Introduction to Smart Microgrids in Remote Communities

Renewables in Remote Communities

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CanmetENERGY

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Microgrid Topography

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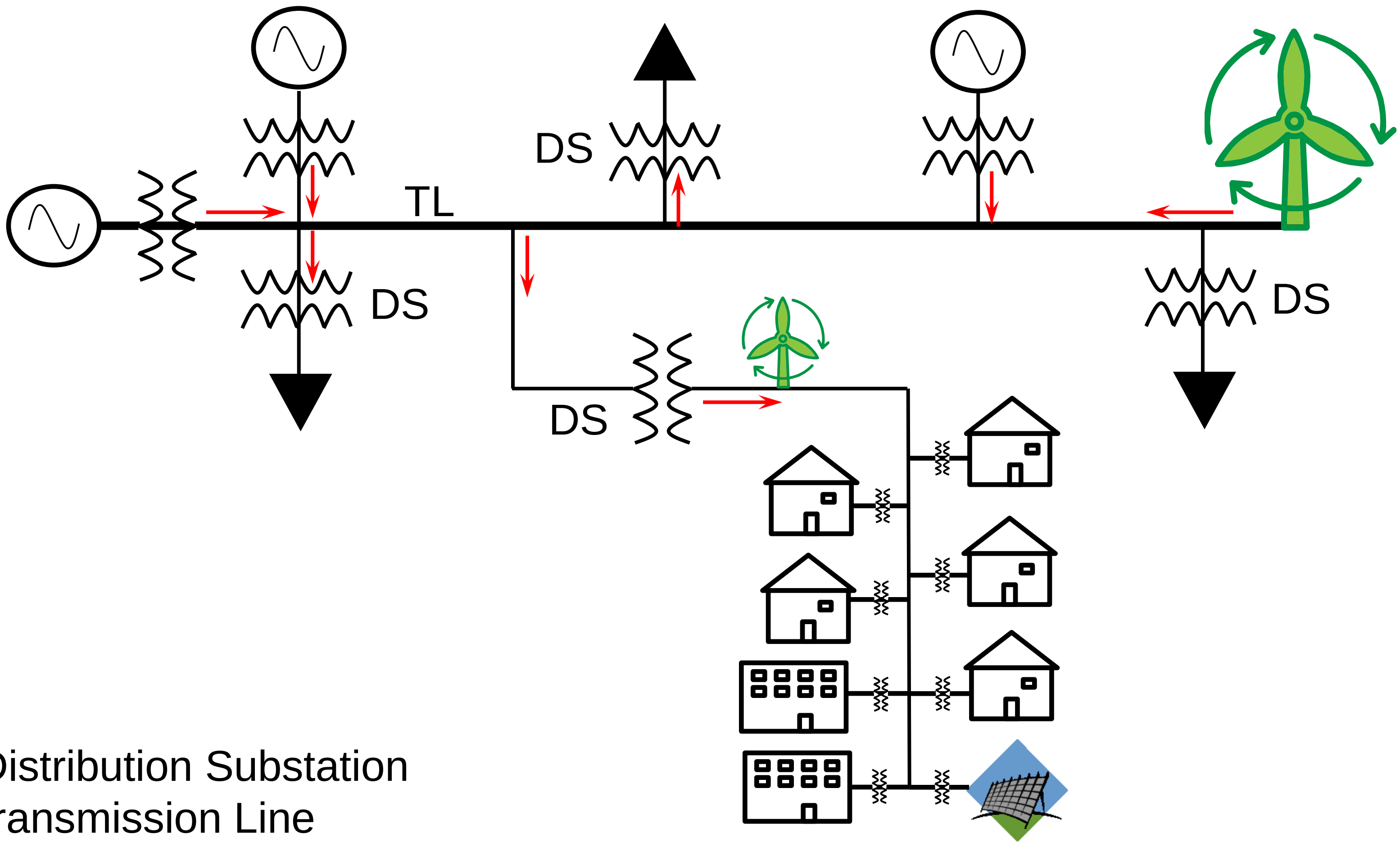
Bulk Grid Power Systems



DS: Distribution Substation
TL: Transmission Line

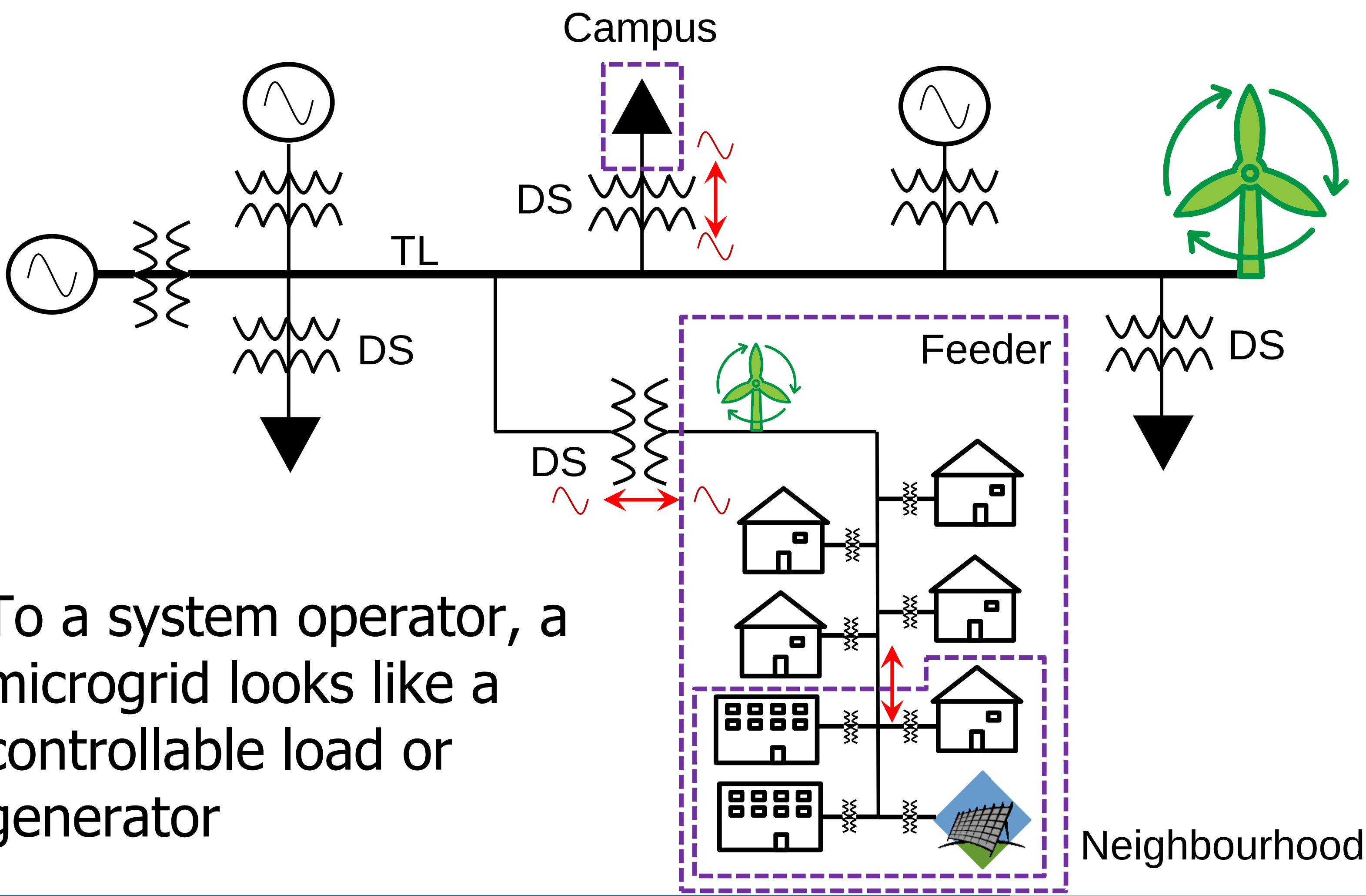
Bulk Grid Power Systems

- Power is mostly sourced from large generators
- Power flows from source to load (unidirectional)
- Advantages
  - Large sources are easy to scale
  - Many standards and codes/well established
- Disadvantages
  - Homogeneous customer/load base requiring high power reliability
  - Costly upgrades/not scalable
  - Lower reliability in some regions
    - E.g. remote, but grid-connected regions; developing countries

Microgrid Definitions

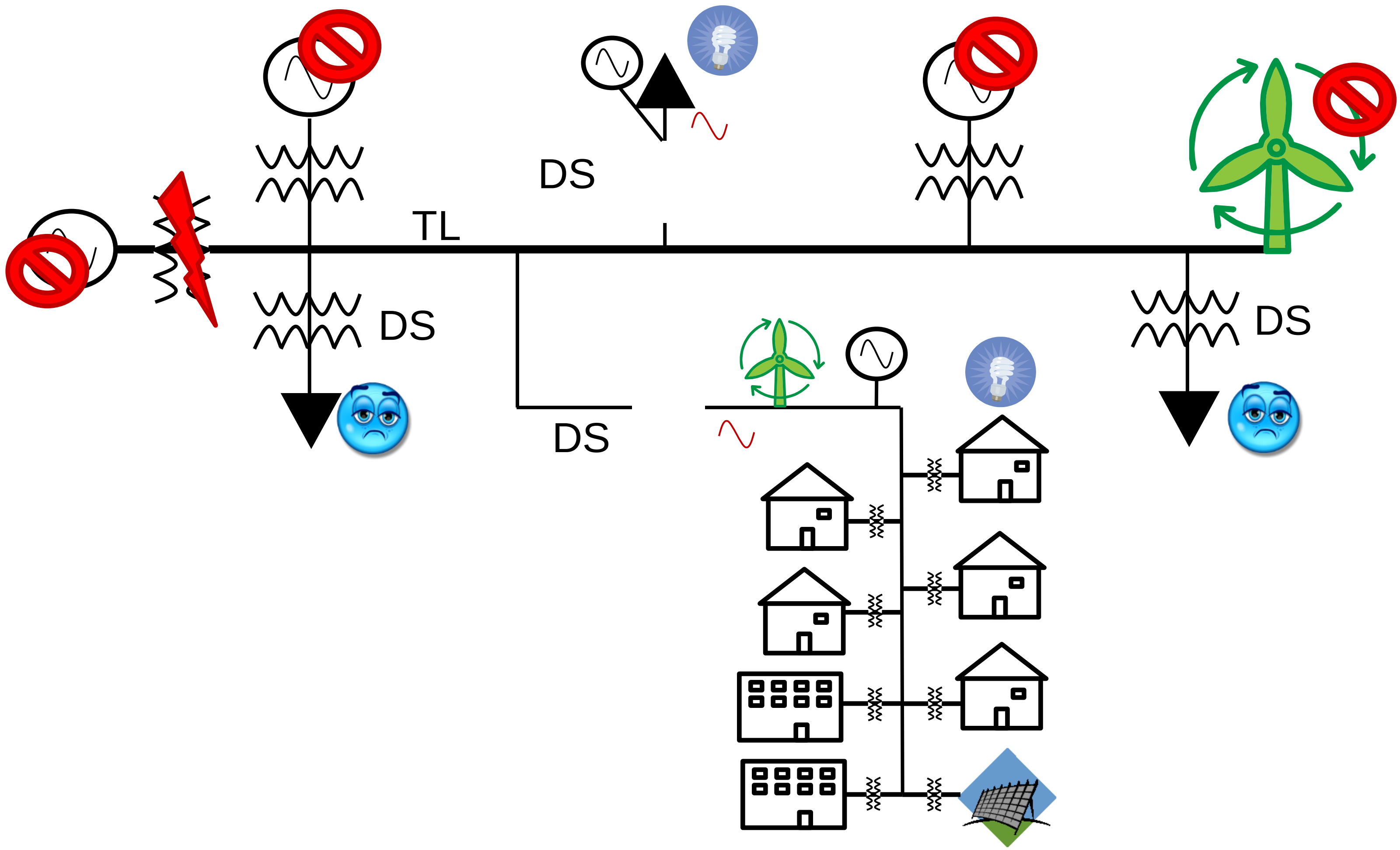
- *U.S. DOE:* A microgrid is a localized grouping of electricity sources and loads that normally operates connected to and synchronous with the traditional centralized grid (macrogrid), but can disconnect and function autonomously as physical and/or economic conditions dictate.
- *CIGRÉ Working Group:* Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded.

A Microgrid - Defining



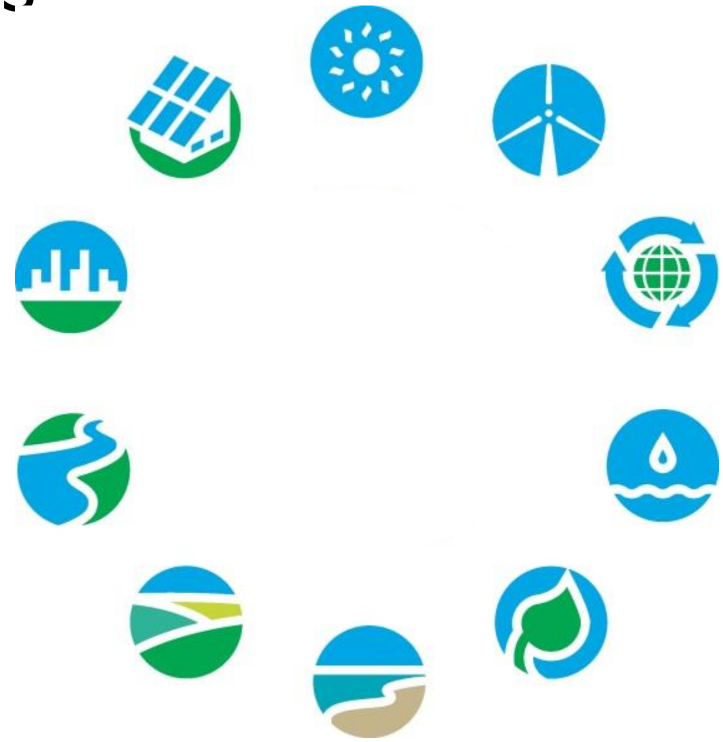
To a system operator, a microgrid looks like a controllable load or generator

A Microgrid - Islanding



Ideal Components of a Microgrid

- Distributed Energy Resources
  - Generation
  - Storage
- Flexible Loads
- Metering
- Control
- Protection
- Communications



Comparison

- How does this differ from a backup system, like what a hospital has?

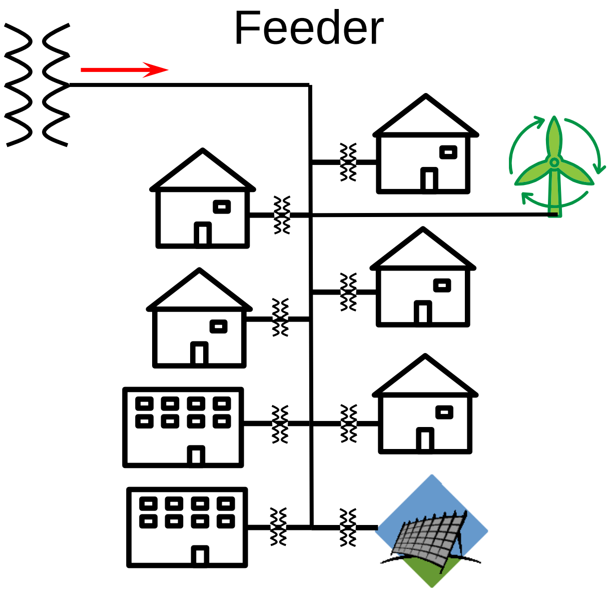
	Microgrid	Campus w/ Backup
Power System		
Bi-directional Flow	Possible	No (unidirectional)
Functionality	Controllable entity	Uncontrollable load
Generators		
Operation	Always on	As needed
Mode Switching	Seamless	Disconnect/reconnect (blip)
Loads		
Flexibility	High	Low
Primary Source	Grid/DER	Grid

Microgrid Features

- (Potential) Advantages
  - Fast installation (small generation quick to install)
  - Locally secure
  - Differentiation of electrical service possible
  - Allows easier integration of renewables
  - A good citizen of the grid
    - Predictable and controllable
    - Service provider
- Disadvantages
  - New concept, largely untested
  - Can be expensive
  - Challenges in integrating it with legacy systems
  - Work yet to be done in controls, operation, and protection

Microgrid Challenges

- Voltage Regulation
  - High impedance (weak) system, non-radial source-demand configuration, multiple sources
- Increased Harmonics
  - Weak system, non-radial source-demand configuration, multiple sources
- Maintenance Safety
  - Non-radial configuration poses complex maintenance strategy
- Increased Short Circuit Levels
  - Sources close to loads, feed from multiple sources



Microgrid Challenges

- Coordination of Protection Devices and Sensitivity
  - Multiple sources, de-sensitized radial protection schemes
- Impact from High Penetration
  - Multiple and complex sources are difficult to model, utility resistance to experimentation
- Islanding Control and Synchronization
  - Re-closure synchronization may be difficult with multiple generators, detection schemes may lack sensitivity
- Legacy infrastructure and government policy
  - Existing systems can be expensive to upgrade, existing government policy restricted to nearly homogeneous power quality

Microgrid Operation and Control

Operation and Control Outline

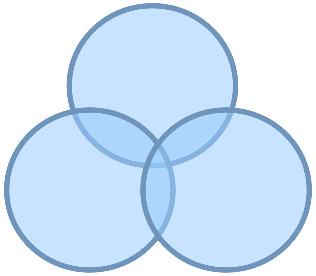
- Operational issues
- Controls
- Modes of operation
- Central controller / Intelligent agent

Operational Issues to Consider

- Stability (momentum and firmness)
  - Constantly changing demands may not match generation capacity
- High impedance
  - Voltage issues and feeder upgrades are required
- Synchronization
  - Solid communications is required for all DER
- Transients
  - Microsecond speed events can resonate system

Control Aspects

- Distributed Energy Resource Control
  - Coordinates demands with generation (P,V,Q Control)
  - Fast response to disturbances
  - Power and voltage control - load changes without relying on communications
- Energy Management
  - Dispatching of power and voltage set points to each microsource controller
  - Demand response to load balance (instant and forecasted)
  - Minute timescale
- Protection
  - Unique solutions to match network
  - Use of power electronics for DER

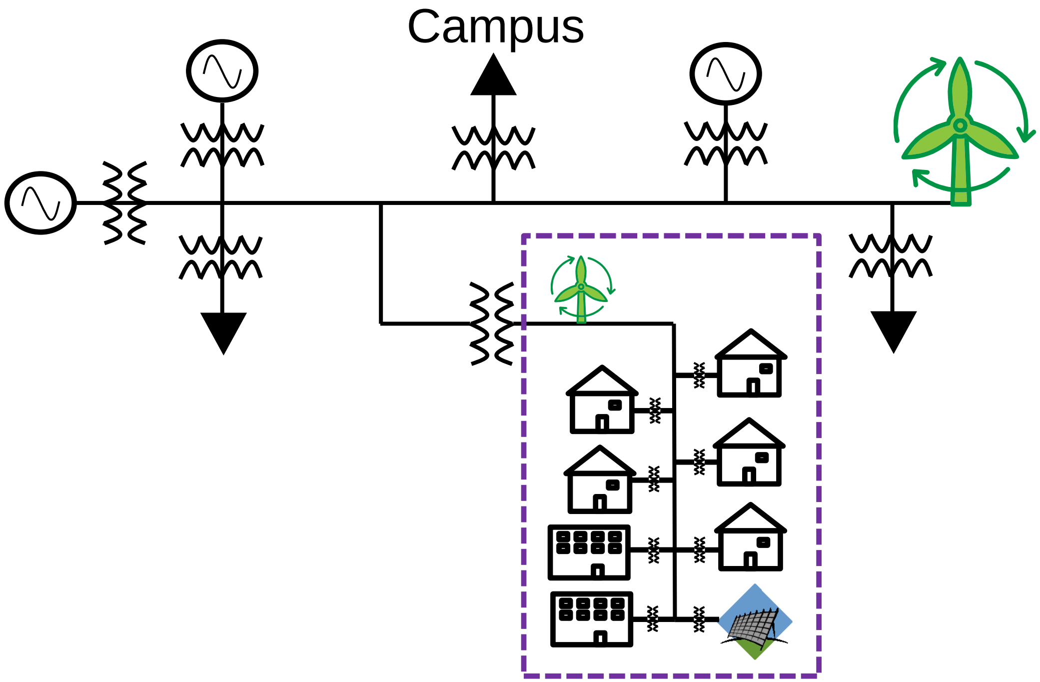


Control Aspects – System Parameters

- Demand
- Voltage
- Frequency
- Efficiency optimization

Modes of Operation

- Grid connected
- Islanded
- Transition mode



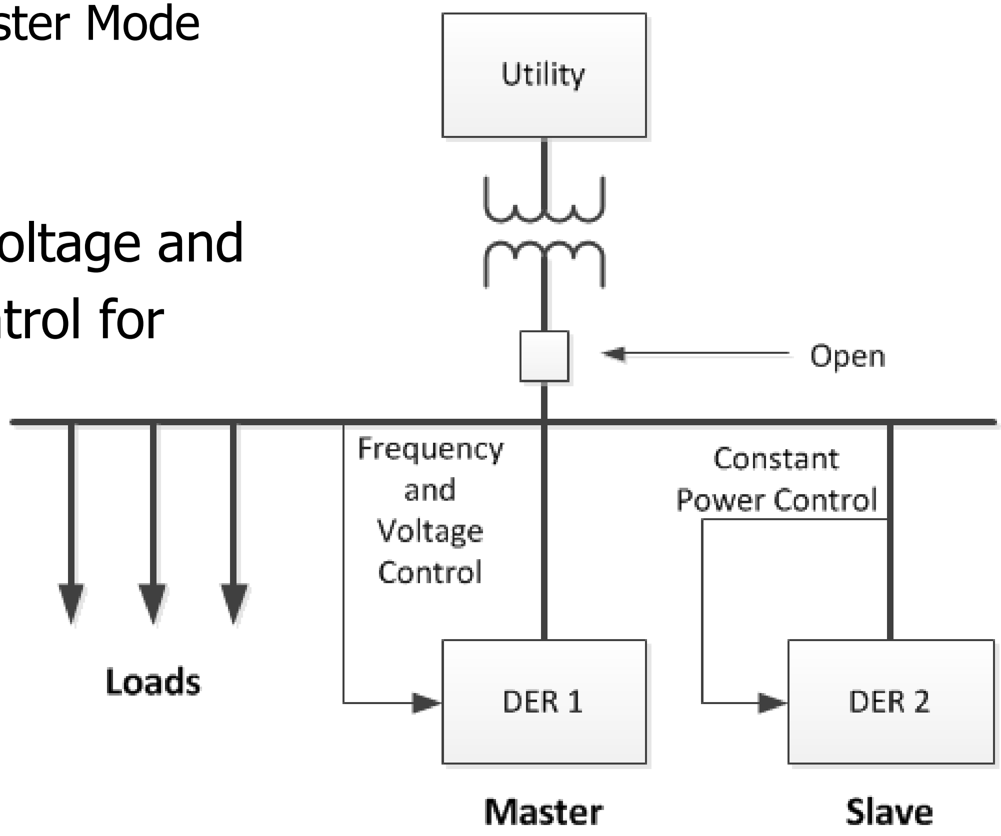
Modes of Operation and Control

Many options for control to consider for each mode

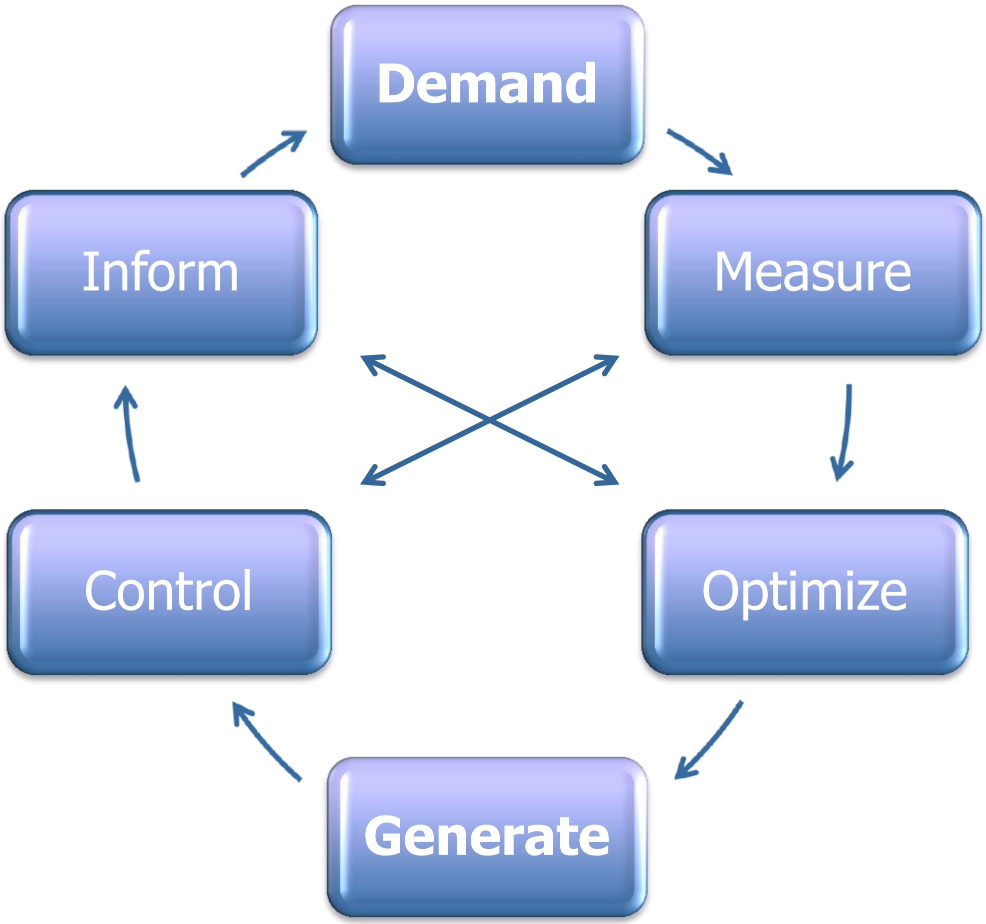
- Grid Connected Mode
  - Constant power mode for all DERs

Modes of Operation and Control

- Islanded Control Options
  - Master/Slave
    - DER 1: Transfer to Master Mode
    - DER 2: Slave Mode
  - Active Load Sharing
    - All DER transfer to voltage and frequency droop control for P and Q supply



Intelligent Agent



Advanced Systems and Control

- Communications
  - How fast is fast enough?
  - Wire/Fibre/Wireless
- Information System
- Grid/Load Controls

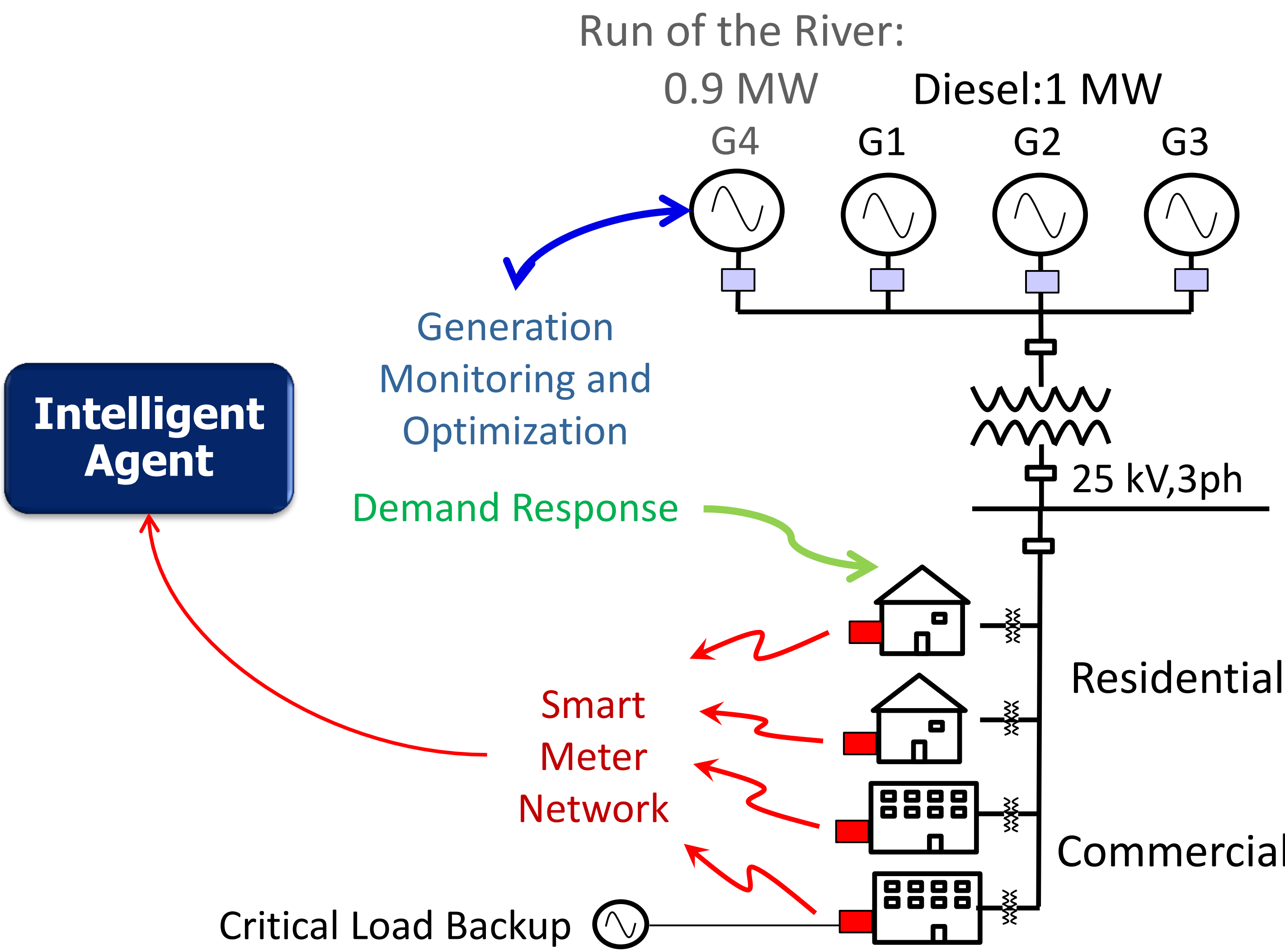
Intelligent Agent

Approach to Systems and Control

Dependencies

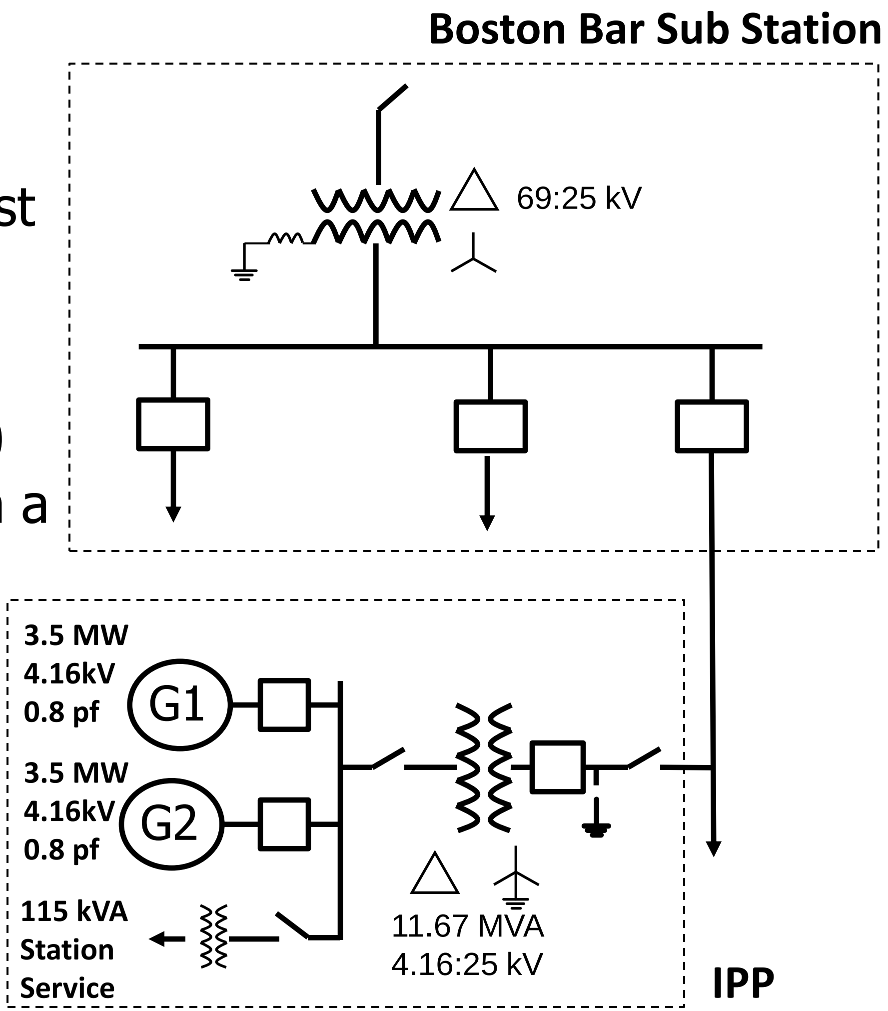
- System
  - Measurement systems?
- Economics
  - To generate or change demand: are they different ?
- Reliability
- DER Types
- Optimization (planned, real time)
  - Demand forecasting
  - Energy forecasting

Approach to Systems and Control



Case Study: Boston Bar

- Background
  - Town of ~850 persons located off the Trans-Canada Highway/Fraser River north-east of Vancouver
- Power System
  - BC Hydro grid-supplied by a 60 km, 69 kV line running through a steep canyon that is frequently subjected to rockslides, mudslides, storms, etc. that frequently knocks out power
  - Nearby independent power producer (IPP) hydro-plant, 8.3 kVA



Case Study: Boston Bar

- Solution
  - Planned islanding of load (from BC Hydro grid) so that it can be fed from IPP

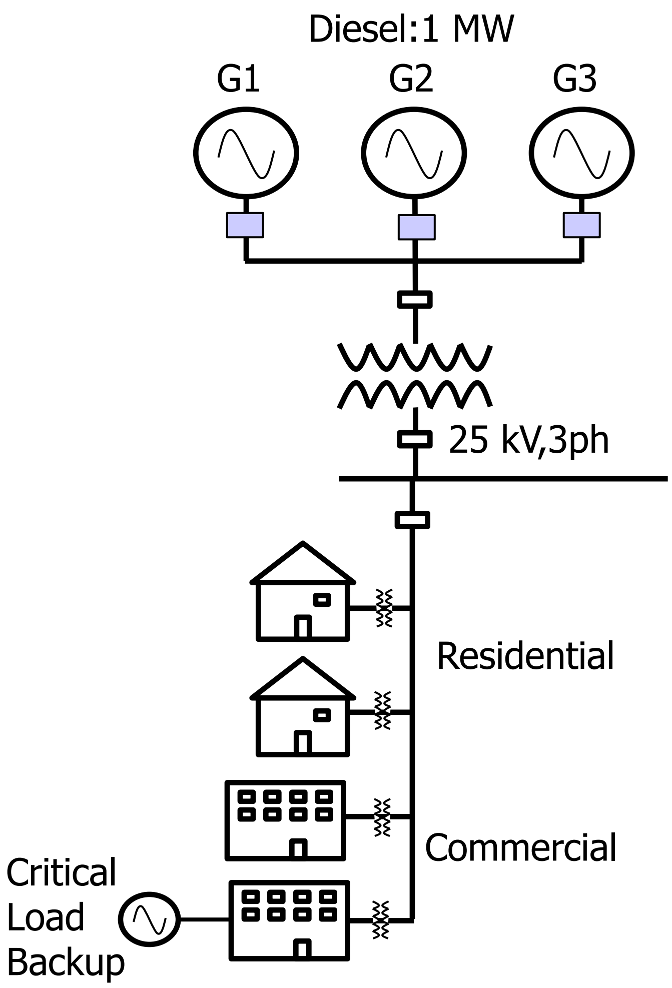
	Normal	Inst. Trip	Delay Trip
Grid Connected	60 Hz	>60.5, 59.5 Hz	N/A
Dead Load Pickup	60 Hz	<55, >67 Hz	N/A
Islanded State	60 Hz	<53, >67 Hz	<59.5, >60.5 Hz, 20 s
All:	Vin Cont: 0.9<V<1.1	Delay 1 s: <0.9, >1.1	

  - Went into development of IEEE 1547.4 guideline for intentional islanding experience

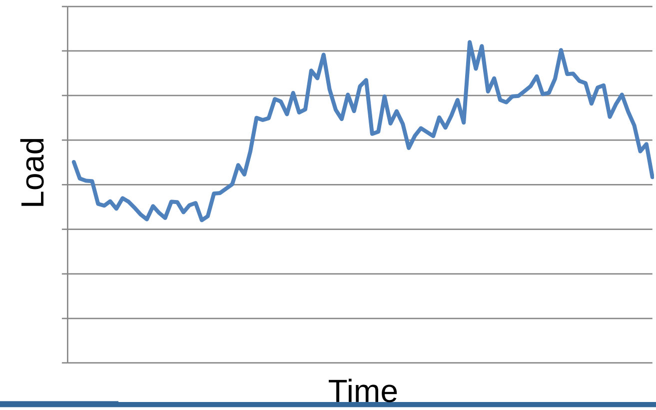
Remote Community Electrical Systems

Microgrids or Minigrids?

A Typical Remote Community Mini-grid



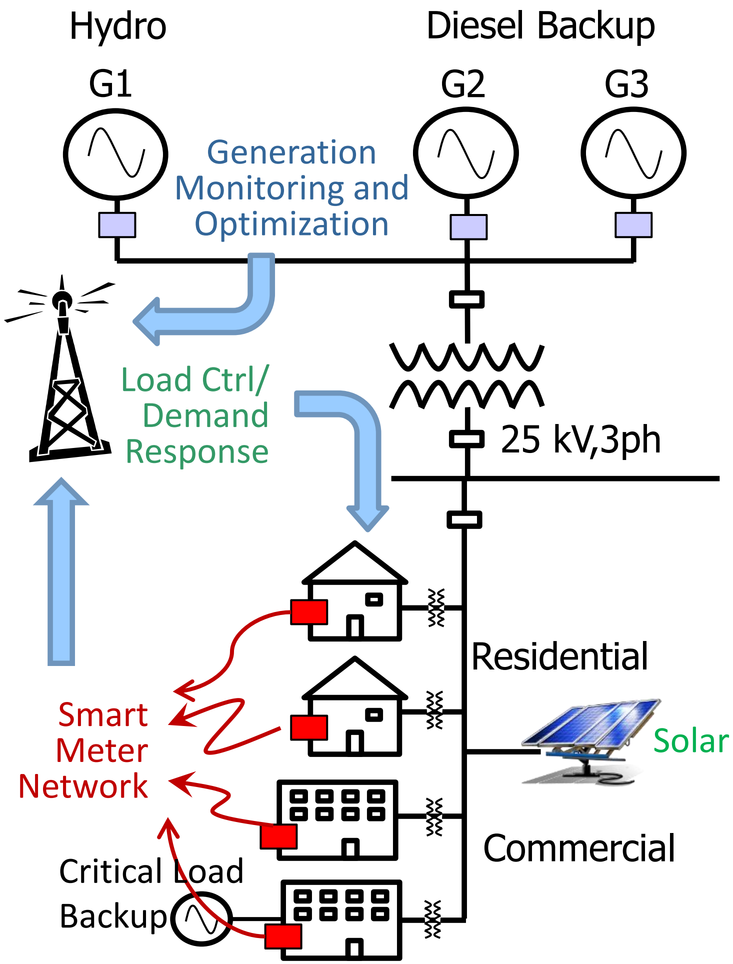
- A typical Canadian remote grid consists of a number of diesel or hydro generators serving community loads.
- No communication between supply and demand.
- Balancing by generators and possibly dump loads.



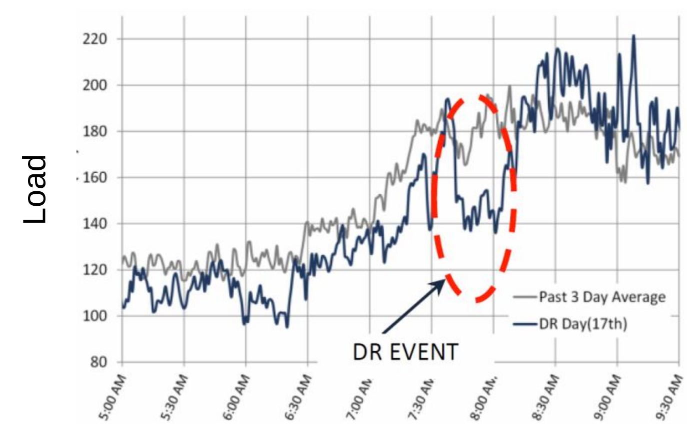
A Typical Remote Community Mini-grid
(100% Diesel)

- Generator sizing strategy
  - Staged sizes to support most common demand profiles (i.e. winter demand, summer demand, service large commercial machine startups)
  - Generator backup sized for typical demand
  - Top 10% of demand often occur for small fractions of the total year (i.e. 3h a year).

An Ideal Advanced RC Mini-grid/Microgrid



- An advanced RC grid incorporates almost all elements of a typical microgrid, except for the grid connection
- Communication between supply and demand.
- Balancing by all components of system.



An Ideal Advanced RC Mini-grid/Microgrid

- Mix of generation sources and must be matched with demand AND total energy to guarantee the delivery of power
- Combinations of dispatchable with non-dispatchable sources will require careful consideration to demand profiles – Why?
  - Voltage and frequency vary with P+Q demands, parallel DERs can lose synchronization
  - Voltage profiles can be difficult to maintain within
    +/-5% standard
- Non-radial overcurrent protection can be difficult to synchronize and coordinate; may lack sensitivity
- Communications is key
  (Advanced IT)

Remote Microgrids

- In effect, a remote community power system will reflect a microgrid if it balances supply and demand using resources from both sides, that is, generation optimization and load control/demand response…
- …where such an approach is only possible with systems possessing the advanced communications infrastructure seen in the future smart grid.

Remote Microgrid Implementation Benefits

- Lower costs of generator operation
  - Reduced fuel consumption
  - Longer equipment lifetime
- Diversified power generation
  - Increased renewables
  - More stable costs
- Lower environmental impacts
- Increased customer engagement

Microgrid Generation

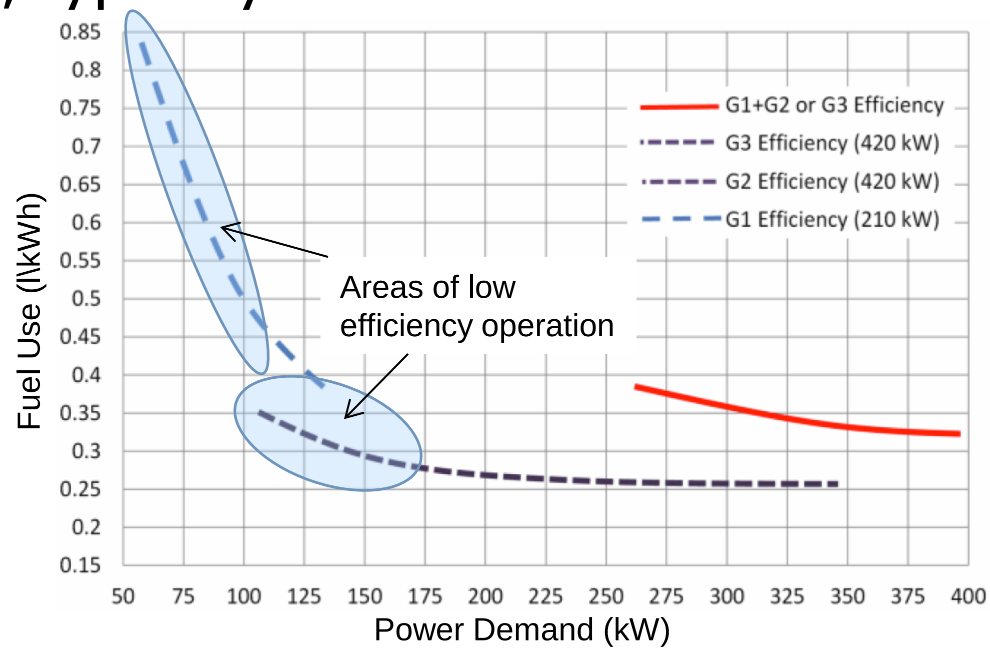
Types of Generation

- **Dispatchable** – can be used at a moment's notice
- **Non-dispatchable** – is not always available nor controllable
- **Firm** – can deliver a guaranteed quantity of power
- **Renewable** – uses replenishing natural resources such as water, sun, biomass, geothermal, wind
- **Induction/Synchronous** – rotating machines susceptible to frequency fluctuations.
- **Electronic** – inverter/converter transistor based generation based systems

Diesel Generation

Dispatchable
Firm

- Conventional
- Very common in Canadian remote communities
- Efficiency depends on power draw (typically best at rated power)
- Have a minimum loading, typically 30% of rated
- Pros
  - Flexible generation
  - Low capital cost
- Cons
  - High operational cost
  - Polluting



Diesel - Typical Configuration

- A set of generators (genset) should be rated to provide 1X0% of anticipated peak load even if a single generator fails
- Most Canadian communities have a small number of large generators, rather than a large number of small generators
- Examples:
  - Nemiah Valley. Peak load of 75 kW supplied by 1x30 kW and 2x95 kW generators
  - Hartley Bay. Peak load ~400 kW supplied by 1x210 kW and 2x420 kW generators

Nemiah Valley Gensets

Dispatchable/Non-dispatchable
Firm/Non-firm

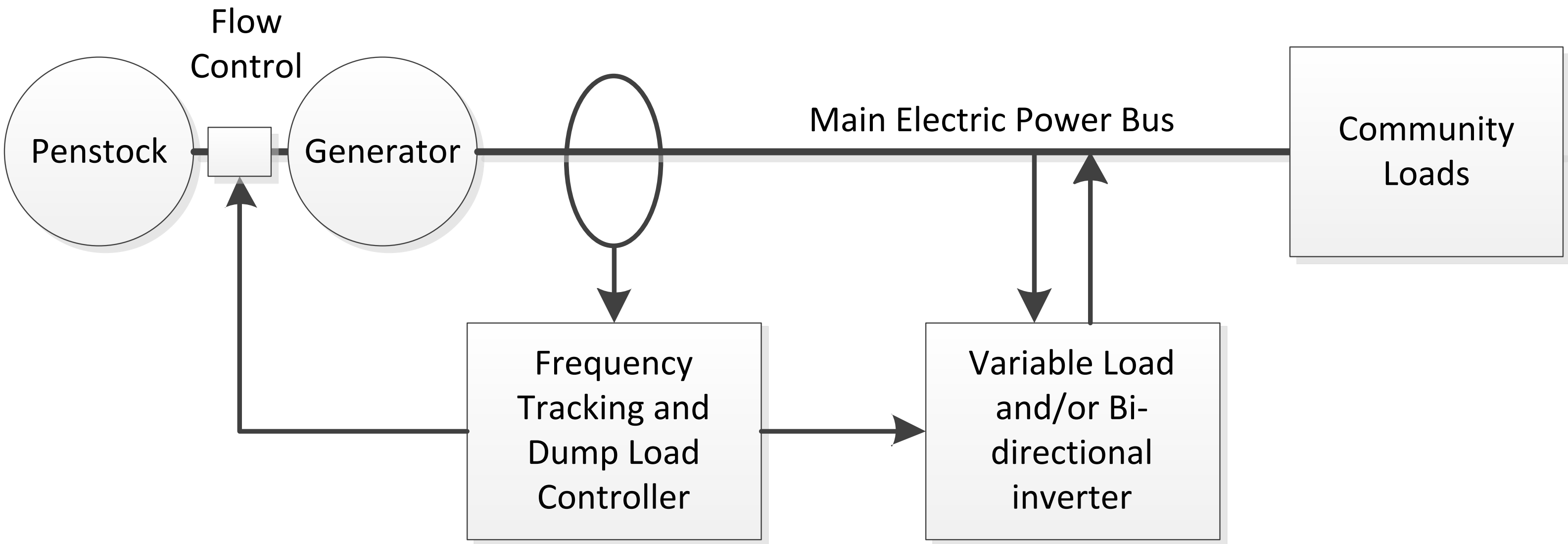
Hydro

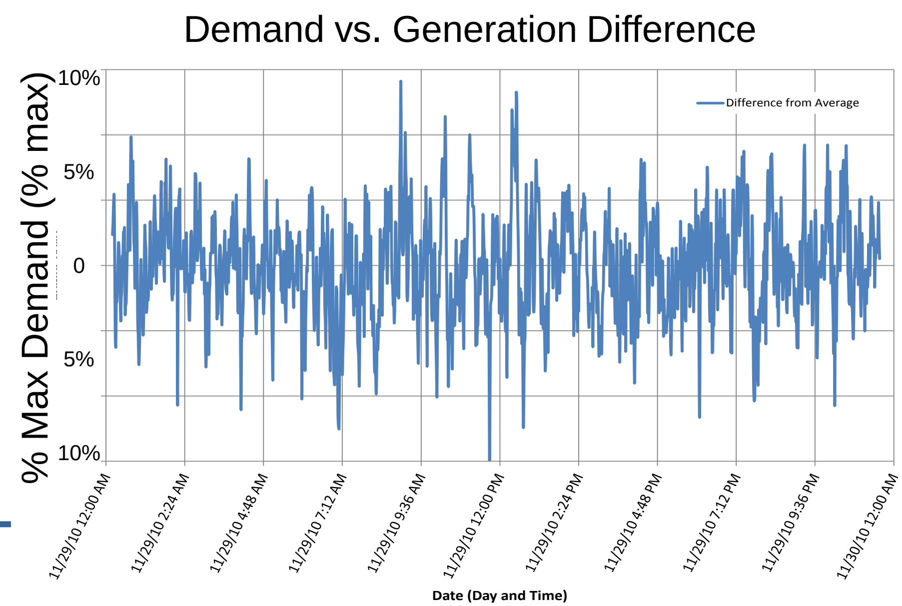
- Conventional
- Renewable
- Common source in Canadian remote communities
  - (Depending on location)
- Two types
  - Run-of-the-river
    - No damming; little or no storage capacity
  - Reservoir
    - Dams create pooling

Example: Fast Load Balancing – Dump Load

- Commonly used for generator systems where the generation dispatching time constant is longer than the load demand delta.
- Dump Loads are used to prevent physical damage such as the water hammer effect in run of the river penstocks
- Common with islanded DER sources such as
  - Run of the river hydro
  - Wind turbines
  - Solar

Example: Dump Load Example – Run of River





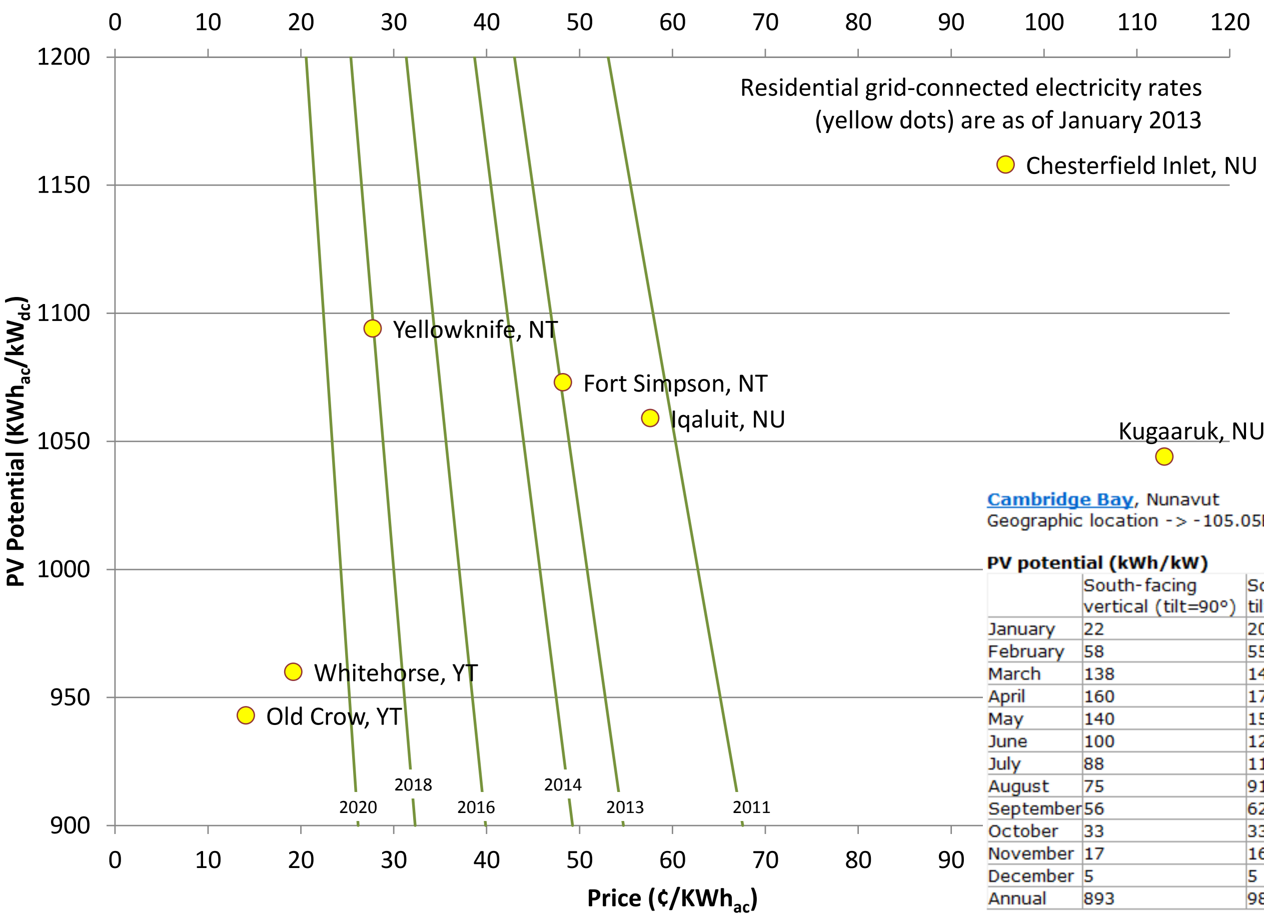
Non-dispatchable
Non-firm

Renewable Generation

- Wind generation
  - <To be discussed in wind-diesel 101>
- Solar PV
  - Composed of two elements
    - PV panel, outputting DC power
    - Inverter, converts DC to AC (what the household uses)
  - Lifetime
    - PV panel: 25-30 years
    - Inverter: 10 years
  - Current costs (installed)
    - $10/Watt in remote Northern communities ($6/Watt elsewhere)
    - Economically preferable in many remote communities

Renewable Generation

- Solar PV (continued)



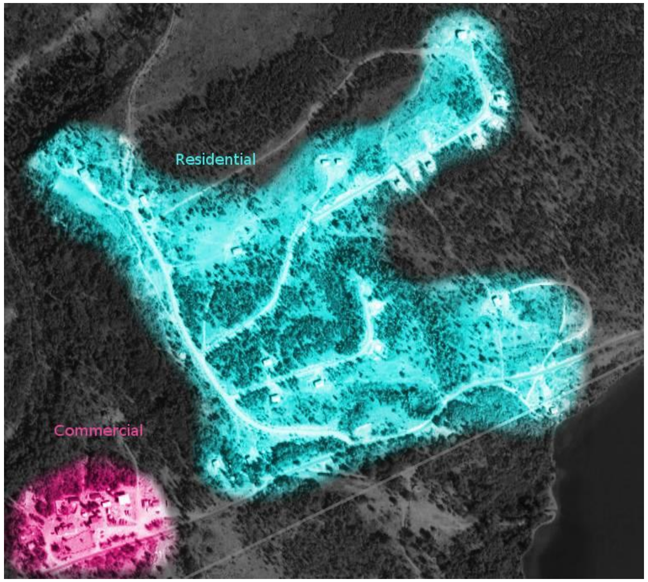
Cambridge Bay, Nunavut
Geographic location -> -105.05E,69.11N

PV potential (kWh/kW)

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°
January	22	20	21	18
February	58	55	58	50
March	138	140	140	131
April	160	171	165	170
May	140	158	147	164
June	100	125	109	137
July	88	112	96	123
August	75	91	81	97
September	56	62	59	62
October	33	33	33	31
November	17	16	16	14
December	5	5	5	4
Annual	893	987	930	1002

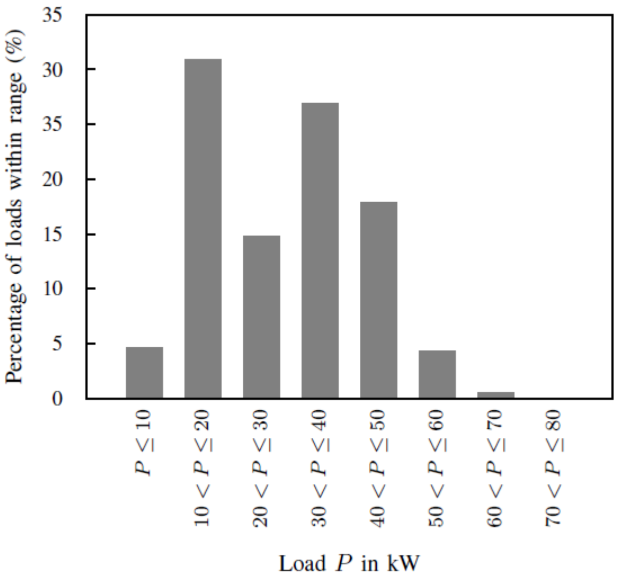
Case Study: Nemiah Valley

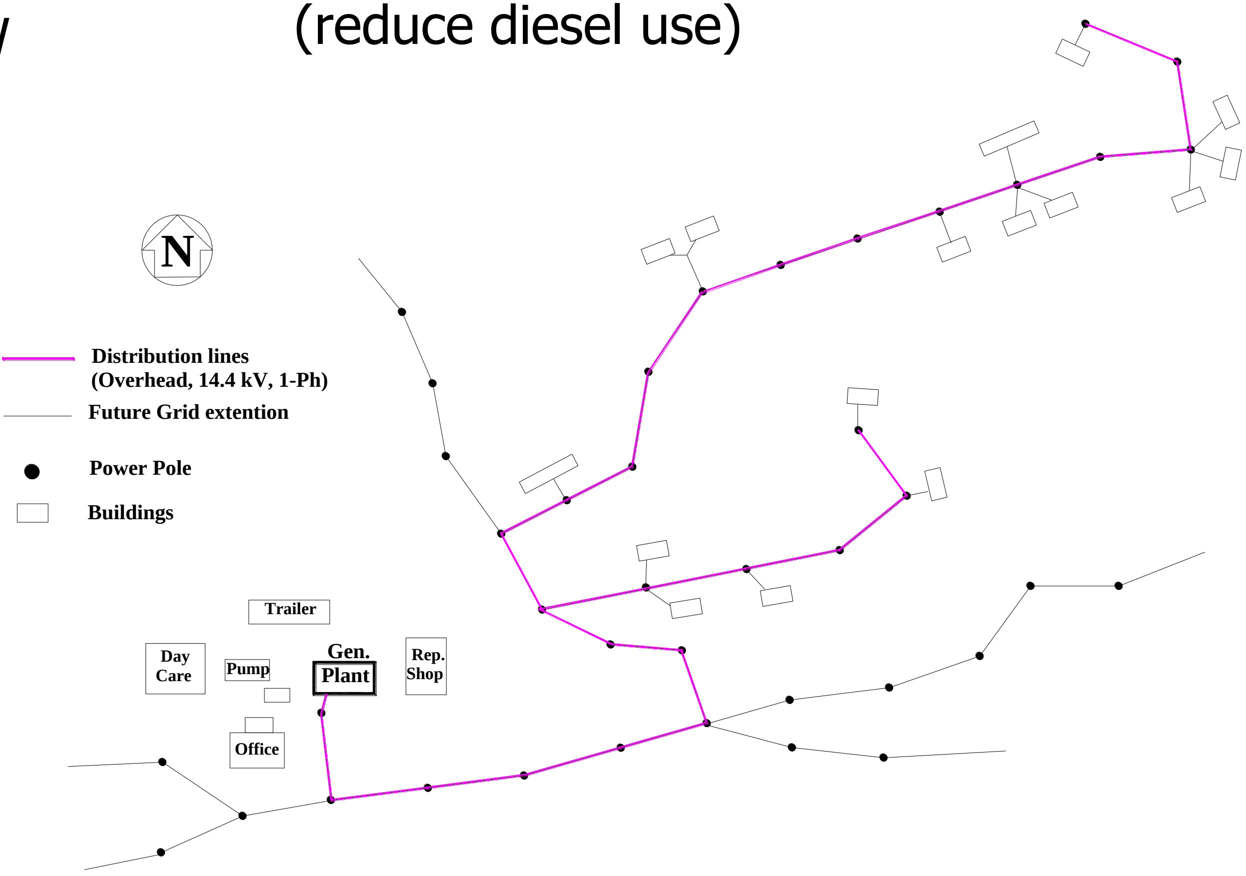
- Background (at the time of project, 2007)
  - Xeni Gwet'in First Nation
  - Remote community in BC
  - Accessible by road
  - 100 km from nearest grid
- Pre-project system
  - New residential system
  - Two load components
    - Residential: 22 housing units (out of 38)
    - Commercial: band office, daycare health centre, Xeni Gwet'in Enterprise etc.
  - Generation
    - Three 95 kW gensets run single phase.



Case Study: Nemiah Valley

- Load Profile
  - Peak of 75 kW
  - Average of 29 kW
- Goal
  - Green system (reduce diesel use)





Case Study: Nemiah Valley

Step 1

- Install smart meters
  - Pre-payed
- Benefits
  - Allow customers to monitor usage
  - Ease of accounting

- Current tariff
- Days of credit remaining
- Daily consumption
- Last month, yesterday, and today usage information
- Emergency credit

Case Study: Nemiah Valley

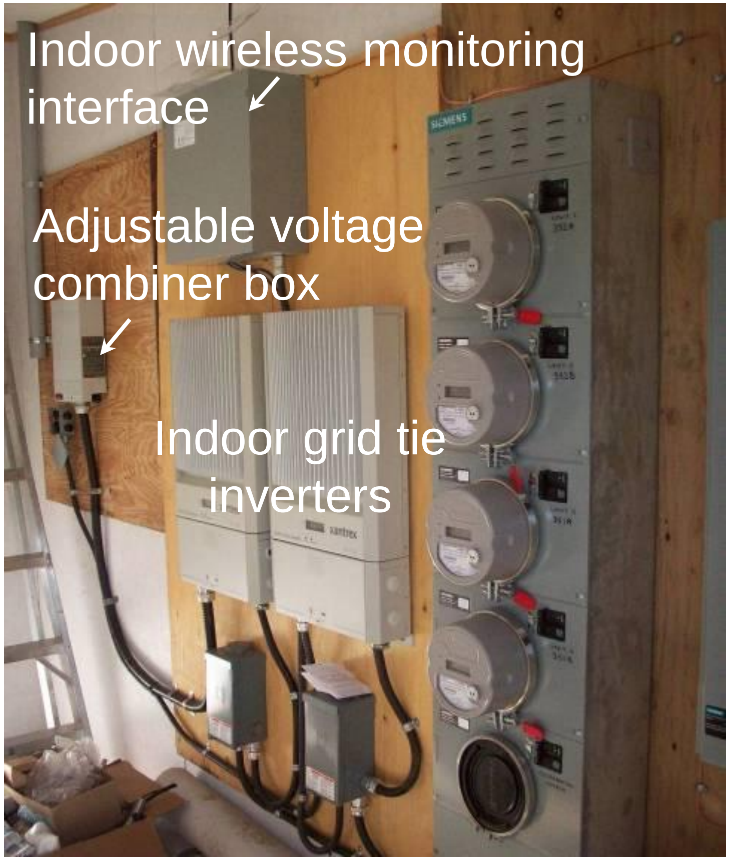
Step 2

- Load and Resource Assessment
  - Required night-time and weekend service loads were very low (average 14 kW), therefore commercial buildings were being run as a "dump load" to maintain generators at minimum loading.
- Fix
  - Install switch at non-critical commercial loads to allow turn-off
  - Replace single 95 kW generator with 30 kW generator

Case Study: Nemiah Valley

Step 3

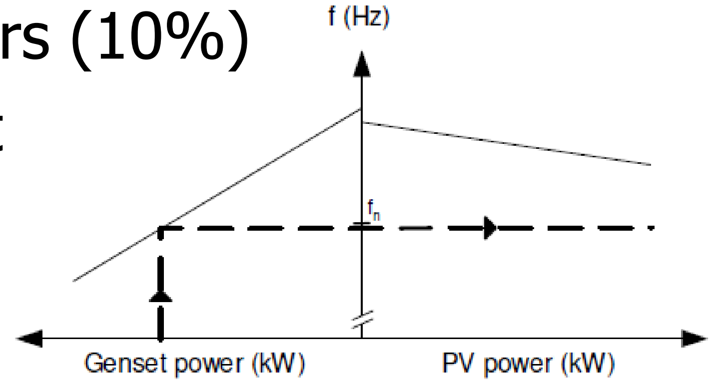
- Install PV
  - Six distributed rooftop PV equalling 27 kW (medium penetration)



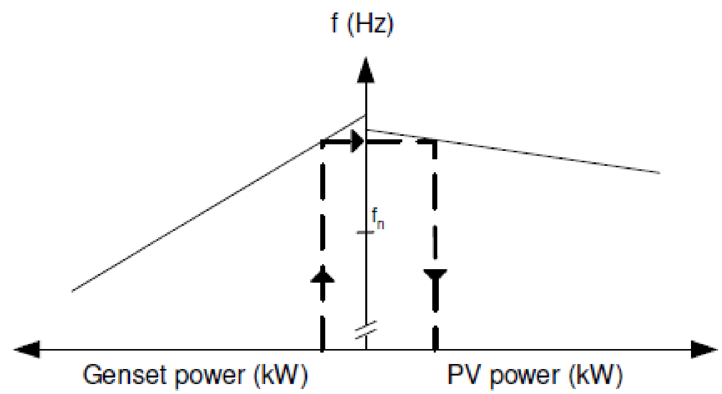
Case Study: Nemiah Valley

Challenges

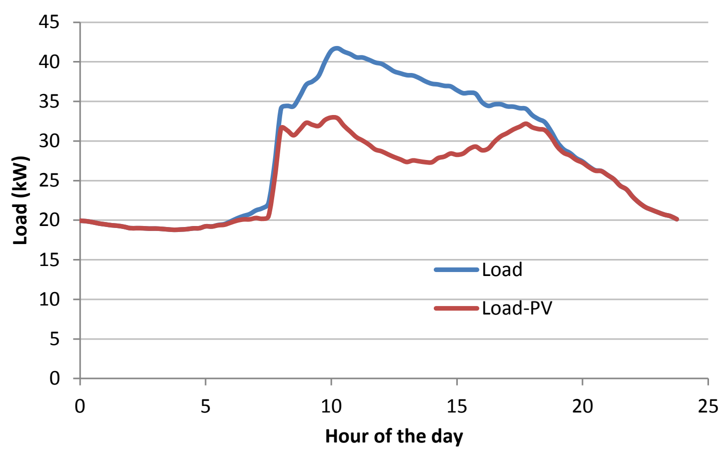
- Inverter would disconnect if output exceeded load, resulting in downtime of 154 hours (10%)
- Problem: Could not curtail output
- Solution (not implemented): droop control



(a) No PV Curtailment



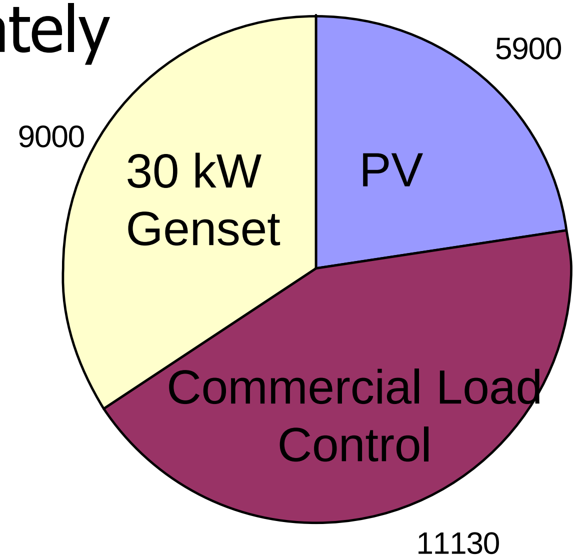
(b) PV Curtailment



Case Study: Nemiah Valley

Savings and Lessons Learned

- Annual fuel savings of 26000 liters, roughly translating to $26000 per year over business as usual (25%)
- Use of dump loads should be investigated and possibly avoided
- Generators should be sized appropriately
- Better utilization of PV would improve its economics

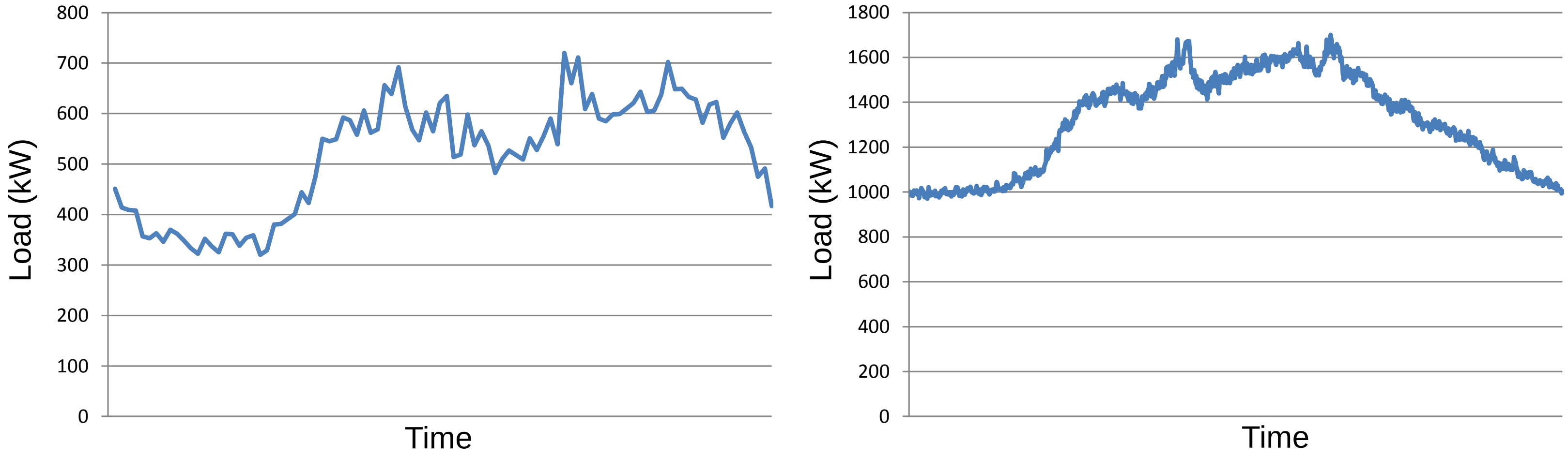


Nemiah Valley Photovoltaic-diesel Mini-grid: System Performance and Fuel Savings Based on One Year of Monitored Data
http://canmetenergy.nrcan.gc.ca/renewables/smart-grid/publications/3104

Microgrid Loads

Supply/Demand Balancing

- Traditionally, generators are called upon to provide the flexibility to balance supply with demand; however, as discussed, this role must now be shared.
- The only other source of flexibility is from the load (including storage).

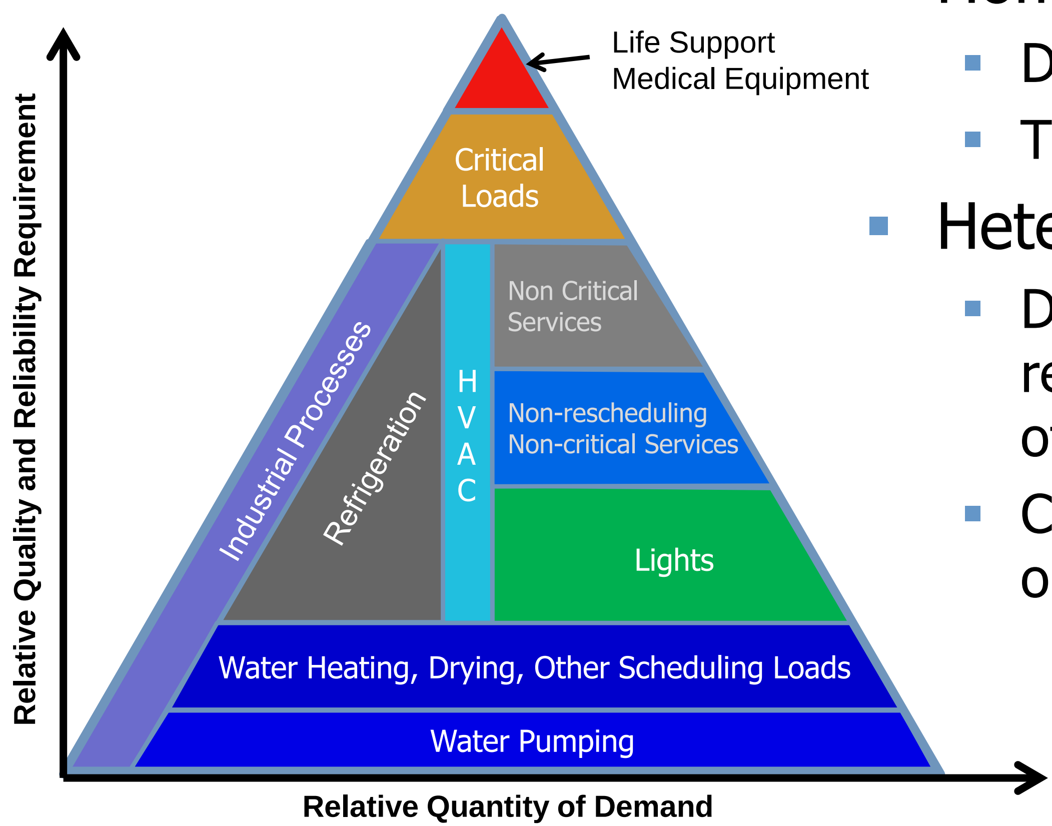


Typical daily fall load profiles of two remote communities (left: coastal; right: northern)

Options for Load Flexibility

- Load flexibility may be attained by
  - Utilizing inherent flexibility in loads
  - Offering electrical service based on heterogeneous load profiles
  - Changing customer behaviour
- Variables to keep in mind
  - Customer impact
  - Period and depth of response
  - Speed of response

Heterogeneous Load Profiles

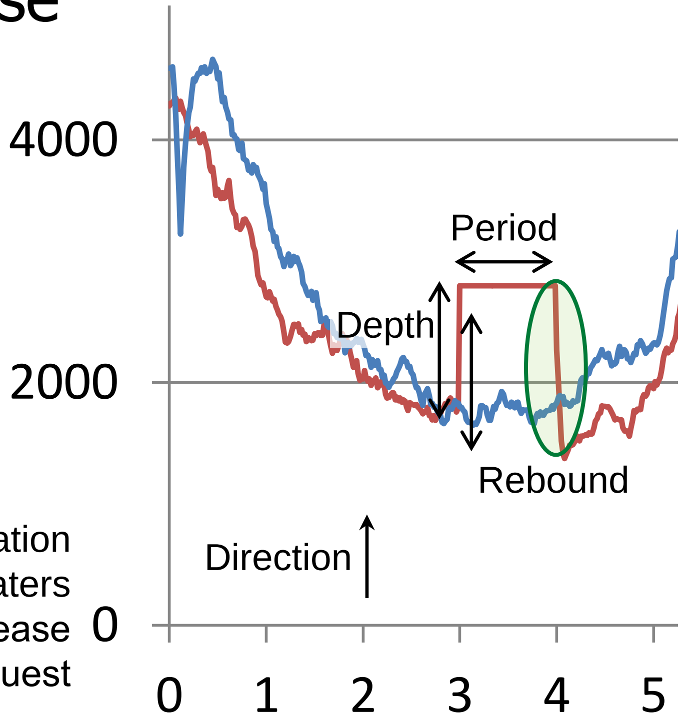


Chris Marnay et al ,"Microgrids for Commercial Building Combined Heat and Power and Power and Heterogeneous Power Quality and Reliability", LBNL, 2007

- Homogeneous demand
  - Default approach
  - Treats all demand as 'critical'
- Heterogeneous demand
  - Differentiates loads by reliability requirements (quality of service)
  - Can differentiate by user or by load

Flexible Loads

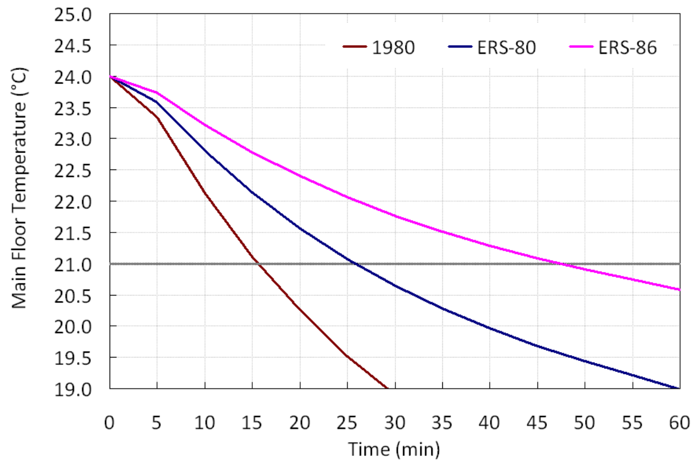
- Flexible loads are those that can shifted from one period to another with, ideally, little or no effect on user comfort
- They offer different levels of response
  - Depth (power)
  - Period
  - Direction
  - Rebound



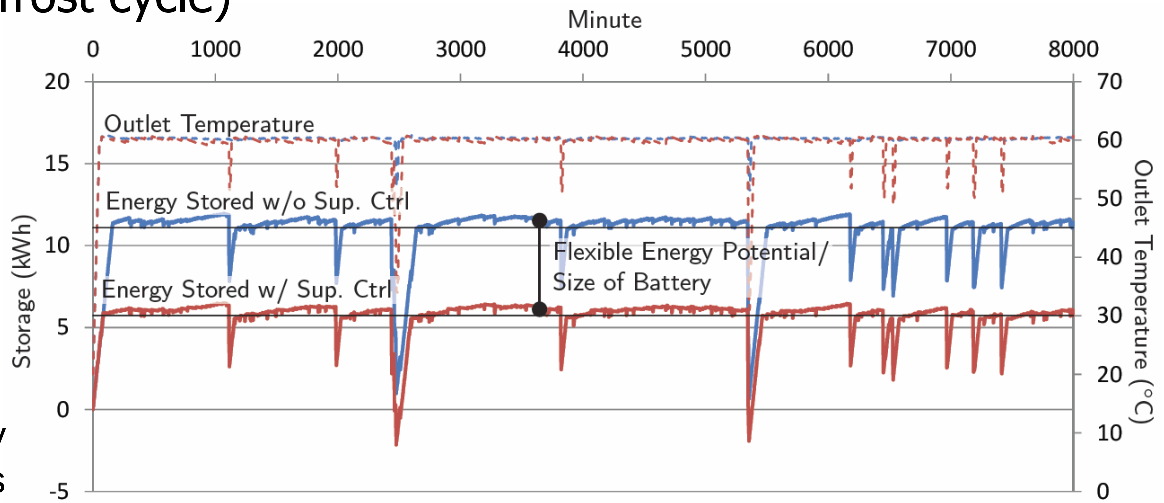
Depiction of a population of electric water heaters responding to an “increase demand” request

Typical Flexible Loads

- Low hanging fruit
  - Thermal loads with "built-in" storage
    - Electric water heaters
    - Electric thermal storage devices
  - Thermal loads with some storage
    - Housing
  - Other
    - Refrigerators (defrost cycle)
    - Electric vehicles



Temperature decay in various households (winter, Montreal)



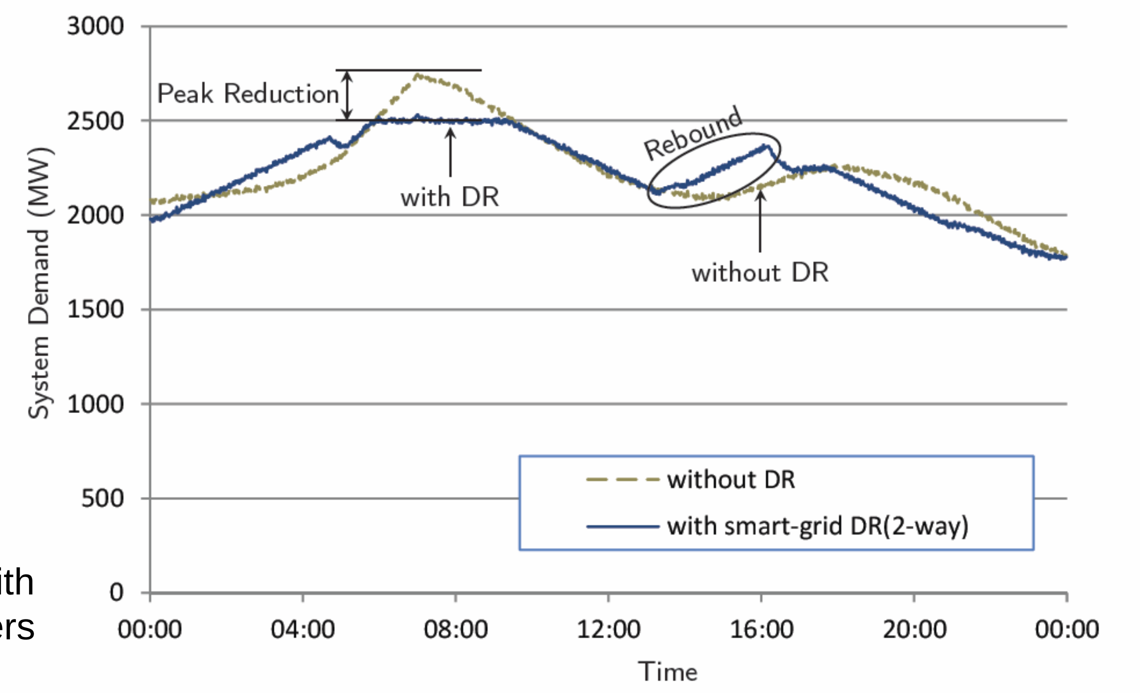
Energy stored in EWH throughout the day at 60°C (blue) and 40°C (red) setpoints

Other Flexible Loads

- Electrical storage devices
  - Can store excess electricity for use during a later period
    - Mostly at “demonstration” stage
    - Include NaS, flywheels, lead, lithium-ion
  - Caveats:
    - Limited applicability to Canadian remote communities
      - Cost
      - Transportation (installation and removal)
      - Complexity
      - Maintenance
- Dump loads
  - Managing excess electrical generation

Demand Response

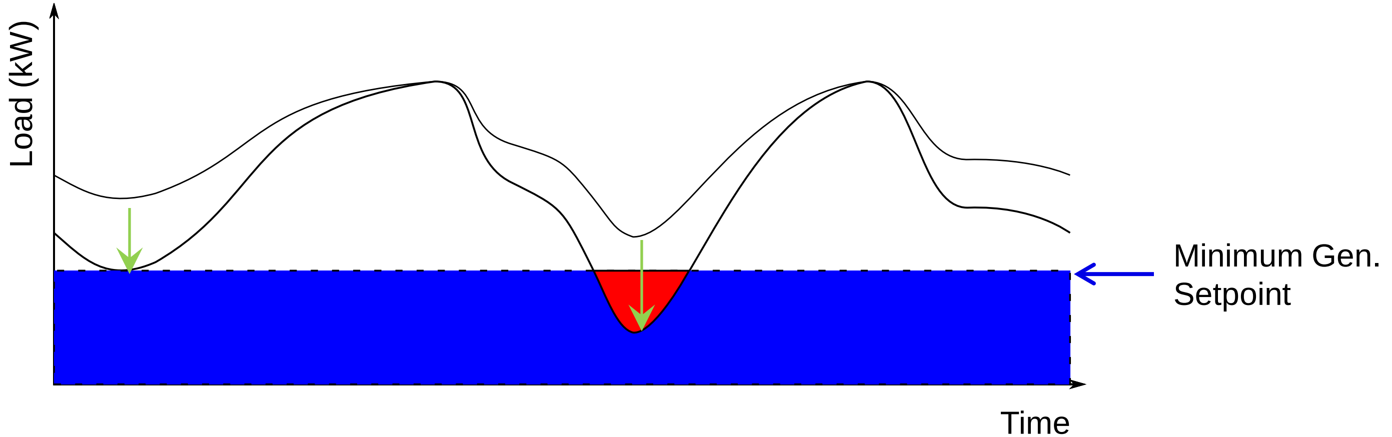
- Altering typical load demand to serve a need of the power systems
- Possible applications:
  - Peak shaving
  - Valley filling
  - Load shifting
  - Load following
  - Reserve



Peak shaving/load shifting with electric water heaters

Demand Response Applications

- Peak shaving
  - Avoid exceeding generation capacity
  - Avoid dispatch of 2nd or 3rd generator
  - Avoid large ramping up in demand
- Valley filling
  - Meet minimum or rated generator dispatch levels
  - Consume excess from renewable power generation (oversupply)



Effecting Customer Behaviour

- Real-time rates
  - Rates based on needs of power system
  - Difficult unless automated
- Time-of-use rates
  - Rates based on time
  - Based on estimate of needs of power system
  - Effective, but need proper design
- Education

What is Smart Meter Technology?

- Real Time Data Acquisition
  - 1 min to 15 min samples
  - 30 to 90 days storage buffer
- Measurements:
  - V, A, W, VAR, PF, f, Harmonics
- Broadcasting of meter data
  - Locally to the user
  - Long-haul to the utility

Case Study: Hartley Bay

- Background
  - Gitga'at First Nation
  - Remote community on the west coast of BC of 170 persons
  - Accessible by air or water
- System
  - Loads
    - 62 residential and 20 commercial/ mixed use
    - 150 – 260 kW avg.
    - 450 kW peak
    - 2 GWh per year

Photo Courtesy *Pulse Energy*

Partners

Village of Hartley Bay
Pulse Energy
CanmetENERGY, NRCan
Aboriginal Affairs and Northern Development Canada (AANDC)
BC Ministry of Energy and Mines

Case Study: Hartley Bay

- Generation
  - 3 diesel generators
    - 210 kW, 2x 420 kW
  - Costs
    - $500,000/year in diesel fuel
    - 67 cents/kWh levelized
- Distribution
  - 25 kV

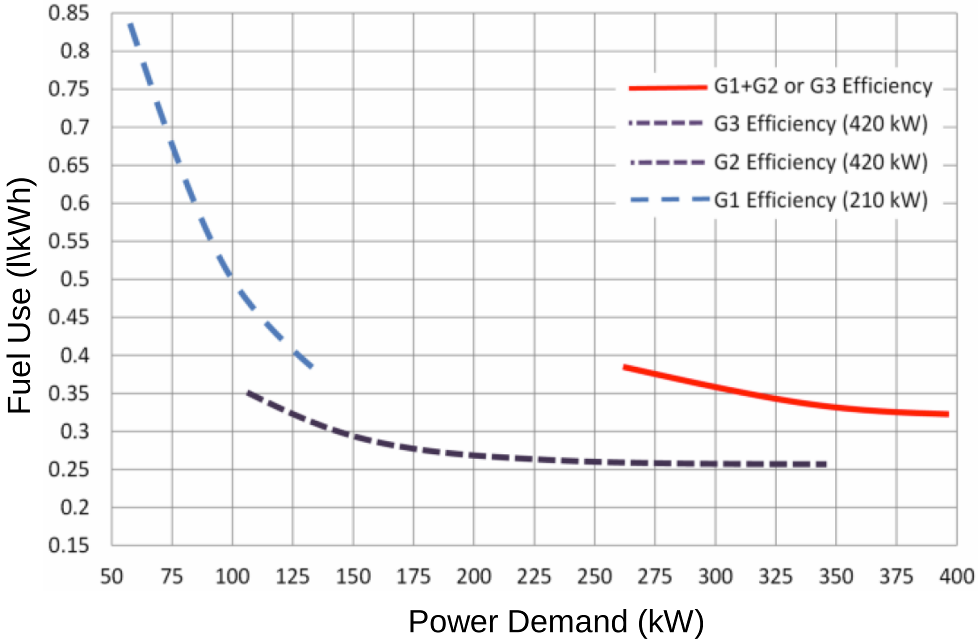
Photo Courtesy
Pulse Energy

Demand Response Implementation for improved System Efficiency in Remote Communities
http://canmetenergy.nrcan.gc.ca/renewables/smart-grid/publications/3161
Demand Response Implementation for Remote Communities - Installation Challenges and Initial Results for the Village of Hartley Bay
http://canmetenergy.nrcan.gc.ca/renewables/smart-grid/publications/2726

Case Study: Hartley Bay

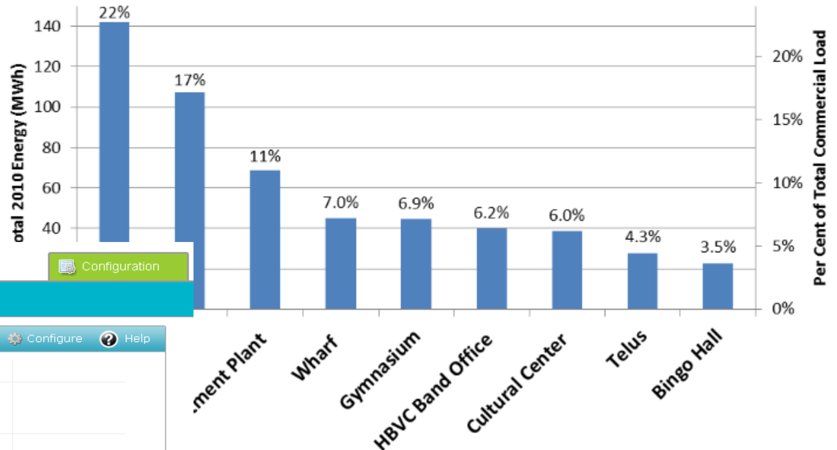
Objective: Take the mini-grid and make it into a smart remote microgrid system

- Step 1: Install monitoring equipment
  - Smart meters onto major buildings
  - Fuel flow meters onto diesel generators



Case Study: Hartley Bay

- Step 2: Assess energy use



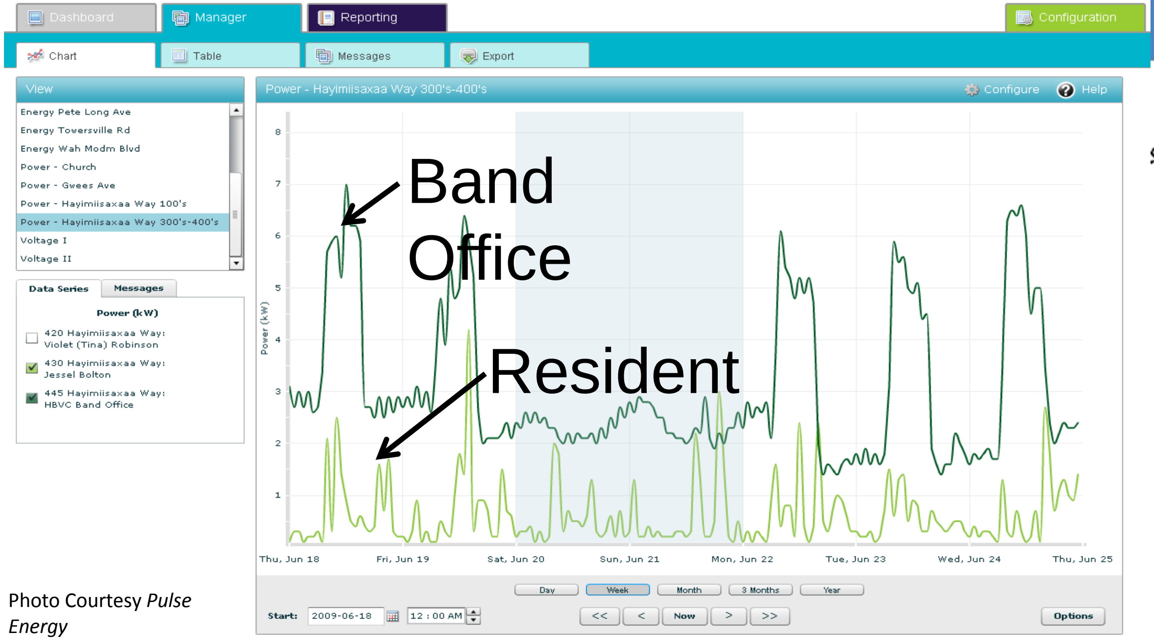
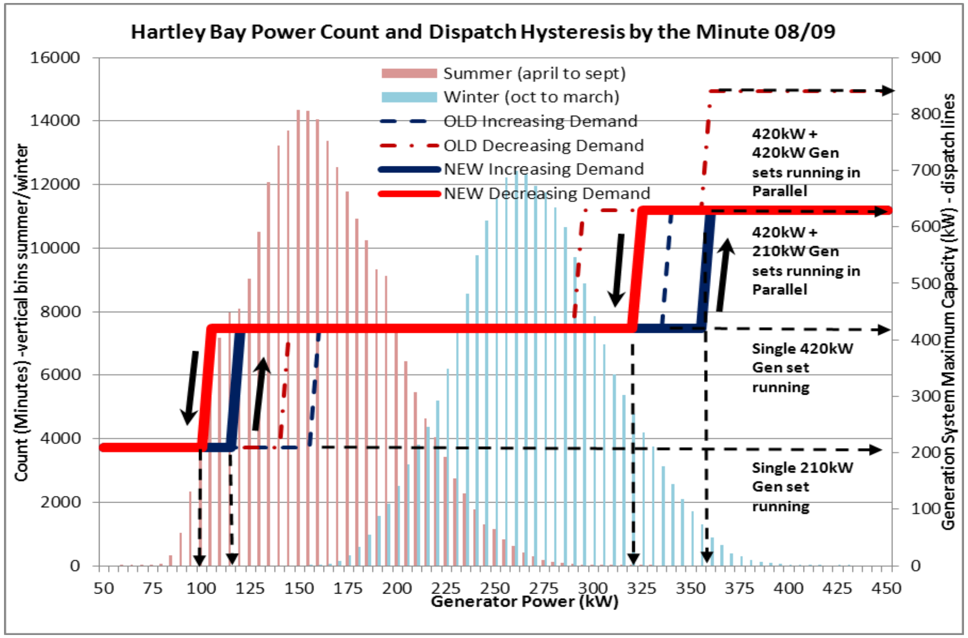


Photo Courtesy *Pulse Energy*

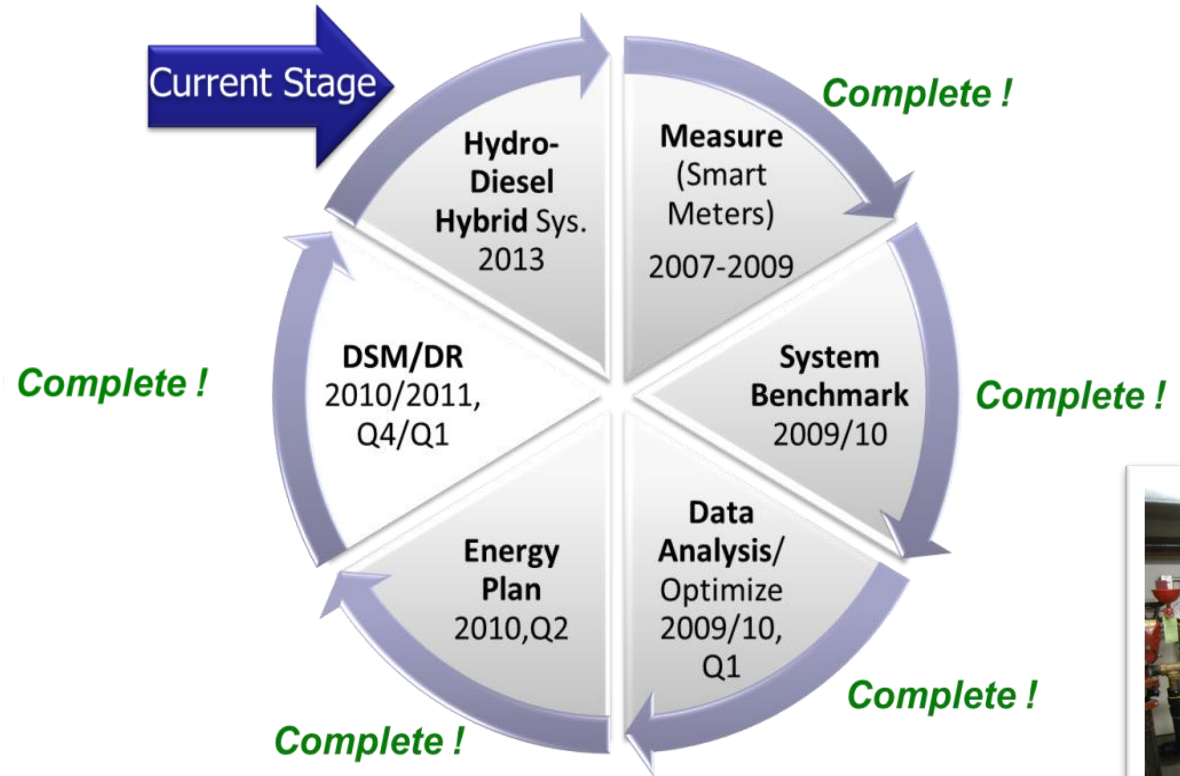
Case Study: Hartley Bay

- Step 3: Identify opportunities for demand response and smart/better controllers/controls
  - Generator dispatching
  - Load demand response/controls
    - Baseboard heaters
    - Hot water heaters
    - HVAC
    - Flood lights



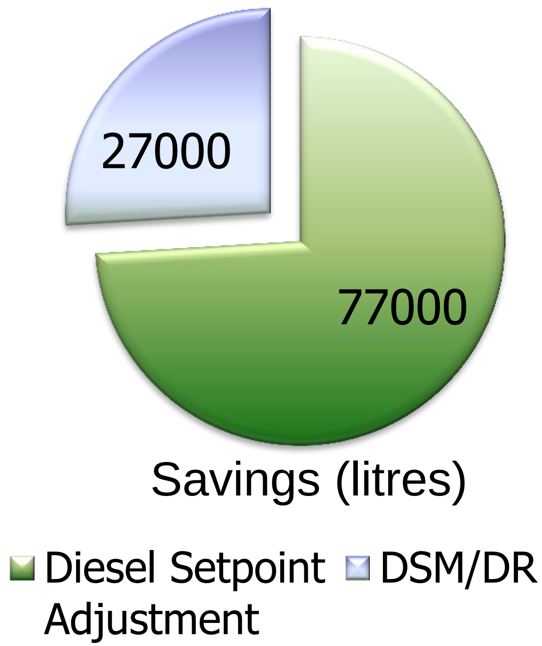
Case Study: Hartley Bay

- Implement!



Case Study: Hartley Bay

- Benefits
  - Large reduction in diesel consumption (20%)
  - Drop in GHG emissions
  - Lower fuel costs
  - Increased community engagement
- Challenges
  - Education and acceptance
- Future steps
  - Hydro/renewable integration



Thank you

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