Introduction to the Smarter Grid – Part 2

Maike Luiken, Associate Editor

In the last issue we identified a number of issues and opportunities associated with the "Future Electrical Grid" as in the "Smarter Grid."

The Bigger Integrated Energy Picture

The trend towards an integrated systems approach to supply electricity, heating, cooling, steam and transportation fuels from various energy sources using different technologies is strengthening, e.g., Combined Heat and Power (CHP) is gaining more traction.

An integrated systems approach is also necessary. A case in point is the experience in New England during the very severe 2013-2014 winter. Like other jurisdictions, that state's interdependency of gas and electricity has risen steeply. The competing high demands for space heating and electricity during that harsh cold season challenged the energy supply system, which was limited by the gas pipeline capacity. How would an actual local gas shortage be managed?

At the local level: communities have generated or are generating integrated energy and water management plans, e. g., Guelph, Ontario.

At the Canadian federal and interprovincial level: discussions about interconnects (Quebec-Ontario) and large hydro projects (see Page 36 in this issue) are gaining attention.

The Canadian Academy of Engineering's Energy Pathways Task Force ("Canada: Becoming a Sustainable Energy Powerhouse," July 2014) proposes NINE BIG Projects – to substantially increase energy production and reduce the carbon content of the energy input from 86% to 61%. Some of these are focussed on Canada's Electric Power potential:

- A high capacity national interconnected electrical grid with regional hubs
- Realization of the hydroelectric potential from 73,000 MW currently installed to potentially 163,000 MW
- More large nuclear generation sites for bulk electricity and process steam production (CANDU), such as Bruce Energy Centre in Ontario.

Internationally: Each year the World Energy Council (WEC) poses the question: What is keeping energy leaders awake at night?

Globally,

- Energy security in all regions
- Energy prices and associated volatility—"the new normal?"
- Lack of climate framework
- Commodity prices
- Electricity storage driven by the increasing reliance on intermittent sources
- Renewable energies and energy efficiency
- Access to capital for more sustainably energy infrastructure
- Political and regulatory risk
- China/India drivers for global demand for energy

Canada (In addition)

- Regional interconnection
- Carbon capture and storage — world's first commercial-scale carbon capture coal plant (Sask Power)
- Unconventional fossil fuels
- Talent shortage

(From the 2014, 2015 World Energy Issues Monitors, WEC)

Back to the Smarter Grid

Today's energy systems must function reliably in an ever-more interdependant world. Read on to learn some of the ways these challenges might be met. ■

Evolution of Smarter Grid

Om Malik
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Since the establishment of the first public supply system in New York, USA, in 1882, power systems engineers have always been on the forefront of exploring and utilizing latest technologies to meet the challenges in achieving their goal of ensuring a reliable and uninterrupted supply of electricity. As new enabling technologies become available, they are embraced to improve the operation of the power systems. Despite the use of the term "Smart Grid" to represent advances having become ubiquitous recently, its definition is flexible. Engineers well appreciate the need for a well defined problem before tackling it. So let us start first with the definition of the term "Smart Grid."

1. Definition

The first-ever reference to the term "Smart Grid" in the technical literature appeared in an article in the September/October 2005 issue of the IEEE PES 'Power and Energy' magazine [1], referring to some existing programs such as: Electric Power Research Institute's (EPRI) IntelliGrid program, EPRI's Fast Simulation and Modeling program, and

continued >

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the US Department of Energy's GridWise program, a self-healing infrastructure being considered by the White House's Office of Science & Technology. The term was possibly in use internally in EPRI. It was later enshrined into law in the U.S. 2007 Energy Independence Act. There was also a commercial newsletter called "SMART GRID NEWS.COM" established around 2005 devoted to "News and analysis for the modernization and automation of electric power." (The term "SMART GRID" is a registered term of this newsletter).

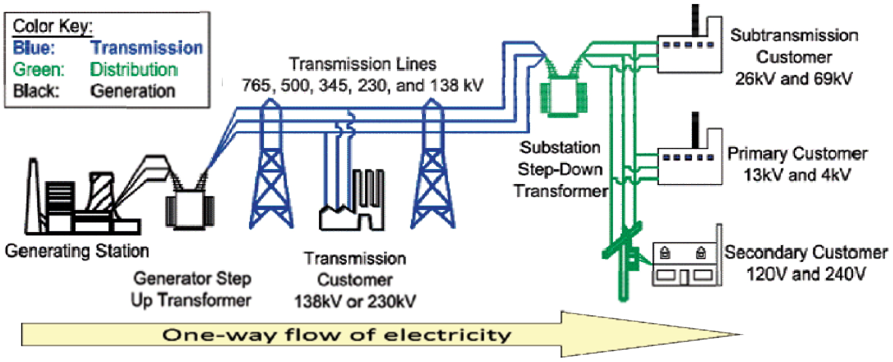

Figure 1. Flow of electricity in a traditional power system [4].

So far there is no standard definition for 'smart grid' even though the term is in common use throughout the power system literature. It means different things to different people. As an illustrative example, a list of 'smart grid' pilot projects under execution in India includes automatic metering, peak load management, outage management, power quality, renewable integration, micro grids, distributed generation [2]. A look at the literature shows that the term smart grid is now applied across the entire spectrum of the power systems as it meets the fancy of the writer and everybody is free to join the bandwagon. In view of this, a generic definition, as good as any, is:

> "*A smart grid is a digitally enabled electric grid that gathers, distributes and acts on information about the behavior of all components in order to improve the efficiency, reliability and sustainability of electricity services*" [3].

2. Vision

A generic vision of smart grid is to provide enhancements to ensure:

- High level of security, quality, reliability and availability of electric power
- Improve economic productivity and quality of life
- Minimize environmental impact while maximizing safety and sustainability.

However, to determine the specific vision it is necessary to see "whose vision", as again every user/country has its own vision.

3. Development and Progress

The desired characteristic of an electric power grid is high reliability of supply of electricity. It requires monitoring and quick reaction to changes in the delivery system and quick power restoration. The operator also tries to realize energy and cost savings for the customer. Every aspect of electric power systems, be it planning, infrastructure design, operation including measurement and control, protection, has made tremendous advances since 1882 to match the desired characteristics.

Technology level and operational requirements in power systems are a moving target as evidenced by new significant developments over the recent past, such as:

- Increased demands of a digital society
- Increased renewable power generation, energy storage and electric vehicles
- Restructured electricity marketplace
- Vulnerability to security threats.

They affect power system operation, control and protection. In response, power systems have continued to evolve in to smarter systems with the deployment of ever advancing techniques to cater to the continuously evolving requirements.

The traditional electric power system infrastructure, designed on the proviso that "electricity flows primarily in one direction" as shown in Fig. 1, [4], is not suitable under the new conditions. However, new developments in the electric power systems area and continuous technological advances in other relevant technologies in the recent past have become major catalysts for advances in power systems. These developments have given rise to new advances that are being pursued.

4. Future – A Smarter Grid

The grid of the future will be based on each and every aspect of the grid being monitored constantly using sensors specially designed to deliver and perform at high speed. It will require the integration of a communications network with the power grid that will enable power grid operators to collect data from the entire electric delivery network, about power generation, transmission, distribution and utilization – all in near real-time – so that advanced controls and intelligent information management systems can be applied to improve power system operation and continuity of electricity supply.

A lot of new research is in progress on all fronts in generation, transmission and distribution. Also, deployment of new technologies, some under the umbrella of 'smart grid', has occurred in all areas of power systems in recent years. However, deployment of new technologies is not without its associated costs. Estimates of cost by EPRI, consultants, International Energy Agency vary from US$ 165 billion to US$ 10 trillion over the next 20 years.

Although there is a lack of consensus as to how to define the smart grid, it is generally agreed that the definition and elements of a smart grid are evolving. Many of the technologies now being touted as smart grid have been in use and deployed long before the term "smart grid" became common. Considering that, one may ask the question:

Is "smart grid":
- A buzzword?
- Old wine in new bottles?
- Expected to contribute something substantial?

The answer to all these questions is, Yes. Much lies ahead for the smarter grids in the future encompassing studies on cyber security, self-healing networks, renewable energy, smart appliances, electric vehicles and policy issues involving data privacy, dynamic pricing, customer behavior, economics and regulation. ■

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For Om Malik's biography, see page 25.

Smart Grid For Canada; Regulatory Reform

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The smart grid is associated with maintenance of environment, economy, and resources and is not defined by "what technologies it incorporates" but rather by "what it can do" [1]. Although more than 16 years has passed since the term was first coined, and over $10 trillion dollars of public and private funding related to research on this area has been dedicated, its implementation has not been as widespread as would be expected. Why? Looking today, the major roadblocks are not unsolvable technical problems, but largely regulatory issues.

In Canada, regulatory reform will be a key enabler for transition from the current power system towards an actual smart grid. This means regulatory laws will need to be modified, completely rewritten, or in some instances created. For example, the Electricity Act, 1998 was amended in 2006 to mandate installation of smart meters in Ontario. It was a good step, but not enough.

Regulatory reform requires a transparent mechanism and easily accessible public reporting. Further development of smart grid in Canada is feasible following more government initiatives and committed investments by national and international consortiums. The investment should focus on expansion of both transmission and distribution systems to ensure they technically are able to accommodate the new stochastic-based generation capacity and implementation of ancillary services. This could be in the form of a temporal matching program to provinces, cities, regional utilities and individual private companies to take steps towards grid modernization.

Another key element is customer buy-in. There is a direct link between a customer's awareness and engagement, and their willingness to accept renewable energy tariffs. Reluctance to absorb additional cost can hold even though the customer may genuinely care about their environment [2]. Tariffs and billing systems must be amended in such a way that mitigates customer confusion and concern about energy bills, transactions, and energy offerings.

The Canadian Electrical Codes are provincially and territorially regulated and are not unified all across Canada. Any given electrical device requires an approval certificate based on these codes to interconnect into the Canadian electricity system [3]. As a result, this lack of uniformity in standards across Canada might cause an obstacle to projects.

In general, in smart grid projects, regulation on the requirements of battery storage and distributed-generator-unit interconnection points, as well as building codes, are imposed. These regulations may also stifle progress in implementing smart grid technologies [4]. In many cases, installation of storage and generation units is subject to a special inspection process to acquire an approval certificate; this is a costly and time-consuming procedure. Essentially, such barriers make the investment unattractive.

Canadian energy policy reform requires strategic planning to ensure the progress of smart grid development in Canada. This will facilitate achievement of the long-term targets of a sustainable low-carbon economy, and energy security and independence. ■

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[3] The Canadian Electrical Code, CSA C22.1, Canadian Standards Association

[4] National Building Code of Canada

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The Smart Grid Gets Competitive

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T. Wilson & Associates

The race is on for global leadership in Smart Grid technology, and though Canada has a shot at being a major contender, it's not in the pole position. The reasons are simple enough: we don't invest enough in research and development, we aren't graduating sufficient skilled engineers to fill demand, and capital investments from the private sector are modest. There has been some progressive government policy, but more needs to be done if we are going to be a player on the world stage.

"Federally, Canada has had a good push toward Smart Grid, though growth has been uneven," says Ravi Seethapathy, Director, Smart Grid Canada and Adjunct Professor at the University of Toronto. "Ontario, for example, is already at essentially 90% smart meter coverage, but if we look across Canada overall coverage is about 55 percent."

In the Canadian context, Ontario's notable leadership role could position it well to compete in the global market. The province's smart meters, time-of-use rates, and its feed in tariff (FIT) program has given a boost to solar and wind, despite the fact that the program is not necessarily built to reward more efficient technologies, or to address dynamic pricing. But that will come.

"Now with time-of-use data we can work on real-time demand management," says Seethapathy. "By getting off of flat rates, the consumer is likely more engaged, and we can begin to have a discussion of consumer choices, with an understanding of what they want, and how, and what kinds of changes are painful for them."

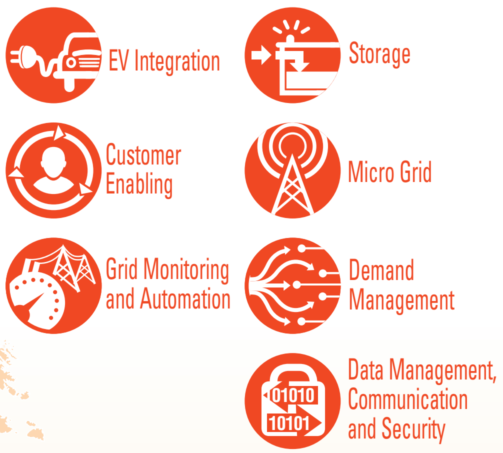
At present, Canada is in the Smart Grid delivery stage, with a focus on intelligent load management, renewables, distribution automation, conservation, and distributed sensors. The next stage – and this is where the country could really position itself as a global competitor – is in smart infrastructure. That means micro grids, visual realization and smart analytics, as well as more advanced energy storage. The problem is we aren't there yet, and we risk losing out on significant opportunity if we don't move fast.

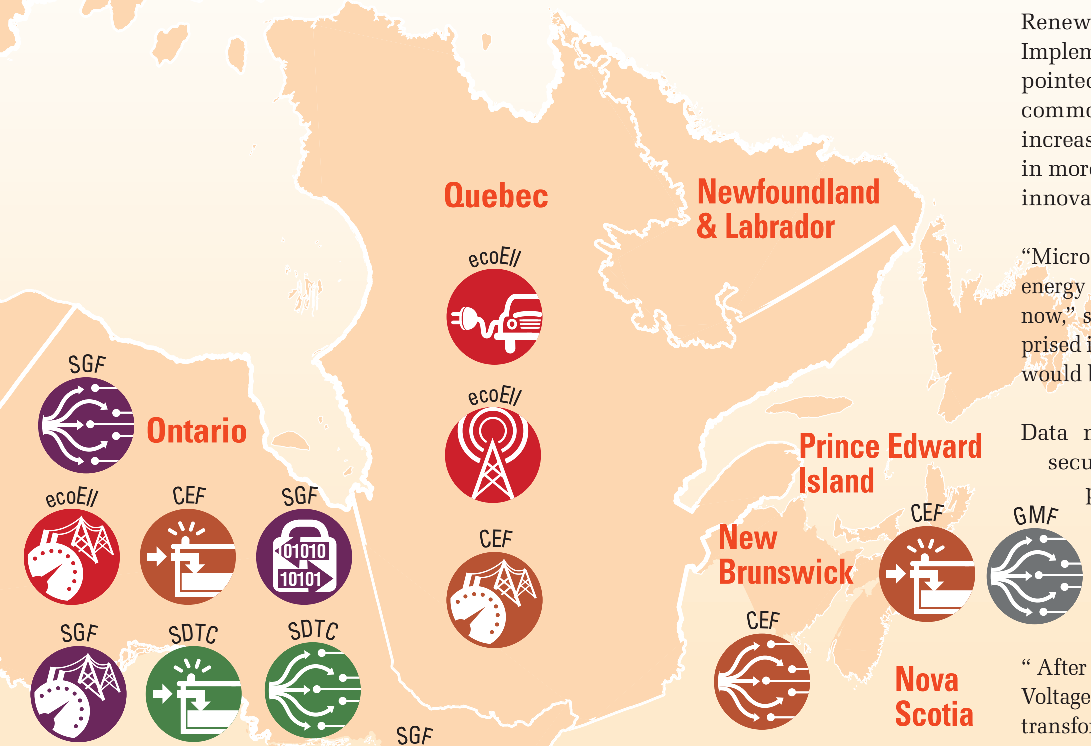
> “Federally, Canada has had a good push toward Smart Grid, though growth has been uneven.”
>
> – Ravi Seethapathy, Director, Smart Grid Canada; Adjunct Professor, University of Toronto

Publicly Funded Smart Grid Demonstrations & Pilots in Canada

$386M	$114M	37	24	24	24	1
in demo projects	invested	projects	companies	utilties	institutions	First Nations

- ● **ecoEII** NRCan – ecoEnergy Innovation Initiative
- ● **CEF** NRCan – Clean Energy Fund
- ● **SDTC** Sustainable Development Technology Canada – SD Tech Fund
- ● **GMF** Fedration of Canadian Municipalities – Green Municipal Fund
- ● **ICE** BC – Innovative Clean Energy Fund
- ● **CCEMC** Alberta – CCEMC
- ● **SGF** Ontairo – Smart Grid Fund





Adapted from Smart Grid in Canada 2012 – 2013, Figure 3, Page 24; Hiscock, Jennifer; Beauvais, David, report # 2013-171 RP-ANU 411-SGPLAN, Natural Resources Canada, October 2013.

Competing for customers

A smart infrastructure would give Canada a decent shot at being a global leader in the emerging customer-focused energy market. There is some good news here, with utilities like Toronto Hydro moving toward a 21st century grid, embracing innovative solutions like community energy storage and power line and transformer monitoring. These initiatives, and others like them, will drive an immense amount of data, which could bode well for the development of technologies that would serve distinct marketplaces around the world. The problem is, we aren’t that good at product development, as is, say, China, Taiwan or Germany.

“In Canada, we have invested in many commercial innovation hubs that look at the business side of things,” says Seethapathy. “However, we don’t have much bench strength when it comes to deeply rooted experience in technology development, or ‘product polishing’.”

From a Smart Grid public/private partnerships (PPP) funding perspective, British Columbia and Ontario, followed by Quebec, are clearly the leaders, with the highest value projects being in grid monitoring/automation and energy storage. Dr. Warren Mabee, Canada Research Chair in Renewable Energy Development and Implementation at Queen’s University, has pointed out that electricity is now energy’s common currency, with use options increasing all the time. That should result in more renewable options, as well as more innovation in managing and storing power.

“Micro-generation, data management and energy security are just beginning to grow now,” says Seethapathy. “I would not be surprised if in the next five years investment here would be similar to that in energy storage.

Data management, communication and security have little public funding at present. However, given Canada’s desire to compete by developing technologies for the consumer-centric Smart Grid, that scenario is likely to change.

“ After nearly 80 years, the Medium and Low Voltage Network is seeing rapid technological transformation,” Seethapathy says. “Central control is giving way to semi/near autonomous local smart controls that can operate much faster than today’s central systems to manage local power quality as a result of two-way power flows. We are just seeing the beginning of this transformation."

Export challenges in a fragmented market

The slowdown in 2008 hit Canada's Smart Grid exports hard. They have barely returned to pre-recession levels, and are not on a strong growth trajectory. According to a McKinsey Technology Assessment in 2012, Wind and Smart Grid were assessed as "highly attractive" markets by 2020, but were also deemed to be areas where other countries have a clear competitive advantage over Canada.

"Canada needs more 'backbone' product and systems engineers, and to make sure they are utilized well," says Seethapathy. "These are the people that will provide the core support to an export-driven market for Smart Grid products and services."

The good news is that although research and development investment in Canada could be better, it is the small to mid-sized enterprises (SMEs) that see the opportunity and are making a difference. One excellent example is Solantro, which has its headquarters in Ottawa and another office in San Jose, California. The company makes chips for distributed energy sources, and is aggressively pursuing global opportunities, with a keen focus on research and development. (See sidebar)

"At any instant we are developing new integrated chipsets, planning future ones, and working on expanding our firmware releases," says Ray Orr, Solantro's CTO. "We continue to work on system solutions in off-grid applications and for grid support."

Solantro is making a splash around the world, including in developing markets where off-grid solar represents immense opportunity. Powering up underserved areas, and getting that energy onto a distributed network, could transform many economies. And though that change is certainly due to Smart Grid technology, it also indicates how the move from a singular grid with a few centralized, large-scale power sources – and a utility-based view of a single consumer – can be a challenge. The Smart Grid market is, almost by definition, a fragmented one.

"'Smart Grid' is one of those ill-defined terms that means many things to many people," says Orr. "Canada has a suite of companies that do 'Smart Grid'-like activities. Temporal Power, Triacta, eCAMION, Eguana Technologies and Electrovaya are a few examples. If we include renewable energy in the definition of smart grid, this list expands considerably."

This market challenge is complicated by a Canadian engineering cohort that, when compared to other professions, tends to have a lower level of employment in their field of expertise. With that in mind, Canada's Smart Grid companies also clearly need help from the engineering and academic community to address the challenge of an aging workforce.

"There is real opportunity here, a perfect storm of sorts, but it is also true that Canada could lose out on all the investments it has already made," says Seethapathy. "Hence the need for more – or perhaps the better utilization of – engineering talent to support this. We need to look at companies that are providing leadership, like Opower."

Opower, which is headquartered in Arlington, Virginia, has a Software-as-a-Service (SaaS) platform that can deliver/analyze energy information directly to customers and utilities. Technology like

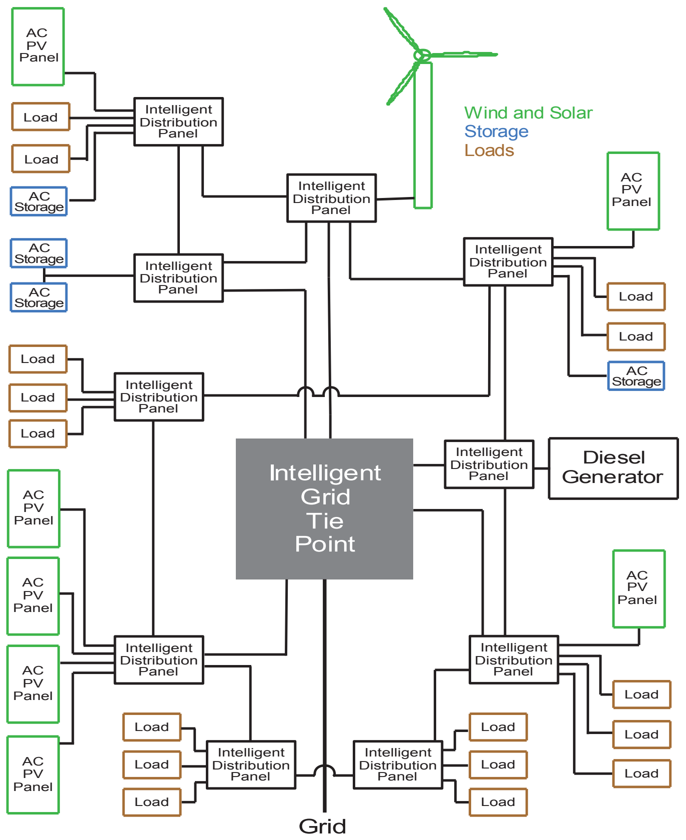
The sun rises on Solantro's global vision

When it comes to seeking business opportunity in alternative energy, it is only logical that companies big and small would want to look beyond Canada's borders, and be careful about their market selection. That is certainly the case with Ottawa-headquartered Solantro Semiconductor Corp., which develops customized chipsets and firmware for power conversion applications.

"In the short term, our market opportunities lie in solar," says Ray Orr, Solantro's CTO. "Applications include inverters, optimizers, safety disconnect functions and arc fault detection. In the longer term the broader renewable energy market, including storage and grid support functions, will be the greatest opportunity."

Founded in 2009, Solantro is a fabless semiconductor company active in both grid-tied and off-grid renewable energy installations. This is a complex business requiring significant technical expertise, but that is only part of the battle. The best people, and the best products, won't succeed globally unless a company has market access.

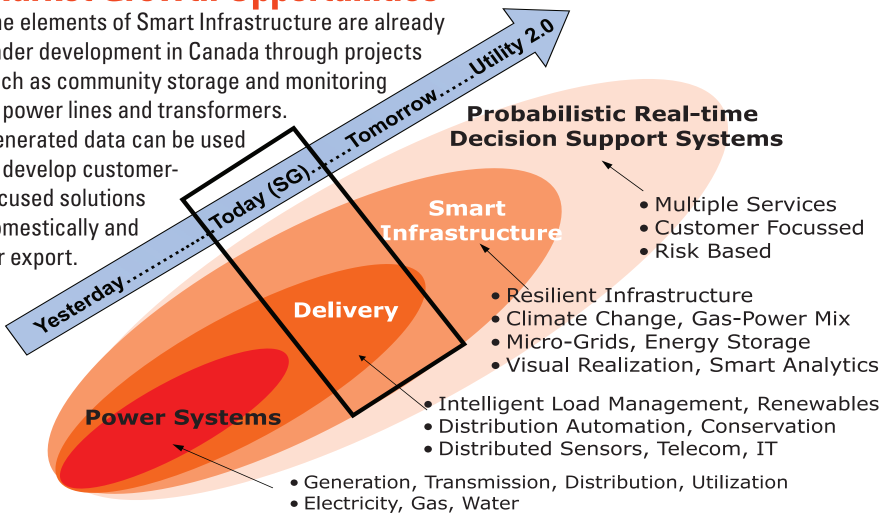
"Partnerships are paramount," says Orr." Small start-up companies do not have the resources to enter large global markets without partners. This comes in the form of co-marketing, strategic alliances where the business aligns well,



Solantro's bottom-up electrification. The company's vision is built on dynamic scaling, beginning with various t wes of power conversion units connected to local loads through intelligent distribution panels. These units can be then be networked for massively distributed intelligent power generation.

Market Growth Opportunities

The elements of Smart Infrastructure are already under development in Canada through projects such as community storage and monitoring of power lines and transformers. Generated data can be used to develop customer-focused solutions domestically and for export.



Source: Ravi Seethapathy presentation at the IEEE Toronto Section AGM, Oct. 25 2014

this, which can personalize consumption by putting data and analytics into the hands of the consumer, is the future of smart grid technology.

"Opower is ahead on this, but even they are only scratching the surface," says Seethapathy. "There will be a transactional feedback loop where customers will be able to see and analyze their data – perhaps using third-party services. This kind of ubiquitous data automation will have to address customer segmentation and cyber security."

It will also mean a bigger role for the private sector, which will then ideally result in technologies that can sell into the global marketplace. More generation and distribution will be in private hands, with an increase in self generation. Many new technologies and software will be transaction-based. They will be sold either directly to utilities or to consumers, and will be delivering analytics off a wealth of data. Ultimately, this technology will be serving a market in which individual customers want to be participatory, and to have service more accurately reflect their needs and habits.

"There is no longer one ubiquitous small customer, as in the past," says Seethapathy. "Customer expectations have changed, and utilities need to reflect that."

Whoever capitalizes on this reality has a good chance of doing very well in the global smart grid market. Some of the technology will be tailored to solar – which has come a long way in the past five years – and some to wind, hydro or even biomass. Juggling these sources with nuclear and fossil fuels to optimize cost-effective delivery, and to make the grid as smart as possible, is a big job. It is also a big opportunity. ■

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and with strategic investors who can make connections in international markets."

Solantro is going after solar for the simple reason that it is the fastest growing new source of power generation in the world. Solar is driven by advances in chip technology, a belief that storage innovation is on the threshold of some major breakthroughs, and a clear understanding that there is a huge untapped global opportunity. Approximately two billion people are on unreliable, aging grids, and another three billion have only partial grid access.

"That's a lot of people living in areas that don't have a reliable grid," Antoine Paquin, Solantro's CEO, told the IEEE Toronto Section AGM last October. "For us, the applications that matter are those that can dramatically affect their quality of life."

Solantro's goal is to be a major worldwide supplier of electronic solutions for distributed generation. It's already on its way, with solutions today in major advanced markets as well as India, the Philippines, and parts of Africa. Off-grid technologies in these markets – such as irrigation pumps in India – are a perfect opportunity for the company, which has solar technology that offers a clean and reliable alternative to expensive diesel generators.

And as Solantro seeks out new markets, it is keeping its eye on its longer strategic vision of being a company that positions its technology to support networked micro- and nano-grids. That's a vision that is particularly well-suited to those parts of the world that have poorly developed central grids, and high solar insolation. But you still need to get to market, and to address that challenge Solantro has put all hands on deck.

"How we sell is dependent on the market," says Orr. "In Asia we have manufacturer's representatives, and we form strategic alliances. We also have people in Europe and companies we partner with."

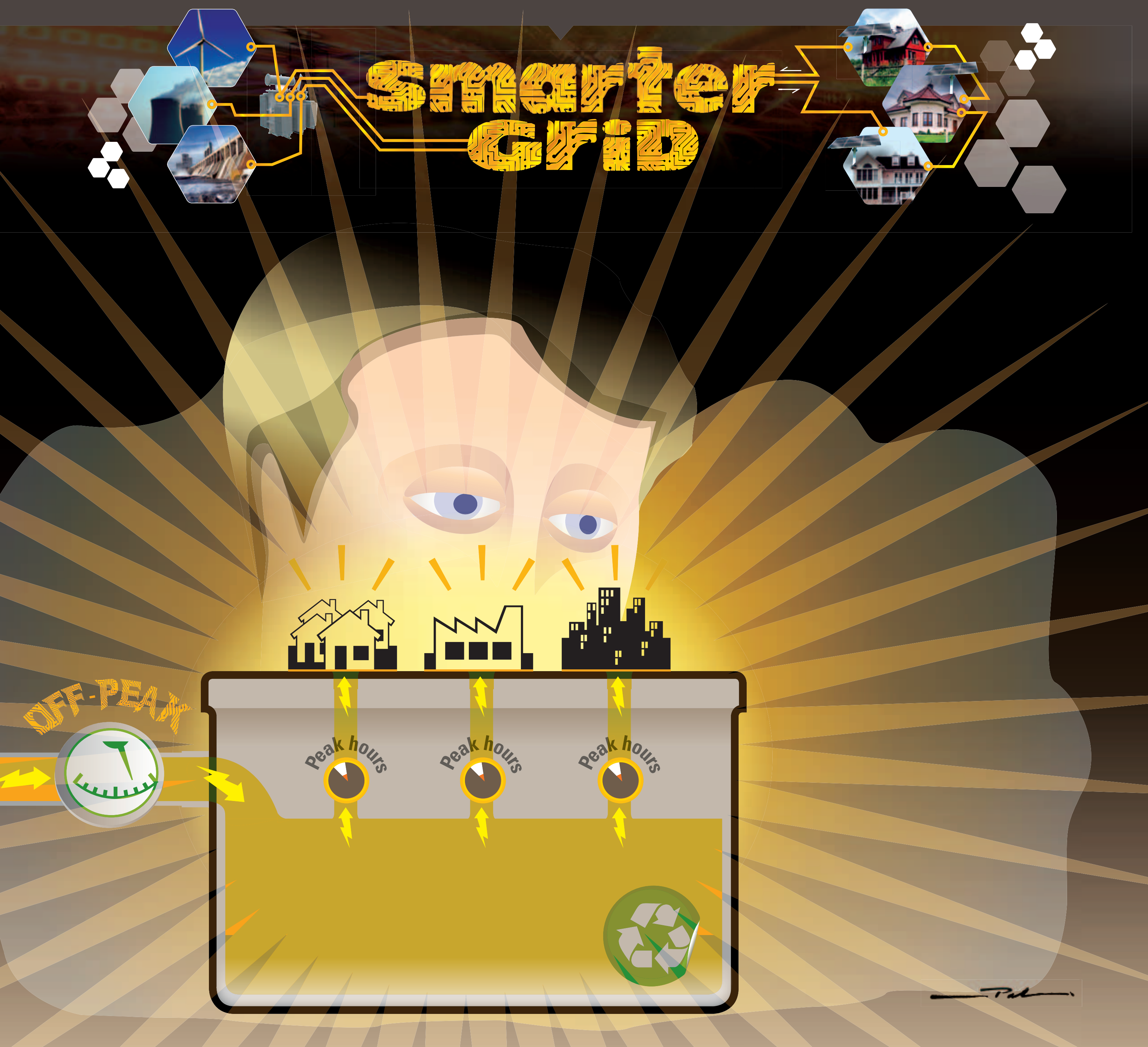
Solantro acknowledges the importance of government support, too. The company accepted a $3.8 million grant from Sustainable Development Technology Canada (SDTC) in 2013 to assist with the development and commercialization of its nano-grid technology. That kind of help can make a big difference for a small company trying to extend its footprint to global markets.

"SDTC has been instrumental in enabling strategic development activities," says Orr. "As a start-up, there is always a tension and a balance between short term execution and strategic developments. The STDC programs have enabled us to reach further towards our strategic goals. This has allowed us to develop system experience and product solutions ahead of a very dynamic market."

And a dynamic market it is: the International Energy Agency (IEA) anticipates that upgrades and extensions to the worldwide electricity distribution network will require $6.8 trillion in investment by 2035. That simply cannot happen without the participation of renewables, with solar photovoltaic technology playing an important role. The fastest movers with the best reputations will be the winners. Fortunately, some Canadian initiatives have helped lend credibility to Solantro.

"The Ontario FIT program has made Ontario a known entity in the solar world," says Orr. "This has contributed to the recognition. As well, our consulates and trade commissioners have been helpful in some markets."

But Orr is also quick to point out that there is "an amazing amount of investment globally." That means sitting still is not an option. In order to keep up with this market you don't lie back and watch the sun set. Instead, you follow it wherever it goes. ■



Repurposing Electric Vehicle Batteries for Energy Storage to Support the Smart Grid

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The increasing popularity of electric, hybrid electric vehicles, and plug-in hybrid electric vehicles (EVs, HEVs and PHEVs) is changing the automotive industry and creating a new stream of automotive waste: used EV batteries. Given that they still have approximately 80% of their power capacity after automotive use, it may be feasible to repurpose EV batteries for use in energy storage and peak-shifting. Such repurposed batteries could be employed in a single home, an office building, a factory or a power plant. The integration of these energy storage systems into commercial and domestic applications would help support the efficient operation of the Smart Grid.

An energy storage system of properly configured repurposed Li-ion batteries provides potential cost savings for business and homeowners by shifting electricity purchases to off-peak times. For utilities, such a system can support an integrated system of renewable energy and help regulate demand. At the same time, it can provide environmental benefits, e.g., improved use of renewables and increasing the lifespan of Li-ion batteries. Our research program considers the capacity, degradation and overall performance of repurposed EV batteries, in addition to the development of business and policy strategies for their use in Canada.

Previous vehicle-to-grid (V2G) models [1]-[3] consider using a battery while it is still in the vehicle to return energy to the grid and suggest that PEVs may profitably provide power to the grid/home when vehicles are parked and connected to an electrical outlet [4]-[6]. In these studies, the economic potential of V2G from PEVs is typically considered to provide power for base load and peak load, as well as electric grid services known as ancillary services, considering energy storage of renewable energy sources. However V2G requires complex power electronics and control systems. Most importantly while the battery pack is in the automotive application it is a 'high value' asset and cycling the battery will degrade its performance and shorten its useful life in the vehicle. Alternatively, in a repurposed remanufactured battery system, storage could be online 24 hours a day to provide energy and storage for the Smart Grid, an advantage over V2G, where power from EVs can be accessed only when attached to the grid for charging. Whereas V2G conceives vehicles attached usually during times of lower energy demand, repurposed batteries can function for peak shifting, that is, contribute to the grid times of peak cost and demand.

Similarly the use of new batteries for load shifting has been studied in a number of demonstration projects [7]-[9]. However, the high cost of new Li-ion battery packs makes this option restrictive. Repurposed packs will be available at low cost, making the potential battery energy storage option economical. Incentives may be initially necessary to encourage users of reused battery systems, but are a positive policy measure because of potential environmental benefits. To encourage homeowners to use repurposed EV battery storage systems, decreases in energy transfer fees and a higher payment for feeding into the electrical grid might be considered. Commercial companies have an added incentive for storing power purchased off-peak, because they can benefit directly from unregulated energy prices. Also, note that with energy storage onsite there is a more effective use of the electrical transmission assets which are congested in some zones at peak hours, and there would be less loss of energy through the transmission system.

80%

of original capacity,
Li-ion batteries generally have
remaining when they are removed
from service in vehicles and
as such are still useful energy
storage systems.

Properly configured batteries could decrease monthly energy costs by shifting electricity purchases to off-peak times and to favour renewable sources.

The benefits of the use of re-purposed packs include cost savings for the end user, more effective use of the transmission grid, emission reductions and integration of renewable power. Because the user can purchase energy during off-peak times, they can take advantage of variable pricing to reduce energy costs. Additionally, using repurposed-packs for energy storage allows for more efficient use of the energy grid by providing constant energy reserves and storage for meeting changes in supply and demand. This can cause a reduction in emissions, for example in Ontario by allowing energy generated using base load nuclear power to be stored and then used instead of coal or natural gas when demand peaks. Finally, using repurposed energy packs for energy storage and peak-shifting makes it easier to integrate intermittent renewable energy such as wind and solar by helping match supply with demand.

A further potential advantage of using repurposed packs is to keep battery packs in service longer, thus making more effective use of the original materials and manufacturing. The effective useful lifespan of 8 years in an EV battery pack is extended by a decade when repurposed for stationary use. Repurposed batteries add a separate life cycle to the manufactured battery and battery management system. When used outside of an EV, batteries have the potential to provide a safe, stable source of energy. Because the battery is first used only to power the EV, the battery is cycled as designed, and performs at optimal efficiency while in the vehicle, increasing

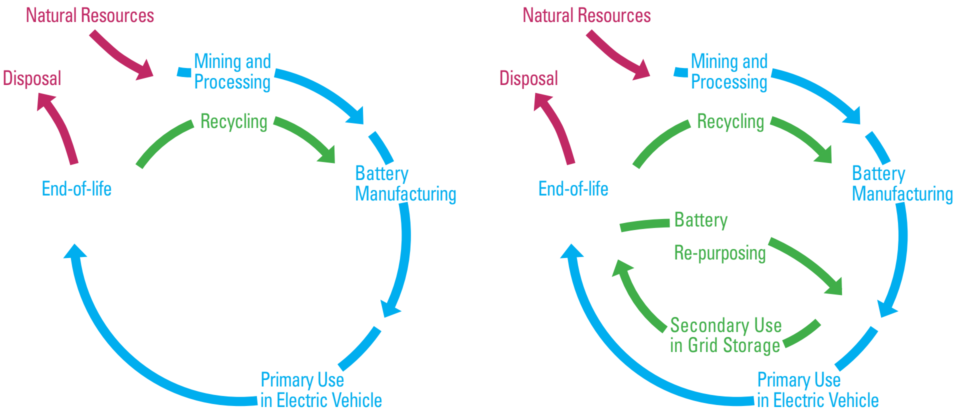

Figure 1. Existing (left) and proposed extended (right) life cycles of EV battery packs [10]

the battery lifespan. Then, the battery is reconfigured to work as a stationary system, repurposed to operate efficiently in a stationary setting. In Figure 1, the process life cycle of repurposing EV batteries for use in stationary settings is shown. Because EV batteries contain a very significant environmental and energy investment in materials and manufacture, it is important to consider the added value provided by extended use in a second life.

Challenges facing the use of repurposed battery packs include energy losses due to 'round-trip' charge efficiency fade, narrow price differentials across times of day in some jurisdictions, the reliability of reused packs and assurance of safety. A key concern with using repurposed batteries for load shifting is that a portion of energy is lost each time a pack is charged and discharged. As a packs ages, the amount of energy lost to heat increases; this is called charge efficiency fade.

For automotive manufacturers, charge efficiency fade has not been a significant concern as in EV operation the total capacity and thus vehicle range are the most important parameters. However, when the packs are being used to store and shift electrical energy, this charge and discharge efficiency critically determines whether energy storage will be cost-effective. Additionally, as energy prices vary geographically and by time of day, the usefulness of repurposed packs for energy storage also varies. There is scant information about the performance of EV battery packs at the end of their life in vehicles. This means that the reliability and future performance of the repurposed packs is also very uncertain.

A key issue facing the use of Li-ion batteries for energy storage is the risk of fire and explosion, so standards will have to be developed. Additionally, recent well-publicized fires in Tesla vehicles and the new Airbus Dreamliner, have brought to the forefront the risk of using Li-ion devices [11], [12]. In large stationary applications which call for greater numbers of battery packs, this risk could be of concern.

Continued research is needed into the technical performance of repurposed EV batteries, in addition to the development of policy strategies for their use in Canada. Future research will develop analytical models using IESO cost data to determine the feasibility of repurposed batteries to provide energy storage and for businesses that purchase unregulated energy.

Most pressingly, analyses of how batteries degrade during their life in EVs are needed to gain a clearer picture of the condition of batteries before they are used to support the Smart Grid. This would allow for better prediction of the performance and lifespan of the repurposed units in repurposed applications. Further, business models must be developed to determine how businesses and residential users can effectively obtain used EV battery systems, and to evaluate how repurposed power products may be marketed in Canada. Finally, there is a need to develop a sound policy strategy in Canada that encourages consumers to purchase the storage units to reduce their energy costs to support the Smart Grid.

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Energy Storage:
Industrial-Sized

Peter Smith
Energy consultant

Power reliability is a concern for all industries. But consider the implications for Canada's refineries: An interruption or voltage reduction lasting a mere blink of an eye can be enough to trip sensitive equipment leading to a plant outage. Processing stops, feedstocks must be flared resulting in increased emissions, and even the best designed and maintained plants risk safety or more serious environmental incidents. The bill can be $millions per event.

New technologies such as large-scale battery banks or flywheels may provide the resilience needed by refineries and other large industries. Storage facilities that can meet a large load (20+MW) for a short period of time could sustain a plant during a transitory interruption, or supply essential equipment for a longer period so a plant can shut down in a safe, managed way, avoiding excess flaring caused by an emergency shutdown. Sufficient storage capacity could even aid in creating a local micro-grid island containing local generation and storage, capable of supporting the area during a major outage like the 2003 wide-scale blackout.

Much of the initial concept testing for this kind of large-scale storage has been in aid of the grid. Demand for power varies widely both seasonally and on a daily basis, and generation always has to match demand. In Ontario, the Independent Electricity System Operator (IESO) sends dispatch instructions to large generators every five minutes, and provides fine adjustments every two seconds. However even the best generators are slow to respond; conventional physical equipment just cannot increase output that quickly. Fortunately, demonstration projects with new storage technologies are starting to show promise as economic alternatives in delivering the fast adjustments required to constantly balance the system.

Feedstock flaring during the northeastern North America blackout of 2003

Commercial application of industry-sized storage will require multi-party cooperation, given the needed capacity and the potential for upstream impacts. A conference held in Nov., 2013, in Sarnia, Ontario, brought together key players to facilitate discussion of the potential benefit to local industry. Titled "Grid Resiliency Through Energy Storage in SW Ontario," presenters included: suppliers of the new technology; representatives from local industry; the province's grid provider, Hydro One; IESO; and, Bluewater Power, the Local Distribution Company (LDC). Keynote and panel speakers provided details of the capabilities of the different technologies and of the needs of industry and the LDC, providing each side with an overview of the potential opportunities and generating further discussion. http://energystorage4swontario.com/

Since much of this technology has been developed or refined in Ontario, and the suppliers are based in Ontario, it would be fitting to see Ontario benefit from the development of a full-scale project in the province. The Sarnia area contains a unique mixture of electricity generation, large industrial loads, and engineering/technical experience and knowledge. With a broad industrial base of energy companies, it provides an ideal location for the practical application of these technologies. However, emerging technologies such as this often need financial support from the government in order to become established and reach economic maturity. As the conference attendees heard, the government is presently supporting some demonstration projects and further support will probably be needed to develop an industrial application in Sarnia. A committee under the auspices of the Sarnia Lambton Economic Partnership has commissioned a study of the available technologies to determine which may offer the best fit for a demonstration project in this unique area. The committee continues to pursue every opportunity. ■

***Peter Smith** is an Energy Consultant living in Sarnia, Ontario. He has 40 years of experience in the energy industry, including the design, construction, commissioning and operation of nuclear, coal fired, gas and oil fired power plants. He spent 10 years managing the commercial operations of 14 power plants in Eastern Canada, including relationship management, economic operation, commercial and government contract negotiations. Prior to this he spent 14 years in a number of roles related to energy purchasing, conservation and management for a large chemical plant in Sarnia. He has experience in purchasing and selling natural gas, thermal energy and electricity.*

Communication & Control

Om Malik
Professor Emeritus at University of Calgary

The idea of smart grid came, not because the existing grid was dumb, but because of a feeling that the grid would benefit by making greater use of communications, sophisticated sensors and controls. Three major aspects of control, to improve power system operation, security and reliability, and make power system smarter, being pursued are; control at the local level, wide area control and control of renewable sources of electricity generation.

A local controller using local information, called the Power System Stabilizer (PSS), is commonly employed on electric generating units to improve its damping and the stability of the power system. The conventional PSS, a fixed parameter controller, is designed for one operating condition using linear control techniques. Power systems are non-linear and operate over a wide range. Due to the non-linear characteristics, wide operating conditions and unpredictability of perturbations in a power system, the fixed parameter PSS generally cannot maintain the same quality of performance under all conditions of operation.

The adaptive control theory provides a possible way to solve many of the problems associated with the control of non-linear time-varying systems, such as power systems. In this approach, the parameters of the plant are estimated as the elements of a vector at any instant k, and the parameters vector of the controller is adapted based on the estimated plant vector. At each sampling instant, the input and output of the generating unit are sampled and a plant model is obtained by some on-line identification algorithm to represent the dynamic behavior of the generating unit at that instant in time. The required control signal is computed based on the identified model. Various control techniques, both analytic and artificial intelligence, can be used to compute the control [1-3]. One illustrative example of how such an adaptive device can improve the stability margin of a generator is shown in Fig. 1. These experimental results show a generator in stable operation with an adaptive PSS (APSS). At 5s, the APSS is replaced by a conventional PSS and the generator loses synchronism. When switched back to the APSS at 25s, it quickly regains synchronism showing that the generator has higher stability margin with the APSS.

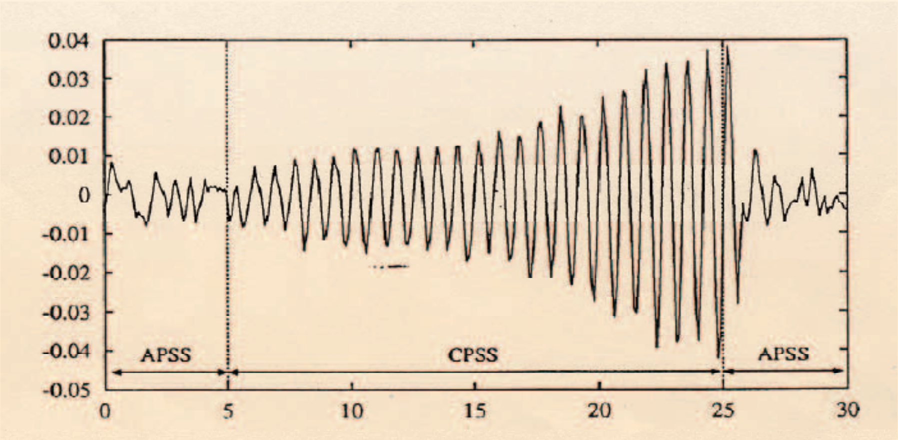

Figure 1. Dynamic stability improvement with an adaptive PSS.

Such controllers have been tested on large thermal, hydro and gas turbine driven generators in Canada and Europe, and are in active service on large hydro and nuclear generating units in Brazil and Europe.

Although local control systems can arrest the propagation of fast developing emergencies, they are not intended for arresting large-scale power system problems that require better observability of the state of the overall system for a wide area coordinated control action. Advances in technology have made possible on-line monitoring, synchronized measurements and fast communication to implement wide area control and protection of large power systems spread over vast geographical areas. A configuration of how a local control can be integrated with wide area controller is shown in Fig. 2. It, of course, can be applied only with the availability of fast communication technologies. Practical application of wide area control systems does require the consideration of a number of points and is evolving at present.

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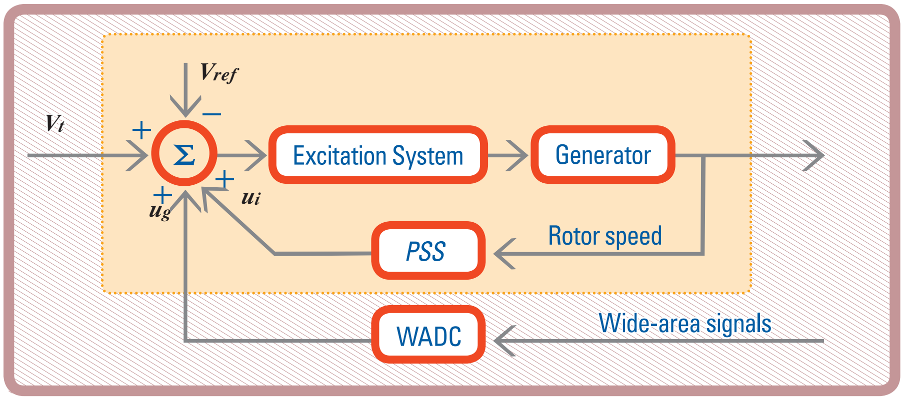

Figure 2. Control configuration with local and wide area control.

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Graduating in electrical engineering in 1952 from Delhi Polytechnic, India, Dr. Malik earned the M.E.degree from the University of Roorkee, India, in 1962. He obtained the Ph.D. degree from the University of London, London, U.K., and the D.I.C. degree from the Imperial College of Science and Technology, London, in 1965 and 1966, respectively.

Dr. Malik has done extensive research in the application of adaptive control and AI techniques to the control and protection of power systems, including smart grid, and has published more than 500 papers in these areas. He is a Life Fellow of IEEE, and also a Fellow of the Canadian Academy of Engineering and the Engineering Institute of Canada.

Power Quality Data Analytics

Maike Luiken
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Monitoring of grid elements, collection of data and analyzing it in real-time and off-line are critical for the modern grid. The needs are many, including: grid operations, system performance optimization, predictive maintenance and system planning.

It is standard practice to collect and analyze data for electrical disturbances that would affect Power Quality (PQ), focusing on the harmful effect of the electrical disturbance to enable mitigation. But what if that data could also be used to identify concerns with the system itself?

In July 2013 Wilson Xu made a Presentation at the PES General Meeting in Vancouver reporting unexpected results of his research efforts in the study of all types of electrical disturbances that affect PQ. Dr. Xu and his team found that PQ monitors, due to their general nature are widely used and also used to meet other monitoring needs. They learned that the data has been used to solve issues beyond PQ, like feeder capacitor status monitoring and feeder fault anticipation.

Analyzing the PQ monitoring data -- particular waveform-level data --can yield information beyond the direct electrical disturbance information; the condition of the system and its equipment can also be revealed. So although electrical disturbances affecting Power Quality have negative impact on the grid performance, power engineers are beginning to be able to take advantage of these disturbances to diagnose the system condition for purposes such as fault location/detection and predictive maintenance. Disturbance analysis expertise has led to the capability to locate the disturbance source location and synchronization of measured data. This work has become accepted as a new field of research: Power Quality Data Analytics (PQDA) – the science of extracting knowledge through the examination of raw electrical disturbance data.

Applications of PQDA include:

1. Distribution Feeder Fault Anticipator. Unusual V&I waveforms are analyzed to determine if a potential fault could occur in a feeder. This capability started from a PQ disturbance monitoring project by US-EPRI; fault anticipation is claimed as a key feature of the smart grid.

2. Fault location

3. Home appliance monitoring. Each appliance is represented in a composite waveform – as monitored at the meter - as a component. The target is to profile major appliances in a home relying on unique harmonic signatures from each appliance (North American homes have about 10 to 20 appliances each). Success of this research will create even "smarter" meters. The anticipated benefits of home appliance monitoring are

- The electricity bill is split to appliance level
- Power cost per use of an appliance is known
- Energy efficiency claims can be verified
- Energy use of similar appliances can be compared
- The replacement of appliances can be simulated
- Malfunctioning or unusual functioning of an appliance, as in drawing more power than expected, can be flagged

4. Load parameter estimation

5. Electricity theft

A key element to the success of PQDA is the development of harmonic signatures for the various individual grid system elements.

Looking at the big picture of monitoring activities in today's grids there are four major monitoring networks in current power systems:

SCADA network: 60Hz magnitude data; For load flow, state estimation & other applications.

... continued on page 35

Delivering More Clean Electricity with Virtual Power Plants

*David Beauvais, Steven Wong, Alexandre Prieur, Wajid Muneer, Salman Nazir and, **Philippe Mabilleau
*CanmetENERGY, Natural Resources Canada, **Université de Sherbrooke.

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 handful of jurisdictions in Canada. Using normal appliances, relays and one-way radio systems, utilities would use the

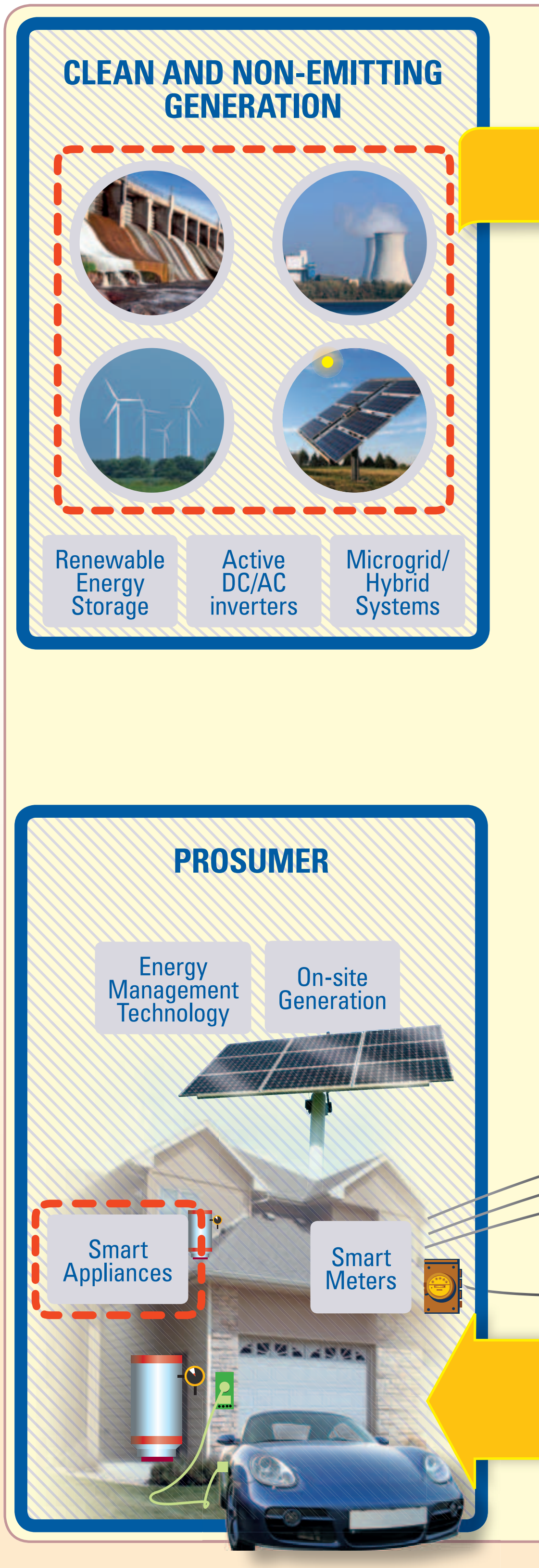
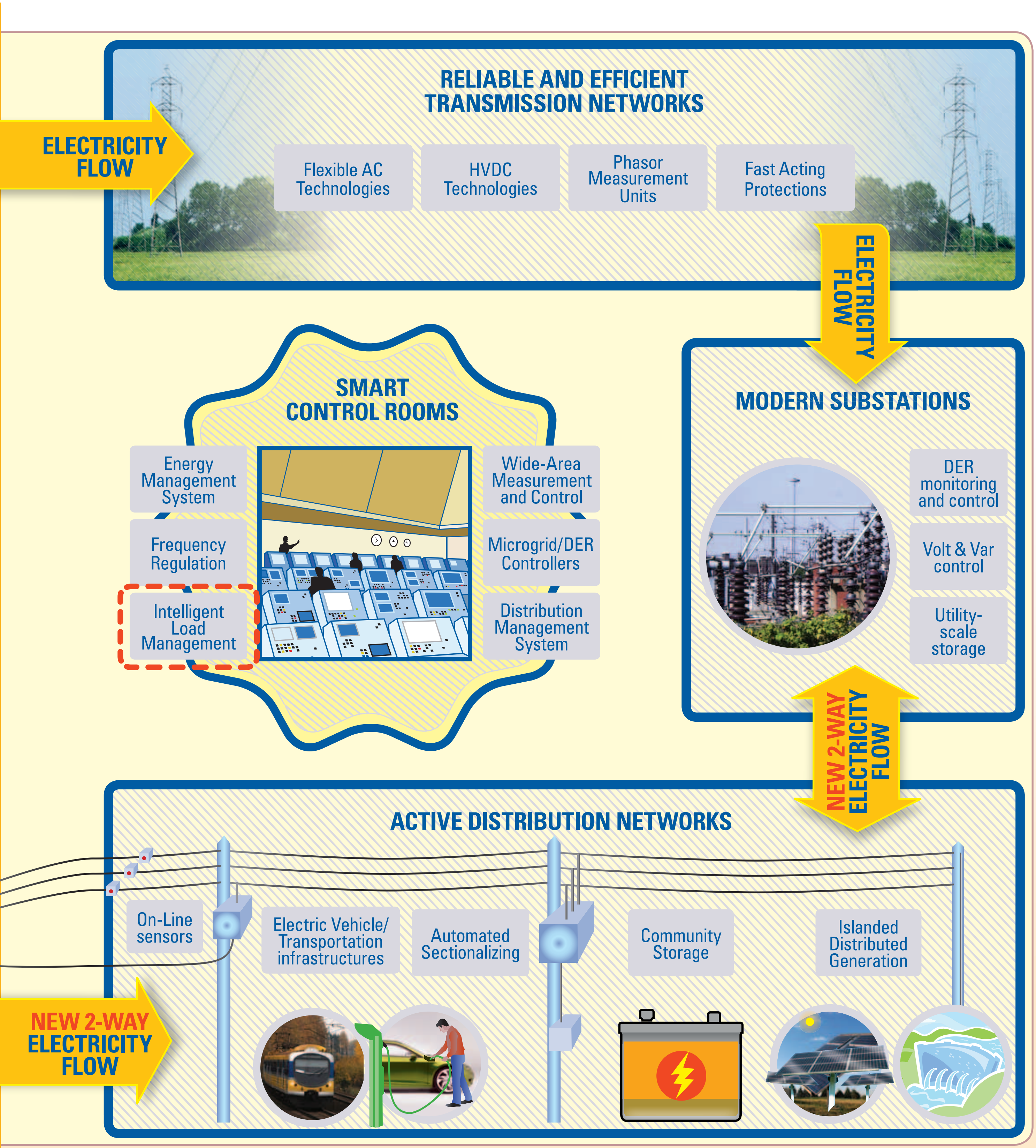


Figure 1: Map of smart grid technologies and applications on different section of the power system. In red rectangles: Clean and non-emitting generation, intelligent load management applications and smart appliances

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.



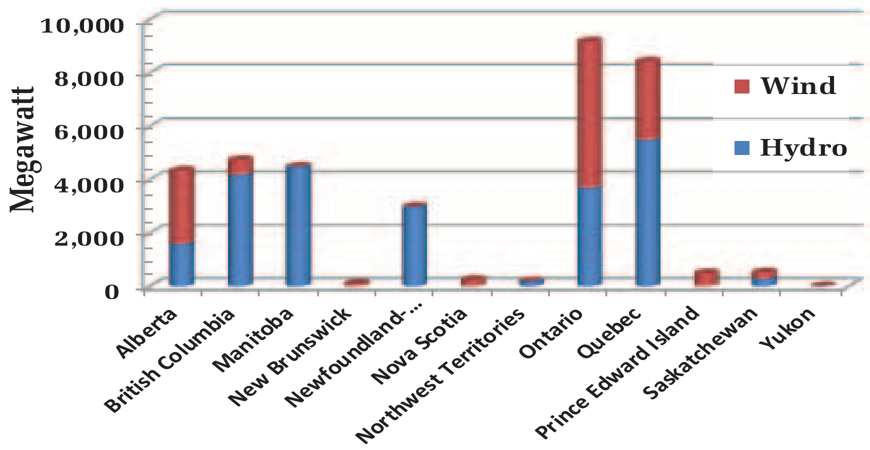


Figure 2: More than 35,800 MW of new hydro and wind generation capacity is projected or committed in Canadian provinces (CanmetENERGY)

> **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.

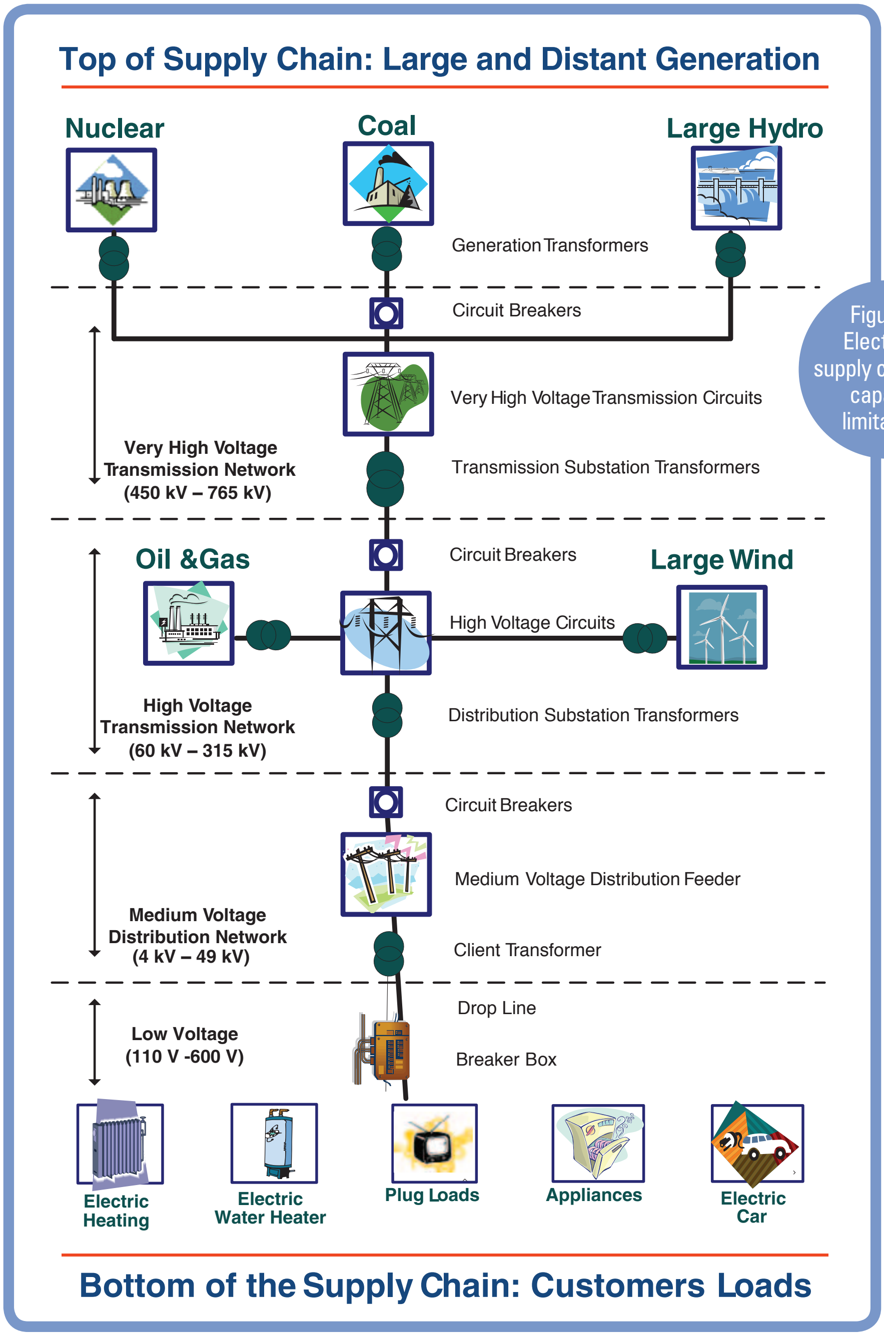


Figure 3: Electricity supply chain and capacity limitations

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.

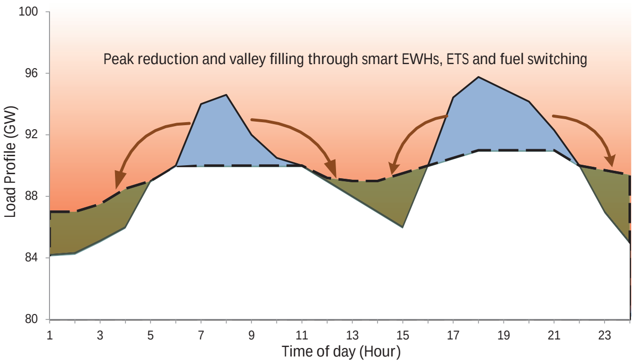


Figure 4: Load shifting on weak distribution network, using dual-fuel heating systems, smart electric water heaters and electric thermal storage devices

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.

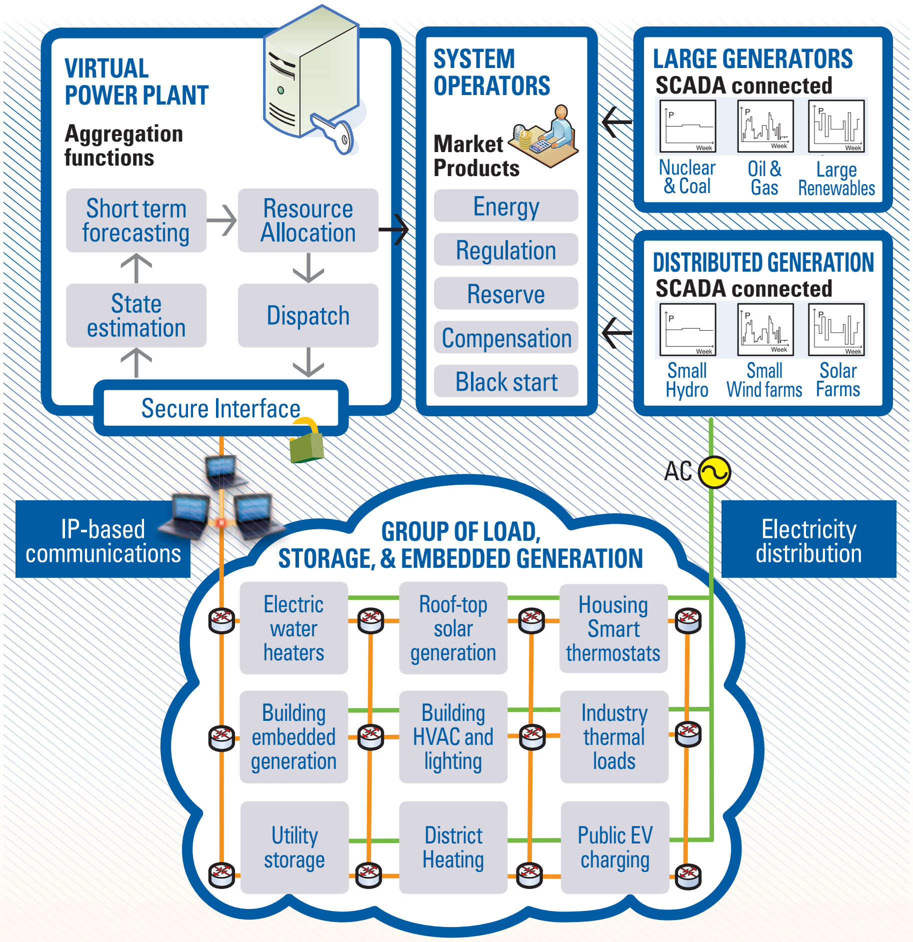


Figure 5: Overview of a virtual power plant: The distributed energy resources are aggregated and used to provide services to the system operator

> 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.

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

> 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. Customers can lower their energy costs while contributing to a cleaner environment.

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.

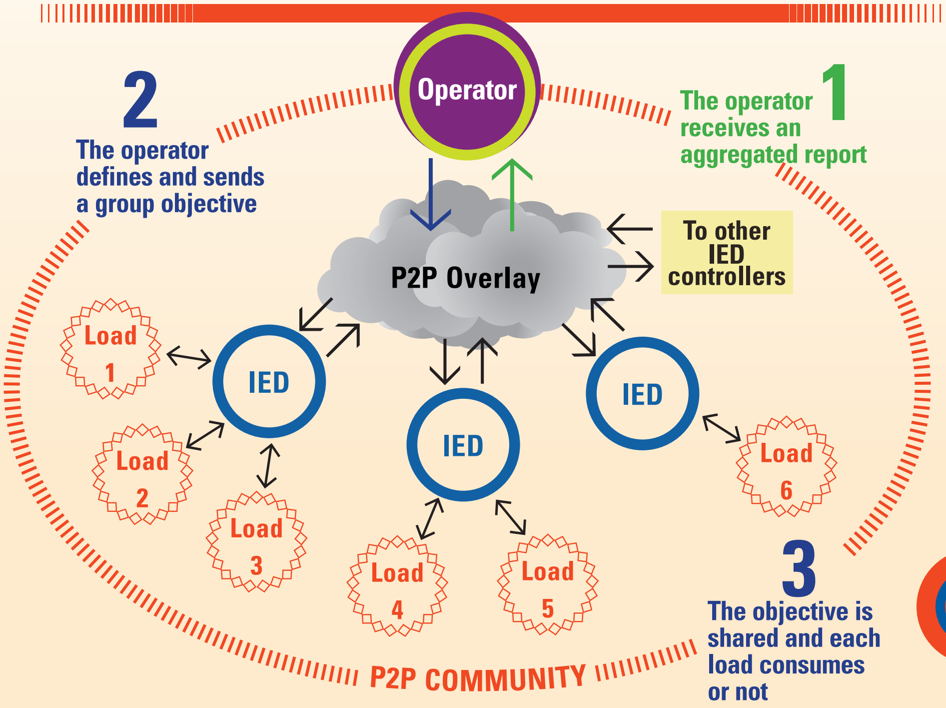


Figure 6: Peer-to-Peer (P2P) communications for power system applications with Intelligent Electronic Devices (IED)

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-

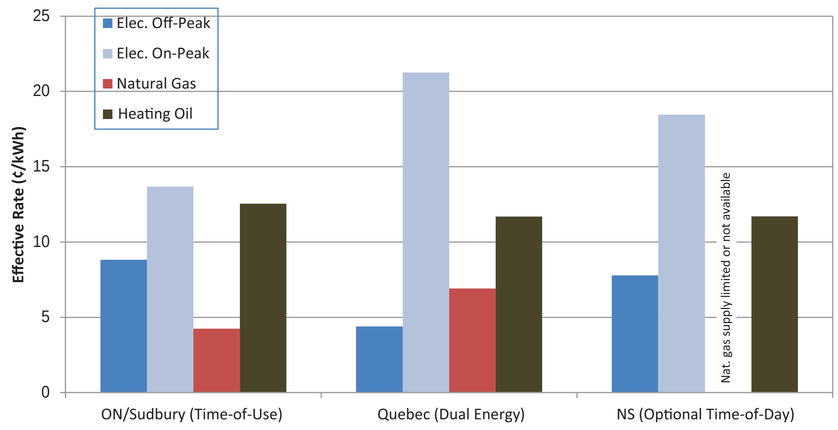


Figure 7: Off-peak prices of electric heating compare to natural gas and oil heating in Ontario, Quebec and Nova Scotia. In these jurisdictions, some utilities cover a share of the off-peak heating equipment.

> 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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Salman Nazir, *B.Eng., graduated in electrical engineering from McGill in 2011 and worked as an engineer at CanmetENERGY from 2012 to 2014. His research interests include operations, planning, control and economics of power systems integrating significant renewable and distributed energy resources.*

Philippe Mabilleau, *PhD, is professor at l'Université de Sherbrooke since 1984. His current research focuses on networked smart devices design and pervasive computing application, especially in the context of smart home and smart grid deployment.*

Micro-Grids: Concept and Challenges in Practical Implementation

Om Malik
Professor Emeritus at University of Calgary

Strain on electrical macro-grids makes them vulnerable as evidenced by large blackouts in various parts of the world over the past few years. With an increasing awareness of the environmental effects and limitations of fossil fuels, and high capital requirements of central power plants, distributed generation (DG) at medium and low voltage levels is gaining importance. Penetration of DG sources at the distribution level causes technical problems in the network operation, e.g. excessive voltage rise, increase in the fault level, etc., because the present electric power infrastructure at the distribution level is designed for current flows predominantly in one direction. To overcome these problems the concept of micro-grid has been developed as an energy management system and is already applied in a number of communities to provide benefits to customers.

Concept

Micro-grids can help make better use of energy generated, stored and used at a local level, thereby enhancing local reliability and flexibility of the electric power system. A micro-grid may consist of multiple generating sources making use of clean renewable sources of energy, customers, energy storage units, etc. within a clearly defined electrical boundary acting as a single controllable entity and be able to operate physically islanded or interconnected with the utility grid. Local generation allows better management in case of emergencies as has been demonstrated in a number of instances recently.

A number of technologies, ranging from conventional, such as small hydro, micro gas turbines, diesel generating units, biofuel, municipal waste, to renewable generation sources such as wind turbines, photo-voltaic and fuel-cells have been applied. An illustrative example of a micro-grid is shown in Fig. 1.

Operation

A micro-grid can be operated in two modes of operation:

1 Connected to the grid. In this case it provides quality of supply, global efficiency, flexibility of use and reduced cost. In times of need it can draw energy from the grid and supply energy to the grid in times of excess energy availability.

2 Operate autonomously isolated from the grid (i) under emergency during grid faults or (ii) as energy source in remote locations where cost of providing transmission lines may be very high.

Challenges and Amelioration

Although micro-grids can be very useful in making use of renewable resources for electricity generation and providing electricity at reasonable cost even to remote communities, challenges exist. These challenges can be overcome by judicious design. Also, integration of protection and control can make a significant contribution in the operation of the micro-grid.

- Electricity generation using wind and solar can be intermittent and unpredictable. They depend highly on the weather systems. Long term and even short time ahead forecast techniques for both wind (gusts) and solar (clouds) still lack the desired accuracy. As micro-grids have relatively small capacity, they are vulnerable to random

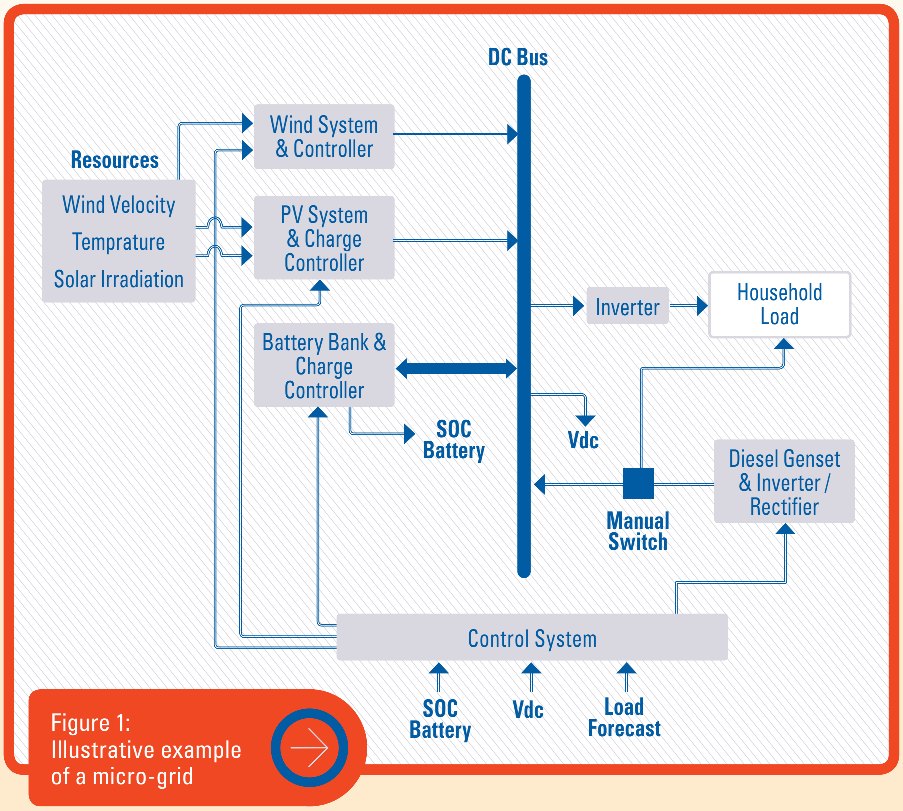


Figure 1: Illustrative example of a micro-grid

variations in generation and load. This may cause problems with operational capability and quality of supply.

- Availability of wind and solar radiation may not match the time distribution of load demand. Thus, providing electricity to meet load at all times in a regular way can be a challenge.

- Design of a hybrid system becomes complicated through uncertain renewable energy supplies.

- In isolated mode, chances of P and Q shortages that must be compensated instantly from somewhere.

- Conventional distribution systems are supplied through one source at one end. Protection schemes are relatively simple. However, presence of generation in the distribution system leads to loss of coordination of protection devices.

- Requires fast detection of islanding conditions to guarantee safety, reliability and integrity of the entire system.

Meeting these challenges requires:

- Strategic deployment of distributed energy sources in respect of location, size and technology to suit the requirement. An example is the integration of solar and wind sources in proper combination using the strengths of one to overcome the weaknesses of the other.

- Use of energy storage devices to balance load demand and generation by intermittent sources of generation.

- Proper control techniques to manage the operation of all components.

- Proper schemes for protection at the distribution level.

Role of Energy Storage

Energy storage is a critical element in the integration of DG into the micro-grid and can impact the economic feasibility of the installation. It can help maintain stability, allow optimization of generation sources, improve power quality, allow black start of the system, exploit off-peak prices and provide short term power supply to act as a buffer not only to counteract power imbalances but also for critical customers in fault situations.

Currently several types of energy storage technologies with different characteristics are available. These include: small hydro pumped storage, batteries, high speed flywheels, super-capacitors, compressed air, chemical conversion to Hydrogen for fuel cells, super heated gas. flow batteries, superconducting magnetic energy storage, etc. Which technology to employ involves a trade-off between power and energy density.

At the current state of technology, batteries are considered the best choice to provide both power and energy densities. Their efficiency varies between 60-80 %. In addition to the better known lead acid battery, several types of new batteries have been developed in recent years, Fig. 2, and are in use for industrial applications. Considerations in battery deployment are the initial and maintenance cost, energy density and response time, charge and discharge cycle life and environmental concerns.

Electric vehicles connected to the grid can also perform as energy storage units. As their numbers increase, with proper control they can play a significant role in frequency stabilization in a micro-grid in the future.

Energy storage units can be either distributed or centralized depending on the size of the micro-grid. They require power electronics interface for access to the micro-grid. For optimal operation and to derive most benefit, it requires consideration of type, configuration and the impact of energy storage system on the micro-grid.

Control Methodology

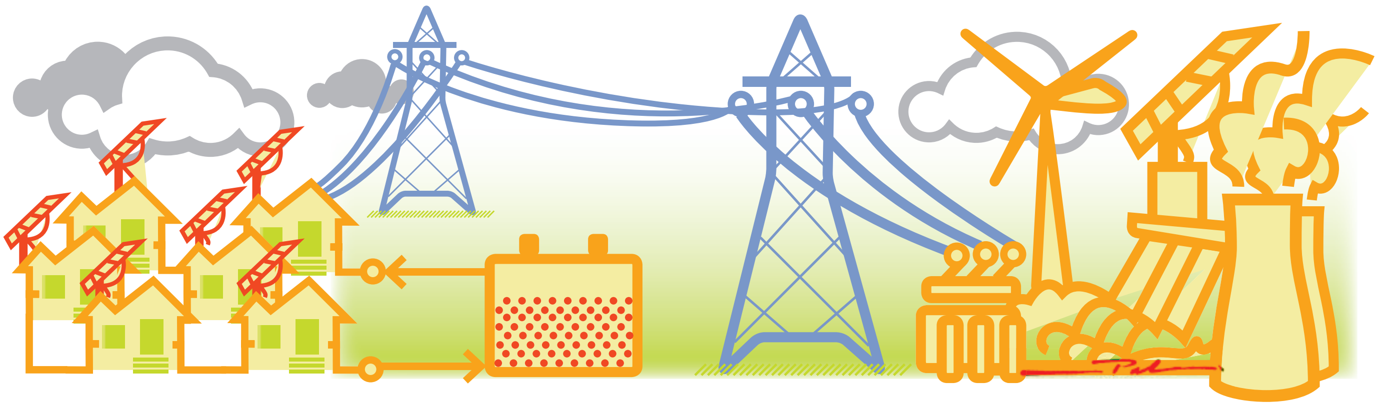
Distributed generation sources are inertia-less or have low inertia that can have a significant impact on voltage and angle stability of the system. It can be compensated by connecting energy-storage to the system, sometimes called "virtual inertia". With this control strategy, electronically interfaced DG will behave as a conventional generating system. Connecting energy storage system requires integration of power electronics interface control in the overall operation of the micro-grid.

Power and VAr injection throughout the distribution network provided by DG alters the original passive nature of the distribution network thus affecting the network voltage profile. It makes it hard to perform voltage regulation, and coordinated voltage and VAr control may be required, thus necessitating a radical revision of control strategies.

Protection

Even though most LV and MV networks are laid out as meshes, they are operated as "normally open" using automatic and manually controlled switches. Most protection schemes at the distribution level are currently designed for radial lines with unidirectional power flow. The presence of generation in the distribution system may lead to loss of coordination of commonly used simple protection devices, such as fuses, re-closers, over-current relays, automatic sectionalizing schemes. It could also result in false tripping, undesirable network islanding, prevention of automatic and asynchronous re-closing.

At a few special locations these circuits are being operated as closed meshes using special schemes such as power electronic



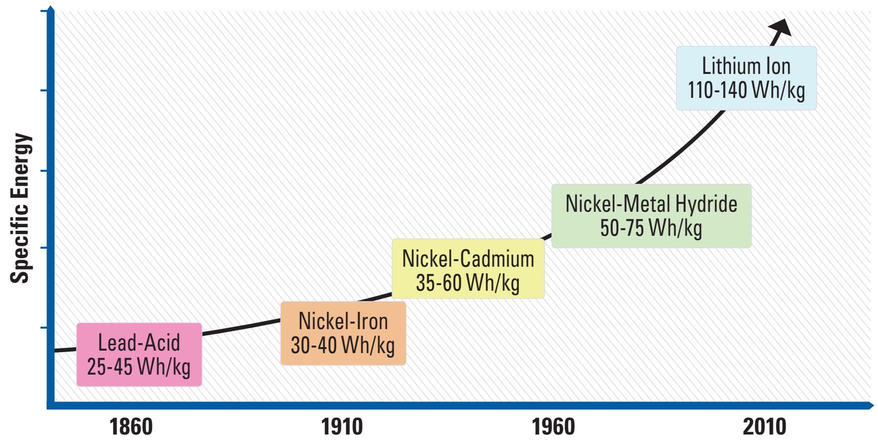


Figure 2. Characteristics of various types of batteries (source EPRI 2008)

devices to control the interface between sections of a mesh. Also, better protective equipment, such as cheaper breakers and intelligent electronic devices for relaying, is being developed that will ultimately aid in the protection of micro-grids.

Protection schemes for diagnosis and isolation of faults to protect distribution system that include DG need to be developed. It is also necessary to establish loss of mains requirements and develop methods for islanding detection.

DC Micro-Grids

One of the latest developments is the establishment of dc micro-grids. Many electric energy utilization applications now require either dc or double conversion from ac to dc to ac. These include large data centers, commercial buildings using variable speed motor drives, electric vehicle charging or anywhere power electronics based devices are used. These involve interconnecting a localized grouping of electricity sources and loads. In these cases, electricity is either predominantly generated or distributed and used in dc form at up to 1500 V dc. They can operate either connected to the traditional centralized grid or function autonomously as physical and/or economic conditions dictate.

Advantages of dc micro-grids are: reduced or complete elimination of ac-dc conversion, reduction in losses, more economical and decentralization of the grid.

However, because they are in the early stages of development, there is still a lack of suitable equipment for dc distribution coupled with lack of application knowledge at distrisbution level dc. Pathway for moving from the existing ac-centric power distribution systems to dc-based distribution systems is still unclear but evolving.

Concluding Remarks

Micro-grids can be very useful in making use of renewable resources for electricity generation. They can also provide electricity at reasonable cost to remote, isolated communities.

However, challenges exist but they can be overcome by judicious design and proper control techniques in the operation of the micro-grid. Integration of protection and control can make a significant contribution. ■

For Om Malik's biography, see page 25.

Power Quality Data Analytics

... continued from page 25

PMU network: 60Hz magnitude & phase data; killer applications have yet to be identified

PQ network: Waveform & transients data; for PQ monitoring and, in the future, for PDA/PQDA

AMI network: Interval E, P, V & I data; for billing purpose and demand monitoring

The PQ monitoring network provides a unique set of data with a significant amount of information on the performance of a network and its elements. It is the best candidate to collect and provide waveform-level data. It is just a matter of time before large-scale waveform-level data will be made available to utility companies. The goal of power disturbance analytics is knowledge extraction and to create killer applications based on such data.

To summarize, electrical power disturbances can provide information quite useful to utilities with applications beyond traditional PQ activities. At present, the PQ monitoring network is the most general platform to provide the data needed for significant knowledge extraction, and will likely emerge as a powerful platform for power system monitoring, in parallel with SCADA, WAMS and AMI.

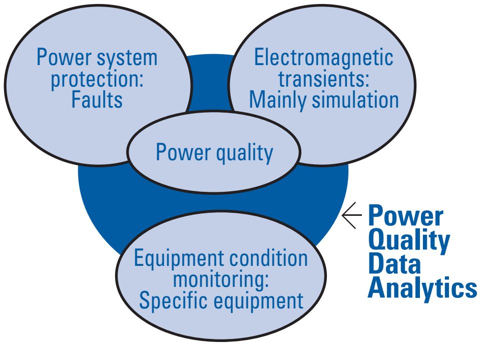


Fig. 2 Various fields contributing to Power Quality Data Analytics

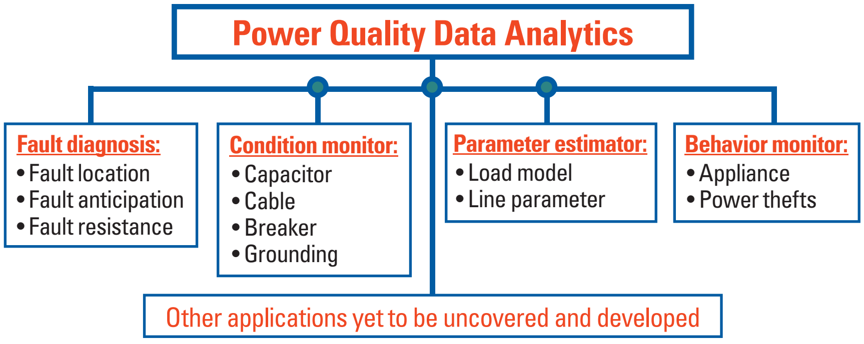


Fig. 1 Overview of Power Quality Data Analytics

For those interested in finding out more about research in this area, there are two proposed IEEE standards addressing these issues: P1836 and P1837; there is also a working group: PES PQDA WG ■

This article prepared with material from Wilsun Xu, University of Alberta.

Manitoba Hydro's plans to meet provincial electricity demands and export opportunities

Hilmi Turanli and
Ronald Mazur[1]
Manitoba Hydro

Manitoba Hydro is experiencing an on-going growth in electricity load in the province as well as increasing export opportunities. This article describes the current power system, and identifies future hydro generation potential along with associated transmission required to deliver this generation to Manitoba load and export customers. Manitoba's hydro power resources offer a very large potential for reliable green clean energy generation for Canada: There are over 5,000 MW of clean hydro electric energy potential to develop; this requires resilient bulk transmission capacity to transfer this power to load centers in the most efficient way. Here we are discussing today's reliability, projects under way and plans for future development of electrical energy and transmission for a smart(er) , highly resilient, electricity grid.

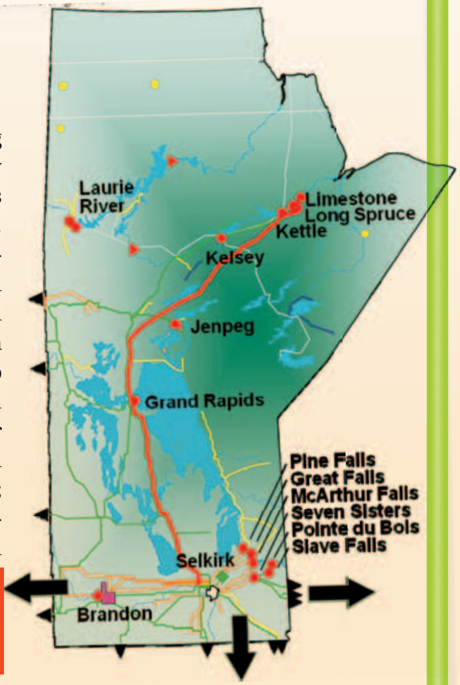


Figure 1: Existing Generation and Major Transmission System

As reported in earlier publications [1, 2, 3], Manitoba Hydro studied the possible development of new hydroelectric generation stations in northern Manitoba. Three sites were under consideration: Gull Rapids on the Nelson River, Notigi on the Rat River and Wuskwatim on the Burntwood River. Manitoba Hydro has recently completed construction of its newest hydroelectric generation station Wuskwatim G.S. (rated 214 MW) on the Burntwood River. New outlet transmission facilities needed for the plant were completed in 2011. The plant was placed into service during the summer/fall of 2012.

Manitoba Hydro has recently studied the possible further development of new hydroelectric generating stations in northern Manitoba. Two sites were under consideration: Keeyask G.S. (formerly called Gull G.S.) and Conawapa G.S., both on the Nelson River. The necessary community consultation, engineering, economic and environmental studies were completed to enable decisions to be made on continuing development. In June 2014, Public Utilities Board (PUB) Need For Alternatives To (NFAT) Panel recommended that the Government of Manitoba authorize Manitoba Hydro to proceed with the construction of the Keeyask Project to achieve a 2019 in-service date.

Existing Generation and Major Transmission System

Manitoba Hydro is a provincial Crown Corporation providing electricity to 548,774 customers throughout Manitoba and natural gas service to 269,786 customers in various communities throughout southern Manitoba [4]. Manitoba Hydro also has formal electricity export sale agreements with a number of electric utilities and marketers in the Midwestern U.S. and the Canadian provinces of Ontario and Saskatchewan.

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[1] Mr. Mazur has recently retired from Manitoba Hydro.

Figure 3: Wuskwatim G.S.

The amount of electricity generated from renewable resources amounts to 99% of the total energy generated [5] where the majority is from self-renewing waterpower. On average, about 33.1 billion kilowatt-hours of electricity are generated annually. Seventy-five percent is produced by five hydroelectric generating stations on the Nelson River; the remainder is generated at nine hydroelectric stations on the Winnipeg, Saskatchewan, and Laurie rivers; two thermal stations; and four diesel sites. The electricity is transmitted over nearly 105,000 kilometers of transmission and distribution lines.

Manitoba Hydro has 5725 MW of generation connected to its network. In addition, 116 MW of wind generation at St. Leon and 138 MW of wind generation at St. Joseph are available to Manitoba Hydro under power purchase agreements. In 2012, wind plants in Manitoba produced 875 GW.h, while in 2013 they produced 900 GW.h. Roughly 2.5% of Manitoba's annual energy generation is supplied by wind turbines.

In 2013, the corporation supplied a provincial gross total peak of 4535 MW (weather adjusted 4432 MW) [4]. The provincial peak load is growing at an average rate of about 1.5% per year (energy 1.5% per year).

The transmission system in Manitoba is interconnected to the transmission systems in the provinces of Saskatchewan and Ontario and the states of North Dakota and Minnesota by 12 tie lines. Of these, three 230 kV lines and one 500 kV line interconnect the Manitoba system to the United States, three 230 kV and two 115 kV lines interconnect to Saskatchewan, and two 230 kV lines and one 115 kV line interconnect to Ontario; see Figure 1, page opposite.

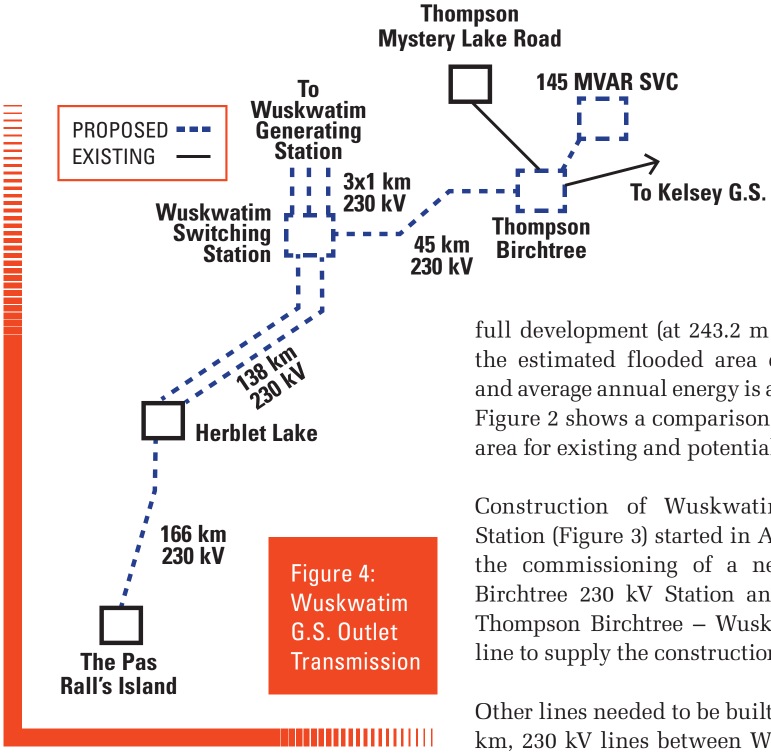

Figure 4: Wuskwatim G.S. Outlet Transmission

The tie lines to the US and Ontario are equipped with a special protection system that reduces the HVDC power (to eliminate the surplus power above tie capability) very rapidly following the loss of a tie in order to prevent cascade tripping of the remaining tie lines.

Wuskwatim Generation and Outlet Transmission Facilities

The initial concept design of Wuskwatim and Gull (now named Keeyask) started in the 1990s. The generation station design was modified to have less effect on the environment, greater public and market acceptability, but at higher cost and lower generation capacity. Flooding was designed to be less than 1-km square at Wuskwatim. When partial development (at 235 m forebay level) of Wuskwatim is compared to full development (at 243.2 m forebay level), the estimated flooded area drops by 90% and average annual energy is about 25% less. Figure 2 shows a comparison of the flooded area for existing and potential hydro plants.

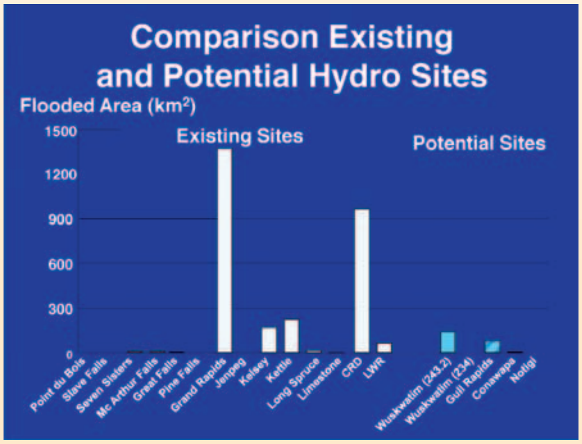

Figure 2: Comparison of flooded area [1,2]

Construction of Wuskwatim Generation Station (Figure 3) started in April 2007 with the commissioning of a new Thompson Birchtree 230 kV Station and 45 km long Thompson Birchtree – Wuskwatim 230 kV line to supply the construction power.

Other lines needed to be built were: two 138 km, 230 kV lines between Wuskwatim and Herblet Lake, and one 166 km, 230 kV line from Herblet Lake to The Pas Ralls Island (Figure 4). A Static Var Compensator, rated -50/95 MVAr continuous, and 145 MVAr for 10 seconds overload rating was installed at the Thompson Birchtree 230 kV Station to provide transient voltage control. In addition to connecting new generation to the system, the new facilities have improved the reliability of the overall transmission system.

Riel Station Reliability Project

D602F, a 500 kV line, connected the Dorsey 500 kV AC Station, north of Winnipeg, to Forbes Station near Duluth, Minnesota in the U.S. A new station, Riel, is to be built just east of Winnipeg adjacent to the right of way of the 500 kV line; see Figure 5 on following page.

The Riel Station is located on the southeast Winnipeg periphery adjacent to major 230 kV and 500 kV transmission corridors, making it an ideal location for a new supply point for Winnipeg load.

The location minimizes the need for new transmission corridors into and out of Riel and reduces the amount of new west to east transmission across Winnipeg as it provides an alternate supply point to Dorsey, which is located on the northwest periphery of Winnipeg.

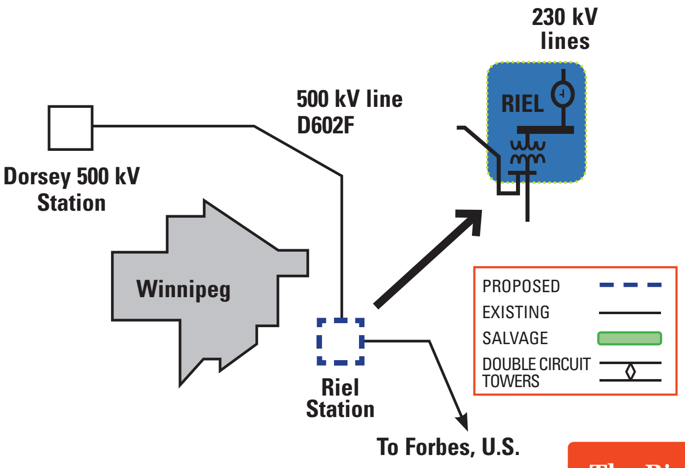

Figure 5: Riel Station Development and Dorsey – Forbes Line Sectionalization[2]

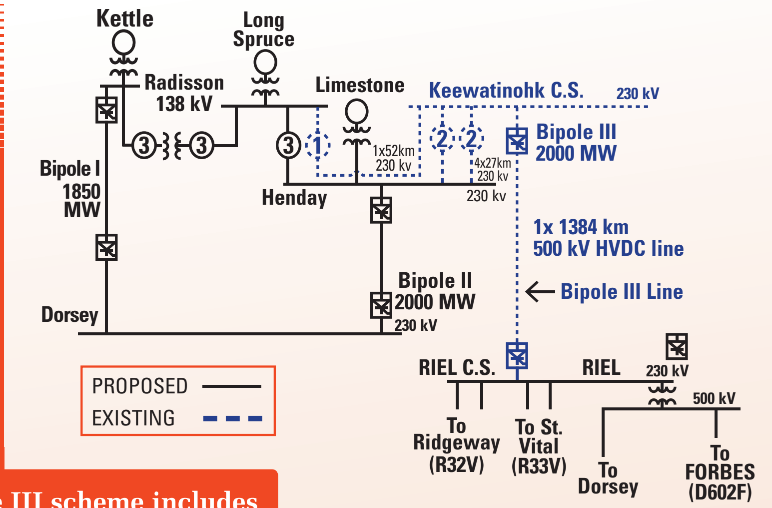

Figure 7: Bipole III Reliability Project

The Bipole III scheme includes
(Figure 7):

- **A ±500 kV HVDC transmission line, about 1392 km long, from Keewatinohk Converter Station to Riel Converter Station.**
- **A 2,000 MW converter station in the north (Keewatinohk C.S.).**
- **One 52 km-long 230 kV transmission line from Long Spruce to Keewatinohk.**
- **Four 27 km-long 230 kV transmission lines from Henday to Keewatinohk.**
- **A 2,000 MW converter station at Riel.**
- **Sectionalizing of the Ridgeway-Richer 230 kV line into the Riel Converter Station.**

The project included establishing the Riel Station site, installing 230 kV and 500 kV switch yards, installing a 1,200 MVA, 230 kV to 500 kV transformer bank, sectionalizing the existing Dorsey-Forbes 500 kV line[2], sectionalizing two existing 230 kV lines (Ridgeway-St. Vital lines R32V and R33V), and installing 500 kV line reactors.

The project will improve system reliability by adding an alternate terminal point for the 500 kV transmission line to the U.S., thereby preserving Manitoba Hydro's system import capability if there is a major outage at Dorsey. The station went into service in October 2014.

Bipole III Reliability Initiative

Enhancement of the reliability and security of HVDC transmission lines and the Dorsey Converter Station has been under investigation for some time. The HVDC transmission lines, Bipoles I and II, are located on a common right-of-way corridor referred to as the Interlake corridor (green line in Figure 6), 905 kilometers in length.

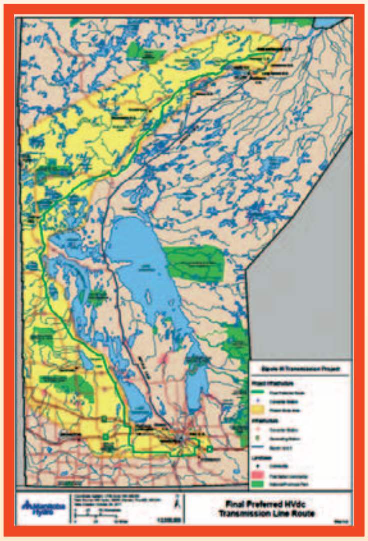

Figure 6: Bipole III Transmission Route

The southern converters of Bipole I and II are both located in the Dorsey Converter Station. The Bipole I & II corridor and the Dorsey Station are vulnerable to rare, but severe weather events such as wind bursts, tornados and ice storms; that could cause extended outages and severe hardship to Manitoba Hydro customers and Manitoba. One such event occurred on September 6, 1996 when straight line winds associated with a microburst resulted in the collapse of 19 HVDC transmission towers north of the Dorsey Converter Station, resulting in the loss of the Bipole I & II lines for about 5 days.

Development of Bipole III will require a Class 3 license under The Environment Act (Manitoba). The environmental impact assessment for the project, including a program of community/public consultation and the identification of potential impacts and mitigative measures, has been documented in an Environmental Impact Statement (EIS). The project EIS was filed with Manitoba Conservation in the fall of 2011 as application for the Environment Act License. The Clean Environment Commission (CEC) began public hearings on Manitoba Hydro's Bipole III transmission project on October 1, 2012. The hearings provided participants with an opportunity to review and comment on the project and its environmental impacts. The hearings were completed in March 2013. An Environmental Act License was received in August 2013.

Bipole III transmission line will run from a new converter station named Keewatinohk in the north located near Conawapa to Riel Converter station south of Winnipeg.

Manitoba Hydro evaluated the converter technology to be used for Bipole III thoroughly [6]. A new technology, referred to as the Voltage Source Converter is available as an alternative to the existing Line Commutated Converter (LCC) technology used for Bipoles I and II, however Manitoba Hydro opted for LCC due to economical considerations

The rating of the Bipole III is planned to be operated at 2,000 MW with a 15% continuous overload. The estimated in-service date for Bipole III is the summer of 2018.

Future Nelson River Generation Development

The planning is underway for two new generating stations, the Keeyask G.S. and the Conawapa G.S., on the Nelson River (Figure 8).

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[2] Sectionalizing the existing Dorsey-Forbes line means cutting the line at Riel and terminating it at Riel to form a Dorsey- Riel line and a Riel-Forbes line.

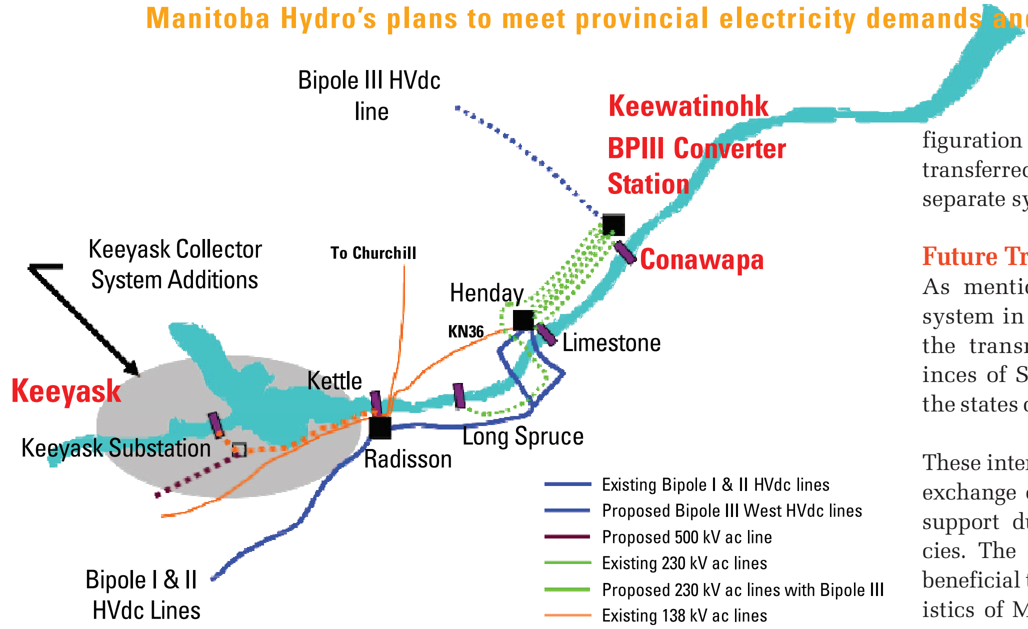


Figure 8: Northern Collector System

The Keeyask G.S. will be located about 61 kilometers upstream from the existing Kettle G.S. (1,224 MW). The Conawapa G.S. will be located about 51 kilometers downstream from the existing Limestone G.S. (1,350 MW).

Future Keeyask and Conawapa Generation and Outlet Transmission Facilities

The 695 MW (630 MW net) Keeyask Generating Station will require new outlet transmission facilities needed to connect the generating station to the Manitoba Hydro grid.

A new Keeyask Switching Station will be established to terminate seven new 138 kV lines including four unit lines (approximately 3 km each) to receive the power from Keeyask Generating Station, and three 138 kV transmission lines (approximately 35 km each) to convey the power to Manitoba Hydro's existing Radisson Converter Station [4]. The 2,000 MW Bipole III, slated to be in-service in 2018, will increase the capacity of the Bipole I, Bipole II and Bipole III HVDC system to accommodate the Keeyask generation.

A construction power station will be built and fed primarily from a 138 kV transmission line with an approximate length of 23 km tapped from existing line KN36. One of the Radisson-Keeyask lines will be constructed earlier than the other two, in order to serve as a back-up source of construction power. Station upgrades at the Radisson station will also be required. In addition to connecting new generation to the system, the new facilities will improve the reliability of the overall transmission system (Figure 9).

The in-service date for the first unit at Keeyask is anticipated to be September 2019. All of the transmission facilities will be in-service on August 2019.

Conawapa Generating Station with a rating of 1,485 MW rating (net 1,395 MW) with an in-service date of 2029/30 at the earliest and subject to further regulatory approvals will be connected into the Northern Collector System (NCS) at Keewatinohk (Figure 9). The only transmission required for Conawapa will be five short lines (7 km each) between the generating station and Keewatinohk. Also NCS will be split into two systems at Radisson to respect the stability limit and associated switching configuration and one Kettle unit will be transferred to the northern ac system (a separate system from NCS).

Future Transmission Interconnections

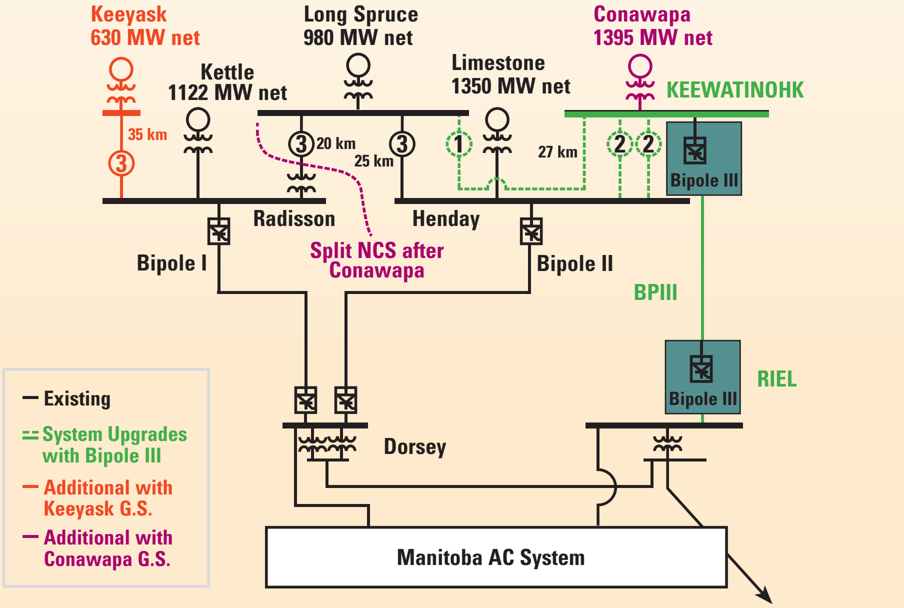
As mentioned above, the transmission system in Manitoba is interconnected to the transmission systems in the provinces of Saskatchewan and Ontario and the states of North Dakota and Minnesota.

These interconnections allow for economic exchange of electricity as well as provide support during electric system emergencies. The interconnections are especially beneficial to Manitoba due to the characteristics of Manitoba Hydro's predominantly hydraulic generation system. As well as exporting electricity surplus to Manitoba's needs, the interconnections allow Manitoba Hydro to import energy when economical or when river flows are low.

Manitoba Hydro has contracted with Minnesota Power (MP) to provide 250 MW over 15 years starting in 2020. Recently, Manitoba Hydro and Minnesota's Great River Energy have signed a memorandum of understanding to look at the province's energy utility selling up to 600 MW of electricity starting in about 2020. In February of 2014, Manitoba Hydro has inked two major power sales to Green Bay based Wisconsin Public Service (WPS) a subsidiary of Integrys Group Inc. (NYSE: TEG) in the United States. The first sale, running from 2016-2021, is for 108 MW of firm power. The second sale – based on electri-

continued >

Figure 9: Northern Collector System Development



city produced by the proposed new Conawapa Generating Station on the Nelson River – is for 308 MW of firm power for up to 10 years. The 308 MW sale is scheduled to start in 2027.

The proposed power sales agreements will require new hydroelectric development in northern Manitoba (Keeyask and Conawapa) and a new transmission line between Canada and the United States. Studies are underway to determine the necessary transmission facilities to boost the firm Canada to U.S. export capability.

There were a number of transmission line options being studied to date. These included a 500 kV line into Fargo, North Dakota area, a 500 kV line into Iron Range area in Minnesota, and a 230 kV line, also into Iron Range, Minnesota. **The Winnipeg (Dorsey)-to-Iron Range line (Option 1 below) has been found at this time as the most beneficial.**

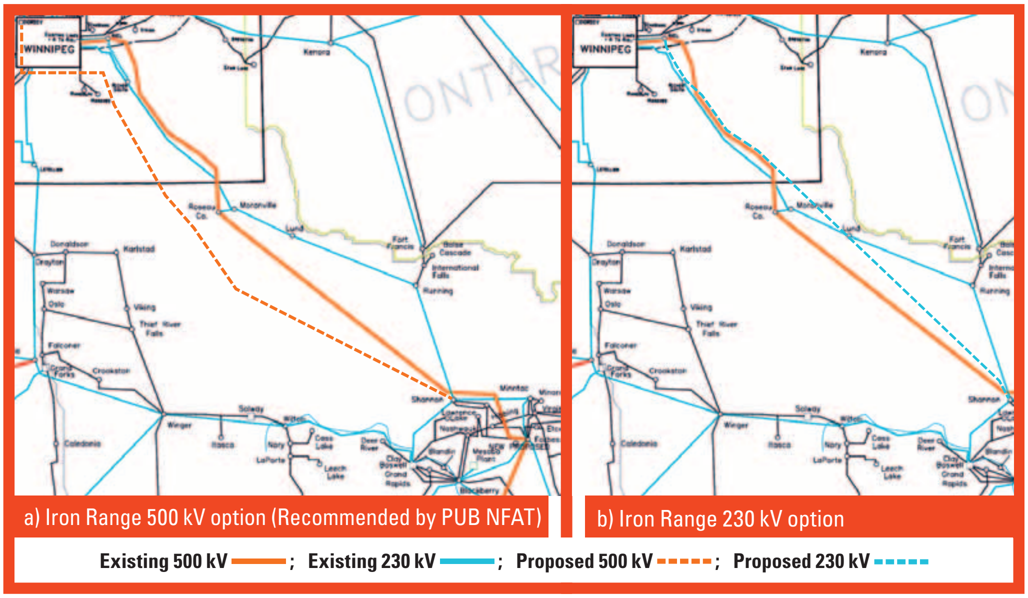
1 Winnipeg (*Dorsey*) to Iron Range (Blackberry, Shannon, or new Iron Range Station); 500 kV line

This 750 MW project consists of a 225-kilometer-long Winnipeg-to-U.S.-border 500 kV line, and a 210-mile-long U.S.-border-to-Iron Range 500 kV line, with a planned in-service of June 2020; see Figure 10(a).

Approval for the project and this in-service date were recommended in June 2014 by Manitoba Hydro's Public Utilty Board through its Needs For and Alternatives To Review (NFAT) Panel. It is now known as the Manitoba-Minnesota Transmission Project. Further provincial and federal regulatory approvals will be required before construction starts. [3]

2 Winnipeg (*Riel*) to Iron Range (Shannon); 230 kV Line

This option (2020) identified as a minimum requirement for MP 250 MW sale consists of a 145-kilometer-long Winnipeg-to-U.S.-border line and 210-mile-long U.S.-border-to-Iron Range line; see Figure 10(b).



a) Iron Range 500 kV option (Recommended by PUB NFAT)

b) Iron Range 230 kV option

Figure 10: Options for New Transmission Line into Minnesota

Conclusions

Manitoba Hydro has over 5,000 MW of clean hydroelectric energy potential to develop. The past development of its hydroelectric generating plants on the Nelson River in northern Manitoba has allowed Manitobans to enjoy some of the lowest electricity rates in North America. Manitoba Hydro is exploring the feasibility of developing new northern hydroelectric generation sites and new interconnections to meet future load growth and new contracts to ensure that these low rates can be sustained in the future. ■

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[3] This U.S. Transmission Interconnection Project has a total line length of about 560 km. It will originate at the Dorsey Converter Station, located near Rosser, northwest of Winnipeg and travel south around Winnipeg. The line will continue south crossing the Manitoba-Minnesota border, and will then connect to the Great Northern Transmission Line that will be constructed by Minnesota Power. The Great Northern Transmission Line will terminate at the Iron Range Station located northwest of Duluth, Minnesota.