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"Smart Grid to Balance Renewable Energies — Contributing Distributed Energy Resources"

"*SMART GRID* TO BALANCE RENEWABLE ENERGIES – CONTRIBUTING DISTRIBUTED ENERGY RESOURCES"

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EXECUTIVE SUMMARY

The electricity markets are making a number of adjustments in order to integrate renewable energies. Indeed, variable production creates certain integration problems, which require increased levels of operating reserves. Furthermore, it is critical that these reserves have dynamic characteristics, which can support and counter generation variability. While major power grids have countered capacity problems with increased production, there are other emerging approaches to grid management. Use of load management, distributed generation or storage provides support for networks coping with energy surplus but capacity deficits.

The current study investigated various resources, focused on networks or customers, which would be capable of offsetting fluctuations in renewable energies or supply reserve on the markets. Air conditioning, water and air heating are applications that lend well to management, due to the thermal inertia inherent to these loads. The development of the smart grid, and adding communication in particular, encourages development of this potential. With the progressive addition of demand-side management technologies, smart household appliances, distributed generation and energy storage, the distribution grids will be the hub for future energy exchange. A major trend related to smart grid development supports deployment of distributed energy resources to reduce grid stress and potentially promote the use of micro grids in cities. Furthermore, the smart grid is an integral part of more intelligent systems aiming, among other things, to improve urban environments (smart city) and road transport (smart transportation).

Developing business models favourable to deployment of distributed energy resources would require significant changes in the power industry structure and regulation. A change of paradigms towards more decentralized solutions is attractive in many respects. However, there is an important political aspect that requires support from a number of stakeholders, industry players, traditional industry, governmental and non-governmental agencies and consumers.

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1 Introduction

In the coming years, power companies will have to integrate more variable renewable energy (VRE). Wind energy, solar energy, marine turbines, run-of-river or tidal power stations green in nature, although generally fluctuating and non-dispatchable.

The variability of renewable energies raises operational problems on certain grids, where generation used for offering ancillary services, such as continuous regulation, is not flexible enough [1] [2]. To assure continuity of electric service, resources dedicated to grid balancing must be able to quickly respond to increased or decreased in variable generation, which sometimes adds up to sudden reduction or increase in demand [3].

> *While major electricity networks have long resorted to electricity production to meet capacity problems, greater participation in distributed generation, smart buildings and storage is expected to reduce network stress and provide balance.*

More intermittent renewables requires more operating reserve [4], and this reserve must respond more quickly to variations in generation and demand [5]. While major power grids have long met capacity problems by producing electricity, increased participation of distributed generation, smart buildings and storage are expected to reduce grid stress and provide balance [6] [7] [8] [9] [10] [11].

Strong drivers have stimulated changes in this field:

- The electricity markets must open the service supply to non-traditional resources, in order to comply with non-discrimination standards [12]. There have been changes in several markets and the regulation service is now open for customers with average power loads [13].
- In many cases, peak load reduction is more economical than dispatching or building power plants. Companies specialized in energy reduction and aggregation of distributed resources gained important shares in the capacity markets [14]. The electricity transmission rates on markets through injecting/ejecting nodes or grid zones (reflecting local congestion) highlight the benefits of resource distribution to reduce demand on transmission grids.
- Consumer energy management technologies for automating consumption (residential and commercial) are gradually being marketed [15]. The use of smart household electrical appliances and smart thermostats will gradually increase as older equipment is replaced, as applicances reach the end of their life cycle or by incentive, by special retail offers, or energy efficiency programs.
- Developing electric transport increases market availability of batteries, reduces purchase and resale costs, and helps to increase efficiency. This development will eventually have the effect of introducing storage into the electricity supply chain which, until now, was a "just-in-time" industry. Automotive companies plan to eventually use electrical vehicles to supply electricity to power grids (vehicle-to-grid) [16].

The development of smart electricity networks (*smart grids*) connects the customer with operators, markets and energy service companies [17]. An "Energy internet" is under development to decarbonise the grid, but also to improve its performance and reliability [18] [19] [20] [21] [22] [23].

This document will focus on the contribution of distributed energy resources (DER), including demand-side management (*demand response*), decentralized storage and production in order to balance the grid and renewable energies. The generic terms “balancing” or “regulation” are used throughout the document to facilitate reading. Appendix 1, at the end of this document, provides further details and clarifies the concepts and services related to ancillary services used to balance the network.

In the first section, we present technical concepts, followed by a technical and scientific review of notable demonstration projects and studies in the field. The last section focuses on issues related to DER commercialization and adaptation of electricity markets.

2 Smart grid and distributed energy resources presentation

The modernization of electricity grids toward a *smart grid* is being developed to improve reliability [24], facilitate integration of renewable energies and electric vehicles, and improve power consumption management. With the development of *smart grid*, more distributed energy resources (DER) can be deployed, such as batteries, decentralized production and technologies for increasing customer demand-side management.

With the development of the smart grid, more distributed energy resources (DER) are deployed such as batteries, decentralized production and technologies for expanded customer demand-side management.

The terms "distributed energy resources", "flexible loads" or "flexible resources" will be used in this study. By distributed or decentralized, we mean an equipment (load, production or storage) connected to a distribution feeder or located on the client side. By flexible, we mean the possibility that these equipment are temporarily dedicated to directly[1] supporting grid operation (by control) or indirectly (by automation based on price or curtailement signal). The term “flexible load" refers specifically to an equipment on the client side and managed by an operator or energy management system.

Here are some technologies which can be used for advanced management:

- Electric water heaters, heat pumps, baseboard heaters and radiant floors;
- Smart household electrical appliances;
- Dual energy heating systems;
- Combined cycle power plants and heating systems;
- Air conditioning and ventilation systems;
- Interior and exterior lighting;
- Distributed generation (generating sets, fuel cells, run-of river power plants, solar energy and wind energy);
- Storage by stationary batteries (one or several units in parallel) or mobile (battery-driven vehicles); and
- Thermal storage of cold (ice floe or cold water) and heat (central and wall).

Some of the technologies presented here are underrepresented on the grid (e.g. stationary batteries and electric vehicles) while others are already deployed on a large scale (e.g. electric water heaters, air-conditioning and heat pumps), but not intelligently joined to the grid.[2]

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[1] In a recent study by the US Department of Energy National Energy Technology Laboratory [10], the expression "demand dispatch" describes the use of the flexible loads in the operation of power grids. Demand dispatch translates the idea that in contrast to generation dispatch, currently used on the grid, load blocks would be programmed, following centralized scheduling or a bid, to absorb or release power. In Europe, the term "Pilotage de charge”(in French) is also used.

Some low-power technologies are more widespread in businesses and residences and are more available. Other higher-capacity equipment has limited availability during the year. Certain technologies lend themselves to consumption management (start delay or shifting consumption), while the others follow stricter operation schedules or, in other cases, it may be very inconvenient for users.

This grouping is slightly limited, since acting or not acting on normal equipment function depends just as much on user preferences, incentives provided and the costs of smart integration, as on the technical challenges. At various levels, information technologies can play a crucial leading role in aggregating these resources and allowing their participation in integrated planning or market dynamics. Access to these resources to support power grids implies the availability of a reliable, fast and secure communications network.

2.1 Smart Grid support to DER integration

The use of electric or thermal storage, distributed generation or demand-side management has been extensively addressed in recent years [25] [26] [27] [28]. Numerous power companies already use interruptible and standby loads for clients, to reduce network peak demands or supply emergency reserve [29] [30].With the development of *smart grids*, the aim is to automate the management, to use these resources for providing markets with quick demand reduction, but also with quick increases during surplus of energy production. Better load management is anticipated, but essentially, smart grids enable DER to provide ancillary services, a market so far reserved for power plants. For example, maintaining network frequency could eventually be carried out, in large proportion, by closely managing demand [31] [32].

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Flexible loads, distributed generation or storage can now provide a number of services. While penetration is still limited, power markets now accept that non-traditional resources are part of ancillary services, such as regulation[3] [33]. In these markets, a large industry or small resources aggregated together could compete directly with power producers. To keep track of those programs, the ISO / RTO Council maintains an inventory of existing demand-side management programs in North America [13] in which services are offered to wholesale electricity markets. As part of the information provided, demand-side management programs are classified by type of service (energy, regulation, reserve and capacity). We note, however, that this list is only about wholesale market programs and does not include programs launched by electricity distribution utilities or retailers to directly manage peak customer demand or to provide emergency services during outages.

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[2] By "smart integration", we suggest that there should be information sharing between equipment, grid operator, the utility or a company specialized in demand-side management.

[3] See Appendix 1 for more details on different ancillary services’ definitions and descriptions.

Several business opportunities could lead to the development of a portfolio of flexible ressources. Here are typical services that could be offered to markets or utilities by DER:

Table 1 : Network services provided by DER and the goals

#	Service	Type	Goal
1	Peak Load Management	Energy (non firm)	Energy reduction bids during peak demand, at lower cost than generation. For local distributors, avoid energy cost or peak demand penalties.
2	Optimal Resource Allocation	Energy (non firm)	Storage for electricity or greenhouse gas (GHG) arbitrage. Avoid costs associated with the starting-up of mid-merit thermal generation.Take advantage of low price of electricity during periods of surpluses.
3	Capacity Management	Capacity (firm)	On request, provide firm energy reduction, at lower cost that additionnal generation or transmission infrastructures. For local distributors, avoid network capacity addition.
4	Spinning reserve	Contingency Reserve	Following major network events, provide reserve to fill energy gaps and to maintain frequency.
5	Non-spinning reserve	Contingency Reserve	Following major network events, provide reserve within 10 minutes to restore spinning reserve levels.
6	Suplemental Operating Reserve	Contingency Reserve	Following major network events, provide remplacement reserve within 30 minutes to restore spinning and non-spinnig reserve.
7	Automatic Frequency Control	Regulation reserve	Continuous adjustments of the frequency through frequency-sensitive relays (not during major events)
8	Automatic Generator Control (AGC)	Regulation reserve	Continuous adjustments of the frequency through operator setpoint (not during major events)
9	Load following	Load following	Fill the energy gaps between dispatch orders (i.e. intra-hour variations).
10	Surplus and curtailement management	Energy surplus storage	Store surpluses of energy on the network to avoid generation curtailement.
11	Isolated Network Management	Local energy storage	Store energy for planned islanding on feeders or for renewable energy integration on remote networks.

At this time, technical[4] or economic considerations limit the contribution of DER to support the network. By developing more intelligent and standardized consumer goods, we anticipate an increase in services provided by loads from residential, commercial or industrial customers. The latter could directly exchange with wholesale markets or be part of the portfolio of a public utility or an aggregator.

2.2 Renewables energies and network flexibility

The variable nature of renewable energy is putting pressure on network operation which could eventually lead to increase in electricity cost. The CAISO study [34] study mentioned four problems related to changeability of VRE[5]. These problems were clearly demonstrated in a study of *Lawrence Berkeley National Laboratory* [35]:

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[4] 100 kW is the typical minimum capacity usually accepted by operators.

[5] Only the costs related to variability of renewable generation are described and not the costs related to integration (extending the grid, replacement of automatic systems and amendments/changes to protection).

a) **Hourly needs related to ramping**: The scheduled availability of greater production capacity with the aim of following greater hourly variations. Variations in wind power increase variations in demand. Some regions experience more windy conditions at night, which decrease in the morning, while electricity demand increases during the same period.

Photo : CanmetENERGY

b) **Intra-hourly production variability**: Using resources to follow unscheduled production variations inside an hourly time block. There are significant costs involved in reserving production units which remain unused (in the event where the forecast was accurate or in the case of wind overproduction) and in purchasing electricity at the marginal price from a local supplier (in case of underproduction).

c) **Surplus generation**: This takes place when baseload plants are at their lowest capacity, exports are at their maximum and internal demand is insufficient to absorb renewable power production (especially that coming from wind turbines). Sometimes load shedding is necessary. Even some markets experience negative pricing, indicating significant energy surpluses in the grid.

d) **A near-instantaneous reduction or increase in power plant output:** Local problems with voltage variations can be created when clouds pass over a solar power farm, for example. In contrast to rotating machinery (such as wind turbine rotors), solar production has no mechanical inertia. Variations of 50% in 90 seconds are possible or even 70% in 5 to 10 minutes [36]. As voltage regulation is not subject to the "ancillary services market", grid modification expenses are often absorbed by off-grid applications or by all users.

On the economics side, the introduction of VRE increases the need for and, consequently, the cost of ancillary services[6] and introduces incertainties in the economic dispatch of generators. According to De Cesaro [38], increased penetration of wind on the markets would increase the units commitment costs more than the costs associated with regulation or load following. On these markets, reservation costs are paid to power plants to insure their availability, if needed. An additional amount goes to dispatched

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[6] See Appendix 1 for more details on different ancillary services' definitions and descriptions.

power plants. The cost is often high, as it is frequently determined by the marginal cost of electricity on the real-time market, reflecting actual start-up costs of the last available *economical* power plant. On transmission networks, these additional wind energy costs are sometimes absorbed by all grid users or wind farm owners. If no market exists, grid operators with an available cyclable generating fleet may require payments for balancing services. For distributors offering this service, the amount required takes into account opportunity costs associated with maintaining a captive load reserve for balancing.

Significant penetration of renewable energies creates challenges to maintaining grid balance. Certain regions have more flexible generator fleets which can more easily balance the intermittent and variable nature of most renewable energies. The concept of *flexibility* can be described as the capacity of a grid to rapidly modify generation or demand in response to evolving uncertain conditions. Hydroelectric complexes with reservoirs are capable of storing some energy and offering balancing services. Internal combustion turbines can be stopped or started at short intervals (i.e. 10 to 20 minutes) and contribute to grid balancing. This is not the case for nuclear power plants, which take longer to increase or reduce production and to start/stop. Interconnections to other grids, market approaches and demand-side management also provide the potential for increased grid flexibility [1]. Numerous studies have shown that strong penetration of fluctuating renewable energy is possible, but involves constant changes in planning and operation of transmission networks [37], [38], [1]. Figure 1 shows flexibility requirements, as well as resources which can balance fluctuations in net load (total load less total variable generation) or respond to contingencies.

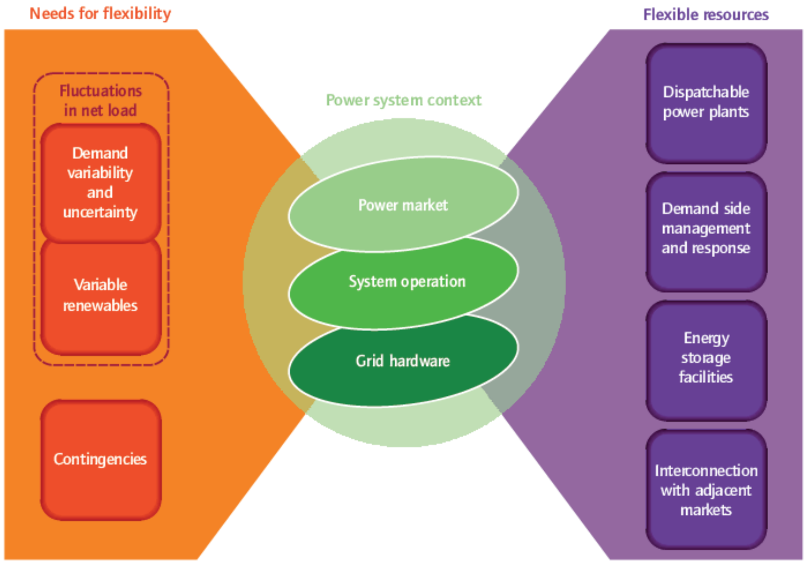

Figure 1: Overview of flexibility and resource needs [1]

As seen in this illustration, DER such as demand-side management, storage, as well as certain types of distributed generators can contribute to increased grid flexibility. However, using DER to support the networks would require addressing small load aggregation, small generation, storage and their integration on the grid and on the markets.

2.3 DER Aggregation

Integration of DER poses a number of challenges. Technically, distributed resources have less power, are numerous and their behaviour is variable and not completely characterized. For operators so far, these resources have been mainly invisible and unmanageable. Integrating these resources into electricity markets creates other challenges. Markets require a certain volume, minimal power with appropriate telemetry, which are not widespread on the distribution network or on the client side.

Using distributed resources to support the transmission or distribution networks would require addressing small load aggregation, small generation, storage and their integration on the grid and on the markets.

To fill this need, a new actor is introduced on electricity markets: the aggregator[7]. This type of business offers energy services to network operators or public utilities by using the flexible loads or generators located on commercial or industrial premises. For the moment, this market is relatively closed to the residential sector or to small commercials. Moreover, network services to be offered by the later are limited or inexistent in many regions.

Considering the current trend in the industry, which appears to be encouraging energy management technology deployments in buildings, on the one hand, and, on the other hand, the greater market openness, those businesses should likely play a greater role in the future. A futurist vision of the load aggregation business justifies the growing interest of research for virtual power plant and microgrids paradigms. As seen in Figure 2:

- A virtual power plant aims to integrate a set of distributed resources to supply energy and/or ancillary services to the grid. When taken individually, these low-power resources have limited impact. Together, however, these distributed resources can provide energy and services comparable to power plants. The physical location of these resources is not a determining factor, as it is with a microgrid (see below), where voltage and frequency regulation are tightly coupled to the microgrid topology and physical location of resources.
- The resources distributed in a microgrid insure electric service (partial or total) during main grid breakdowns. The resources must be nearby, connected to the same power station or distribution line. The microgrid controller must substitute itself for the main grid operator to maintain the frequency and voltage during scheduled and inadvertent islanding.

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[7] Sometime called Curtailement Service Providers (CSP)

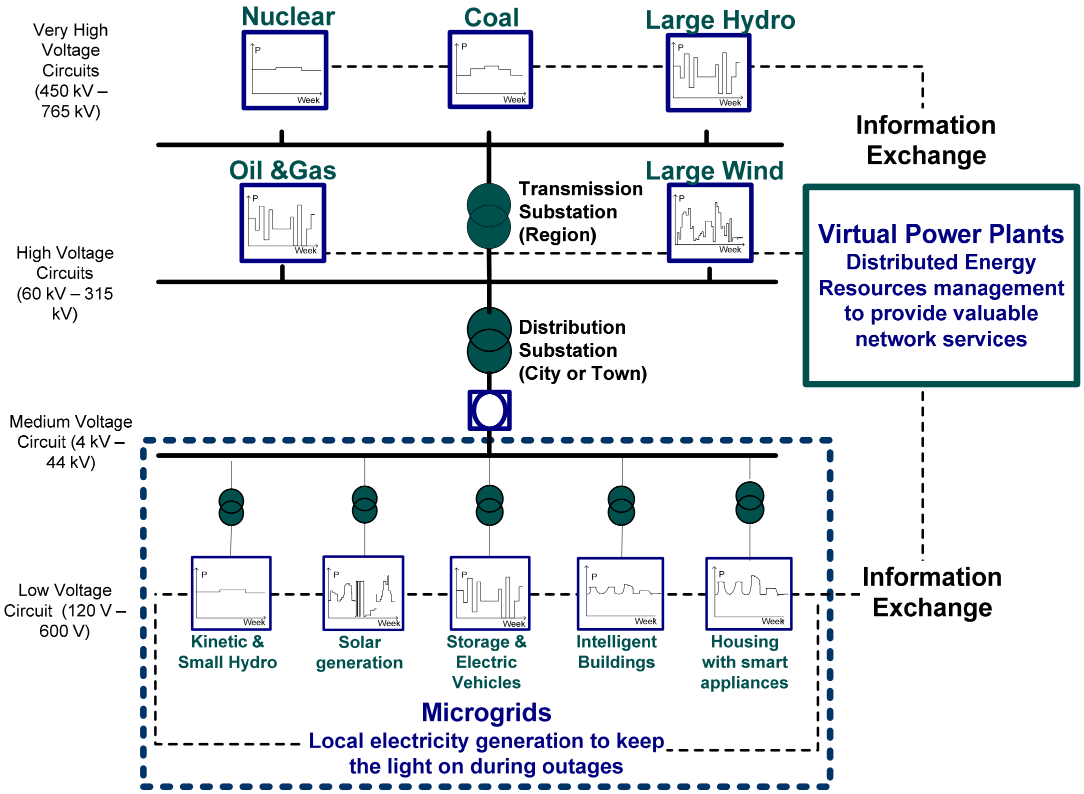


Figure 2: Integration of distributed energy resources, CanmetENERGY, Varennes

2.4 Benefits of distributed energy resources

Depending on the *smart grid* technologies deployed in a microgrid or used in a virtual power plant, the use of these resources can reduce energy consumption, peak demand and other needs for associated with network balancing. These new approaches of integrating distributed resources would maintain continuous supply, meet economic and environmental considerations, and improve energy security for communities. Here are some examples of applications of distributed energy resources integrated into electricity grids. Demonstration project examples are drawn from Canadian projects in the field.

Reducing peak load

Grid use during the year depends mostly on customer consumption characteristics. The grid is used at its full capacity only a hundred of hours per year. Increasing peak load requires more generation, transmission and distribution capacity and induces additional operation and maintenance costs. This increase also requires increased contingency and balancing reserves to mitigate losses on transmission and distribution grids during peak load.

Shifts in consumption, use of thermal storage or batteries as well as firm and decentralized electricity generation can reduce grid stress and avoid costs associated with power increase on the whole supply chain. They also allow supply, transmission and distribution companies to postpone investments in increased capacity. For residential, commercial or industrial customers, peak load reduction reduces their electricity bill if an incentive supports demand modulation in time (e.g. time-of-use tariffs, peak demand charge, real-time rates, critical period pricing, etc.). Automated demand management, fed by market prices, can help coordinate load reduction for customers and on the grid [39]. On the markets, capacity thus generated or self-generated in distribution can be sold on capacity markets, by electric utilities or other companies specialized in peak management, i.e. aggregators.

Avoid commissioning costly or polluting power plants

Sometimes, it is necessary to commission power plants to supply electricity for short periods or to meet demand fluctuations. These plants can be more expensive to operate than power plants offering baseload production. They are often fed by fossil fuels, such as diesel, fuel oil or natural gas. Certain coal plants are also used for a few hours per year. Load management can help avoid greenhouse gas emissions linked to commissioning peak-load generating stations [40].

Increase reserves to facilitate integration of intermittent renewables

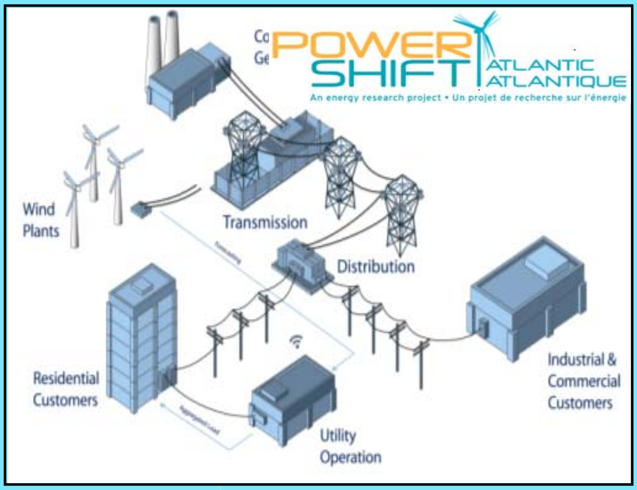
Several major power grids do not have enough "flexible resources" to offset significant capacity fluctuations in wind generation or other types of variable generation. Several operators are considering available flexible loads and storage resources, in order to increase the supply of reserve resources to be allocated to follow variable generation or act on contingencies. It is the subject of several demonstration projects, like the ongoing project *PowerShift Atlantic* in the Maritime Provinces.

PowerShift Atlantic Project [41]

Principal promoter: NB Power

Region: Four maritime communities in New Brunswick, Nova Scotia and Prince Edward Island

Budget: 32 M$



Michel Losier, Powershift Atlantic

The Maritime Provinces have significant wind potential, while utilization factors of up to 40% are recorded in various areas, particularly on Prince Edward Island. To obtain the full potential of this variable resource, a collaborative research and demostration project was launched in 2010 through the Clean Energy fund of Natural Resources Canada (NRC), led by New Brunswick Energy, the government of Prince Edward Island, Maritime Electric, Nova Scotia Power, New Brunswick System Operator (NBSO), University of the New Brunswick (UNB) and the government of the New Brunswick. This four-year project focuses on remotely adjusting fluctuations in wind production with client-side load management. By using flexible loads for a large number of participating customers, it could be possible to offset a thermal plant to provide load following or spinning reserve. This situation arises at a some times of the year, when hydroelectric production cannot supply this service. With more wind energy on the NBSO network and the reconnexion of the Pointe Lepreau nuclear power plant this situation can occur more frequently.

As part of this project, various residential, commercial and industrial technologies are being tested, such as load control for water heaters, thermal storage and energy management systems in commercial buildings. Demand management for some industrial processes or the adjustment of refrigeration set points are also being considered. A maximum of 2000 customers should participate in this demonstration project.

A significant challenge of this project is insuring reliable real-time grid operation with a new type of generator: a virtual power plant, owned by NB Power

The innovative aspect of this project is the development and implementation of a virtual power plant. Indeed, commercially-available energy management systems do not support continuous load management and demand response systems do not support ancillary service provision satisfactorily. Consequently, the consortium decided to develop a genuine virtual power plant solution to provide load following and to provide spinning reserve on demand.

The Maritime consortium, along with SAIC, Stantec and T4G companies are working on customer commitment, on deployment of technologies and on developing one of the first virtual power plants to run on actual power grids worldwide.

Allow operation of micro-grids

On some distribution lines or sites, there is enough distributed generation to insure preservation of the electric service for a portion of the feeding area when the main grid supply is lost, so to operate as a *microgird*. When disconnected from the grid, a microgrid works independently to insure, as a replacement of the integrated grid, frequency control through demand-supply balance, voltage maintenance and protection of the grid and its personnel.

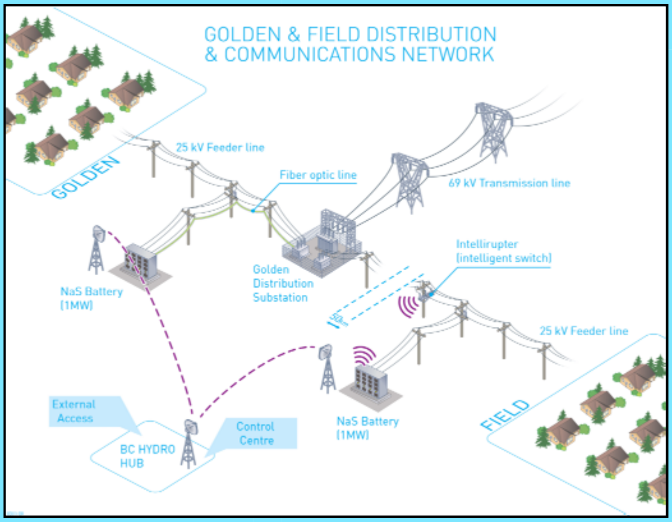
This operation is complicated when the generation on the islanded system is variable, as it is with wind energy, solar energy and certain run-of-river generating stations (variable water flow). Additional resources, such as flexible loads and storage could facilitate this operation. Although this practice is not widely used, this approach could increase the available electric service during outages. BC Hydro explores this possibility in the following demonstration project.

Energy storage and demand-side management for transformer stations near maximum capacity

Principal promoter: BC Hydro

Region: Golden and Field in British Columbia

Budget: 15 M$



Whittaker,Helen, BC Hydro, October, 2011

This project demonstrates energy storage to supply the communities of Golden and Field during power outages on the main grid or during peak load periods.

Two batteries of 1 MWh each will be installed: one in Golden, to reduce stress on substation during peak hours. The other will be installed in Field, to support loads during an outage. The principles of planned islanding maintain service to the community during periods of up to seven hours. The project is planning technologies to increase the response time during breakdowns. "*We are keeping the lights on in B.C. with integrated planning and the advancement of our system through the use of new technology*", says Greg Reimer, Executive Vice-President of Transmission and Distribution, BC Hydro.

Indeed, electricity distributors rarely apply strategic islanding. BC Hydro, with a number of remote communities, is interested in this new approach to grid operation, which can maintain service with support from distributed resources, such as run of river power plants or storage [42]. Finally, this project could also reduce environmental impact and costs associated with diesel generators used during prolonged outages and peak loads.

NGK Insulators Limited of Japan will supply the sodium sulphide batteries. Quanta and S&C Electric Company, specialized in grid automation networks and integration of the renewable energies, will be responsible for the system engineering.

This solution could benefit a number of remote Canadian communities, which have poor network reliability and high costs of increased grid capacity.

Optimize power grids in remote communities

Numerous isolated grids, particularly in Northern Canada, operate on expensive diesel fuel. Improved distribution of generating sets or twinning with variable generation could reduce diesel costs, as well as noise and pollution. Some wind-diesel or solar-diesel twinning projects [43] [44] are being promoted, as well as projects for optimal distribution of diesel production [45].

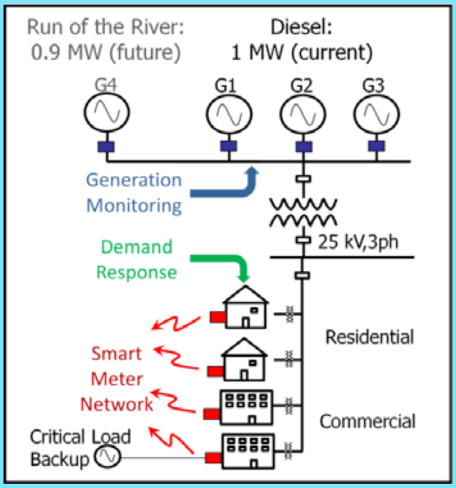
Without storage or flexible loads, certain diesel groups operate in a low efficiency zone. Load control or renewable production can optimize grids for these communities, and shut down low-efficiency generator sets. Flexible loading can also improve surplus renewable production events, during twinning in the local grid.

Using renewable energies in remote communities poses significant integration problems and is the subject of constant research. A good load management and storage are key elements of a sturdy twinning solution.

Example: Hartley Bay

A power demand management system was established in Hartley Bay, a remote community in British Columbia, Canada. The objective was to improve overall distribution efficiency of generating sets. There are 170 residents in this community and its small electric grid, supplied by three diesel generator sets, is inadequate. The power demand management system is designed to add or remove loads if algorithm detects an imminent lack of efficiency. For load-shedding on demand, 30-ampere adjustable thermostats and load controllers were installed in commercial buildings such as the schools, hospital and community center. The total load-shedding capacity is 20% of the winter peak.

The preliminary results demonstrate that the community did not see any change in the service supply. A run of river power plant will be soon be set up in the community and the load management system will be able to optimize production by generator sets by taking into account the power plant's variable production and client-side flexible loads. This demonstration project was the result of cooperation by the village of Hartley Bay, Pulse Energy, CanmetEnergy, Aboriginal Affairs and Northern Development Canada and the British Columbia Ministry of Energy and Mines.



Diesel generation management in Hartley Bay

3 Technical and scientific review

By presenting studies and results of demonstration projects, this section aims at highlighting the range of non-traditional, i.e. non-central generation-based, technologies which can be used to assist with balancing renewable energies. Sixteen (16) studies and projects aiming at supplying different services to the grid are summarized. The technologies are in the residential, commercial, municipal and transportation sectors. These examples are gathered around load types and more information about the publication/demonstration title, a summary, and the services provided[8] are presented.

3.1 Residential – Air conditioning

#1 – Title: D. S. Callaway, "Tapping the Energy Storage Potential in Electric Loads to Deliver Load Following and Regulation, with Application to Wind Energy" [46]

Network service: Automatic Generation Control (AGC) and Load Following

Callaway (2009), shows that a population of thermostatically controlled loads (TCL) can be managed to serve as virtual storage to follow generation variability in renewable electricity generators or variation in demand from other loads. Although some TCL are capable of continuously modulating demand for heating or air-conditioning demand, they normally have a single setting (set point) which activates the equipment to maintain a temperature range (deadband).

This article focuses on how small thermostat set point manipulations can turn on and off only the TCL nearing the upper or lower limits of thermostat deadbands. This approach would regulate power, with minimal deviation between the original thermostat set points, avoiding conflicts with customer comfort.

While monitoring the status of thermostats (temperature and power demand) for an entire load population, the method presented in this article is based on the fact that, although it would be challenging to track the status (i.e. temperature and power demand) of every load in a population subject to control, it is possible to accurately estimate the *probability* that each load in the population is in a given state.

The method proposed was tested by simulating thermal building properties and their AC needs as well as data from a wind power plant. The 1-minute actual wind power data was collected by the National Renewable Energy Laboratory and result from a large wind power plant near Lake Benton, Minnesota. (138 wind turbines of 750 kW each). Average thermal properties from other scientific articles were used to simulate 60,000 loads.

These simulations showed that major changes in demand can be achieved without significantly changing the TCL set points. Consequently, regulation service can be provided to offset supply or demand changes without compromising the end-use function of the loads subject to control.

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[8] See Appendix 1 for more details on the differents ancillary services

In the simulation, every thermostatically controlled load (60,000 in total) supplied the energy and power equivalent to 0.5 kWh and 0.75 kW storage units.

In the case study, approximately each MW of wind power required a 3.4 MW to balance in order to reduce error between the forecast and actual demand to its minimum. During the simulations, the maximum deviation of the temperature set point never exceeded 0.1°, suggesting that this type of management would not compromise customer comfort.

Other conclusions:

- The magnitude of load population response to a small change in thermostat set point is a function solely of the size of the set point change and the width of the thermostat deadbands of the population under control. Smaller thermostat deadbands provide larger responses to set point changes.
- Load populations with more heterogeneity (diverse load profiles) are better candidates for this control method. It is in direct contrast to previous direct load control studies, which have been forced to consider homogeneous load groups.
- Load populations with lower thermal capacity are better candidates for this control method, when the need to increase and reduce consumption is equally important (regulation service).

#2 – Title: J. H. Eto, Lawrence Berkeley National Laboratory, "Demand Response Spinning Reserve Demonstration – Phase 2 Findings from the Summer of 2008" [47]

Network Service: Spinning Reserve

This study by Lawrence Berkeley National Laboratory (2009) and previous works [48] shows that using air-conditioning load control as rotating reserve, instead of peak management programs, can triple load reduction. We suggest that the full air-conditioning load can be completely interrupted during a major grid event.

Although air conditioners are not available to supply rotating reserve year round, their availability highly correlates to grid demands and the cost of contingency reserve. In fact, the costs of energy and ancillary services increase when air conditioning demand increases.

This study shows a close correlation between errors in short term energy demand and the contingency reserve: when air conditioning loads increase, so does the need for available reserve, showing a major advantage in using air conditioners to supply contingency reserve. If the current demand forecast is in error and underestimates the current load, the grid operator must commission additional power plants to handle the load. By using air-conditioners instead of generation to provide reserve, generation can be saved for electricity supply rather than for providing ancillary services.

Several ways demand management programs can manage air-conditioners. They can be interrupted (or cycled) for several minutes by controlling their supply. A contactor can interrupt the compressor; the compressor motor uses about 80 to 90% of the air conditioner's total power [49].

3.2 Residential – Household appliances

#3 –Title: Intelligent Energy Europe, “Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)” [50]

Network Service: Surplus and curtailement management

The study by *Intelligent Energy Europe* (2009) estimated the potential contribution of smart household electrical appliances to balancing European electricity grids. The study included the following appliances: air conditioners, circulation pumps for heating, dishwashers, thermal accumulators, freezers, refrigerators, ovens, stoves, dryers, electric water heaters and washing machines.

First, the study compiled information on the hourly use profile and operating procedures of these devices through Europe, using studies and available data. According to the average daily profile, electricity demand at minimum load is, at most, between 200 and 850 W. The contribution of electric heating, used occasionally or only in certain regions is not presented, even though this equipment uses considerable power.

Afterward, the equipment was sorted by two management approaches: change in start-up time (*smart timing of appliance cycles*) and temporary interruption (*interruptions of appliance cycles*). In the first case, the user sets both the start-up time and the latest time at which the operation must be finished. Washer and dryer use can be postponed by 3 to 6 hours, dishwashers from 3 to 8 hours, and refrigerators/freezers from 15 to 30 minutes and other appliances from 15 minutes to one hour.

In the second case, for some electrical appliances, the cycle can be temporarily interrupted for a certain length of time and under certain conditions. However, this is not suitable for all appliances. Washing machines could be interrupted for 15 minutes, dryers for 30 minutes, dishwashers for 15 minutes, refrigerator / freezer for 15 minutes and other appliances for 5 minutes.

Every appliance was qualitatively evaluated with four criteria: appliance power (*specific load during operation*), availability (*availability*), flexibility of load to be shifted (*shifting flexibility*) and customer acceptance (*convenience for consumers*).

These results were applied according to a grouping of five European regions, consisting of countries exchanging electricity generation and balancing service between them. A "flexible" capacity was estimated between 100 kW and 150 kW for 1000 residential customers (100 W to 150 W per customer).

Results: Demand-side management options in the residential sector can reduce wind production load-shedding by 50% during periods of reduced power demand. Furthermore, using these appliances could reduce fossil fuel demand for European grids by 4.5% [50].

It is worth noting that peak load management, with automatic timers installed on water heaters, is already widespread in Europe. This reduces the balancing potential of wind power:

"As a result of this assessment, it is no surprise that the most interesting options for load management, electric storage heating and water heaters are those appliances which are already exploited for load management, typically based on a static night tariff operation."[50]

The conclusions from the Smart-A study regarding other equipment:

- Customers accept the idea of delaying use of dishwashers for long periods. However, these appliances are not widely available;
- Cold-generating appliances, such as refrigerators and freezers, can be fully automated. However, these are low-energy appliances and their use can only be delayed by a few minutes;
- Washing machines and dryers are interesting options, but require more user interaction. The dryer's heating element be more useful in emergency situations, such as load-shedding to restore grid stability;
- Stovetops are not suitable for this type of load management;
- Air conditioners and circulation pumps are not suitable for this type of management.[9]

3.3 Residential-Water heating

#4 – Title: L. Paull, H. Li & L. Chang, "A Novel Domestic Electric Water Heater Model for a Multi-objective Demand-side Management Program" [51]

Network Service: Load Following and Spinning Reserve

The study *by Paull et al*. (2010) is part of the Project PowerShift Atlantic project [41]. Researchers at University of New Brunswick (UNB) developed a platform for aggregation and management of electric water heaters in order to supply ancillary services.


Photo CanmetENERGY

Because of their thermal storage capacity, water heaters have the capacity for up-regulation or down-regulation when integrated with a virtual power plant. The aggregated water heater loads are distributed to supply ancillary services or reduce peak load with no effect on the customer consumption profile. The thermal status of every water heater is estimated using available data from smart electricity meters or other sensors.

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[9] In the context of the study (surplus management)

Aggregated water heater control system is seen in Figure 3.

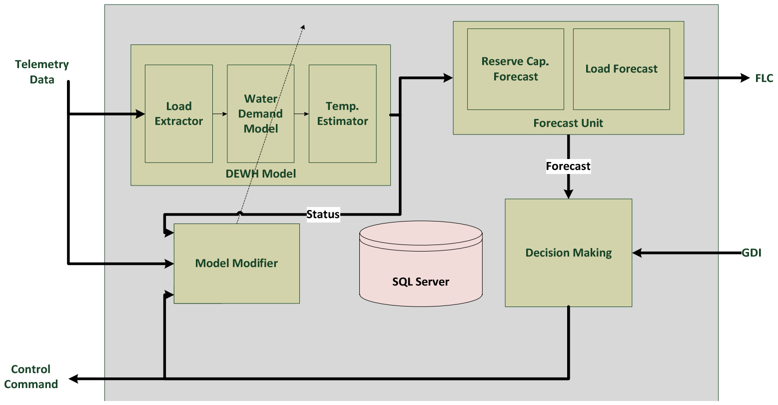

Figure 3 : Block diagram of aggregated load control system for electric water heaters

A smart meter measures the power demand of a residence; the smart grid communications infrastructures sends the information to the model (DEWH Model Unit), which extracts the power consumption of each water heater (load extraction), its water usage and internal temperature, based on thermal models of each heater. The *load forecast unit* estimates future consumption for every water heater, using the water usage profile model and applying the thermal model on power measurement during the forecast window. A multi-agent control system adds the consumed power of several water heaters to calculate demand forecast to identify potential up regulation and down regulation, or the available capacity for ancillary services.

The following table shows the simulation of potential up- and down- regulation of a virtual power plant, using smart meter data from 700 homes.

Table 2: Simulated results of water heater load control for supplying ancillary grid services

Number of homes	Average controllable load (kW)	Average up-regulation (kW)	Down-regulation capacity (%)	Average up-regulation (kW)	Up-regulation capacity (%)
200	172.85	19.92	11.52	18.45	10.67
400	307.95	34.54	11.22	33.04	10.73
700	442.95	48.97	11.06	47.46	10.71

The preliminary results indicate that from 10 to 11% of aggregated water heater loads can help balance power grids, without negatively affecting residential customers.

#5 – Title: J. Kondoh, N. Lu & D. J. Hammerstrom, "An Evaluation of the Water Heater Load Potential for Providing Regulation Service" [52].

Network Service: Automatic Generation Control (AGC)

Kondoh *et al.* (2011) estimated the potential of using water heaters to supply regulation service to power grids. In this study, the authors characterized the thermal behaviour of a typical water heater, the water usage profile and monitoring of a typical control population. With this model, they developed a direct control for the bottom element of the heater (which has two heating elements), not the entire heater. According to this algorithm, each water heater receives a set point every minute.

The conclusion of this study is that, according to the proposed approach, approximately 33,000 water heaters are needed to provide a 2-MW regulation service 24 hours a day. However, if water heaters only provide regulation from 6:00 to 24:00, approximately 20,000 will be needed.

#6 – Title: P. Steffes, "Grid-Interactive Renewable Water Heating Analysis of the Economic and Environmental Value" [53].

Network Service: Optimal Resource Allocation

An analysis by the Steffes Company (2010) shows the environmental and economic value of using water heaters to balance renewable energies.

The authors used wind generation and market data to analyze balancing needs and determine the potential for load usage. They compared the consumption curves for interactive water heaters with market price data.

In this study, a 105-gallon water heater (approximately 400 litres) represents the equivalent of a 26 kWh battery (about the quantity of energy accumulated in warm water). The analysis concludes that it is possible to reduce the operating cost of a water heater by 50% using electricity only off-peak and only when there is wind production. According to this hypothesis, 25% of the energy consumed for heating water would be simultaneous with wind generation could come exclusively from wind generation.

#7 – Title: M.-A. Moffet, F. Sirois and D. Beauvais, École Polytechnique de Montréal et CanmetÉNERGIE, « Études de cas: Équilibrage de la production éolienne à l'aide d'accumulateurs thermiques et de chauffe-eau électriques » "Balancing wind generation with thermal storage and electric water heaters" [54]

Network Service: Optimal Resource Allocation

Moffet *et al.* (2012) present a case for using electric water heaters and thermal storage to balance wind generation. The case study specifically targets use of these resources in order to provide balancing for time horizons of six hours. The chosen time horizon offsets balancing problems issuing from daily cycles, or costs associated with optimal allocation of generation resources (unit commitment) and the environmental problems related to using intermediate power plants for only several hours.

The study applied current wind generation data from Ontario's Independent Electricity System Operator (IESO) website, using data from a one-week period, during which a noticeable increase and decrease in wind generation was recorded. It applies a moving average of six hours (three hours on either side of each datum) to these data to smooth the curve and keep only the long-term fluctuations. The behaviour of 20,000 water heaters was generated by a water heater model available in the literature [55] with a single 4500 W element and a single uniform temperature zone. Water drawing was determined by a Markov chain from [55]. The temperature was monitored within a 55 to 65°C range, which represents storage equal to 3.2 kWh (energy accumulated in the total volume of water for a difference of 10°C). The power variations of the water heaters follow the curve of the wind production presented in Figure 4.

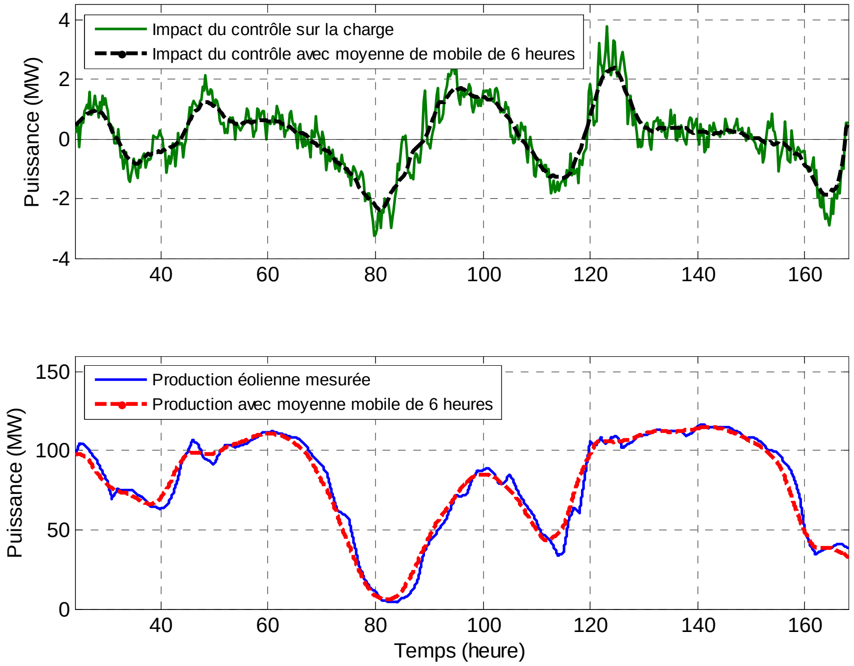

Figure 4: Balancing wind generation with water heaters

In the studied scenario, the 20 hours drop in wind generation and the associated 3 MW load drop suggested that each water heater provided 150 W of balancing during that period. During that event, the storage capacity of each electric water heater was well used, using 1.5 kWh of a theoretical value of 1.6 kWh (half of 3.2 kWh). Table 3 sets out the balancing need filled by the water heaters over the 6 days:

Table 3: Average power variation by water heater over six-hour period

Power variation by water heater (W)	< -150	-150 to -100	-100 to -50	-50 to 0	0 to 50	50 to100	100 to 150	>150
Percentage of time	1.2%	6.0%	17.7%	34.4%	22.4%	10.0%	5.6%	2.7%

During 56.8% of the time blocks for this period, water heaters provided up to 50 W of positive or negative balancing. They provided from 50 W to 100 W 27.7% of the time, 100 W to 150 W 11.6% of the time, and finally, over 150 W of balancing 3.9% of the time

#8 – Title: A. Moreau, Institut de Recherche d'Hydro-Québec/Hydro Quebec Research Institute, "Control Strategy for Domestic Water Heaters during Peak Periods and its Impact on the Demand for Electricity" [56]

Network Service: Peak load Management

This study by the Hydro-Québec Research Institute (2011) presents a control strategy for water heaters that reduces load pickup. More specifically, the author suggests integrating a control algorithm into water heaters, which can be used to directly control or program water heaters (timer). That minimizes the pick-up demand when heating elements are reactivated at the end of a load-shifting period and ensures, in all cases, the client's hot water supply. The study is based on a simulation model of a water heater that was experimentally validated and takes into account the diversity of the population's hot water withdrawal profile. More specifically, the data of 8,167 real water withdrawal profiles of several clients were input into the simulation model in order to evaluate the performance of water heaters under different operating conditions. The results give profile diversified by water heaters, such as seen by the network.

The findings of this study are:

- The electricity demand of a 270-litre water heater (60 gallons) can be almost totally wiped out during the morning (6:00 am-10:00 am) and evening (4:00 pm-9:00 pm) peak loads. On the other hand, because of their smaller tanks, deletion is less important for 180-litre water heaters (40 gallons imp), because their electric elements must activate more frequently to maintain a water temperature higher than 50°C. However, in spite of this, the reduction remains significant, as seen in Figures 5 and 6.
- If the demand pick-up is not controlled after load shifting periods, the demand is significant and is approximately equal to the nominal power of the water heaters. A new set point can be created if a large number of water heaters are left to their own devices.
- Phased reactivation can significantly reduce pickup demand after load-shedding periods. The more the resumption is phased over a long period, the lower the pickup demand will be. For example, phasing the reactivation within two hours (as in Scenario 2) halves the non-phased pickup demand.

- Water heater load-shedding has little impact on their hot water supply capacity. Indeed, in the case of both the 270-litre and 180-litre water heaters, the results show that hot water supplied to the clients is, 90% of the time, at a temperature higher than 55°C in all the simulations and higher than 50°C nearly 100% of the time.

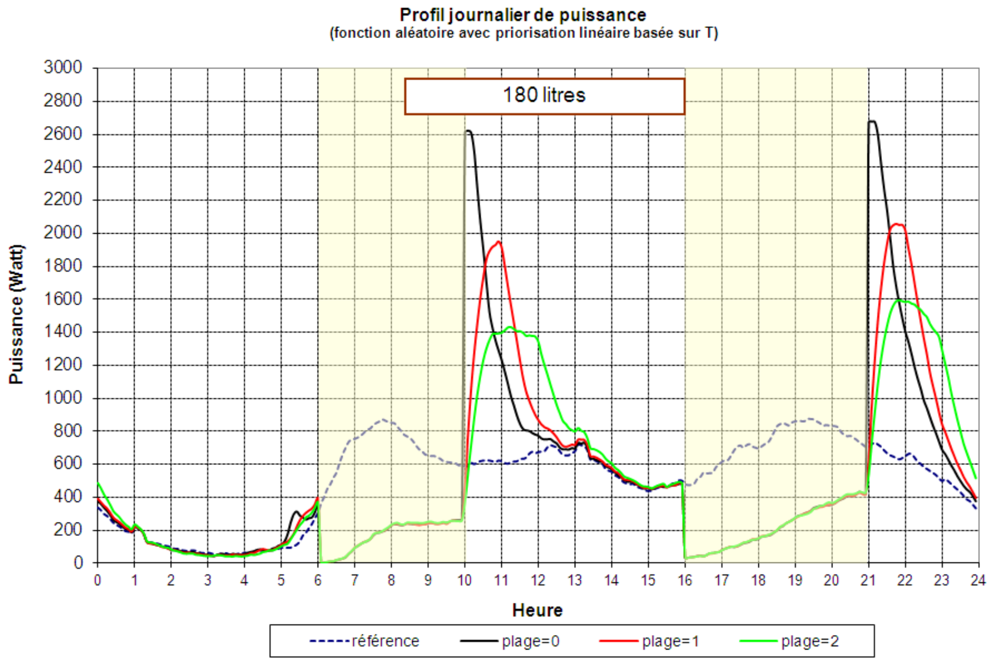

Figure 5: Diversified profile of water heater power demand during load-shedding (180 litre tank)

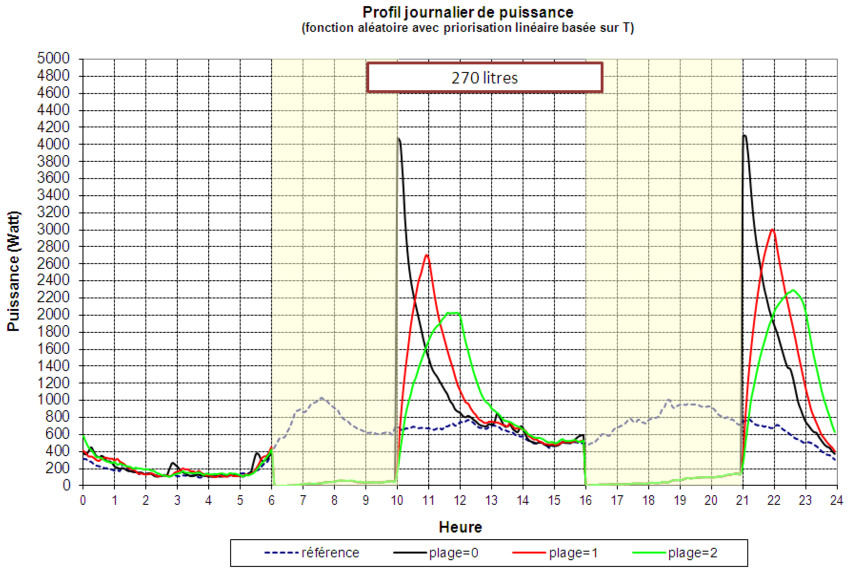

Figure 6: Diversified profile of electricity demand by water heater with periods of load-shedding (270 litres tank)

Phasing the reactivation of the electric elements has the effect of significantly accentuating the potential peak load reduction by delaying the occurrence of a new peak, due to reactivation of water heaters at the same time. Based on Quebec's power grid demand scale and according to the methodology of this study, phased reactivation of water heaters over two hours can nearly triple potential peak load reduction, compared to an uncontrolled reactivation. Indeed, the peak load reduction potential is approximately 600 MW with a reactivation phased within a period of two hours, whereas it is 225 MW for an uncontrolled reactivation.

3.4 Residential – Thermal storage

#9 – Title: L. Hughes, "Meeting Residential Space Heating Demand with Wind Generated Electricity" [57]

Network service: Isolated Network Management

The study of Hughes (2010) evaluated potential for using wind generated electricity to heat homes, using Electric Thermal Storage (ETS) thermal storage systems developed by Steffes.

The results showed that feeding ETS with wind generation could meet the heating needs of 500 homes. It also shows that ETS capacity (120 kWh, 180 kWh or 240 kWh) only affects the heating portion provided by generation (which can reach up to 99.5%).

The study took place in North Cape, Prince Edward Island, with an established capacity of 5.15 MW, and an annual wind power capacity factor of 38.6%.

 # 10 – Title: M.-A. Moffet, F. Sirois et D. Beauvais, École Polytechnique de Montréal and CanmetÉNERGIE, « Études de cas: Équilibrage de la production éolienne à l'aide d'accumulateurs thermiques et de chauffe-eau électriques /Case studies: Balancing wind production with thermal storage and electric water heaters » [58]

Network Service: Optimal Resource Allocation

A second case study, from Moffet *et al.* (2012), evaluated the potential for balancing production with ETS stored in homes. This study used the wind generation curves used in the water-heater case study (#7, above), and used the Steffes thermal storage unit with 180 kWh capacity and 28.8 kW maximal output. The ambient temperature data was taken from Environment Canada and the building envelope parameters were from a typical home in the Maritime region [59].

The case looked at load control of 500 ETS, in a context where 10,000 out of 20,000 homes used electric heating. Thermal storage heated 500 of the electrically heated homes.

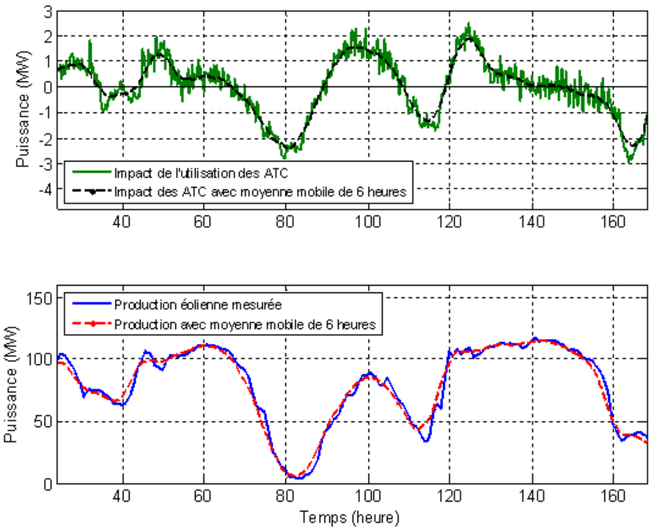

Figure 7: Balancing wind generation with electrical thermal systems

Figure 7 shows that during a 24 MW drop in wind generation, the ETS reduced the load from 0.9 MW, or 1.8 kW average per ETS.

3.5 Residential – Electric heating

#11 - Title: M. Togeby, EA Energys, "Intelligent Energy Systems - A White Paper with Danish Perspectives" [60] C. Kofod & M. Togeby, (2004), "Demand Response Offered by Households with Direct Electric Heating. Demand Response in Energy Markets" [61], Risø National Laboratory for Sustainable Energy, "Risø Energy Report 8: The Intelligent Energy System Infrastructure for the Future" [62]

Network Services: Peak Load Management

The studies of Togeby (2010), Kofod *et al.* (2004) and **Risø** National Laboratory for Sustainable Energy (2009) show the results of various initiatives aimed at balancing wind generation.

Various approaches are being tested in Denmark for electric heating as a source for grid balancing. An economic approach was tested as part of a 19-month demonstration project, involving 46 electrically-heated homes. A control system in every home used electricity prices to adjust consumption on an hourly basis.

For a 0°C exterior temperature, when prices were low, demand increased by 0.2 kW per home. When prices were higher, demand dropped by 0.25 kW. When a number of high prices appeared online, the effect was reduced. The consumption profile would follow the electricity price profile, which varied by about 5% compared with the average price.

Further to this project, the effect on power was lower than anticipated. In the document, we see that use of a single thermostat could explain the smaller variations.

During the demonstration project, heating interruptions of up to three hours caused only minor comfort issues [61] in normally insulated homes.

The potential for demand-side management from electric heating is estimated at more than 500 MW. The peak for the Danish Grid in 2009 was 6,300 MW, with potential peak reduction evaluated at 8%. For 400,000 electric heating subscribers, this represents a potential of about 1.2 kW per subscription.

In Denmark, it is estimated that using 100,000 heat pumps could release 200 MW of additional capacity or 2 kW per home.

The study shows that heat pumps used for radiant floors have significant thermal inertia, due to the concrete and ceramic floor covering. They can be deactivated for longer periods without inconvenience or discomfort. The thermal inertia of the hydronic system used for heated floors has an advantage compared to direct electrical heating, as that equipment has little or no thermal inertia.

3.6 Commercial – Centralized HVAC operation

#12 – Title: PG&E Participating Load Pilot 3 and S. Kiliccote, P. Sporborg, I. Sheik, E. Huffaker, & M.A. Piette, Lawrence Berkeley National Laboratory, “Integrating Renewable Resources in California and the Role of Automated Demand Response” [63]

Network services: Peak Load Management, Non-spinning reserve and Load Following

The *Lawrence Berkeley National Laboratory* report (2010) shows the results of the *Participating Load Pilot 3* (PLP) project. This demonstration project involved Pacific Gas and Electric (PGE), the *California Independent System Operator* (CAISO) and three commercial facilities[10]. The three businesses participated in the electricity market by submitting their real-time demand reduction bid based on the market price. The data was used later in the *real-time electricity market*.

This project tested the OpenADR protocol on the electricity market. CAISO’s Automated Dispatch System (ADS) was linked to the buildings through a Demand Response Automated Server. The OpenADR protocol, an information exchange model to communicate Demand Response events, delivered signals to the facilities' energy management and control systems and met their peak demand during bidding[11].

By using Client Logic, The Integrated Relay (CLIR) box[4] meant that Demand Response strategies could be initiated without human intervention at each facility. The device communicates price and reliability signals to each building's Energy Management and Control System (EMCS).

According to the authors, this experimental project showed that flexible load response time could be the same as generators (less than 10 minutes). The CAISO report pointed two major advantages:

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[10] An (IKEA) store, a government office building (Contra Costa County) and a bakery (Svenhard’s Swedish Bakery).

[11] According to the authors, the same infrastructure is being used for PG&E's price-based Auto-DR programs, such as *Automated Peak Day Pricing* and *Demand Bidding* programs.

1- Customers with Auto-DR capability can automatically respond to pre-defined instructions from the ISO and curtail loads, requiring no human intervention.

2- A real-time feedback mechanism would *fine-tune* load-shedding, so that flexible loads could closely follow ISO dispatch instructions from the grid operator.

The flexible resources used in this project reached an average ramp of 0.25 MW / min and the response time is established at 47 seconds.

Another project, the *Integrating Renewable Resources* (IRR) pilot project was a collaborative effort between PG&E, the LBNL PIER *Demand Response Research Center* (DRRC) and CAISO. It aimed to address the challenges and opportunities of integrating over 6,000 MW of variable generation resources in California. The primary objective was to determine the feasibility of demand-side storage capabilities: thermal mass, process mass, ice and cold-water storage, in a dynamic demand management strategy for air-conditioning in buildings. The strategy aims to provide *load following* and ramping products that the CAISO will need to manage the grid under a 33% Renewable Portfolio Standard.

The pilot used research previously conducted by the DRRC using Open Automated Demand Response (OpenADR) in commercial and industrial facilities and providing non-spinning reserves to the CAISO. The project launched in 2011.

3.7 Commercial – Emergency generators

#13 – Title: Flemming Birck Pedersen, Energinet.dk, "Demand Response Progress in Scandinavia"

Network Service: Regulation with Automatic Generator Control (AGC)

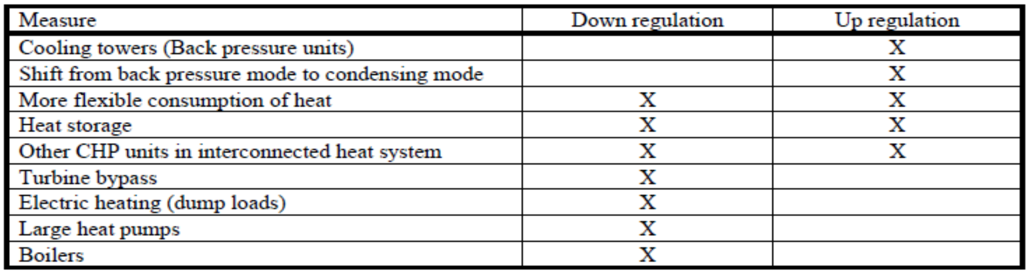
A study by Energinet.dk (the transmission system operator) in Denmark shows the outcome of a demonstration project in the eastern portion of the Elkraft Transmission System between 2004 and 2007. The project used emergency and flexible load generators, such as pumps, to provide regulation service on power grids. A regulation power of 33 MW was tested on 30 participating customers. The study concluded that generators used for this service could be initialized within one minute. The Generators had 100 kW to 1 MW typical output.

3.8 Municipal – Cogeneration and urban heating systems

#14 – Title: Energinet.dk, "EcoGrid.dk Phase 1 - WP4: New Measures for Integration of Large Scale Renewable Energy" [9]

Network Services: Regulation with Automatic Generator Control (AGC), Load Following and Surplus and curtailement management

Various measures are being studied within the Danish EcoGrid project to attain 50% wind power penetration before 2050. The Energinet.dk report (2007) includes a review of usable technologies, improvements for grid operation and potential markets. In 2009, 54 MW of electric boillers were included in the balancing market, which provided down-regulation service (*down regulation)* [60]. The document includes studies on several residential, commercial or industrial technologies, as well as thermal storage in central heating networks. Figure 8 shows some measures identified in EcoGrid [9], related to urban heating systems:



Measure	Down regulation	Up regulation
Cooling towers (Back pressure units)		X
Shift from back pressure mode to condensing mode		X
More flexible consumption of heat	X	X
Heat storage	X	X
Other CHP units in interconnected heat system	X	X
Turbine bypass	X	
Electric heating (dump loads)	X	
Large heat pumps	X	
Boilers	X	

Figure 8: Ecogrid Project (Denmark) – Potential balancing resources

3.9 Municipal – Water pumping stations

#15 – Title: EPN Demonstration for High Lift Relay Pump Station, Enbala Power Networks, July 2011;

Network Service: # Regulation with Automatic Generator Control (AGC)

ENBALA Power Networks have successfully completed a pilot at a municipal high lift pump station which demonstrated how electrical loads can participate in the provision of Regulation (grid balance) services to an ISO, without impacting water distribution operations. The primary project goals were met with objective evidence that the pump station is an ideal candidate to generate additional revenue by participating in PJM’s ancillary services market through ENBALA’s regulation (EPN) platform. The project scope included:

- Defining the load and plant’s primary operating constraints.
- Installation of a Local Communications Panel (LCP) and electrical metering.
- EPN demonstration and optimization.
- Demonstrate EPN operation with benign impact to equipment and plant operations.
- Establish Regulation range and revenue potential for the site.

In this project, a Relay Pump (RP) at the high lift pump station was integrated in the EPN with an operating range between 85-100% of VFD speed, translating into a 180-200 kW operating range. Using the ISO regulation signal, it was demonstrated how the operation of the Relay Pump can integrated in EPN and an assessment of the impact on plant operations was performed. The equipment was operated in the demonstration phase for a total of 120 hours. The demonstration network consisted of a total of seven devices including the Relay Pump. Along with the Relay Pump, there were three high lift pumps at different municipal water pumping stations and three pumps at different wastewater treatment plants.

One of the water pumps and one of the wastewater pumps were real live devices while the other 4 pumps were simulated devices.

The range of the network was 1,705 kW with a bid range of 65% or 1,108 kW. The bid range is less than the maximum range as EPN devices need spare operating room to respond in priority to plant process requirements. The pump provided 180-200kW of range operating from 85% to 100% speed setting representing 11% of the total pumping network range.

The EPN Regulation environment is very dynamic and as such the position request for any given load in the network is highly variable, although always within the owner's specified and controlled conditions. To characterize the relay pump operation, the following were considered: range (amplitude) of power change, frequency of change and how fast the change occurs. To characterize the range of operating conditions for the Relay Pump, the following histogram and movement graphs found on Figure 9 were generated from the data collected during the demonstration phase.

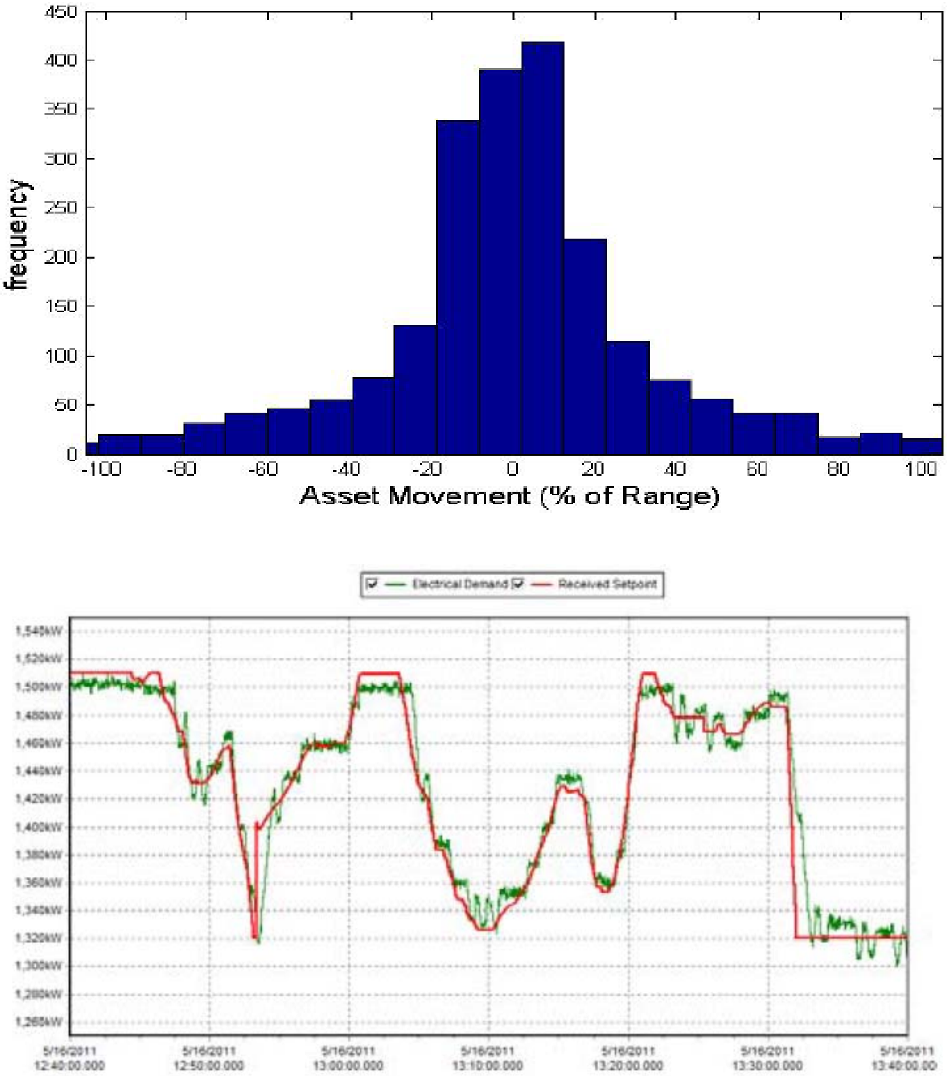


Figure 9: ENBALA – Regulation supply

Data from the plant recorded in the LCP for electricity demand and water flow was used to compare energy efficiency (kWh/Mgal.) for water pumping when the Relay Pump was on EPN control vs when the Relay Pump was off EPN control. The results of the comparison indicated that there was a -0.2% change in energy needed for pumping when the Relay Pump was on EPN control compared to when it was off EPN control, verifying that the regulation process does not negatively impact pumping efficiency.

A regulation range of 180–200 kW was consistently available. Based on the ISO's projections for regulation prices, the network configuration used for testing, the performance of the RP during the demonstration and 200 kW of projected range, one can estimate the EPN revenue potential for at this site to be $13,000 per year.

3.10 Transportation – Electric vehicles

#16 – Title: F. Tuffner & M. Kintner-Meyer, Pacific Northwest National Laboratory, *"Using Electric Vehicles to Meet Balancing Requirements Associated with Wind Power*" [64]

Network Service: Regulation with Automatic Generator Control (AGC)

Tuffner *et al.* (2011) features the potential of using electric vehicles to balance wind generation. The context was the Northwest Power Pool (NWPP), with a potential additional wind capacity of 10 GW (from 3.3 GW in 2008 to 14.4 GW in 2019). According to the methodology defined in Kintner-Meyer et al. 2010 [65], the authors predicted an additional balancing need of about 1.85 GW (3.7 GW in total).

To reproduce the mobility of cars, the authors used data from the 2003 National Household Travel Survey (NHTS) (U.S. Dept. of Transportation). These surveys included measurements on the average availability of automobiles, power needs based on distance, as well as parking time at work or home, departure and arrival times and vehicle occupancy, to establish refill/discharge scenarios. In this study, the authors used two types of electric vehicles: The first was a PHEV-33-based plug-in hybrid electric vehicle expected to go approximately 33 miles before requiring a recharge. The second vehicle utilized was a PHEV-110, expected to travel 110 miles before a recharge or alternative energy source.

The authors simulated two different strategies: Smart recharge without discharge to the grid *(V2G Half),* and smart discharge (*V2G Full*). The study concluded the emerging electric vehicle fleet (PHEV-33) can significantly contribute to grid balancing services. In V2G Half, modulating the refill of 13% of vehicle fleet (2,100,000), can fully balance wind production. V2G full reached the same results with 30 to 35% fewer vehicles.

The study showed how the number of cars needed for balancing depends largely on available charging stations at work or in public places, but only up to a point. The authors mention that about 10% of public charging stations can achieve 80% of improvement.

The authors presented a potential case that where vehicles were available 24/7, performing V2GFull, type 2 recharge service. This is identical to the simulated stationary energy storage system, dedicated to balancing services. This case would use a total number of about 560,000 vehicles but the authors did not illustrate the impact on the transmission and distribution grids.

3.11 Other loads

Other studies in the field concerned other load types (lighting [66], refrigerators, freezers and geothermal pumps [67]) to determine their potential for peak demand-reduction or optimization strategies. With rapid developments in the field, other studies demonstrating the potential for using these loads for grid balance could soon be published. The potential in the industrial field has not been assessed because of the diverse processes involved, even though, in this sector, potential is contained and thus easier to identify. Since there is a significant capacity for load-shedding in this sector, we can deduce that there is also technical potential for balancing.

These numerous studies, pilot projects and other reports [68] demonstrate the technical feasibility of distributed resources in balancing power grids. Section 4 will continue with issues related to integration of these resources, with a closer look at electricity markets.

4 The role of markets in the integration of distributed energy resources

This section complements the technical review presented by approaching topics related to markets, regulation, business and societal environments surrounding the integration of DER. A short introduction on generation planning and market structures is presented at the beginning of this section, followed by information on aggregation, integration challenges and factors for commercially successful DER deployments.

4.1 Planning production resources

The dynamics of power grid operation are characterized by the need for balancing generation and real-time demand. This fundamental technical characteristic of power grids is heightened because large scale power storage is technically difficult and costly. On a typical day, a number of power generation technologies respond to power demand. The various technologies must come into play based on fluctuating demand and operating costs. These daily technological cycles create dramatic variations[12] in the marginal cost of a kilowatt-hour of energy over the same day (from very low at night to very high at the peak).

Power plants are optimally dispatched in order to supply various commodities, mainly energy, as well as various ancillary services including regulation and spinning or non-spinning reserve. The limits of network congestion and power plant output, such as start-up and switch-off lead times (minutes), and ramping capacity (MW/minute) are considered in the economic allocation of power plants. The responsibility for economic dispatch can be assigned to a central organization (a vertically integrated enterprise), to a system/grid operator or market operator. The grid operator's role varies between countries and regions, especially its involvement in market operation[13].

4.2 Market structures and philosophies

A reason for developing electricity markets is to aid the incorporation of more participants, including small distributed resources. This would minimize major capital costs related to building new power plants [69]. The number of different electricity market structures and philosophies is as vast as the number of markets. However, there are two major approaches, one North American and the other European.

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[12] This daily volatility has no equivalent in the world of finance, for example, and it cannot be compared to the volatility of gasoline prices which have weekly cyclical components, but where the relative amplitude of variations is still much smaller than with electricity.

[13] The book *Power System Restructuring and Deregulation* [69], p. 179, mentions three types of ISO: MicroISO, MiniISO and MaxiISO. These are not enough to account for the variations in the industry.

North American approach

In the North American approach, the *independent system operator* (ISO) holds the control over the market and the transmission network. The ISO is a crucial market actor responsible for operating the 'day-ahead' market. The *day-ahead* market considers, in an integrated manner, technical characteristics of generating plants and the effect of the transmission network and needs for ancillary services.

The role of this market is to anticipate real time process in order to set revenue and costs for producers and resellers, instead of waiting for real time operation where prices, vulnerable to demand fluctuations or equipment breakdown, are only known after the fact (*ex-post*). This particular version of a futures market is purely financial and does not involve any parties in supplying or delivering the next day's energy supply. This market also allows players currently involved in pre-established bilateral transactions to secure transmission capacity necessary to implement physically their transaction in real time. As a by-product, the ISO provides marginal electricity prices at each network node; these prices are used to obtain total compensation for producers and payment for resellers. If offers to supply and bids to consume are maintained until *gate closure*, the market becomes physical and short-term delivery is planned (i.e. for the next hour). With a day-ahead market, players have a more precise picture of the purchase and sale price of electricity before consumption (*ex ante*) and can tailor their bids and offers as a result.

The ISO also runs a real-time market (which is physical, unlike the day-ahead market). The real-time market involves energy deliveries and load extraction reflecting the dispatch pattern established at gate closure. It thus includes centrally-based market settled deliveries as well as bilateral transactions which have reserved grid access. In the real-time market, the ISO, while maintaining an overview of its grid, ensures that the generation dispatch is such that it balances demand by using the operating reserve capacity (i.e. ancillary services) from the most economical power plants. When there is excessive need for regulation, new dispatches (i.e. set point changes) can be set within the hour. After the fact *(ex post)* marginal prices for each node are calculated for billing. These nodal prices reflect the marginal costs of congestion and losses associated with the physical implementation of the market outcomes. It should be noted that the volume of energy traded in the real-time market is generally small when compared with that of the bilateral and day-ahead markets—often real-time markets are called “adjustment” markets.

The European approach

Unlike the North American approach, European transmission grid operators play no part in the market until producers and retailers have to provide their position, reflecting the aggregation of numerous bilateral contracts, sometime before real-time delivery. Unlike North American ISOs, European grid operators do not operate formal day-ahead markets wherein network and complex generation technology constraints are represented. In fact, European operators manage a balancing resources market followed by a real-time market, where gaps between the production and load are eliminated by dispatching balancing resources and previously acquired ancillary services. The gaps between positions and telemetry are adjusted through prices which reward (penalize) the gaps that contribute in reducing (increasing) the overall gap in the power grid. In Europe, unlike North America where the market considers the effects of the transmission gri, transmission network congestion is managed with balancing resources. Moreover, in European markets, congestion costs are socialized unilike in North America where congestion is settled through nodal prices.

Distinctions and opening to DER

These two approaches involve the conduct of a real-time/balancing market. These two approaches include the supply of ancillary services to maintain frequency and voltage, which may be procured competitively. However, a major distinction of the American approach is the two-phased market solution (*two settlement system*), enabled by running succesvively a managed day ahead market and then the real-time market. This solution allows for more accurate optimization and lesser risk because more elaborate generation models are used and because it incorporates the effects of the grid. However, this comes at the price of much higher complexity and less market transparency.

In the North American approach, electricity prices are set a posteriori (*ex post),* by accounting for congestion and grid losses at zones or nodes. In the European approach, these technical parameters are dealt with on an *ad hoc* basis and the associated grid costs attributed to them are socialized after the fact.

In terms of distributed energy resources, the North American approach has the virtue of:

- Allowing modifications in electricity demand or production before operation of the real-time market. Flexible demand and storage can be thus optimized based on projected electricity costs;
- Promoting decentralized solutions for reducing congestion, as price signals are provided to reflect nodal or zonal congestion; and,
- Promoting distributed generation, because injecting power at a point in the transmission network and consumption at another creates losses that add to generation costs.

Another dimension of the electricity markets is its handling of congestion related costs. The North American approach includes financial instruments (financial transmission rights), which allow for system actors to hedge against the cost impacts of congestion on their activites, while the European approach includes these in the cost of the transmission service. In that case, actors cannot do much to avoid those charges.

4.3 Load aggregation

The essential element of commercial success for demand-side management involves load aggregations. Aggregation acts as a lever, creating a critical mass which i) supplies demand-side management volumes of interest to markets and ii) smooths load uncertainty and the variability of its flexibility in time. The role of an “aggregator" arose from the need for commercially significant demand response volumes and to limit the risk associated with delivering demand management resources. We can add that aggregators act as brokers who provide consumers access to energy and other ancillary services markets. To secure revenues and leverage investments in demnd response technologies, aggregators often participates in capacity auctions, like the the Reliability Pricing Model (RPM)[14] in PJM [14]. Those markets tend to organise the long term planning of resources in a region to avoid future congestion.

Aggregation seems to be the wave of the future for demand-side management, and there are already several flexible load aggregation companies. The Australian corporation Energy Response Pty Ltd. (Acquired by EnerNOC in July 2011) has established itself by aggregating interruptible loads for large Australian consumers. In September 2010, CPower Inc., with load aggregation services established in several North American states and provinces, was recently bought by Constellation Energy. Demand-side management is now an integral part of their services.

On the European side, a large majority of public utilities and small companies are active in this area[15]. For example, GDF Suez (major group) and Flextricity (SME) have been operating as aggregators in Great Britain as aggregators already for five years.

4.4 Integration challenges

As mentioned earlier, the bulk integration of DER, particularly demand-side response, requires ajustements to system and market operation rules. First, these resources introduce many more players and pose technical challenges to integration. Secondly, these resources appear diffusely on the grid, making it difficult to tell one from the other without monitoring equipment for each. Thirdly, due to their small size, these players will not generally have any or enough access to major market structures; hence, new market rules and the definition of new services are necessary to facilitate market access.

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[14] http://www.pjm.com/markets-and-operations/rpm.aspx

[15] For Great Britain : www.nationalgrid.com/uk/Electricity/Balancing/demandside/aggregators/

Sample market integration projects

A challenge to integrating distributed energy resources lies in the adaptation of rules and philosophies to market design. We begin to see proposals appearing in the scientific literature where the contributions of the demand in ancillary services markets are explicitly recognized. Certain publications argue in favour of effects related to recovery of curtailed energy within market mechanisms. This indicates that in time, we can help create real flexibility markets of flexibility where demand will compete directly with other resources [70] [71] [72].

European projects ADDRESS (www.addressfp7.org) and FENIX (www.fenix-project.org) developed the concept of load aggregation and flexibilities. FENIX concentrated on large-scale consumers (institutions and industries) in the context of virtual power plants. ADDRESS leaned toward aggregation for smaller commercial and residential consumers.

ADDRESS is distinguished mainly by efforts in developing operational methods and concepts of aggregation for small consumers. The results of the European ADDRESS project go as far as suggesting three basic flexibility products [73] which could potentially lead to emergence of more liquid markets instead of a multitude of small low volume niche markets, which prevent them from standing out. The project is currently in its final test phase at three European sites (In France [Brittany], Spain [Castellon] and Italy [Carpinone]).

The Intelligent Energy System [60] project, implemented as part of the EcoGrid initiative in Denmark, aim at developing new market operations to integrate a large number of small distributed resources to supply grid regulation. The project proposed the strategy of maintaining the current markets (day-ahead, hour-ahead), but to allow smaller, flexible loads to participate in the regulation market by sending unidirectional signals.

The PowerShift Atlantic project in Canada [41], Consolidated Edison's EPRI project in Illinois [74] and the Olympic Peninsula project in the state of Washington are North American demonstration projects involving the integration of markets and virtual power plants into an electricity market [75].

Obviously, new services are not developed in isolation. The local context, the regulation and the technical environment of the power industry shape the mechanisms and philosophies that do or do not promote these services. The implementation of demand-side response programs and distributed storage presents a number of commercial, technical and sociocultural challenges. Here are a few of them, along with some of their corresponding success factors.

4.4.1 Technical challenges

Distributed nature of the resource: Consumers are scattered through the network and are generally difficult to characterize individually. It is thus difficult to evaluate potential of aggregated resources without a smoothing “mass effect” where the variability of each individual load is masked the variability of other loads. This problem is magnified where network constraints would limit the number of consumers able to take on the challenge.

Payback effect: As mentioned above, the great majority of loads and energy storage systems can delay (loads) or anticipate energy consumption (storage). As part of demand shifting, the operator must anticipate reactivation of the released energy without creating additional grid stress. Furthermore, these resources are not pure substitutes for generation capacity (that is, purely negative demand). Given the losses associated with delay and anticipation of consumption, the total quantity of energy ultimately consumed can potentially increase. The idea, however, is increased energy demand is produced by resources which are cheaper and/or less polluting.

Need for adapted measurement: Given the distributed character of this resource, it is imperative to establish infrastructure and demand measurement protocols which can (i) help establish the demand-side contribution to network management at different scales and (ii) allow the correct and adequate remuneration for participating consumers.

Measuring and benchmarking

An important factor in the flexibility concept in power systems is the idea that flexibility is defined from an initial position. If we want to reward consumption modifications related to consumer action (automatic or not), following a distributor, reseller or aggregator signal, it must be determined if this change is due to consumer flexibility and is not just coincidental. Furthermore, we also must determine the scale of the modification. The method usually applied to do so uses a reference consumption curve for every consumer or type of consumer (baseline). The use of basiline consumption curves is widespread but remains controversial, because consumers can cheat by overconsuming during benchmarking periods. These curves are suitable for large-scale consumers, given that it is easier to anticipate their consumption according to simple data (e.g. weather reports, day of the week, season). It is more difficult with smaller consumers because of the inherent complexity and costs, as well as consumption variables within a family unit. Development of alternative solutions for benchmarking should be promoted, to improve flexibility evaluation and remuneration. The ADDRESS project (www.addressfp7.org), applies the solution of consumption tiers referenced to the nil consumption; these indicate to customers whether they would benefit from increasing or decreasing consumption. Finally, the development of real-time rates renders benchmarking (and aggregation in general) useless. Indeed, according to this incentive, the end customer replaces the aggregator to benefit from low electricity market prices and manage risks associated with higher prices. This type of pricing is currently available only for large-scale consumers.

The need to predict load behaviour: It is important for the operator to anticipate the power demands of participating loads and to characterize them in order to predict their dynamic performance in time. Ultimately, for transmission network or distribution network operators, knowledge of loads and associated models will establish a decision-making tool for optimized management. For that purpose, advanced versions of *energy management systems,* using neural networks, for example, are developed to characterize loads coming from various aggregators.

4.4.2 Commercial challenges

The need to satisfy requirements of existing markets: In many cases, such as ancillary services markets, there are pre-existing technical constraints, which discriminate against the use of small-scale resources. The most convincing example is the necessity of supplying capacity blocks over a certain minimum (i.e. 1

MW) in tendering processes. Most traditional generating resources have little difficulty meeting these minimums, but they can cause problems for distributed resources. Therefore, there is a choice between adapting existing market structures or opening up to aggregation. These two means are used often.

Minimal blocks

The majority of electricity and ancillary service markets have lower volume limits. In 2008, Ofgem, however, the electricity market regulator for Great Britain, mandated the transmission network operator for England and Wales (National Grid plc) to reduce minimal volume for services in the primary reserve market (frequency response) from 10 to 3 MW [76] [77]. This would allow the use of resources from aggregated loads.

Monpoly regulation: Vertically-integrated utility companies hold a monopolistic position in several regions and countries. These firms can resist to the entry of new players on the market supplying energy, regulation, reserves or capacity. The absence of appropriate economic regulation can also be a hurdle to interested companies. Without incentive mechanisms, several public utilities regulated through *cost of service regulation* have an economic incentive to increase grid capacity rather investing in alternative solutions, which are usually less capital intensive. The organizational relationships existing between divisions in a vertically-integrated company can also be an obstacle, especially if the operation of one (i.e. distribution) impacts negatively the expansion plans of another (transmission and generation).

The emergence of perverse effects: In a deregulated industry, actions of a player using demand-side response can inconvenience other network players. The best example is the creation of portfolio imbalances for resellers following third-party (i.e. aggregator) load changing instructions. Another perverse effect could lead energy resellers to manipulate demand so it affects wholesale prices to the benefit of certain producers, and the detriment of consumers [78].

Legal implications

In an industrial context with diverse competing market players, the emergence demand-side response can negatively affect some players. The most famous case of this type was the complaint d'Électricité de France (EDF) (their commercial retail branch) filed with the French electricity industry regulator, the Commission de régulation de l'énergie (CRE), against Voltalis. Voltalis operated as a flexibility aggregator for small consumers, reselling to RTE (transmission system operator) as a load-shedding service, or spare capacity. The motive for EDF's complaint was based on the following: Actions by Voltalis' on its share of EDF's retail consumers caused an imbalance in EDF's portfolio, resulting in penalties on the balancing market for EDF. Initially, the CRE ruled in favour of EDF in 2009, forcing Voltalis to compensate EDF for consumption changes resulting from its actions. This decision was reversed by the Council of State in 2011 [79]. This example shows how demand-side response contributes to change the power industry. It is clear that that in-depth analysis is needed to understand all the implications of demand-side response. This case highlights a legal gap regarding energy property rights, which change over time by storage and demand management. A number of questions exist, but mainly: does the aggregator own the energy consumed that he postponed or scheduled? The issue is even more delicate when a grid operator is responsible for aggregation, because the operator would de facto be taking a stand in the market, which, in a European context, would be almost impossible.

Promoting demand-side management and appropriate incentives: The supply of ancillary services by demand-side response requires that its value is larger than the amount of incentives and payments to participating consumers. Where a large number of consumers can contribute to the flexibility supply on a network scale, this can contribute to marginalize one consumer's contribution and considerably limit rewards. If a risk premium is applied on top of the projected value of the accumulated rewards, the potential financial gain to the consumer is often limited and must be supplemented by a subsidy mechanism operating outside the market.

Equipment purchase costs to support flexibility: It is undeniable that harnessing load flexibility goes hand in hand with a number of enabling technologies (e.g. smart household electrical appliances, sophisticated temperature controls, communication equipment, etc.). Potential consumer rewards are relatively small, so the player who wants to provide in demand-side response must generally cover the equipment costs. Equipment purchase costs for demand-side response technologies can be greatly reduced by gradually deploying electrical equipment with embedded "smart" features and gradually replacing consumer's obsolete electrical equipment.

4.4.3 Social and cultural challenges

Consumer acceptance of demand-side management: It can be difficult to convince consumers to install equipment adapting their consumption habits and business practices for a relatively low return, as individual economic incentives may not be quite limited. A focus on moral and environmental values, for both businesses and individuals, can contribute to demand response success with certain segments of the clientele. Furthermore, the public is frequently opposed to installation of certain technologies (such as smart meters) or setting rate schedules which send price signals to incentivize demand-side management (e.g. time-of-use pricing).

Respect for privacy and personal information: Demand-side management relies on information sharing. This can be seen as infringing on privacy and confidential information of consumers.

Potential incentives and advantages

As previously mentioned, when an entity such as an aggregator supplies any ancillary service, it can involve a large number of participating consumers. The value of this service at the system level must eventually be transferred to the consumer (minus a certain margin for aggregator). We can imagine that the potential reward for consumers is small as the effort is diluted among all responsive consumers. Therefore, in the meantime, with available flexible network resources, it may be difficult to establish demand-side response and render it commercially viable. In fact, to develop distributed energy resources, energy policies must promote the intangible benefits, by appealing to the public's sense of morals and environmental consciousness, as well as those of institutions and businesses [80]. If companies have a dominant position in countries where climate change is top priority, there is a proactive trend toward promoting brand names and the company's social consciousness (green credentials). In Great Britain, many major retail chains (e.g. Tesco, Sainsbury's and Marks and Spencer) launched programs for streamlining energy consumption, some chains connecting the thermal mass of their stores (as storage medium) with wind production.

4.5 Success factors

The general environment of the power industry in a region (e.g. availability of hydroelectric power or other type of cyclable generation, an open market or the magnitude of electricity prices) greatly affects viewpoints on demand-side response, storage and other emerging products and services related provided with aggregation. The following section will present several success factors associated with commercial exploitation of DER.

4.5.1 Analysing the local context

To evaluate conditions for success, the ADDRESS project highlights elements favourable or unfavourable to demand-side management [81]. The project was based on four European scenarios, which analyzed local conditions related to developing intermittent renewable energies, load types and balancing needs. It identified the following characteristics:

- The geography of the scenario location. The geographical aspect refers to the climate and both average and extreme temperature conditions;
- The characteristics and density of customers in the area where the scenario develops;
- The existing power industry infrastructure (i.e. technological mix of the generating system in the market and the regulatory context) at the place and at the time as the scenario develops;
- The technological context (i.e. mainly the customer practices and technologies connected to the network) at the place and at the time as the scenario develops.

In general, a scenario showed good potential for success when more flexibility was necessary in the region (i.e. to accommodate intermittent renewables) and if flexible loads were available among consumers.

Here are the results for the four ADDRESS scenarios:

1. The *Southern City* scenario showed the greatest potential for the following reasons:
    - There is a clear need for flexibility sources affordable to industry players. This is because a high proportion of intermittent renewables is connected to the transmission network. They have created a constant increase in demand for ancillary services and balancing capacity.
    - The potential flexibility based on load is attractive because:
        - The significant density of clients,
        - The lion's share of the load is flexible (air conditioning), and
        - The emergence of electric vehicles toward the end of the scenario's horizon.

2. The *Southern countryside* scenario has good success potential because:
    - It has an increased need for flexibility because of the gradual disappearance of the capacity margins in the generating system;
    - On the other hand, the potential for load use in this scenario is low, because of low consumer density and highly seasonal agricultural load.
3. The *Scandinavian Suburb* has the lowest potential for success:
    - Flexibility supply is sufficient on a national level because of hydroelectric production capacity and numerous international interconnections;
    - Consumer flexibility has little initial potential, given the average population density and little flexible power usage. As there are very few heat pumps, heating is mainly supplied by urban heating systems and local burning of fossil fuels.
4. Finally, the *Multi Unit community in a Temperate Zone* had interesting characteristics, which could insure successful use of load flexibility:
    - There is a growing need for flexibility on a national scale, given the number of new and sizeable renewable generating facilities. Furthermore, it is accepted that producers use the potential for load suppression to respond to requirements for supplying standby capacity;
    - There is great supply potential due to high customer concentration and use of electric heating and air- conditioning.

4.5.2 Aggregation in virtual power plants

Virtual power plants (VPP) can have a significant impact in the future, because they constitute the logical result of the *demand response* market. VPP could aggregate a large number of resources to provide more services than just peak demand reduction. As presented in Figure 6, a virtual power plant may include emergency generators, smart appliances (in homes, businesses and industries), smart buildings and storage. These resources may be located on the same feeder or situated at different electrical locations and may all provide energy, capacity or balancing in the same market.

Virtual power plants (VPP) can have a significant impact in the future, because they constitute the logical result of the demand response market.

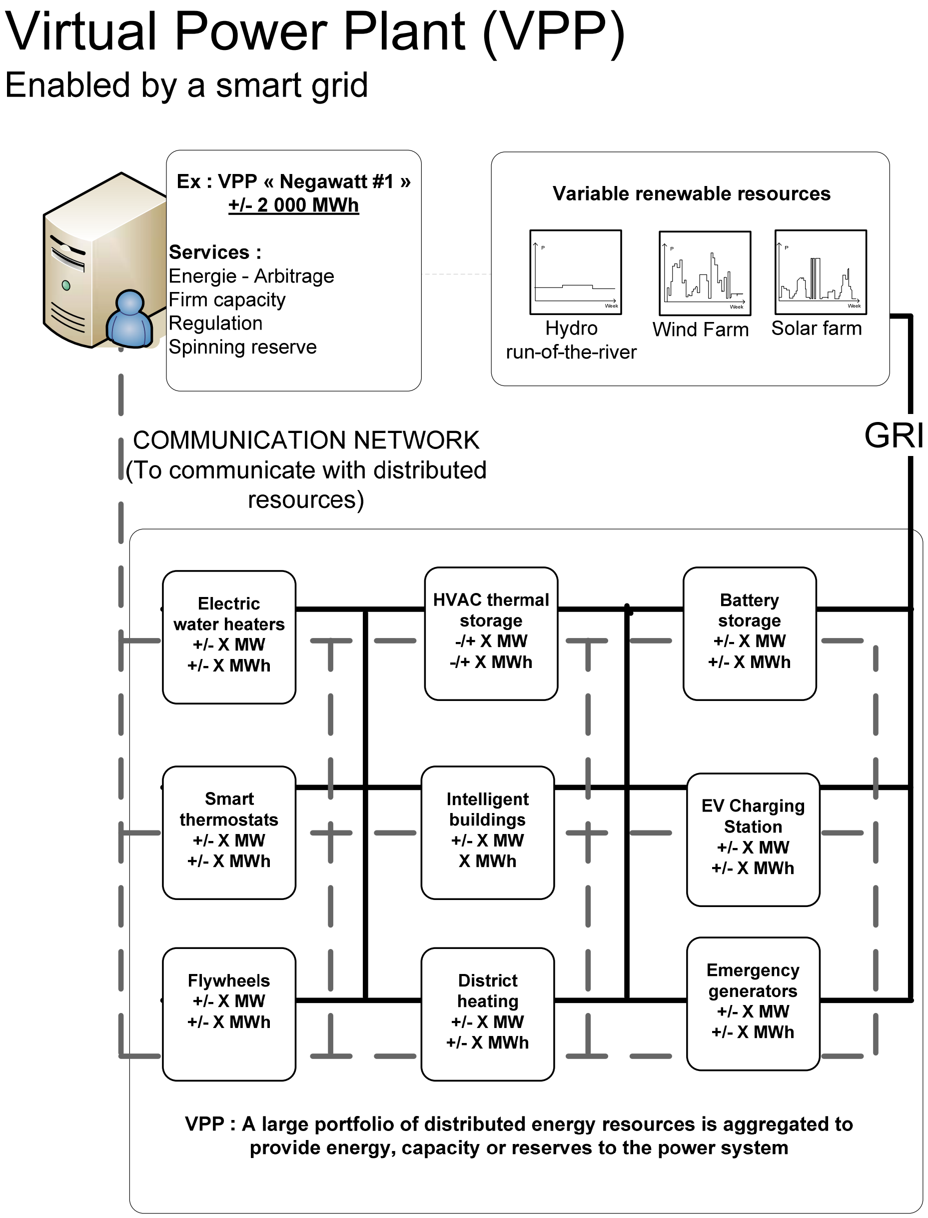


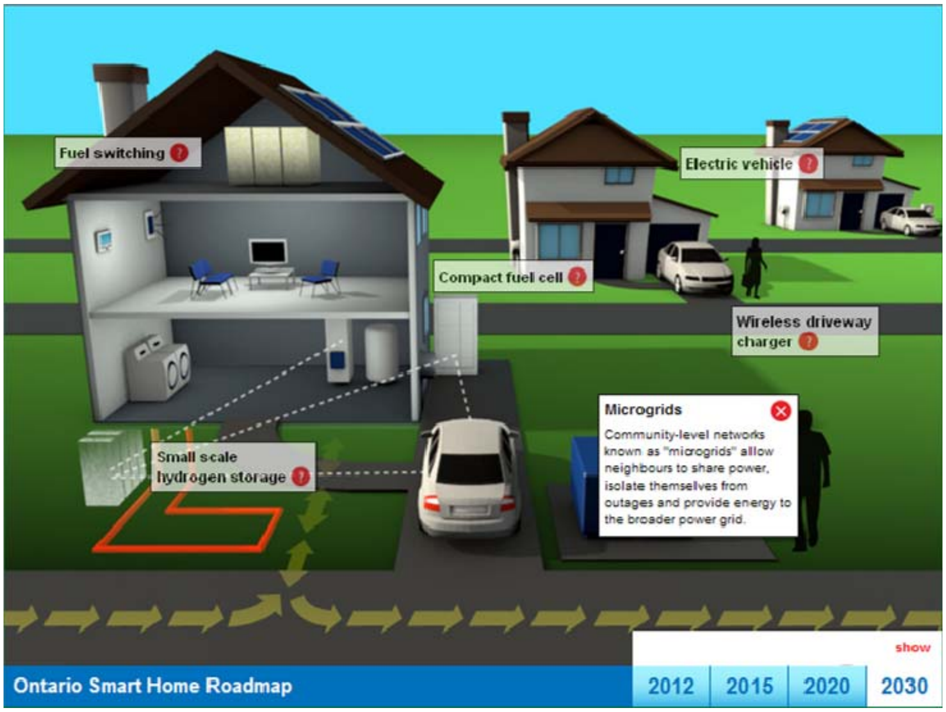
Figure 10: Virtual Power Plants

If market structures and regulation permit, traditional electric companies can develop this business model prior to building new centralized power plants. This market could also be opened to companies specialized in peak management, to aggregators, retailers and major industrial clients. Of course, for virtual power plants third party business or new utility departments to become a reality, the cost of the technologies should be competitive. While mass market technologies in the residential sector is not widely available, at low cost, new ventures should focus, on the short term, on larger customer demand response or more valuable services to the grid.

4.5.3 Micro grids: the final acheivement of the smart grid

In the book *Power System Restructuring and Deregulation* (2001) [69], we see that distributed generation could play a significant role in the future structure of power grids. According to the author, electric production close to consumption provides a combination of technical, economic, environmental and even political advantages. In that respect, it mentions that a power grid with distributed generation would be stronger and less vulnerable to natural disasters. This vision of the future, shared by several energy industry stakeholders, suggests that distributed generation will eventually insure safe energy in cities, districts and even for individual clients. According to this vision, the gradual increase of distributed generation and storage will allow the creation of autonomous micro grids, which could maintain electric service. Unlike a virtual power plant, a micro grid is electrically and geographically confined. We can thus imagine that in several years, we could see the development of local electricity markets with local prices and ancillary services.

Figure 11 illustrates the "*smart home*" vision of the Ontario Independent Electricity System Operator (IESO) [82], which predicts that in 2030, that entire city districts could generate their own electricity.



Community-level networks known as "microgrids" allow neighbours to share power, isolate themselves from outages and provide energy to the broader power grid.

Figure 11: Vision smart home/smart grid in Ontario 2011 [82]

In this image, we can see the interaction of micro-grids with other technologies such as solar output, smart household appliances and electric vehicles. We also see fuel cells and hydrogen storage, technologies that according to their views, would be accessible by 2030.

Although the proportion of renewable energy on the distribution network remains low, distributed generation capacity increases yearly in several markets. Electricity storage is in the beginning phase on the grids, but the number of units should increase with numerous feed-in tariff programs and deployment of electric vehicles.

Developing this vision involves integrating distributed resources into urban planning study[16] scenarios, such as need for water, electricity, heating, air-conditioning and transportation. By considering targeted programs in certain overloaded districts and zones, it is possible to compensate for the higher costs of these resources by avoiding upstream infrastructure costs. Such changes can begin now and be staggered over a long period. However, they require that mechanisms (markets and regulations) be in place so that decentralized solutions are promoted in the same way as centralized resources.

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[16] Refering to the “smart city” concept

5 Summary

The discussions presented in previous sections show the technical potential and socio-economic aspects regarding integration of distributed energy resources. The demonstration projects and technical studies conducted thus far show that there is a significant potential for available flexible loads.

In summary:

- Thermostat controlled loads are highly flexible. To some extent, setpoints can be changed without affecting the consumer/user. Air-conditioning, smart water heating or ambient air conditionning can benefit from the thermal inertia of the reservoir or the building.
- Dual-energy or multi-energy systems add flexibility to power grids, supplying both load-shedding and storage capacity. In the context of a smart grid, these resources could be managed dynamically, supplying load-shedding at peak demand from the operating reserve.
- Urban heating systems with combined electricity and heat are one of the ways to make cities more energy secure and to reduce electric grid stress. Based on local resources, these facilities can integrate various primary energy sources, and these systems can simultaneously absorb surplus power to produce the heating or self-generate when needed. In the same vein, water pumping apprears to be flexible enough to provide regulation service.
- Electric vehicles are making their market appearance. Using smart recharge follows the availability of local capacity and the grid power. It would automatically disconnect when detecting grid disruption. Future developments could allow electric vehicles to discharge into the grid, but this will depend on the evolution of this new industry and its technology..
- Emergency generation units in the commercial or industrial sector can temporarily contribute to emergency power supply or reduce peak power. Smart management of these facilities could prioritize lower-polluting generators (e.g. natural gas) over initializing less economic and more polluting power plants (e.g . fuel oil), when ohter flexible resources are exhausted.
- Smart homes and buildings using renewable energy, geothermal heat pumps and smart appliances to reduce grid stress. The deployment of energy management systems can change the load model for buildings and residences. Their optimum network integration will have to consider the occupants primarily, and later, ask them to participate in supplying energy for their community.

These resources, integrated into several aggregators or virtual power plants, could avoid capacity costs and begin the transition to a grid comprised of several interconnected micro-networks. To achieve this level of distributed resources in communities, protocols, equipment and practices must be standardized.

The development of the *smart grid* answers a number of technical challenges, such as measurement, individual resource management or data integration. Beyond the technical problems, this development brings its share of economic, social and commercial concerns. Changes to existing industry, markets and regulatory structures is likely and necessary:

- The introduction of distributed resources can initiate major changes in the industry. While new technologies and new players appear, traditional industry, which holds a monopoly on solutions to grid problems, may have an incentive to maintain market inertia. Several companies, emergent or traditional, are called upon to contribute to this development. An opening to changes seems to be a prerequisite among all industry participants.
- Changes to industry structures and market rules are needed to broaden the range of energy services. The opening to aggregation of smaller loads, distributed generation and storage seems to be a strong trend, as well as new and innovative pricing regimes offered by electricity resellers.
- In terms of economic regulation, it must be noted that the economic regulation within the electricity network businesses, i.e. transmission and distribution, (*cost of service regulation),* most widespread in North America favours investing in grid assets rather than investments on customers's assets. Statutory changes may be necessary to incite public utilities to invest in customers and communities, rather than in their grid.

Finally, the local context should influence strongly how smart grid programs are deployed. In fact, commercial success of development of distributed energy resources will depend simultaneously on a greater need for flexibility (high penetration of variable production or need for emergency supply) and the local availability of balancing resources among consumers, small producers and storage operators. This will determine the value of their service and the amounts shared between participants. Beyond the economic considerations, there must be consumer acceptance as well as measures ensuring the confidentiality and privacy of all actors, especially consumers. To that end, it would be necessary to have a stronger value proposition and the assurance of information security to obtain customer commitment.

6 Conclusion

The development of smart grids and improved information technologies are bound to facilitate communications and data management with a large number of players in the electricity business. A number of distributed resources should be then in a postion to assist with balancing renewable energies or provide other ancillary services. By observing the scope of new and older technologies and the possibilities in adapting the markets, it seems that demand-side response, storage and distributed generation are destined to succeed. In the medium term, with the increase of distributed generation and available storage in battery-driven vehicles, the dynamics of electricity networks and the industry can be completely transformed as more resources will be available to support the operation of markets or supply emergency energy during breakdowns.

Nowadays, power generation, transmission and distribution assets have depreciated for decades and sometimes up to 100 years. By accepting the idea that costs of distributed generation, storage or demand-side management will continue to decrease, it would be wise to consider these new resources in electricity supply plans and to design systems capable of managing these distributed resources. Developing the full potential of demand-side response is the starting point of several jurisdictions. In the United States, the potential for demand response is estimated at 15% of the value of the grid's power peak, from 90 to 140 GW. To harness this potential, aggregation has to be allowed on wholesale markets and technologies need to be standardized so customers can have recourse to automated demand management opportunities. With peak reduction as the main current achievable outcome of demand response, peak power reduction can make network expansion projects useless. Hence, public utilities should develop aggregation businesses as competitive complements to electric grid assets management.

The development of these resources represents a significant business opportunity for many companies and in some cases, an opportunity for customers to curb the effect of increasing electricity prices. As careful investors, traditional public utilities have to recognize the scope of changes to come [22] and to ensure that they are key figures in this new industry. However, new business cannot emerge without structural or regulatory changes in that industry sector. Openness to changes by key figures in the sector, governments and customers especially, is essential to the emergence of a modern, green and competitive power industry, aligned on the 21st century economy.

7 Appendix 1 – Network ancillary services

Ancillary services fulfill several network management functions aimed at power and voltage regulation and restoration of network service after a major outage [83]. These services are procured by the transmission operator from mostly generation assets sometimes through annual or short-term markets (*spot*).

To maintain continuous electricity service and standard frequency, electricity demand and generation must be equal. Each grid must comply with a minimal reserve level, a value that differs according to grid characteristics and criteria of current regional reliability. The following table presents ancillary services involved in keeping the balance of active power consumed and generated, their goal and an approximate response time. Please note that various terminologies may be used for ancillary services [84].

Table 4 : Power System ancillary services

Services	**Goal**	**Category**	**Response time**
Contingency Reserve	**Stabilize the frequency** during major events (i.e. loss of circuit or generation)	Spinning reserve	3 seconds
		Non-spinning reserve	10 to 30 minutes
		Supplementary reserve	30 to 60 minutes
Regulation Reserve	**Continuously stabilize the frequency** (no major event)	Primary control - Automatic frequency control	0-3 seconds
		Secondary control - Automatic Generator Control (AGC)	3 seconds
Load Following	Fill the **energy gaps** between dispatch orders (i.e. intra-hour variations).	Load following	Between 3 seconds and 10 minutes

Essentially, the contingency reserve quickly resolves exceptional events, such as the loss of network and generation equipment. This reserve should stabilize the frequency and fill the energy gaps when a generator falls offline or during any other major event. Depending of the contingency reserve category, spinning, non-spinning of supplementary, this type of reserve should sometime be very quick at responding (spinning) or available following a call from the system operator within several minutes (non-spinning and supplementary). Primary control reserve is deployed initially through automatic action of generator governor control (primary control). The spinning reserve is used to contribute to resetting the frequency to its nominal value (secondary control), and, finally, spinning reserve can contribute to replace lost generation and replenich primary and secondary control reserves in the longer term (tertiary control). As lead times needed to call in non-spinning and supplementary reserves, these generally can only contribute to tertiary control, which is based on transmission operator manual actions.

The regulation reserve uses the same controls (as under contingency operation) to maintain the frequency within limits under normal operations; however, the rate of response needed by regulating generators is much lower due to the generally slow variations of the load. Primary control is automatic and reacts to fluctuations in network frequency, without involving the system operator. The secondary control uses the Area Control Error (ACE) generated by the insufficiency primary reserve to reset frequency errors and adjusts the generation set points of certain power plants to restore primary reserve capacity and the frequency, by considering supply gaps in electricity exchanges with neighbouring balancing areas and the current frequency value and its nominal set point. This control is usually called the *Automatic Generation Control* (AGC). Tertiary control is additional capacity, acting last, which restores the secondary reserve when gaps are wider, which also restores grid safety. These capacities are "reserved" on power plants producing electricity.

Although definitions differ between countries and regions within countries, generators providing the contingency spinning reserve can also provide regulation, through secondary and tertiary control [84]. Figure 12 shows the relation between spinning reserve and regulation:

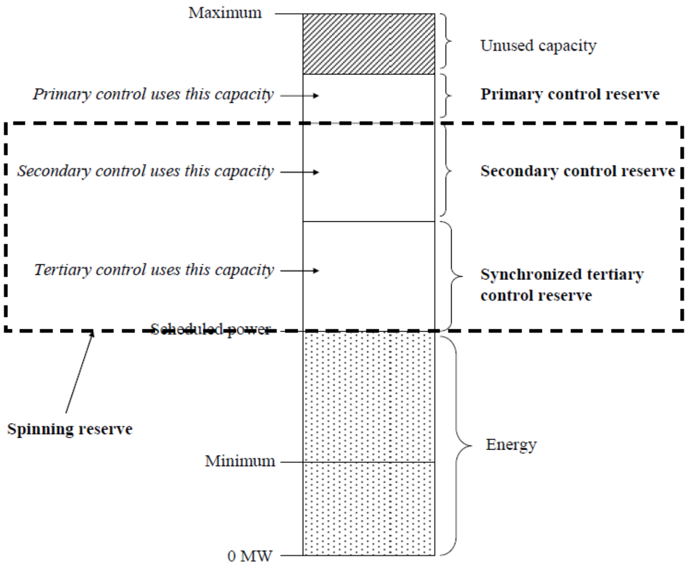

Figure 12: Spinning reserve of power plant and link to primary, secondary and tertiary reserves [84]

While reserve is mainly dedicated to regulate the slow movements of the frequency, its capacity to cope with important variation in generation and demand is limited. For example, important ramps in demand may occur between two economic dispatch intervals. Depending on each market or region, new dispatch instructions to generators providing energy could take a few minutes to be implemented. To help follow the longer-term (minutes to hour) dynamics of demand, some system operators are calling for a load following service to help balance the network. Power plants dedicated to load following should respond within 10 minutes to system operator instruction. The following illustrates the dynamics between regulation and *load following*.

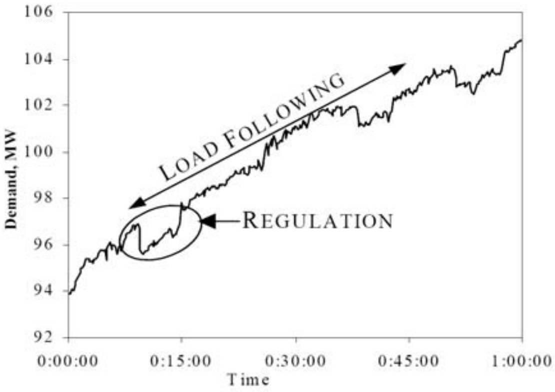

Figure 13: The spinning reserve of a power plant and its link with the primary, secondary and tertiary reserves [83]

Beyond the previously described time horizons, the longer lasting variations, or hourly and intra-daily variations, are continuously filled by the economic dispatch done through a market or from centralized planning of production resources.

Over more than one hour, these variations involve committing peak-load power stations or intermediate power plants. Efficiency, cycling time, as start and stop time of power plants, are important parameters to evaluate power system capacity to accommodate a large penetration of renewable energy.

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