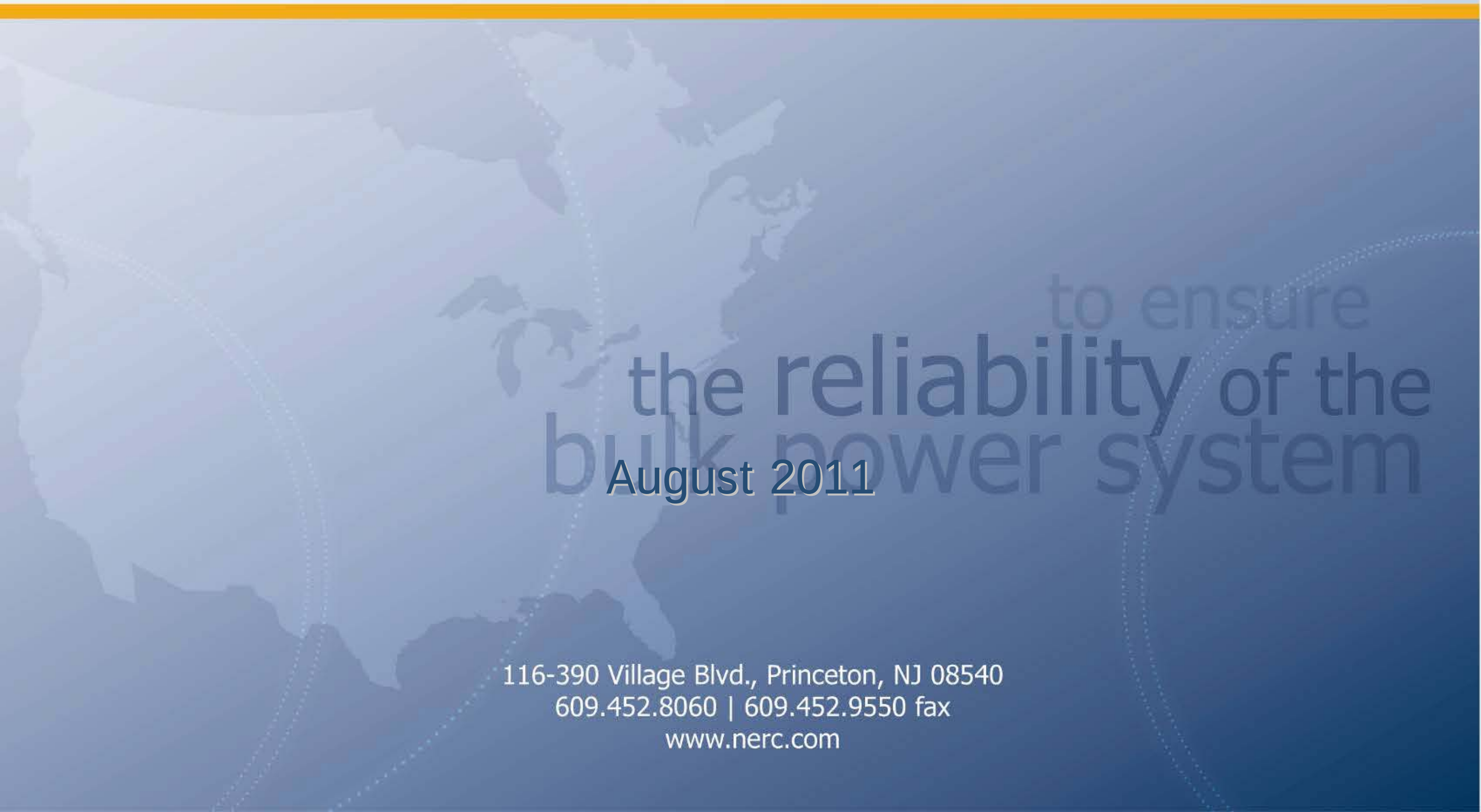
NERC

NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Special Report

Potential Bulk System Reliability Impacts of Distributed Resources



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NERC's Mission

The North American Electric Reliability Corporation (NERC) is an international regulatory authority established to enhance the reliability of the bulk power system in North America. NERC develops and enforces Reliability Standards; assesses adequacy annually via a ten-year forecast and winter and summer forecasts; monitors the bulk power system; and educates, trains, and certifies industry personnel. NERC is the electric reliability organization for North America, subject to oversight by the U.S. Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada.[1]

NERC assesses and reports on the reliability and adequacy of the North American bulk power system, which is divided into eight Regional areas, as shown on the map and table below. The users, owners, and operators of the bulk power system within these areas account for virtually all the electricity supplied in the U.S., Canada, and a portion of Baja California Norte, México.

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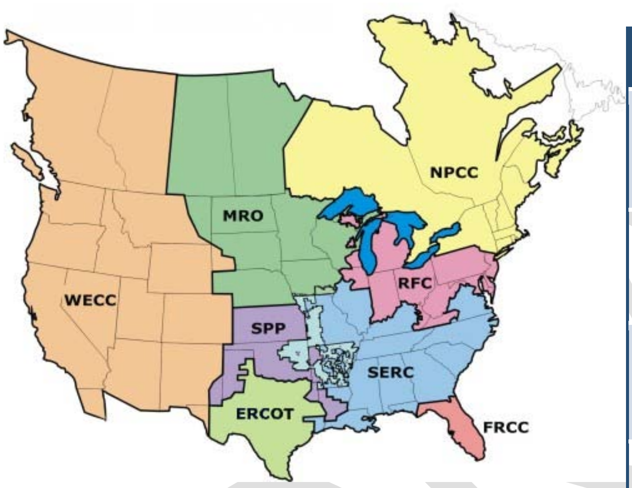

Note: *The highlighted area between SPP RE and SERC denotes overlapping Regional area boundaries. For example, some load serving entities participate in one Region and their associated transmission owner/operators in another.*

Table A: NERC Regional Entities

ERCOT Electric Reliability Council of Texas	**RFC** Reliability*First* Corporation
FRCC Florida Reliability Coordinating Council	**SERC** SERC Reliability Corporation
MRO Midwest Reliability Organization	**SPP** Southwest Power Pool, Incorporated
NPCC Northeast Power Coordinating Council, Inc.	**WECC** Western Electricity Coordinating Council

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[1] As of June 18, 2007, the U.S. Federal Energy Regulatory Commission (FERC) granted NERC the legal authority to enforce Reliability Standards with all U.S. users, owners, and operators of the bulk power system, and made compliance with those standards mandatory and enforceable. In Canada, NERC presently has memorandums of understanding in place with provincial authorities in Ontario, New Brunswick, Nova Scotia, Québec, and Saskatchewan, and with the Canadian National Energy Board. NERC standards are mandatory and enforceable in Ontario and New Brunswick as a matter of provincial law. NERC has an agreement with Manitoba Hydro making reliability standards mandatory for that entity, and Manitoba has recently adopted legislation setting out a framework for standards to become mandatory for users, owners, and operators in the province. In addition, NERC has been designated as the "electric reliability organization" under Alberta's Transportation Regulation, and certain reliability standards have been approved in that jurisdiction; others are pending. NERC and NPCC have been recognized as standards-setting bodies by the Régie de l'énergie of Québec, and Québec has the framework in place for reliability standards to become mandatory. NERC's reliability standards are also mandatory in Nova Scotia and British Columbia. NERC is working with the other governmental authorities in Canada to achieve equivalent recognition.

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Executive Summary

The amount of distributed energy resources (DER) present in the electrical grid is forecast to grow in the next decade. This report considers all types of DER including generation, storage and demand response, but many of the potential reliability impacts are driven by variable, uncontrollable generation resources such as solar photovoltaic generation (PV). It is also recognized that many types of DER (demand response and storage, for example) may improve bulk system reliability if managed properly. In the past, the distribution system was based mainly on distributing power from the transmission network, and therefore its impact on bulk system reliability was relatively small. As Smart Grid developments increase resulting in more bi-directional flow of energy and provision of ancillary services from the distribution system, the impact on bulk system reliability needs to be understood and managed. This report identifies the potential impacts these resources may have, identifies potential mitigating strategies, reviews the existing NERC Registry Criteria specific to DER applications, and proposes potential future approaches to ensure continued reliability in systems with large amounts of DER.

Distributed resources currently account for a relatively small portion of generation in the US. DER are expected to increase, however, and it is envisaged that solar PV resources could grow to over 10 GW by 2016; PEVs and stationary storage could reach nearly 5 GW in the next decade, and demand response could increase from the current 40 GW to 135 GW in a decade. There is already a significant amount of reciprocating engines connected at the distribution level, as well as a micro CHP plants. These resources all have different characteristics which in large numbers may aggregately affect the bulk system. Most, if not all, are not presently visible or controllable by the bulk system operators, and many are connected according to the IEEE 1547 standard, which requires disconnection from the system for abnormal system conditions raising issues with fault ride through with high penetrations of DER. High levels of distributed variable generation connected to the system may cause particular problems due to the uncontrollable nature of its output. PV with inverters designed without grid-support functions, if present in large amounts, can affect the frequency response and voltage profile of the system.

The following potential bulk system reliability impacts of high levels of DER have been identified:

- Non-dispatchable ramping/variability of certain DER
- Response to faults: lack of low voltage ride through, lack of frequency ride-through and coordination with the IEEE 1547 interconnection standards for distributed generation
- Potential system protection considerations
- Under Frequency Load Shedding (UFLS) and Under Voltage Load Shedding (UVLS) disconnecting generation and further reducing frequency and voltage support
- Visibility/controllability of DER
- Coordination of system restoration
- Scheduling/forecasting impacts on base load/cycling generation mix
- Reactive power and voltage control
- Impacts on forecast of apparent load seen by the transmission system

These issues may impact the bulk system at different levels of penetration, depending on the characteristics of the particular area to which the DER are connected. Some factors will need to be managed by technical requirements (grid codes) for the DER itself, while others need the bulk system operator to adapt new planning and/or operational methods. Significant amounts of DER can affect the power flow on the transmission and sub-transmission systems, which can result in thermal overloads or significant changes in profile. The uncertainties associated with the variable output (in aggregate) can create additional uncertainties in net demand to be served by transmission and balancing resources, with an added complication to the system operator of limited monitoring and control of the output from distributed resources. Certain regions, such as Hawaii or Germany, are already seeing significant challenges of the type outlined here. Studies and real world experience have shown the potential impact of significant penetrations of DER. In particular, much attention has been focused on both the impact of variability and uncertainty, which can be invisible to the bulk system operator, and low voltage or low frequency response of DER. High DER penetrations have been shown to affect the transient and small signal stability of the system – this can be either positive or negative depending on the type of DER (e.g. inverter connected DER can adversely or beneficially affect stability depending on control schemes employed).

The conflict between the transmission need for low voltage ride-through and the IEEE 1547 standard, which mandates disconnection of DER to allow distribution protection systems to operate and to prevent islanding, has to be addressed. At high levels of DER, a significant amount of DER disconnecting just when there is a need for them can have cascading effects for the bulk system. The German grid code, for example requires voltage ride through and reactive power control similar to that required from transmission connected wind. Studies in Ireland have shown that the Rate of Change of Frequency relays used to protect DER can accentuate frequency response issues when there are low amounts of inertia due to high DER penetration. Up to now, however, experience with significant DER has shown very few actual events caused by DER impacting bulk system reliability; those that have been seen were caused by large changes in the output due to underfrequency disconnection or changing weather patterns. This meant that due to reduced operator visibility it was more difficult to produce an accurate forecast and to make use of real-time information to adjust to changing conditions for variable generation DER

Based on studies and experience, various mitigation measures can be introduced to ensure potential adverse reliability impacts can be managed. This will require the development of standards, and in some cases BAs will need to:

- Develop operating policy/procedures to deal with potential real-time problems,
- Discuss technical challenges with developers and work with manufacturers to address identified challenges,
- Develop interim solutions until manufacturers are able to develop and market fixes,
- Modify existing standards or requirements or develop new standards or requirements.

The reconciliation of IEEE 1547 requirements, which considers the impact on the DER resource and distribution network, and the needs of the bulk system is an important mitigation measure. In particular, DER may need to be able to ride through low voltage or frequency situations, and provide voltage control. Active power management may be necessary to ensure transmission network overloading is avoided. Variability and uncertainty of DER can be better managed by increasing visibility; smart grid technologies such as smart meters or SCADA could be used to better communicate the state of the local distribution network, and this could then be used by the BA to ensure reliable operation by managing its flexible resources to better deal with ramping issues.

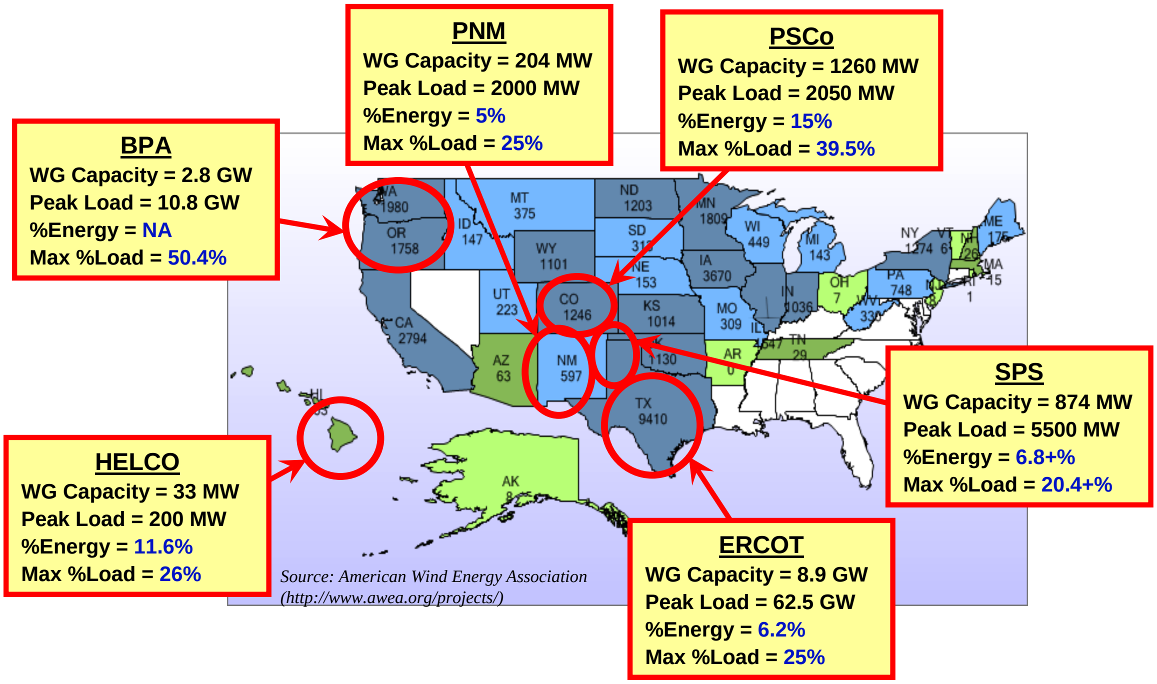
The NERC Registry Criteria has been reviewed to assess how high penetration of DERs is considered presently. It is noted that NERC's existing scope does not extend to DER and there are potential legal considerations in expanding that scope. As such other vehicles for addressing potential reliability impacts of DER are noted. Additions or adjustments of state regulations and programs are one potential vehicle. Addressing some of the reliability issues associated with high DER penetration in certain areas may be best resolved through updated grid codes or interconnection requirements ensuring certain characteristics for DER, i.e. voltage ride through or reactive power control. Importantly, addressing many DER issues are beyond NERC’s current scope, as small scale PV, for example is not usually considered a bulk system concern. Should DER penetration reach a sufficient market threshold, DER will impact resource management and transmission reliability, resulting in the need for more information to be provided to system and transmission operators. However, current practices in many areas do not require information to be provided from DER to the bulk system and therefore cannot be considered in either bulk planning or operations. The level of DER which will cause issues in BAs will vary by BA and DER technology so there may not be a ‘one-size-fits-all’ solution.

While specific recommendations for guidelines or standards are not provided, the following general recommendations are made:

1. NERC, state regulators, and/or industry should develop an analytical basis for understanding the potential magnitude of adverse reliability impacts and how that magnitude changes with penetration of DER and system configuration/composition.
2. Based in part on the analytical results from #1 and the broad experience of generation, transmission and distribution owners and operators, specific recommendations for changes to operating and planning practices, state programs, and pertinent NERC Reliability Standards should be developed.
3. As many DER issues may be beyond the scope of NERC’s authority, and since it may be feasible to address these issues through non-NERC avenues (such as through market rules, vertically integrated operations, or state programs), it is recommended that NERC work with the affected entities in the different regions, including state agencies having jurisdiction over DER, RTOs, and vertically integrated utilities, to develop appropriate guidelines, practices, and requirements to address issues impacting the reliability of the BES resulting from DER.

Chapter 1: Introduction

Renewable generation resources such as wind generation and PV use weather-based fuel sources, the availability of which can vary over time. Subsequently, the electric output of these resources also varies creating a new class of resource categorized as variable generation (VG). Large increases in installed wind generation capacity in some balancing authority areas (BAs) have resulted in relatively high penetrations in North America on a regional basis. Figure 1 shows a recent state installed wind capacity map from the American Wind Energy Association (AWEA) highlighting selected BAs that have a high installed wind generation capacity relative to the BA peak load. For each of these BAs, the following parameters are provided: installed wind capacity (*WG Capacity*), peak BA load (*peak load*), percentage of annual energy derived from wind generation from most recent available data (*%Energy*), and the maximum instantaneous percentage of load served from wind generation (*Max %Load*). As the graphic shows, for some BAs in the U.S., wind generation is already instantaneously supplying as much as 25-50 percent of system supply requirements.



PNM
WG Capacity = 204 MW
Peak Load = 2000 MW
%Energy = 5%
Max %Load = 25%

PSCo
WG Capacity = 1260 MW
Peak Load = 2050 MW
%Energy = 15%
Max %Load = 39.5%

BPA
WG Capacity = 2.8 GW
Peak Load = 10.8 GW
%Energy = NA
Max %Load = 50.4%

SPS
WG Capacity = 874 MW
Peak Load = 5500 MW
%Energy = 6.8+%
Max %Load = 20.4+%

HELCO
WG Capacity = 33 MW
Peak Load = 200 MW
%Energy = 11.6%
Max %Load = 26%

Source: American Wind Energy Association (http://www.awea.org/projects/)

ERCOT
WG Capacity = 8.9 GW
Peak Load = 62.5 GW
%Energy = 6.2%
Max %Load = 25%

Figure 1: Selected Balancing Authorities w/Significant Wind Generation

BAs with increasing penetration levels like those shown in Figure 1 have already begun experiencing operational challenges,[2] though integration of variable generation typically has not appreciably affected the reliability of the bulk electric system (BES). Anticipating substantial growth of variable generation, NERC's Planning and Operating Committees created the Integration of Variable Generation Task Force (IVGTF) which prepared a report, entitled, "*Accommodating High Levels of Variable Generation*,"[3] which was released in April 2009.

In addition to defining various technical considerations for integrating high levels of variable generation, the IVGTF report identified a work plan consisting of thirteen follow-on tasks to investigate potential mitigating actions, practices and requirements needed to ensure bulk system reliability. These tasks were grouped into the following four working groups with three tasks each: 1) Probabilistic Techniques, 2) Planning, 3) Interconnection and 4) Operations. This report describes the results of Task 1-8 from the Planning activity, which evaluates the potential bulk system reliability concerns arising from integration of large amounts of *distributed* resources, such as distributed solar PV, plug-in electric vehicles (PEVs), distributed electric storage, and Demand Response programs.

Bulk System Reliability and High Penetrations of Distributed Resources

This NERC IVGTF task differs from the other IVGTF follow-on tasks in the following respects:

1. Task 1-8 focuses on the bulk system impact of distributed resources and not resources interconnected to the bulk system itself, and
2. Task 1-8 considers the bulk system impact of all distributed resources and not just variable generation resources.

The increasing penetrations of wind generation illustrated in Figure 1 are almost completely attributable to large, bulk system interconnected wind plants. Although there are distribution interconnected wind turbine generators in North America, they are small in number and smaller in size such that they have no impact on the reliability of the bulk electric system in North America. While it is unlikely that additional distributed wind generation will be built in quantities to significantly impact the bulk system, the potential for high penetrations of other distributed resources exists.

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[2] For example, see NERC's *2010 Summer Assessment*, Regional Reliability Assessment Highlights, at http://www.nerc.com/files/2010%20Summer%20Reliability%20Assessment.pdf

[3] *Special Report -- Accommodating High Levels of Variable Generation*, NERC, http://www.nerc.com/files/IVGTF_Report_041609.pdf

The EIA projects that distributed solar PV will grow to over 10 GW by 2016 under the federal climate change legislation (H.R. 2454, or Waxman-Markey) that was proposed in 2010.[4] In addition to variable distributed generating resources such as distributed wind and solar PV, other distributed resources such as conventional distributed generation, PEVs, distributed energy storage, and demand response resources can also impact the bulk system. PEVs are projected to grow to potentially 3,800 MW in the next decade[5]. Distributed energy storage is expected to increase to approximately 1000 MW in the same period. There is currently 40 GW of demand response programs in the US; this has the potential to grow to135 GW by 2019[6]. These resources, while potentially controllable in comparison to wind or solar PV generation, in most regions are still largely unobservable or controllable by the bulk power system due to their distributed nature and small individual sizes. As such, these resources still need to be considered when examining the effect of distributed resources on the reliability of the bulk power system.

It should be noted that many of these same distributed resources offer potential reliability benefits to the BES due to the additional flexibility and energy they might supply. Many of these potential reliability benefits were examined in the separate NERC IVGTF report "*Potential Reliability Impacts of Emerging Flexible Resources*[7]." Due to their distributed nature, however, they are typically unobservable to the BES with currently implemented technology. Thus, as DER become more prevalent serving large portions of energy or ancillary service requirements, the lack of BES visibility and controllability for these resources represents a potential for adverse BES reliability impacts. High levels of distributed resources can potentially impact bulk system reliability in numerous ways, including the following:

- General lack of visibility/controllability of distributed generation ("DG")
- Non-dispatchable ramping/variability issues that could affect bulk system operations
- Response to faults: lack of low voltage ride through, lack of frequency ride-through and coordination with the IEEE 1547 interconnection standards for distributed generation

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[4] Noah Long, "The changing role of distributed renewable generation," Presented at the NARUC Conference, July 18, 2010

[5] Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems, KEMA, Inc and Taratec Corporation, ISO/RTO council, March 2010, p. 29

[6] A national Assessment of Demand Response Potential, http://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf. Potentially achievable estimates correspond to "Achievable Participation" estimate in the report, which is based on the "Best Practices" scenario

[7] NERC IVGTF Task 1-5, "Special Report: Potential Reliability Impacts of Emerging Flexible Resources," December 2010, http://www.nerc.com/files/IVGTF_Task_1_5_Final.pdf

- Potential system protection considerations
- Under Frequency Load Shedding (UFLS) disconnecting generation and reducing frequency further
- Potential market mechanisms/impacts
- Coordination of system restoration
- Scheduling/forecasting impacts on base load/cycling generation mix
- Reactive power and voltage control
- Impacts on forecast of apparent net load seen by the transmission system

Chapter 2: Distributed Energy Resources

This report considers the potential BES impacts of a range of distributed resource technologies that are deployed for a variety of reasons: renewable and conventional generation, demand response, PEVs, and storage. Distributed solar and wind generation add to net-load variability and uncertainty while distributed conventional generation, demand response, storage, and plug-in electric vehicles can be flexibility resources used by the system operator to respond to overall system variability and uncertainty. The IVGTF Task 1-5 report "*Potential Reliability Impacts of Emerging Flexible Resources*"[8] provides greater detail concerning many of these technologies.

Distributed Generation

Several types of distributed generation are in use today. Some are controllable such as reciprocating engines, combustion turbines, or fuel cells. Other distributed generation is associated with combined heat and power (CHP) and runs at fairly constant output when it is needed for thermal output. Renewables can be either reasonably constant or variable. Run-of-river hydro and land fill gas fired generation have fairly constant output. Distributed wind and solar PV are variable and uncertain. Consequently, some distributed generation can be a reliability asset, some simply modifies net load without increasing volatility, and others do increase variability and uncertainty.

In addition to variability and uncertainty, the way the distributed generator interfaces with the power system is an important consideration when evaluating potential system impacts. Some DG use rotating synchronous generators to convert mechanical power to electrical while others use power electronics based inverters. The first type is similar to conventional synchronous generators and may therefore have a lower adverse impact on reliability.

Reciprocating Engines

Reciprocating engine based generators are the most mature DG technology and account for about 90% of current DG installations. The generators themselves are typically synchronous machines that can provide dynamic reactive power and voltage control if desired. Applications include utility power generation, peak shaving, and customer remote and back-up power. They can run on a range of fuels including diesel, natural gas, gasoline, propane, methane, etc. They are typically fast starting, fast ramping, and have good part-load

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[8] NERC IVGTF Task 1-5, "Special Report: Potential Reliability Impacts of Emerging Flexible Resources," December 2010, http://www.nerc.com/files/IVGTF_Task_1_5_Final.pdf

performance making them a good reliability resource when responsive to system operator commands.

Combustion Turbines

Traditional utility combustion turbines are too large for DG applications, but smaller units are especially useful for CHP applications. The steam generated by the CHP plant is often more valuable than the electricity. Total CHP efficiency can approach 60%. Combustion turbines typically drive synchronous generators for the electricity production, but because the electrical output of the generator is often a secondary product it can be somewhat variable based on the thermal load

Micro-turbines are small, high-speed combustion turbines designed for dispersed, customer applications. They can be used to simply provide electric power or they can be used in CHP operations. The turbines spin too fast to directly drive a utility connected synchronous generator so the generated power is converted to direct current and then converted to nominal power system frequency through an inverter.

Fuel Cells

Fuel cells produce electricity directly from fuel oxidation rather than by powering an engine that mechanically rotates a generator. The DC power is converted to nominal power system frequency through an inverter. Efficiencies are typically high (40% to 50%). There are several technologies available but none have achieved high market penetration.

Solar PV

Distributed solar generation is typically based on photovoltaic cells which product DC power directly from sunlight. An inverter is used to convert the DC power to nominal power system frequency for use by the owner or for injection into the distribution system. Continued advances in PV technology have significantly reduced cost. Lower costs, coupled with tax incentives and other programs to promote PV use have resulted in a recent increase in distributed PV installations. The installed solar PV capacity in the US grew by 878 MW in 2010 to a total installed capacity of 2.1 GW by the end of 2010.[9]

Cloud movement can make the output of individual PV installations extremely volatile. While this variability is greatly reduced through aggregation of multiple PV installations across a balancing area footprint, local PV variability may remain quite high. For example; some distribution circuits in areas of high load are very condensed spatially and could see high

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[9] Solar Electric Industries Association, "U.S. Solar Market Insight™ 2010 Year in Review," http://www.seia.org/galleries/pdf/SMI-YIR-2010-ES.pdf

variability with installed PV. There are numerous on-going research efforts to characterize the exact nature of the variability of PV and diversity benefits over varying spatial footprints, but results are limited thus far.[10,11] Individual distributed PV installations are typically too small to be individually monitored by the power system operator. Consequently the aggregate output is not directly observable in many areas.

Wind

The majority of wind generation in the U.S. is in large plants with centralized monitoring and control and a common point of interconnection with the power system. Distributed wind power consists of individual utility-scale wind turbines (0.5MW-3MW) or small clusters of them interconnected at distribution voltage levels or smaller 5-50 kW wind turbines installed behind the meter at residential or commercial facilities. The total installed capacity of distributed wind in the US is only approximately 1,000 MW. As with distributed PV, individual wind turbines are often not monitored by the power system operator.

Demand Response

Demand response is a resource that the system operator can use in a number of ways to enhance reliability. Industrial, commercial, and residential demand response have been effectively used for decades for peak reduction. Advances in communications and controls technologies are expanding the ability of all types of consumers to both respond to system operator directives and to respond to price signals and are especially helpful in facilitating the use of distributed demand response. Demand Response is not a single technology. Rather, Demand Response is any technology that controls the rate of electricity consumption rather than the rate of generation. FERC defines the term Demand Response to include "consumer actions that can change any part of the load profile of a utility or region, not just the period of peak usage."[12] FERC goes on to recognize Demand Response as including devices that can manage demand as needed to provide grid services such as regulation and reserves, and changing consumption for the "smart integration" of variable generation resources.

Demand response technologies that can meet established performance criteria should be considered as part of the pool of resources available for all power system balancing needs including the integration of renewable generation. Different technologies will be successful

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[10] Chris Trueblood etal, EPRI, Elizabeth Philopot, Southern Company Services, "Distribution Photovoltaic Monitoring Program," presented at the 4th International Conference on Integration of Distributed and Renewable Resources, Albuquerque, NM December 6-10, 2010 http://www.4thintegrationconference.com/downloads/2.03.pdf

[11] K. Orwig, "Solar Data Hub," at UWIG 2011 Spring Solar User Group Meeting, Kansas City, MO, April 2011

[12] National Action Plan on Demand Response, Federal Energy Regulatory Commission, p. 7, http://www.ferc.gov/legal/staff-reports/06-17-10-demand-response.pdf

for different applications in different locations, depending on the specific characteristics of the local loads.

NERC and NAESB (North American Energy standards Board) characterize the full range of demand response options as shown in Figure 2 below. Demand side measures can be very fast-acting, as with under frequency load shedding, very slow-acting, as with efficiency improvements, or anywhere in between. ERCOT currently obtains half of its responsive (spinning) reserves (1,150 MW of the 2,300 MW total) through a demand response product called Loads-Acting-As-Resources (LAARS). These load customers have under-frequency relays set to 59.7 Hz so that they trip off-line automatically during under-frequency events. During emergency conditions, these loads will also disconnect upon receiving instructions from ERCOT. ERCOT also has an Emergency Interruptible Load Service (EILS), a separate program of loads that will separate from the system during emergency conditions upon receiving instructions from ERCOT.

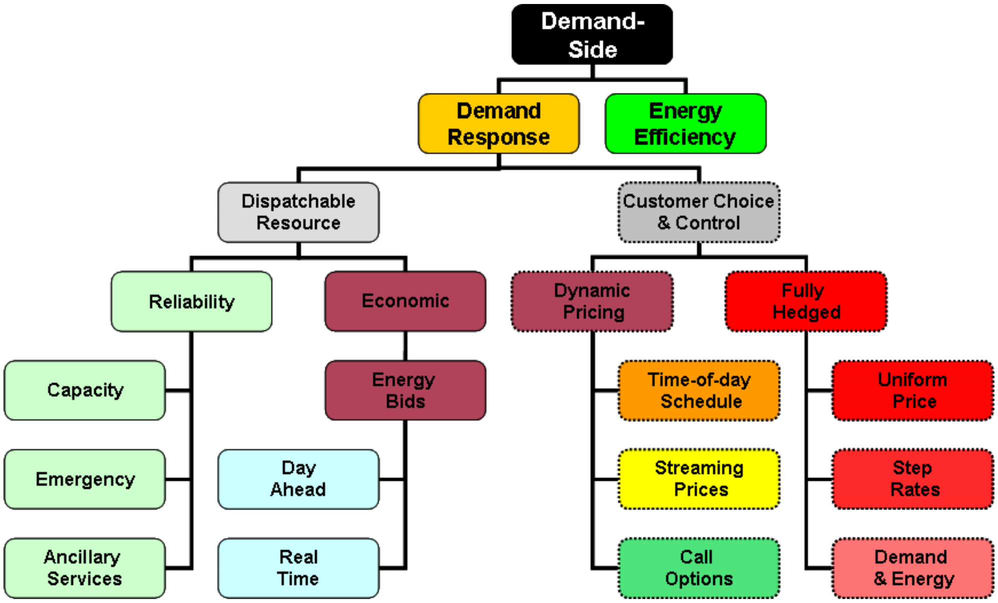

Figure 2: NERC and NAESB categorization of demand response

NERC and NAESB characterize demand response as either being “Dispatchable Resource” or “Customer Choice and Control”. Dispatchable Resources give the power system operator either direct physical or administrative control of the load’s power consumption. Customer Choice and Control response is based on the consumer’s voluntary response to price signals. Both types of programs can be effective in obtaining reliable response from loads. Figure 3 shows the significant amount of demand response currently being used in each of the NERC regions.

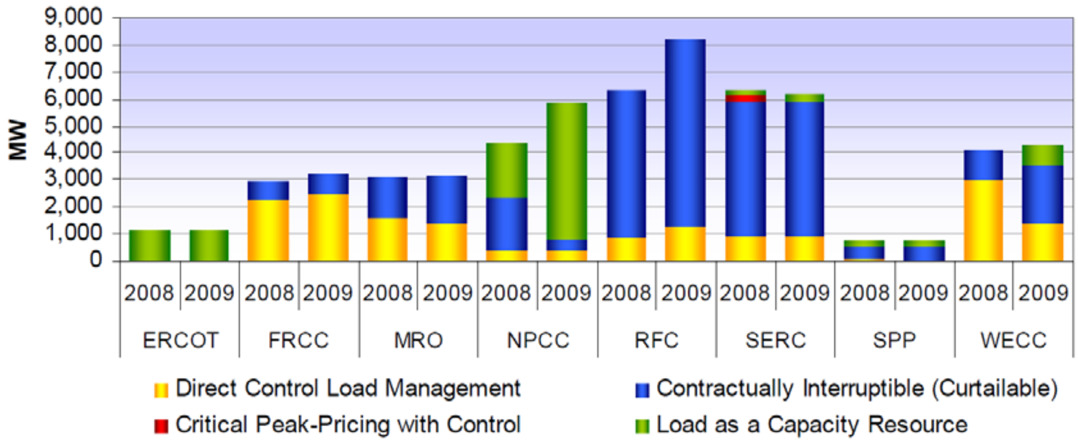

Figure 3: Existing demand response resource contribution by NERC Region & program type[13]

Using demand response as a capacity or energy resource in wholesale electricity markets is a relatively new concept and grid operators are still working out how best to incorporate demand response resources for ramping, balancing and regulation. Organizations such as utilities, load-serving entities, grid operators, and independent third party demand response providers are developing ways to enable demand response to be used more broadly as a resource in energy, capacity, and ancillary services markets. New types and applications of demand response are emerging as a result of technology innovations and policy directives. These advances have made it increasingly feasible (from a technical perspective) and economically reasonable for consumers to respond to signals from a utility system operator, load-serving entity, RTO/ISO, or other demand response provider to be deployed to provide reliability services to the bulk system.

Example: Residential Air Conditioning Response

Residential air conditioning provides an example of an existing distributed demand response technology. Residential AC response programs can provide peak reduction and they can provide contingency reserves. They can also be credited with capacity value. Residential AC can also participate in real time pricing programs. Residential AC response is particularly valuable because it is typically available during peak load times when energy and ancillary services are expensive and when generation is typically in short supply.

From the loads' perspective, in addition to the technical requirements of the reliability function to be provided such as response speed, frequency, and duration, other important characteristics include sensitivity to electricity price and storage capability. Storage of intermediate product or energy at the load's premise is valuable to free the load to respond

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[13] North American Electric Reliability Corporation, *2009 Summer Reliability Assessment*, May 2009, p. 10, http://www.nerc.com/files/2010%20Summer%20Reliability%20Assessment.pdf

to power system needs without hurting the loads' primary function. Sensitivity to electricity prices is typically required for the load to be incentivized to respond to power system needs.

The majority of demand response programs currently in use are designed to reduce peak demand. Demand response programs might also provide contingency reserves, as is the case in ERCOT. Most recently a few loads have started to provide minute-to-minute regulation, providing an example of one extreme of demand response capability.[14] Air conditioning loads (residential and commercial, central and distributed) can be ideal suppliers of spinning and non-spinning reserves.[15] Many pumping loads are good candidates (water, natural gas, and other gasses).[16] Any industrial process with some manufacturing flexibility is a good candidate (cement, paper, steel, aluminum, refining, air liquefaction, etc.). There are numerous other candidate load types.

Demand response technologies not only respond to the signals of a utility, load-serving entity or other demand response provider, but may also be designed to respond directly to conditions of the bulk power system, such as a change in system frequency. Competitive market forces enabled by the deployment of advanced metering infrastructure and dynamic pricing are expected to continue to develop more customer-based demand response and greater consumer control over energy usage. Further, the advancement of demand side technologies are expected to yield cost-saving opportunities for consumers as well as increased opportunities for using demand reductions as real time energy resources. Thus, demand response-based energy resources have the potential to support bulk system reliability as variable generation increases the need for certain reliability services.

Plug-in Electric Vehicles

Policy makers and energy industry professionals foresee the modernization of the electric grid moving forward in partnership with the electrification of the transportation sector. The development and use of the plug-in electric vehicles (PEV) typify this nexus. While PEVs may eventually present a significant new load on the electrical system, they may also provide new

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[14] B. Kirby, M. Starke, S. Adhikari, 2009, *NYISO Industrial Load Response Opportunities: Resource and Market Assessment*, New York State Energy Research and Development Authority, Oak Ridge National Laboratory,

[15] B. Kirby, J. Kueck, T. Laughner, K. Morris, 2008, *Spinning Reserve from Hotel Load Response: Initial Progress*, ORNL/TM 2008/217, Oak Ridge National Laboratory, October

[16] B. Kirby, J. Kueck, 2003, *Spinning Reserve from Pump Load: A Technical Findings Report to the California Department of Water Resources,* ORNL/TM 2003/99, Oak Ridge National Laboratory, November

opportunities for improved operational management and gird efficiency. PEV can be organized according to three broad categories:

- Plug-in Hybrid Electric Vehicles (PHEV): Vehicles that contain an internal combustion engine and a battery that can be recharged through an external connection to an electricity source. They have larger batteries than traditional hybrid vehicles (2-22 kWh) that allow them to be operated in an all-electric driving mode for shorter distances, while still containing an engine, effectively giving them an unlimited driving range.
- Extended Range Electric Vehicles (EREV): PHEVs with larger batteries (16-27 kWh) capable up 40-60 miles on a single charge. An EREV's battery can be recharged from an electrical connection or the internal combustion engine providing for unlimited range.
- Battery Electric Vehicles (BEV): All-electric vehicles with no supplemental on-board combustion engines. BEVs have the largest of the PEV batteries (25-35 kWh) and require re-charging from an external source of electricity at the end of their driving range, which varies greatly, between 60 and 300 miles depending on the vehicle.[17]

This report refers to these vehicles collectively as PEVs. As these technologies mature, their connection with the electric power system is likely to evolve.

Control of electric vehicle charging can provide significant reliability benefits to the power system. With sufficient communications and control vehicle chargers could provide regulation, contingency reserves, peak reduction, minimum load relief, and response to variations in renewable energy production. While still several years away from commercial application, a number of industry research efforts to evaluate the viability and benefits of this concept have been conducted.

Distributed Stationary Energy Storage

Most of the following description of energy storage technologies is based on EPRI energy storage resources[18,19].

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[17] *Assessment of Plug-In Electric Vehicle Integration with ISO/RTO Systems*, KEMA, Inc and Taratec Corporation, ISO/RTO council, March 2010, p. 13.

[18] *EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications,* EPRI, Palo Alto, CA, and the U.S. Department of Energy, Washington, DC: 2003. 1001834

Energy storage has the potential to play a critical role in the future of the electric industry, offering much needed capabilities to maintain grid reliability and stability. Other than pumped hydro facilities (which are central rather than distributed resources), however, utility-scale energy storage projects have been built in limited numbers in demonstration type efforts due primarily to lack of cost-effective options. With increasing requirements for system flexibility as VG levels increase and potential predicted decreases in energy storage technology costs, distributed stationary energy storage applications may become more viable and prevalent.

Storage may be used for load shifting and energy arbitrage – the ability to purchase low-cost off-peak energy and re-sell the energy during high peak, high cost periods. Storage also might provide ancillary services such as regulation, load following, contingency reserves, and capacity. It could also prove beneficial in storing excess output from variable renewable generation, and therefore avoiding curtailment due to minimum load or network congestion reasons.

Figure 4 compares various energy storage options based on typical device power capacity relative to discharge time. As such, each technology can be generally categorized as to typical system applications for which they are applied.

Solid Electrode Electrochemical Batteries

Lead-acid, nickel-cadmium, and sodium-sulfur batteries are rechargeable electrochemical batteries. Electrochemical batteries store energy in chemical form by using input electricity to convert active materials in the two electrodes into higher energy states. The stored energy can then be converted back into electricity for discharge later. Lead-acid batteries are the oldest and most mature form of rechargeable electrochemical battery. Lead-acid batteries use lead electrodes in sulfuric acid electrolyte. They have been in commercial use for well over a century with several utility applications at both distribution and transmission levels including the Southern California Edison Chino plant and the Puerto Rico Electric Power Authority Sabano Llano plant. Most of the lead-acid battery systems were considered technical and economic successes, but the initial expense of such plants and their uncertain regulatory status resulted in limited follow-up to these projects.

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[19] *EPRI-DOE Handbook Supplement of Energy Storage for Grid Connected Wind Generation Applications,* EPRI, Palo Alto, CA, and the U.S. Department of Energy, Washington, DC: 2004. 1008703

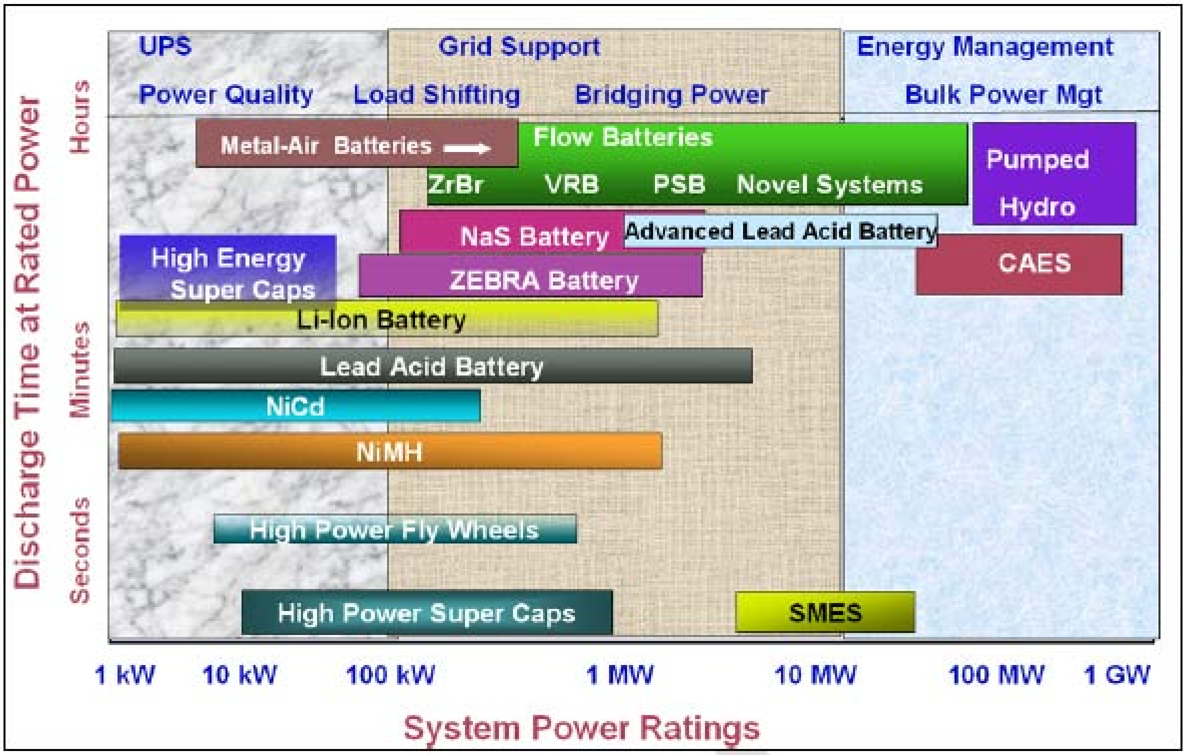

Figure 4: Energy Storage Options: Discharge Time vs. Capacity Ratings[20]

Nickel-cadmium batteries are similar in operating principal to lead-acid batteries, but with nickel and cadmium electrodes in a potassium hydroxide electrolyte. The best-known utility project constructed with nickel-cadmium batteries is the Golden Valley Electric Association Battery Energy Storage System (GVEA BESS), completed in 2003 in Fairbanks Alaska. The GVEA BESS is sized to provide 27 MW for 15 minutes or 46 MW for 5 minutes. It is used primarily for spinning reserve for the Fairbanks region.

Sodium-sulfur batteries are based on a high-temperature electrochemical reaction between sodium and sulfur. The Tokyo Electric Power Company (TEPCO) and NGK Insulators, Ltd., have deployed a series of large-scale demonstration systems, including two 6 MW, 48 MWh installations at TEPCO substations. In 2002, the first NAS battery was installed in the U.S. at an American Electric Power (AEP) laboratory at Gahanna, Ohio. Sodium-sulfur batteries are expected to be considered for peak shaving and load leveling applications at the distribution level if costs decrease.

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[20] *Energy Storage Program: Electric Energy Storage Technology Options: Primer on Applications, Costs and Benefits*, EPRI, Palo Alto, CA: 2009.

Liquid Electrode Electrochemical (Flow) Batteries

Flow batteries are electrochemical batteries that use liquid electrolytes as active materials in place of solid electrodes. These electrolytes are stored in tanks sized in accordance with application requirements, and are pumped through reaction stacks which convert the chemical energy to electrical energy during discharge, and vice-versa during charge. Flow batteries are attractive for long duration discharge applications requiring energy to be delivered for several hours. The nature of flow battery systems makes them particularly suited to large-scale systems. Flow batteries are a relatively immature technology and have not yet been tested widely. There are several types of flow batteries of which two types are available commercially: vanadium redox flow batteries, and zinc-bromine batteries.

Flywheel Energy Storage

Flywheels store energy in the angular momentum of a spinning mass. During charge, the flywheel is spun up by a motor with the input of electrical energy; during discharge, the same motor acts as a generator, producing electricity from the rotational energy of the flywheel. Flywheels are capable of several hundred thousand full charge-discharge cycles and so enjoy much better cycle life than batteries. They are capable of very high cycle efficiencies of over 90%, and can be recharged as quickly as they are discharged. Beacon Power Corporation manufactures high energy-density flywheels for frequency regulation applications at the transmission level. Beacon currently has 3 MW of flywheels operating in the ISO-NE market and 60 MW under development in 3 other projects in the NYISO and MISO markets.[21]

Thermal Storage

Thermal storage works by keeping a fluid in an insulated thermal reservoir above or below the temperature required for a process or load. A common application is production of ice or chilled water (or other fluid) for later use in space cooling. Similarly, water or other fluid can be heated for later use in space heating or for domestic hot water. Distributed-connected thermal energy storage options are commercially available, and the application is typically peak shaving or demand shifting in response to time-of-day rates. Energy density is much higher when there is a phase change involved (e.g., conversion of water to ice). This method is called latent heat storage, and it offers advantages versus sensible thermal storage (no phase change) when size and weight are important considerations. Like residential and commercial AC, distribution-connected thermal storage can be cycled over short time frames to provide regulation, load following, and contingency reserves. From the bulk system point of view, distribution-connected thermal storage is a form of demand response.

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[21] Chet Lyons, “Application of Fast-Response Energy Storage in NYISO for Frequency Regulation Services,” Presented at the UWIG SPRING TECHNICAL WORKSHOP, April 15, 2010.

Chapter 3: Potential Reliability Impacts of DER

Introduction

Potential adverse reliability impacts of high penetration of distributed resources (relative to the circuit load) on the distribution circuits to which the DER is interconnected are well documented.[22,23,24] Potential adverse reliability impacts of the DER, in aggregate, upon the bulk power system are less well understood, however. This chapter identifies and describes these potential bulk system reliability considerations.

For purposes of this report, DER includes generation, dispatchable/responsive load, or energy storage resources that are interconnected into the area Electrical Power System (EPS) through a low to medium voltage feeder (up to for example 34.5kV) that serves load. In the U.S., the majority of load-serving feeders are operated in a radial (or potentially open-loop) configuration; though in some areas (e.g. metropolitan areas) load-serving feeders may be meshed in a network arrangement. Aggregately, high penetrations of DER offer potential benefits to the BES in that they can be used in peak-shaving operation to extend the load serving capability of a balancing area's generation fleet and import capability and/or to provide ancillary services as detailed in the NERC IVGTF Task 1-5 report.[25] Clearly much of this potential benefit depends on whether or not the output of the DER is controllable or occurs at times of peak demand. At the transmission level, the primary concern with DER is that, due to its lack of visibility and non-centralized control, it may complicate operation of the power system in several ways.

The potential adverse BES reliability impacts of high penetrations of DER include several different aspects. DER affects the power flow on the transmission and sub-transmission systems, which can result in thermal overloads or significant changes in profile. Without any visibility or controllability from the BES level, the uncertainties associated with the variable DER output (in aggregate) can create additional uncertainties in demand to be served by transmission resources. Distributed generation can change the voltage and frequency response of the power system by displacing conventional generation which would otherwise

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[22] *Planning Methodology to Determine Practical Circuit Limits for Distributed Generation: Emphasis on Solar PV and Other Renewable Generation*. EPRI, Palo Alto, CA: 2010. 1020157.

[23] *IEEE Std 1547.2™-2008, IEEE Application Guide for IEEE Std 1547™*, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

[24] Walling, R.A., Saint, R., Dugan, R.C., Burke, J., Kojovic, L.A., Working Group on Distributed Generation Integration – "Summary of Distributed Resources Impact on Power Delivery Systems," *IEEE Transactions on Power Delivery*, Volume: 23 Issue: 3 Publication Date: July 2008 Page(s): 1636 - 1644

[25] NERC IVGTF Task 1-5, "*Special Report: Potential Reliability Impacts of Emerging Flexible Resources,"* December 2010, http://www.nerc.com/files/IVGTF_Task_1_5_Final.pdf

be online, or by forcing responsive generation to operate closer to its limits (changing the available range of operation on responsive units). An aggregate loss of distributed generation can affect the bulk power system if it does not remain connected, or if output is altered, during and following depressed frequencies and voltages that occur during transmission system disturbances. A lack of coordination between the planning and connection of distributed resources with overall system planning can make it difficult to incorporate accurate information in system planning and reliability analysis for the bulk power system. These potential concerns are reviewed in more detail in the remainder of this chapter.

Timeline to Address Potential Impacts to Bulk Power System

When DER resources comprise only a small portion of the overall system generation, the impacts on the bulk power system are typically insignificant. Technical requirements for interconnected DER to mitigate bulk power impacts and/or changes on the bulk power system necessary to mitigate the impacts of DER can be difficult to justify in advance of a high penetration. However, due to the rapid pace at which DER resources can be brought online and estimates for significant growth in coming years, it is critical to identify and develop any needed reliability tools and requirements necessary to preserve bulk power system performance in advance of high penetration on the system, to avoid possible negative impacts.

DER has become a significant contributor in some power systems in a short time period when economic or other incentives have been established to encourage development. An environment which encourages DER may be created by high costs of energy in general, which increases the attractiveness of DER for cost stabilization for the consumer. Another driver of rapid development of DER is subsidies such as tax incentives or tariff mechanisms such as net energy metering and feed-in tariffs. The expedited technical review and interconnection processes typically available for DER result in a much shorter time frame from application to installation than generation connected to transmission systems. Further, the impacts of DER in aggregate on a power system are not studied through the interconnection process for DER, which focuses on the impacts to a given distribution circuit or, at most, area network impacts from the project or group of projects. As a result, technical issues relating to impacts of DER on the transmission network as a whole are not investigated.

Figure 5 shows the growth of distributed PV from load-offsetting PV and Net Energy Metering on the Hawaii Electric Light Co (HELCO) system from 2001 to 2010 as a percentage of 160 MW, a typical daytime demand level for HELCO. HELCO expects additional projects from a proposed feed-in-tariff to increase the installed DER capacity by 10 MW or 6.25%.

In Spain, subsidies through a feed in tariff for solar PV created in 2007 resulted in more than 2600 MW of solar PV being installed in 2008, which was far more than predicted.[26] As a result, Spain altered the incentive structure to control the pace of new capacity additions. It should be noted, however, that the subsidies have resulted in Spain being a leader in solar PV with a total installed capacity of over 4 GW anticipated at the end of 2010.

In Germany, a rapid growth of solar PV has occurred largely as the result of a feed in tariff. Solar PV energy accounts for approximately 17 GW of installed RES capacity, of which 80% is in low-voltage distribution grids and 70% is from resources of less than 100 kWp. Approximately 7.4 GW of new capacity was added in 2010 alone. The fast growth of distributed resources led to the issuance of new grid connection requirements for generators connected to medium voltage (the equivalent of distribution voltages in the North American power systems) in June 2008. These grid codes contain generator requirements specifically designed to improve the impacts of DER resources on the bulk power system stability through transient and steady state conditions.[27]

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[26] Couture, Toby D. (February 23, 2011). "Spain's Renewable Energy Odyssey". Greentech Media. http://www.greentechmedia.com/articles/read/spains-renewable-energy-odyssey/. Retrieved 2011-03-06

[27] Martin Braun, "Integrating PV in Local Distribution Systems – German" IEA PVPS Task 14 Meeting Golden Colorado, USA December, 2010

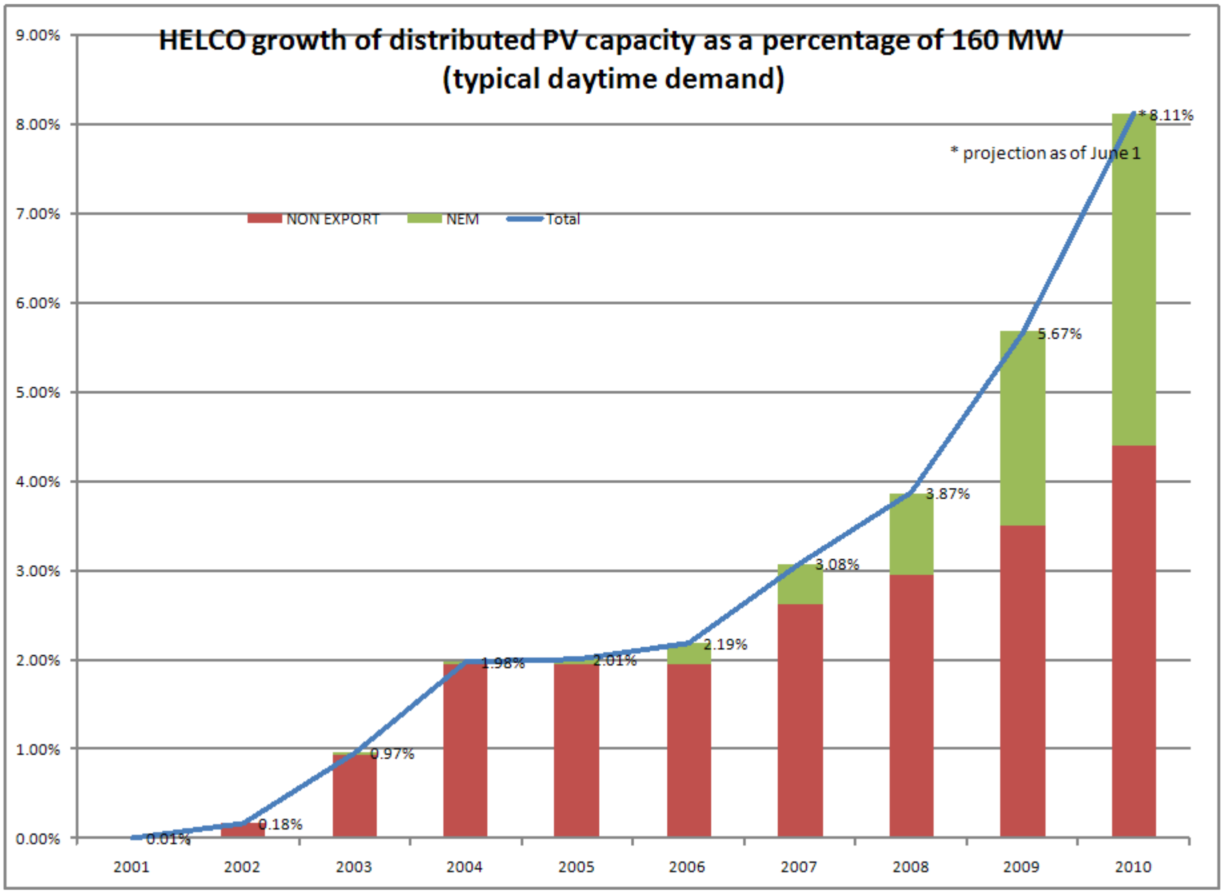

Figure 5: Growth of distributed solar PV on the Hawaii Electric Light system showing contribution from non-export (load-offsetting) and Net Energy Metering

From the above examples, DER penetration levels are reaching levels that can impact on the bulk system in some areas. This potential impact is expected to spread and increase in the next decade with the large anticipated increase, particularly in solar PV.

Ramping and Variability Impacts

An additional layer of complexity to the integration of large amounts of DER is added when the DER prime-mover is a variable energy source that does not allow for complete operational control. This is the case for DER whose "fuel" source is wind velocity or solar irradiance. The source of the additional complexity is the variability of the resource and the uncertainty with which the output of the DER can be predicted at any particular instant in time. Some of the potential bulk system reliability impacts due to the variability and uncertainty of distributed wind and PV are similar to of the impacts of bulk system variable generation: all variable generation contributes to system balancing, and may also contribute to excess energy conditions depending on time of production and correlation of the variable resources with other variable resources. Variable generation DER differs from bulk system variable generation, however, in that most existing bulk variable generation is from large wind plants whereas most variable DER is expected to be from small, distributed solar PV plants, which may result in the following fundamental differences in the nature of bulk system variability seen at the bulk system from variable DER: the diversity in output variability and uncertainty across many small solar PV installations over a large geographic footprint may prove to provide more smoothing in output variations once the resource is available (sun rises), but more correlation in output as the sun rises and sets daily.

For any variable resource, the tendency of the resource output to correlate with load will be a factor in the ability of the system to accommodate it. A resource that generates energy in proportion to the load served is more useful than a resource that generates energy in inverse proportion to the load served. Variable generation DER units often fall somewhere in-between these two extremes. Often variability is semi-controllable in that there is a maximum upper bound that a DER unit could theoretically produce and the unit can be controlled to produce less than this limit, but not more than the limit. Semi-controllable variability and uncertainty are present to varying degrees in all generation resources, however, the levels of variability and uncertainty of conventional generation are such that they may be ignored or modeled using well-understood probabilistic approaches in combination with a deterministic overall structure that uses reserves to cover unexpected outages. In contrast, the variability and associated uncertainty of the majority of variable energy source DER is such that these effects must be accounted for in order to ensure system adequacy (or prevent system operators from having to carry large reserve margins). It should also be noted that DER types other than distributed PV and wind could have impacts on the variability and predictability of apparent demand seen by the bulk system, in particular uncontrolled EV charging.

DER can cause significant changes in the system apparent demand patterns, due to the offset of the local demand. Analyzing or measuring the impact of variability from the variable generation DER is complicated by the fact that the typical capacity factors, production profile, degree of variability and correlation between sites is not often known to the planners and operators, and there is generally limited or no visibility and control of numerous small resources to collect such information. It is known that there is a large potential for fast ramping and fast variation in output of individual variable generation DER. As noted previously, however, it is theorized that diversity due to geographic dispersion of the resources will prevent such changes from being completely correlated and lessen the degree of variability for the aggregate DER output.

Reactive Power Control

DER is not allowed to regulate voltage if installed under the typical IEEE 1547[28] requirements, which states that a distributed generator is prohibited from regulating the feeder voltage. As a result, if high penetrations of DER that complies to 1547 aggregately displace central station generation which is providing voltage regulation, it can result in significant changes to the voltage response of the bulk power system during disturbances. This consequence might be mitigated if the DER provides voltage or reactive power control based on the secondary voltage level to which they are connected, but the voltage regulation of DER would need to work in concert with all voltage regulation mechanisms on the circuit. The controls would need to be tuned to the grid voltage response, and there may need to be two control loops based on the voltage and the power output.

Loss of DER during Low Frequency and Voltage Conditions

In order to allow distribution system protective schemes to operate and to avoid potential unintentional islanding, it has been the practice of utilities in North America to set up distributed generation to trip during off-normal frequency and voltage conditions. This practice is in accordance with IEEE 1547 recommendations, as tripping DG during off-normal voltage and frequency conditions is a relatively simple and inexpensive means to avoid potential power quality problems associated with unintentional islanding. Unintentional islanding can occur on a distribution circuit with installed DG if the circuit is opened and creates an island with the circuit supplied by the distributed generator. The typical IEEE 1547 trip settings are intended to ensure the DG disconnects so that the distribution protection can properly clear the originating disturbance and preclude the possibility of unintentional islanding of the circuit.

The problem is that the IEEE 1547 requirement that DG trip during abnormal voltage or frequency events is directly opposed to NERC reliability requirements that generators remain connected during frequency and voltage disturbances.[29] The IEEE 1547 settings can result in DER tripping even when it is not required for distribution protective system to clear a fault or for anti-islanding. When DG levels are significant relative to the size of the system to which they connect, system disturbances can result in a significant aggregate loss of generation to the system due to nuisance tripping of the DG. At very high DG levels this could result in a contingency that is much larger than the power system is designed to survive that could potentially lead to a cascading blackout. As noted in IEEE 1547, the settings are designed to protect circuits, but do not consider system impacts. The fact that this approach will result in

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[28] *IEEE Standard for Interconnecting Distributed Resources wind Electric Power Systems*, IEEE Standard 1547-2003, July, 2003

[29] See draft standard PRC-024 *Generator Performance During Frequency and Voltage Excursions*, for example.

reliability impacts due to unnecessary tripping when the penetration of DG is high, is understood in the industry, but in most North American power systems is only a theoretical issue as penetration is low relative to the interconnected power system. This conflict in requirements of the bulk system and distribution systems is such a concern that NERC IVGTF Task 1-7 is solely focused on identifying a solution to the potential resulting bulk system reliability concern.

While penetrations of DER are not yet significant enough for this issue to be realized in most systems, it has been recognized on the Hawaii Electric Light Co (HELCO) power system. HELCO is a small autonomous power system in the state of Hawaii with a maximum system demand of just less than 200 MW. For this system, the typical IEEE 1547 trip settings represent voltage and frequency deviations that commonly occur during generator contingencies and transmission system faults (the transmission voltage is 69 kV). The system has a relatively large amount of distributed generation, primarily PV, which in late 2009 reached a level of up to 5.5% of a typical day peak, projected to increase up to 10% of a typical day peak in 2010. The impacts of the projected amount of DG on HELCO have not been completely analyzed; in particular, study is necessary to understand the possible impacts of DER loss during system low-voltage events. The possible aggregate loss of DG during underfrequency was of the most immediate concern due to frequency being a system-wide parameter, resulting in possible loss of all connected DG, if all have similar trip settings. An aggregate loss of generation during low-frequency worsens the existing low-frequency condition. An assessment of the power system response during low-frequency, which included modeling the aggregate loss of DER connected with typical IEEE 1547 settings, found the HELCO system was significantly affected at relatively small amounts of DER with typical IEEE 1547 underfrequency trip settings. The impacts included lower system frequency minimums and/or additional load-shed during loss of generation events. This HELCO analysis supports the observations of HELCO Operations personnel that load-shedding is occurring for losses of generation that previously did not result in underfrequency load-shed. The impact is exacerbated during periods when few responsive units are available and there are limited reserves in the “up” direction on the responsive units. As a result of the findings, HELCO requested DER operators change the frequency trip settings for existing and anticipated DG projects to levels which coordinated with the underfrequency load shed scheme, where possible. By extending the clearing time, it is expected the inverters should continue to work through low-frequency events. HELCO plans to verify this through field measurements during disturbances.

Similar to the underfrequency trip concern, the bulk power system can be affected by the aggregate loss of distributed generation (DG) connected according to minimal IEEE 1547 guidelines for under voltage disturbances due to grid faults. According to IEEE 1547 recommendations, if the system voltage drops below 50%V then the DG must be cleared in 0.16 seconds. If the voltage is less than 88% V and greater than or equal to 50% V, distributed generation will be tripped off-line in 2.0 seconds. The DG trip settings dictate that they must be cleared in 160 milliseconds, or approximately 10 cycles. The clearing time includes the time for the interrupting device to act, which means that the decision time to initiate may be far less than 10 cycles based on the interrupting device. This issue requires additional investigation. Unlike system frequency, voltage disturbances result in levels that vary throughout the network and therefore the impact can be specific to the location and proximity to faults. Of particular concern is the effect of a large aggregate loss of the DER during a system low-voltage condition, which will result in additional apparent demand on the system as the circuit load is effectively increased with loss of the DER, which can then cause an additional reduction in voltage.

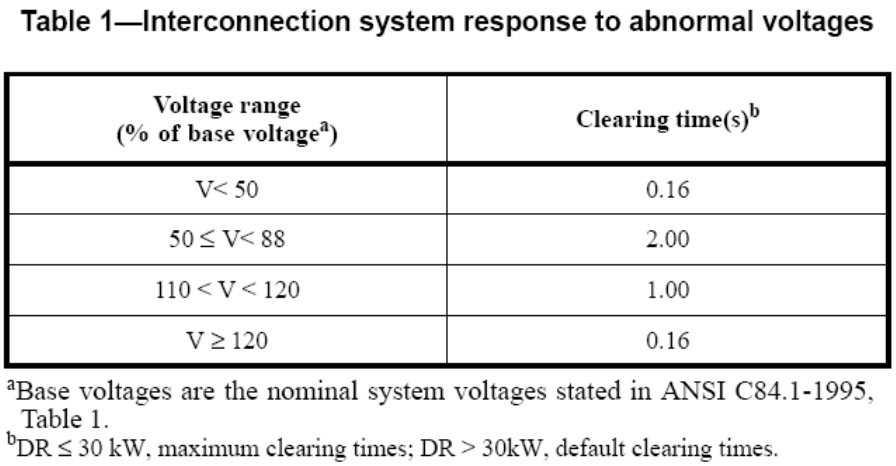

Table 1—Interconnection system response to abnormal voltages

Voltage range (% of base voltage[a])	Clearing time(s)[b]
V< 50	0.16
50 ≤ V< 88	2.00
110 < V < 120	1.00
V ≥ 120	0.16

[a] Base voltages are the nominal system voltages stated in ANSI C84.1-1995, Table 1.

[b] DR ≤ 30 kW, maximum clearing times; DR > 30kW, default clearing times.

System Protection Considerations

As DER penetration increases, the impact of the DER on system protection requirements of the bulk power system should be evaluated. However it can be challenging to incorporate these effects into the bulk power system planning tools, due to often limited data available about the capacity and power production profile of the DER and the behavior during disturbance conditions.

Generators that use inverters to interface to the grid (e.g. DFIG wind turbines and solar photovoltaic) are generally current limited devices. As a result, these generators can only supply relatively small amounts of short circuit current. Typically, inverter short circuit current is limited to a range of 1.1 to 1.4 per unit. As the penetration levels of these generators increases and displaces conventional synchronous generation, the available short circuit current on the system will decrease. This may make it more difficult to detect and clear system faults.

Under Frequency and Under Voltage Load Shedding (UFLS/UVLS)

At high levels of DER, the effectiveness of existing underfrequency and under voltage load shed schemes may need to be reviewed. Due to the influence of distributed generation, the profile of circuit loads can change and may no longer conform to the assumed circuit demand curve. For example, with a large amount of native solar DER, a circuit may have less apparent demand to the transmission system during daytime periods than during nighttime periods even though the load itself is greater during daytime periods. If the circuits are part of an underfrequency or under voltage load-shed scheme during periods of high DER production, the reduction in system demand may be less than assumed in the design of the scheme and will not result in the loss of load being proportional to the overall demand curve. If the quantity of DER is large enough to actually result in export to the bulk power system, isolation of the circuit as part of a load shed scheme could result in increasing, rather than reducing, system demand. Under- voltage load shed schemes may need to be revised to take into account the effect of loss of DER during low-voltage events.

Visibility/Controllability of DER at Bulk System Level

The dynamic nature of distribution system can cause more uncertainty in the planning process. The distribution system changes configuration and load much more dynamically than transmission. Demand served can shift from one circuit to another, or go away entirely due to a change in business or economic conditions. As a result, DER which may have been load-offsetting on one circuit may export to the transmission system due to decline in load. There is limited visibility of changes on the distribution system to the bulk system operator.

Lack of visibility will have an impact on metering of demand and generation, which will not be as easy to analyze with large amounts of DER, particularly variable DER. Potential market mechanisms/impacts will arise from the addition of DER which is less visible and controllable for system operators – markets may have to adopt to receiving energy and ancillary services from the distribution network, which will require new mechanisms to ensure market efficiency. Another impact of lack of visibility is the effect on scheduling large generation units, due to lack of forecasting; in particular the cycling of base-loaded units to meet the increased variability in apparent load. This impacts on the efficiency of these plants, and will require that the flexibility of the plant mix to manage variability and uncertainty be incorporated into generation planning. If the facility happens to be within a market footprint, market rules may require the facility to provide metering for accurate models for market settlements. Unless required by the state driven tariff, interconnection agreements, or market rules, there are presently no requirements for the facilities to provide meteorological data for forecasting.

One of the operational impacts that lack of visibility of DER, particularly variable DER, can have is to negatively affect the accuracy of load forecasts, due to generation that is not visible to the system operator. The underlying load may not change due to DER; it is just that some loads are being compensated by DER. This will have the effect of detuning the accuracy of the load forecast. Variable generation DER compounds this issue in that the variations of the DER generation can be random and difficult to forecast. In theory, it should be possible to include a correction term into the load-forecasting algorithm if the exact locations and power production specifications of the variable DER is known. Presumably the correction term would be developed by creating a forecast for the variable DER. In some cases there is a relationship of the resource to the load at the point of interconnection and many cases the resource has no relationship to the load on the distribution system.

At this time, evaluation of the variable DG impacts is difficult due to the absence of data. The aggregate impacts of numerous small DER will typically not be visible to the system operator. The typical capacity factors, variability, and correlation between sites are not known. Larger

DG sites may have a monitoring and control interface, but at this time, commercially available, cost-effective means through which to communicate and control numerous smaller DG throughout the system and bring the data to the System Operator are not in place.

Through the Smart-Grid initiatives and other ongoing efforts for communications and controls to the distribution systems, it is hoped there will emerge technologies and commercial solutions for this purpose.[30] Visibility and control over a large number of small resources for the system operator would facilitate capturing the impact of aggregate DER on the demand from transmission-side resources as well as refining forecasting models; this may be feasible with the development of "smart-grid" technologies. If this is the case, then the impact of variability and uncertainty will be similar to that seen when connecting wind generation to the transmission level

Research into monitoring and control of DER will become important as the total penetration level reaches a level which significantly affects real-time operational decisions. A forecast of the variable DER will be necessary for unit scheduling and may require changes to reserve policies for effective frequency control. System restoration can be affected by DER due to the automatic reconnection of non-controllable DG. This will require evaluation when significant levels of DER are achieved and incorporated into operational restoration plans.

DER connected behind the meter of a customer taking service at the transmission level can create a reliability concern. In some cases these resources are requesting transmission service but in some cases, no transmission service is being requested and therefore the impact to the system is not being studied by the transmission planners. Without the resource requirement to schedule their output and therefore having no associated transmission service, there is confusion within the industry about the ability to curtail these resources. If the resource is within a market footprint and subject to market clearing prices, there will be financial incentive to reduce output. The conflict arises for the models that are used to sell transmission service. If the facilities on the distribution system are not in the models that are used for the sale of transmission service, the impact of those resources are not considered when selling transmission service. The generation resources on the distribution system will have the same or similar impact on power flows that resources on the transmission system have that have acquired transmission service.

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[30] NERC – *Reliability Considerations from the Integration of Smart Grid,* December 2010 http://www.nerc.com/files/SGTF_Report_Final_posted_v1.1.pdf

Chapter 4: Overview of Related Study Work

There has been interest in DER for some time due to a variety of reasons which include such potential benefits as deferral of transmission and distribution (T&D) system upgrades, increased reliability for loads being served by DER (including increased resilience towards natural and man-made disasters), reduction in cost of electricity, and reduced T&D losses [1]. The actual definition of *distributed resource* is still a matter of some debate with differing definitions [2], although it appears as though consensus is beginning to form around the definition that distributed resources are “Sources of electric power that are not directly connected to a bulk power transmission system.” [3]. A distinction can be drawn between DER that is controlled in a dispatchable manner (a customer-sited standby generator that can be started at a few moments notice and whose output is tightly controlled) and DER whose participation in the power system is of a more stochastically variable and uncontrollable nature (e.g. a wind turbine whose power output generally depends on the forcing of the wind) [4][32].

Using resources embedded in distribution networks is a topic of much current interest; this is due to perceived potential problems and solutions that DER pose both at the distribution and transmission system levels. Several studies and academic work regarding the effects of integrating large amounts of variable energy DER have been performed. Additionally there is some experience in integrating large amounts of variable energy DER, though this experience is somewhat limited for most of the North American power systems.

An underlying issue for the majority of studies is how best to model a large number of generation sources spread out over the sub-transmission and distribution system; however, generally the results seem to indicate that DER will affect flows on the transmission system and, given enough DER, these flows may change in a fundamental manner [4]. In general, while DER may relieve congestion by offsetting load, it may be observed that DER that may export significant quantities of power onto the bulk system cannot be added to transmission systems that are fully used without causing thermal overloads [5, 6]. Significant penetration of DER can lead to mixed results with regard to transient and small-signal stability, with studies indicating that some types of DER can improve transient stability and that DER that has reduced (or no) inertia (e.g. inverter interfaced DER) can degrade the system small signal stability [7]. Further work has shown that the effect of significant penetration of DER on system transient stability is highly dependent on the control scheme used by inverter interfaced DER [8]. Additionally, the stochastic nature of variable energy DER complicates the stability analysis, and results from [9] indicate that systems with high penetrations of variable energy DER may in some instances be more stable and in other instances be less stable than indicated by results provided from deterministic transient analysis. Jahromi, *et. al.* show that the stochastic nature of variable DER also has a negative impact on the small-signal stability of small systems [10]. The higher impedance of the low voltage connection from DER to the main system may also contribute negatively to system stability [11, 9]. Guttromson also shows that DER can have a beneficial effect on stability by supplying reactive power.

As discussed in chapter 3, the reconciliation of Low Voltage Ride Through and Under Frequency disconnect requirements for transmission connected generation with the IEEE 1547 standard for interconnected DER still needs to be resolved. In the event of a frequency or voltage excursion, DER connected in accordance with IEEE 1547 will disconnect. For a high penetration of DER, this could negatively affect system reliability [12]. These concerns may be magnified if DER replaces large generators [13]. The degree to which stability concerns increase may be counter-intuitive [14]. In [14] the stability impact of increasing DER penetration first has little effect on system stability, then as levels of DER increase the system immediately becomes unstable, and at still higher levels of DER penetration the system returns to stability albeit at a reduced quality as compared to the system with no or only small amounts of DER—this appears to be due to the reduction of system inertia as penetration of DER increases (detrimental to system stability), in combination with reduction in power flows at higher DER penetration levels (beneficial to system stability). A 2008 study on the transmission level effects of significant solar PV distributed generation shows that the effects of high penetrations of solar PV DER are similar to those of high penetrations of wind power DER [15].

In direct contrast to IEEE 1547 and in recognition of the issues that connection of large amounts of DER under the modes required by IEEE 1547 can present, recently, Germany has enacted a grid code for medium voltage interconnection (i.e. distribution level voltages) that are more in line with grid codes applicable to interconnection with the transmission system, requiring for instance low-voltage ride-through, active power management (in a controlled and granular manner), and reactive power management capability [28]. Given the capability that will be required of the medium voltage connected generation by the German grid code, it is unclear how islanding will be prevented. As you increase LVRT, make sure anti-islanding schemes are sufficient. Concern about islanding and its potentially detrimental effects at the distribution level (e.g. on safety; and on generation, distribution, and load equipment damage) is one of the primary drivers of IEEE 1547. Much work is being performed on islanding, and Chowdury et al [26] provides a thorough review of work being done on the topic including proposed measures to decrease the negative consequences of islanding by, for instance, supplying DER with reference signals via FM or GPS based signals in order to maintain synchronism.

A recent study in Ireland examined technical and operational challenges associated with integrating large volumes of wind power there, with 40% of energy provided from wind, a significant portion of which is distribution connected, by 2020 [30]. Using detailed models, it examined a range of possible issues which could be seen with high wind: frequency, voltage and transient stability, voltage control, power balancing fluctuations, network loading and fault levels. It found that frequency stability, particularly after loss of largest unit, was the most fundamental issue (Ireland is a small synchronous system and therefore this may become an issue in that system at a different time than others). This would limit the maximum amount of wind to somewhere between 60% and 80% of the total generation plus maximum export, depending on how close to a minimum frequency the system is willing to go. An interesting result related to this report is that the rate of change of frequency (ROCOF) relays had a significant impact on the result. Due to cascading effects, active ROCOF relays at distribution connected wind farms may increase frequency deviations when wind makes up a large part of the generation. Disabling ROCOF relays increases the minimum frequency after a fault to a more acceptable level. Another study result of interest here showed that, by assuming an increase in the share of turbines connected to the distribution network (from 65% to 80%), the voltage stability of the system decreased.

To date there have been relatively few occasions where DER and/or variable energy DER have been involved in actual transmission system level incidents [20, 21]. The most notable is perhaps the sudden disconnection of a significant portion of, especially, older squirrel cage induction generator wind turbines due to under-frequency tripping during a disturbance in the UCTE portion of the European grid during November of 2006 [22, 23]. Another contributing cause to the disturbance was that the real-time generation and connection status of the DER was not visible to the System Operators, which clouded the situational awareness [22]. Another example of the lack of visibility of variable energy DER contributing to operational challenges for the transmission system, also from Europe, occurred during hurricane Gudrun (aka Erwin) in January 2005 [24]. Due to the high winds from the hurricane, a high-wind cut-out event occurred with a maximum drop of 600MW in one hour and an overall drop of 2100MW over ten hours of wind power. The wind speeds for much of the time during this incident were just above the wind turbines' cut-out wind speed, and the coincident wind power forecast was for wind speeds to remain just below the wind turbines' cut-out wind speed for a much longer period [25]. Though the Danish power system was able to accommodate the change in generation, incorporating meteorological data from the affected wind turbines (e.g. along the leading edge of the storm) would have resulted in a more accurate forecast and therefore more time for the system to react. One aspect that helped mitigate the rate of the drop in wind generation in this instance was the geographic diversity that the distributed nature of the wind power installations in Denmark. The salient point from this event for variable generation DER is that due to reduced operator visibility it may be more difficult to produce an accurate forecast and to make use of real-time information to adjust to changing conditions for variable generation DER. One technique used by, for example, the German transmission system operator E.ON is to use some combination of wind plants and meteorological data to create a region wide forecast that does not require information from every distribution system connected wind turbine [27].

The primary focus of this report is on the potentially adverse reliability impacts of increased amounts of distributed resources, but distributed resources can also be a responsive resource that aids the system operator to reliably integrate variable energy resources. As wind and solar increases power system variability and uncertainty, they increase the need for system flexibility to respond. Since wind and solar also displace conventional generation, they can reduce the amount of on line generation that is available to provide response. Demand response, PEVs, and distributed stationary energy storage may be able to fill this gap, benefiting renewables by facilitating integration, the responsive load through paid services, and all customers through lower costs. Demand response may be particularly appropriate to provide reserves specifically designed to respond to large, infrequent variable renewable ramps which are slower than conventional contingencies. 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 [31].

Responsive load is still the most underused reliability resource in North America. It has the potential to provide balancing capability over all time frames: from seconds to seasons. Historic demand response programs have focused on reducing overall electricity consumption (energy efficiency) and shaving peaks. More recently, responsive loads have started to provide contingency reserves and even minute-to-minute regulation. ERCOT currently obtains half of its contingency reserves from demand response. 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, typically providing greater response from the same resource. This is made possible by advances in communications and controls, and has benefits for the power system and the load [32].

The potential positive contributions of DER to bulk system reliability are addressed fully in the NERC IVGTF Task 1-5 report [33].

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Chapter 5: Potential Mitigation Approaches

As more and more variable generating resources connect to the distribution system there will be times when a substantial percentage of the load served by a Balancing Authority (BA) would be from DER. At high penetration levels, DER will adversely impact overall system reliability as noted in Chapter 3 unless system operators are provided visibility to real-time DER data and the ability to send dispatch signals to control DER. This chapter proposes potential solutions to some of the adverse reliability impacts of high levels of DER that are presented in Chapter 3. Note that solutions are not suggested for all of the problems identified in Chapter 3. Further, the detail included for potential solutions presented here varies.

In addition to stand-alone DER, smart grid devices and aggregated DER will bring new modes of operation with consequences of failure to the system that could have a negative impact on real-time control of the bulk system. As smart grid technology develops further, the nature of the grid topology will change more frequently with smart grid technology, and the impact of failure will change as the grid topology changes.[31] In one potential topology, distributed energy resources could have little or no impact on system reliability and integrity. In alternative operating topologies, bulk system control may be adversely or beneficially impacted.

Today, bulk power system operations are substantially isolated through various levels of transformation from the distribution and customer side of the business. With the development of smart grid technology, the separation between operations at wholesale and retail, and transmission and distribution may be increasingly blurred. For example, the bulk power system operations will need visibility into distribution operations when demand response, distributed generation, and distributed storage are offered as ancillary services. Thus, in order to maintain a secure energy supply and ensure adequate operating reserve margins are maintained, it will likely be necessary that minimum levels be established above which aggregated DER or smart grid networks at the distribution level should comply with appropriate guidelines, procedures and requirements to address potential reliability impacts upon the bulk electric system.

Potential Solutions and Recommendations for Addressing Challenges

Potential problems due to the integration of DER resources would differ from one location to the next depending on the size of the BA, flexibility of the BA's existing conventional

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[31] NERC – *Reliability Considerations from the Integration of Smart Grid,* December 2010 http://www.nerc.com/files/SGTF_Report_Final_posted_v1.1.pdf

generation fleet, its load profile, network topology and amount of DER on the system. In other words, the integration of 50 MW of DER in one location may create operating problems in the vicinity of that location and no problems if integrated in another location. It is therefore essential to establish recommendations and policies to help address these potential problems and in some cases a BA may have to:

- Develop operating policy/procedures to deal with potential real-time problems,
- Discuss technical challenges with developers and work with manufacturers to address identified challenges,
- Develop interim solutions until manufacturers are able to develop and market fixes,
- Modify existing state or NERC standards or requirements or develop new standards or requirements (recognizing that many DER issues are beyond NERC’s current scope).

Ramping and Variability Impacts

Variable DER adds variability and uncertainty to the bulk system, and at high penetration levels can impact the reliability of the bulk system as noted in Chapter 3. Variability is due to the fuel supply (wind and solar) while the uncertainty arises due to forecasting errors and the inability to predict the energy production patterns. The system impacts of this variability and uncertainty are not unlike that of bulk system variable generation. Accordingly, the tools required by system operators to mitigate these impacts are similar – good forecasts of the expected variable DER output levels over time and adequate flexibility from other system resources to follow the variability. Over-forecasting errors in production levels of DER resources would require dispatching of conventional resources to higher levels and under-forecasting errors in DER production levels would require the curtailment of conventional resources connected to the bulk system. In addition to the flexible capacity requirement from conventional resources, the system operator has to ensure adequate ramping capability is available to manage the dispatch of conventional generation within the operating hour. Likewise, the system operator has to ensure enough ancillary services is available to address any real-time imbalance between generation and demand.

Reactive Power Control

The existing NERC Standard VAR-002-1 “*Generator Operation for Maintaining Network Voltage Schedules*”[32] requires each generator connected to the transmission system to operate in an automatic voltage control mode. FERC Order 661-A states that wind resources connected to the transmission grid should be able to maintain a power factor within the range of .95 leading to .95 lagging measured at the high voltage side of the substation transformers.

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[32] NERC Standard VAR-002-1 “*Generator Operation for Maintaining Network Voltage Schedules*”, August 2, 2006

As conventional bulk system resources are displaced with DER, static as well as dynamic voltage control of the bulk system may be impacted as detailed in Chapter 3. Static voltage control is essentially the ability of a BA to control voltage under normal operating conditions so any voltage deviations from schedules can be kept within acceptable limits. As the penetration levels of DER increases, DER must be able to provide voltage control similar to conventional resources and transmission connected wind resources. Maintaining end-use customer voltages is essential; therefore DER should not cause the scheduled voltage at the distribution substation to exceed 1.05 per unit, or fall below 0.95 per unit. Further, a reasonable minimum response time constant for DER voltage, power factor or reactive power control may be comparable to a synchronous generator operating under similar grid conditions. Implementing such requirements for DER will obviously have to be carefully coordinated with distribution system planners and operators to ensure that distribution protection schemes and safety standards are not compromised.

Depending on the location of the DER, post contingency voltage drops could result in unintentional tripping of DER which may result in the requirement of some level of dynamic voltage support. As an example, Germany with an installed capacity of over 9000 MW of distributed PV has recognized the need to integrate DER into the dynamic support of the network and has proposed the following[33]:

- Prevent DER from disconnecting from the system due to faults on the system,
- Require DER to support the network voltage during faults by providing reactive power into the system, and
- Require DER to consume the same or less reactive power after the fault clearance than prior to the fault.

Loss of DER during Low Frequency and Voltage Conditions

FERC Order 661 A states that a wind resource should not disconnect from the system in the event the voltage drops to 0 volts at the point of interconnection and remains there for as long as 150 millisecond. NERC draft standard PRC-024: Generator Performance During Frequency and Voltage Excursions is extending that requirement to all new generators. The Germans are further proposing to have this same requirement apply to all DER.

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[33] German Technical Guidelines *"Generating Plants Connected to the Medium-Voltage Network, guideline for operating plants connected to and parallel operation with the medium-voltage network"*, bdew (Bundesverband der Energie – und Wasserwirtschaft), June 2008.

Similarly in the US, it is desirable for DER to stay connected to the system during fault conditions for similar duration of time. However, this requirement conflicts with IEEE 1547 standard as discussed in detail in Chapter 3. Should a significant amount of DER trip for faults, an added real-time burden would be placed on the bulk system.

It may be possible to mitigate the impact of nuisance tripping during under-voltage and under-frequency events by expanding the ride-through requirements. One issue created by expanded ride-through is that DER must also avoid unintentional islanding that could occur when the feeder breaker opens and cause problems at the circuit-level. IVGTF Task 1-7 is addressing solutions to this problem specifically, including suggested revisions to the ride-through durations for specific voltage levels that would still allow distribution system protection to operate as needed for distribution faults, but would allow more time for transmission protection systems to operate for bulk system faults without the loss of the DER that might accentuate the disturbance.[34]

Visibility/Controllability of DER

With smart grid technology, aggregation of DER resources, and the participation of distribution connected resources in ancillary services, additional communications and controls infrastructure will have to be installed on the system. The associated software systems need to be able to predict the actions of the end use customers and relay this information to the system operators of the bulk system. As realized on the bulk system, it is reasonable to assume that some distribution metering devices may not be synchronized to the grid and information may not be correctly time stamped. Coordinating and integrating distribution data with the bulk system energy management system data may create operational challenges.

Should the aggregated DER at a given substation become sufficiently high provisions must be in place to provide SCADA capability to transmit data and receive instructions from the transmission operator (TO) or BA. The TO or BA should determine what SCADA data is essential taking into account the size of the aggregated resource, location, and importance in maintaining generation resource adequacy and transmission system reliability. The facility must be able to respond to Automatic Dispatch System (ADS) instructions and any other form of communication authorized by the BA. The response time should be capable of conforming to the periods prescribed by the BA.

System Inertia and Frequency Response

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[34] D. Brooks and M. Patel, “Panel: Standards & Interconnection Requirements for Wind and Solar Generation NERC Integrating Variable Generation Task Force,” to be presented at 2011 IEEE PES General Meeting, Detroit.

As noted in Chapter 3, as DER displaces synchronous generation, there may be times when there is insufficient system inertia and primary frequency response to arrest frequency decline and stabilize the system frequency following a contingency. This could result in under-frequency relays picking up and disconnecting load from the system. Therefore, careful operating guidelines and communication and telemetry requirements must be in place to ensure system operators are aware of the total DER production in real-time.

Higher than scheduled or expected DER production levels can result in over generation conditions and ultimately over-frequency if the BA's conventional resources are already at minimum load levels and regulation down capability has been exhausted. It is therefore essential for DER to have the capability to automatically reduce energy output in response to high frequency once the aggregated DER capacity is sufficiently high. This frequency control system must continuously monitor the system frequency and automatically reduce real power output proportional to frequency deviations similar to governor action on conventional resources.

Active Power Control

Aggregated DER greater than or equal to some minimum level must have the capability to limit active power output in response to instructions from the BA. The aggregated DER must have the capability to limit power ramp rates automatically, except for downward ramps resulting from decrease of the available energy supply (wind and solar). The capability of the aggregated facility should extend from the minimum operating limit to the maximum operating limit in increments of 10% (or other suitable value – 10% is value for Germany) of the aggregated facility per minute.

The system operator should also have the ability to temporarily instruct DER to limit power production or disconnect from the system due to but not limited to issues such as:

- Reliability issues,
- Congestion or risk of overloads
- Risk of islanding,
- Risk to steady state or dynamic network stability,
- Rise in system frequency,
- Routine or forced maintenance,
- Reconnecting to the system post-contingency

Power Quality

Power quality, although a measure of the quality of service to the end-user, can provide intelligence and data on how the bulk power system is operating and can help in identifying equipment problems. System operators and planners need to be mindful of potential harmonic and flicker problems created by DER. Frequent switching of loads in response to smart grid technology may result in flicker. Although flicker and harmonic problems are expected to remain on the distribution level due to the robustness of the bulk power system and transformation between the two systems, aggregated DER may result in power quality issues on the bulk power system.

Chapter 6: NERC Registry Criteria/State Requirements

The NERC IVGTF "Special Report: Accommodating High Levels of Variable Generation,"[35] that established the need for the work presented in this Task 1-8 effort states that one of the primary outcomes of the effort should be a review of the Registry Criteria and recommendations as to whether DER owners and operators need to be recognized.

Summary of Existing NERC Registry Requirement Relative to DER

The NERC Statement of Compliance Registry Criteria (Revision 5.0)[36] specifies NERC's criteria as to which entities are required to register with NERC and accordingly be subjected to relevant NERC standards compliance, monitoring, and enforcement. The Registry Criteria generally states that registration is required for owners, operators, and users of the bulk power system, which is generally defined as 100 kV and above. This requirement alone would tend to exclude most DER from the NERC Compliance Registry (NCR), but there are additional criteria specified that provide additional guidance for specific NERC functional types as to whether registration is required. And as such, the NERC functional specifications map to certain NERC standards that must be followed for fifteen separate function types defined, however, the functions that potentially relate to consideration of DER are the following:

1. Generation Owner (GO) – owns and maintains a generator
2. Generation Operator (GOP) – operates generating unit(s) supplying energy and other interconnected system services
3. Distribution Provider (DP) – provides and operates the wires between the transmission system and the end-use customer
4. Load-Serving Entity (LSE) – secures energy, transmission service, and other interconnected system services to supply its end-use customers

The Registry Criteria for DP/LSE allows entities with a peak load less than 25 MW to be excluded from registration. It is not believed that either of these designations would potentially apply to demand response resource if aggregated to be of sufficient size.

The Registry Criteria states that in order for GO/GOP to be subject to registration, they must meet at least on of the following:

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[35] *Special Report -- Accommodating High Levels of Variable Generation*, NERC, http://www.nerc.com/files/IVGTF_Report_041609.pdf

[36] NERC, Statement of Compliance Registry Criteria (Revision 5.0), October 16, 2008. (http://www.nerc.com/files/Statement_Compliance_Registry_Criteria-V5-0.pdf)

- Individual generating unit > 20 MVA and directly connected to the bulk power system
- Generating plant/facility > 75 MVA and one or more units connected to bulk power system
- Blackstart unit or otherwise part of transmission operator's restoration plan

These criteria do not appear to be applicable to most distributed generators and especially not to small, individual residential or commercial PV installations that are expected to drive much of the DER development over the next few years.

Amending NERC Registry Criteria or Additional State Regulatory Programs

The existing NERC Registry Criteria do not presently appear to explicitly require registration that would provide visibility to most of the DER resources that might be developed going forward even if the aggregate DER capacity is high. The Registry Criteria does, however, generally state that *"NERC will include in its compliance registry each entity that NERC concludes can materially impact the reliability of the bulk power system."* Given the potential reliability concerns described in Chapter 3, it is conceivable that at some level of penetration, DER aggregately will "materially impact the reliability of the bulk power system." The penetration level at which such impacts might begin to be experienced will vary based on the design and operating practices of each system and on the regulatory environment under which the system operates. For example, vertically integrated utilities have fewer barriers to obtain all of the information that they need to achieve the requisite level of visibility than de-regulated systems where the transmission provider, load serving entity and distribution provider may not be the same entity. It should also be stated that the visibility of DER resources may be obtained through new or revised state programs potentially negating the need for amending the NERC registry. Because the bulk system is an inter-state system, however, there would need to be sufficient action across the states.

As noted in Chapter 3, large capacities of variable DER can be added to the distribution system in a short time frame if there are financial/regulatory incentives. Depending on the size of the BA, the threshold of the amount of PV or other variable distribution resources that can be incorporated without causing operational issues will vary. Additionally, if sufficiently high penetrations do evolve in a given BA, it is critical that the system operators have visibility of the DER through DER information flowing back to the control center(s) and that the planning contingencies are adequately captured. Presently, NERC Standards do not require that DER information be specifically supplied back to the control center(s). Most of the requirements for the metering of DER are set by state regulations and tariffs and these requirements are primarily focused on settlement purposes and not on operational needs.

These requirements, in many cases, are not currently sufficient to meet the information needs of the bulk system operators, although they could be revised. Nonetheless, all generation that is registered on the NCR must be metered and therefore providing generation information to the appropriate control center(s). Lastly, to aid the operator in balancing its control area, information as to the generation patterns and availability incorporated in the BA's resource forecasting tools would be advised in certain geographic areas.

One of the solutions to the Visibility and Control issue noted in Chapter 5 is that DER exceeding some minimum capacity should be required to supply operational information to the Balancing Authorities for the purpose of forecasting load and resources. In many cases, they are not. This information is needed to forecast necessary resource commitment, evaluating ramping requirements, identifying excess generation events, and resolving other issues noted in Chapters 3 and 5. In order to accommodate higher levels of DER, DER exceeding the same minimum capacity should allow for operational control of the resource(s) to address real time operational issues. Smaller commercial and residential DR will not have any real time personnel for manual control. These requirements are currently covered in COM-001 and FAC-001 for the resources that are required by the NERC standards. Further consideration needs to be given as to how these needed communications and controls requirements might be standardized for aggregations of DER exceeding some specified minimum capacity and whether compliance can be effectuated by new or revised market rules. In regions characterized by vertically integrated utilities, these visibility issues would likely be significantly mitigated due to the transmission provider, load serving entity and distribution provider all being the same entity. To the extent additional information is needed from a DER, such a vertically integrated utility would appear to be able to receive it directly from that retail customer or through new or revised state regulatory programs. While the regulatory/institutional barriers would be mitigated, technical considerations of communications infrastructure and aggregation requirements to supply information to the bulk system operators would need to be addressed regardless of regulatory environment.

DER generator resources connected to the distribution system will usually be smaller in size as compared to renewable resources connected on the transmission system. For the purposes of applicability to the NERC functional model, these smaller resources at the connection interface would not individually be covered by the NERC reliability standards. For resources that are made up of individual units less than 20 MW gross output rating or total facility connected to a common bus are below 75 MW rated gross output, they are exempt from the NREC compliance program unless they have been identified as material to the bulk electric system. Entities have been reluctant to use the material impact clause of the functional model.

While the aggregation of very small distributed PV resources (2-10 kW) represents one level of consideration of DER impacts, the impacts of larger distributed generators must also be considered. Some DER developers have developed several small generating facilities at distribution levels that in aggregate total up to a significant amount in a geographical area. This is a model that allows a developer that may not have a relationship to the load to integrate several smaller resources in the system without going through the system impact study process and the transmission service study process. When these aggregate resources are not procuring transmission service, they are not in the models that transmission service providers use to study new transmission service request, which can lead to incorrectly granting new firm service request. This can cause real time overloads that have to be mitigated through re-dispatch and the NERC Transmission Load Relief (TLR) process. Both of these procedures will impact firm users of the transmission system when the underlying cause may not be identified. These constraints will be accommodated through re-dispatch if available but a reliability issue could arise if curtailments are required, as resources with firm transmission may need to be curtailed. The Regional Entities through the TLR process may not see or be able to identify these DER resources for curtailment purposes. While it is clear that above some aggregate installed capacity level some provision needs to be made for such DER in system planning studies, there are still questions as to how best to achieve this goal. How do you coordinate studies across potentially numerous different entities? How do you forecast or predict DG placement in advance for longer-term studies? How do you manage the significant amount of additional data not required presently? As such, it is recommended that further consideration be given as to what guidelines, procedures, and/or requirements should be established to ensure DER resources are acceptably included in planning studies when their aggregate output is sufficient to impact reliability.

Presently, small DER facilities that may aggregately impact bulk system reliability may be exempt from the NERC reliability standards that would require compliance with reliability concerns if the same aggregation was composed of larger transmission connected resources. These standards would include but are not limited to communication requirements, planning requirements, facility requirements, and protective relay requirements unless specified in the interconnection or tariff agreements with the host transmission operator/owner. Since some of these connection agreements are state tariff driven, coordination with the states may need to be pursued to effectuate needed revisions or modifications to such existing state-regulated programs. Since any new requirements for communication or control can increase costs to either the resource or the distribution facility, making changes to tariff language can take significant time to agree on the requirements. To address these concerns, a concerted effort is needed to identify the necessary requirements that should be in place for DER resources.

Significant care needs to be taken to ensure that NERC Reliability Standards are not established where they are not needed. The NERC compliance process requires thorough attention to requirements that can result in potential significant costs to the entities subject to the standards. For large, transmission connected generation, telemetry, SCADA, intensive contingency analysis, special relaying systems, etc. are a small part of the project cost. These elements for medium to small DGs can represent a much higher percentage of the project cost and make a project economically unviable. Most state public utility commissions (PUCs) are under intense pressure to keep DG interconnection costs at a bare minimum. Any proposed standard changes that do not recognize these very different economics of distributed resource projects will likely not be readily accepted.

In addition, seeking to make DER subject to NERC requirements may raise legal issues that are beyond the scope of this report pertaining to (among other things) impacts upon state jurisdiction and whether such DER resources are users, owners, and operators of the bulk power system for purposes of Section 215 of the Federal Power Act. Accordingly, many (perhaps all) of these DER-related reliability issues may be best addressed through coordination with state regulators and the industry rather than by expanding the NERC registry. The bulk system, however, is an interconnected system spanning numerous states such that inadequacies in requirements in a few states could impact the entire system. As such, addressing these issues through state regulation and programs would require that sufficient action be taken across all states in the interconnected system.

Regardless of the jurisdiction through which the issues are addressed, the considerations as to what guidelines, procedures, and/or requirements should be enacted needs to be based on sound, rigorous analysis of the expected impacts for various levels of DER for various system types. Such quantitative analysis will provide a foundation for understanding the potential magnitude of reliability impacts at increasing levels of DER penetration and will help to ensure that unnecessary costs are not forced on distributed resource development projects. This analytical basis does not yet exist, but should be undertaken by industry.

Chapter 7: Conclusions & Recommended Actions

High penetrations of distributed resources (DER) will impact bulk system reliability in various ways if sufficient care is not taken to ensure that potential adverse impacts are mitigated. This report examines possible impacts relating to all DER: conventional and renewable generation, storage (stationary and PEVs) and demand response. Certain aspects of these resources, particularly in the case of non-renewable DER, can positively contribute to the reliability of the bulk system through providing additional flexibility. This report mainly examines the potential adverse reliability effects, particularly seen with variable distributed generation. Due to various government measures, utility initiatives and reduction in costs, these resources are expected to increase significantly in the next decade. Certain regions in the NERC footprint are likely to see circuits or areas with very high penetration of DER on distribution networks. Therefore, knowledge of the effect of DER on bulk system reliability will be crucial when planning and operating the system in the future. The potential adverse impacts on reliability span several specific considerations as detailed in Chapters 3, 5, and 6, but generally relate to the lack of visibility and control of the DER by the bulk system operator. This may become apparent in ramping and uncontrolled variability on the system, particularly with high distributed wind or solar PV. Voltage and frequency, both in steady state operation and in response to faults may become affected with increasing amount of DER, particularly non synchronous inverter connected technologies. Certain schemes such as under frequency load shedding will become more difficult to implement with large amounts of generation on the distribution network which will disconnect and exasperate problems at times of low frequency.

The potential adverse impacts of DER can be mitigated. Greater visibility and control through smart grid technologies will increase communication and visibility to the system operator; this will then have the impact of aggregating forecasted variability so the BA can manage this in much the same way as they will deal with transmission connected wind, i.e. by using flexibility in their generation mix to accommodate ramping. Guidelines, procedures, and requirements will need to be developed, however, to ensure that interconnection of DER does not significantly affect bulk system reliability. These programs/standards may take the form of a grid code similar to that established in Germany for medium voltage generation interconnection. The potentially competing interests of distribution system and bulk system needs as evidenced between these types of standards and IEEE 1547 will have to be reconciled. It will also mean bulk system operators requesting and using data from a level of the grid in which they have previously had very little or no jurisdiction, which may require changes to the NERC Registry Criteria. While specific recommendations are not provided, the following general recommendations are made to move toward that end:

1. NERC, state and provincial regulators, and/or industry should develop an analytical basis for understanding the potential magnitude of adverse reliability impacts and how that magnitude changes with penetration of DER and system configuration/composition.
2. Based in part on the analytical results from #1 and the broad experience of generation, transmission and distribution owners and operators, specific recommendations for changes to operating and planning practices, state/provincial programs, and pertinent NERC Reliability Standards should be developed.
3. As many DER issues may be beyond the scope of NERC's authority, and since it may be feasible to address these issues through non-NERC avenues (such as through market rules, vertically integrated operations, or state/provincial programs), it is recommended that NERC work with the affected entities in the different regions, including state/provincial agencies having jurisdiction over DER, RTOs, and vertically integrated utilities, to develop appropriate guidelines, practices, and requirements to address issues impacting the reliability of the BES resulting from DER.

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