CanmetENERGY Research Summary:

Smart Zone Planning with Variable Renewable Generation

Introduction

A five year project spanning 2011-15, the Smart Zone research project focussed on developing knowledge and tools for electric grid planning with variable renewable generation. Its research contributions centered on

a. the modelling and characterization of residential loads, renewable generation, and storage; and
b. the design and simulation of electric grid architecture and smart grid solutions to enable high penetration renewables and increased grid security and reliability.

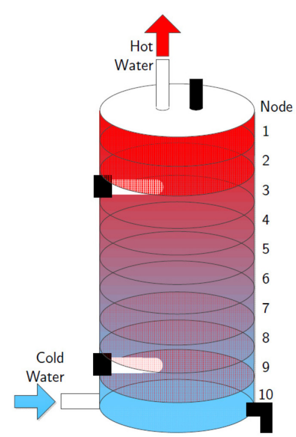
This research emphasized new and upcoming opportunities. The smart grid, with its two-way communications capabilities, is believed to facilitate new and exciting opportunities for residential loads to actively participate in the electric grid. Making up one-third of Canada's electric consumption, the residential sector's large number of small loads is good candidates for providing demand response (DR, controlled deviation of a load's power draw away from normal behaviour) and inexpensive (non-battery) storage.

Modelling of Residential Thermal Storage Options

The residential sector's largest loads are electric space heating, space cooling, and water heating; they account for significant overall energy use and are major contributors to system load peaks. These attributes, coupled with each load's intrinsic thermal storage capacity, make them worth exploring as potential DR candidates. Here, CanmetENERGY characterized, modelled, and appraised major residential loads for their potential as a DR resource.

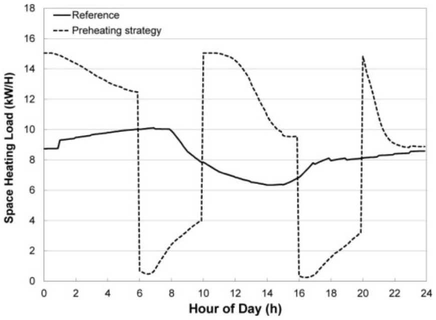
Smart Grid Integration of Electric Water Heaters

Electric water heaters (EWHs) have long been used in simple DR programs such as for peak shaving. With recent advancements in smart grid technologies, the full storage potential of EWHs can now be realized. In this research, studies backed by theory, simulations, and lab experiments were carried out to better appreciate how EWHs operate individually and as a population. It was discovered that between 3 and 6 kWh of thermal storage per EWH could effectively be used for DR by capitalizing on temperature stratification. The impacts of seasonal effects and population sizes were also explored in this work, which has been summarized into a useful guide, "Designing, Operating, and Simulating Electric Water Heater Populations for the Smart Grid [4]" for any audience looking to building and controlling smart grid EWHs.



The benefits of water stratification for EWH DR applications were observed experimentally and through simulation.

Housing Models to Evaluate Space Heating & Cooling DR Potential



Space heating load profiles for 1000 Quebec homes – preheating reduces load by 9 kW/home at 6 am and 7 kW/home at 9 am

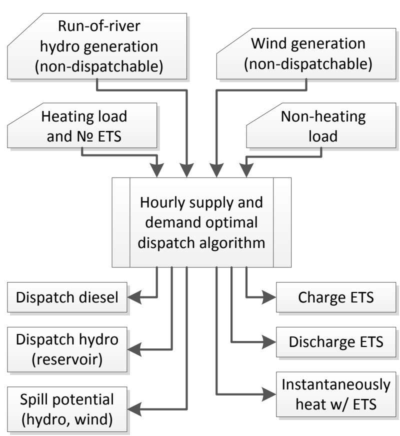
While smart thermostats have been opening up opportunities for capturing thermal storage inherent to residential homes, there were yet any tools or models to quantify this potential for large populations. Under this research, an easily deployable model and simulation tool to estimate space heating and cooling DR potential for all major communities in Canada was created, "A Housing Model to Evaluate the Impact of Space Heating and Cooling Demand Response Strategies in Canada [6]". This 4-capacitance model was designed to accept readily available household data and predict, e.g., temperature and power draw, response to thermostat schedules on minute to hourly time-scales. This model is suitable for fast simulations of large-scale regional population studies.

This model was used to explore the mechanism behind using thermal envelopes for DR. Methods for evaluating the DR potential from the thermal envelopes of buildings were developed and typical reserve and peak shaving potential were evaluated for Canadian houses showing the opportunity to use temperature setbacks for peak shaving and reserve provision.

Renewable Energy System Integration Studies

A number of system integration studies were also carried out on different provinces, exploring the capabilities of residential DR to enable renewable generation (wind and solar PV) amongst existing generation and loads.

Yukon –Integrating Wind with ETS

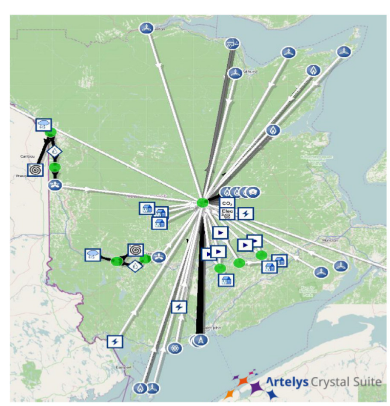


A mathematical model was created to predict how a mid-sized system would integrate with ETS and wind.

Electric thermal storage (ETS, basically heated bricks in an insulated box) can be used to alter electric heating demand without affecting occupant comfort. In this work, a methodology was created to evaluate how ETS can be used in an isolated hydro-electric grid to increase adoption of variable renewable generation [10]. A case study of Yukon's electric grid showed that ETS could be effective in complementing wind to reduce diesel consumption by capturing otherwise spilled wind energy (though with high capital costs still a barrier). Furthermore, it was shown that at higher penetrations, smart ETS (as opposed to those controlled through time-of-use) were a necessity.

New Brunswick – Reducing Generation Costs with Residential DR

The New Brunswick bulk generation system was reproduced, using readily available data, to study how flexibility from residential ETS and EWH DR could benefit existing and proposed wind projects [8]. Using optimal unit commitment and dispatch (generation costing) approaches, it was found that ETS' higher capacity enabled greater savings in energy costs while the year-round availability of EWHs were especially suited for reducing curtailment of renewable generation. Similar to the Yukon study, smart devices were found to have benefits over and above what could be achieved using time-of-use approaches.



New Brunswick was selected for its wide composition of generation types (nuclear, coal, oil, hydro, and wind).

Ontario – Measuring and Mitigating Options for Wind Oversupply

Oversupply can generally be defined as when (i) most or all baseload generators are supplying power at their minimum loading levels; (ii) one or more baseload generators are curtailed off to prevent excess generation; or (iii) one or more renewable energy generators are curtailed off to prevent excess generation. It can lead to a variety of drawbacks, including low or negative electricity prices, curtailment of generation from renewable sources, increased greenhouse gas emissions, and added limits on renewable energy. In this research, various methods to identify oversupply using readily available and public data were explored; these methods were then demonstrated on Ontario's system with a variety of renewable generation mixes imposed [1]. Through this work, the potential benefits of EWH DR to enable high penetrations of renewables were identified [2,3].

DR Potential and Opportunities Survey

The greatest technical potential for residential DR originates from electric space heating, space cooling, and water heating. However, for geographic, climatic, resource and historical reasons, the availability of these DR sources varies widely across the country (e.g., electric space heating is common in QC but not in AB). Taking into account this variability, it is estimated that there is more than 39 GW/85 GWh of DR potential from residential loads [7].

Service	BC	AB & SK	MB	ON	QC	NB	NS	PE	NL
Space Heating									
Regulation	↗	–	↗	↑	·	–	↗	–	·
Load Following	–	–	–	–	–	–	↑	–	·
Spinning	↗	–	↗	↗	·	↑	↑	–	·
Non-Spinning	↗	–	↗	↗	·	↗	↗	–	·
Replacement	–	–	–	–	·	↑	↑	–	·
Space Cooling									
Regulation	–	–	↗	↗	–	–	–	–	–
[Other Services]	–	–	–	–	–	–	–	–	–
Water Heating									
Regulation	↗	–	↗	↑	·	–	↗	–	·
Load Following	–	–	–	–	–	–	↑	–	·
Spinning	↗	–	↗	↗	·	↑	↑	↑	·
Non-Spinning	↗	–	↗	↗	·	↗	↗	↗	·
Replacement	–	–	–	–	·	↑	↑	↑	·

Combined ancillary service and DR residential potential, as evaluated by weighing DR technical potential with the size and value of the AS market in each province, is ranked as low (–), moderate (↗), or high (↑). (A [·] denotes insufficient data.)

In addition to enabling more renewables, there are other business cases for DR – among then, providing ancillary services (ASs, resources engaged to support the transmission of energy through the bulk electric grid.) Like DR potential, the value of these services varies widely across the country. This research characterized the existing ASs and determined the potential of each against the different possible DR resources while considering technology and availability [7].

Outreach and Other Outputs

- Demand Response Workshop (held biennially, contact for more info)
- Contributions to various International Energy Agency reports, including "Harnessing Variable Renewables: A Guide to the Balancing Challenge", "Smart Grid Roadmap," "Energy Technology Perspectives," and "Impact of Smart Grid Technologies of Peak Load"
- IEEE Canada Magazine Article "Delivering more clean electricity with virtual power plants" [5]
- DSMLab, A tool for assessing the demand response and renewable integration potential of distribution systems [9]

Project Team Members and Partners

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Partners: Artelys Crystal · École Polytechnique de Montréal · Sherbrooke Hydro · Yukon Energy Solutions Centre

Further Info

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Publications

[1] Steven Wong and Sophie Pelland, "Power System Oversupply: Scenario Analyses with and without Renewable Energy," Report No. 2012-201 (RP-TEC), CanmetENERGY, Varennes Research Centre, Natural Resources Canada, Jan. 2013.

[2] Steven Wong and Sophie Pelland, "Mitigation Approaches to Power System Oversupply with Residential Electric Water Heater Demand Response," Report No. 2012-246 (RP-TEC), CanmetENERGY, Varennes Research Centre, Natural Resources Canada, Jan. 2013.

[3] Steven Wong and Sophie Pelland, "Demand response potential of water heaters to mitigate minimum generation conditions," *2013 IEEE Power & Energy Society General Meeting*, Vancouver, BC, 2013.

[4] Steven Wong, Wajid Muneer, Salman Nazir and Alexandre Prieur, "Designing, Operating, and Simulating Electric Water Heater Populations for the Smart Grid," Report No. 2013-136 (RP-TEC), CanmetENERGY, Varennes Research Centre, Natural Resources Canada, Oct. 2013.

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[6] Véronique Delisle, Alexandre Gagné and Steven Wong, "A Housing Model to Evaluate the Impact of Space Heating and Cooling Demand Response Strategies in Canada," Report No. 2015-054 (RP-TEC), CanmetENERGY, Varennes Research Centre, Natural Resources Canada, Apr. 2015

[7] Steven Wong, "Canadian Residential Demand Response and Ancillary Service Market Opportunities," Report No. 2015-022 (RP-TEC), CanmetENERGY, Varennes Research Centre, Natural Resources Canada, Apr. 2015.

[8] Steven Wong, "Residential Smart Heating Benefits: A New Brunswick Case Study," Report No. 2015-158 (RP-TEC), CanmetENERGY, Varennes Research Centre, Natural Resources Canada, Apr. 2015.

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[10] Steven Wong and Jean-Paul Pinard, "Opportunities for Smart Electric Thermal Storage on Electric Grids With Renewable Energy," *IEEE Transactions on Smart Grid*, 2016 [In Press]