Delivering More Clean Electricity with Virtual Power Plants

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Virtual power plants (VPPs), defined as collections of managed loads and distributed energy resources, can be used to facilitate the delivery of clean electricity on congested grids. While enabling Canada to capitalize on its vast renewable resources, VPPs bring about many benefits to consumers, generators, and transmission and distribution owners and operators. This article highlights the rationale of adopting VPPs and introduces a smart communications approach between loads and operators that is being explored at CanmetENERGY.

In Canada, smart grid technologies, such as those illustrated in Fig. 1, are being developed and integrated at all levels of the power system, from generation to the consumer. The modernization of power systems has many objectives – an important one is to transit more electricity through existing transmission & distribution (T&D) infrastructure. With a strong penetration of electric space and water heating in the country, T&D circuits must support a high peak demand that lasts only a few hours a year, contributing to annual load factors of 40% to 65%.

To value energy surpluses while mitigating the impact on the peak demand, dual-fuel heating systems and interruptible electric water heaters were deployed in a handfull of jurisdictions in Canada. Using normal appliances, relays and one-way radio systems, utilities would use the

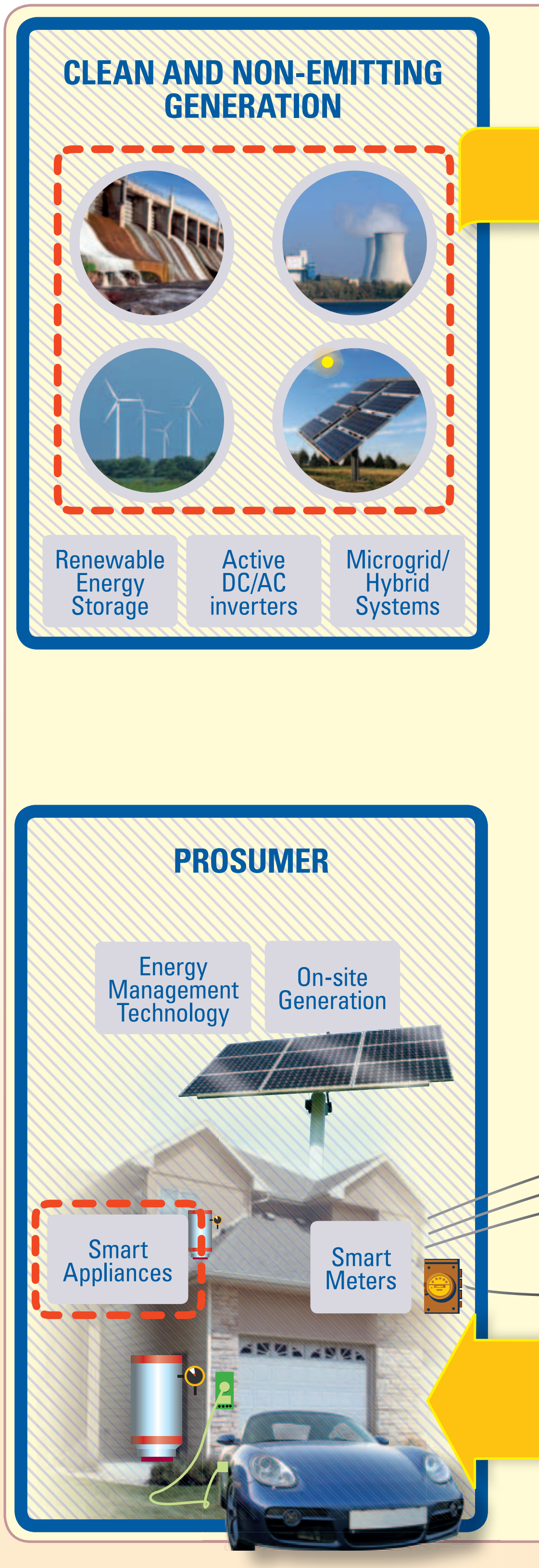

Figure 1: Map of smart grid technologies and applications on different section of the power system. In red rectangles: Clean and non-emitting generation, intelligent load management applications and smart appliances

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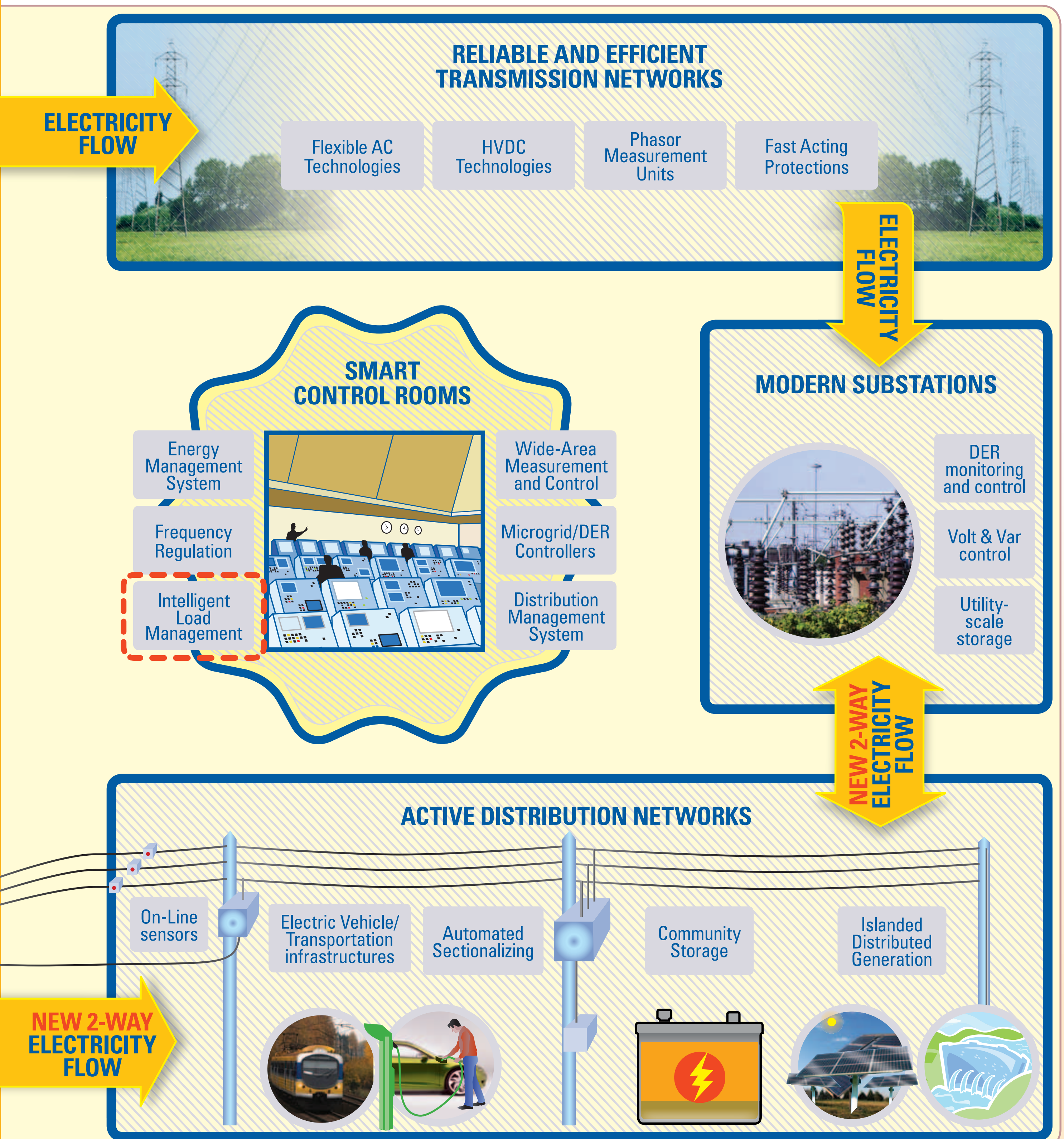


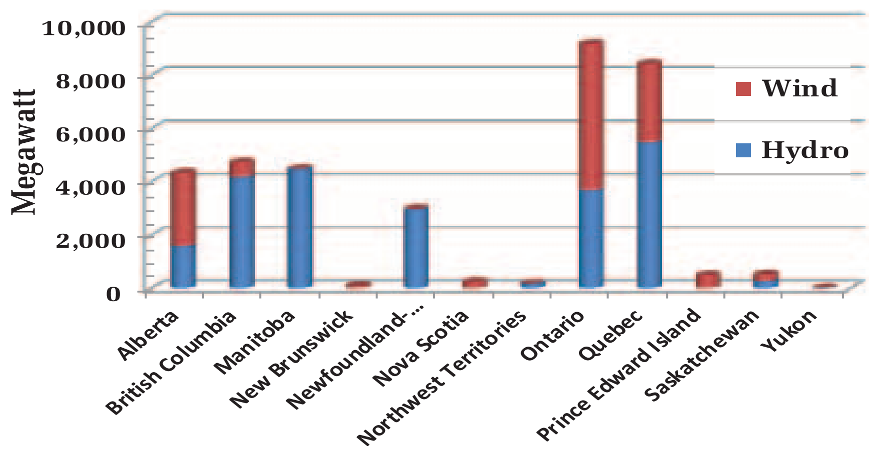


Figure 2: More than 35,800 MW of new hydro and wind generation capacity is projected or committed in Canadian provinces (CanmetENERGY)

Currently, about 75% of Canada's electricity is from clean generation sources. At the time of writing this article, 35,800 MW in hydro and wind generation is projected or committed by the provinces and territories in Canada.

system to reduce the demand during peak or emergency situations.

In a handful of jurisdictions, dual-fuel systems (electricity/wood or electricity/fuel oil) were deployed to lessen the impact of heating loads to peak demand; for control, these approaches used either local temperature sensors or one-way signals from the utility. With new Intelligent Load Management (ILM) technologies and smart appliances, utilities can not only start offering discounted electricity, but also balance renewable energy locally (Fig. 1, in red rectangles). The benefits are twofold: lower electricity prices and minimized GHG emissions.

Currently, about 75% of Canada's electricity is from clean generation sources. At the time of writing this article, 35,800 MW in hydro and wind generation is projected or committed by the provinces and territories in Canada (Fig.2). With more clean generation coming online and new smart grid technologies being deployed, there is an excellent opportunity to further decarbonize the energy sector in Canada and in the export markets.

Along with investments in large generation, programs to increase the adoption and integration of demand-side distributed energy resources (DERs), such as distributed generation, thermal and battery storage, smart thermostats and water heaters are being explored. While the integration of large centralized generation with a large number of small and geographically dispersed decentralized resources presents a dichotomy of sorts, a smarter grid can be used to facilitate their harmonious integration and draw out synergies. Together, these options can extend the boundaries of traditional utility investment, beyond network capacity, all the way to customer-side equipment.

Introduction to Demand Response

Demand Response (DR) programs and technologies aim to enable customer loads to respond to market electricity prices or stresses in the power system. Such response from the demand-side helps to mitigate costs in the power system that might otherwise be shouldered with load growth. As presented in Fig. 3, electricity from new bulk generation must be transmitted through the T&D network to the end user. Along this supply chain are infrastructure capacity limits constraining the amount of new demand that can be served during peak periods. Should peak demand increase beyond existing capacity, expensive infrastructure investments will be needed. Shifting electricity use from on-peak to off-peak times is a key strategy for deferring or avoiding capital expenditures and can help utilities to better utilize capital, remain competitive and keep costs low.

In Canada, all provinces but Ontario have winter peaking systems; residential heating plays a major role in contributing to these peaks (which typically occur in the morning and evening). Traditionally, the few DR deployments in Canada and the United States have relied upon the use of VHF radio or pager systems to communicate with thermostats or relays connected to these appliances. Participants in such DR programs often received special rates or incentives for allowing interruption of their load during system contingencies (including peak demand periods or emergencies).

With evolving Information and Communications Technology (ICT) and Intelligent Load Management (ILM), a new type of demand response is made possible. This smart grid application supports more grid services than just peak demand reduction and could lead to a more effective load management than with, e.g., a VHF system. ILM can be used by the operator (or utility) to shift, shed, or shape demand according to power system needs or market opportunities. It could be used to provide both energy and reserve to the operator.

An example of ILM capabilities was demonstrated in PowerShift Atlantic's project, where load-based spinning reserve and a new service, called "load shape management," is being tested to wind balance generation fluctuations in the Maritime Provinces. However, managing large numbers of intelligent loads requires an appropriate set of customer engagement programs and technologies. These technologies need to sense and control the demand while minimizing its effect on the end user, exploiting, e.g., heat storage or fuel-switching capabilities in real-time to optimize the network from end-to-end.

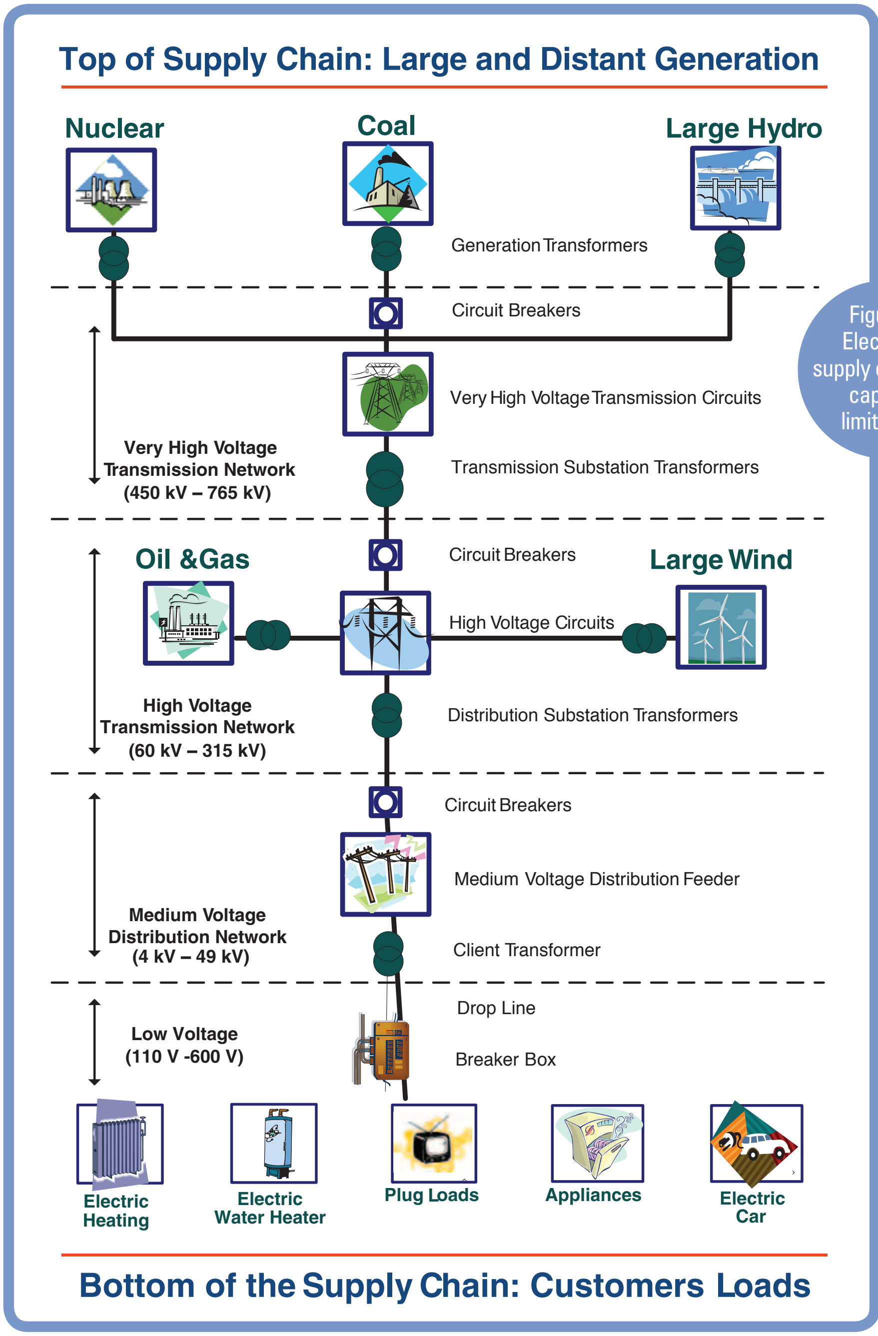


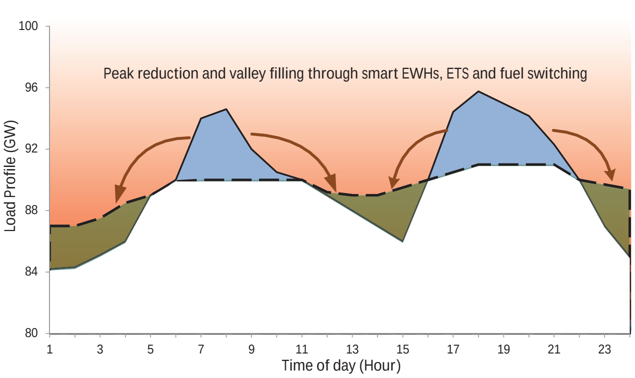
Figure 3: Electricity supply chain and capacity limitations

Off-peak heating opportunity

In Canada, only 30% of the residential space heaters and 45% of the water heaters are electric. Replacing heating oil in many regions makes economic sense for customers, but weak distribution networks may limit the capacity of utilities to tap into this market. New smart heating appliances may be used for that aim. As presented in Fig. 4, electric thermal storage units and electric water heaters, interruption devices, or dual-fuel technologies can be used to deliver more clean electricity during power system valley periods. With the right set of technologies, ILM can be made transparent to the end user by utilizing the inherent storage or substitution potential of each smart heating appliance.

Even without growing the electric heating system market, the current stock of electric space and water heaters in Canada could be easily either replaced or retrofitted to capture thermal storage potential. Currently, 6 million Canadians use electric water heaters. With a typical electric water heater having 3-5 kWh of storage (through varying temperature within the dead-band) there is 18-30 GWh, in Canada, of thermal storage capacity that is available with little required capital investment.

Additionally, central or wall-mount electric thermal storage units can be used with some of the 5.5 million electric heating systems currently in place to even further increase the storage capacity of the residential sector. Replacing or supplementing baseboard or central heating units, these units contain high-density bricks capable of reaching temperatures of 700°C that store heat for later use. In other words, they can store



With the right set of technologies, Intelligent Load Management (ILM) can be made transparent to the end user by utilizing the inherent storage or substitution potential of each smart heating appliance.

Figure 4: Load shifting on weak distribution network, using dual-fuel heating systems, smart electric water heaters and electric thermal storage devices

enough off-peak energy (up to 45 kWh in a single unit) to heat a home for peak periods of up to 16 hours. They also come in different sizes and shapes, with or without embedded communications. Alternatively, dual-fuel heating technologies can be utilized such that electricity is used during all but peak periods, when the units switch to natural gas, biofuel or wood pellets.

Virtual Power Plants

In the past, loads have usually been regarded as passive or uncontrollable elements by power system planners and operators. Managing a large volume of these small resources to draw power, at the right time, will require a new mindset and more automated intelligence in the control room. To meet these ILM requirements, the VPP concept is proposed. Still in its infancy, VPP leverages the storage or operational flexibility of DERs to provide energy and ancillary services; in essence, VPP controlled DERs act as a single generator.

Illustrated in Fig. 5, a VPP aggregates several DERs to deliver products and services to the system operator or market. By aggregating these DERs, the need for a wholesale energy market, ancillary service market, or dynamic pricing structure to drive individual DERs is alleviated. If operated by a vertically-integrated utility, a VPP would discern, for example, whether it is of a lower cost to use energy stored in a dam's reservoir or that within a population of electric water heaters. Like bulk generation, the two-way flow of information will enable DERs to be optimized and dispatched every five minutes. Applications include hedging (buying electricity when it is low cost and selling later at a high price); regulation, e.g., to smooth fluctuations in wind generation; provision of contingency reserves; reactive power compensation (voltage support); and facilitation of cold-load pickup (black-start capabilities). VPPs could also utilize, for example, the pre-heating and pre-cooling capabilities of DERs to relieve system stresses from ramping.

The functionalities of VPPs are not all that different from that of legacy energy management systems used by system

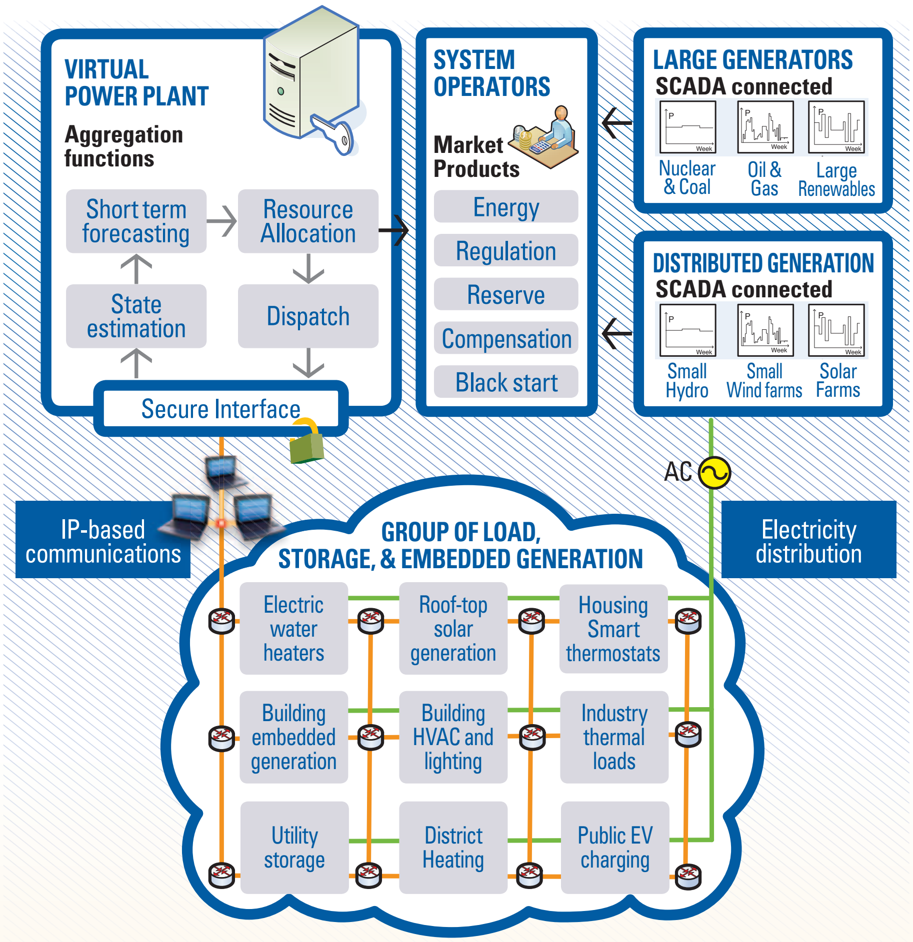


Figure 5: Overview of a virtual power plant: The distributed energy resources are aggregated and used to provide services to the system operator

A virtual power plant (VPP) aggregates several distributed energy resources (DERs) to deliver products and services to the system operator or market. By aggregating these DERs, the need for a wholesale energy market, ancillary service market, or dynamic pricing structure to drive individual DERs is alleviated.

operators, except that they can also manage loads. Load management requires the monitoring of resources, as well as forecasting, optimization, and dispatch capabilities. Note that while Fig. 5 depicts direct access of the VPP to DERs, a VPP platform would also be capable of managing DERs through different DER aggregators or third-party technologies.

The Information and Communication Challenge

A great challenge of the VPP concept lies in having the right information and ICT for communicating to and from smart appliances. Performance requirements, reliability, privacy and (cyber) security must all be taken into account. The acquisition of customer data

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through the internet enables greater DR potential, but at the same time poses new challenges that would not otherwise have been an issue with legacy pager systems. ICTs must be properly built to manage the fast, bi-directional flow of data and, most importantly, follow the "privacy by design" philosophy. Solutions to these challenges can be found in many different ways. Using an end-to-end mesh communication network like the Internet enables multiple paths of information and removes the possibility of a single failure on any point of the system disabling it.

On top of the physical connection, many different private and secure information technology approaches can be used to comply with information security standards. For example, to meet the "big data" and privacy requirements of vertically-integrated utilities, information exchange based on peer-to-peer (P2P) communication, instead of client-server architectures, can be used. This approach, currently being explored by CanmetENERGY, has been popularized by web applications such as Skype and is being laboratory tested for power system applications.

As presented in Fig. 6, P2P ILM solution involves intelligent electronic devices (IED) both receiving and transmitting information to their peers through a secured overlay network, without an explicit need to directly communicate with a central server. Applied to VPPs, P2P communications can be used by loads to share their status with one another to aid in their decision making to meet objectives as set out by the system operator. When receiving the information, individual entities can decide whether or not to consume electricity based on the customer's preference, the control entity's request, and the status of other peers (rather than decisions received from or negotiated directly with a central entity). With no operator in the loop of the P2P data exchanges this communication is "private by design." With the right set of operational tools for scheduling, the utility using this technology would be capable of employing energy resources from smart appliances to fill different grid service needs.

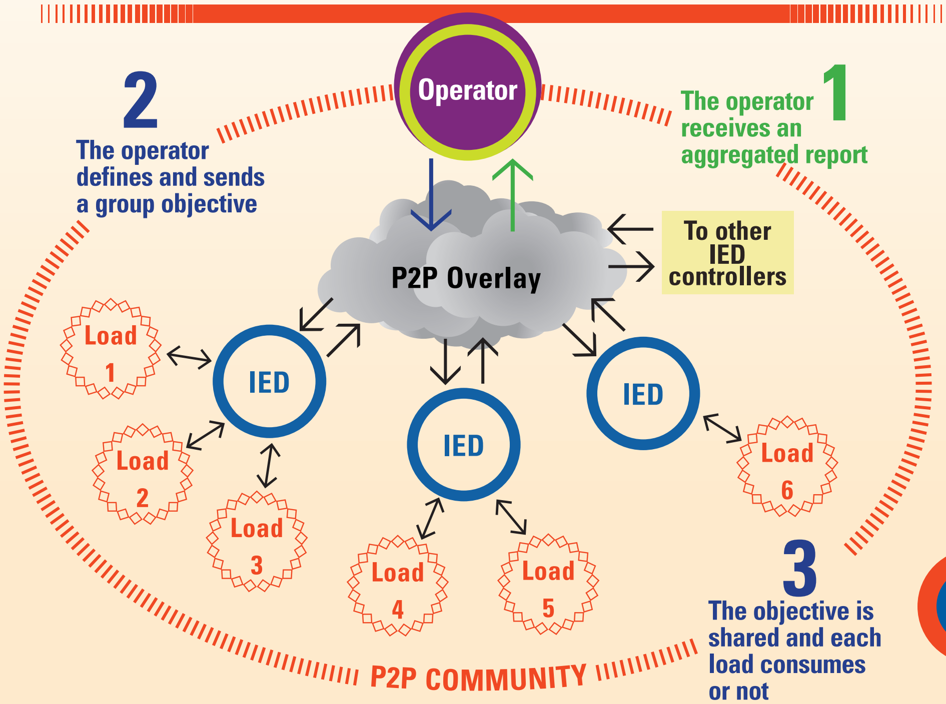

Figure 6: Peer-to-Peer (P2P) communications for power system applications with Intelligent Electronic Devices (IED)

Conclusion: The intelligent load management business model

Smart grid technologies have the potential to revolutionize utility-customer relationships. They represent an opportunity for Canadian utilities and generators to sell more clean electricity while benefitting from higher operational efficiencies. For customers, there is the opportunity to lower their energy costs while contributing to a cleaner environment.

ILM and smart appliances offerings could enable electric utilities to gain and retain customers in the face of increased competition, and lead to new export opportunities. With low-priced natural gas competing with electric heating and clean/renewable energy, off-peak rates may be necessary to increase market share and remain competitive (while delivering as much energy as possible). On the plus side, off-peak rates are a natural market response to supply and demand needs. As was shown in Fig. 3 and Fig. 4, off-peak delivery of energy does not create any stresses (and costs) along the electricity supply chain that peak delivery entails. Coupled with typically higher costs for generation during peaks, peak electricity rates will have an economic tendency to be higher than off-

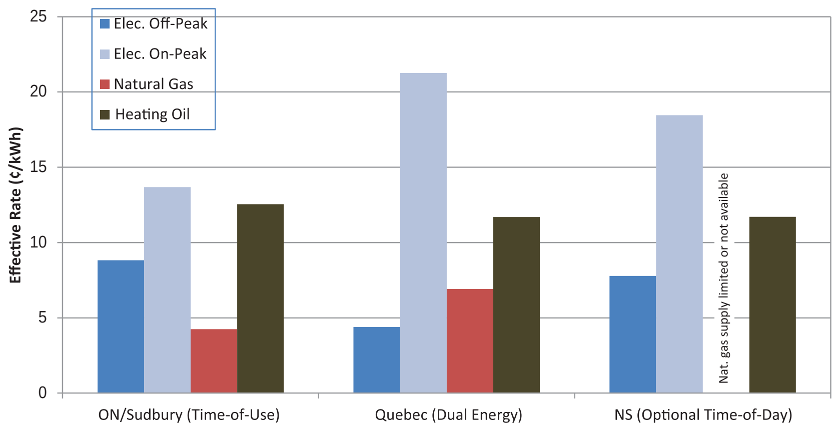

Figure 7: Off-peak prices of electric heating compare to natural gas and oil heating in Ontario, Quebec and Nova Scotia. In these jurisdictions, some utilities cover a share of the off-peak heating equipment.

Through smart grid concepts such as intelligent load management, loads will become active members in balancing the power system, banding with generation and transmission/distribution entities to contribute to a cleaner and more flourishing electricity sector in Canada.

peak rates. As presented in Fig. 7, there are already a few off-peak/dual-fuel rates offered in Canada in a mandatory (Ontario) or an opt-in fashion (Quebec, Nova Scotia). At Greater Sudbury Hydro, electric thermal storage installation cost is being covered at 75% by the utility to take advantage of off-peak electricity price in Ontario. At Hydro Sherbrooke (Quebec), 75% of the integration cost of a dual-fuel system and a cheaper tariff is offered to customers as part of their load management program. At Nova Scotia Power, an optional Time-of-Day rate is offered to customers with electric thermal storage devices.

Since using demand-side resources to balance the system also reduces the burden on the power system and reduces greenhouse gas emissions, a “green or grid-friendly tariff” valuing this benefit could be applied to further reduce off-peak prices. To engage new clients, a utility could make investments at a lower cost in customers' home appliances, rather than on their own network. Costs, and benefits of these smart appliances could be shared with customers and distributed through rate adjustments. The availability of these technologies could also lead to a new business model in the industry, where utilities would evolve from commodity providers (of kWh) to service providers (of water and space heating, for example).

Virtual power plants have the potential to herald in a new paradigm in utility and customer relationships. Through smart grid concepts such as intelligent load management, loads will become active members in balancing the power system, banding with generation and transmission/distribution entities to contribute to a cleaner and more flourishing electricity sector in Canada. ■

Further Reading on Virtual Power Plants:

1. D. Beauvais, A. Prieur, F. Bouffard, *Smart Grid to balance renewable energies – Contributing Distributed Energy Resources*, 2012 177 (RP TEC) 411 FLEXIN, 65 pages. http://www.nrcan.gc.ca/energy/publications/sciences-technology/renewable/smart-grid/6165

2. S. Wong, W. Muneer, S. Nazir, A. Prieur, *Designing, Operating, and Simulating Electric Water Heater Populations for the Smart Grid*, Report No. 2013-136 (RP-TEC), CanmetENERGY, Varennes Research Centre, Natural Resources Canada, August 2013.

3. D. Beauvais (CanmetENERGY), Michel Losier (New Brunswick Power), *A Virtual Power Plant to Balance Wind Energy – A Canadian Smart Grid Project*, Report No. 2013-057 (RP-TEC), June 2013. http://www.nrcan.gc.ca/energy/offices-labs/canmet/publications/smart-grid/14697

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