Impacts of High Penetrations of Home Energy Management Systems under Time-Based Electricity Prices

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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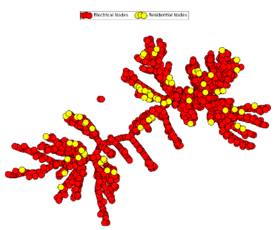
Objectives

The objective of this work is to evaluate the opportunities for buildings to increase system-wide energy efficiency and to provide services that reduce the cost of generation, transmission, and distribution infrastructure through advanced integrated control of distributed energy resources (DERs) such as solar photovoltaics, demand response, and distributed storage. This work also aims to understand how high penetrations of home energy management systems (HEMS) reacting to time-based electricity prices impact the power system. The analysis uses NREL's Integrated Energy System Model (IESM) that was developed to evaluate various combinations of tariffs and technologies.

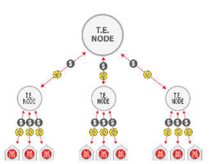
Methodology of Study

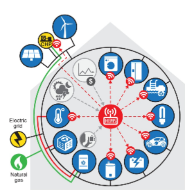
A feeder was chosen that represented a heavily populated suburban area with a moderately populated urban area [1].



Nodes	946
Voltage (kV)	22.9
Load (kW)	12,000
Residential Transformers	284
Commercial Transformers	14
Houses	505

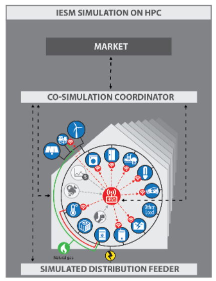
HEMS participating in a transactive energy market can help meet the objective of both residential customers and utilities. For this work, model predictive price-responsive HEMS [2] were deployed for every residential consumer on the feeder, allowing consumers to respond to time-of-use prices. Weather data for Charlotte, North Carolina was used for a typical meteorological year.





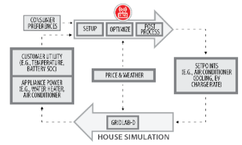
Simulation Framework

The IESM [3] was employed as a simulation framework.

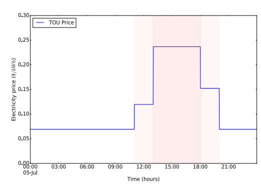


The IESM is a co-simulation platform that links models and, when desired, hardware. It employs a distributed, real-time capable, discrete-event modeling and simulation paradigm to manage time. GridLAB-D was used to simulate a distribution feeder and the residential houses that are connected to it. The HEMS controllers were developed in the General Algebraic Modeling System (GAMS) language and solved using Gurobi.

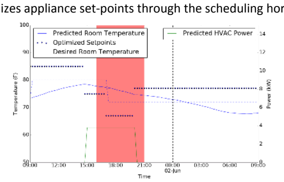
The IESM was designed to run on a high-performance computing cluster, taking advantage of the parallel execution of hundreds of instances of complex controllers.



Consumer preferences such as objective component weights and desired set-point profiles were supplied as an input to every HEMS controller.

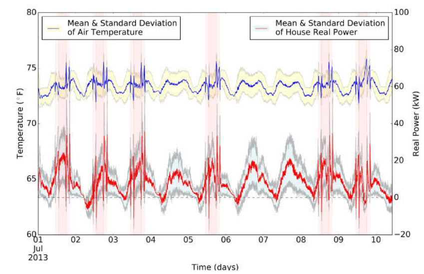


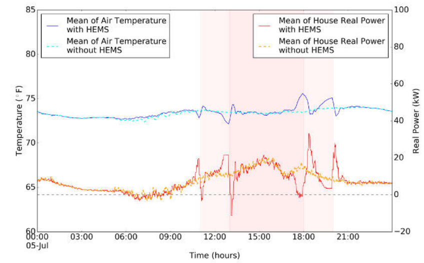
The HEMS optimizes appliance set-points through the scheduling horizon.



Results

System behavior differs prior to and after changes in price signals. Specifically, the air-conditioning units being on prior to an increase in price results in an increase in the average real power consumption and a decrease in the average indoor air temperature.





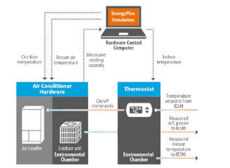
These changes are caused by the HEMS as a result of the model-predictive-control-based optimization it performs, anticipating the price increase and precooling the houses subject to comfort requirements prior to the price increase.

Conclusions

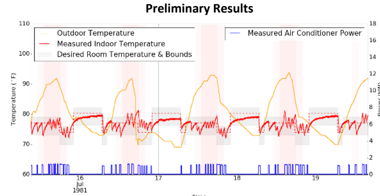
The presence of many HEMS on the system, all responding to the same price signal, results in the synchronization of the operation of the air conditioners. This synchronization shifts the system peak from higher-price periods to lower-price periods, fulfilling one intent of TOU pricing; however it also increases the system's peak load by more than 50%, increases the distribution transformers' peak load, and causes larger ramps, all of which place more strain on grid infrastructure. Because of the high penetration of HEMS, these changes also negatively impact voltage profiles, with lower voltages observed at times of higher peak and more variability in voltage due to power swings. These effects are undesirable for a system operator and they highlight the need for coordinated operation.

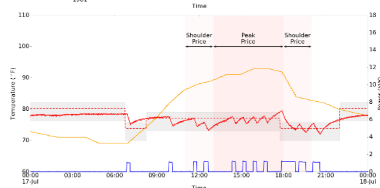
Smart Home Hardware-in-the-Loop (HIL)

HIL experiments combine large-scale software simulation with hardware evaluation of a small set of representative systems to reduce costs and provide high fidelity modeling.

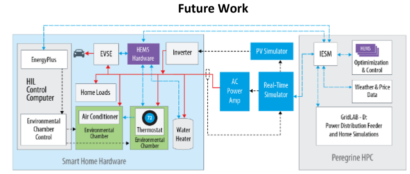


Preliminary Results





Future Work



References

[1] K. P. Schneider, Y. Chen, D. Engle and D. Chassin, "A Taxonomy of North American radial distribution feeders", IEEE Power & Energy Society General Meeting, Calgary, AB, 2009, pp 1-6

[2] H. Wu, A. Pratt and S. Chakraborty, "Stochastic optimal scheduling of residential appliances with renewable energy sources", 2015 IEEE Power & Energy Society General Meeting, Denver, CO, 2015, pp. 1-5

[3] S. Mittal, M. Ruth, A. Pratt, M. Lunacek, D. Krishnamurthy, and W. Jones, "A system-of-systems approach for integrated energy systems modeling and simulation", Proceedings of the Conference on Summer Computer Simulation, pp 1-10. Society for Computer Simulation International, 2015

Additional Reading

A. Pratt, D. Krishnamurthy, M. Ruth, H. Wu, M. Lunacek and P. Vaynshenk, "Transactive Home Energy Management Systems: The Impact of Their Proliferation on the Electric Grid", in IEEE Electrification Magazine, vol. 4, no. 4, pp. 8-14, Dec. 2016

A. Pratt, M. Ruth, D. Krishnamurthy, B. Sparn, M. Lunacek, W. jones, H. Wu, S. Mittal, J. Marks, "Hardware-in-the-Loop Simulation of a Distribution System with Air Conditioners under Model Predictive Control", 2017 IEEE Power & Energy General Meeting, Chicago, IL (to appear)

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