

Towards Renewable Energy Integration in Remote Communities

A Summary of Electric Reliability Considerations



Energy and Mines Ministers' Conference

Iqaluit, Nunavut

August 2018

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Introduction

Canada has approximately 280 remote and northern communities and commercial sites that are not connected to the North American electricity grid, the majority of which are reliant on diesel as their main power source¹.

Remote communities are supplied electricity in large part by diesel generators, due to their reliability and familiarity of the local utilities with the technology. Integrating renewable sources of energy into these systems has the potential to reduce diesel consumption, limit greenhouse gas emissions, and lower the cost of electricity. While technically feasible to use wind and solar energy to reduce a communities' reliance on diesel, the reliability of a community's energy supply remains paramount.

This paper provides an overview of electric reliability considerations that local utilities, and the off-grid communities that they serve, must consider in looking to reduce diesel consumption through the integration of renewable sources of energy. Flexibility of the existing power system, short-term and seasonal variability of wind and solar resources, site accessibility and extreme weather conditions, as well as local capacity to build, operate, and maintain hybrid power systems, all contribute to how much renewable energy any given remote community may reliably integrate.

Background

Communities are either connected to the North American electricity grid (the bulk power system), or they are powered by remote micro-grids. For grid-connected communities, the reliability and security of the bulk power system is ensured through a common set of electric reliability standards predominantly defined by the [North American Electric Reliability Corporation](#) (NERC), adopted by the utilities, and enforced by regulators². For remote micro-grid systems, NERC standards do not apply however, the utilities that provide the power are responsible for reliability and are regulated by applicable Utility Boards.

Whether grid-connected or remote, the **essential reliability services** that support the reliable operation of these systems have the same objective – to continuously balance generation and demand (load) in real time which maintains system frequency and voltage within acceptable limits, and to ensure the system recovers to normal frequency following disturbances. Doing so will allow the system to meet the community's electricity demand, protect the integrity of the interconnected loads and generators, and avoid unplanned outages.

Isolated systems face unique reliability challenges relative to facilities connected to the bulk power system. A remote micro-grid has a limited number of generators and cannot rely on neighbouring

¹ <http://atlas.gc.ca/rced-bdece/en/index.html>

² <http://www.nrcan.gc.ca/energy/electricity-infrastructure/18792>

jurisdictions for support or back-up. For this reason, the failure of any one generation source could have a disproportionate impact on the micro-grid and the ability of the isolated system to continue to meet load. Integrating renewable energy sources, such as wind and solar that are variable in power output, can further test these systems.

[“Essential Reliability Services”](#) (ERS) involve a suite of capabilities designed to maintain the electricity system within standard operating limits of frequency and voltage. When frequency and voltage values move outside tolerable levels, the electricity system components must respond to restore conditions or risk an outage. ERS are classified into three main areas, outlined below and illustrated in [short videos](#):

- 1) **Frequency Support:** These resources seek to halt frequency increases or decreases following an event, and then work to restore frequency back to normal levels.
- 2) **Ramping & Balancing:** These resources seek to ensure a close match between supply and demand at all times. While this can be considered a form of frequency control, ramping and balancing occurs during normal system operations, vs. frequency support resources that seek to restore frequency following a disturbance.
- 3) **Voltage Support:** These resources seek to ensure sufficient voltage locally, in order to ensure power can move to where it is needed. Sources of active and reactive power are used to provide this service.

As discussed in the following sections, while lower levels of energy from variable renewable sources can be reliably integrated, higher penetration levels may require additional measures to ensure their operation does not introduce additional reliability issues for the remote community’s power system.

Diesel Generation

Conventional diesel generators are able to ‘ramp’ production up or down in response to changes in load, or in response to variable renewable energy production, in order to balance generation and demand in real time. Ramping does however have limitations. All generators have safe and efficient operating ranges and ramp rates. Where the penetration of renewable sources of power stretch existing diesel assets beyond their allowable operating ranges, impacts to electric power reliability could result if additional measures are not put in place.

Conventional diesel generators cannot operate (ramp down) below 30-50% of their maximum loading point for extended periods without experiencing carbon build up or ‘glazing’. For this reason, minimum loading constraint of a diesel generator is normally set between 30-50% to reduce premature aging of the generator and limit any risk of engine failure.

Operating conventional diesel generators at lower loads will also reduce the fuel efficiency of the generator. As a generator’s output is ramped down to accommodate higher levels of renewable energy – efficiency may drop 25% (e.g. from 4 to 3 kWh/litre) as illustrated in Figure 1.

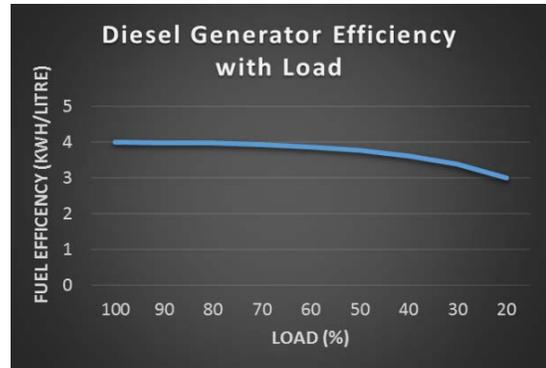


Figure 1: Efficiency with Load

Diesel generators with rated capacities that significantly exceed load – i.e. oversized systems – may already be operating at or near their minimum loading. This will limit the degree to which wind and solar may effectively contribute to the system, as illustrated for a 100 kW load in Table 1.

Table 1: Illustrated Impact of generator size on solar penetration for a 100 kW load³

Generator Rated Capacity	Minimum Loading (40% load factor)	Net Load Available to be serviced by solar ⁽¹⁾	Solar Power Penetration (instantaneous)
kW	kW	kW	%
150	60	40	40
200	80	20	20
250	100	0	0

(1) 100 kW load minus minimum loading required for generator

The number and sizing of diesel generator units employed and the use of appropriate cycling strategies can however help to optimize the degree to which wind and solar energy may contribute.⁴

- In 2004, Ramea, an island community in Newfoundland and Labrador integrated a medium penetration of wind into a system served by a diesel plant with three equally sized (925 kW) diesel generators. A snapshot of this project is provided in the Annex.

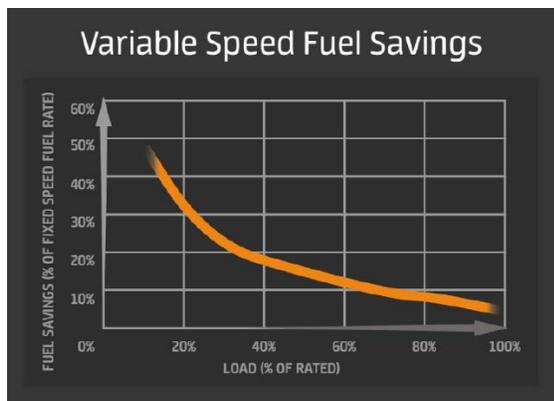
Control systems which include resistive loads and appropriate storage may also be used to optimize the overall efficiency and reliability of an energy system with conventional diesel generators, by balancing diesel efficiency and solar or wind generation.

Solar PV output can vary in the order of seconds to minutes, while wind turbines respond in the order of minutes. Diesel generators can be challenged to balance the generation from solar PV and wind in a timely manner – i.e. to generate electricity to meet the community demand not being met by the variable renewable energy source(s). There are technological means to mitigate these variations and slow the required response of the diesel generators. These include simple resistor load banks that can accept peak power output from the renewable generation. Solar PV advanced inverters can set a power production target that limits the power output or have slow ramp rate settings. Large wind turbines (1

³ <http://acep.uaf.edu/media/87693/SolarDieselGridHandbook.pdf>

⁴ [Diesel Plant Sizing and Performance Analysis of a Remote Wind-Diesel Microgrid](#)

MW and larger), have a similar capability to adjust their power output to a value that follows pre-set limits and they can also limit the rate of power increases. For systems utilizing energy storage, the storage can also dampen the cycling from PV and wind generators as noted further below.



Innovative diesel technologies such as Variable Speed Generators (VSG), while more complex, provide additional flexibility as they are able to ramp quickly and efficiently, and can operate more efficiently at lower loading points than conventional generators.

Figure 2 illustrates fuel savings from VSGs with changing loads relative to conventional diesel generators. This allows VSGs to support more efficient integration of higher renewables penetration in remote-grids systems.

Figure 2: VSG Fuel Savings with Load

- Northwest Territories Power Corporation (NTPC) is piloting VSG technology in Aklavik. In February 2018, NTPC announced the successful commissioning of the test unit, beginning a 1-year trial period to assess performance. A snapshot of this project is provided in the Annex.

The operational limits of a diesel-based power system coupled with variability of wind and solar energy sources can constrain effective penetration of these renewable energy resources. Wind-diesel systems without energy storage, for example, operating with continuous use of one or more diesel generators, may have to impose limits on energy that can be imported. This may in turn lead to renewable energy that must be dumped or spilled if the generator is operating at minimal loading and cannot be further ramped down.

Energy Storage

Energy storage is becoming an important component in the reliable operation of micro-grids, and increasingly so as the share of renewables grows. Technologies such as flywheels, thermal storage and batteries are able to respond very quickly to changes in demand, and can provide Essential Reliability Services (such as frequency support and reserve capacity) in ways that conventional diesel generators cannot. As needed, energy storage systems can act as a generation source or a demand source (depending on whether they are discharging or charging), and can adjust their output very quickly, allowing energy storage to contribute significant system flexibility.

- A battery system was installed as part of the diesel/solar hybrid power plant at Colville Lake in order to support higher solar penetration and plant efficiency. A snapshot of this project is provided in the Annex.

Storage systems in remote micro-grids provide power balancing and can be used to dampen or mitigate short-term variations in wind and solar resources as noted earlier. The variable power is directed into

the energy storage system which feeds out the power in a controlled manner. However they are not able to address the seasonal change in solar resources as discussed in the next section.

Advances in storage technologies and their application in remote power systems are expected to support increasing levels of reliable renewable energy penetration in future. Site specific applicability and associated constraints, as well as operational and maintenance complexity must also be considered.

Solar Generation

The annual solar resource potential in northern communities such as Clyde River, Nunavut corresponds to 70-90% of the annual potential of southern locations such as Ottawa. However, at higher latitudes its availability becomes more concentrated in summer months - and much less available in winter months, as seen in Table 2 and illustrated in Figure 3.

Table 2: Solar resource potential by location

Location	Latitude [°]	Mean Annual/Monthly Insolation [kWh/m ² -day]		
		Annual	December	June
Ottawa, ON	45°25'	4.38	2.66	5.24
Labrador City, NL	52°57'	3.93	2.61	4.40
Inukjuak, QC	58°45'	3.95	1.39	5.07
Whitehorse, YT	60°43'	3.51	0.70	5.15
Inuvik, NT	68°21'	3.27	0.02	5.69
Resolute, NU	74°41'	3.08	0.00	5.97

- Colville Lake’s solar array⁵ routinely generated over 300 kWh of energy daily in May 2016, averaging 54% of generation. In June 2017, generation averaged over 340 kWh/day. Declining daylight however, drives daily production averages below 1 kWh in December and January.

Solar energy and its seasonal variation creates periods of extended reliance on diesel, over weeks and months, that cannot be addressed through existing storage technologies.

Due to annual variability, the ability of Canada’s northern remote communities to achieve high penetration of solar energy faces barriers unique to Arctic communities. A remote community’s need for heat and power ‘peaks’ in the winter (i.e., the highest demand for heat and power occurs in the winter), which are often met nearly entirely with diesel. Thus, investments in solar may not necessarily reduce required investment in diesel *capacity*, however the overall volume of diesel consumed to *generate* energy throughout the year will decline (e.g., solar PV has great potential to displace diesel consumption). Further, solar and wind energy can be complementary, as times of optimum production from each may

⁵ https://enlighten.enphaseenergy.com/pv/public_systems/xrDs481206/overview posts daily production values.

not be aligned (e.g., it is often windy at night, in the winter and autumn, noted as times/seasons with low solar output).

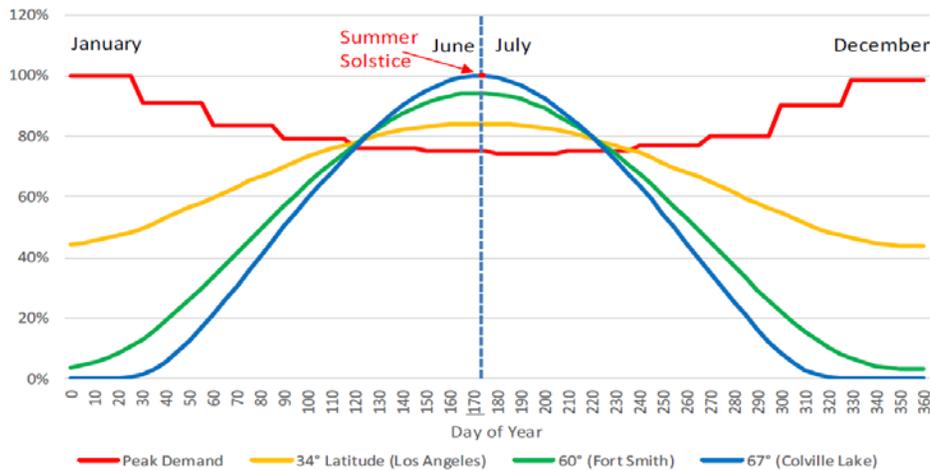


Figure 3: Peak Demand vs Solar Insolation - Courtesy of NTPC

Solar PV systems can experience very fast changes, in the order of seconds to minutes, to their power output caused by shading from clouds moving across the solar panels. In large solar PV systems, the accumulation of power output from many panels across a wide geographic distribution can dampen these variations. However, solar generation for most remote communities may be in the order of 100s of kW, which means fewer panels over a smaller area, and less inherent capacity to mitigate variable power output. As noted above, conventional diesel generators can be challenged to respond to these variations however solar PV advanced inverters can be used to set the power output or have slow ramp rate settings.

Solar PV has the advantage of few mechanical components, particularly for fixed panels. Advanced solar farms use panel systems that track the sun as it travels through the sky from dawn to dusk and, in the most sophisticated systems, as its height in the sky changes with the seasons. These tracking systems use mechanical actuating systems that require maintenance. Extra expense may be justified by the increased power output from the solar farm. It is less likely that solar tracking systems would be applied in northern and remote communities, as the increased power output would not justify the additional cost, increased maintenance demands, and associated reliability considerations.

Solar PV has few maintenance requirements however they must still be met. The primary reliability concerns are keeping the solar panels intact and clean, and ensuring the electrical power system components are durable. Regular inspections and cleaning of the solar panels address the physical concerns. The power electronics in PV systems have international and CSA standards that define their capabilities and good engineering in the project design will specify system components that meet the anticipated power and environmental conditions.

Solar PV generation can be an important technology for introducing remote and northern communities to renewable energy technology. Relatively small projects can be integrated with the existing diesel generation at displacement levels that are acceptable to the responsible local utility. As the utility and

the community learn of solar PV performance and reliability, it can be scaled up to further reduce diesel consumption.

Wind Generation

While wind energy is variable, wind turbines may produce energy year round, and therefore can mitigate the seasonal variation of solar experienced at higher latitudes. For any given turbine, power output is dependent on wind a speed, as illustrated in Figure 4, with high and low speed cut offs.

Wind turbines have mechanical systems and it is important that a project include a complete operations & maintenance (O&M) plan of scheduled maintenance that ensures a wind turbine’s availability⁶. Large wind turbine manufacturers typically provide availability guarantees, with consideration of availability up to or exceeding 99%.

Consideration for local capacity, specialized equipment (which could include cranes) and spare parts is critical to ensure reliable wind turbine operations and to maximize availability. Most of the well-established wind turbine manufacturers can provide “Long Term Service Agreements”, which carefully consider the needs and capabilities of their clients to ensure reliable operations. Such a plan could consider using a blend of local on-site labour and capacity, as well as specialized trades/equipment supplied by the manufacturer.

Large wind turbines sold in Canada typically include “cold climate packages”, which include features for operating at temperatures as low as – 40 degrees Celsius and the associated increase in air density, such as the Enercon wind turbines installed at the Diavik Mine in Northwest Territories. Wind turbines with cold climate packages may have heated blades to prevent ice build up, or cold temperature oils and lubricants, as well as heaters in the nacelle to ensure components do not freeze. Additional considerations associated with cold climate include worker safety and site access.

Large wind turbines (1 MW and larger) may also have the capacity adjust their power output to a value that follows pre-set limits and limit the rate of power increases in order to address ramping challenges as noted earlier.

Accurate forecasts become necessary as the wind penetration begins to increase to a point where it can affect reliability. As the penetration of renewables grows, other measures may also be needed to ensure reliable remote micro-grid operations. These measures can include, in addition to provision of an accurate forecast, storage, dispatching load (demand side management), and complex control systems to manage all of the various components of the integrated remote micro-grid power system.

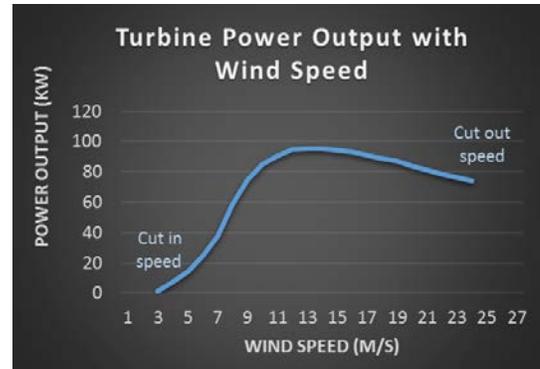


Figure 4: Illustration of Turbine Output with Wind Speed

⁶ Availability is the percentage of the time the wind turbine is available to produce power to the grid, within the operating wind speeds of the wind turbine.

Control Systems

Reliable and efficient integration of multiple components (e.g., diesel, storage, solar, and/or wind) within a hybrid system requires control or energy management systems (EMS) to dispatch generation assets and optimize overall system operation.

- Control systems when combined with storage technology can stabilize an electricity network by rapidly absorbing power surges from the renewable energy source, or by injecting power to make up for short term lulls, to maintain voltage and frequency within acceptable ranges.

These systems can become increasingly complex as additional components are integrated in remote micro-grid power systems; however, intelligent systems can also optimize power production leading to increased overall utilization of renewable sources of energy.

Reliable wireless networks and local capacity required to operate and maintain these systems further supports the reliable integration of clean energy into remote communities. Ultimately, a system must be understood in order to be managed.

Approvals and Agreements

Integrating renewable energy sources into a community's power system must meet certain requirements in order to ensure safety and the reliability of the overall system. Each province and territory maintains its own regulatory regime with approvals and technical requirements for North American-grid connected or remote micro-grid systems, as applicable. These may include periodic inspections as well as the need for protective devices to meet frequency, voltage, and other power control protection in the system, as well as safety requirements.

- Under the Government of Yukon's [micro-generation program](#), systems tied to the regional grid must meet required program approvals, while remote micro-grid systems must pass electrical inspection.
- For the Northwest Territories' [Net Metering](#) program, renewable energy installations must meet the requirements set out in the [Technical Interconnection Guideline](#), including compliance with the Canadian Electrical Code, safety standards, and required voltage and reactive power control.

All renewable energy projects that tie into local power systems also require interconnection and operating agreements with local utilities or distribution system owners. These agreements define responsibilities and ensure safety and electric reliability of the overall system is maintained. Jurisdictions or local system operators may need to define limits for project capacity in order to ensure they may reliability balance power generation and demand.

- The Government of NWT defines how much solar energy may be installed within a specific community in order to ensure electricity reliability⁷.

⁷ https://www.inf.gov.nt.ca/sites/inf/files/resources/solar_energy_in_the_nwt.pdf

- Nunavut’s Net Metering Program⁸ allows up to 10 kW renewable energy capacity to be installed per eligible customer, NTPC’s Net Metering Program in the Northwest Territories generally allows for no more than 15 kW⁹, and Hydro Quebec’s Net Metering Program for remote micro-grid communities generally allows for up to 50 kW¹⁰.

The utilities, which serve remote communities, may set a limit on variable renewable energy capacity in order to protect the overall system and its customers. However, as new technologies are introduced to the current electricity systems and are proven reliable, it is expected that capacity limits may be increased or the constraint removed altogether.

Summary

The integration of renewable energy resources into remote communities reliant on diesel is an overarching objective of governments, communities, and utilities alike. At the same time, for these communities that are not connected to the North American bulk power system, the reliability of their electricity system is paramount.

Low levels of variable renewable energy penetration, primarily solar PV, may be done reliably with limited modification to existing power systems. Increasing levels of renewable energy penetration, whether solar, wind, or hybrid systems that may include storage, can further reduce fuel consumption, but also require increasing system flexibility, controls, and associated resources and local capacity necessary to maintain reliable and efficient operations.

The addition of wind and solar resources to remote micro grids will reduce annual diesel consumption but will not replace capacity. To ensure reliability, the existing diesel capacity necessary to meet the demand on a remote power system is still required and must also be operated and maintained. This will likely remain the case for many years to come. Electricity storage or other technologies will need to develop to a state where seasonal variation of renewables for remote communities can be economically managed.

Regulated utilities and power providers remain responsible to provide accessible power to their customers and ensure that reliability is not compromised. As such, all clean energy projects need to meet criteria set by the utilities in order to connect to the remote grid or local power system. Agreements with local utilities will also clarify operating requirements necessary to maintain system stability.

Opportunities to integrate renewable energy resources into remote and northern communities unconnected to the North American electricity grid must be pursued in a manner that carefully considers and addresses the challenges of ensuring and maintaining electric reliability.

⁸ <https://www.gec.nu.ca/customer-care/net-metering-program>

⁹ <https://www.ntpc.com/customer-service/net-billing>

¹⁰ <http://www.hydroquebec.com/data/documents-donnees/pdf/tarifs-electricite.pdf> (Option III, DN)

Annex

A series of five snapshots of remote clean energy projects in Canada are presented which highlight electric reliability considerations for the integration of variable renewable energy in northern and remote communities.

Wind/Diesel Hybrid Power Plant

Location: Diavik Mine, Northwest Territories ~ 300 km northeast of Yellowknife
Access: Fly-in commercial operation. The annually constructed winter ice road is the world's longest heavy haul ice road.

*The world's largest wind-diesel hybrid power facility at a remote site
A leader in cold climate renewable energy*

Owner/Operator: The project was developed and is owned and operated by Diavik Diamond Mines Inc. Diavik is a joint venture between the Rio Tinto Group (60%) and Dominion Diamond Corporation (40%).

The system: Four 2.3 MW 100 meter high Enercon turbines, with a rotor diameter of 71 meters, provide a total capacity of 9.2 MW. Energy production of ~ 17 GWh per year is integrated into the mine's diesel-powered system with the objective of reducing diesel consumption by ~ 10%. The wind turbines, with gearless direct-drive design, are guaranteed operational to -40 degrees Celsius.

Status¹¹:

- The power plant was commissioned in 2012 at a total cost of \$31 million
- 90.8 GWh of energy produced and diesel offset of 22.1 million litres (Oct 2012 to Dec 2017)¹²
- For 2017, 17.2 GWh produced, 3.9 million litres of diesel offset, energy penetration of 9.2%

Key Reliability Considerations:

- Wind-Diesel hybrid plant reduces risk exposure of changing climate conditions – by reducing reliance on diesel which must be flown in if winter ice road access is limited.
- Power outages are a major concern as they present a risk of flooding to the underground tunnels and the challenge to re-activate instrumentation at low temperatures.
- Turbines specifically designed to extend operations from -30 to -40 degrees Celsius.
- Upgraded de-icing technology, lubricants post-commissioning to mitigate cold climate impacts.
- A specific grounding system required for the turbines to protect from lightning strikes in the permafrost environment.
- Using employees and people in the region, wherever possible, to plan, build, and commission the units provides expertise for troubleshooting, ongoing operation, and maintenance.

Additional Benefits:

- A three year renewable energy feasibility study confirmed the wind resources available.
- The meteorological tower used for the feasibility study was donated to Det'on Cho Earth Energy Giant Mine wind study.
- On mine closure, turbines with remaining service life will be donated to a local community.

¹¹ http://www.riotinto.com/ourcommitment/spotlight-18130_19357.aspx

¹² Rio Tinto Diavik Diamond Mine 2017 sustainable development report

Wind/Hydrogen/Diesel Research Project

Location: Ramea, Northwest Island, off the south coast of Newfoundland
Access: Via Ferry
Demand¹³: Population ~ 450, Peak load of ~ 1.1 MW, annual consumption of ~4,200 MWh

One of the first medium penetration Wind-Hydrogen Storage installations integrated into an isolated diesel system

Owner/Operator: Newfoundland and Labrador Hydro (NLH) is responsible for the community's electricity supply while Nalcor Energy leads the Ramea project. Frontier Power Systems (Frontier) installed a 390 kW wind farm in 2004. Frontier has a Power Purchase Agreement in place until 2019.

The system: 390 kW of wind energy (6 x 65 kW) was integrated into the existing diesel (3 x 925 kW) system and has been operating since 2004. In 2010 a hybrid system was installed including wind turbines (3 x 100 kW), storage provided by a hydrogen electrolyser, and a hydrogen fueled generator set, and an energy management system.

Status:

- 390 kW Wind-Diesel system provides ~ 10% of the system's electricity needs under a PPA between Newfoundland and Labrador Hydro and Frontier.
- Wind/Hydrogen/Diesel system commissioned in 2010/11 at a total cost of \$11.8 Million.
- From 2010 to 2015 the system produced approximately 680 MWh of renewable energy¹⁴.
- Plans are underway to add hydrogen fuel cells, expected to address current technical challenges, increase reliability and improve overall system efficiency.^{15, 16}

Key Reliability Considerations:

- Wind turbines were designed for northern and extreme environments.
- Without storage, less than 50% of the energy generated from wind may be absorbed and thus unlikely to meet more than 15% of the community's power requirements.
- Using storage, excess wind energy is utilized to produce hydrogen for future energy use
- Current storage system can meet the community's average load for 2 hours
- Effective integration of multiple energy sources identified as a challenge by Nalcor Energy

Additional Lessons Learned:

- Use commercially available technologies rather than one-off products to ensure reliability.
- Train and employ local personnel to maintain and repair equipment in order to reduce downtime associated with off-site personnel travel times to remote locations.
- Ensure appropriate spare parts and materials are available on site in order to reduce downtime due to logistics associated with access to remote sites.

¹³ Nalcor Energy 2010 Wind-Hydrogen-Diesel Energy Project presentation by Greg Jones

¹⁴ NL [Energy Plan Progress Report 2015](#)

¹⁵ NL [Hydro Dec 31, 2016 Q Report](#)

¹⁶ Nalcor NLHydro [2014 Annual Performance Report](#), June 2015

Variable Speed Diesel Generator/Solar Pilot Project

Location: Aklavik, Northwest Territories, 1.6 degrees above the Arctic Circle
Access: Fly-in community. Via barge or ice road only for large equipment
Demand: Population ~ 590 (2016), Peak demand ~ 560 kW (2017)

*Variable Speed Generator provides improved efficiency
and renewable energy integration*

Owner/Operator: The Northwest Territories Power Corporation (NTPC), a government-owned utility, owns and operates the generating station at Aklavik. NTPC's objective is to assess performance of the variable speed generator (VSG). The performance of the VSG will be assessed for one year, at the end of which the results will feed into decisions for further investment in VSG and variable renewable generation systems in the Northwest Territories.

The system: A 55 kW solar PV array feeds directly into the community's distribution system while a 590 kW converter-based Variable Speed Generator (VSG) platform provides the potential to integrate more variable renewable energy in future, without the need for storage. The Innovus Platform includes proprietary control system software.

Status¹⁷:

- The Project was successfully commissioned in February, 2018 at a total cost of approximately \$2.1 million, including purchase of the generator and platform, design engineering, project management and contractor installation and commissioning costs.
- A 1 year trial period is underway to assess the performance of the Innovus Platform.

Key Reliability Considerations:

- The Innovus Platform¹⁸ is reported to be able to run at very low loading conditions of around 10% of its rated capacity, to provide for fast start up capability, and a dump load to facilitate increased renewable energy (solar, wind) integration without storage requirements¹⁹.
- These characteristics could result in:
 - Increased operational life of generator engines
 - Increased reliable penetration of variable renewable energy
 - Reduced O&M and associated costs to maintain a less complex system

¹⁷ <https://ntpc.com/about-ntpc/news-releases/2018/02/16/variable-speed-generator-in-aklavik-successfully-commissioned>

¹⁸

<http://www.ppdiuc.com/presentations/The%20Future%20Backbone%20of%20Distributed%20Generation%20Power.pdf>

¹⁹ <http://www.innovus-power.com/wp-content/uploads/2017/09/WISE-Innovus-Feasibility-Release.pdf>

Solar/Diesel Power Plant with Storage Project

Location: Colville Lake, Northwest Territories ~ 50 km north of the Arctic Circle
Access: Fly-in community. Via winter ice road only for large equipment
Demand: Population ~ 150, Peak demand ~ 160 kW (2014)

A battery charged by solar energy to meet community needs during the summer

Owner/Operator: The Northwest Territories Power Corporation (NTPC), a government-owned utility, owns and operates the Plant. NTPC's objective was to replace end-of-life diesel generators, integrate renewable energy, improve generator efficiency, and reliably meet the community's growing demand.

The system: Installed in two phases, it includes 132.5 kW of ground-mounted Solar PV (330 fixed and 212 adjustable tilt panels), 200 kWh of battery storage, 3 (2 x 100 kW, 1 x 150 kW) fixed speed diesel generators and an energy flow management system. Components can be monitored remotely by both intranet and internet-based control systems.

Status²⁰:

- Hybrid plant commissioned December, 2015 at a total cost of \$7.97 million
- For 2017/18, total generation was 20% PV, 80% diesel, 38,337 litres of diesel fuel were displaced, and in July 2017, 53% of the community's power generation provided by solar and battery energy storage system²¹.
- Solar PV electricity production is tracked and can be seen [here](#).
- Plant preliminary diesel efficiency: 2.91 kWh/L (2014/15) to 3.76 kWh/L (2016/17)

Key Reliability Considerations:

- Maximum feasible PV integration calculated to be 136.5 kW in order to balance system efficiency, reliability, and overall footprint.
- Battery and control system provide increased overall plant flexibility and efficiency to manage variable renewables for a system operating fixed speed diesel generators.
- Total diesel generation capacity must be sized to meet full base load of community, however the number and size of the diesel generators provides flexibility to manage large seasonal variability of solar energy generation.
- Remote control enables off-site troubleshooting and updates - considered a 'must-have'
- Site secured to limit/avoid unintended damage or risk of vandalism
- Inspection and maintenance cost estimates included in project planning and financing
- Operator has capacity/resources to operate and maintain plant over long term.

²⁰ <http://www.nwtpublicutilitiesboard.ca/supporting-documents/ntpc-colville-lake-post-construction-report-exhibit-1619-phi-ntpc-x053>

²¹ NTPC correspondence to NRCAN, April 25, 2018

Independent Solar Power Producer Project

Location: Lutsel K'e, Northwest Territories, on the east arm of Great Slave Lake
Access: Fly-in community. Via barge or ice road only for large equipment
Demand: Population ~ 350 (2016), Annual demand ~ 1460 MWh (2012)

*The first independent solar power producer
in Canada's Northern Territories*

Owner/Operator: Lutsel K'e owns and operates the solar PV system as an independent power producer, and has a power purchase agreement with the Northwest Territories Power Corporation (NTPC). Ownership provides the community with revenue from the sale of the electricity.

The system: A ground-mounted, 35 kW solar PV array connected to the local power utility. The 144 panels, in 24 panel modules, are fixed tilt at 60 degrees. Each row of panels is connected to a separate inverter that is metered and feeds into the grid. The community's diesel capacity was reported as 820 kW (2012).

Status^{22,23}:

- Project successfully launched in 2016, with an estimated construction cost of \$350,000
- The expected annual electricity generation from the solar PV array is 39 MWh/year
- The array was sized at 20% of the community's power load however, given weather-dependency, the actual output may be closer to 10-15%.

Key Reliability Considerations:

- The system will run year-round however November to January are expected to be very low production months.
- The community developed relationships with a range of partners to ensure project success.
- The community worked with the Arctic Energy Alliance to issue requests for proposals and the selected bid included solar training for community members, and time in the local school teaching students about renewable energy and the new system.
- Providing training opportunity to a large number of community members helps to ensure a good community knowledge base
- Community ownership, economic benefits, and capacity building supports safety, ongoing maintenance, and reduced risk of vandalism

²² Pembina Institute Solar PV Case Study, Lutsel K'e Dene First Nation, Northwest Territories

²³ <http://www.cbc.ca/news/canada/north/lutsel-ke-power-business-1.3602415>

Glossary of Terms

Battery storage: represents a category of storage whereby electricity is stored in a chemical medium such as lead-acid, lithium-ion, Na-Ni, etc. Each medium has different trade offs with regards to cost, size, capabilities, discharge rates, etc.

Bulk power system: This term describes the interconnected North American electrical system, typically referring to electrical systems that fall within the responsibility of the North American Electric Reliability Corporation or NERC. In North America, the frequency of the bulk power system is maintained at approximately 60 Hz, although in practice, slight deviations from this, within acceptable limits, is expected.

Cut in and Cut out Wind Speed: these terms refer to the minimum wind speed at which the blades of a wind turbine overcome friction and begin to rotate (cut-in) and the wind speed at which the turbine blades are brought to rest to avoid damage from high winds (cut-out).

Demand response: Demand response refers to the ability to adjust the electrical demand of an interconnected load within an electrical system. Demand response can be implemented by the customer in response to price signals, or from the central dispatcher/utility in response to security constraints (e.g., when peak demand exceeds the combined capacity of the supply options to meet that demand).

Dispatch: a term used to describe setpoint signals sent to interconnected generators to bulk electricity systems, whereby the system operator requests changes to a generators output based on ever-changing system needs (e.g., load, outages, etc.). Generators will generally be dispatched based on their price offer for electricity and their ramp rate. The system operator will dispatch generators in real time using an economic dispatch model, but may “commit” generators in a day-ahead market based on forecasted needs.

Flexibility: A term that qualitatively describes a resource’s ability to adjust its output, and how quickly the resource can maneuver. Inherently, nuclear plants are not designed to adjust their output very quickly, however (modern) inverter based sources of generation such as wind or solar can adjust their output rapidly. Other sources of flexibility include demand response, some storage technologies and some conventional hydropower plants.

Flywheel: represents a specific type of storage whereby electricity is stored as mechanical energy. In the cast of flywheels, electricity is stored in a spinning mass with significant inertia.

Frequency: Electric power is delivered through alternating current (AC), which alternates at a *frequency* of 60 times per second (60 Hz) in North America and 50 Hz in Europe. Therefore, frequency is defined as the number of oscillations per second of the alternating current.

Inertia: When used in an electrical system, the term inertia is used to describe how well a particular grid can respond to deviations in frequency. Systems with high levels of inertia can typically respond to frequency excursions far quicker than systems that have low levels, or weak, inertia.

Integration: A term used to define the technical and operational process of adding sources of energy such as wind or solar to an existing electricity system. Wind and solar facilities are integrated into electrical systems using a variety of tools including forecasting, use of storage, leveraging/building flexibility (load or supply), modernization of market structures, etc.

Load: the term load refers to anything that consumes electrical energy and transforms it into other forms such as light, heat, work etc.

Micro-grids: Micro-grids refer to a collection of loads that are powered by smaller grids that are not interconnected to the bulk power system. Micro-grids are typically located far from large load centers, transmission systems or large sources of power generation, and therefore must meet all of their electrical needs using local resources. Historically most micro-grids in Canada relied nearly exclusively on diesel fuel for power and heat; increasingly, sources of renewable energy like wind and solar are being investigated to reduce the reliance on diesel fuel.

Operational mitigation of wind/solar plants (e.g., curtailment): Curtailment refers to a centralized control demand to temporarily reduce the output of a wind or solar plant in response to an event, such as excess capacity on the system coinciding with times of low demand.

Penetration: a term used to describe the percentage of load that is met by a particular resource, generally measured as the relationship between energy production (e.g., GWh) and energy demand (e.g., GWh). The approximate wind energy penetration rate in Canada is ~ 6 – 7% however, some regions, such as Prince Edward Island, have wind penetration values of ~ 25%. Denmark has the highest penetration rate for wind energy approaching 50%.

Ramp rate: A term used to describe the increasing or decreasing output of power from a generating facility, typically measured in MW/second or MW/minute. A fast ramp rate represents a more flexible source of energy relative to a source that has a slow ramp rate. Wind and solar generators can typically change their output very quickly, and most easily ramping down. In order to provide ramp rate increase capabilities, such facilities will have to hold back power below their maximum threshold in order to provide “room” to ramp up their power production.

Seasonal variation: A term used to describe how the output of a renewable source of power varies with seasons. “Diurnal” is a term used to describe the daily variation (typically between daytime and nighttime) of a renewable source of power.

Thermal storage: represents a category of storage whereby (typically) excess electricity from renewable sources of power is used to heat a medium (e.g., air, water, water/glycol, thermal bricks) for use at a later time. In some instances, thermal storage can provide significant flexibility to micro-grid operators that wish to offset significant portions of their generation.

Variable renewable energy: Sources of energy such as wind turbines and solar photovoltaic panels are considered renewable since the fuel needed to produce energy is unlimited; however, because the availability of fuel (wind and solar) can vary, the energy produced from wind turbines and solar photovoltaic panels will also vary. The use of the term “intermittent” is inappropriate, since this term implies either on or off, when in fact such sources are generally producing energy in between states of “on” or “off”.

Voltage: The voltage is a measure of the difference in electric potential between two end points. The voltage between two end points represents the amount of work that would have to be done in order to move the charge from one point to the other. The voltage between the two ends therefore represents the total energy required to move a small electric charge along that path, divided by the magnitude of the charge.

Wind turbine OEM: OEM is an acronym for “Original Equipment Manufacturer”, representing companies that sell completed wind turbines. The six most common utility scale wind turbine OEMs selling wind turbines in the Canadian market include (in no particular order), Acciona, General Electric (GE), Siemens, Vestas, Enercon and Senvion.