

Load-Side Grid Management: Power Monitoring and Load Control Automation

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ABSTRACT

Load-Side Grid Management is enabled and made practical because of advancing technologies and today's supportive regulatory climate. Load-side controls are helping provide an avenue toward a grid that uses responsive load reductions as a means of managing load fluctuations, supporting ancillary services and fulfilling capacity requirements. This paper highlights the favorable regulatory climate and technologies that facilitate this load control and could support a market transformation toward Load-Side Grid Management. Grid-to-load metrics will demonstrate the inherent relationship between individual loads and the grid characteristics that need to be managed.

This paper also highlights the implementation dynamics of a load management approach that automates demand reduction, utilizes power monitoring and facilitates remote demand response dispatch capabilities. Valuable synergies can be achieved from an implementation approach that utilizes advanced information and communication technologies for monitoring and automating Load-Side Grid Management. The framework for the technologies is maturing, and includes wireless communications (including mobile phone apps), cloud based Demand Response Automation Server (DRAS) protocols and Demand Response Management System (DRMS) control interfaces.

Loads that are variable, have storage characteristics or are associated with distributed generation are those most viable for responsive and effective load control techniques. The ability to deploy and control responsive load is essential for the successful adoption of Load-Side Grid Management.

Introduction

The prospect of a merger between traditional distribution system management controls and the control of end-user loads on those distribution systems is closer to being realized than ever before. Developments in technology, regulatory policies and market forces are creating an environment that is driving change. Distribution system management issues have traditionally included peak load, voltage regulation and power factor correction. However, overvoltage conditions can exist when penetration of photovoltaic supply is high. This condition is most prevalent when photovoltaic output is at its peak and is also becoming a system management issue. Prices for photovoltaic units and, to a lesser degree, battery storage and smart inverters are dropping to levels that are causing accelerated adoption. Maloney (2015) indicates that lithium-ion battery prices for utility scale units fell 53% percent over the period 2012 to 2015; by 2019 prices are predicted to drop another 50%.

Photovoltaic units paired with battery storage and smart inverters can also be used to mitigate the adverse impacts of the photovoltaic power and provide ancillary services to support grid management. Battery storage, photovoltaic units and responsive load control are the technologies that enable Load-Side Grid Management capabilities. Ideally, control logic used to

operate these technologies, in harmony with the grid, require input signals that represent feeder and substation electrical conditions as well as real-time wholesale electric energy prices.

The acknowledgement of responsive demand integral to Federal Energy Regulatory Commission (FERC) Order 745 (Moeller 2011) provided a regulatory framework for the role of responsive demand for balancing supply and demand in energy markets. Over the years there has been opposition to several aspects of FERC's Order 745. However, the question of jurisdiction over demand side resources was settled in favor of FERC by the Supreme Court in 2016. This regulatory framework is now a matter of law. The U.S. Department of Energy (DOE) is sponsoring research into architecture that envisions a more active role at the distribution level, with electric distribution companies operating as Distribution System Operators (DSOs) (Taft 2015). This DSO Model envisions a role as facilitator of two-way power flows and enabler of prosumers by settling end-users' energy and power transactions. Metering of distribution system feeder conditions is essential to optimizing Load-Side Grid Management but, is not generally supported by regulation.

A change from traditional grid management approaches to Load-Side Grid Management would be a significant disruption for electric distribution companies. This disruption would impact not only operations but, also financial structure. As the electric industry moves forward there are several important considerations. It is critical that business executives and regulators take the appropriate steps to ensure that alternate approaches to grid management are; 1) adopting in a cost effective manner, 2) providing system benefits to end-users and 3) maintaining the financial health of electric distribution companies.

System Balancing and Ancillary Electrical Characteristics

Grid Management is the balancing of electric supply with the inherently fluctuating demand for electric power and the nominal operation of ancillary electrical characteristics (voltage, power factor and frequency). Traditional Grid Management relies on large wholesale generators and smaller quick starting generators at the transmission and substation levels. Distribution level controls utilize voltage regulators and capacitors. Load-Side Grid Management controls utilize distributed generation, energy storage and responsive demand.

System balancing and management of ancillary electrical characteristics are traditionally shared by the electric distribution company (EDC) and the system operators (ISOs and RTOs). Overall balancing is handled by the system operators through scheduling and dispatch of large generators. Operating reserves and peak load operations are also controlled by the system operators. EDCs manage substation capacity as well as power factor and voltage on the feeders. The equipment used for this management tends to have coarse control with limitations due to the static nature of their fixed location and fixed peak capacity.

Load-Side Opportunities and Alternative Approaches

The dynamic nature of electric power systems has historically been limited to daily ramping as activity rapidly increases in the morning, with a peaking period later in the day, and the inevitable steep reduction in demand as daily activity ends. Today we are seeing new

influences on system dynamics and new opportunities to manage these dynamics. High penetrations of photovoltaic units have introduced new challenges such as the Duck Curve load profile (Denholm, Connell and Brinkman 2015) with its negative reliance on a rapid switch to traditional generation as the sun moves to west, and an over generation condition when output is at its peak. However these issues are offset by the renewable nature of this asset and its help with peak load.

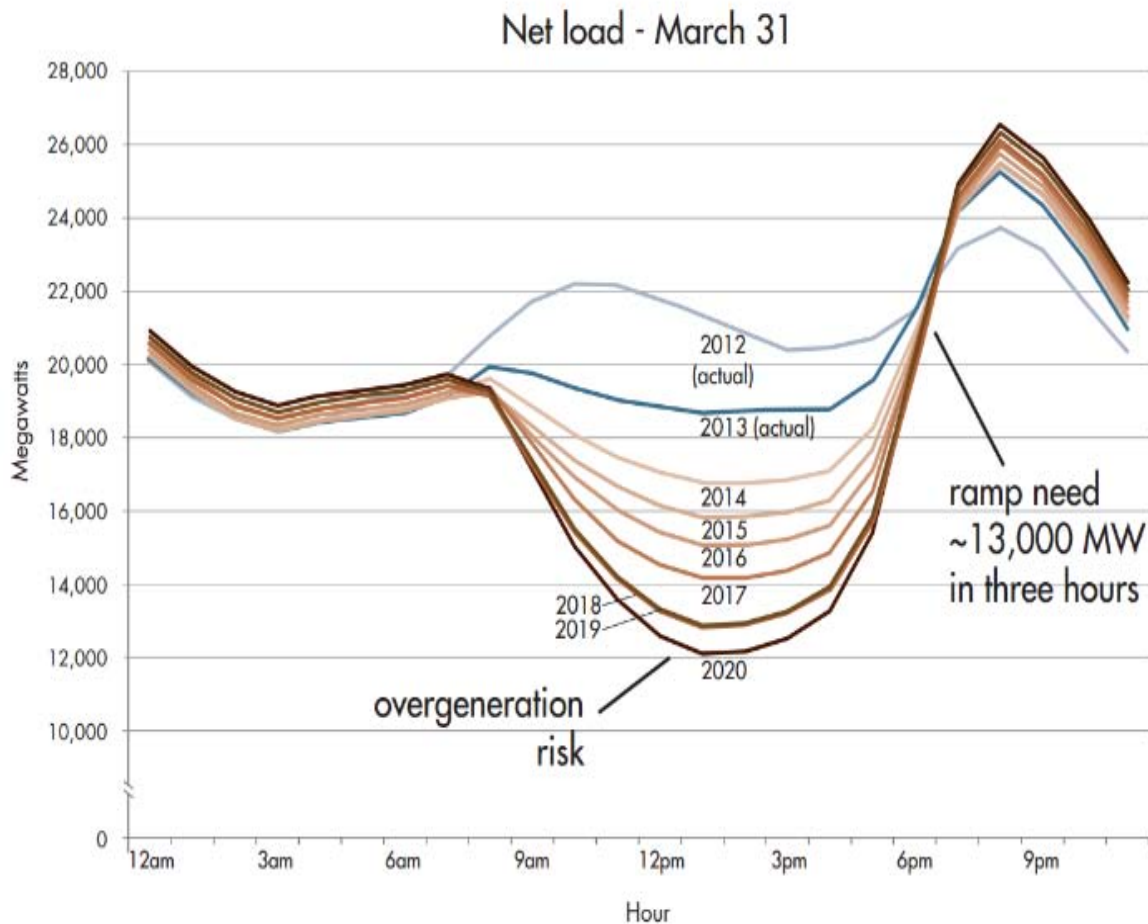


Figure 1. The CAISO "Duck Curve" *Source: CAISO 2013.*
https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Also, Smart (Advanced Feature) DC to AC inverters used in conjunction with photovoltaic units (Schauder 2014) are capable of providing voltage and power factor support. Storage is well suited for use as a mitigation tool, with its flexibility to charge when photovoltaic power is abundant relative to load and discharge at times of steep demand ramp up. Storage pricing continues to fall but, cost is still a barrier to broader adoption.

This dynamic nature of the electric power system is inherently the driver of system balancing and management issues and is an unavoidable characteristic of how we use electric power. However, with technologies and policies designed to facilitate demand responsiveness, it is becoming a natural place to look for efficiency improvements. Photovoltaic units, storage and

a keen understanding of electric equipment operation, coupled with, controls software and demand response strategies are the keys to exploiting Load-Side Grid Management opportunities.

Electric Utility Paradigm Shift and Disruptive Forces

Today's energy climate is one where energy efficiency programs are achieving higher levels of penetration and energy efficiency technologies more rapidly moving to mature commercialization. In this climate, controls and operational issues are becoming the new frontier for incremental system efficiencies and operational cost reductions (Talon 2016). As with traditional energy efficiency these new solutions are associated with the customer side of the meter. As discussed above, the dynamic way we use electricity is an inefficiency to the system. *The load, with its demand for electric power and its natural volatile nature is the source of the system balancing and management issues. It seems natural but, not intuitive to look at load for mitigation of these system balancing and management issues.*

Grid management issues can be thought of in two categories, 1) issues associated with seasonal peak load profiles (including emergency conditions with capacity loss) and 2) issues associated with daily load (ramping and real time fluctuations).

Load-Side Opportunities associated with seasonal peak load

System Peak Load issues are typically a seasonal occurrence, even when winter data is removed from the analysis, summer only load duration curves can yield low load factors. This is a metric indicating that electric power usage is dynamic. Looking to load for solutions led to a hypothesis that individual end-user's load duration curve characteristics (Fig. 3) correlate with system load duration curve characteristics. It would follow that controlling the load duration curves of individual users would have a position impact on the system peak (Mehta 2005). The impact would depend on the degree of coincidence between the individual end-user peaks and the system peak. This degree of coincidence is measured as a diversity factor. A diversity factor of 1.0 represents exact coincidence and a diversity factor of 0.0 represents no coincidence.

Peak Load Factors charts and Load Duration Curves illustrate variation of load. For example, the ISO-NE Summer Peak Load Factor (Fig. 2) has decreased from 0.64 in 1993 to 0.56 in 2014. Load factor is a quotient; (energy used over the time period) divided by (the peak load, multiplied by, the time period duration). Peak load is growing disproportionate to energy use, thus driving the peak load factor lower.

Identifying the sources of these seasonal peaks and determining their level of coincidence with the system peak are the essential first steps of adopting responsive load controls. Utilizing load-side technologies to manage the individual end-use sources of peak load, coincident with system peak, is the final step of enabling seasonal peak load controls.

Figure 2 is the resultant plot of ISO-NE's Summer Peak Load Factor Analysis covering the years 1991 to 2013 with actual data, and years 2014-2023 with predicted data. Reducing

seasonal peak load through Load-Side Grid Management techniques increases system load factor and system efficiency. The primary system efficiency gain is associated with a reduced installed capacity requirement.

ISO-NE 50/50 Summer Peak Load Factor Analysis WeatherNormal 1991-2013 2014CELT 2014-2023

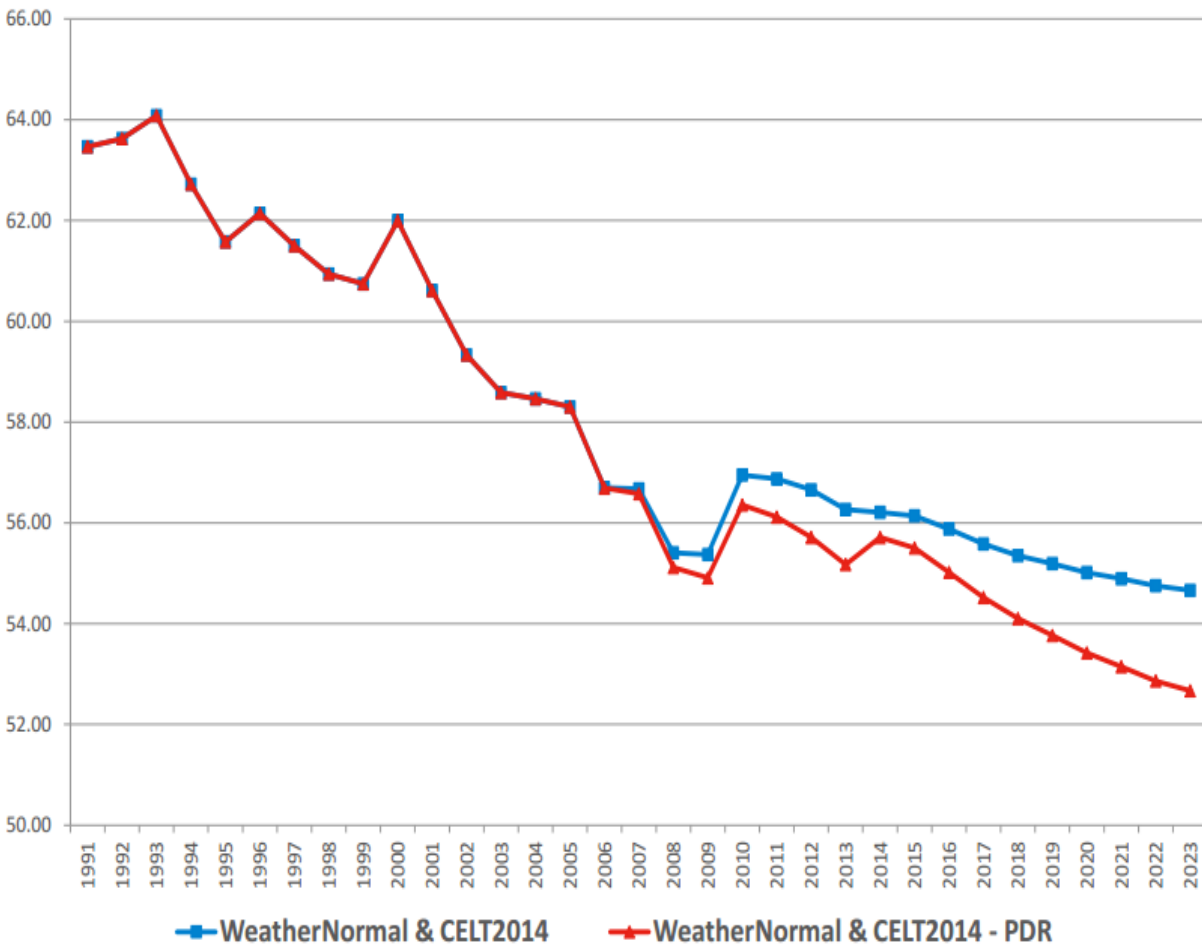


Figure 2. ISO-NE Summer Peak Load Factor Analysis. *Source:* ISO New England 2014. http://www.iso-ne.com/trans/celt/fsct_detail/2014/pac_19feb2014_prelim_iso_energy_peak_forecast.pdf

The Load Duration Curve plots demand over a given time period as a percentage of occurrence. Visually, two important parameters can be derived from the load duration chart illustrated in Figure 3. The load factor equates to about 0.18 [$50(\text{area under the curve})/275(\text{Peak Load}) = 0.18$] and 64% of the demand only occurs for 4% of the time ($175/275 = 0.64$). Operations that occur on the more vertical portion are associated with non-base loads or variable-load equipment operating at higher than normal capacity. Control of this equipment or operation of distributed generation during these load spikes will have the biggest impact on feeder and

system peak loads. Metering and information on system electric conditions, at the feeder and substation level would aid the control decisions needed to respond coincidentally with system needs.

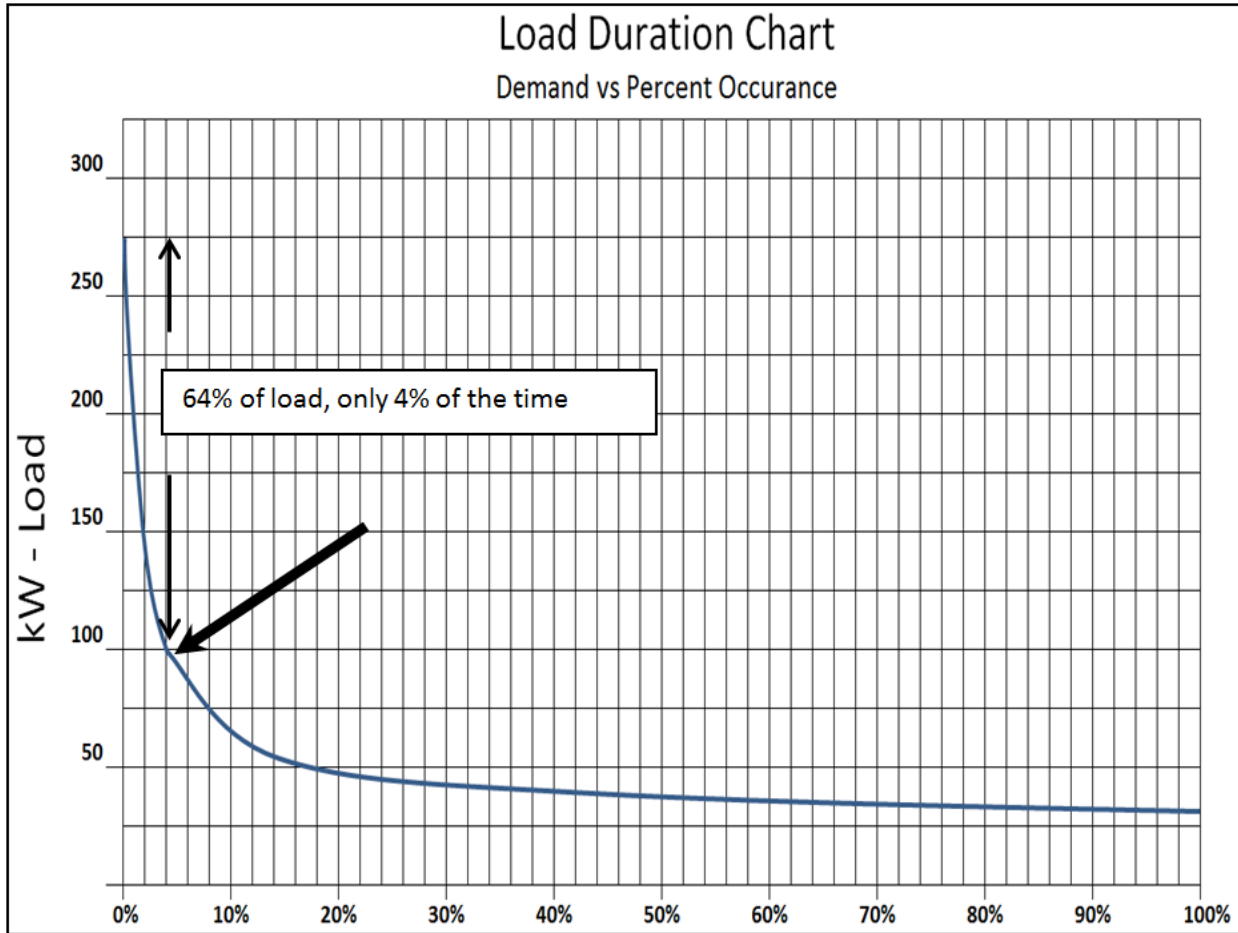


Figure 3. Hypothetical Load Duration Curve. *Source:* Dobratz 2016.

Load Curtailment used for emergencies. Actions by end-users that result in emergency load reductions could also be thought of as traditional demand response. If load is high at the time of these conditions, techniques used for seasonal peak load control can also be used for this purpose. Emergencies at times of low load require more disruptive interventions.

Load-Side Opportunities associated with Daily Load

Unlike the seasonal peak and emergency balancing and management issues, the issues associated with daily load are more dynamic. Grid-Management issues associated with daily loads typically include ramping, load matching, price spikes, nominal operation of ancillary characteristics and mitigation of impacts from distributed generation like photovoltaic units.

Feeder monitoring, advanced information/communication technologies and automation controls driven by optimization algorithms are technologies require daily level control. These technologies allow for the operation and coordination of photovoltaic units, battery storage, smart inverters and rapid demand responsiveness strategies. With these technologies daily loads can be balanced and used to address grid management issues at their source (load on the customer side of the meter). A conceptualization of monitored values and control actions are highlighted in Table 1 below.

Table 1. Monitored Values and Control Actions. *Source:* Dobratz 2016

Monitor Point	Parameters Monitored	Controls
Feeder Meter	<ul style="list-style-type: none"> • Volts • PF • kW Static • kW Change Rate 	PV energy to load or storage?
Facility Meter	<ul style="list-style-type: none"> • Volts • PF 	Discharge Storage?
End-Use Equipment	<ul style="list-style-type: none"> • Loading level • Load Reduction Availability 	Inverter Operations: <ul style="list-style-type: none"> - Voltage output - VAR output
Solar PV	PV output - kW	
Battery Storage	Storage output - kW Storage charge - kWh State of Charge - kWh	Demand Response Dispatch
ISO	Peak Load Conditions Actual Load vs Forecast Reserve margin Wholesale price	

Disruptive Forces are challenging the traditional electric utility business model

The primary disruptive challenges facing electric distribution companies include a climate of flat or declining load growth, end-use efficiency and growing adoption of Distributed Energy Resources (DER), like photovoltaic units and other types of DERs (Kind, 2013). The disruptive forces are a concern from a financial stability perspective. If load grows, electric distribution companies grow by acquiring new assets which allow them a higher return on top of covering the cost to provide the electric service. Without load growth they cannot grow using their traditional business model. Disruption and loss of business to new entrants is not a new occurrence for large industries and their dominant leaders. With lower cost alternatives and less load to cover infrastructure assets, utilities rates will increase. This tends to further encourage the adoption of efficiency and DERs leaving less load to serve, leading to more rate increases. This set of circumstances is the Vicious Cycle from Disruptive Forces (Fig. 4).

Vicious Cycle from Disruptive Forces

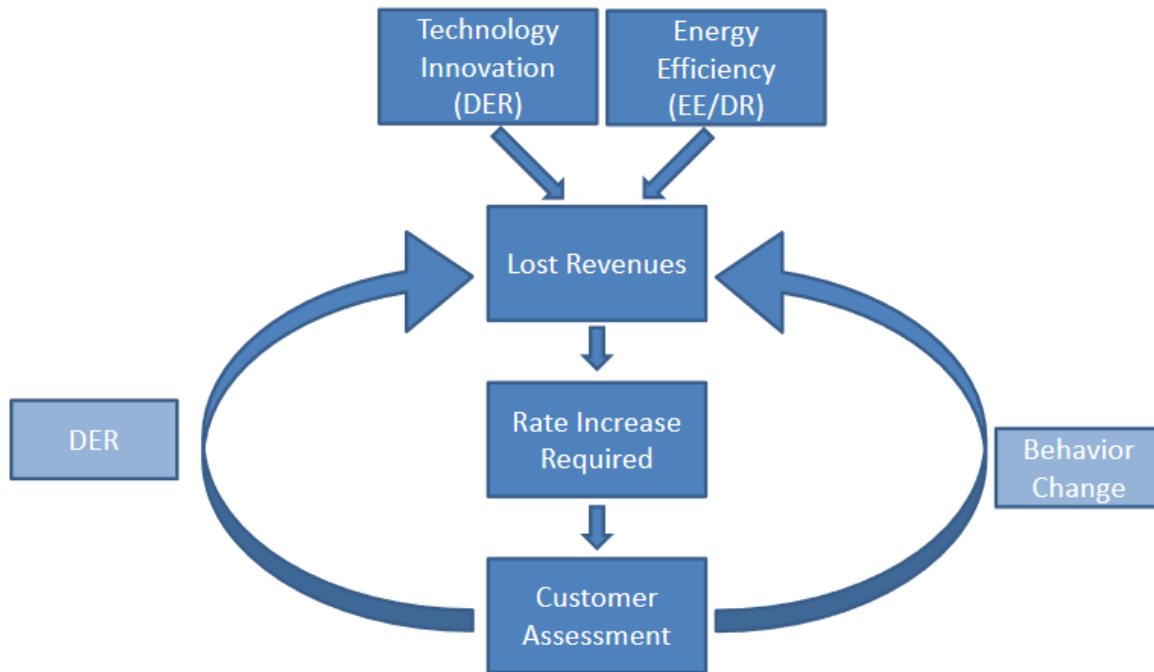


Figure 4. Vicious Cycle from Disruptive Forces. *Source:* (Kind, 2013).
<http://www.eei.org/ourissues/finance/Documents/disruptivechallenges.pdf>

If revenue declines, credit ratings can be negatively impacted. As credit tightens it becomes harder to invest in the technologies and the process changes needed to adjust to the disruptive forces. Another possible impact is loss of shareholder interest and a resulting reduction in market capitalization.

Conclusions

Load-Side Grid Management is not only viable but, if the technologies continue to advance and policies continue to be supportive, it has the potential to disrupt the companies that are currently distributing electricity and will necessitate a business model change. Movement toward Load-Side Grid Management requires adopting a load-centric view that envisions system balancing and management solutions generated from the end-users, because end-users are the source of the issues. This load-side management concept is not new; however, the technologies available today are able to handle intraday issues where traditional load-side management approaches could only operate at a macro level with equipment efficiency upgrades and load matching controls.

Policies and regulations are encouraging these activities but, barriers remain. Costs for battery storage are still dropping but, currently are still cost challenging. Further cost reductions for battery storage is critical. Access to monitoring of feeder electrical characteristics, for use as building control input signals, is potentially a significant barrier.

With the upholding of FERC Order 745, FERC's jurisdiction over demand resources and how they are compensated in organized capacity and energy markets has been confirmed. FERC's continued guidance is critical for determining how advanced and dynamic load side assets can be best utilized and compensated for as market resources. Opportunities associated with a load centric view are centered around facilitating the semi-autonomous operation of building systems and feeders in a concerted fashion. This approach is technically feasible and costs are falling. As the use of photovoltaic units and other distributed energy resources continue to grow, mitigation at the source has the potential to reduce costs when compared with traditional solutions (Sims 2007).

Summary

Technology advances, regulatory policies and the adoption of DERs is driving electric industry change. This change is associated with acknowledging the potential for developing the responsive nature of demand. This responsive ability can impact installed capacity requirements, mitigate energy price spikes and help mitigate the negative impact of distributed generation.

To fully appreciate the potential of Load-Side Grid Management, a load centric view is essential. This envisions system balancing and management solutions generated from end-users, because end-users are the source of the issues. With a load centric view it seems natural but, not intuitive to look at load for mitigation of these system balancing and management issues.

In spite of the potential benefits associated Load-Side Grid Management, it is not without its barriers to adoption. Barriers include:

- Access to real-time metered electrical characteristics at the feeder level
- A more developed framework for distribution system operations that include distributed generation, responsive demand and other DERs.
- FERC guidance on the status of electric distribution companies and measures to mitigate the negative impact of the disruptive forces associated with adopting Load-Side Grid Management technologies

The disruption of electric distribution companies is an important concern associated with the adoption of Load-Side Grid Management approaches. There are other disruptive forces impacting electric utilities; including flat or declining load growth, end-use efficiency and growing adoption of distributed generation (like photovoltaic units and other types of DERs). This disruption would not only change operations but, it could also impact financial stability as the return-on-assets based business model weakens. At its worst, this disruption could further reduce load growth and increase rates. This worst case scenario feeds upon itself with sustained load growth reductions, rate increases and increased adoption of energy efficiency and DERs.

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