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Utilizing Load Response for Wind and Solar Integration and Power System Reliability

Michael Milligan and Brendan Kirby

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Utilizing Load Response for Wind and Solar Integration and Power System Reliability

Brendan Kirby
National Renewable Energy Laboratory
Consultant
2307 Laurel Lake Rd
Knoxville, TN 37932
kirbybj@ieee.org

Michael Milligan
National Renewable Energy Laboratory
1617 Cole Blvd., Golden, CO 80401
michael.milligan@nrel.gov

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Abstract

Responsive load is still the most underutilized reliability resource in North America. It has the potential to provide balancing capability over all time frames: from seconds to seasons. Responsive load could significantly aid in the integration of variable generation sources like wind and solar if institutional frameworks can be developed that will induce loads to respond to price or other signals. This paper examines the balancing requirements imposed by large penetrations of wind generation and characterizes them in terms that are relevant for load response. The relative magnitude, frequency, and duration of events are all important, as are ramp rates and notification times. Responsive loads and generation may interact synergistically to provide better overall response. The statistical behavior of large aggregations of small loads may work well with wind and solar integration. Very large penetrations of wind generation create light load reliability concerns for the power system. These reliability concerns may be economic opportunities for a number of loads that are dependent on low cost energy but which are also flexible in their use. We discuss response potential in the short-run, given a fixed level of resources, and in the long-run where the resource mix can change. Before building or otherwise acquiring new resources, entities (either load or generation) must be assured of a reasonable level of price stability and energy availability. This paper examines the characteristics of concern to the power system, the renewables, and to the loads. The roles of local and regional transmission in facilitating load response are examined.

Introduction

Wind and solar generation add variability and uncertainty to the power system. These are not new characteristics; load itself is variable and uncertain. Sudden unplanned failures make conventional generation variable and uncertain. Wind and solar simply increase the variability and uncertainty of the aggregate power system. The power system deals with uncertainty and variability by having a series of reserves available to respond. The reserves are characterized by their response speed, response magnitude, response frequency, and response duration. Some are dedicated ancillary services, explicitly designed and procured to address a narrow aspect of variability and uncertainty. Others are a characteristic of how energy is scheduled in real-time. All of these efforts deal with controlling the balance of generation and consumption of real power. Historically, this control has concentrated on the generation side, but that is not necessary. Control of energy consumption can be equally effective and often more economic than control of energy supply.

Historic demand response programs have focused on reducing overall electricity consumption by increasing economic efficiency via price-response mechanisms, and by shaving peaks. More recently, responsive loads have started to provide contingency reserves and even minute-to-minute regulation. Rather than reducing overall power system stress by reducing peak loading over multiple hours, these programs are targeted to immediately respond to specific reliability events. This is made possible by advances in communications and controls, and has benefits for the power system and the load. Many of these programs have been successful but demand response remains a limited resource.

As wind and solar increase power system variability and uncertainty, they increase the need for response. Since wind and solar also displace conventional generation, they can reduce the amount of generation that is available to provide response. Demand response may be able to fill this gap, benefiting renewables by facilitating integration, the responsive load through paid services, and all customers through lower costs. Existing ancillary services and reserves specifically designed to respond to large, infrequent ramps which are slower than conventional contingencies are important. The renewables community should support efforts by FERC and others to increase opportunities for demand to provide response to the power system.

Response Requirements

Wind and solar generation are variable and uncertain in all time frames, but wind ramps tend to be slower than load ramps.[1] Figure 1 shows the annual hourly aggregate load and wind for the Northwest balancing areas for 2006 with enough wind generation added to meet 16% of the annual energy requirement (12,026 MW of wind in a 38,952-MW peak load region), while Figure 2 shows one week in January. The seasonal and daily load pattern is apparent as is the slower but less predictable wind variability. Figure 3 presents the hourly energy duration. The net load (load less wind) is naturally lower than the load alone, but the duration curve also has a more pronounced "S" shape with a shorter peak and a sharper minimum. Meeting the net load will require more flexibility than serving the load alone.

The changed load duration shape itself presents an increased opportunity for demand response. There is greater value in reducing load during the super peak because the capital cost of generation designed to serve those last few hours has fewer hours over which to be spread the cost. For example, the highest 4000 MW of demand (roughly 10%) lasts 124 hours for the load alone, and only 66 hours for the load-net-wind. The hourly capital cost of a combustion turbine dedicated to

[1] Both wind and solar generation (excepting of solar thermal with storage) are variable and uncertain. Significantly more wind data and experience is available, however, so this section will concentrate on wind response requirements. However, some of this discussion will also apply to solar, and can be re-visited once more solar data is available for analysis.

supplying those last hours would rise from $605/MWh to $1136/MWh, likely making additional demand response more attractive.

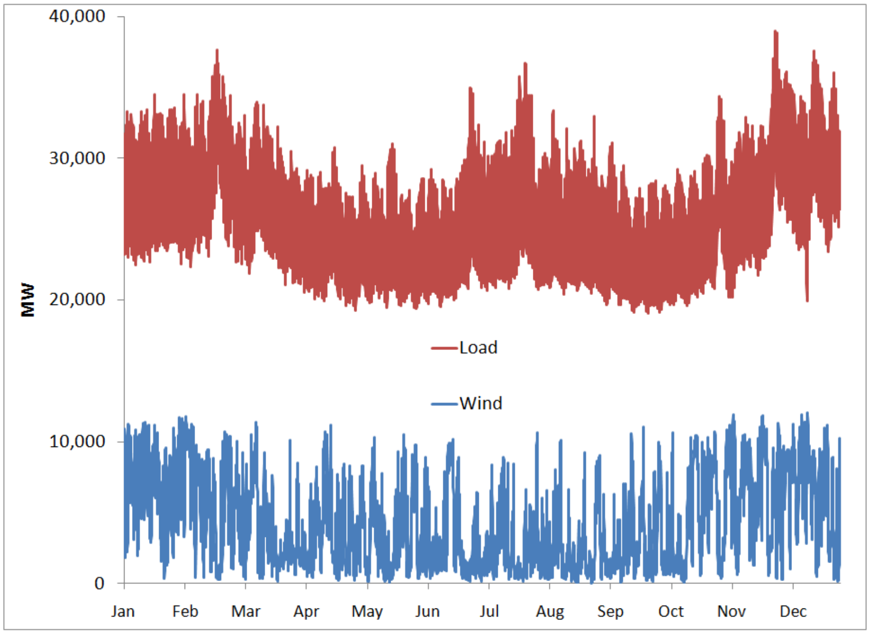

Figure 1 − Load and wind are both variable on time scales ranging from minutes to seasons.

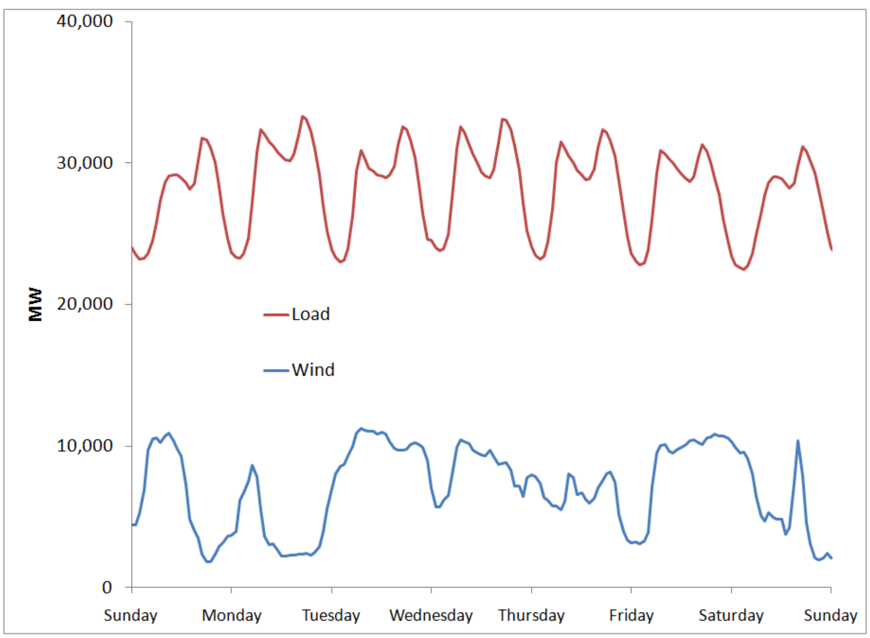

Figure 2 − The slower, less predictable nature of wind is evident when compared with the typically daily load pattern.

Figure 3 also shows that wind typically reduces the system minimum net load. This can create a problem for baseload generation that is unable to back down. Either wind must be spilled or baseload generation must be decommitted when net load is below the minimum load capability of the conventional generation fleet. Decommitting baseload generation may have adverse impacts on the optimal generation mix for the following day. The ability to spill wind addresses the reliability concern but it leaves the economic problem of wasting free energy and loosing environmental credits. As will be discussed later, the minimum load "problem" may be a real opportunity for the appropriate type of responsive load.

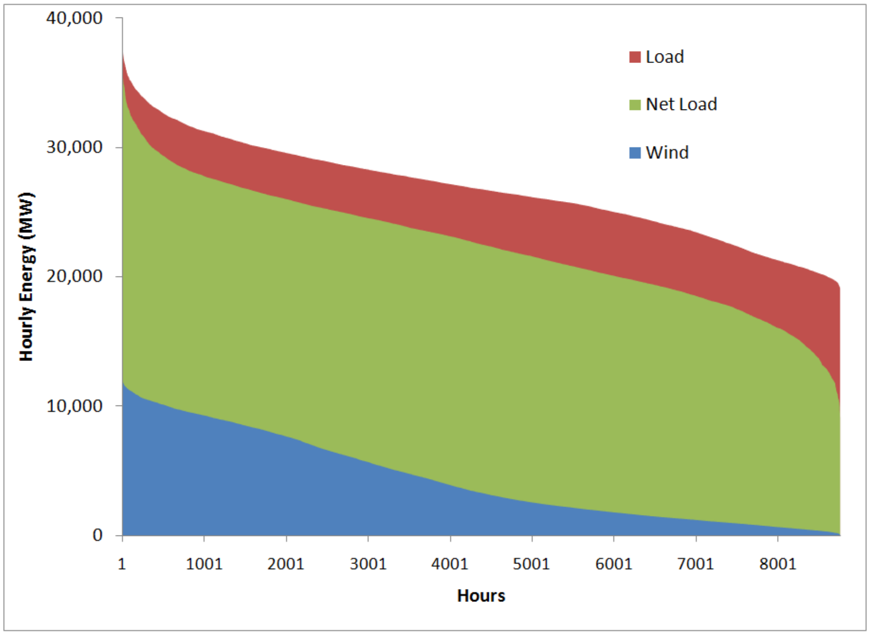

Figure 3 − Adding wind accentuates the "peaky" nature of the load duration curve.

Wind also impacts the system ramping requirements. Figure 4 shows the annual 1-hour ramp duration curve for load, wind, and load-net-wind. For most of the hours, the load ramping requirement exceeds the wind ramping requirement and the net ramping requirement is not greatly increased. Wind ramping differs from load ramping in three important ways, however. First, wind is less predictable than load. The daily load ramping pattern is clear in Figure 2, while a wind pattern is not. Second, the wind ramp duration curve in Figure 4 has a clearer "S" pattern than load; there are a few hours with significantly higher wind ramping requirements in both the up and down directions. Third, wind and load ramping patterns are not symmetric. This last point is made clearer in Figure 5 where the highest 50 hours are shown. Both Figures 4 and 5 are referenced to load and net load so negative numbers actually represent wind increases.

The "peaky" nature of the wind ramp duration curve says that there are few large ramps. This makes wind ramps similar to conventional generation and transmission contingencies: large, infrequent events that can threaten reliability. The relatively infrequent nature of the large wind ramps also suggests that, like conventional contingencies, reserves should focus on standby costs rather than on response costs.

The lack of symmetry in the wind ramp duration curve is important as well. Load increases (and wind decreases) are a reliability concern. If there is insufficient conventional generation or voluntary demand response, the power system is in serious trouble. Load drops (and wind increases) are less of a reliability concern. If other more expensive generation physically can not back down, then properly equipped wind plants can be curtailed to maintain the load/generation balance. The wind up ramps (and load down ramps) can be a serious economic concern, as well as an opportunity for responsive load, but typically not a reliability concern. The lack of symmetry is shown in Figure 5 where there are five hours when the one-hour wind down-ramp rate exceeds the maximum load up-ramp rate. There are 78 hours, however, when the one-hour wind up-ramp rate exceeds the maximum load down-ramp rate. The maximum one-hour load up-ramp rate is 1200 MW/hr greater than the maximum load down-ramp rate, while the maximum wind up-ramp (equivalent of load down-ramp) exceeds the maximum wind down-ramp by 612 MW/hr. Unfortunately, load ramps harder in the up direction. Fortunately, wind ramps harder in the down direction.

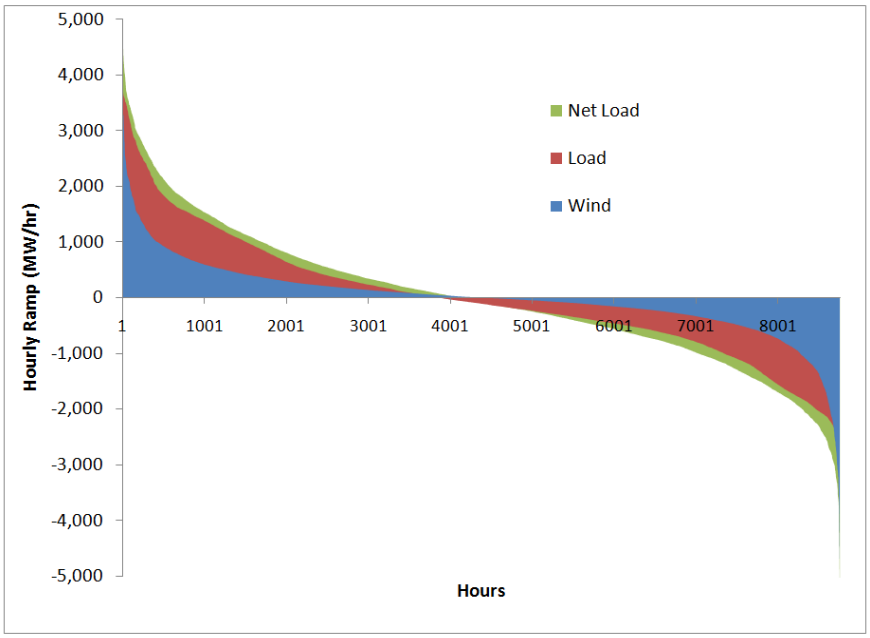

Figure 4 − Large wind ramps are relatively infrequent while load ramps are more evenly distributed.

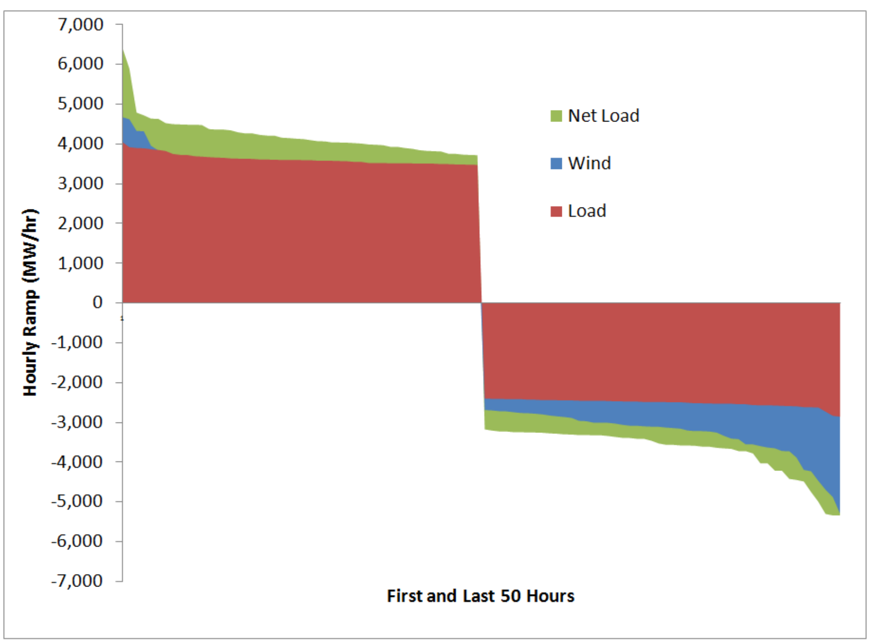

Figure 5 − The non-symmetric nature of large wind ramps is evident from the first and last 50 hours of the ramp duration curve.

Figure 6 extends the analysis to look at ramping requirements over a range of ramp durations from 10 minutes to 12 hours. The curves show the maximum daily MW ramping capability required for ramps of different durations. For example, the maximum daily 12-hour load up-ramp is 6757 MW 50% of the time. These capacity numbers are not completely definitive, of course, since a one-hour ramp may be followed by another one-hour ramp; shorter ramps are often parts of longer ramps. Still, the curves provide insight into the amount of ramping that is required over different time frames. As above, the wind ramps in Figure 6 are referenced to the load ramps for ease of comparison (+ for both the load ramps and the wind ramps is movement in the direction of increasing net load). This analysis confirms that large wind ramps of any duration, but especially for ramps lasting 4 hours or less, are less frequent than load ramps. Large wind ramps are again more like contingencies.

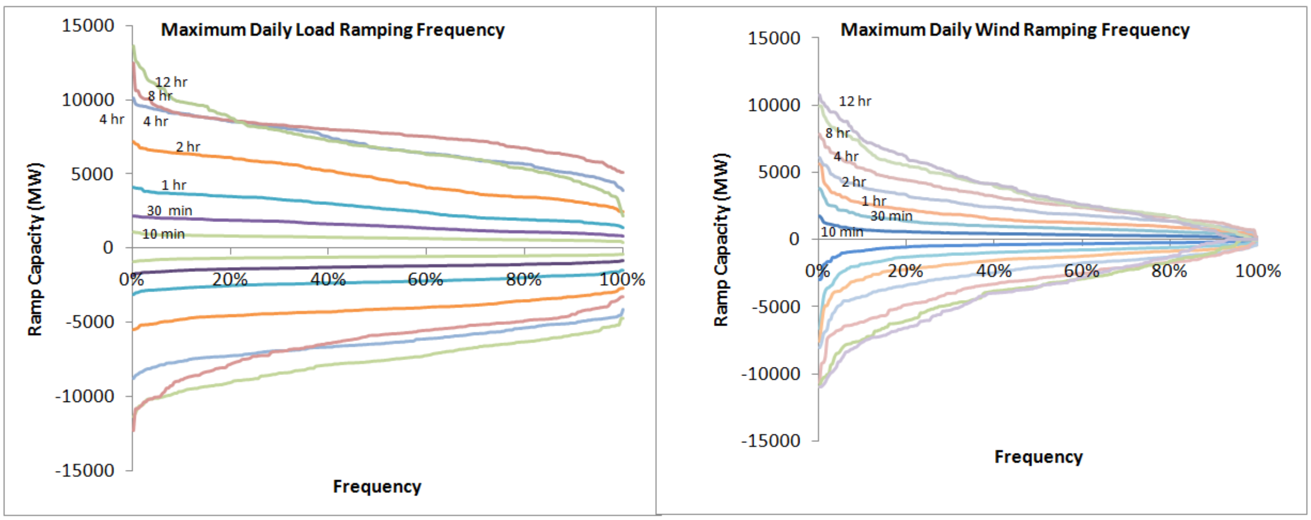

Figure 6 − Maximum daily load and wind ramp frequency for ramps with durations from 10 mintes to 12 hours.

Response Characteristics

Four basic characteristics determine what type of response loads can provide: response frequency, response duration, response speed, and response magnitude. Response notification could also be listed, and is an important consideration for demand response that addresses peak load conditions. We do not list it because, unlike peak load days which are reasonably well predicted the day ahead, wind and solar variability is not well predicted far in advance. Demand response used for wind and solar integration needs to respond with little notification, although it may be possible in some cases to provide information on the *likelihood* of potential response.

Response Frequency

Broadly speaking, response is required continuously (regulation and load following) or infrequently (contingency reserves). Regulation and load following deal with the constant variability and uncertainty, while contingency reserves deal with large, sudden, infrequent excursions. The distinction in event frequency is important because it drives the desired reserve characteristics. The standby cost for contingency reserves is more important than the cost to actually respond because response is required relatively infrequently. Regulation and load following response is constantly required, so the cost of response itself is more important. This distinction can be seen in the selection of generation that supplies response. Non-spinning reserve is often supplied by fast-start combustion turbines whose low capital cost makes standing by inexpensive. The high fuel cost when operating is not a major concern since they do not operate often. Similarly, some loads are better able to provide infrequent contingency response more easily than continuous regulation or load following. The frequency of response (and duration) is more important to some responsive loads than response speed or predictability. Large wind and solar ramps are similar to conventional generation contingency events in terms of infrequency and large magnitude. They tend to differ in that they are slower than the instantaneous failure of a conventional generator. They may require a response that is similar to non-spinning or supplemental operating reserve.

Response Duration

Response duration is not critical to most generators. Once operating, they can continue to do so indefinitely.[2] Costs typically decline with response length as startup costs, for example, are spread over more MWhs. Responsive loads often differ in that response is interrupting their normal flow of business. Longer interruptions are often more disruptive and costs rise with response duration. This is true for loads as diverse as residential air conditioners and aluminum smelters: short interruptions are low cost, but long interruptions are expensive or intolerable. Demand response for wind and solar tail events can be especially effective in dealing with the initial disruption with energy markets providing the slower response that releases demand to return to its normal business.

Response Speed

Response speed is a major concern for generators supplying ancillary services with faster services commanding significantly higher prices. Regulation is the most expensive ancillary service while load following is typically extracted from sub-hourly energy markets at little or no cost. Spinning reserve is two to ten times the price of non-spin in hourly ancillary service markets. Some responsive loads require so much advanced warning that they are not able to provide contingency reserves. For loads that can supply contingency reserves, response speed is typically a communications and control concern rather than a limitation of the demand response itself.

Response Magnitude

Response magnitude distinguishes regulation from contingency reserves. The minute-to-minute random variability of aggregate load is typically one to two percent of the system peak. Wind and solar are typically more variable than load in the regulation time frame per-unit, but not dramatically. The daily load pattern swing is much larger, but it is predictable and it is compensated for through the energy markets or through economic dispatch rather than with a dedicated reserve. Conventional generation and transmission contingencies can be 2000 MW or greater. Wind and solar variability follows a similar pattern with frequent small variations and infrequent large ramps. A difference is that wind and solar ramps are slower than the instantaneous conventional contingency events, with large wind ramps that may take two hours to move two-thousand MW.

[2] Emissions-limited or energy-limited (hydro) generators are an exception.

Existing Demand Response Programs

Utilities have effectively implemented demand response programs for decades, primarily for multi-hour peak load reduction. While many of these programs have been successful, demand response remains a limited resource. The Federal Energy Regulatory Commission (FERC) has recently issued two reports that assess the current state of demand response and begin to draft a national plan for increasing demand response: "A National Assessment of Demand Response Potential" (FERC, 2009) and "National Action Plan on Demand Response (Draft)" (FERC, 2010). FERC found that there is a significant amount of demand response being used today, and the potential for a great deal more with current demand response programs tapping less than a quarter of the resource. FERC's assessment is significant because it is influencing policy that is likely to result in reliability and market rule changes that increase the amount of demand response. Further, FERC specifically recognizes demand response as useful in supporting variable generation integration.

Figure 7 shows five basic types of demand response (Kirby, 2006). All types except simple energy efficiency are potentially useful in providing response that facilitates variable renewable generation integration. Traditional programs focused on peak shaving and price response. These are two quite different methods for achieving essentially the same physical effect; reducing aggregate demand for a few hours during times of actual or expected system stress. Loads as diverse as residential water heaters and large industrial processes can be used. Response can be either manual or automatic. Time-of-use pricing programs are structured around fixed daily schedules. Interruptible load programs give control to the power system operator, often with restrictions on when and how often response can be called for.

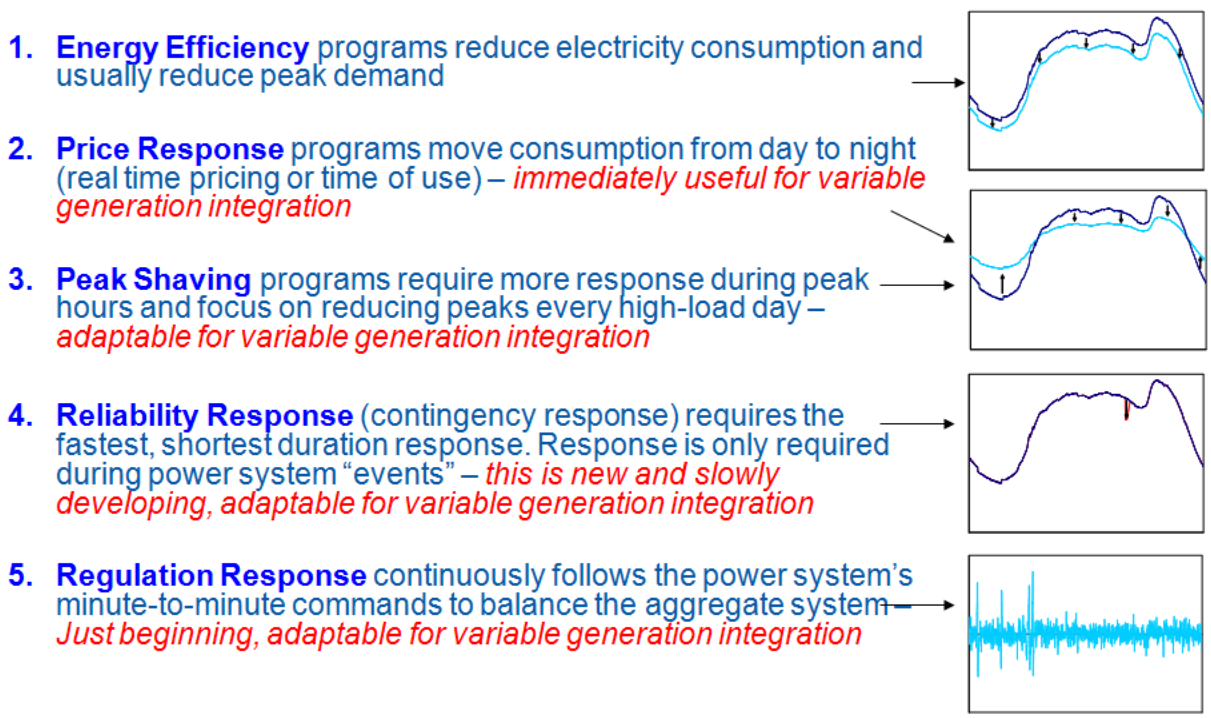

Figure 7 − Four of the five basic types of demand response are potentially useful for facilitating integration of variable renewable generation.

More recently, demand response has begun to be used to directly supply ancillary services to the power system. Rather than reducing overall power system stress by reducing peak loading over multiple hours, these programs are targeted to immediately respond to specific reliability events. This is made possible by advances in communications and controls. A few responsive loads have just begun supplying minute-to-minute regulation, responding to the power system operator's automatic generation control signals. Institutionally, the North American Electric Reliability Corporation (NERC) and the North American Energy Standards Board (NAESB) have recognized that demand response can provide essentially all of the types of response as generation. Figure 8 shows the structuring of demand response hierarchy. Both direct control and customer price response options are covered, as are real-time and day-ahead notification programs.

Nationally, FERC finds that current demand response programs can reduce peak consumption by 4%. Response is greater in some states and lower in others, partly because of regulatory disposition. California, Florida, and New England lead the country while Alaska, Montana, and Wyoming have little or no demand response. Demand response is increasing in the organized markets. ISO/RTOs currently obtain nearly 32,000 MW of response, 6.6% of peak load. If demand response were to spread to areas with little demand response, the total U.S. demand response would be a 9% reduction capability in peak demand. NERC shows current demand response by region and projected response in 2018 in Figures 9 and 10. (NERC, 2009)

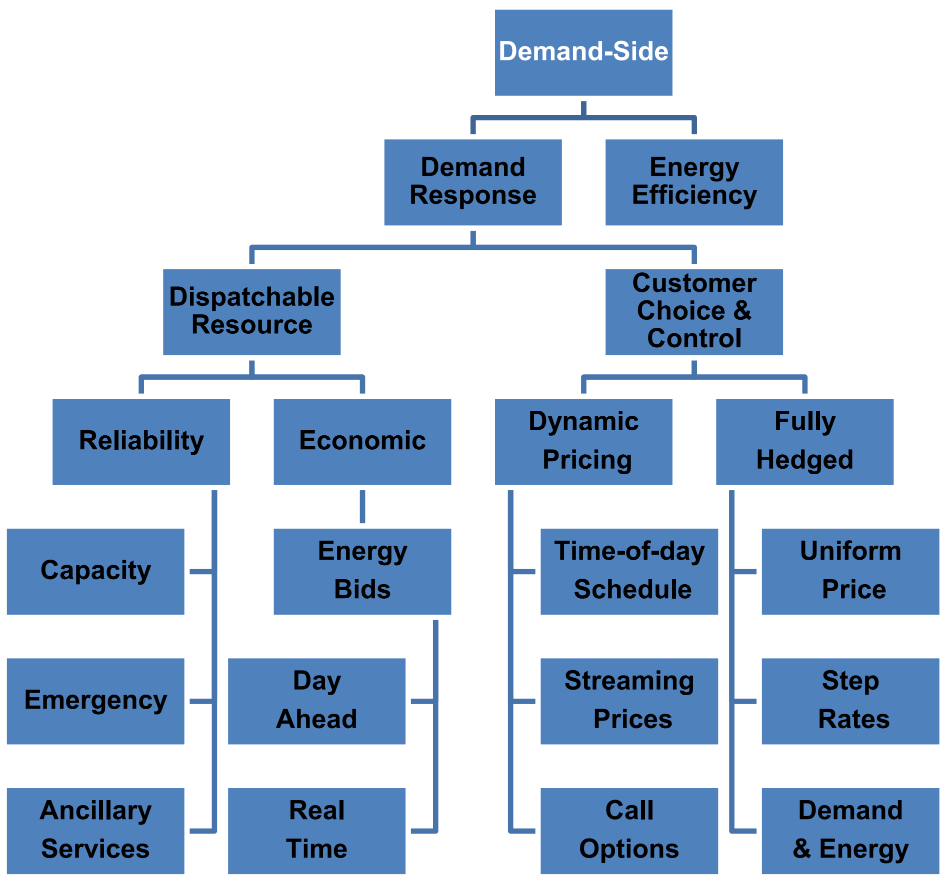

Figure 8 − NERC and NAESB have outlined a full array of potential demand response program options.

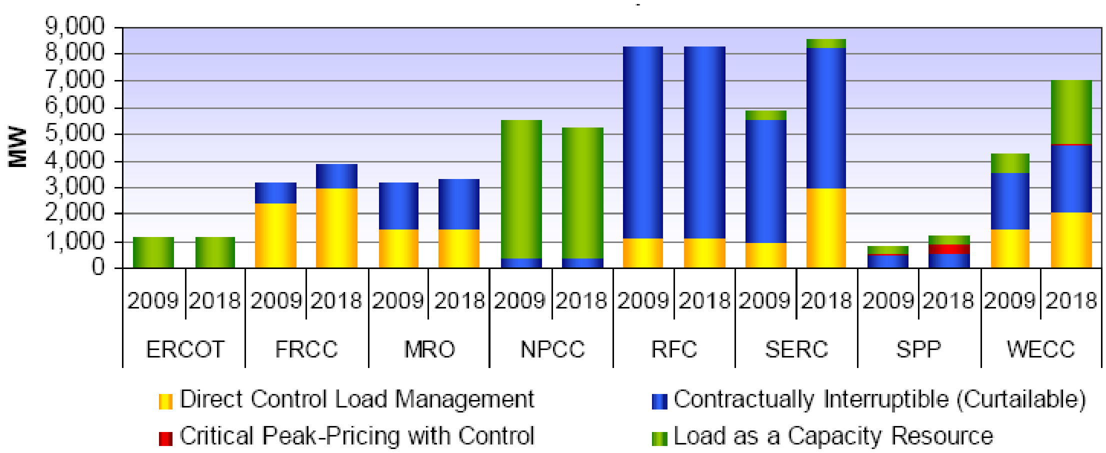

Figure 9 − Regional differences in the current and projected use of demand response are significant (NERC, 2009).

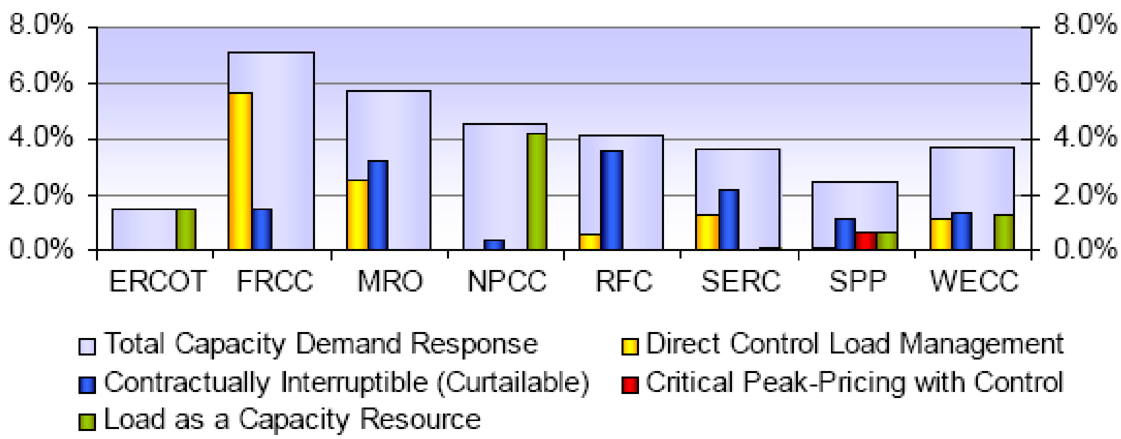

Figure 10 − FRCC obtains the highest percentage of demand response (NERC, 2009).

While NERC shows relatively modest projected increases in demand response over the next eight years, FERC concludes that up to 188 GW of demand response could potentially be available by 2019 (see Figure 11). FERC also differentiated demand response by customer class and finds that, while participation from all customer classes can be increased, residential customers offer a significant potential that will not be realized if business continues as usual (2019, Figure 12).

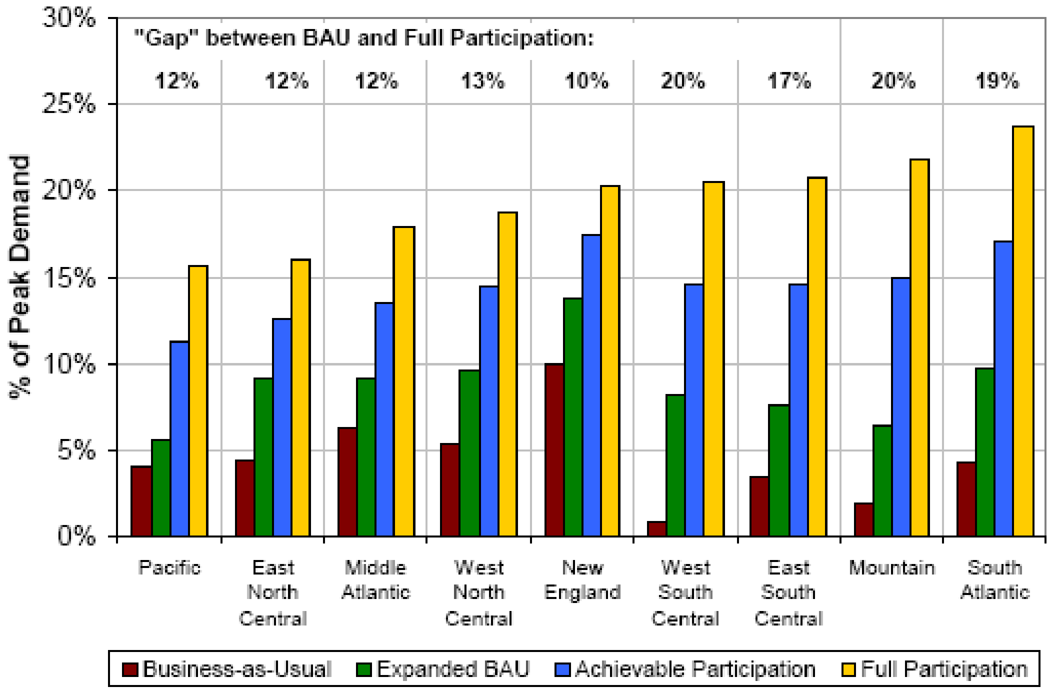

Figure 11 − FERC estimate of regional demand response potential (FERC, 2010).

Dynamic pricing may be an effective method for dealing with variable generation, especially over generation but also response to generation shortfalls. Unfortunately, there is little dynamic pricing in the U.S. today. Thirty-five states have no dynamic pricing programs. One state has a 3% impact while the rest have a 1% to 2% impact. FERC estimates that dynamic pricing could help reduce peak consumption by 14% to 20% (see Figure 13). This is an example of regulatory obstacles as many state regulators feel the need to protect retail customers from price volatility. While the intent is laudable, this denies retail loads the ability to profit from response and blocks the power system (and renewable generation) from obtaining need response.

Responsive loads are beginning to provide the fast ancillary services: regulation, spinning reserve, non-spin, supplemental operating reserve, and emergency response, as shown in Figure 14 (NERC, 2009). Loads provide ancillary services by voluntarily bidding into day-ahead markets. Once selected, the load is obligated to provide the contracted response for the selected hours, often under direct system operator control. Capable responsive loads want to supply ancillary services because ancillary service prices are high, with higher prices for faster response. Regulation is the most difficult ancillary service to provide, requiring the load to adjust consumption every few seconds in response to the system operator's automatic generation control (AGC) commands. Providing contingency reserves (spinning, non-spinning, and supplemental operating reserves) is also attractive to some loads because the response duration is short (11 minutes for spin and non-spin on average in ISO markets) and response is called for relatively infrequently (every few days on average). Advances in technology make the fast communications and control practical. Equipment like air conditioners, water pumping, and appropriate industrial process that can tolerate sudden interruptions are selected. Table 1 shows the annual average ancillary service prices for several regions. Prices declined in 2009 due to the economic downturn but are expected to rebound.

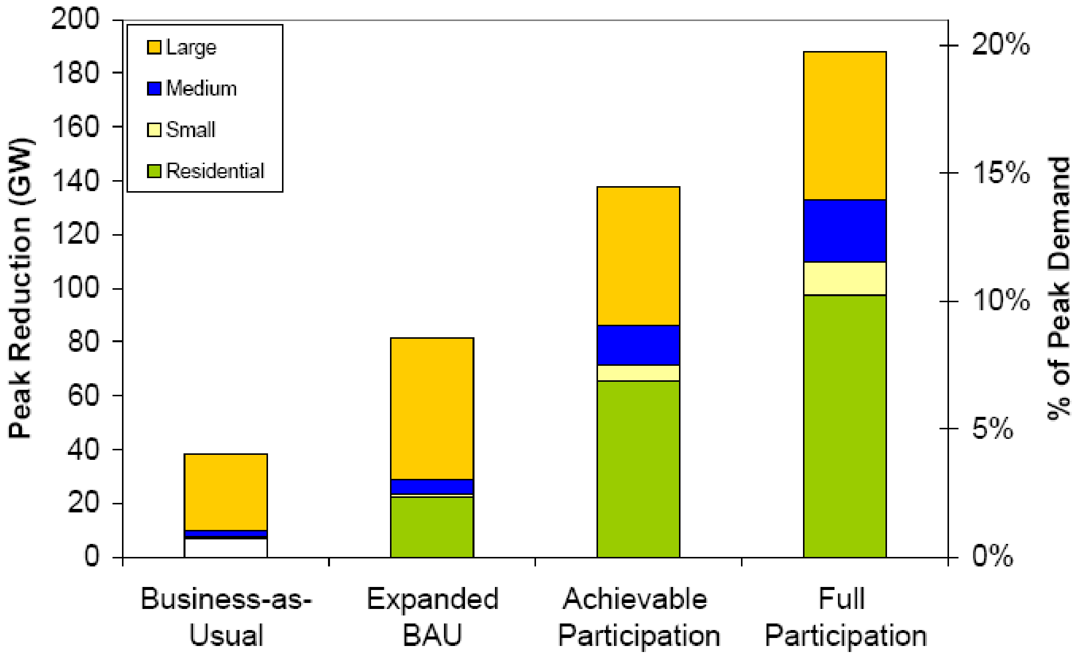

Figure 12 − Demand response can be increased by 2019 if current obstacles are addressed (FERC, 2009).

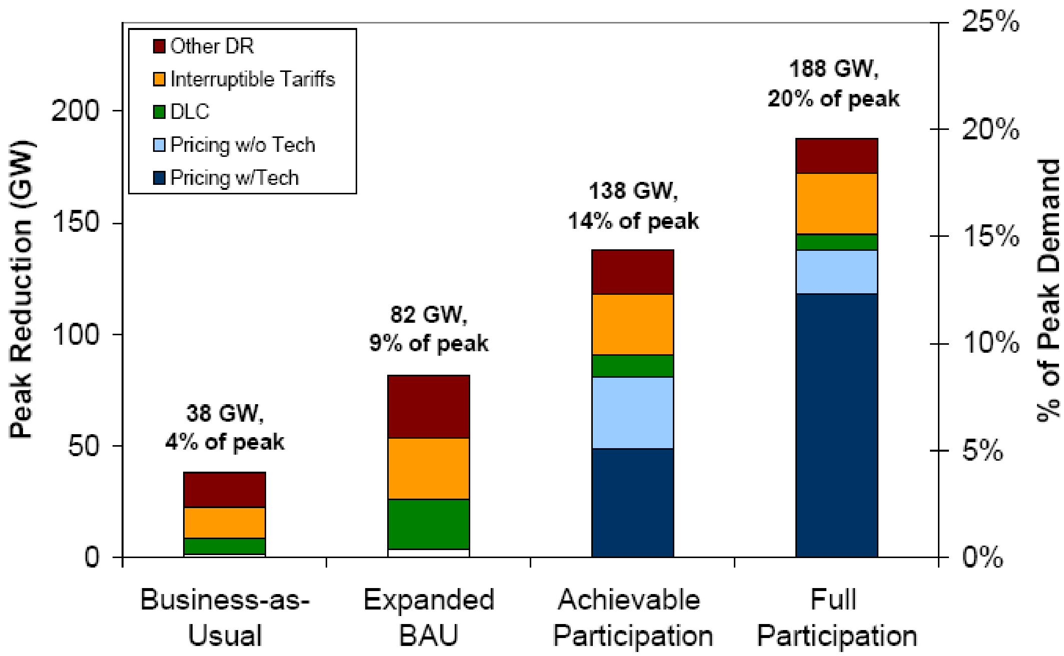

Figure 13 − FERC projects increased potential for price responsive load by 2019 (FERC, 2009).

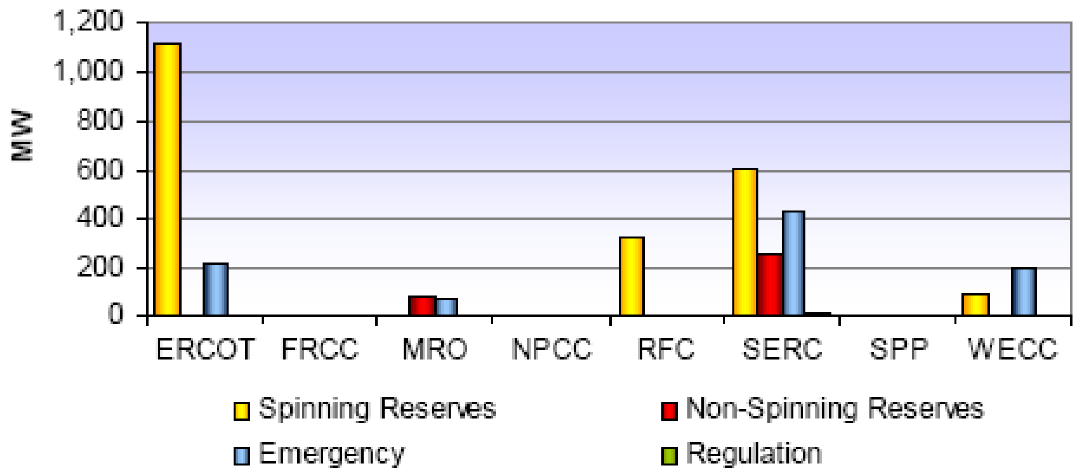

Figure 14 − Responsive loads are beginning to provide the fast ancillary services that are critical for reliability (NERC, 2009).

Table 1 − Non-spin and supplemental operating reserves are 10 to 20 times cheaper than regulation and a better match to wind ramping characteristics.

	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
				Annual Average $/MWh				
California (Reg = up + dn)								
Regulation	**26.9**	**35.5**	**28.7**	**35.2**	**38.5**	**26.1**	**33.4**	**12.6**
Spin	**4.3**	**6.4**	**7.9**	**9.9**	**8.4**	**4.5**	**6.0**	**3.9**
Non-Spin	**1.8**	**3.6**	**4.7**	**3.2**	**2.5**	**2.8**	**1.3**	**1.4**
Replacement	**0.90**	**2.9**	**2.5**	**1.9**	**1.5**	**2.0**	**1.4**	
ERCOT (Reg = up + dn)								
Regulation		**16.9**	**22.6**	**38.6**	**25.2**	**21.4**	**43.1**	**17.0**
Responsive		**7.3**	**8.3**	**16.6**	**14.6**	**12.6**	**27.2**	**10.0**
Non-Spin		**3.2**	**1.9**	**6.1**	**4.2**	**3.0**	**4.4**	**2.3**
New York (east)								
Regulation	**18.6**	**28.3**	**22.6**	**39.6**	**55.7**	**56.3**	**59.5**	**37.2**
Spin	**3.0**	**4.3**	**2.4**	**7.6**	**8.4**	**6.8**	**10.1**	**5.1**
Non Spin	**1.5**	**1.0**	**0.3**	**1.5**	**2.3**	**2.7**	**3.1**	**2.5**
30 Minute	**1.2**	**1.0**	**0.3**	**0.4**	**0.6**	**0.9**	**1.1**	**0.5**
MISO (day ahead)								
Regulation								**12.3**
Spin								**4.0**
Non Spin								**0.3**
New England (Reg +"mileage")								
Regulation			**54.64**	**30.22**	**22.26**	**12.65**	**13.75**	**9.26**
Spin					**0.27**	**0.41**	**1.67**	**0.71**
10 Minute					**0.13**	**0.34**	**1.21**	**0.47**
30 Minute					**0.01**	**0.09**	**0.06**	**0.08**

Demand Response for Renewables Integration

We have shown the increased variability and uncertainty characteristics of high penetrations of variable renewable generation. While the data shown is based on wind, conceptually similar results are expected for solar. We have also shown that demand response is technically proven but under developed. There is a significant potential for increased demand response that could facilitate wind and solar integration.

The response required by wind and solar matches some of the characteristics of existing demand response programs. Large wind ramps are infrequent, like conventional contingencies, but slower than conventional contingencies taking hours to unfold. Solar ramps are faster than wind ramps, but ramps from large collections of solar plants (thousands of MW) will likely still be slower than conventional contingencies. This makes response easier, but may require the creation of an additional response service that is similar to supplemental operating reserve. Fortunately, supplemental operating reserve is the lowest cost ancillary service and an additional slow reserve might be similarly low cost.

Wind and solar also benefit from sub-hourly energy markets to help balance the variable output. Increasing the depth of the sub-hourly market by expanding price responsive load, as envisioned by FERC and shown in Figure 13, will help reduce integration costs.

Minimum Load Conditions

While wind and solar are variable and uncertain in the minutes to months time frame, the annual production is more stable than for hydro. It should be possible to predict minimum load problems on power systems with high wind penetration with reasonable accuracy years in advance. The exact times that surplus energy will be available will not be known, but the magnitude of the surplus (MWh/yr) should be. Publicizing the surplus energy forecast would allow loads to design processes with sufficient flexibility to use the excess energy, benefiting themselves, the power system, and the wind plants.

Loads that might profitably use large amounts of surplus wind energy will need flexibility in their consumption and will need the cost of energy to be a significant factor in their overall operations. Flexibility comes from having some form of storage within the process (thermal energy or intermediate or final product, are examples). Flexibility also comes from having excess production capacity and from a process where product quality is not adversely impacted by stopping and starting the process. The process need not depend exclusively on surplus wind power. Including surplus wind power in the mix could reduce costs for the load, but other supplies could be used when production schedules demand.

Responsive loads could be controlled by the power system operator when minimum load conditions were imminent, but response to real-time price signals will likely be easier and more efficient. From the load's point of view, surplus nuclear power is nearly as useful as surplus wind. Loads that might be modified to be flexible enough to profit from responding to surplus wind power include:

- Water pumping –
    - Irrigation
    - Municipal: supply and treatment
- Thermal storage –

    - Hot and cold
    - Commercial and residential
    - Space conditioning and cold storage
- Electrolysis −
    - Chlor-alkali
    - Aluminum
- Electric vehicle charging
- Shale oil extraction

Note that significant development will be required for some loads to be able to provide the suggested response, hence the need for an accurate forecast. For example, aluminum smelters are currently optimized to operate at a constant power level. As will be discussed later, some are beginning to supply ancillary services in order to reduce their effective electricity costs. No current aluminum smelter can withstand a multi-hour power interruption without ruining the pot line however. Purchased power accounts for roughly 1/3 of the production cost for aluminum and it is increasingly difficult for domestic producers to compete in the world market. *If* it was known that a high penetration of wind generation was going to be built and that significant surplus energy was expected for many years, then it might be worth developing and investing in a dramatically different aluminum smelting process. Other loads will incur similar capital costs as they are modified to increase their flexibility. A good forecast of the annual surplus energy is required, but the potential for a technical solution is significant.

Three Especially Responsive Loads

Electric vehicles, aluminum smelting, and shale oil extraction provide three examples of responsive loads that potentially can be especially helpful for wind integration. These loads will not provide response simply to help renewables. Rather, they will provide response because it will lower their electricity cost and/or provide ancillary service income. That response also reduces wind integration costs and reduces costs for all customers while improving power system reliability. These three loads are of interest because they are especially flexible. They can provide fast response for regulation and contingency reserves. They can also respond to real-time energy prices, accommodating minimum load conditions and mitigating large wind and solar ramps. None of the loads exist with the full degree of flexibility yet. One or all may be significant by the time wind and solar reach 20% to 30% energy penetration.

Electric Vehicles

Electric vehicles (EVs) are expected to use smart chargers that will incorporate significant communications and control capabilities. Owners will be free to charge whenever necessary to accommodate their driving needs, and some will occasionally charge during the day or as soon as they get home after work, but 80% to 90% are expected to charge overnight. The communications and controls, coupled with the solid-state chargers, will let the utility schedule obtain regulation and/or contingency reserves from the EV fleet. The utility will also be able to schedule EV charging to follow variable generation or to alleviate minimum load problems as long as they complete charging by the time the owner is ready to drive to work. The utility will offer a reduced electric rate for EV charging as compensation for obtaining all of this response.

The ISO/RTO Council expects one-million EVs (plug-in hybrids, extended-range electric vehicles, and battery-electric vehicles) within five years (Kema, 2010). Each EV is expected to consume about 300 watt-hours per mile and average 33 miles per day. That represents a new 10 kwh/day load per EV. The usual "Level 2" 220-volt home charger will be capable of fully charging the car within 1.5 hours. If all the EVs charged simultaneously at their full Level 2 rate, the system would see an additional 5500-MW load. Instead, the utility will have 8 to 12 hours to accomplish the charging. Fast communications and controls will give the utility a significant resource for mitigating variability while still providing the utility with an additional paying load.

Aluminum Smelting

Regulation is the most expensive and most difficult ancillary service to supply. It requires the load to continuously respond to power system operator AGC signals to move up and down. Response must be fast and accurate. Recognizing a new opportunity to reduce net power costs by responding to power system reliability needs, Alcoa modified its Warrick, Indiana, aluminum smelter to provide regulation when the MISO ancillary service market opened in January 2009 (Todd, 2009). Warrick provides regulation by continuously adjusting pot-line voltage in response to MISO-AGC signals. Pot-line chemistry and temperature must be continuously monitored and controlled in response to the power changes. This is an impressive accomplishment for a process that was designed and optimized to operate at a constant power level. Regulation is hard enough, but longer term response is even more difficult for aluminum smelting since the cryolite in the pots must be kept molten by the power being consumed. A plant that was designed with flexibility in mind from the start could likely provide significantly more response.

Evaluating the potential for a load to provide regulation involves: 1) a technical assessment of the underlying process' physics to determine if control is possible, 2) an assessment of the capabilities of the specific factory where the implementation is proposed, 3) an evaluation of the required communications and control equipment including the equipment costs, 4) an evaluation of any increased process losses and maintenance costs, 5) an evaluation of the lost opportunities when the factory production capacity is switched from making product (aluminum in this case) and is instead used to supply regulation, and 6) a comparison of the expected benefits from selling regulation with the expected costs (including program startup costs) involved in supplying regulation. The physical and economic analyses are heavily intertwined.

Alcoa operates ten aluminum smelters and associated facilities in the United States with a combined average load of 2,600 MW, representing a significant demand response potential. Many other industries can provide similar or greater response. At least one other industrial load is preparing to supply regulation to NYISO.

Oil Extraction from Tar Sands and Shale Deposits

In site heating of oil deposits represents a potentially large and extremely responsive load. There are large deposits of shale oil that may be able to be economically extracted by heating the oil in place before pumping. Two electric power technologies are being tested and show promise of being commercially viable; resistance heating and radio frequency (RF) energy. In both cases, electric heaters are placed in the rock formation and warm the oil deposit in about a month. What makes these loads so interesting from a power system perspective is the decoupling of the load's time constant from that of the power system. While the load needs a month of electric heating, only the average energy is important. Heater power level can be controlled as rapidly as desired (sub-cycle in the RF heater case) to provide any response that is helpful to the power system. The load will likely be price responsive and avoid consumption during times of generation shortage, but it can also supply regulation and contingency reserves when heating. It can also help with minimum load problems and be responsive to wind ramps in either direction. Plant size could be quite large. A 100,000 bbl/day oil shale plant will require 870 MW of average power. Oil shale deposits are estimated to be large enough to support a 10 million bbl/day industry.

Conclusions

Demand response is a proven set of technologies that have been used by utilities to improve reliability for decades. Improvements in communications and controls now make it practical to obtain regulation and contingency reserves as well as peak reduction from responsive loads. Real-time price response is also technically feasible though regulatory barriers exist. FERC has assessed the current state of demand response in the United States and concluded that significantly greater capability exists.

Increasing the pool of responsive resources is beneficial for wind and solar since they add variability and uncertainty to the power system at the same time that they displace generation that itself can provide response. Both voluntary price response and command and control are useful. Variable generation up-ramps are typically not a reliability concern since wind or solar can be spilled. Up-ramps are an economic concern that load response can help with. Down-ramps can be a reliability concern and are certainly an economic concern. Here too load response can help. Wind and solar ramps are slower than conventional contingencies. Responding to large ramps will require price responsive load and may require a new reserve that is similar to supplemental operating reserve. Renewable generation advocates should work to remove barriers to demand response.

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Responsive load is still the most underutilized reliability resource in North America. This paper examines the characteristics of concern to the power system, the renewables, and to the loads.

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