a high-frequency square wave destabilizing the grid. Fourth, when devices shut down in response to a high price, there is risk that reduced power consumption will result in low prices that will induce a resumption of consumption. The ensuing oscillations are precisely what a control engineer would anticipate from such a "high gain feedback loop".

The current direction of market structure, controls, and pricing policies for distributed generation, demand response and other distributed energy resources is conflicted and questionable with respect to providing consistent, market based price signals for reliable distribution system operation and investment for customer DER and distribution infrastructure. In California, for example, there are both prices from the California Independent System Operator (CAISO) as well as utilities under their demand response programs available to qualifying customers that may be connected to the same distribution circuit and/or fed by the same distribution substation transformer. Figure 1 below illustrates a simplified view of the current market-control structure. There are three basic control loops; bulk system, distribution system and customer/aggregator. Within and across this schema, there are multiple DER prices signals and inconsistent feedback paths on non-aligned time sequences that lead to non-scalable outcomes.

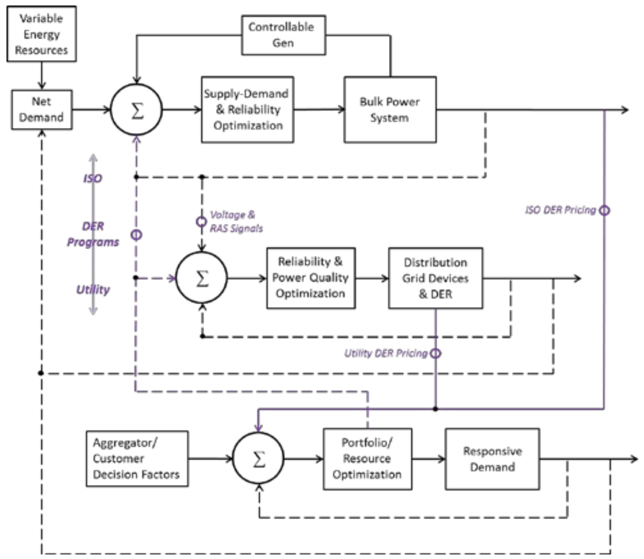

Figure 1. Current Day-ahead/Intra-day Pricing-Control Schema

DER Pricing and Grid Controls

The current Federal policy regarding the use of dynamic wholesale spot pricing inherently creates a form of decentralized real-time control, where each customer or aggregator sets device response characteristics based on thier preferences. Unfortunately, these prices do not reflect distribution level information related to location, reliability or power quality considerations. Also, the notion that consumers maintain direct control of their devices is a bit illusory, as devices are responding directly to variations in price based on a local control policy fixed a priori. The inherent closed-loop feedback between volatile spot price and aggregate demand could result in undesirable cycling of devices (and feedback into market prices) [2]. In this context it is important to understand the volatility associated with Locational Marginal Pricing (LMP) markets. Figure 2 below illustrates the current difficulties of price volatility due to resource variability at wholesale that will be compounded at retail, using a typical hour at the Midwest Independent System Operator (MISO).

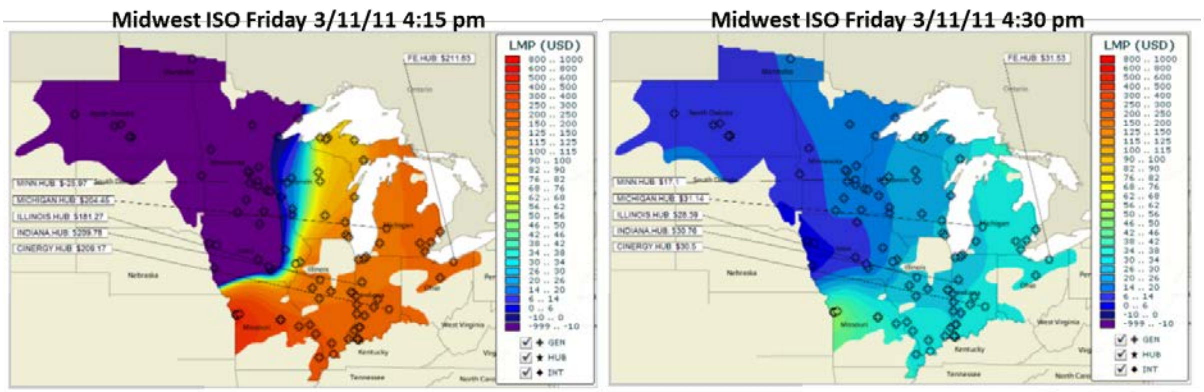

Figure 2: Locational Prices at Midwest ISO

Naturally, questions arise with respect to whether LMP is an appropriate market pricing mechanism for a hybrid electric system with tens of millions of distributed resource actors as envisioned by US policy. In theory, this sounds reasonable. In practice it becomes problematic. In the Pacific Northwest National Lab's (PNNL) Olympic Peninsula project [3], building heating ventilation and air conditioning (HVAC) systems provided feedback of their state in the form of automated variable bids which in turn caused a simulated 5 minute clearing price to move so as to re-establish the balance between supply and demand, and moves in the clearing price cause changes in available responsive demand. The resulting price volatility-responsive device behavior illustrated in Figure 3 created unacceptable oscillations for customer comfort and electricity bills. At scale, it would create power quality and stability problems on distribution circuits. An analysis of the Olympic pilot [4] interpreted this behavior as the result of high gain proportional control – more appropriate feedback architecture (such as phase lag rather than proportional feedback) would naturally reject these oscillations.

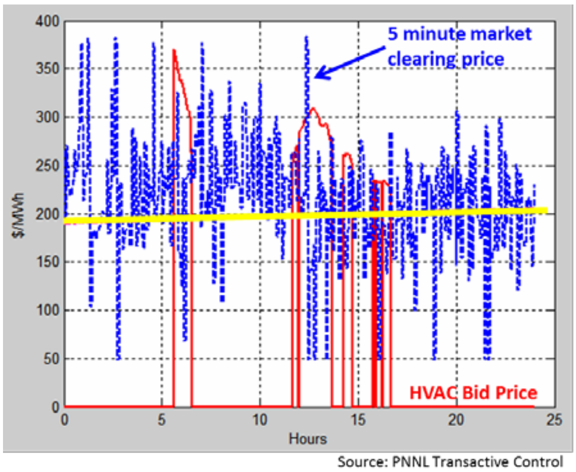

Figure 3. Volatility from Responsive Demand under Real-time Pricing

A class of pricing mechanisms that both induces deep customer participation and enables efficient management of their end-use devices to provide both distribution and transmission grid support is needed. The basic challenge resides in *reliably* extracting the *desired response* from customers on short time-scales – real-time control. Ideally, prices need to reflect the locational value of the resource, temporal attributes consistent with the distribution reliability considerations and capital investments. Such a distributed resource price schema would be based on two principles:

a) Convergence of wholesale price with concurrent distribution level engineering-economic values (positive or negative) to reconcile the relevant bulk system factors with the distribution level line loss, reliability, power quality and constraint factors on concurrent time periods.

b) Simple price signals (or possibly an alternative metric) that satisfy customer and aggregator requirements to (i) provide a means to monetize the value and (ii) enable innovation in customer products and services based derivative prices and commercial contracts.

Distributed Markets & Controls

Advocates of real-time wholesale market prices to customers and devices will argue that (b) above is achieved; however, this point of view has not considered the effect of a wholesale based optimization on the lower tier distribution system. Traditionally, distribution was allowed to "float" based on tightly managing transmission system since power flowed in one direction. In a future with perhaps 30% of power being provided by distributed generation at customer sites, these models break down quickly. It is becoming clearer that new distributed market mechanisms are needed. The CAISO acknowledges that distribution level factors need to be considered in a recent paper on DER pricing [5]. However, the CAISO's paper does not recognize the control loop issues present and actually suggests a pricing model, illustrated in Figure 4 that creates several control architecture problems:

- It prevents control federation, which makes resolving hidden coupling issues and preventing multi-objective clashes difficult.
- It prevents disaggregation, which makes it difficult to take into account local tier conditions and grid state so as to maintain grid manageability at all levels.
- Market clearing prices and customer economic decision models are likely misaligned with the timing required for maintaining distribution stability/power quality
- Adding new feedback loops without a well-defined framework introduces new opportunities for feedback-based oscillations or runaways, such as with flash crashes and both price and power grid instability

Figure 4. CAISO Demand Response Pricing Proposal

What role should markets play to achieve the pricing goals?
Markets generally provide a mechanism to (a) efficiently allocate resources and (b) enable innovation. The envisioned scale of distributed resources adds significant complexity and drives a level of convergence across the electric markets and physical operation. While this simplifies aspects of wholesale market operations, at scale this approach may result in undesirable outcomes in terms of power quality or system reliability. This is because some market designs cause the market function to act as a control element in a feedback control loop, whether intended or not. This loop is closed around a substantial portion of the power delivery system, including multiple tiers as illustrated in Figure 5 below.

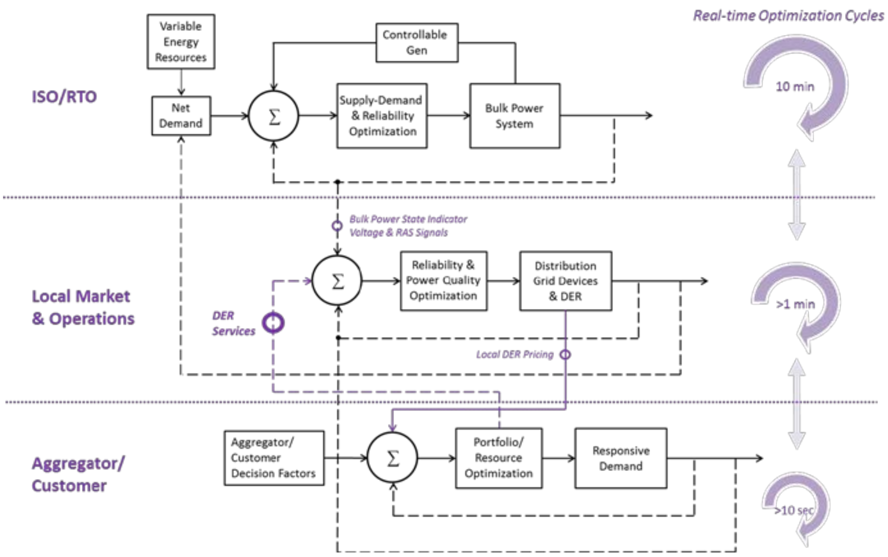

Figure 5. Multi-Tier Market Structure

To resolve the controls issues described, it is necessary to deconstruct the market into several tiers to create a hierarchical control scheme as represented in the simple model above. Each tier needs to be able to simultaneously satisfy its control objectives as well as coordinate with the adjacent tier [1] [6].

Of the three tiers, the middle tier – “local market and operations”, is the least developed. In particular, there are several aspects of local markets that would benefit from further research. Distribution systems have become more dynamic with the potential for multi-directional power flows. To understand the operational dynamics, stochastic power flow models that can account for more than one feeder and ideally the related regional transmission system are required. Engineering-economic based services specifications for DER to support distribution operations are needed along with pricing and contracting schemes for these services and associated market rules – e.g. [7]. Appropriate organized market structure to facilitate direct controls-based transactions and bi-lateral 3rd party transactions is also desirable. The relevance of local markets is that without such a market structure, it will be impossible to achieve the level of DER integration required under existing policy and concepts like microgrid cannot become reality.

Conclusion

Public policy belief is that wholesale market prices and bi-lateral transactions will resolve not only resource allocation, but also the reliability considerations for distributed resources. Specifically, this logic this belief suggests that “prices to devices” can ensure investment, reliability and power quality. This is conceptually appealing in its simplicity; however, in practice at scale it becomes challenging. It is not clear that any market has yet been able to construct an effective pricing scheme for distributed resources that can simultaneously address distributed energy resource economics with both physical distribution grid reliability considerations, and the control considerations required to maintain reliability in the face of dynamics and uncertainty.

Stakeholders must consider this reality more fully in the design of markets and integration rules. Currently, the pattern has been to apply wholesale spot market principals developed for balancing large centralized and transmission connected resources to distributed resources. This approach is questionable given the scale and scope of distributed energy resources envisioned in public energy policy. As such, there are several areas to consider:

- Effective market based prices reflecting distribution factors for distributed resources
- Balancing markets at the distribution level as a means to ensure local reliability and power quality, and create prices for DER investment
- Market pricing and participation rules can be devised to ensure a robust market place
- Gaps and conflicts between related Federal and state regulatory rules

Significant research, development and demonstration is necessary to address the issues in these areas highlighted by this paper.

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