NREL CITIES Support

Cooperative Research and Development Final Report

CRADA Number: CRD-14-00558

NREL Technical Contact: Benjamin Kroposki

NREL is a national laboratory of the U.S. Department of Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-77641
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Suggested Citation
Kroposki, Benjamin. 2020. *NREL CITIES Support: Cooperative Research and Development Final Report, CRADA Number CRD-14-00558.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-77641.
https://www.nrel.gov/docs/fy20osti/77641.pdf.

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This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Grid Modernization Laboratory Consortium (GMLC). The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

Cooperative Research and Development Final Report

Report Date: August 14, 2020

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Technical University of Denmark

CRADA Number: CRD-14-00558

CRADA Title: NREL CITIES Support

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Sponsoring DOE Program Office(s): U.S. Department of Energy Grid Modernization Laboratory Consortium (GMLC)

Partnering Facilities: Energy Systems Integration Facility (ESIF)

Joint Work Statement Funding Table showing DOE commitment:

No NREL Shared Resources

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$.00
TOTALS	$.00

Executive Summary of CRADA Work:

The Technical University of Denmark has received a Grant from the Danish Council for Strategic Research for the project "CITIES - Centre for IT-Intelligent Energy Systems in Cities", a strategic research centre, which involves industrial partners and universities. The Alliance for Sustainable Energy, LLC will participate with DTU as an industrial partner in "CITIES" under this Cooperative Research and Development Agreement (CRADA).

The Centre for IT based Intelligent Energy Systems in Cities (CITIES) Project is a Danish national research center focused on work in building short-term operational integrated energy system models that feed longer term plam1ing models, considering the spatio-temporal variations, interactions, dynamics and stochastics in the energy system, from production to consumption. CITIES will harness the extensive expertise and experience of its industrial and academic partners to conduct meaningful research with tangible outputs, including a roadmap to a fossil free future. Decision support tools will be developed to inform stakeholders of the impact of investment, control and policy measures and to identify further opportunities for energy system efficiency.

Dissemination and transferring knowledge is a key value to this CRADA, and the use of results by Danish policymakers, industry and society is vital. All participants in the Centre for IT based Intelligent Energy Systems in Cities (CITIES) Project are therefore encouraged to use all means to communicate their findings to society. Wherever possible, and compatible with applicable intellectual property regulations, publications should be produced and disseminated under Open Science, Data, Source and Access principles.

Summary of Research Results:

Task 1: CITIES Research Support
Under this task, NREL will provide support by provide guidance on modeling, simulation and analysis of integrated energy system and evaluate the use of the Energy Systems Integration Facility (ESIF) for supporting this project. The ESIF capabilities incorporate large-scale testing of energy system components and complete systems as well as high performance computing and visualization.

Results
The project task was completed by NREL and results are summarized below.

In order to achieve the ambitious goal of a fully renewable Danish energy system, an overhaul of the operation, monitoring and planning of the entire energy system is necessary. By moving from the traditional view of the power, heating, cooling, water and other systems as completely separate, centralized and mostly radial, to recognizing the significant opportunities for efficiency and emission reduction brought about by allowing these systems to fully integrate and interact with one another. Integration of previously distinct energy systems allows for flexibility throughout the system, so that society's needs for energy can be met while considering the fluctuating nature of many renewable energy resources. Integrated Information and Communications Technology (ICT) powered systems offer the possibility of intermediate conversion and storage of energy in forms including power [sub-daily], heat (including the district heating network) [daily] and gas [seasonal], providing an essential service to balance the variations in wind and other forms of renewable energy production and ensure the security of energy supply. The high density and diversity of energy use and networks within a city environment, coupled with the expressed desire to achieve sustainability within cities maims them an ideal framework for this research activity.

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system models that feed longer term plam1ing models, considering the spatio-temporal variations, interactions, dynamics and stochastics in the energy system, from production to consumption. Low level models of system components will inform higher-level aggregate models employed in market and control framework design. Cities, with a high density of energy activity and networks, offer the greatest potential for flexibility at the least cost, and play a dominant role in current and future energy consumption, making them an ideal basis for the research in CITIES. CITIES will harness the extensive expertise and experience of its industrial and academic partners to conduct meaningful research with tangible outputs, including a roadmap to a fossil free future. Decision support tools will be developed to inform stakeholders of the impact of investment, control and policy measures and to identify further opportunities for energy system efficiency.

The novelty of this project lies in its integrated approach, focus on cities, and also its recognition that the planning and simulation of complex energy systems are not possible without simulation and understanding of the effects of operational tools, such as forecasting, control and demand side management.

One of the largest accomplishments of this project was to define Energy Systems Integration (ESI) and describe its value proposition. ESI was defined as the process of coordinating the operation and planning of energy systems across multiple pathways and/or geographical scales to deliver reliable, cost- effective energy services with minimal impact on the environment[1]. ESI includes interactions among energy vectors (electricity, thermal, and fuels) and interactions with other large-scale infrastructures including water, transport, and data and communications networks—which are an enabling technology for ESI as shown in Figure 1.

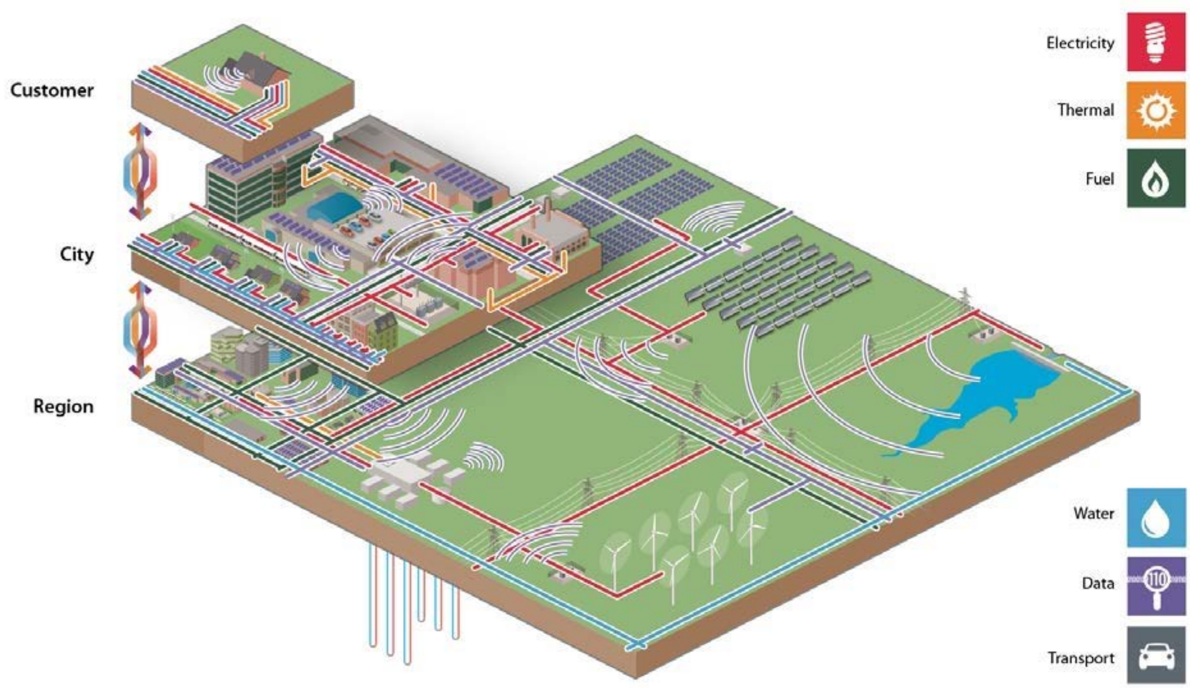

Figure 1. Overview of Energy Systems Integration

ESI is most valuable at the physical, institutional, and spatial interfaces, where there are new challenges and opportunities for research, demonstration, and deployment to reap its commercial and societal benefits. ESI is a multidisciplinary area ranging from science, engineering, and technology to policy, economics, regulation, and human behavior. It is this focus simultaneously on breadth and depth that makes ESI such a challenging and exciting area. ESI is an important concept to make the energy system more flexible, enable the efficient integration of renewable energy and to reduce carbon emissions. ESI solutions can range from the very simple to the very complex, are system specific, and impact different actors in distinct ways. They can require expertise from a single discipline or from a multitude of disciplines. It is important to understand the ESI value proposition and to communicate it in order to educate energy professionals and foster knowledge creation and transfer.

Additional results in the project focused on examining demand response (DR) as a way to increase flexibility in the operation of energy systems. DR proponents widely laud its prospective benefits, which include enabling higher penetrations of variable renewable generation at lower cost than alternative storage technologies, and improving economic efficiency. In practice, DR from the commercial and residential sectors is largely an emerging, not a mature, resource, and its actual costs and benefits need to be studied to determine promising combinations of physical DR resource, enabling controls and communications, power system characteristics, regulatory environments, market structures, and business models. The work during this project focused on the enablement of such analysis from the production cost modeling perspective[2]. In particular, a bottom-up methodology for modeling load-shifting DR in production cost models was developed. The resulting model is sufficiently detailed to reflect the physical characteristics and constraints of the underlying flexible load, and includes the possibility of capturing diurnal and seasonal variations in the resource. Nonetheless, the model is of low complexity and thus suitable for inclusion in conventional unit commitment and market clearing algorithms. The ability to simulate DR as an operational resource on a power system over a year facilitates an assessment of its time-varying value to the power system. The graphical representation of DR for power systems is shown in Figure 2. Each population of flexible DR devices can offer a number of demand response products which resembles a battery sufficiently to use this description in a power system model, subject to some additions. Each product has a defined maximum power supply to and draw from the grid, and a period within which the response and recovery must balance. This model describes the maximum flexibility of a load-shifting device in the form of a saturation curve, which illustrates the relationship between a power adjustment in a flexible load and the duration for which the adjustment can be maintained.

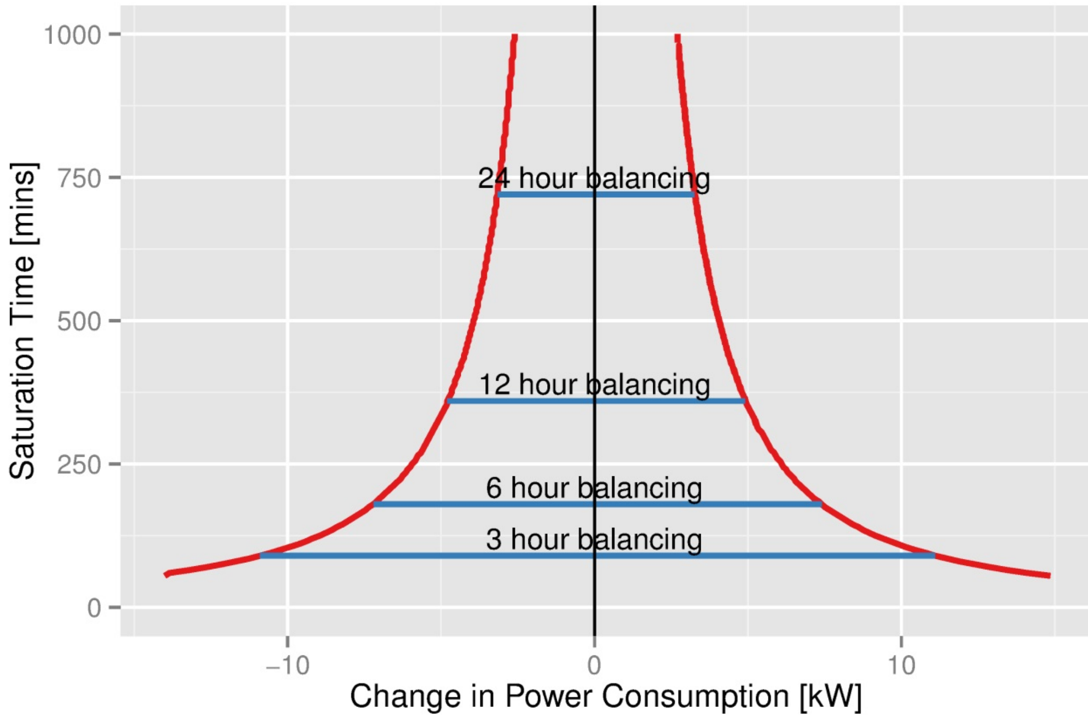

Figure 2. DR saturation model

The modeling methodology is demonstrated through a case study of aggregated supermarket refrigeration systems providing balancing energy reserves in real-time markets at different levels of variable generation. This DR resource is implemented in a test power system that represents a subset of the U.S Western Interconnection centered on Colorado.

The project also examined the concept of "Transactive Energy" (TE) and conducted significant work simulating transactive control in distribution systems [3] . NREL, University of Colorado, South Dakota State and DTU performed their simulation using the Integrated Energy Systems Model (IESM) co- simulation platform. The team implemented network-aware TE controls in the IESM co-simulation framework that manages distribution feeder voltages based on real-time optimal power flow. This is one part of a multi-timescale TE control approach that NREL is developing to reduce costs for both balancing power supply and demand and managing distribution feeder voltages. This multi-timescale TE approach uses a price signal based on two components: an energy price based on wholesale prices and bids by participating DERs that adjusts on a 5-15 min market cycle, plus an incentive signal overlay for fast grid services, updated every 1-10s.

For the TE Challenge, NREL simulated only the calculation of the incentive signals for voltage regulation services and used the time-of-use (TOU) price as the energy price. A distribution network controller monitors voltage at each house, estimates future power usage and flexibility of homes, runs a power flow model, and uses this information to generate per-house incentive signals for both active and reactive power. Collectively, the TOU energy price plus the per-house incentive signal enables the controllable house devices (air conditioners and PV) to provide voltage regulation services in addition to managing energy costs and comfort for house occupants.

The team found that PV system response to active and reactive power incentive signals and air conditioner response to active power incentive signals provided an effective tool to reduce voltage violations in addition to the load shifting produced in response to the TOU price. The TE approach reduced voltage violations by approximately 80 % as compared to the scenario with the same weather and no control while holding the average air temperature to within 2 °F of the desired set point (indicating only a small impact on occupant comfort).

Analysis of the TE approach, as compared to the case of no control, showed nearly the same average energy cost but with wider cost variation, and a few houses with costs significantly higher or lower than the median cost. More extensive analysis using a longer test period is required to determine appropriate levels of compensation for PV curtailment and reactive power support that will ensure fair compensation to houses that provide voltage regulation services. Future work is also warranted to address how unique per-house prices can be applied while ensuring a socially acceptable level of fairness.

The research also examined integration of a very large share of variable renewable energy sources into the energy system [4]. To do this, an integrated energy planning approach was used, including ice storage in the cooling sector, a smart charging option in the transport sector, and an excess capacity of reverse osmosis technology that was utilized in order to provide flexibility to the energy system. A unit commitment and economic dispatch tool (PLEXOS) was used, and the model was run with both 5 min and 1 h time resolutions. The case study was carried out for a typical Caribbean island nation, based on data derived from measured data from Aruba. The results showed that 78.1% of the final electricity demand in 2020 was met by variable renewable energy sources, having 1.0% of curtailed energy in the energy system. The total economic cost of the modelled energy system was similar to the current energy system, dominated by the fossil fuel imports. The results are relevant for many populated islands and island nations.

Finally, Center Denmark, which is a new Danish national digitalization hub for data-intelligent and integrated energy systems was created. As Denmark approaches 50% variable renewable in the power systems (on average), the need for digitalization and sector coupling has become crucial. In the establishment and design of Center Denmark has been heavily influenced by this research and the NREL Energy Systems Integration Facility. A main difference is that Center Denmark is controlling Living Labs in real-world settings.

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Subject Inventions Listing:

None

ROI #:

None