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Evolution of the US Power Grid and Market Operations through the next Decade

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1. INTRODUCTION

The current evolution of supply resources on US power grid as with grids in other countries is focused on expanding power production from cleaner, lower emission, renewable resources. This trend in supply resources creates many benefits, opportunities, requirements and consequences. One notable consequence is a reduction in operational flexibility caused by incentivizing the retirement of legacy resources that are being replaced by resources with significantly different characteristics and capabilities. The current class of intermittent resources in the US such as wind and solar power are characterized by limited ramping and control capabilities. Legacy thermal resources are becoming even more operationally constrained due to emission restrictions imposed by environmental regulations. On the other hand, there are growing benefits in the areas of smart grid technologies, storage technologies, distributed supply resources and smart metering infrastructure. These evolving benefits have the potential to make power transmission, distribution and consumption more flexible than it has ever been in the past. Further efficiencies can be gained by aligning wholesale market prices with retail rates to take advantage of the capability to deploy real-time retail pricing to allow for more efficient use of demand control technology in response to system supply conditions. As these changes in the power system continue to evolve, both system and market operators will be required to leverage these changes in flexibility to maintain the reliability of the bulk electric power system.

2. EVOLUTION OF SUPPLY RESOURCES

The US power industry is being either encouraged or mandated to move to more clean energy sources by both the federal government and the state regulators. The development of renewable resources of various types is being incented by government policies. In the US, 29 states plus the District of Columbia and Puerto Rico have implemented mandatory Renewable Portfolio Standards (RPS). These RPSs create value for renewable resources by requiring load serving entities to acquire some portion of the energy required to serve their customer electricity demand from renewable resources. These standards are generally implemented by establishing Renewable Energy Certificates (RECs) which are issued to a renewable resource for each megawatt-hour of energy produced. The economic value of the RECs is driven by the respective state RPS targets. Additionally, the federal government

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funds a production tax credit for wind resources that was created by the Energy Policy Act of 1992[1].

In 2011 the US Environmental Protection Agency (EPA) issued the final Cross-State Air Pollution Rule (CSAPR), and the final National Emission Standards for Hazardous Air Pollutants Rule (NESHAP). These two rules will have significant impact on existing coal-fired resources. In the short term, the rules will require expensive retrofits to control emissions which will force older, smaller coal plants to retire. In the longer term, additional EPA actions are likely to further limit coal viability and operational flexibility. The CSAPR rule emission limits are also expected to reduce gas-fired plant flexibility.

Advances in horizontal drilling techniques have spurred a significant increase development of the extensive shale gas formations in the US. This development has substantially reduced the price for natural gas and has increased interest in development of natural gas-fired power plants. As coal-fired generation continues to face increasing economic and environmental pressures, the US power industry will need to develop viable operational alternatives. It appears the shale gas will facilitate growth of natural gas-fired electric generation, especially in the Midwest and Mid-Atlantic states. Such development will require more extensive coordination between electric market operations and gas market operations.

The most significant concerns related to the projected evolution of supply are the unpredictable nature and availability of intermittent renewable resources, the degradation of system inertia as fossil plants retire, the reduction in finely controllable resources and a general reduction in operational flexibility of generation resources. Dispatchable resources and resources that provide ancillary services are required to meet federally mandated operational reliability standards and to balance the system on a minute-to-minute basis. The downward trend in conventional, frequency-responsive, dispatchable, resources will require the renewable replacement technologies to develop expanded operating flexibility to avoid degradation in system control. The reliance on these needed developments in flexibility concerns many entities responsible for controlling and regulating power systems.

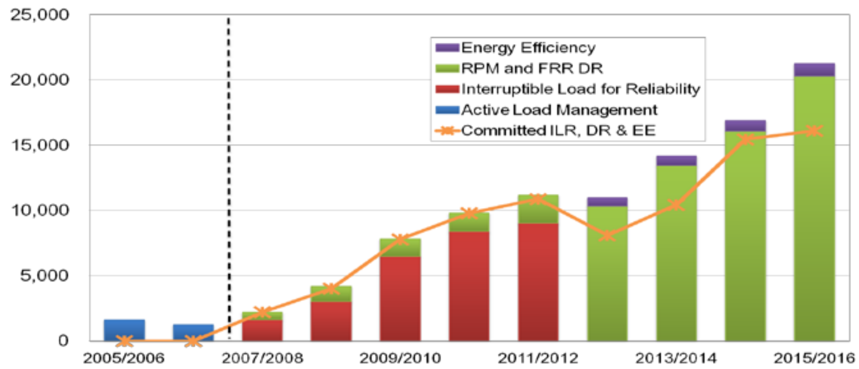
3. EVOLUTION OF DEMAND RESPONSE

As wholesale electricity markets have evolved in the US, customer response to the hedging alternatives and revenue opportunities have increased. In the PJM market, for example, customers participate in the Forward Capacity market, Energy market, Synchronized Reserve market and Frequency Regulation market by submitting offers to curtail demand in response to system operator instructions for which they receive compensation which can offset a portion of their electricity costs.

The PJM Forward Capacity market secures commitments from resources to provide energy during peak demand conditions to satisfy Installed Reserve requirements to comply with federally mandated and enforced reliability standards. Since the Forward Capacity market opened in 2007, PJM has experienced a significant increase demand response resource commitments. Figure 1 illustrates this trend of demand resource commitment offers. In the Forward Capacity market auction for the June 1, 2015 through May 31, 2016 commitment period, 15,755.3 MW of demand-based resources cleared in the auction. These resources represent 8.4 percent of the capacity requirement for the PJM region.

[1] Energy Policy Act of 1992 (http://www.ferc.gov/legal/maj-ord-reg/epa.pdf)

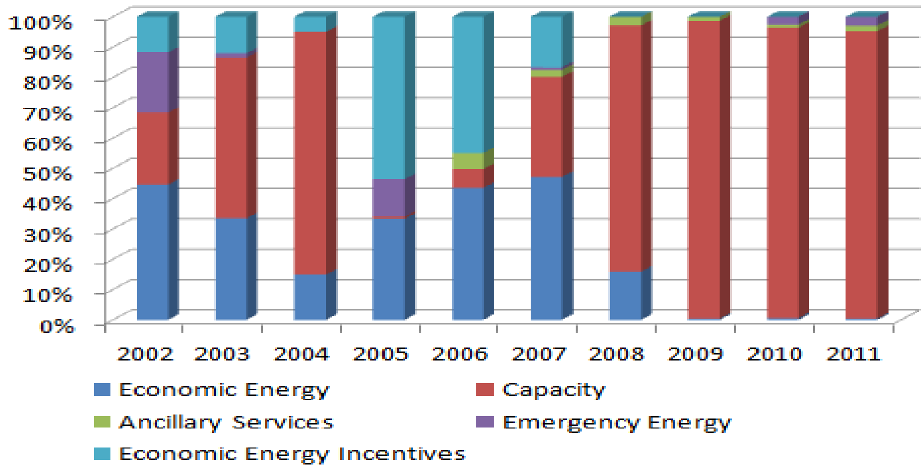
Figure 1 – Demand curtailment commitments in Forward Capacity Market



The PJM Synchronized Reserve market is an hourly market in which PJM secures resources to provide a 10-minute response to a system event. The Synchronized Reserve market has provided opportunity for competitive development of demand reduction response through investment in demand response infrastructure. The payments to resources that clear in the Synchronized Reserve market are compensation for the demand reduction resource capability to respond within ten minutes. Although demand reduction resources must install infrastructure to allow them to curtail their consumption of electricity within ten minutes, they will only be requested to curtail when system conditions require the 10-minute response. Since 2006 the participation by customers in the Synchronized Reserve market has grown steadily. In 2011, on average 10 percent of synchronized reserve supply was demand based. In some hours, as much as 20 percent of the synchronized reserve requirement has been met by demand-based resources. The deployment of Smart Response technology has enabled aggregated demand resources to provide synchronized reserves.

The evolution of demand response revenue opportunities in the PJM market has evolved over the past 10 years. As illustrated in Figure 2, the revenue opportunities for demand response participation in the PJM market include economic energy, ancillary services, capacity and emergency energy. Total demand response resource revenues grew from around $1.4 million in 2002 to over $500 million annually in 2011.

Figure 2 – Demand Response Revenue Opportunities in the PJM Market



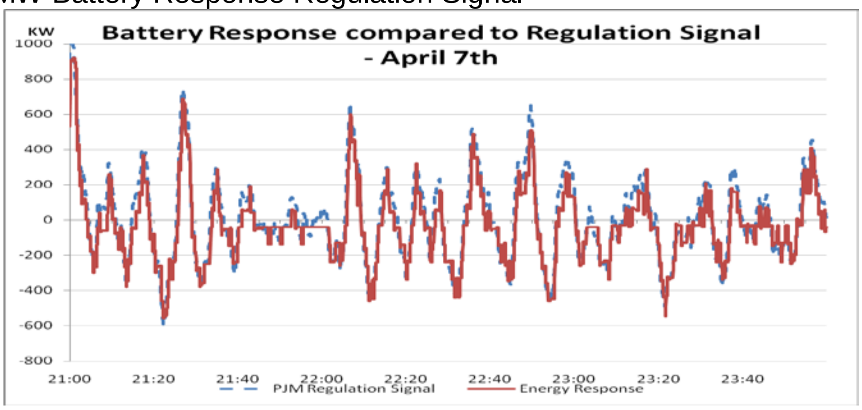
A look to the future shows many financial opportunities as well as technical challenges. The trend of consumer flexibility will continue to grow and will expand to the energy market. The

US government has made billions of dollars available via the Recovery Act of 2009[2] to fund smart grid programs and initiatives to create jobs and drive innovation in these areas. A number of states and utilities are pursuing demand-response based on dynamic and time-differentiated retail prices and encouraging utility investments in Advanced Metering Infrastructure (AMI), often as part of Smart Grid initiatives. These developments could produce large amounts of Price Responsive Demand, demand that predictably responds to changes in wholesale prices. Through enabling technology and behavioral changes, consumers would modify their demand as prices change without either being centrally dispatched or bidding demand reductions into formal energy markets. To harness this flexibility, some percentage of retail rates must be linked to real-time wholesale prices. The resulting flexibility in response to price will enable grid operators to manage load generation balance more efficiently and will replace some of the reduced generation flexibility. The electrification of personal and public transportation through electric or plug-in hybrid vehicles will likely stimulate the growth of time-differentiated retail rates in order to prevent cost-shifts to other consumers.

4. EVOLUTION OF ALTERNATIVE RESOURCES

Alternative resource technologies such as large-scale battery projects are beginning to penetrate into the electricity industry and have demonstrated the capability for a nearly instantaneous response to a control signal sent by a grid operator. Current installations have a limited duration with which they can sustain a response but they are capable of following extremely rapid and volatile control signals. Figure 3 illustrates the response of a 1 MW Lithium-ion nano titanate battery installation that has been participating in the PJM regulation market for 2 years. The resource has proven its capability to respond much more quickly and accurately to frequency regulation signals than conventional regulating resources. Although the resource has 15 minute limit on delivering at full capacity, PJM experience indicates that such resources can follow specially designed fast regulation signals for an extended period of time. The battery technology appears to be commercially viable. Such a battery installation can earn up to $800 per MW per day in the regulation market. At current technology level the installed cost of a 20 MW installation is $22 Million ($1100/kW), assuming a $16,000 per day revenue, the breakeven point on the investment is under 4 years. Given these economies, the PJM region is expecting growth in this technology and future projections indicate expanded growth rates as technology costs decrease. Although these resources are currently used as for frequency regulation service in the US, with some innovative designs they may also be capable of providing a surrogate governor response.

Figure 3 – 1 MW Battery Response Regulation Signal -



5. EVOLUTION OF GRID AND MARKET OPERATIONS

[22] American Recovery and Reinvestment Act of 2009 (javascript: setLink('http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h1enr.pdf', 'ARRA Full Bill');

As explained above, significant and unprecedented trends are driving the evolution of supply and demand in the electric power industry in the United States. However, power system operating fundamentals of maintaining reliable grid operations, maintaining adequate reserve margins and operating based on a minimizing overall cost through markets and economic dispatch will likely continue to be the focus. The fundamental trends which are reducing supply side flexibility and driving the resource mix to reduce reliance on coal-fired capacity and maintain but not expand nuclear will require alternative resource development which will likely increase electricity prices. The growth of renewable, natural gas-fired and alternative resources does not appear to be capable of replacing all of the functionality of current resource mix without increasing costs substantially. Additionally, grid services, such as such as blackstart, frequency response and voltage control, that to some extent are implicitly supplied by the conventional generation resources of today, may need to be secured in a more comprehensive manner in the future.

These increases in cost, combined with smart grid technology and innovation in retail rate design will drive electric demand to be more flexible and to respond to price and environmental signals to enhance reliable grid operation and potentially replace some of the operational flexibility lost on the supply side. As a result the demand side of the power balance equation will incur the largest state change. Some amount of the relatively inelastic demand we have today will likely be replaced by Price Responsive Demand (PRD). The PRD will add an additional degree 'load-following' capability in power system operations.

Future grid operations will likely require changes in the amounts of grid services such as frequency regulation, 10-minute synchronized reserve, 30-minute operating reserve, blackstart, frequency response and voltage control. Such a trend will increase value of these products creating more opportunity for development in alternative technologies to supply these products. Forward market development may need to be augmented to include commitments and incentives for resources that can provide these services to ensure adequacy.

As grid operations become more dependent on advanced technology development, the real-time nodal price-based balancing market can be expected to expand across the US. Locational Marginal Pricing (LMP) will continue to drive appropriate locational incentives and market clearing prices to accurately value energy and promote system reliability. The main change to the energy market from today's model is the price variability of demand and consequently its ability to determine market clearing prices. Currently in the US, LMPs are often derived by the market-based offers of supply resources because demand resources are often not flexible enough to curtail in response to price. However, over the next 20 years it is anticipated that the installations of advanced metering, development of dynamic retail rates and more flexible devices such as air conditioners, chillers, etc., will lead to the widespread acceptance and deployment of price responsive demand. While this adds another level of complexity to energy market modeling, it will likely have a moderating effect on energy market price volatility due to the quick ability to respond to perturbations in LMP. In fact, it is anticipated that PRD will become sufficiently widespread by 2030 that demand's willingness to pay will likely be a primary driver of market clearing prices. This is a paradigm shift from today's model where supply costs determine market clearing prices and demand is largely unresponsive.

For supply resources, the change between the LMP markets of today and those of 2030 will not be significant but for the fact that price responsive demand will likely be on the margin a significant amount of the time. For resources that are inflexible like nuclear, solar, and other green technologies, the tendency will be to hedge against real-time market volatility by either locking into long-term contracts or through the day ahead energy market. Intermediate resources like hydro and natural-gas combined-cycle resources will have the incentive to respond to price spreads between the Day Ahead and Real Time energy markets much like they do today. It is likely that when demand is not setting LMP in the energy market the next most likely marginal resources will be natural-gas combined-cycles and combustion turbines. The extremely flexible resources like battery storage and thermal storage will be able to maximize their value in both the energy and ancillary service markets. Their capability to move quickly and respond to control signals accurately will allow them to take advantage of peaks and troughs in the Real Time LMP and make them ideal ancillary service providers.

Ancillary Service markets will expand and play a critical role in securing future grid operations. The trends discussed in this paper indicate that faster response resources can be available to provide grid services. This trend will drive the development of real-time ancillary markets for more grid services. Additionally, the need to hedge increasing ancillary services costs could drive development of forward markets for such grid services which would further drive investment in the following technologies.

- Frequency Response: The innate ability to respond without outside controls to changes in system frequency. Resources are typically not compensated for this in the US.
- Regulation: Used for second-to-second fine control of the power system. Managed via control signals from a system operator roughly every 2-4 seconds.
- Spinning Reserve: The capability of synchronized responsive resources that can be achieved in 10 minutes.
- Non-Spinning Reserve: The capability of off-line resources that can be started within 10 minutes.

Frequency responsiveness and regulation will likely be the two ancillary services in the highest growth in quantity requirement in the future. This will be driven by replacement of conventional resources with what will largely be inertialess resources like solar and wind that are not adept at following a control signal. As the need for these services increase, the prices will also rise.

6. CONCLUSIONS

In 2030, the widespread deployment of the aforementioned advanced technologies has the potential to offset reductions in flexibility of supply side resources which should enable continued development of a more flexible and reliable power system. System operators will have the flexibility to deploy distributed resources, storage technologies and controlled demand response virtually instantaneously in response to market prices. This flexibility will allow innovative grid assets to respond to and capitalize on real-time energy market prices. The ability take advantage of real-time market volatility will provide a physical risk hedge for consumers which will help manage volatility in forward contract prices. Forward contracting is projected to emerge as primary investment signal for technology deployment and real-time spot markets will drive forward contract prices. The general formulation of the LMP-based markets that exist in the US today will efficiently clear the market but will likely need rule augmentations to allow demand's willingness to respond market clearing prices or to environmental signals. Today's economic dispatch algorithms will also treat demand as price-elastic whereas today demand is often model largely as being inelastic.

An operational impact of the shift in resource types from today's conventional resources to newer technologies will be the continued decline in system inertia and primary reserves (governor response). As a result, markets will likely be initiated and or altered in the US to create incentives for both the interconnection of alternative technology resources with the ability to provide this product and the additional incentives for providing it.

In summary, the drivers behind market evolution between now and 2030 will likely be the advancement of technology and how it shapes the operation of the power grid. Markets will be designed around the capabilities of these new devices and the new market needs created by the large-scale deployment of those devices.