Performance Analysis of the PV-Storage-Diesel Hybrid Microgrid of Colville Lake, Northwest Territories, Canada Based on One Year of Monitored Data

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Background

- Canada's northern remote Arctic communities are heavily dependent on diesel fuel for electricity generation
- Transportation of diesel fuel to remote locations significantly contributes to high electricity costs
- Electricity rates in the Arctic can reach 2.44 USD/kWh (rest of Canada: 0.05–0.13 USD/kWh)
- The community of Colville Lake in the Northwest Territories is the first high penetration renewable energy microgrid installed within the Canadian Arctic Circle

Photo credit: Northwest Territories Power Corporation (NTPC)

Objectives

- Evaluate the performance of a high penetration renewable energy system in Canada's Arctic
- Increase utility acceptance, awareness and adoption of high penetration renewables
- Optimize the operation of renewables for reduced diesel fuel consumption and GHG emissions in arctic conditions
- Reduce risks associated with the integration of significant levels of renewables
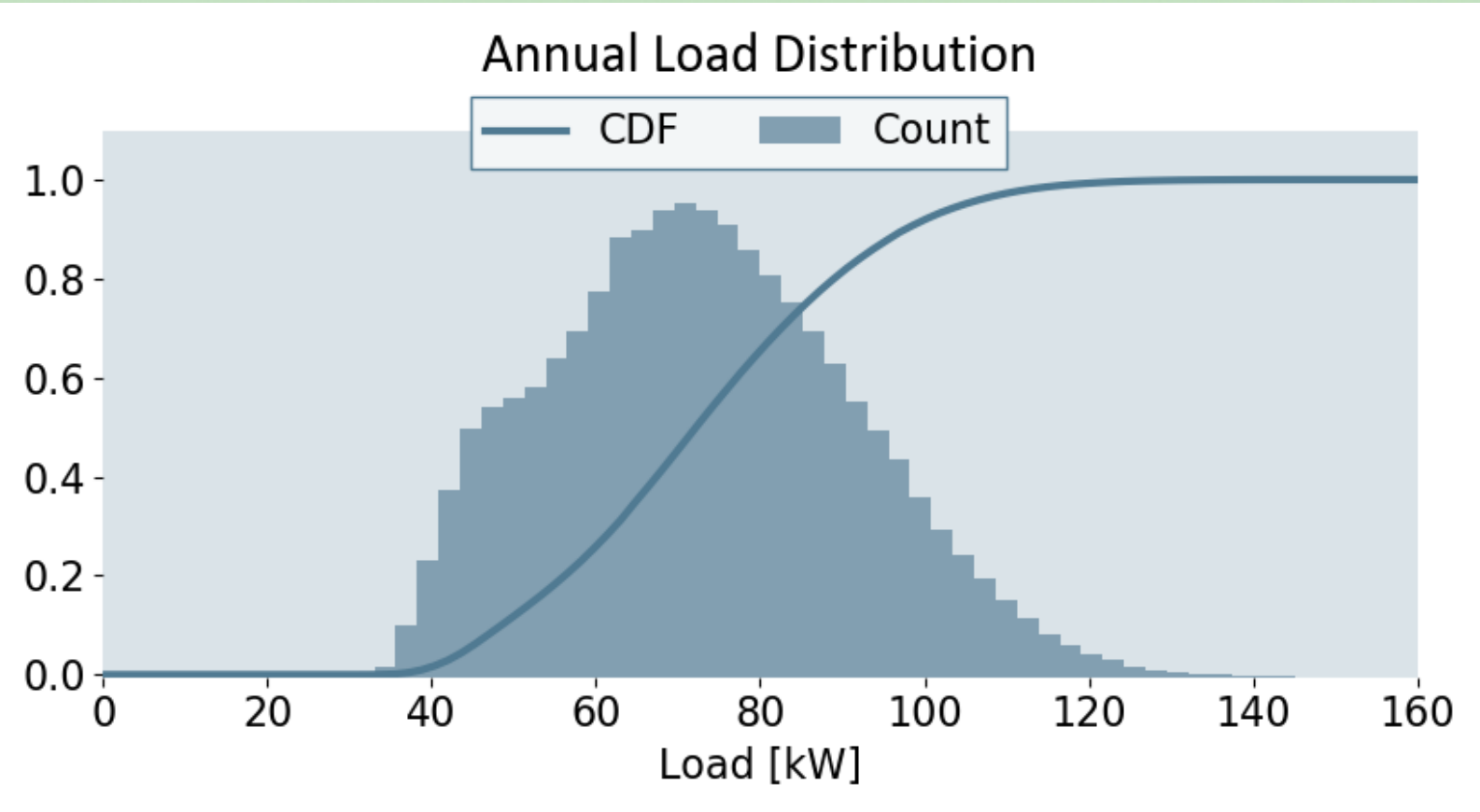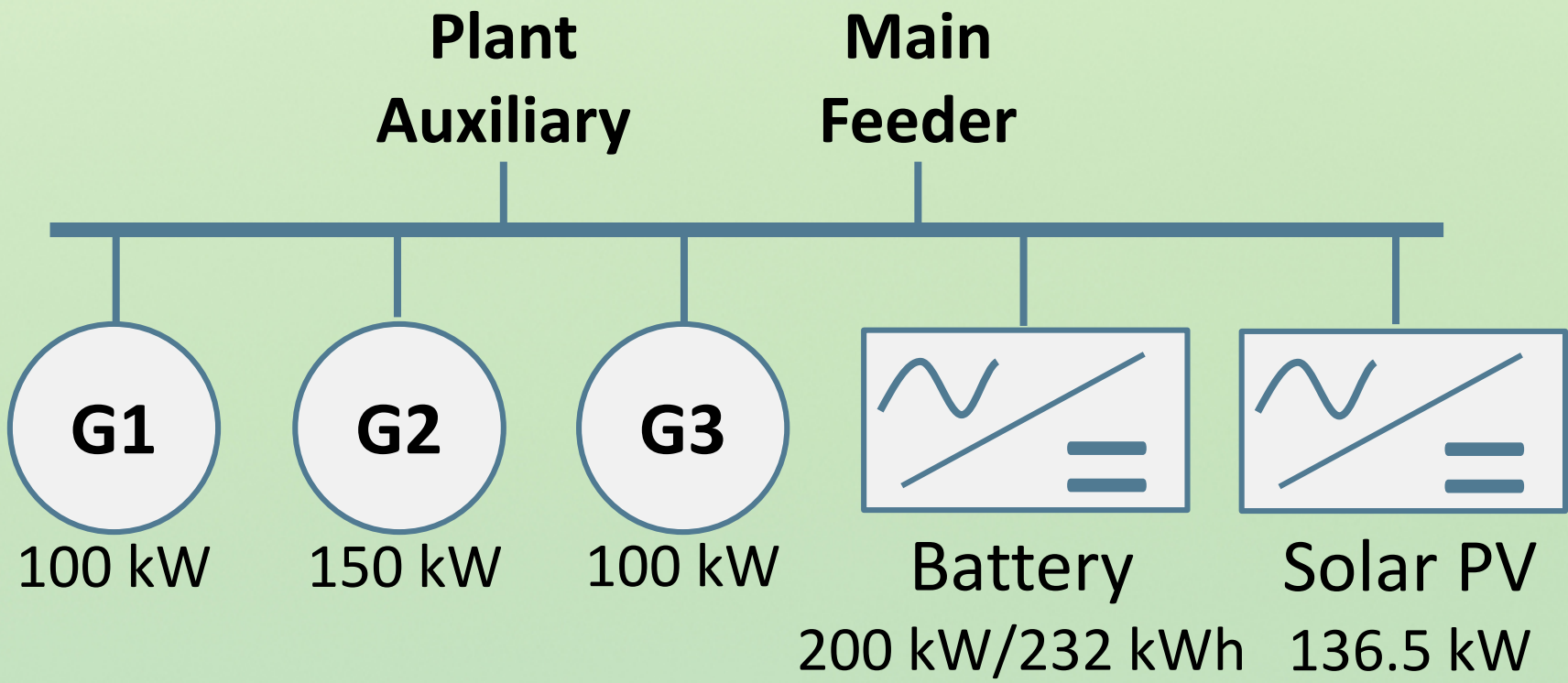
Power System Use and Control

System Characteristics

- Battery converter is grid-forming when in operation
- PV capacity can be curtailed in steps to reduce output power

Plant Auxiliary — Main Feeder

G1 100 kW | G2 150 kW | G3 100 kW | Battery 200 kW/232 kWh | Solar PV 136.5 kW

Annual Load Distribution

Community Load

- Peak load is 160 kW (73 kW avg., 30 kW min.)
- Annually, average power station consumption is ~10% of the system load

System Control Strategy

Few details about the control strategy are shared by the master unit controller (MUC) manufacturer. Therefore, a state flow diagram was reconstructed from the 2017 load data. This helped design a computer model of the microgrid for further performance analyses.
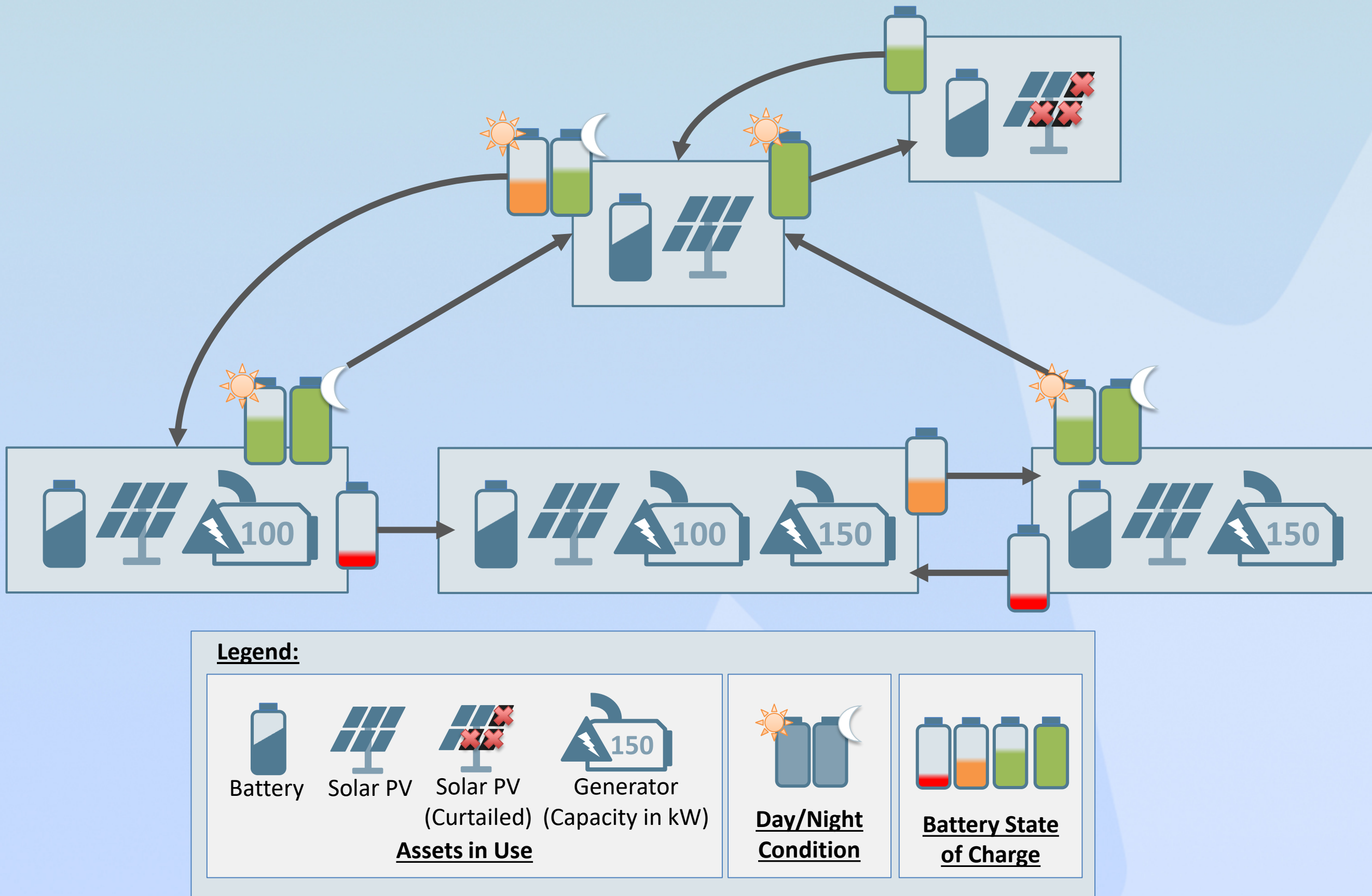
Inputs:
- Battery state of charge
- Day/night information

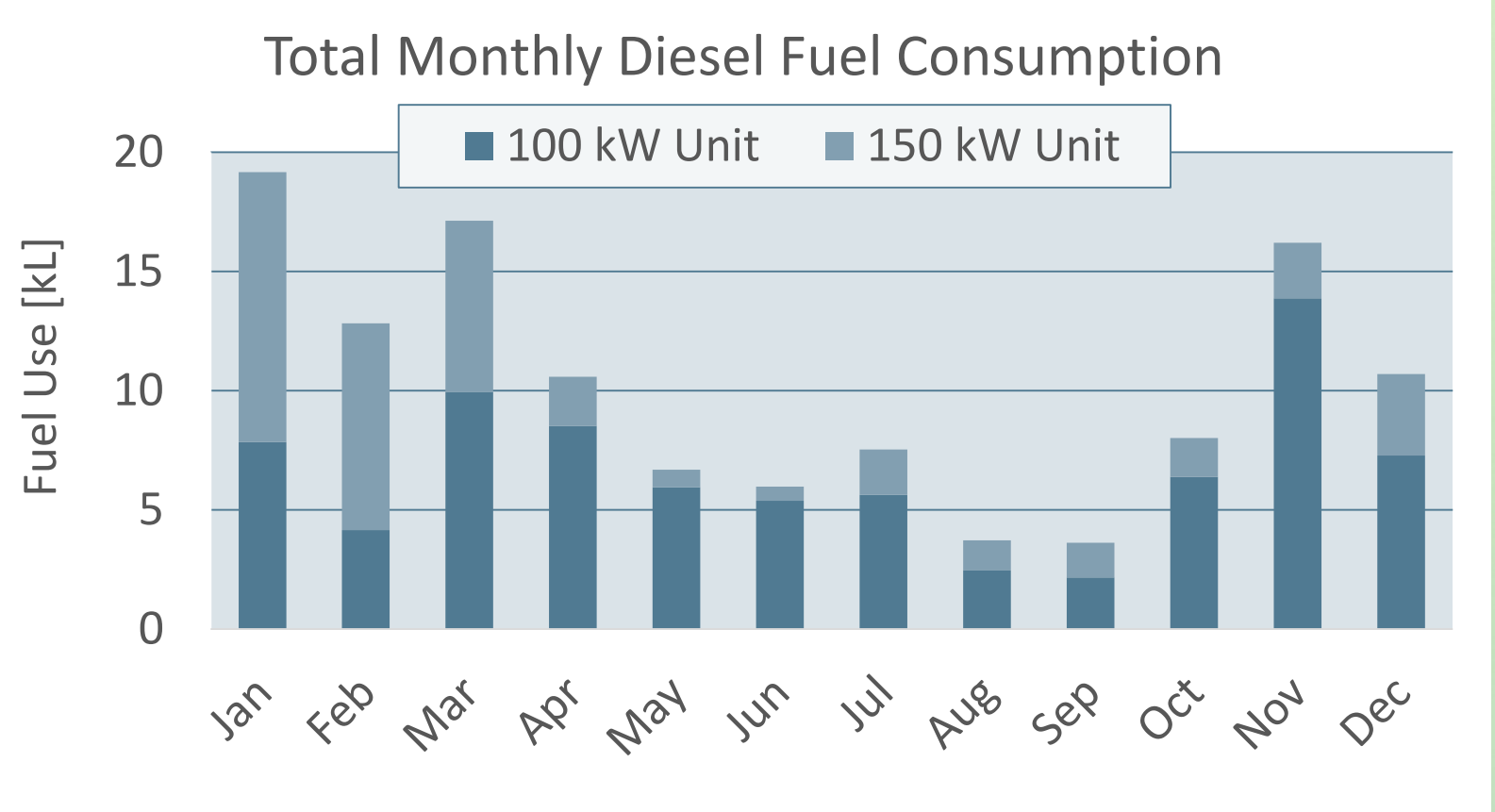Outputs:
- Generator set dispatch
- Solar PV curtailment level

Colville Lake Control State Machine

Legend:
Battery | Solar PV | Solar PV (Curtailed) | Generator (Capacity in kW)
Assets in Use | **Day/Night Condition** | **Battery State of Charge**

System Performance

Total Monthly Diesel Fuel Consumption

Diesel Generators
One-year performance is as follows:

	100 kW	150 kW
Fuel efficiency (kWh/L)	3.65	3.55
Uptime (h)	4,781	1,430
Cycles	1,174	301

Solar PV System

- Annual PV system yield including curtailment is 884 kWh/kW$_p$
- PV contributes to ~50% of May's total generation and 17% annually
- Curtailment peaks at 12% in May and June

Solar PV Generation and Curtailment
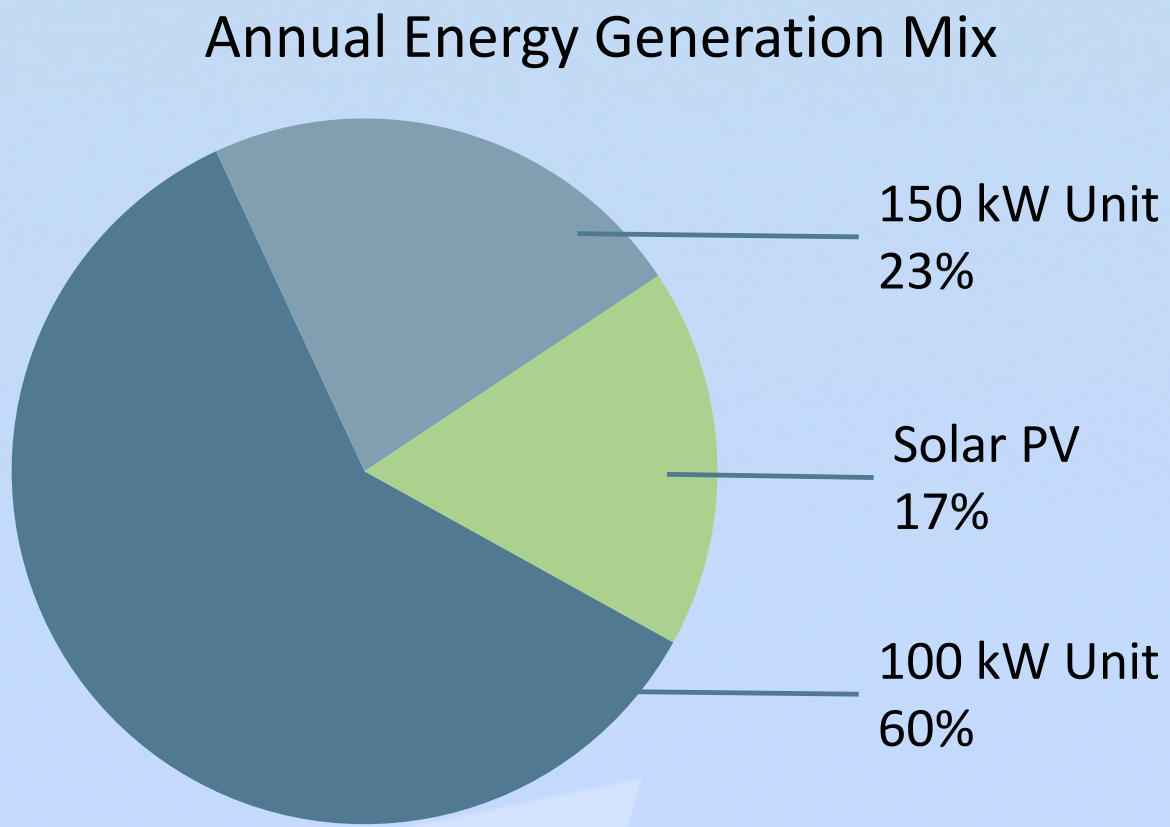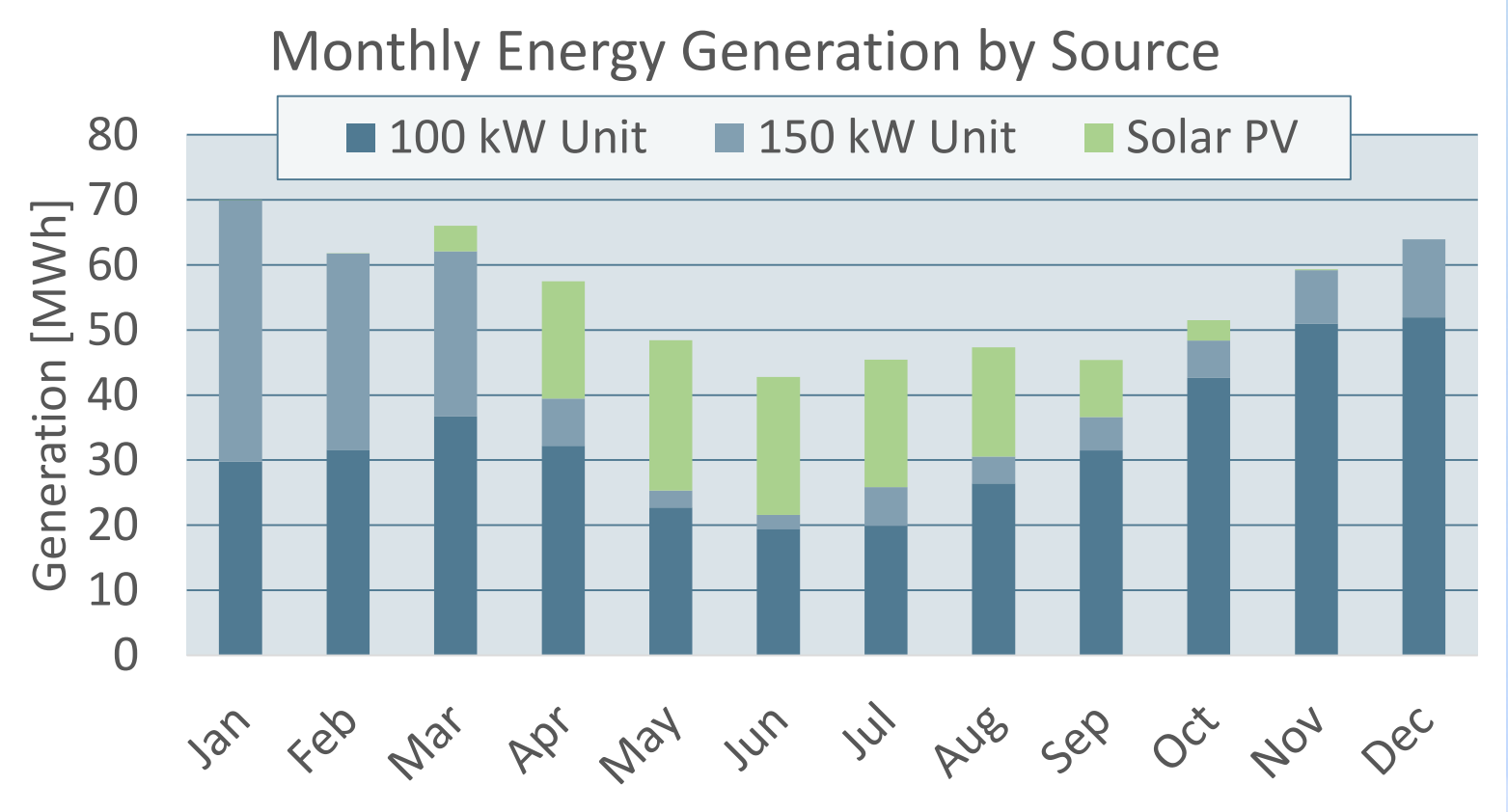

Annual Battery Power Distribution
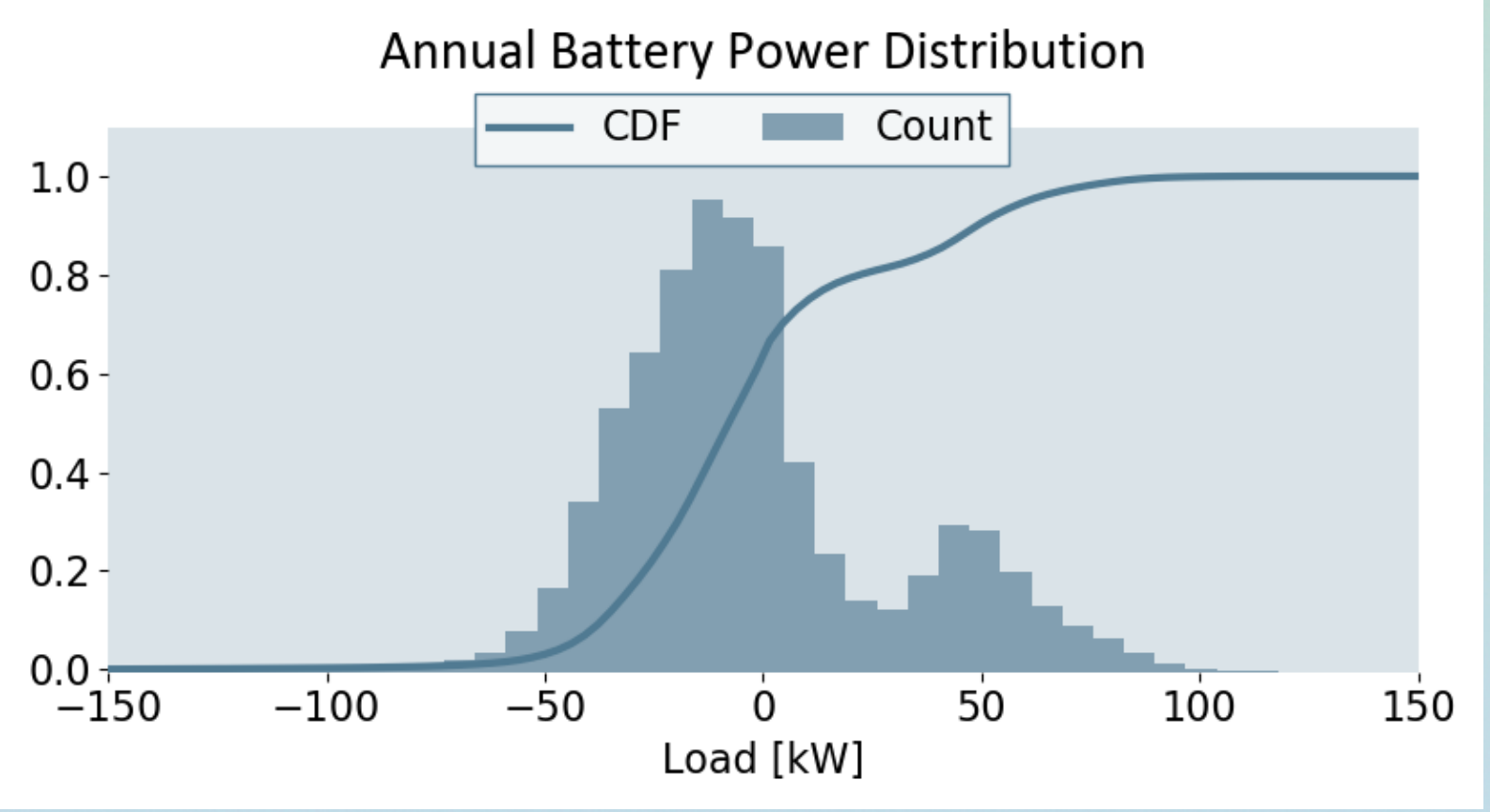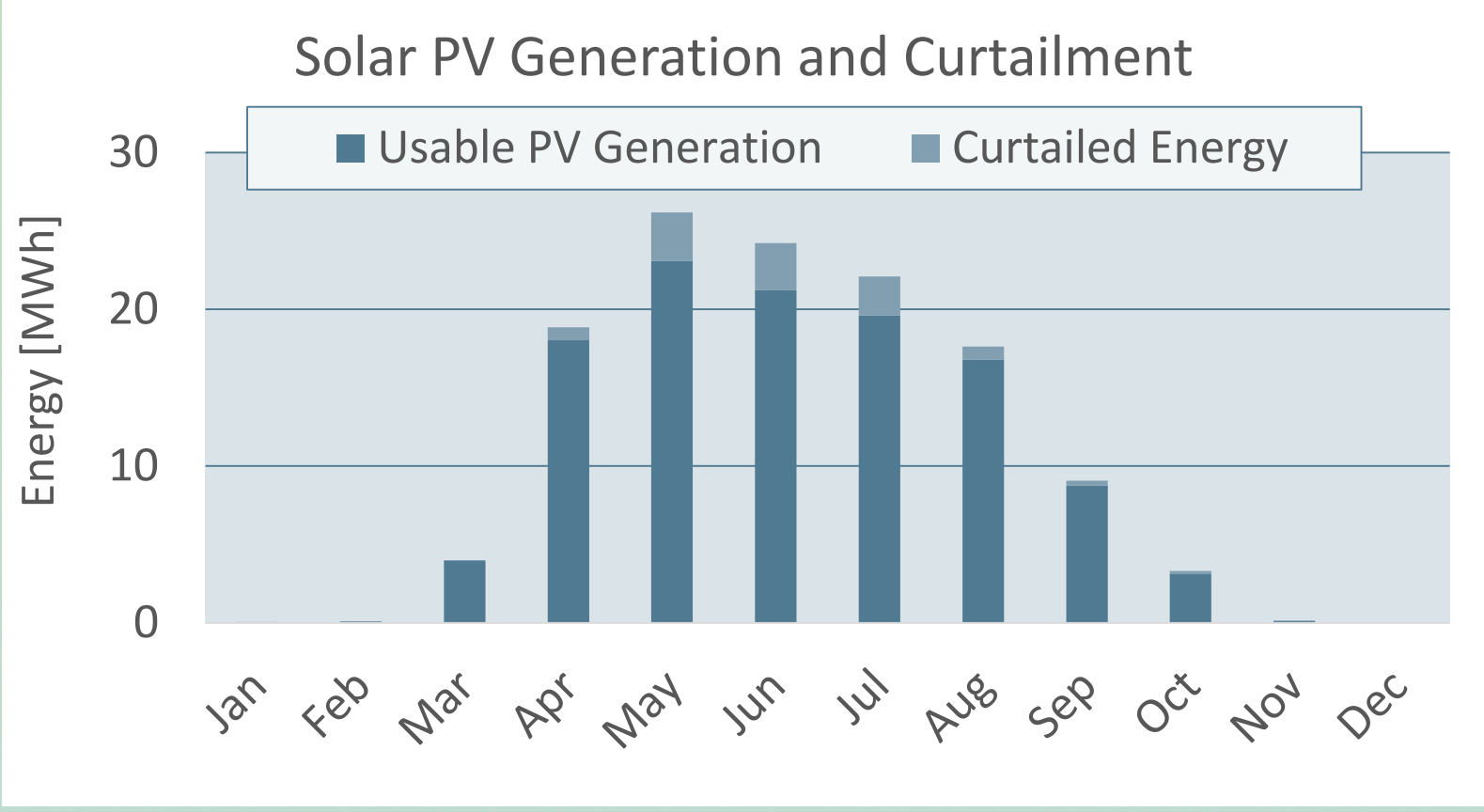
Battery Energy Storage System

- Battery use is higher during the summer months when solar PV is generating power
- Round trip efficiency is 83%
- Average annual converter efficiency is 98% (inverting) and 89% (rectifying)

Energy Analysis

- Total annual generation is 640 MWh with a total fuel consumption of 151,000 L
- Solar PV contributes to over 31,000 L of diesel fuel savings
- The transformer contributes to ~500 W continuous losses in the PV system

Monthly Energy Generation by Source

Annual Energy Generation Mix
150 kW Unit 23%
Solar PV 17%
100 kW Unit 60%

Conclusions and Future Work

- The hybrid PV-storage-diesel system has contributed to significant reductions in diesel fuel consumption and the associated GHG emissions
- Improvements to the control strategy could help in reducing solar PV curtailment and in optimizing generator efficiency
- Future work includes project life cycle analyses through better utilization of the battery and lowering of system costs (conventional & AI control techniques)

Canada