Merits of Localized Demand Control in Preparing Local Grids for Solar PV and Electric Vehicles

Ryan Tulabing
The University of Auckland, New Zealand
rtul220@aucklanduni.ac.nz

Research Team: Brian Mitchell, Jason James, Heejong Park, John Boys, Zoran Salcic, and Grant Covic
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Agenda

- Background
- Solutions
- Localized Demand Control
- Case Study
- Results and Discussion
- Conclusion

Background

- Increasing adoption of Distributed Energy Resources (DERs) e.g., solar PV, Electric Vehicles (EV)
  - Decreasing prices
  - Sustainability goals

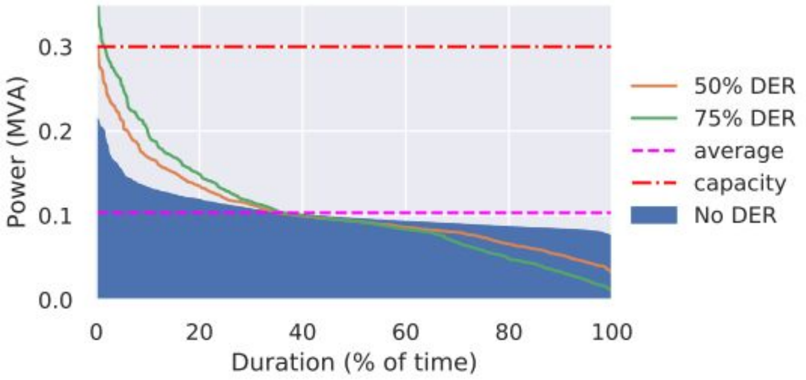
Rate of adoption for solar PV and electric vehicle in New Zealand as of October 2020.

Source: https://www.emi.ea.govt.nz/ https://www.transport.govt.nz/

- Issues:
  - Intermittent
  - Increase demand peaks (due to EV)
    - overloading, undervoltage
  - Reduce demand troughs (due to PV)
    - reverse power flow, overvoltage
  - Reduces load factor (low efficiency)

Traditional Solution:

- Increase System Capacity
  - Risky Investments
  - Higher costs of power delivery



$$LoadFactor = \frac{P_{average}}{P_{peak}}$$

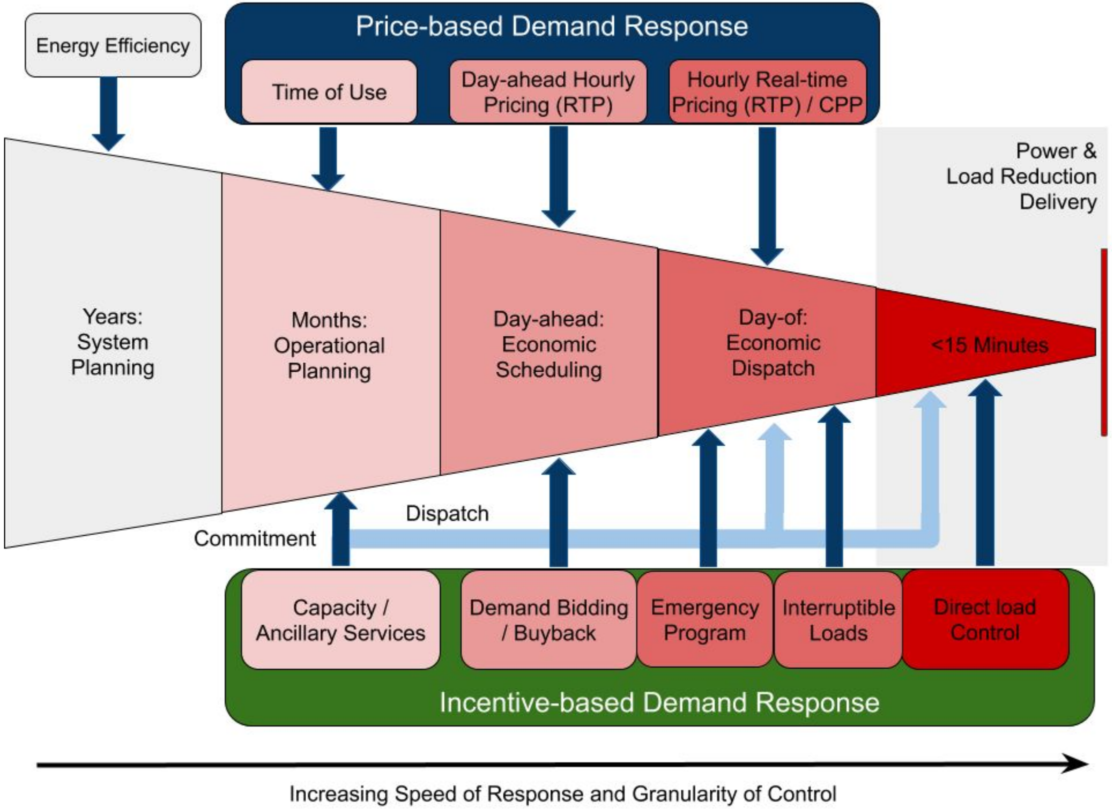
Solutions

"Non-wire" solution:

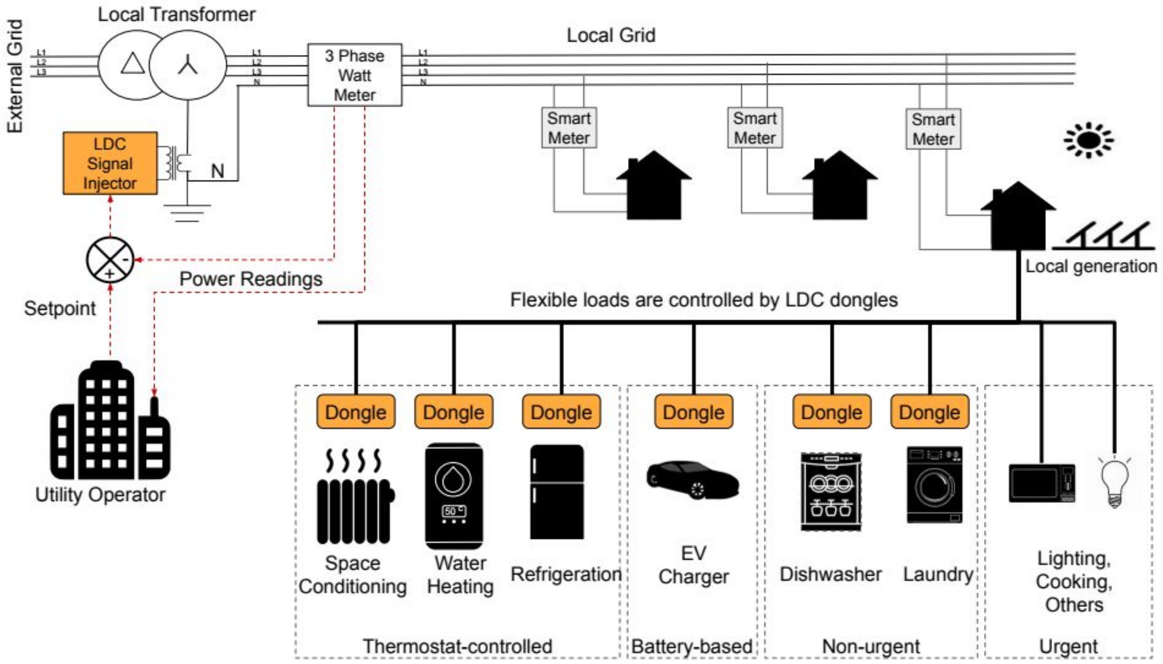
- ❖ Demand-side management
  - ➢ wide scope
  - ➢ "blind" to local issues

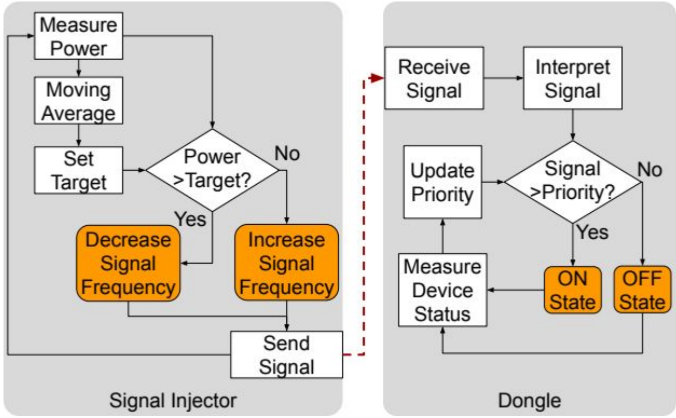
Design Criteria:

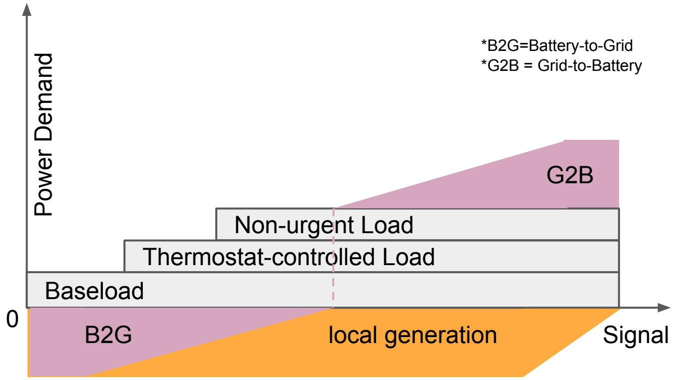
- ❖ Control aggregate demand
  - ➢ Permanent peak reduction
  - ➢ Respond to utility requests
- ❖ Localized but scalable
  - ➢ Manage local issues
  - ➢ Respond to operator command
- ❖ Autonomous
  - ➢ Respond to local grid limits
- ❖ Consider user comfort
  - ➢ Fair response burden
- ❖ Consider user privacy
  - ➢ No central server
  - ➢ User data stay within their premises



Localized Demand Control



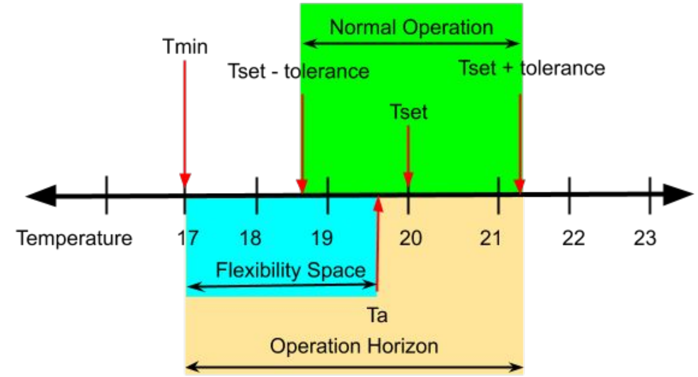




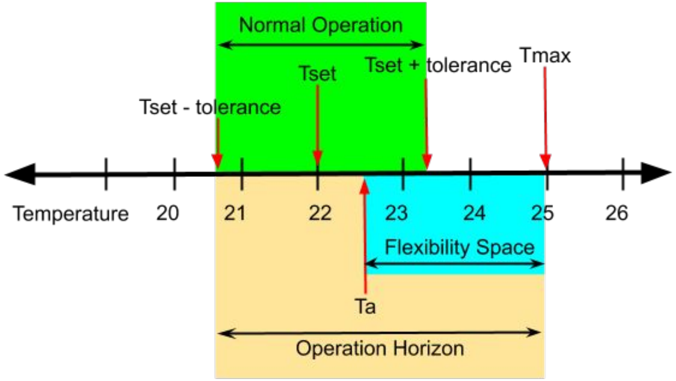
Ramping up the LDC signal will enable more loads to come online. If there is not enough load to consume extra power from the local generators, generation curtailment will happen at higher values of LDC signal. Meanwhile, as the signal ramps down to reduce power demand, batteries will start to discharge power to help out in supplying energy locally.

LDC is a type of demand response that can enable local grids to control the aggregated demand at a specific level...
i.e., ramp up, ramp down, or stay relatively flat, subject to the constraints of available flexible loads.

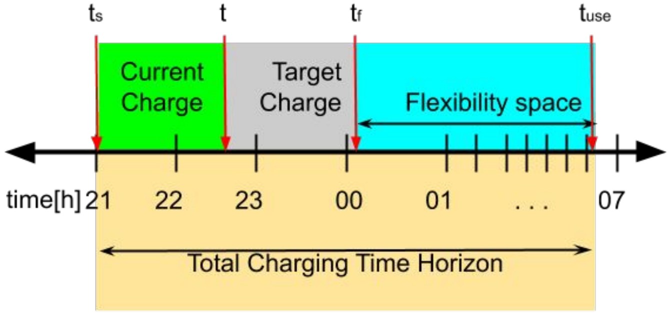
Load Flexibility



Cooling

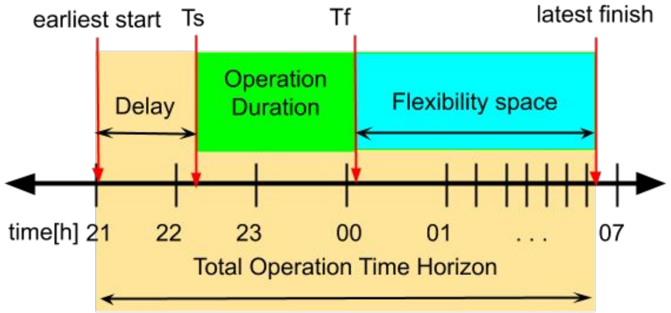


Heating



EV Charging

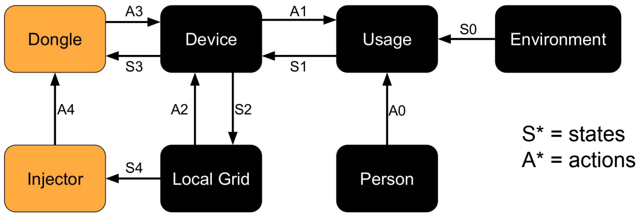
*For battery storage, flexibility is based on state of charge.



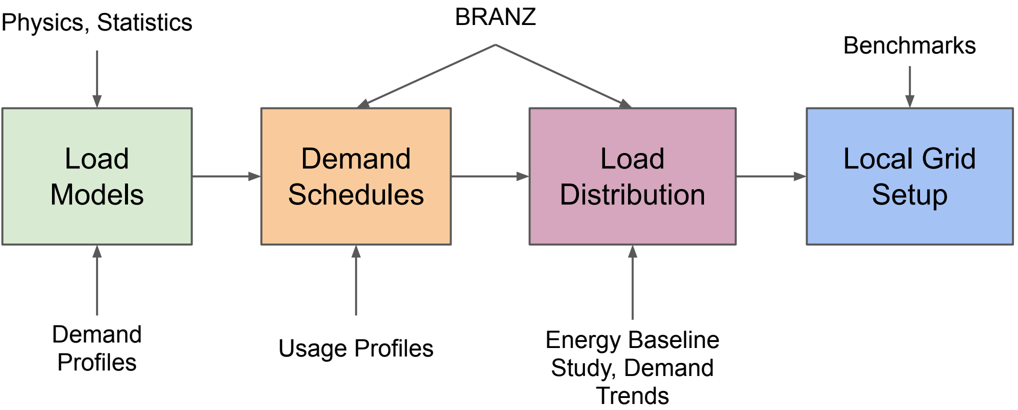
Non-urgent Load Process Delay

$$flexibility = \frac{flexible\ space}{operation\ horizon}$$

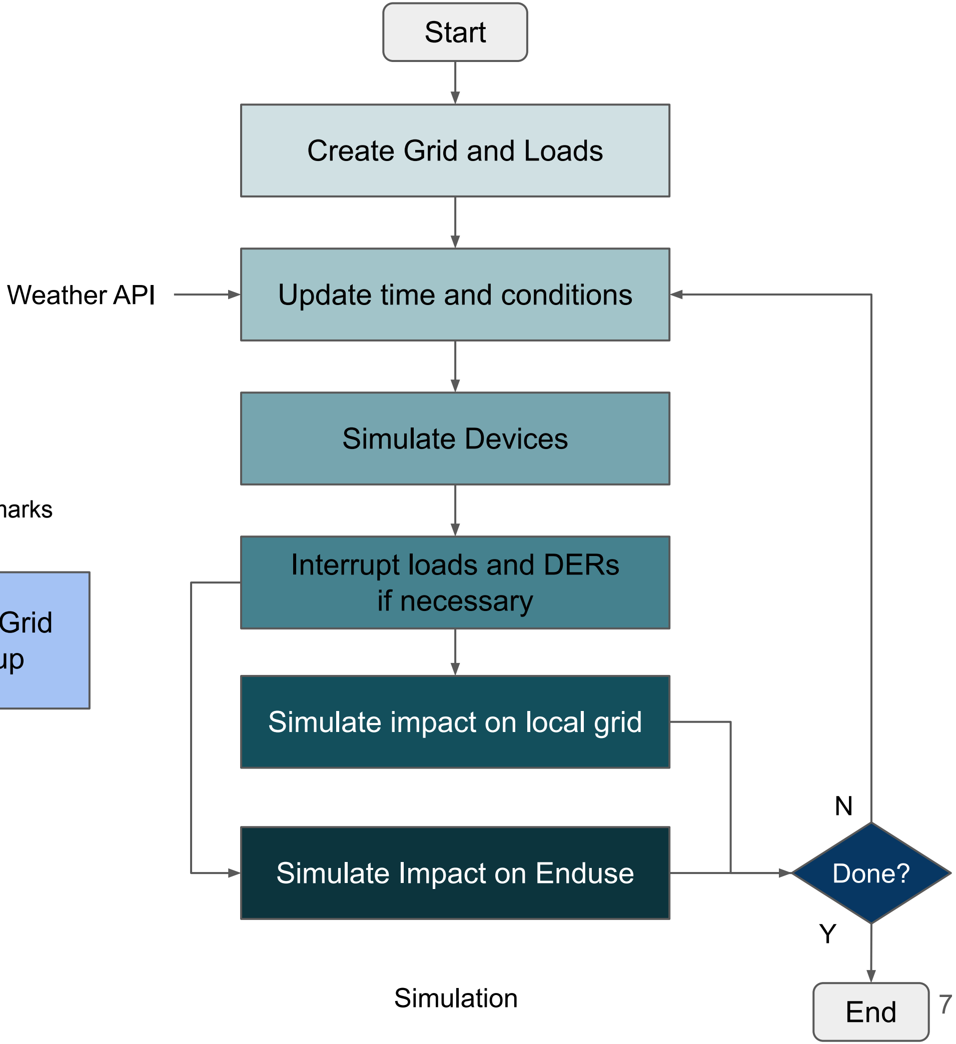
System Modelling and Simulation



System Model

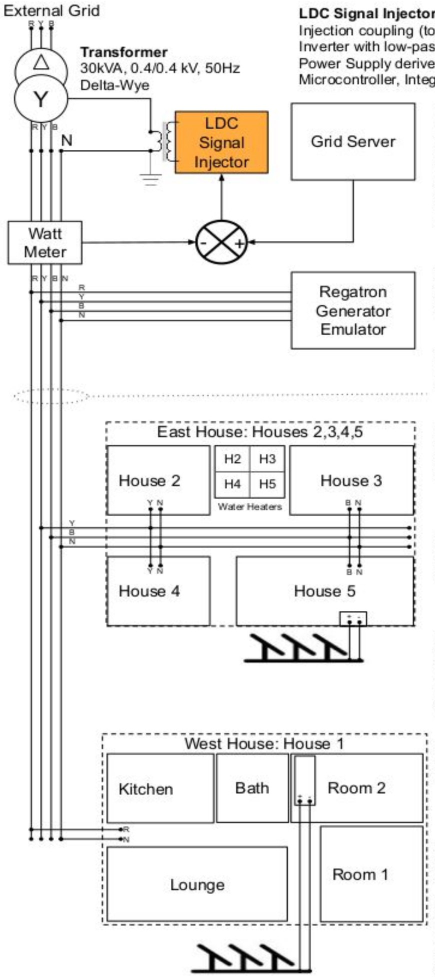


Dataset sources: GREEN Grid Project (NZ), Tracebase (Germany), Pecan Street Database (USA), GREEND (Austria), REFIT (UK)



Simulation

Ardmore Microgrid Setup



LDC Signal Injector
Injection coupling (toroidal core, split-core)
Inverter with low-pass/band-pass filter (LCL), 750-850Hz
Power Supply derived from 230Vac
Microcontroller, Integral Loop Control

Grid Server
Dell Optiplex 7050, 500GB SSD, 16GB RAM,
Intel I7-7700 3.6GHz CPU
Graphics User Interface
Data Logger
Emulation Control
Simulation: Base Case
Simulation: LDC Case

Regatron Power Supply
Generator Emulator
30 kVA, 3-Phase, 400V, 50Hz

Supply Cable
NAVY-J 4x185MM2 SE 0.6/1kV, ~250 meters
Buried 1m, 250A fuse at trafo, 160A fuse at each house

East House
Subdivided into 4 Houses
Real Loads: Heat Pumps, Water Heaters
Emulated Loads: Baseloads (e.g., Lighting, Cooking), Electric Vehicle, Battery Storage, Freezers, Fridges, Clothes washer, Clothes dryer, Dishwasher
Resistor Bank Capacity: 15 kVA
Electronic Load: Chroma 63800
Connections:
House 2: Y-N, House 3: B-N
House 4: Y-N, House 5: B-N

Solar Panels
Connection: House 5, B-N
Capacity: 20 x 270 Wp 30.8VDC,
Storage: 8 x 120Ah, 12 VDC
Orientation: ~60 deg facing North (winter optimum)

West House
Real Loads: Heat Pumps, Water Heaters
Emulated Loads: Baseloads (e.g., Lighting, Cooking), Electric Vehicle, Battery Storage, Freezers, Fridges, Clothes washer, Clothes dryer, Dishwasher
Resistor Bank Capacity: 15 kVA
Electronic Load: Chroma 63800
Connections: House 1: R-N

Solar Panels
Connection: House 1, R-N
Capacity: 20 x 270 Wp 30.8VDC,
Storage: 8 x 120Ah, 12 VDC
Orientation: ~30 deg facing North (year-round optimum)

Test Houses

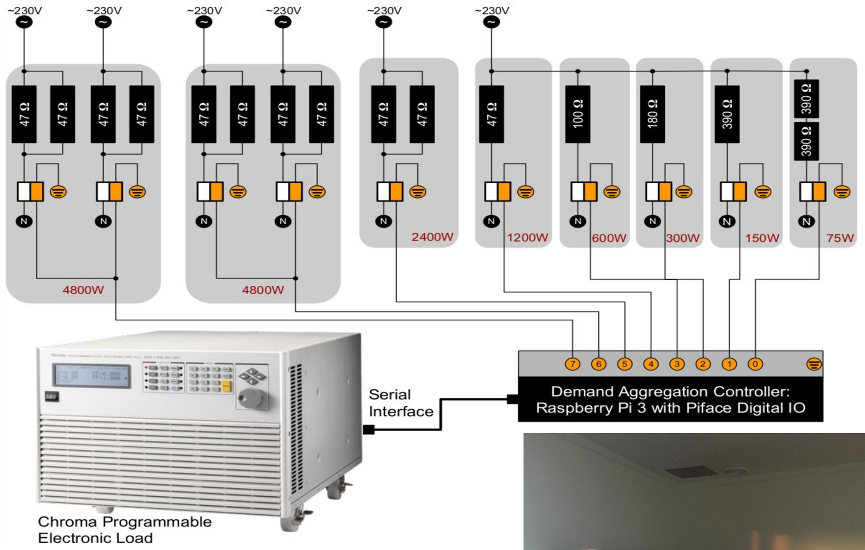
Lounge

Water heaters

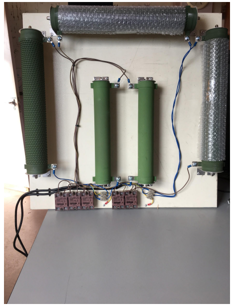
Heat pump

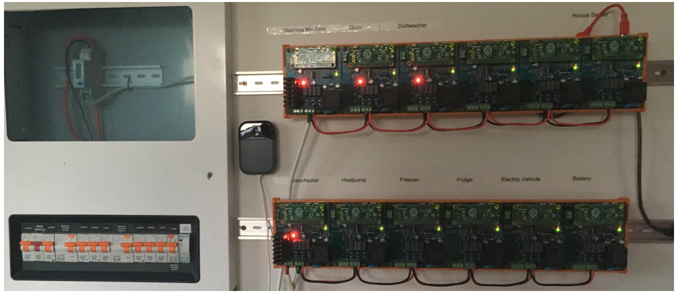
Ardmore Microgrid Setup

Signal Injector



Load Emulator





Control Dongles

Solar PV/Battery Controller

Localized Demand Control

Status

Microgrid Status

Plot Range:
2020-10-10

Target:
2.3 kW

Signal:
850.0 Hz

Gain:
512.0

Algorithm:
- No LDC
- Basic
- Advanced
- Ripple Control

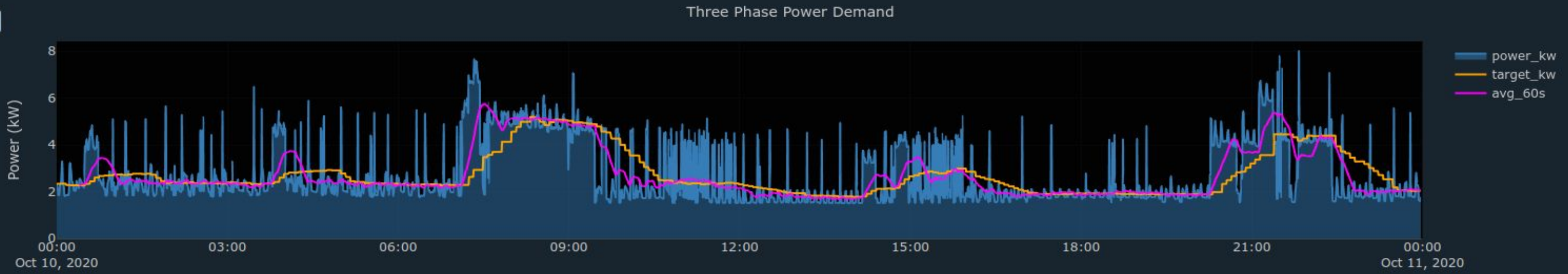
Set Target:
- Auto (avg_1h)
- Manual (kW)

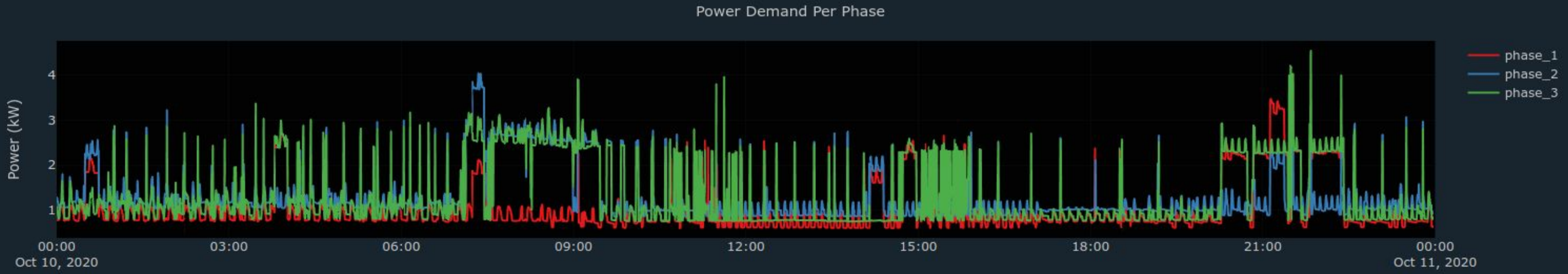
Set signal (Hz):

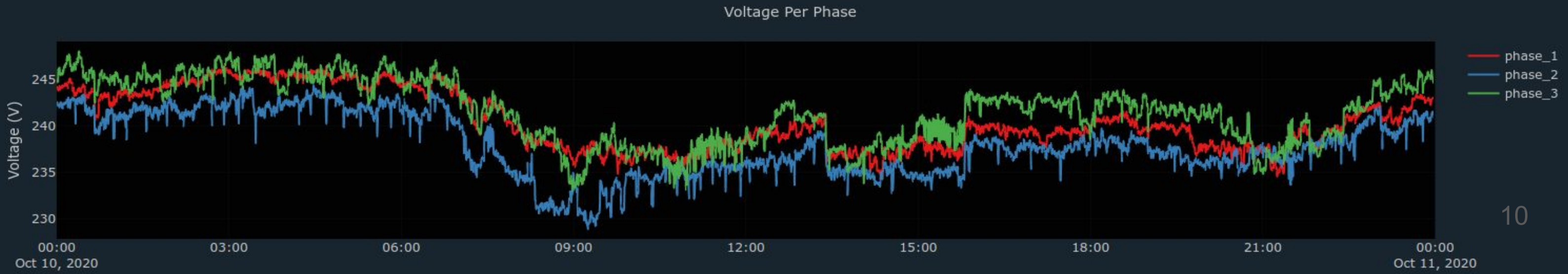
Set gain:

Emergency load shedding:

SHED!







Localized Demand Control

Home Status

House 1 House 2 House 3 House 4 House 5

Plot Range:

2020-11-11

Priorities

Heat Pump:

Fridge:

Freezer:

Washing Machine:

Dryer:

Dishwasher:

Device State

Total Power: 0.354 kW

Power Factor: 0.874

Voltage: 234.08 V

Baseload

Actual Demand: 60.6

Waterheater

Temp In: 52.93

Temp Target: 57

Flexibility: 0.266

Priority: 0

Actual Demand: -0.509

Ldc Signal: 98.0

Actual Status: 1

Connected: 1

Heat Pump

Temp Out: 16.419

Humidity Out: 0.75

Windspeed: 7.802

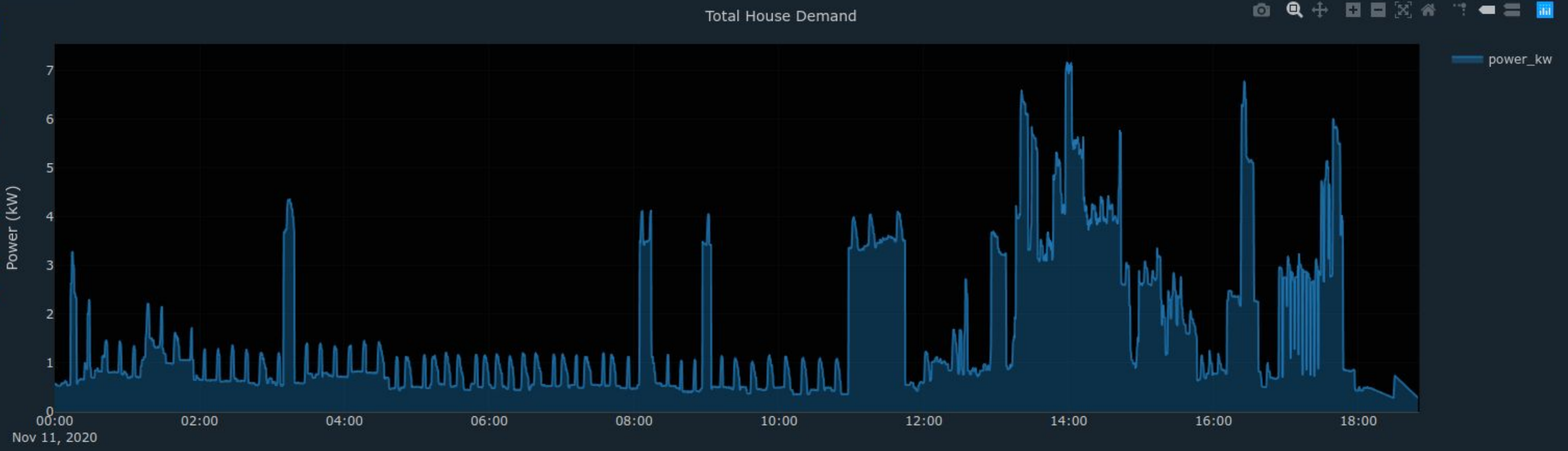
Temp In: 24.5

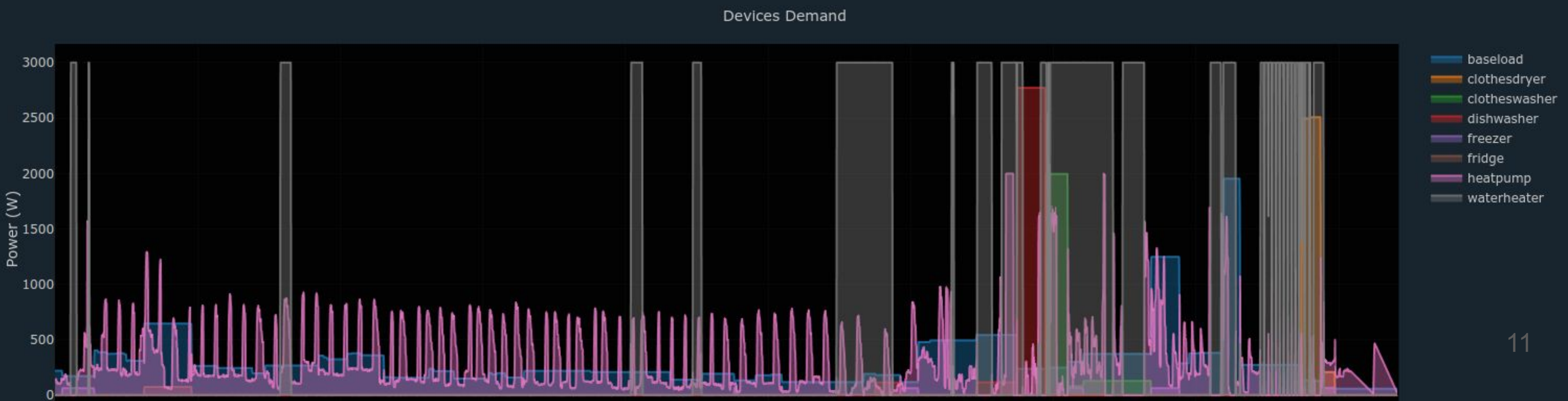
Temp Target: 20

Humidity In: 98

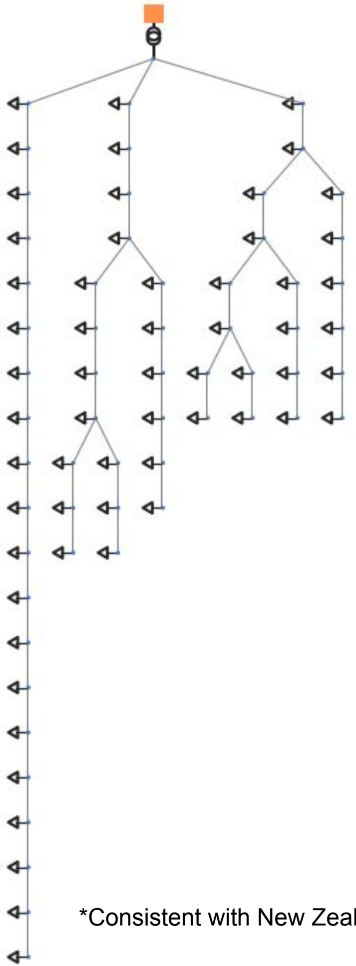
Flexibility: -0.062

Priority: 0





Case Study: Load Factor Enhancement



Network:

- Dickert Benchmark Residential LV Network*
- Trafo: 300 kVA, 20/0.4 kV, Delta-Wye
- 60 Houses
- 40m average distance between ICPs

Weather:

- Winter 7-days
- Summer 7-days

Location:

- Ardmore, Auckland, New Zealand

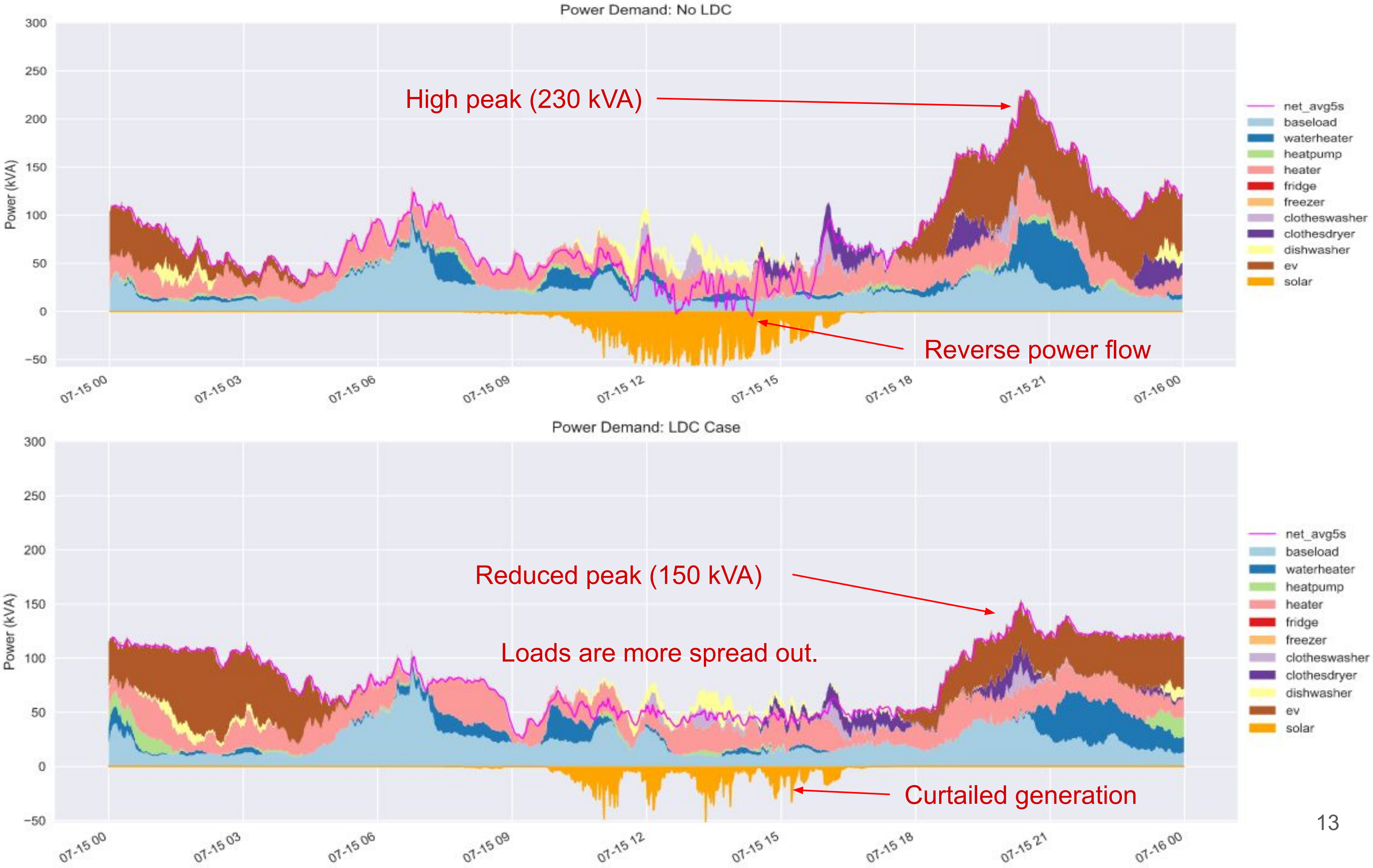
Cases:

- DER adoptions: with LDC vs no LDC
- LDC adoption at 40% DER adoption

	no. of units	units per house
House	60	1.0
heat pump	37	0.61
electric heater	79	1.31
water heater	48	0.8
fridge	79	1.31
freezer	30	0.5
clothes washer	65	1.08
clothes dryer	47	0.78
dishwasher	41	0.69
electric vehicle	*var	*var
solar PV	*var	*var

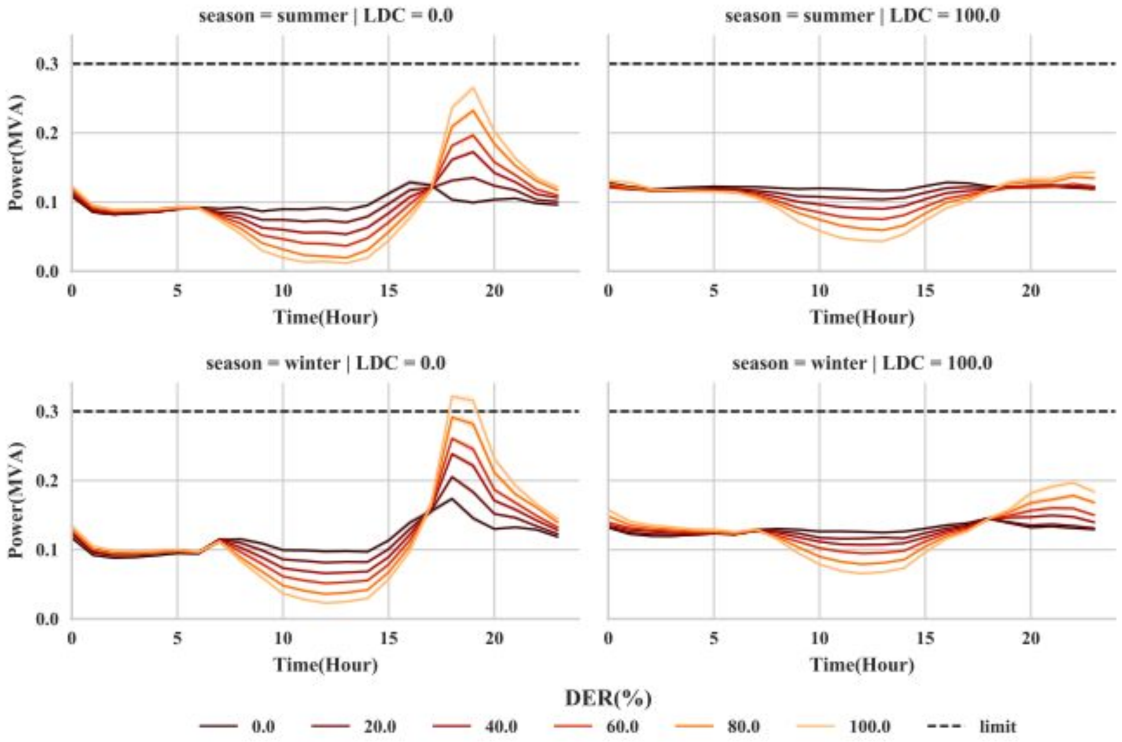
*Consistent with New Zealand networks as studied by Watson et al.

Results

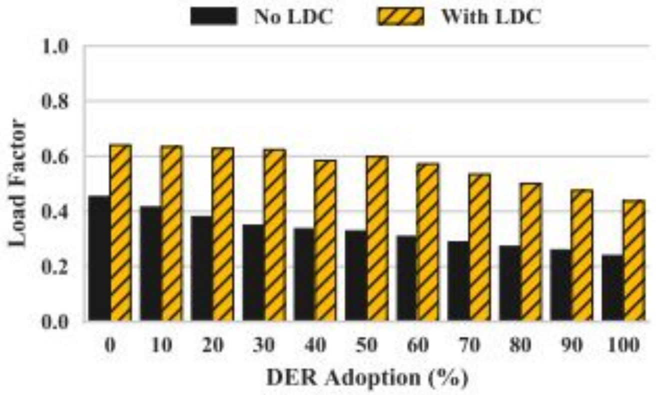


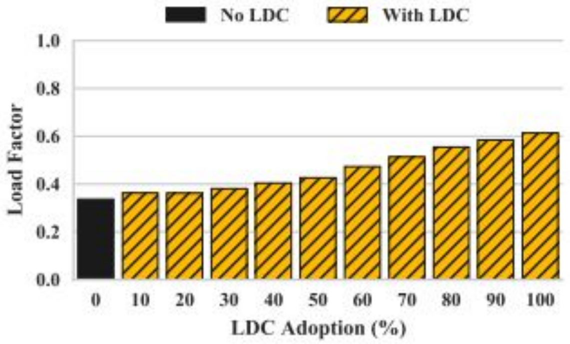
Power Demand: No LDC
High peak (230 kVA)
Reverse power flow
Power Demand: LDC Case
Reduced peak (150 kVA)
Loads are more spread out.
Curtailed generation
Power (kVA)
net_avg5s
baseload
waterheater
heatpump
heater
fridge
freezer
clotheswasher
clothesdryer
dishwasher
ev
solar
07-15 00
07-15 03
07-15 06
07-15 09
07-15 12
07-15 15
07-15 18
07-15 21
07-16 00

Results



Note: EV and PV adoption are assumed equal: %DER = %PV = %EV





While setting DER Adoption at 40% the highest improvement in Load Factor happens between 50% to 80% LDC adoption.

Summary of LDC Merits and Potentials

LDC Functionalities

- Shift local demand
- Curtail local generation
- Manage battery-based loads
- Follow target net power demand

Local Applications

- Reduce peaks
- Increase load factor
- Avoid reverse power
- Integrate PV and EV
- Implications:
  - Defer costly upgrades
  - Better asset utilization

Future Applications

- Dispatchable demand
- Better load forecasting
- Ancillary service
  - change setpoint based on f, V
- Assist blackstart
- Offer demand response service
- Vehicle to Grid
- Implications
  - Opportunity: revenue stream
  - Savings-->Reduce power cost

Conclusion

- Increase in adoption of DERs is inevitable
- DERs causes issues at the local grids
- Traditional “wire” solutions are risky
- Existing Demand Response program may overlook the issues of the local grids
- Localized Demand Control can help prepare local grids for more DER adoption

Research progress and recommended future topics...

- Priority loads for enrollment to LDC system (done)
- Advanced algorithms (on going...)
- Scaling up for the wider grid (optimal demand settings)
- Application for vehicle to grid
- Pilot test on a local grid with more ICPs
- Cost-benefit analysis of LDC vs alternative solutions
- Market structure for shared value for all stakeholders
- Policy requirements

Our team is actively talking with potential partners in the industry to develop and bring the LDC technology to reality.

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