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IEA IMPLEMENTING AGREEMENT FOR A CO-OPERATIVE PROGRAMME ON SMART GRIDS (ISGAN)

Smart Grid Contributions to Variable Renewable Resource Integration

ISGAN white paper

Annex 4, Subtask 3.2

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From the ISGAN Annex 4 Programme of Work, adopted October 2011:
"This white paper will elucidate the key areas in which smart grid technologies and systems can assist in the grid integration of VRR. It will identify examples of integration in various ISGAN countries, and will identify appropriate roles for smart grid systems to play in this challenge, generally."

Abstract:
This report describes the specific capabilities offered by smart grid technologies in resolving some of the challenges in achieving high penetrations of variable renewable resources (VRR). The report describes the relationships between existing smart grid solutions and a range of VRR integration challenges, and smart grid solutions are placed in the larger context of conventional tools for VRR integration. Relevant VRR integration projects from ISGAN member nations are described where applicable, and recommendations for research collaborations are suggested.

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1. Introduction

Efforts to decarbonize both the electric power and transportation sectors are driving significant investments in renewable energy technologies. While these technologies make important contributions to global energy challenges, the variable nature of their generation may pose integration challenges. In other words, renewable energy alone will not keep the lights on. Globally, modernization of electrical grids is taking place alongside rapid deployment of these variable renewable resources (VRRs), although these two trends are not always coordinated. The need for new balancing resources and for a “seamless grid”[1] capable of integrating both large-scale and small distributed energy resources (DER) are among the driving forces of smart grid development.

Smarter grids are an important enabling tool for achieving higher penetrations of VRR on transmission and distribution networks. Depending upon the relative share and geographic distribution of large-scale and DER resources, various technologies, regulations, and policies are required to support high levels of VRR generation. In this context, policy makers will benefit from an understanding of how smart grid technologies contribute to VRR integration, and all stakeholders will benefit from increased alignment between smart grid development roadmaps and national and regional visions for renewable energy development.

The objective of this report is to give insights for decision makers on the various contributions of smart grid systems in achieving VRR integration. A variety of tools and solutions exist for achieving high penetrations of VRR generation, and the smart grid solutions outlined in this report are considered alongside a range of integration best practices.

This report is organized as follows: in Section 2, a framework for understanding VRR integration is briefly described. In Section 3, the main challenges posed by VRR integration are presented, followed by a description of smart grid systems that can contribute to overcoming these challenges, in the context of other conventional tools for integration. In Section 4, key issues and barriers to the implementation of various solutions are discussed. In Section 5, we conclude by indentifying guiding principles for aligning smart grid development with renewable energy development.

2. Context -- Smart Grid and Variable Renewable Resources

The study of technical VRR integration issues has accelerated as larger shares of VRR generation have been deployed. The IEA published a comprehensive study of VRR integration in 2011, [2] and many national and regional governments and system operators have conducted rigorous grid-integration studies to understand the technical, market, and economic issues associated with higher shares of VRR.

From these efforts, analysts have identified a range of tools available to system operators to manage the challenges presented by large shares of VRR. Many of the tools are “soft” operational changes, for example changes in system operation procedures and market rules. In addition to these soft measures, the IEA identifies four types of technical flexibility resources that can aid in the integration challenge: [3]

- **Dispatchable plants**: Generators with capabilities to ramp up and ramp down to provide load-following generation, regulation service to balance minute-to-minute variability, and generators with short start-up or shut-down times.
- **Storage**: Devices and systems used to store electricity (e.g. batteries, pumped hydro, compressed air, flywheels) which can provide load-following, load-shifting, and intra-hour regulation capacity.

- **Interconnection**: Connections to neighboring power areas to share generation resources, smooth VRR variability, and take advantage of different load profiles across power systems.
- **Demand-side measures**: Customer participation in power system operation, leveraging capabilities to shift their demand away from peak demand, to shed loads during emergencies, or to shape their consumption in response the availability of VRR generation.

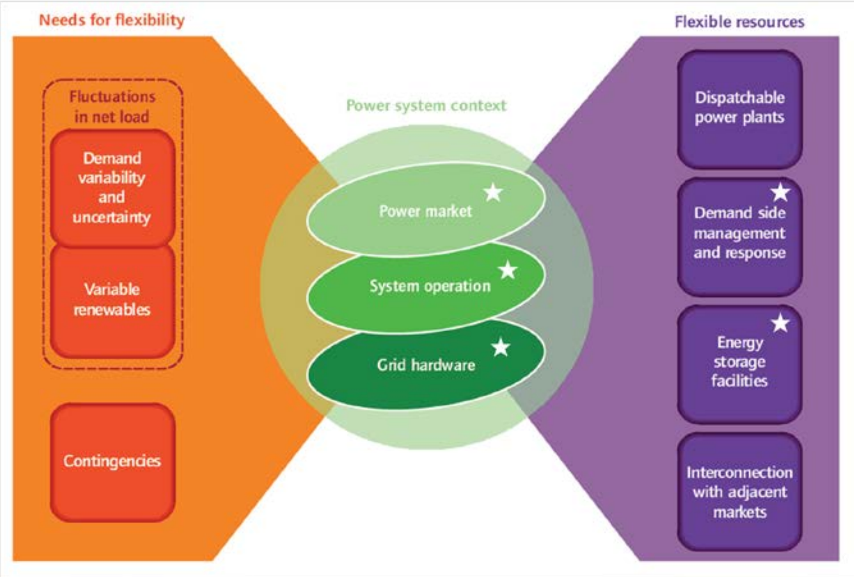

Figure 1: VRR flexibility needs, and available flexibility resources, are deeply related to power system context. Categories in which smart grid systems and technologies can currently play a role are marked with a star. Source: International Energy Agency, "Harnessing Variable Renewables -- A Guide to the Balancing Challenge", p.36

Within the IEA framework shown in Figure 1, grid hardware such as smart grid technologies can play several important roles to balance the fluctuation in "net load."[†] Specifically, smart grid technologies are integral components of the categories of "Demand side management and response" and "Energy storage facilities." To a lesser extent, smart grid technologies could also facilitate the "Interconnection with adjacent markets". Finally, smart grid technologies are also enabling innovative solutions in operational tools and power markets.

Beyond these interfaces with the IEA framework, smart grid technologies can play a role in:

- Enabling the coordination of Plug-In Hybrid Vehicles (PHEVs) charging;
- Modernizing grid operation, through advanced control-room technologies and systems;
- Enabling more efficient and inclusive power markets with participation from new storage and demand-side resources to balance VRR;
- Facilitating the establishment of micro-grids to maintain the electricity service in small areas during outages on the main grid.

2.1. Enabling Both Utility-scale and Distributed Generation

Several longer term scenarios envision greater shares of generation from large, utility-scale facilities – including offshore wind energy sites, large continental wind farms, or solar generation located in arid deserts.[3] While electricity can typically be generated more cost-

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[†] Net load is defined as renewable generation subtracted from normal load.

effectively in these resource-rich locations, such scenarios often involve major transmission expansions and interconnections to bring electricity to demand centers. Smart grid technologies, especially advanced transmission and substation technologies, can aid in this challenge by increasing transmission line capacity, reducing system losses, and improving voltage and frequency control.

In addition to enabling greater penetration of utility-scale resources, smart grids can also lower barriers to the deployment of distributed energy resource generation.[4][5] DER generation, such as small solar and wind installations, combined heat & power, fuel cells, and small thermal generators, are typically connected to distribution networks. These resources have the potential to play a role in supplying permanent, emergency, or balancing energy in many cities, towns, and campus facilities.[6] Achieving greater shares of DER generation requires enabling technologies to ensure the proper operation of local distribution networks, another domain in which smart grid technologies can contribute. In several regions with transmission expansion constraints, low levels of grid reliability, and high electricity prices, DER generation may be an attractive pathway for achieving a significant share VRR generation.

A common feature across high-penetration VRR scenarios is that information and communication technologies render the power system more flexible, reliable, and cost-effective. A more detailed overview of how smart grid solutions contribute to integrating VRR is described in the next section.

3. VRR Integration Challenges and Smart Grid Solutions

ISGAN uses the European Technology Platform Smart Grid (ETPSG) definition for a Smart Grid:

> *“A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies”.*

In light of this definition, smarter grids play a role in several domains within the IEA categorization of flexible resources. We now focus on a deeper discussion of how smart grid applications and technologies could enable power system flexibility in support of VRR integration.

Research to date indicates that in most existing large-scale grid systems, modest shares of VRR (e.g. less than 10% of peak capacity)[‡] have little impact on system operation. [7][8][9] Larger shares, on the other hand, present new challenges for system operators, requiring a mix of flexibility resources and changes to markets and operating procedures. The challenges presented by VRR integration will vary significantly by region, grid topology, and type of VRR resources on the grid. Consequently, the appropriate portfolio of integration tools will be specific to each grid system. In order to better contextualize smart grid tools within the full toolbox available to system operators, the next section provides a broad overview of key VRR integration challenges and outlines four categories of available tools: *smart grid, markets, system operation,* and *other*.

[‡] Research also indicates that wind and solar impact system operations differently, and the percentage shares of each are important for accurately estimating impact on system operation.

3.1. Transmission

In many cases, with the notable exception of residential solar PV in locations with significant solar resource, the highest quality variable renewable resources are located at a significant distance from load centers. In these cases, the cost of transmission construction and siting will burden the construction of new VRR generation facilities. While some studies show that transmission costs are more than offset by the production advantages of higher quality resources,[8][10] new transmission lines or limits on current transmission lines may pose challenges to additional VRR generation. Potential solutions for transmission challenges may include a regionally-appropriate mix of the following tools:

Smart grid tools	Dynamic Line Rating systems provide real-time ratings of transmission circuit capacity through monitoring of transmission line sags. Wide-Area Situational Awareness and Phasor Measurement Units increase the visibility of grid system health and the power quality impacts of renewable energy generation. Voltage Source Converter-based High-Voltage DC transmission systems increase the efficiency of large-scale onshore and offshore VRR electricity delivery. Flexible AC Transmission systems (FACTS) enable the full use of circuit capacity while maintaining system stability and providing voltage support.
Market tools	Pricing systems that incorporate the cost of congestion (nodal pricing, Locational Marginal Pricing) can send price signals that incentivize adequate investment in transmission expansion. For example, see the NORDPOOL in Europe, and markets in New Zealand and the US (PJM, ERCOT, and New York).
System operation tools	Advanced simulation systems, including probabilistic tools for improved load forecasting, assist in optimizing power flow over the grid. Larger balancing areas, cross-border interconnections, and better balancing-area coordination can ease transmission constraints. Transitioning from day-ahead unit commitment and hourly dispatch down to five minute dispatch intervals removes constraints on generation flexibility and reduces demand for regulation service.
Other tools	“Reconductoring” with new low-sag conductors can increase line capacities without need for replacing a line with a higher voltage design. New transmission lines can be constructed, using either conventional AC or High-Voltage DC at current or higher voltages.

3.2. General Ramping Requirements

System operators "ramp" the output of generators in response to the demand for electricity, a vital grid function known as "load-following." While the magnitude of load-following requirements has traditionally been driven solely by fluctuations in electricity demand, the introduction of greater shares of VRR into system operations adds additional variability to this equation.[11] The unique patterns of renewable energy generation present different ramping requirement challenges. At large penetrations, solar energy requires up- and down-ramping on a daily basis (morning and evening), as well as during cloud cover changes. Wind power generation generally increases at night and decreases in the morning, but also poses less predictable up- and down-ramping requirements. In some instances, the ramping requirements driven by variable generation and variable demand may offset each other, while in other cases they may combine to require even more ramping capacity. Additionally, the interplay between different VRR sources may be important, for example in regions where wind speeds tend to increase in the evening during the same time that solar begins to decrease.[12]

Potential solutions for hourly ramping challenges may include a mix of the following:

Smart grid tools	In conjunction with appropriate market design and utility programs, demand response and demand-side storage capabilities -- e.g. thermal mass, process mass, water heaters, chilled water storage, and dimmable ballast lighting -- can provide load-following services.
Market tools	Introduction of imbalance energy markets or competitive load-following services aim to increasing compensation for ancillary services, such as ramping capacity. Market mechanisms can provide incentives for fast-start and fast ramping capabilities. Sub-hourly wholesale power markets can provide more adaptive responsive resources to balance fluctuations from VRR generation. Shorter gate closure allows VRR producers to more efficiently update their offers into power markets during ramping events.
System operation tools	Expanded balancing areas and coordination with neighboring balancing authorities can play a key role in reducing the volatility of overall net ramping requirements. Better wind and solar forecasting allow for better scheduling in the day-ahead and hourly markets. Improved energy management systems, including load forecasting, load dispatch with Advanced EMS, and virtual power plants, can provide more responsive system operation.
Other tools	Conventional solutions for meeting load-following needs include large hydro and cycling thermal generators (e.g. natural gas and coal). Retrofits and procurement of new generation such as large hydro or pumped-storage plants can provide greater flexibility and performance.

3.3. Near-instantaneous production ramps

While the day-and night production profile of solar is much more predictable than the variable production of wind, high-penetrations of solar present other integration challenges. For example, the passage of clouds over solar PV panels can result in more rapid production ramps, including changes in output of +/- 50% over 90 seconds and +/- 70% over 10 minutes.[13]

Where significant amounts of rooftop or utility-scale PV are connected directly to distribution networks, such production fluctuations may pose challenges for Distribution System Operators (DSOs) to maintain proper voltage levels. On traditional distribution feeder networks without adequate voltage regulation, quick variations from inverter-based generation (like solar) can impact the voltage delivered to end users. In the case of weak distribution grids, a single large solar installation located at the end of the distribution feeder can strain the voltage regulation scheme. While similar problems may occur with other distributed generation types, the quick changes in solar generation typically require more rapid response time. A mix of tools can be used to mitigate these issues:

Smart grid tools	Volt & var optimization systems facilitate voltage regulation in areas of high penetration of distributed generation, and also enable PV installations to contribute to voltage regulation. Fault Detection Identification and Restoration (FDIR) technologies are used to quickly detect outages and restore service. Transfer trip schemes allow for proper disconnection and reconnection of distributed generation when an outage is detected. Automation of reclosers and switches allows distributed generation and/or utility-scale battery storage to island load during outage. Active power electronics in conjunction with smart meters can also mitigate rapid production ramps.[14] Coupling new PV inverters and power quality monitoring systems can minimize feeder voltage fluctuations. Short term load management from the distribution system operator may help reducing the impact of voltage fluctuations.
Market tools	No market tools are currently available for distribution-level ancillary services, such as voltage regulation. New concepts and business models for microgrid markets might emerge, which would provide local generation, load and storage with the ability to respond to distribution or substation needs, such as voltage regulation.
System operation tools	Distribution Management Systems integrate grid-monitoring applications to support operation of the grid, allowing improved visualization of the distribution network state, and facilitating fault detection, restoration and voltage regulation with strong simulation capabilities.
Other tools	Upgrading distribution feeders to a higher voltage or conductor replacement are standard tools, as is the modification of relays and transformers in distribution substations to limit the impact of reverse power flow or to improve voltage regulation.

3.4. Regulation Capacity and Intra-hour Variability

The intra-hour variability of VRR can place strains on traditional grids. Historically, intra-hour variability has been driven by unplanned drops or spikes in demand, for example the switching on of significant amounts of air conditioning or cook stoves.[15] Such minute-to-minute changes can impact the frequency of electricity delivered over the grid, requiring "regulation capacity" to ensure stable grid operation. As with load variations, significant increases and decreases in wind production are typically accommodated by adjustments of generators providing continuous regulation reserves. However, regulation reserves are often limited. The ability of thermal and hydro plants to provide all necessary regulation capacity may be stressed at high levels of VRR penetration and additional regulation capacity may be required.

Similar to the discussion in section 3.2 on ramping requirements, smart grid technologies represent one of many potential tools to mitigate these challenges:

Smart grid tools	Direct control of large loads through wholesale markets for regulation service. [16] "Fast" demand response through automated participation of commercial and industrial loads, or in the future, fleets of PHEVs, can provide regulation service on the time scale of less than one minute. [12] Flywheel and some battery storage systems can provide rapid regulation service. With appropriate power electronics, VRR generators themselves can provide down-regulation capacity, and if operated slightly below maximum output can provide up-regulation capacity.
Market tools	Markets for ancillary services, which typically include regulation service and 'spinning reserves,' ensure that market participants receive compensation for providing capacity. Sub-hourly wholesale power markets could provide more adaptive responsive resources to balance fluctuations from VRR generation. Shorter gate closure allows VRR producers to more efficiently update their offers into power markets during regulation events.
System operation tools	Improved load and VRR generation forecasts, as well as automated decision support tools, reduce uncertainty and permit more accurate unit commitment, as discussed in Section 4.5. Improved energy management systems with load forecast, load dispatch with Advanced EMS, and virtual power plants, can help mitigate frequency excursions. Expanded balancing areas and coordination with neighboring balancing authorities can play a role in reducing the net volatility of sub-hourly generation.
Other tools	Using large hydro and spinning thermal generators is the conventional option of meeting regulation and spinning reserve needs. Retrofits and procurement of new generation, such as large hydro or pumped-storage plants, can provide greater flexibility and improved system performance.

3.5. Over-generation

Over-generation typically occurs when VRR generation is high, loads are relatively low, and there is a significant share of non-dispatchable[§] and baseload conventional generation on the grid. This challenge is more common with wind generation, as it generally has been more widely deployed. In these situations, which are typically more prevalent during low-load, high-hydro periods of the year, VRR energy is “curtailed,” exacting a cost of lost revenue on VRR generators, or baseload generators are curtailed, potentially resulting in cost, maintenance, and operational issues. In a study of their grid operations, the California Independent System Operator found that the level of over-generation was generally directly correlated to the amount of non-dispatchable generation in the system.[11]

A mix of tools can be deployed to manage over-generation challenges:

Smart grid tools	In conjunction with high-quality forecasting, demand response can serve as a load-shifting resource to absorb excess generation. For example, PHEVs can be pre-charged during excess wind generation; ice can be made for building HVAC, and industrial refrigerators can be pre-cooled. In the residential sector, electric thermal storage systems (e.g. electric water heaters) have been used to absorb excess generation, and new devices on the market offer improved two-way communication capabilities. The use of heat pumps, smart thermostats, and Home Energy Management Systems for pre-heating and pre-cooling of homes is also envisioned in the mid-term to absorb excess wind energy. Large industrial loads such as aluminum smelting can also be varied to match VRR excess energy and other system needs.
Market tools	Market design that allows greater customer participation in the energy market can minimize lost revenues due to curtailment.
System operation tools	Expanded balancing areas and coordination with neighboring balancing authorities can play a key role in reducing net over-generation. Improved energy management systems with load forecast, load dispatch with Advanced EMS, and virtual power plants, can help mitigate over-generation impacts.
Other tools	Curtailment of VRR generators is a standard method for dealing with over-generation. Ramping thermal units down is another standard method. Using large hydro or pumped storage may provide long term storage for excess wind generation, as well as for sustained periods of under-generation.

4. Integrating Solutions

The key challenge for decision-makers (i.e. system or market operators) is to prioritize and implement the appropriate mix of integration solutions detailed above given the specific grid topology, current and future VRR mix, and market structure. The design of smart grid systems to enable greater VRR generation should be driven by analysis of the types, timing, and magnitude of grid challenges posed by the portfolio of VRR sources on each individual grid, as well as the relative cost of the potential solutions.

Understanding the relative costs of these solutions is a key challenge and is a growing area of research. Establishing methodologies for defining the relative costs of the range of tools

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[§] Generation that cannot be ramped up or down, for example due to operating rules.

available to grid operators would allow for the creation of a ranking or “merit order” of flexibility resources, so that demand-side resources could be evaluated in relation to other tools (for a figurative illustration, see Figure 2).

The economics of flexible resources are unique to each electricity market and regulatory landscape, and conducting resource assessments and simulations will be critical to estimating the most cost-effective path to integrating large shares of VRRs. The following sections provide a discussion of this and other key domains in which smart grid solutions can be deployed in support of VRR integration.

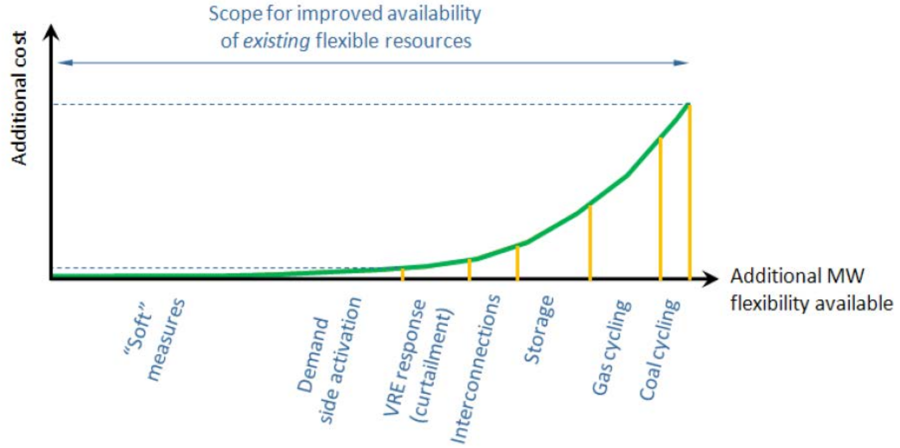


**Figure 2: Illustrative “flexibility merit order” of measures to support VRR integration
Source: IEA FAST presentation to IRENA, October 6, 2011**

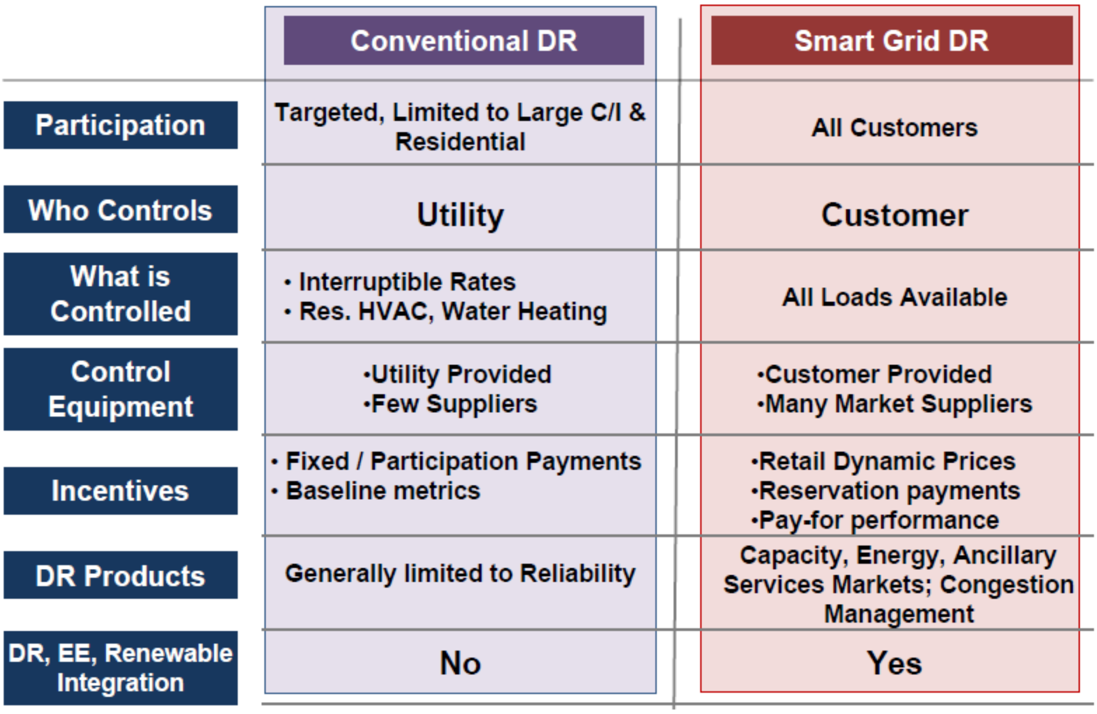
4.1. Activating demand-side intelligence

Smart grids can enable greater customer participation in power system operations. By sending real-time information on cost of electricity, or offering information about real-time incentive payments, engaged customers and grid-networked housing and commercial buildings can participate in reducing stress on the network caused by system events, such as increasing peak demand or VRR integration events.

As noted in Figure 2, behind “soft measures,” demand-side resources are generally one of the most cost-effective flexibility resources, followed by VRR curtailment, larger interconnection areas, storage, and finally increased cycling of existing thermal plants. However, DR is a highly heterogeneous resource, and the specific cost, magnitude, and rank of DR resources within the flexibility merit order will change over time in each grid system.

Technological innovation is also likely to change this merit order over time, especially if low-cost, dispatchable storage technologies become widely available (for example, grid-networked batteries recycled from first generation hybrid vehicles). While relatively inexpensive, demand-side measures will require a mix of technical, market and policy steps to fully realize their potential. Enabling demand to actively respond to load and price conditions can have a dramatic impact on the integration of VRRs. US researchers report roughly 38,000 MW of existing demand response capacity in the United States.[17] Activating demand-side flexibility is not simply a technical question however -- it requires a mix of complementary policy, regulatory, and market measures, which should be coordinated with the desired type of demand-side participation in mind.

Smart grid technologies and systems can cost-effectively enable demand-side flexibility in several ways. On the one hand, traditional (or *managed*) DR leverages networks and machine-to-machine communication protocols to manage demand based on real time price and/or load conditions. On the other hand, *price-responsive* (or *active*) DR leverages consumer and market participant responses to price in order to shift load. Traditional demand response is centrally controlled by the vertically-integrated utility and has historically focused on reliability operations (e.g. managing load peaks). Price-based demand response, managed through a market with increased customer participation, encompasses a wider range of potential products, potentially playing significant roles in capacity, energy, and ancillary services markets, as well as in congestion management.[18] The differences between traditional and smart DR are detailed in Figure 3.



	Conventional DR	Smart Grid DR
Participation	Targeted, Limited to Large C/I & Residential	All Customers
Who Controls	Utility	Customer
What is Controlled	• Interruptible Rates • Res. HVAC, Water Heating	All Loads Available
Control Equipment	•Utility Provided •Few Suppliers	•Customer Provided •Many Market Suppliers
Incentives	• Fixed / Participation Payments • Baseline metrics	•Retail Dynamic Prices •Reservation payments •Pay-for performance
DR Products	Generally limited to Reliability	Capacity, Energy, Ancillary Services Markets; Congestion Management
DR, EE, Renewable Integration	No	Yes

Figure 3: Primary characteristics of Traditional vs. Smart Grid DR
Source: Sedano, Levy & Goldman, 2010

Automated demand response ("AutoDR" or "ADR"), which facilitates direct communication between building automation systems and electricity markets, is now technologically mature, but focuses mainly on demand response for peak demand reduction. Demonstration of technologies (including AutoDR) for load-following generation are now being conducted in several countries:

- California ISO's "Integrating Renewable Resources" project[11] engages industrial chillers, municipal water management, and other large commercial and industrial loads.
- Lawrence Berkeley National Laboratory in the United States and CanmetENERGY in Canada are conducting research on energy management, energy prediction, and development and implementation of automated demand response projects with commercial buildings.
- Pacific Gas & Electric's "Peak Energy Agriculture Reward" is a program for automated agricultural irrigation pump demand response.[19]
- Bonneville Power Authority (United States) and New Brunswick Power (Canada) are developing Virtual Power Plants to balance wind generation with demand response.

Active, smart grid–enabled DR promotes greater price-responsiveness of customers and market participants through real-time pricing delivered via machine-to-machine communication, in-home devices, or mobile devices. The magnitude and flexibility of such resources is potentially quite large, but significant hurdles remain to its mainstream adoption in VRR-relevant power market operations – not least of which are uncertainties around likely rates of consumer participation.

The critical policy issues facing greater activation of price-responsive, next-generation DR include market design, pricing, rules of participation, and technical resource assessments. This area represents a possible focus for ISGAN collaboration.

4.2. Activating delivery-side intelligence

Awareness and control of transmission and distribution networks - delivery-side intelligence - can also aid in grid integration of VRR. A range of technologies can assist both DSOs and Transmission System Operators (TSOs). A brief explanation of how Dynamic Line Rating and its associated system operation tools could improve transmission network congestion problems is provided below.

Dynamic Line Rating

Transmission lines are given a static thermal capacity rating that limits how much current can be delivered across the line. These ratings are typically formulated using worst-case scenarios for ambient temperature and current flow.[20] In congested areas, grid operators regularly limit electricity transmission due to these capacity ratings. But in reality, transmission line capacity is highly dynamic, as it is affected by sag, the level of current flowing across it, and ambient weather conditions. Weather conditions can dramatically alter the real capacity of transmission lines, and has been shown to enable up to 50% more transmission capacity,[20] often when it is needed most: during very windy periods. For example, a 10° C drop in temperature can increase line capacity by 11%, cloud shadowing can increase capacity by 2-3%, and shifts in wind speed and direction can impact capacity by ~10%.

“Dynamic line rating” systems consist of tension and/or temperature sensors deployed on high-voltage transmission lines to provide grid operators real time insights into thermal capacity. Such intelligence can allow for greater amounts of electricity to be delivered, which at times can reduce the level of curtailment of VRRs. Over 300 transmission line-monitoring systems have been installed at 95 utilities in many countries, including the United States, Canada, the United Kingdom, Finland, Sweden, Denmark, Belgium, Germany, Spain, Argentina, Norway, Poland, the Netherlands, Brazil, Australia, New Zealand and the Middle East.[21]

Congestion management is increasingly important for wind integration. New lines are costly, and a technically-feasible solution is to deploy these smart grid systems and technologies in order to approach better real-time capacity management. However, to date, no international standards development organization has explored loosening the rules of line ratings to allow for these sensor networks to actually guide grid operation and allow more wind onto T&D systems.

4.3. Activating markets

Electricity market structure and design is a priority consideration in ensuring that variable resources can be integrated into existing grids in the most reliable and economical way. Information technologies improve the ability of markets to accommodate complex power flows and economic dispatch, while smart grid technologies may facilitate greater market participation by active customers, storage facilities, and smaller generators.

Across the 21 ISGAN country members, a significant number of electricity generation markets are “deregulated” or “contestable,” while others feature vertically integrated electrical utilities, or a mix of both. In contestable markets, the generation assets and retail side of the utility business are competitive, while the transmission and distribution system is typically regulated.

In both the near- and long-term, market design is vitally important for activating smart grid solutions. In the near-term, it is a critical component of activating flexible distributed energy resources in sub-hourly, hourly, and day-ahead dispatch markets, as well as in longer term capacity markets. Appropriate market design ensures that balancing of supply and demand (on the scale of minutes to hours) takes place efficiently. In the long term, capacity markets ensure that investment in transmission, generation and demand-response resources is committed to adequately follow the growth of the demand and the need for additional balancing resources.

Effective market design also facilitates transmission investments to cope with congestion, or to provide balancing resources from remote flexible generation, such as large hydro.

In the case of systems operated by Investor-Owned Utilities (IOUs), investors will likely require credible signals that smart-grid-enabled delivery and demand-side measures will be adequately rewarded. Without strong signals to this effect, investment is likely to be sub-optimal. Market readiness for smart grid solutions is still low in most regions.

The specific cost, magnitude, and rank of flexibility resources will continue to change with the improvement of technologies. At the moment, wholesale aggregation of flexible load into DR programs usually requires telemetry for regulation. Technological innovation is likely to reduce the price of aggregation, when standardized embedded communication will be included into new appliances and building automations systems.

While wholesale DR markets already involve several thousand megawatts of capacity in the US and European markets, further innovations in customer aggregation business models and DR communication platforms could further facilitate the integration of small customers into the market. With the normal replacement of residential, commercial, and industrial appliances with devices with embedded communication capabilities, the capital costs of DR aggregation capabilities are likely to decrease.

4.4. Enabling distributed generation and microgrids

The connection of small generators to the grid, such as rooftop PV, combined heat and power, diesel generators, gas turbines, fuel cells, and run-of-the-river hydro, is not a new phenomenon. For safety reasons, the traditional approach in integrating distributed generation is to set the protection and the voltage regulation of the generator to avoid cases of islanding during an outage. Islanding occurs when a generator is running, feeding the customers, while the main source is removed, either intentionally or through an unintentional service outage. Planned islanding is now being introduced in some areas, where the distributed generators reinforce service reliability.

Concurrent with advances in integrating VRR into existing grids, at the other end of the spectrum, smarter grids offer significant capabilities to efficiently provide power via micro-grids.

Microgrids are defined as electrical systems that include multiple loads and distributed energy resources that may be operated either interconnected with the grid or as an electrical island. Such applications are sometimes desirable and cost-effective in rural areas, residential subdivisions, large corporate campuses, and military installations. The cost of key technologies and capabilities that enable more widespread operation of micro-grids are declining.

As with bulk grid operation, maintaining service during an islanding situation requires a real-time balance of generation and demand, as well as attention to power quality issues including voltage, frequency, and other operating characteristics. These are all functions of a microgrid controller, which typically includes a human-machine interface that allows the microgrid manager to view and manage the micro-grid.

Below is a sampling of active programs in ISGAN member countries that support distributed generation:

- Denmark, where the EcoGrid EU project in Borholm, uses local wind generation to maintain the electricity service on the island.
- Australia, where programs such as the Smart Grid Smart City project are underway to validate systems that support urban and rural distributed generation, with a focus on solar (PV) panels, small scale wind, and gas-powered fuel cells.
- Japan, where a market is being established for in-home fuel cell generation, and research projects are underway to deploy residential smart homes, encompassing solar / battery systems, building energy management, and integrated PHEV charging (See Figure 4).
- Canada, where the Ontarian government promotes distributed generation through a Feed-In tariff program and Hydro One is developing smart grid applications in Owen Sounds, where 10,000 small generators will be connected. In its 2030 roadmap, the system operator envisions neighborhood microgrids with generation provided by smart homes.

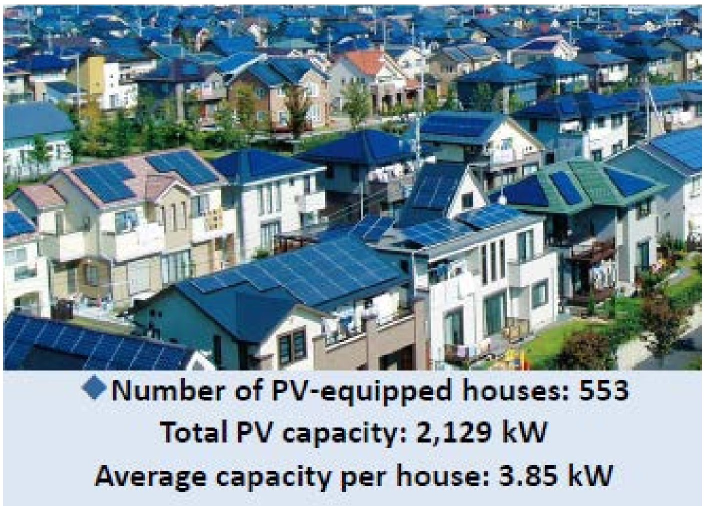


Figure 4: Ota City, Japan, pilot project incorporating high penetration of rooftop PV capacity with smart homes.

- France, where NiceGrid, one of the Grid4EU Projects, aims at deploying smart grid infrastructure to support a high concentration of distributed PV installations coupled with demand response systems and energy storage.
- Norway, where the SmartGrid Centre conducts research on distributed generation control and management.
- Sweden, where the Gotland Island project aims to achieve integration of large-scale wind generation in a small island grid.
- Spain, where the “Málaga Smart City” will integrate distributed generation in an actively-managed distribution network.
- United States, where a wide range of demonstration projects are underway to incorporate high levels of solar energy on distribution networks.

From a system control room perspective, smart grid technologies will play a key role in enabling faster, more accurate, and more flexible management of utility-scale and DER generation resources, as well as demand-side resources.

4.5. DSO and TSO Coordination

Greater shares of VRR generation will challenge existing control operations and technologies of both transmission and distribution system operators, and will require greater coordination between transmission and distribution networks. The present structure of grid control schema is based on a division of the electrical network into two parts: a distribution network connecting end-users to the electricity supply system and a transmission network connecting power plants and tie-lines to the network. So far, little operational coordination has been required between the two networks, whether under normal conditions or in emergency situations.

An important basis for developing modern grid control strategies is to recognize that the distribution network can no longer be considered as a passive appendage of the transmission network, but both networks must be designed and operated as a tightly integrated unit. Therefore, the control hierarchy between bulk and regional control rooms may need to be revised to accommodate the possibilities of load islanding with regional generation resources.

At the distribution network level, DSOs with high penetrations of variable generation will need to incorporate new technologies and operational procedures in order to transition to a more “active” distribution grid. In these systems, the combination of distributed energy resources (generators, loads and storage) will change the traditional functions of the distribution system. In recent years, advanced Distribution Management Systems have been deployed by DSOs to improve visibility of and control over power system equipment and DER generators.

At the transmission network level, Energy Management Systems are increasingly capable of managing complex generation and demand portfolios. Such systems can accommodate both conventional generation as well as various types of VRR (utility-scale and small generators operating independently or aggregated by utilities or third-parties), active demand response customers, and storage devices. These systems can manage resources located on distribution networks, but impacting the bulk transmission network. The importance of this interface was highlighted by the Strategic Energy Technology Plan Working Group in 2009: [22]

> *“In general, TSOs and DSOs still have to devise strategies to address in a systematic way the interface issues deriving from developments towards smart grid concepts. In order to make the transmission and distribution grids work together efficiently and safely, an increased coordination in their development and operation must be actively pursued. Both transmission and distribution need to be further developed, not only in terms of carrying capacity but also via advanced ICT infrastructure and communication and control platforms.”*

One example of progress on this issue is the FENIX[23] project in Northern and Southern Europe, which has convened 18 partners to conceptualize, design, and demonstrate a technical architecture and commercial framework that would enable DER-based systems to become the solution for a cost efficient, secure, and sustainable European electricity supply system. The project investigated the aggregation of DER into a Virtual Power Plant to maximize the contribution to the electric power system. During the project, several work packages were delivered to ensure the ability of both DSO and TSO network operators to manage these new resources during simulations and field trials. New generations of EMS and DMS tools were deployed by both TSOs and DSOs, and field trials were organized at 2 DER sites.

4.6. Transmission control room improvements

Large-scale integration of renewable energy is also a driver of transmission control room improvements. In a 2011 global survey of TSOs, 94% of respondents agreed that integrating wind energy depends upon decision support systems in the control room.[24] Furthermore, respondents observed a clear ranking of needs at the control room level for effective integration of VRR (see Figure 5).

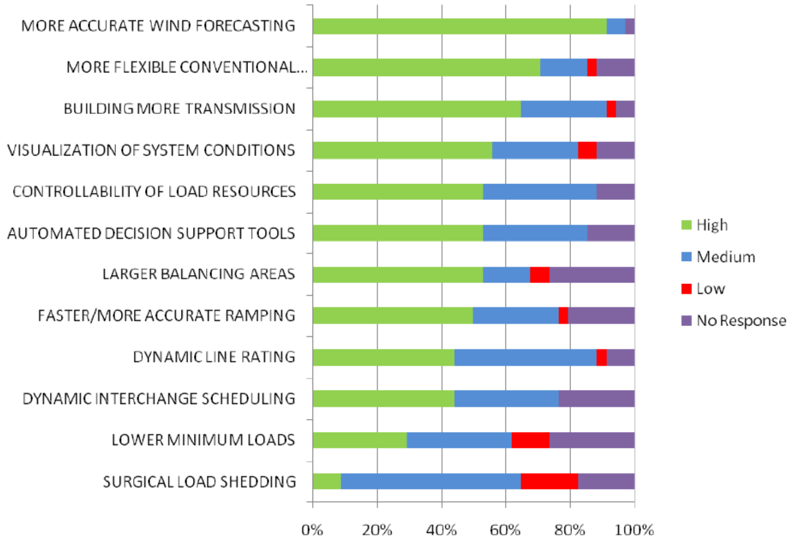


Figure 5: Surveyed value ratings of potential tools for large-scale integration of wind power. Colored bars denote the percentage of grid operator respondents indicating a value of high, medium, low, or no response. Source: Lawrence E. Jones, 2011

The adoption of advanced information and communication technologies into grid control rooms is enabling dramatic advances in power system management. Key enabling systems include high-resolution visualization of grid status and health, automated demand management, algorithms that identify critical (i.e. intermittency) events, integrated forecasting software that allows for more accurate market dispatch, and the ability to manage the connection (and disconnection) of large micro-grids.

In Texas, a pilot project has installed 14 phasor measurement units to monitor the voltage, current and frequency of electricity within the Electric Reliability Council of Texas (ERCOT) transmission grid and to convert the data into a phase vector, or “phasor.” By evaluating time-synchronized data from across the transmission system, ERCOT operators can gain a real-time picture of system health, allowing better grid management during major fluctuations of wind-generated power[25] and other system contingencies.

The California Independent System Operator has installed a leading visualization system in their control room that collects current information about grid operational metrics (Figure 6a and 6b). Innovation in this area promises to allow grid managers better visibility into VRR generation conditions in real time, early warning systems for balancing mismatches, management of congestion issues, and control of demand response resources. Continued advances in information and communications technologies can be expected to impact the state of the art in control room capabilities.

Figure 6(a): Photo of the 80 ft (24.4m) visualization wall in the CAISO control room. Source: Space Time Insight. Figure 6(b): Real-time visualization of frequency conditions on the CAISO grid Source: Space Time Insight

5. Conclusion

While it is generally accepted that a greater share of future generation will be drawn from renewable resources, and that smarter grids can help integrate higher shares of these resources, key questions remain with respect to enabling systems and policies:

- What is the regionally-appropriate sequence and priority of smart grid applications needed to facilitate the development of high-penetration VRR power systems?
- What types of policy frameworks best engage customers in participatory energy markets?
- What is the regionally-appropriate model for renewable energy development (e.g. what share of VRR resources should be distributed?)
- What smart-grid VRR integration solutions are most strongly affected by institutional barriers? Market barriers? What policy changes would mitigate these barriers?

Considering the strong linkage between VRR and smart grid development and the magnitude of investments at stake, the following recommendations could help decision-makers in defining the appropriate course of action:

> **Recommendation 1**: **Ensure alignment between smart grid roadmaps and scenarios for future renewable energy supply**. Smart grid technologies will be an increasingly important resource for integrating both large-scale and distributed renewable energy resources. The specific types of renewable resources to be developed, as well as the target mix of utility-scale and distributed resources, should inform the development of smart grid policies and capital investments. Scenarios that prioritize large-scale VRR will require a special focus on intelligent transmission solutions, while programs that prioritize DER, such as feed-in tariffs for small scale VRR development, will require a special focus on the way distribution networks are upgraded and operated.
>
> **Recommendation 2**: **Evaluate smart grid VRR integration solutions in the context of the full range of integration solutions.** The pathway to successful VRR integration will be highly specific to each region, and will likely include various changes to system operation, power markets, and the cycling of dispatchable power plants. The integration of balancing areas, the development of efficient and open markets, and new or expanded transmission interconnections to dispatchable renewable plants (such as large hydro generators), may all be key candidates for addressing the VRR integration challenge. Smart grid solutions will typically complement these strategies, and in other cases they may represent cost-effective alternatives.

In the next few years, continued technological evolution in generation, transmission and distribution technologies, as well as information technologies for system and market operation, will converge to enable greater integration of variable renewable generation. This technological convergence will accelerate the transition to secure, low-carbon energy independence in many countries. Achieving the vision of a high share of renewable energy requires policy makers to understand the possibilities and the promise of a 21st century grid infrastructure.

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