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Energy Benchmark Study for Northern Remote Microgrids

Nayeem Ninad, Dave Turcotte & Yves Poissant, CanmetENERGY, Varennes Research Centre

Background

Canada has a number of northern remote communities which mostly rely on diesel fuel for electricity and heating purposes. These communities are usually characterized by high electricity generation costs due mostly to the cost of transporting diesel fuel to remote locations and they also have environmental impacts by emitting greenhouse gases (GHG). These high costs drain financial resources either from bands or from governments offering subsidies. Most remote communities in the North are small but their situations are not necessarily homogeneous and neither are their community structures and priorities. Therefore, there is no one-size-fits-all solution to improve the energy efficiency and conservation in these communities. Even small improvements in the utilization of the diesel fuel consumption of these remote microgrids (isolated off-grid system) can have substantial economic and environmental benefits. As such the use of renewable energy technologies, i.e., PV and wind, can substantially reduce the cost of electricity generation and associated GHG emissions in these remote communities. However, even with the integration of renewable energy in the remote communities, a less than expected reduction in fuel consumption may be observed due to the improper sizing of renewables or absence of storage and energy management capabilities. Still the remote Northern communities are eager for solutions to remedy their dependence on diesel fuel for electricity generation and heating.

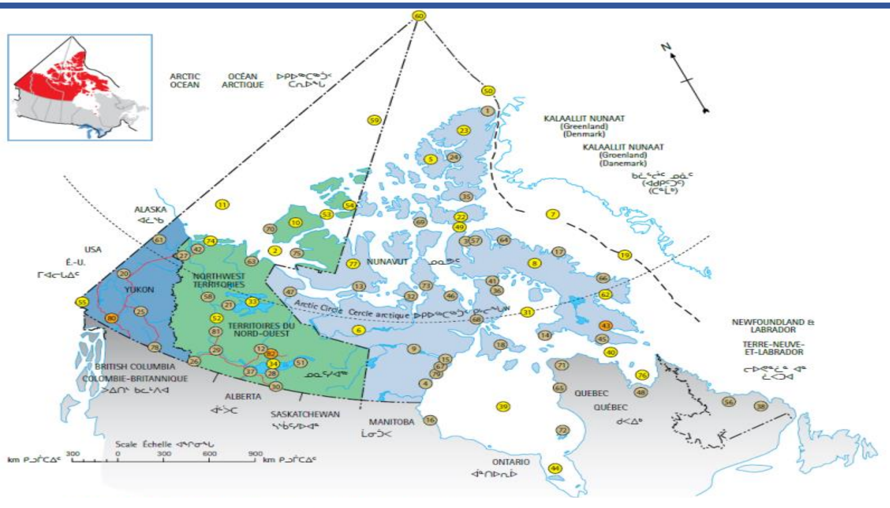


Figure 1: Canada's Northern Strategy Map

Objective

The main objective of the research project is to optimally design and operate remote microgrids and efficiently control and manage their loads and generation mix. This will help to increase utility acceptance, awareness and adoption of improved and cost effective techniques for optimally operating remote microgrids while lowering the risks associated with the integration of significant levels of renewable resources.
The optimal operation and energy management of a PV-storage-diesel hybrid microgrid for a typical northern community close to the Arctic Circle is investigated in this work. This region gets most of its solar insolation during the spring and summer months (the annual PV potential ranges from 850-1150 kWh/kW). A performance comparison is presented for conventional diesel-only, diesel-storage, PV-diesel and PV-storage-diesel hybrid microgrid scenarios.

System Description & Modeling

Microgrid Systems: The different microgrid scenarios are defined by the different combinations of diesel generators (two 100 kW units and one 150 kW unit), one 200 kVA 232 kWh Lithium-ion battery energy storage system (BESS) and a PV system (34.5 kW for the PV-diesel scenario and 136.5 kW for the PV-storage-diesel case).

- A multi-rate simulation model was developed for the different scenarios.
- The dynamic behaviour of components is neglected.
- Efficiencies of transformer and the power converter of BESS are assumed constant for different loading condition.

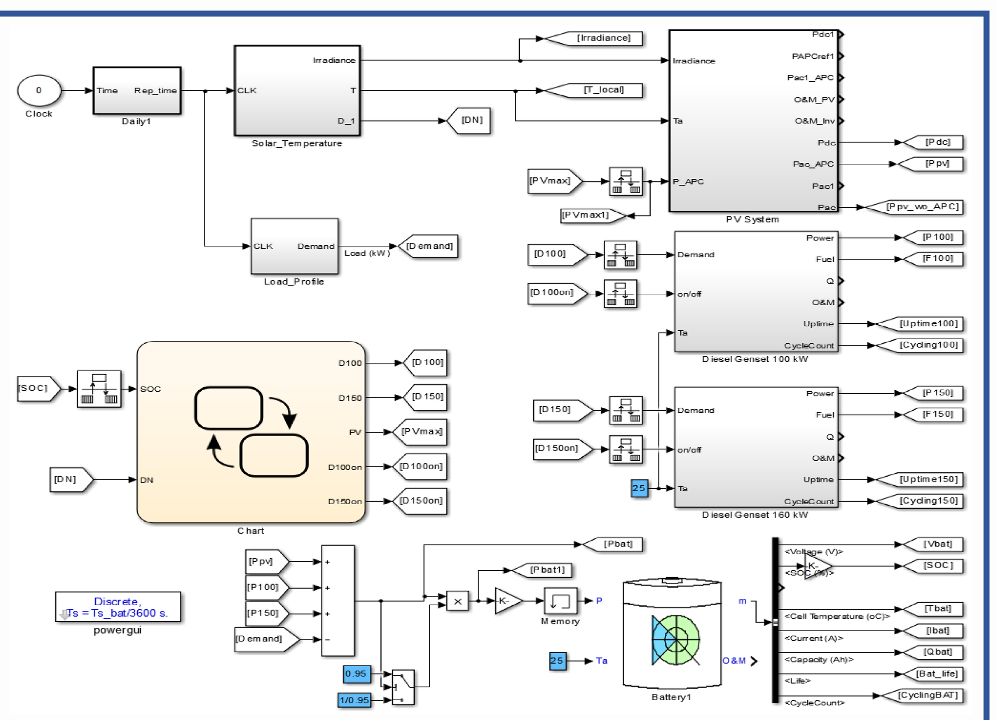


Figure 2: MATLAB-Simulink Model for the PV-Storage-Diesel Hybrid Microgrid Scenario

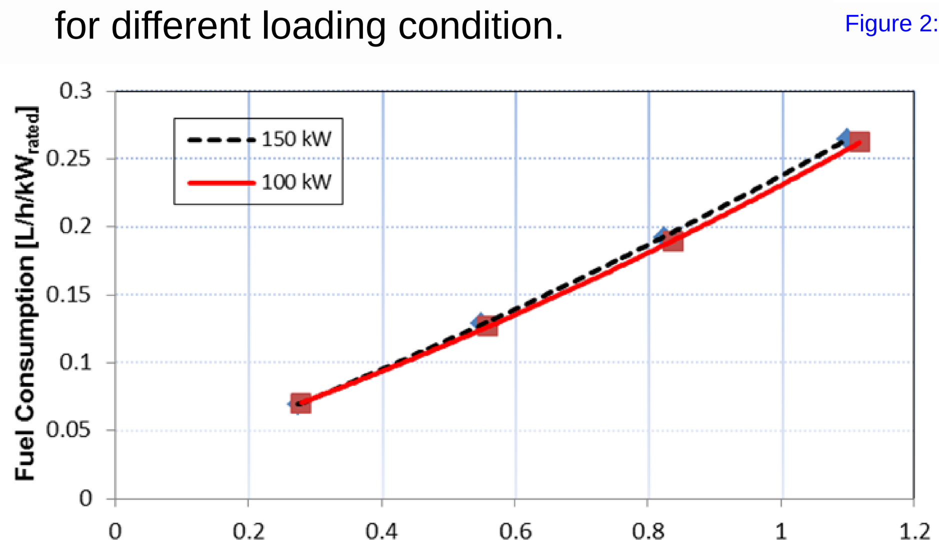


Figure 3: Fuel Consumption Characteristics for the Diesel Gensets

PV System :
• Modeled with PV modules and microinverters.
• PV module: Monocrystalline Si, MPPT.
• Inverter: calculates the AC power fed to or drawn from the grid, sleep mode during night time to reduce energy consumption, model includes CEC inverter efficiency.
• Power curtailment strategy: 0 - 82 kW for the 136.5 kW system and 0 - 34.5 kW for the 34.5 kW system.

BESS : 200 kW, 232 kWh Lithium-ion battery energy storage system (BESS). Based on the battery power and battery ambient temperature, it keeps track of the battery state of charge (SOC) and provides information on its voltage, current, cell temperature, battery maximum capacity, battery life and cycling measures.

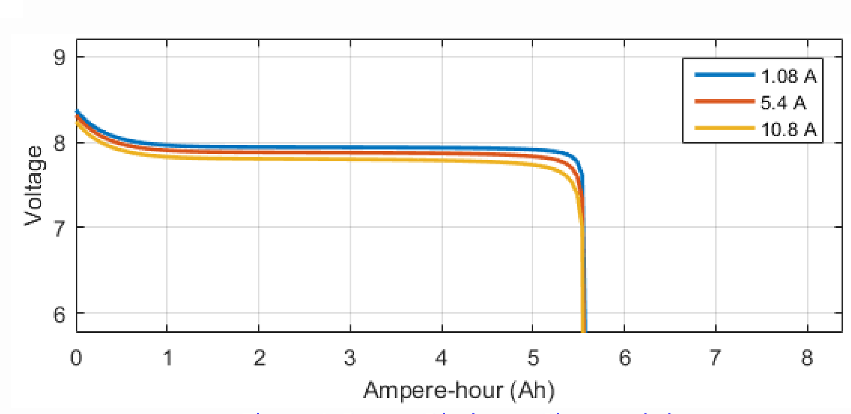


Figure 4: Battery Discharge Characteristics

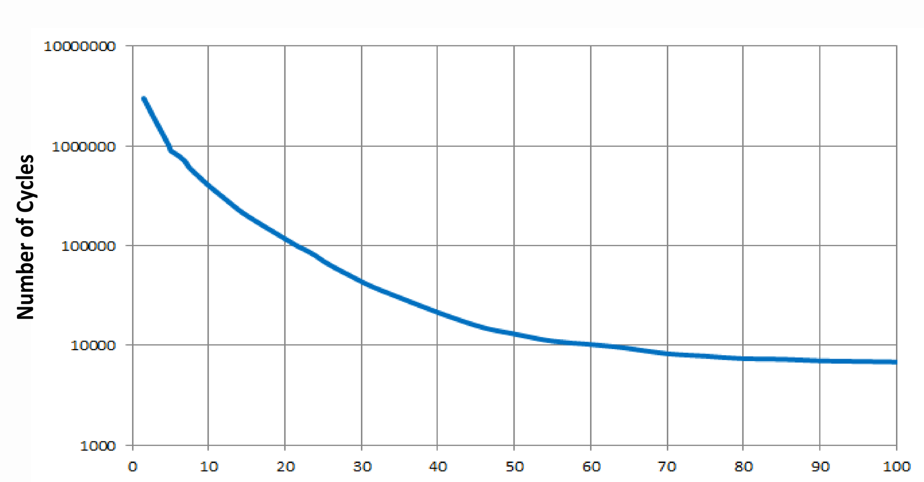


Figure 5: Cycle Life Characteristic with EOL=20%

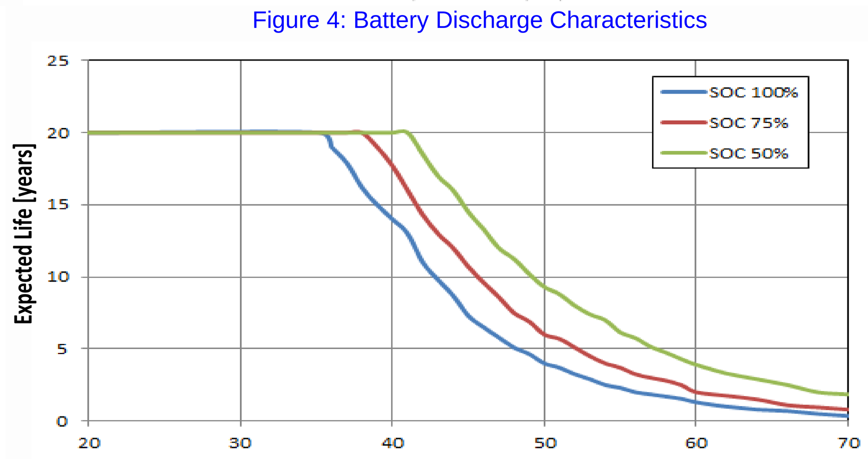


Figure 6: Calendar Life Characteristic with EOL=30%

Control System :
• Power curtailment is applied to 34.5 kW PV system to ensure genset operation above 30% of its capacity.
• Diesel-storage and PV-storage-diesel system
  ✓ The BESS operates in grid forming mode and the diesel gensets in base load mode when turned on to charge the battery and/or supply the load demand.
  ✓ When the BESS has high capacity with low net load, power curtailment is applied to the PV system.

Table 1: Dispatch in Diesel only and PV-Diesel Microgrid Scenarios

Capacity Change [kW]	Generator Combination (G1 = 100 kW,G2 = 150 kW)	Pickup / Dropout Power
100 to 150	G1 to G2	90 kW
150 to 100	G2 to G1	85 kW
150 to 250	G2 to G1 + G2	135 kW
250 to 150	G1 + G2 to G2	130 kW

Load Profile: A generic (historical) annual load profile for a small northern arctic community is considered. The average annual load is 50 kW and the peak load is 150 kW. The annual community energy consumption amounts to 610 MWh.

Weather Data: Generic annual solar irradiance data and the temperature data for the PV system were generated using WATGEN. A translational algorithm was used for computing the tilted irradiance at given locations.

Simulation Results & Performance Comparison

Baseline Comparison

		Diesel Only (D)	Storage Diesel (SD)	PV Diesel (PD) 34.5 kW	PV Diesel (PD) 136.5 kW	PV Storage Diesel (PSD) 136.5 kW
Energy production with respect to load energy consumption (%)	2X D100	82%	100%	79%	72%	75%
	D150	18%	2%	15%	14%	5%
	PV	-	-	6%	14%	22%
Total Fuel Consumption (x10³ L)		146	144	139	128	113
Annual Diesel 'off' operation hour			22%			40%
Fuel Savings			2%	5%	13%	23%
Diesel Plant Efficiency (kWh/L)		4.16	4.32	4.15	4.11	4.31
PV Energy curtailed				5.67%	42%	5.50%
GHG (x10³ kg)		399	392	378	349	307

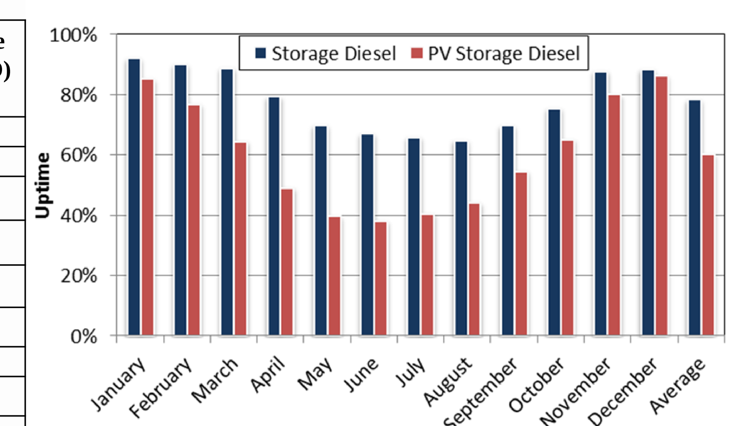


Figure 7: Uptime of Diesel Power Plant

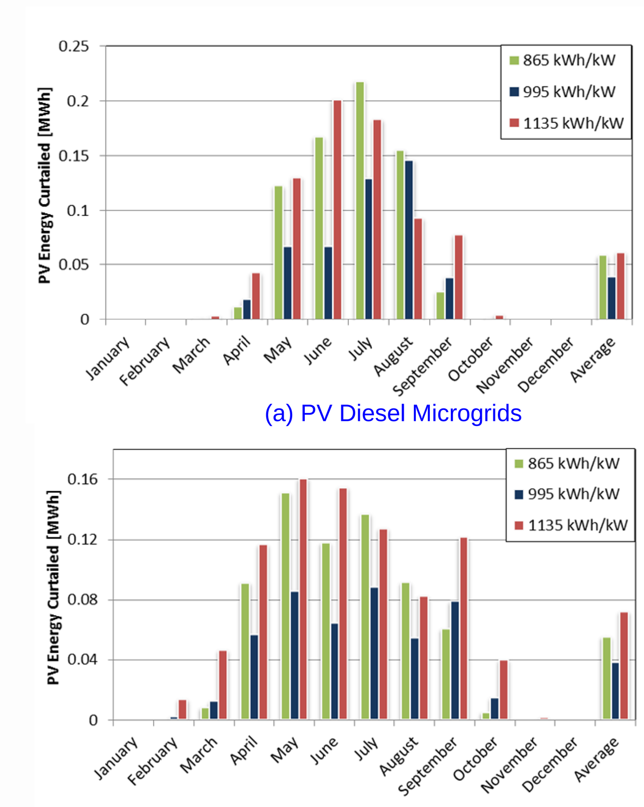
- As PV penetration increases, the energy contribution from the PV system increases. High penetration of PV in the PD scenario meets up to 14% of load demand and with storage, PV can provide 22% of load demand.
- As the PV energy contribution increases, diesel fuel consumption and GHG emission are reduced.
- Storage-based microgrid scenarios shows better fuel efficiency as they run the diesel gensets in base load mode close to their maximum capacity.
- Storage units allow diesel-off operation. During winter time with high load demand, fig. 7 shows small diesel off operation. During summer time, characterized by high PV production and low load demand, diesel off operation can reach as high as 62%.

Impact of Solar Potential

- Three different small northern arctic community with PV potential of 865, 995 and 1135 kWh/kW were considered.

		PV Diesel (PD)			PV Storage Diesel (PSD)		
PV Potential (kWh/kW)		865	995	1135	865	995	1135
Energy Production with respect to Load (%)	2XD100	77.9%	78.9%	79.0%	74.1%	74.6%	70.8%
	D150	16.6%	15.5%	14.2%	6.3%	5.1%	4.8%
	PV	5.5%	5.6%	6.8%	21.7%	22.4%	26.5%
Total Fuel Consumption (x10³ L)		139.0	138.7	137.0	113.7	112.6	106.8
PV Energy Curtailed		9.62%	5.67%	8.58%	9.40%	5.50%	9.79%

- The higher PV potential causes higher PV energy curtailment for both scenarios.
- The lower PV potential also causes higher PV energy curtailment as the location is further north in the arctic circle with high PV resource during summer days and almost zero PV energy during the peak winter months.
- The lower PV potential is associated with the maximum PV energy curtailment in July compared to other PV potential scenarios for both PD and PSD systems.



(a) PV Diesel Microgrids

(b) PV Storage Diesel Microgrids

Figure 8: PV Energy Curtailment

Impact of ±25% load variation in the small communities

		34.5 kW PV + Diesel (PD)			PV Storage Diesel (PSD)		
Scaling factor for load profile		75%	100%	125%	75%	100%	125%
Energy Production with respect to Load Energy Consumption (%)	2XD100	94.4%	78.9%	48.6%	76.4%	74.6%	56.3%
	D150	0.1%	15.5%	46.6%	0.0%	5.1%	26.5%
	PV	5.4%	5.6%	4.8%	27.1%	22.4%	18.7%
Total Fuel Consumption (x10³ L)		106	139	176	81	113	148
Annual Diesel 'off' operation hours		-	-	-	56%	40%	29%
PV Energy curtailed		32.1%	5.7%	0.01%	14.1%	5.5%	1.1%
GHG (x10³ kg)		290	378	479	220	307	403

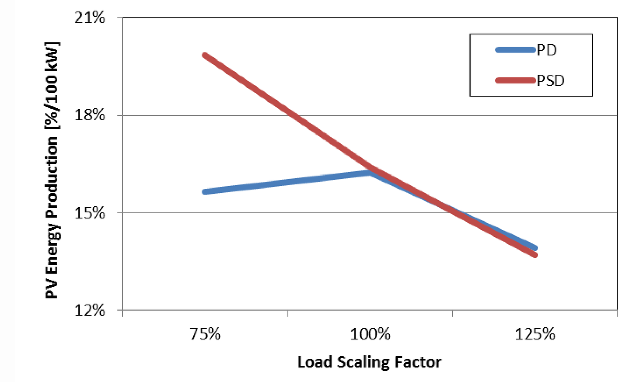


Figure 9: Per Unit PV Energy Production

- Load factor change from 100% to 125% decreases the PV energy contribution, as the net load increases, so less power curtailment of PV system is required.
- In the PD scenario as the load decreases from 100% to 75%, the system energy requirement decreases resulting in less contribution from the PV system with high PV energy curtailment (fig. 9).
- However, the presence of a battery in the PSD system allows the excess PV energy to be stored and used under the lower load profile scenario, therefore the PV contribution increases while curtailment decreases.

Conclusions & Future Work

The integration of a PV system can reduce the diesel fuel consumption and associated GHG emissions. With the addition of storage, these results can be further improved. However, storage technology is still costly and an economic analysis is required to assess the financial aspect of the project and compare it to conventional diesel-only and PV-diesel microgrid scenarios.

Project Team

- Nayeem Ninad (CanmetENERGY, NRCan)
- Dave Turcotte (CanmetENERGY, NRCan)
- Yves Poissant (CanmetENERGY, NRCan)
- Lisa Dignard-Bailey (CanmetENERGY, NRCan)

Acknowledgements
Financial support for this work was provided by Natural Resources Canada through the Program on Energy Research and Development (PERD).

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