December 2016

Electricity Use in Rural and Islanded Communities

Electricity is fundamental to the nation's economy, quality of life, health, and safety. However, there is wide variability in the technological, institutional, and regulatory features of electricity systems and end users across the country. Rural, isolated, and islanded communities face unique challenges in maintaining electric reliability, affordability, and resiliency compared to more densely populated urban areas. For example, isolated villages in Alaska and customers in the state of Hawaii rely heavily on imported petroleum fuels for electricity generation, which results in high electricity prices that are several times the national average and exposes these communities to greater supply chain vulnerability. In the continental United States, rural communities have low population densities separated by large distances and are often located on the remote edges of an aging electricity infrastructure. In part because of these challenges, many rural and islanded communities are on the leading edge of deploying new technologies, operational strategies, and financial mechanisms to improve end-use efficiency and affordability, increase electricity system resilience, and reduce electricity-related greenhouse gas emissions. An example of this is shown in Figure 1, which depicts one rural electricity cooperative's proposed net metering rate structure—a potentially contentious decision facing the electricity industry broadly—that avoids fixed charges while sustaining the growth of distributed generation.

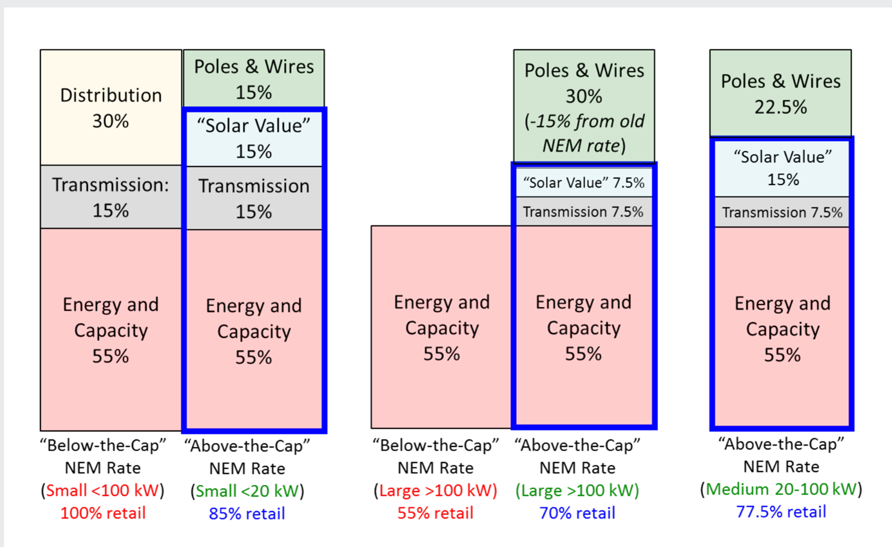


FIGURE 1 - New ("above-the-cap") net metering rate structures compensate customers with a variable percentage of the full retail cost for power based on the size of installation, while allowing the New Hampshire Electric Cooperative to collect the remaining amount for costs associated with grid maintenance and administration. Customers who established net metering accounts prior to reaching the statutory cap ("below-the-cap") retain original rates. NOTE: Percentages shown are illustrative, and actual values vary. SOURCE: Modified from Ken Colburn, Regulatory Assistance Project, "Rate Design: New Times Warrant New Approaches," presentation to the workshop, February 8, 2016.

In support of the Department of Energy's Quadrennial Energy Review public outreach efforts, the National Academies of Sciences, Engineering, and Medicine convened the Workshop on Electricity Use in Rural and Islanded Communities on February 8-9, 2016, to better understand the challenges, opportunities, and strategies emerging from these unique areas. Karen Wayland, Deputy Director for State and Local Cooperation in the Office of Energy Policy and Systems Analysis at the Department of Energy, opened the event with an overview of the Quadrennial Energy Review and emphasized the importance of understanding operational, historical, and regional differences in the U.S. electricity sector prior to developing national electricity policy. Speakers from Hawaii, Alaska, and rural electric cooperatives throughout the continental United States then shared best practices and suggestions for future federal activities to improve electricity systems serving these communities. This document highlights themes that emerged from these presentations and ensuing discussions. Workshop presentations, along with a complete workshop summary, are available on the website of the Board on Energy and Environmental Systems (www.nas.edu/bees).

RURAL COOPERATIVES ARE THE NATION'S LABORATORIES FOR ELECTRICITY

Electricity service in rural areas is largely provided by more than 900 electric cooperatives, whose service territories cover 75 percent of the U.S. land area but supply electricity for only 15 percent of the population (Figure 2).[1] Innovations in technology, demand-side management, end-use efficiency financing, and alternative rate structures demonstrated on small scales by rural electric cooperatives can prove viabil-

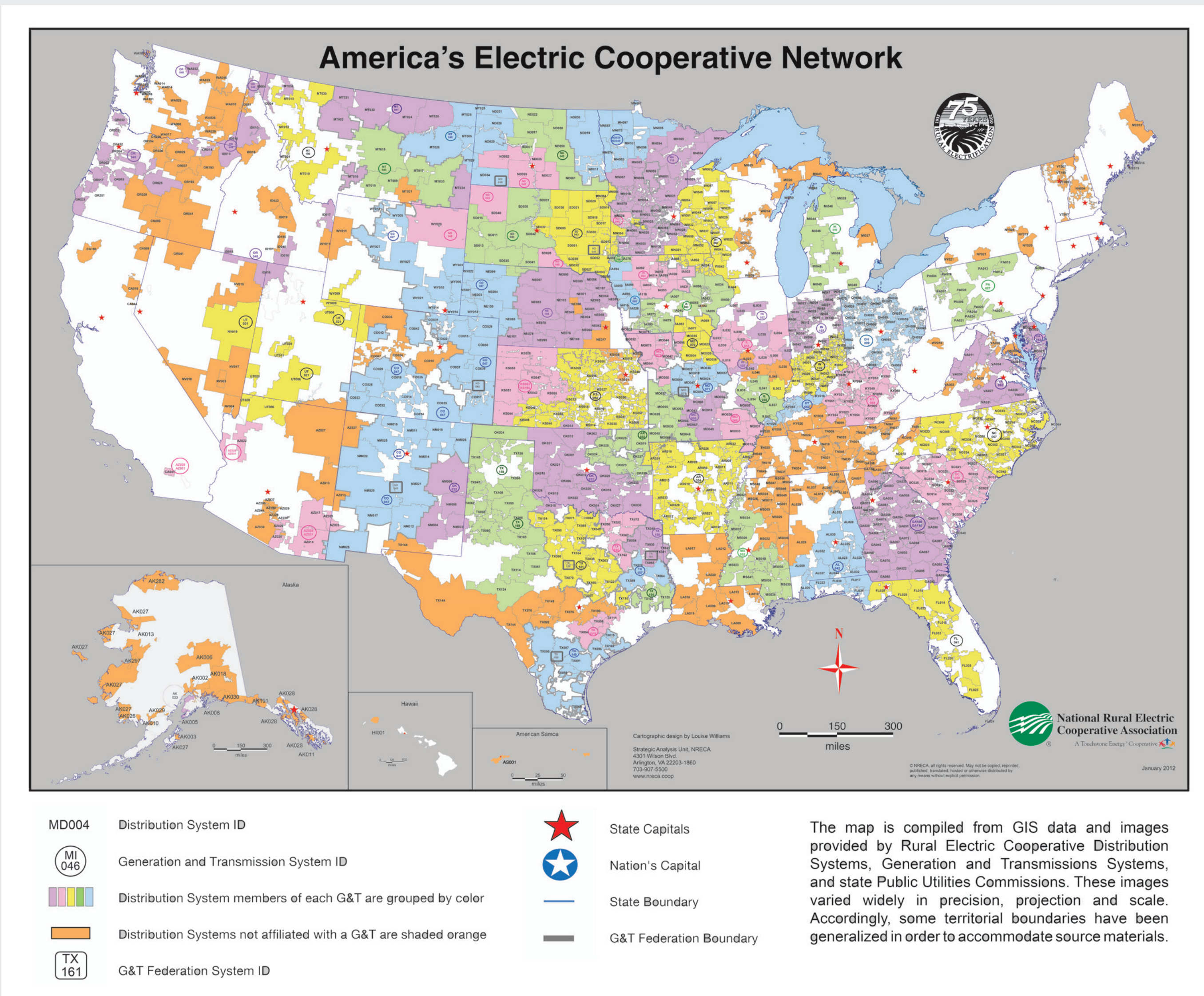
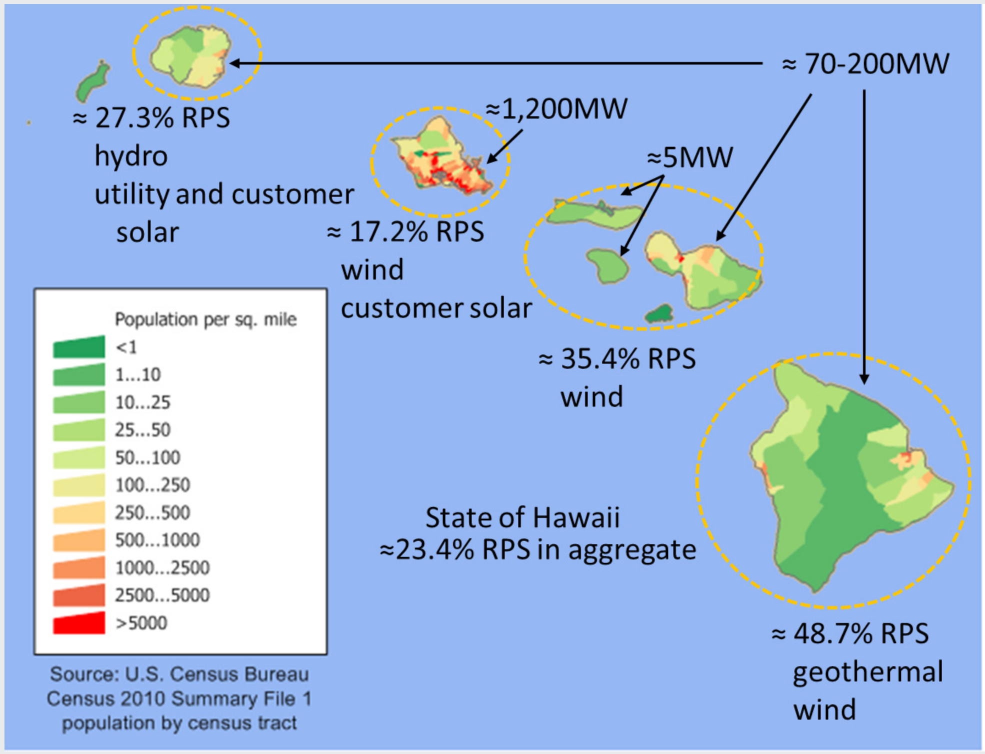


FIGURE 2 - Map of the more than 900 electric cooperative service territories across the United States. Distribution cooperatives are grouped by color according to generation and transmission (G&T) cooperative membership, while distribution cooperatives not affiliated with a G&T are shown in orange. Cooperatives cover approximately 75 percent of the country's area but serve less than 15 percent of total customers. SOURCE: Reproduced with permission from the National Rural Electric Cooperative Association.

FIGURE 3 - The Hawaiian Islands have diverse population densities and electricity system characteristics, with isolated grids ranging from 5 megawatts (MW) up to 1,200 MW. Each island has different levels of renewable generation and resource mixes. NOTE: Data shown is for calendar year 2015,[2] and values do not include distributed generation. RPS stands for Renewable Portfolio Standard as described in footnote links. SOURCE: Modified from Chris Yunker, Hawaii State Energy Office, "Islanded Communities: Issues and Differences," presentation to the workshop, February 8, 2016. Population density map © Jim Irwin, licensed under creative commons 3.0 (CC-BY SA 3.0).



ity and pave the way for wider adoption across the United States. Emphasizing the opportunity for cooperatives to provide leadership, workshop speaker Ken Colburn, New Hampshire Electric Cooperative, said, "Just as the states are laboratories for democracy, cooperatives are laboratories for electricity . . . use those laboratories to identify, evaluate, and promote best practices" to create a virtuous cycle of innovation and improvement across all electric cooperatives and the industry more broadly.

The workshop featured presentations from several cooperatives that demonstrated how streamlined decision making and close alignment with their member-owners allowed them to operate flexibly and resourcefully despite their relative lack of resources. Gary Connett, from the Minnesota co-op Great River Energy (GRE), told participants that GRE controls more than 110,000 hot water heaters to store 1 gigawatt-hour of energy every night. Combining this "battery in the basement" with community solar projects allows GRE to supply renewable energy to customers who value it while providing the utility with more tools to balance variable generation and load. Colburn described how New Hampshire Electric Cooperative established a new net metering rate structure (Figure 1) that avoids fixed charges, recovers sufficient funds for distribution system maintenance, and sustains the growth of distributed generation. Curtis Wynn of Roanoke Electric Cooperative presented an innovative home efficiency improvement program that leverages low-interest financing from the U.S. Department of Agriculture Rural Utility Service to save money for customers and the cooperative. These and other presentations called attention to the potential for rural cooperatives to provide a testing ground for new technologies, operational strategies, and business models in a rapidly changing electricity system.

HAWAII PAVES THE WAY TO GRIDS WITH LARGE FRACTIONS OF VARIABLE RENEWABLES

In aggregate, utilities in the state of Hawaii reached nearly 25 percent renewable electricity sales in 2015, with some is-

[1] *National Rural Electric Cooperative Association, "The Value of Membership," Annual Report, 2015, http://www.electric.coop/wp-content/uploads/2016/02/2015_NRECA_AnnualReport_final_FINAL.pdf.*

[2] *Kaua'i Island Utility Cooperative, 2016, "2015 Annual Renewable Portfolio Standards ('RPS') Status Report," http://puc.hawaii.gov/wp-content/uploads/2013/07/RPS-KIUC-2015.pdf; Hawaiian Electric Company, 2016, "2015 Renewable Portfolio Standard Status Report," http://puc.hawaii.gov/wp-content/uploads/2013/07/RPS-HECO-2015.pdf; Kaua'i Island Utility Cooperative, 2016, "2015 Adequacy of Supply Statement," https://puc.hawaii.gov/wp-content/uploads/2015/ 04/Adequacy-of-Supply-KIUC-2015.pdf.*

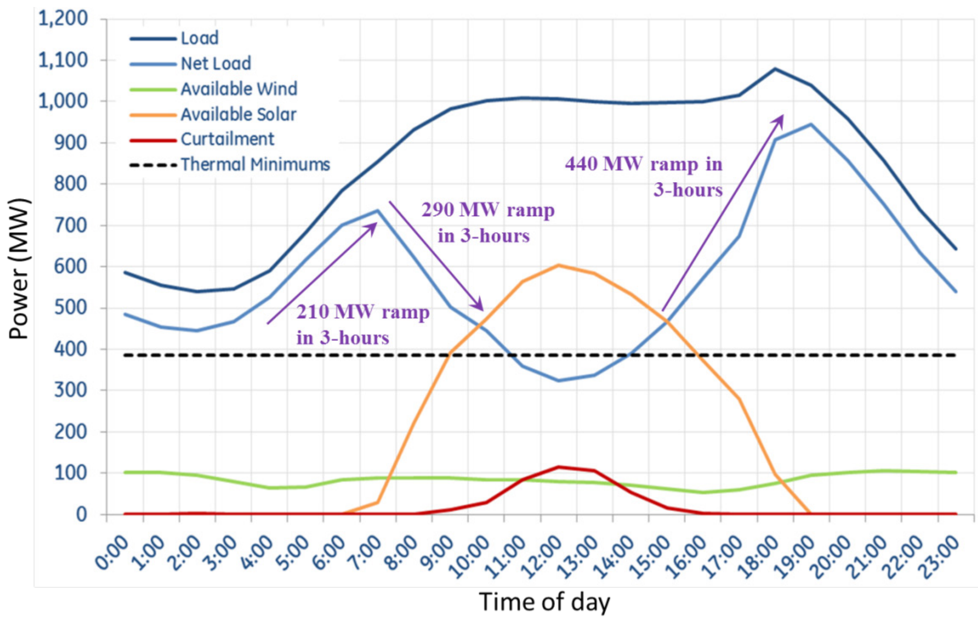


FIGURE 4 - High deployments of solar photovoltaics and associated power production in the middle hours of the day (orange line) result in large ramp rates for thermal generators (black arrows) and create the need for curtailment of renewable generation (red line), storage, or other load management strategies. SOURCE: Richard Rocheleau, Hawaii Natural Energy Institute, "Impact of Distributed Energy Resources on Small Systems is Significant," presentation to the workshop, February 9, 2016.

lands already reporting nearly 50 percent renewable electricity sales (Figure 3). The estimates shown in Figure 3 do not include generation behind customers' meters. Chris Yunker of the Hawaii State Energy Office explained that achieving the state's goal of 100 percent renewable electricity and transportation systems will require advances in technologies, planning processes, operations, and public engagement to expand the level of variable renewables and plug-in electric vehicles while maintaining high electricity reliability. The State Energy Office uses scenario-based planning tools to develop successive 5-year plans that support the state's long-term goal while being cognizant of the limitations of existing systems. Richard Rocheleau, Hawaii Natural Energy Institute, described research collaborations between utilities and the state to evaluate the potential for electric vehicles to reduce peak power consumption through time-of-use electricity rates that encourage daytime charging, thereby providing storage for excess renewable electricity. James Connaughton of C3IoT (formerly C3 Energy) introduced an ongoing project with the state of Hawaii and the utility Hawaiian Electric to develop a common platform to manage all utility data flows—from customer meters through generation facilities. Aggregating such abundant and diverse data flows into a common platform facilitates development of a suite of applications, ranging from customer engagement tools to predictive maintenance and outage prediction, which can greatly improve utility performance.

In leading the way, Hawaii is wrestling with how to address technical challenges and siting and land constraints, as well as managing public perception and engagement efforts. For example, high fractions of solar photovoltaics can result in large ramp rates (i.e., increases and decreases that are technically challenging) for thermal generation stations and may require mid-day curtailment or electricity storage (Figure 4). Terry Surles of the Hawaii Natural Energy Institute explained that some distribution circuits already have installed solar in excess of 250 percent of their minimum daily load, prompting utilities to halt further installation of rooftop solar which in turn caused negative public perception. In discussing the implications of high mid-day renewable generation and associated ramp rates for conventional thermal generators, Ron Meier of La Plata Electric Association described how implementing time-of-use (TOU) rates gave the Colorado cooperative greater control over the shape of their load curve (Figure 5). Specifically, by charging more for electricity during peak load times, La Plata was able to lower peak demand and shift consumption toward the middle of the day. This same approach could help utilities in Hawaii shift consumption to times with high solar generation, thereby reducing the risk of curtailment, although TOU rates can also create challenging ramp rates, as shown in Figure 5. As electricity providers, regulators, and consumers in the state of Hawaii negotiate both public acceptance and technical challenges, Hawaii offers a "postcard from the future"[3] for states moving towards high deployment of renewables. Several speakers illustrated how investments in electricity systems in Hawaii will help fill the toolbox with solutions that other isolated communities and mainland utilities can use when facing similar challenges.

ALASKAN COMMUNITIES FACE UNIQUE ELECTRICITY CHALLENGES, PARTICULARLY IN ISOLATED VILLAGES

Henri Dale, retired from Golden Valley Electric Association, introduced the Alaska Railbelt Electric System, which serves population centers in Anchorage, Fairbanks, and the Kenai Peninsula. These regions are served by long, single transmission lines that are often operated on the edge of defined limits to maximize electricity production from the cheapest sources and improve the economic efficiency of the system. To help improve reliability, the Railbelt system includes a large nickel-cadmium battery energy storage system that can provide power during periods when operators are bringing a generation facility online. The system has reduced load shedding, will allow modulation of system frequency and voltage, and has made operators more confident in running the transmission interties close to defined limits.

Outside of the few relatively populous Alaskan cities, there are numerous isolated villages across remote Alaska that do not have a large transmission system to connect to and instead operate as small islanded grids. The nearly 30,000 members of the Alaska Village Electric Cooperative (AVEC) are spread over large distances, rely predominantly on imported diesel fuel for electricity generation, and face exaggerated capital expenditures for electricity infrastructure. Taken together, these factors result in high electricity prices between $0.50 and $0.80 per kilowatt-hour (Figure 6), which is approximately five times the national average, explained Meera Kohler of AVEC. Electricity systems in Alaskan cities and rural villages have large seasonal variations in electricity consumption and relatively small scales of operation, which makes it difficult to achieve higher system and economic efficiencies. Incorporation of some renewable generation can result in substantial fuel savings, and AVEC is the state's largest owner of wind turbines. However, there are cost and technical limitations to how much power renewables can provide in these villages, explained Marc Mueller-Stoffels of the Alaska Center for Energy and Power. Furthermore, diesel generators are ubiquitous in part because they provide important functions beyond electricity generation, such as production of waste heat and maintenance of sufficient inertia to

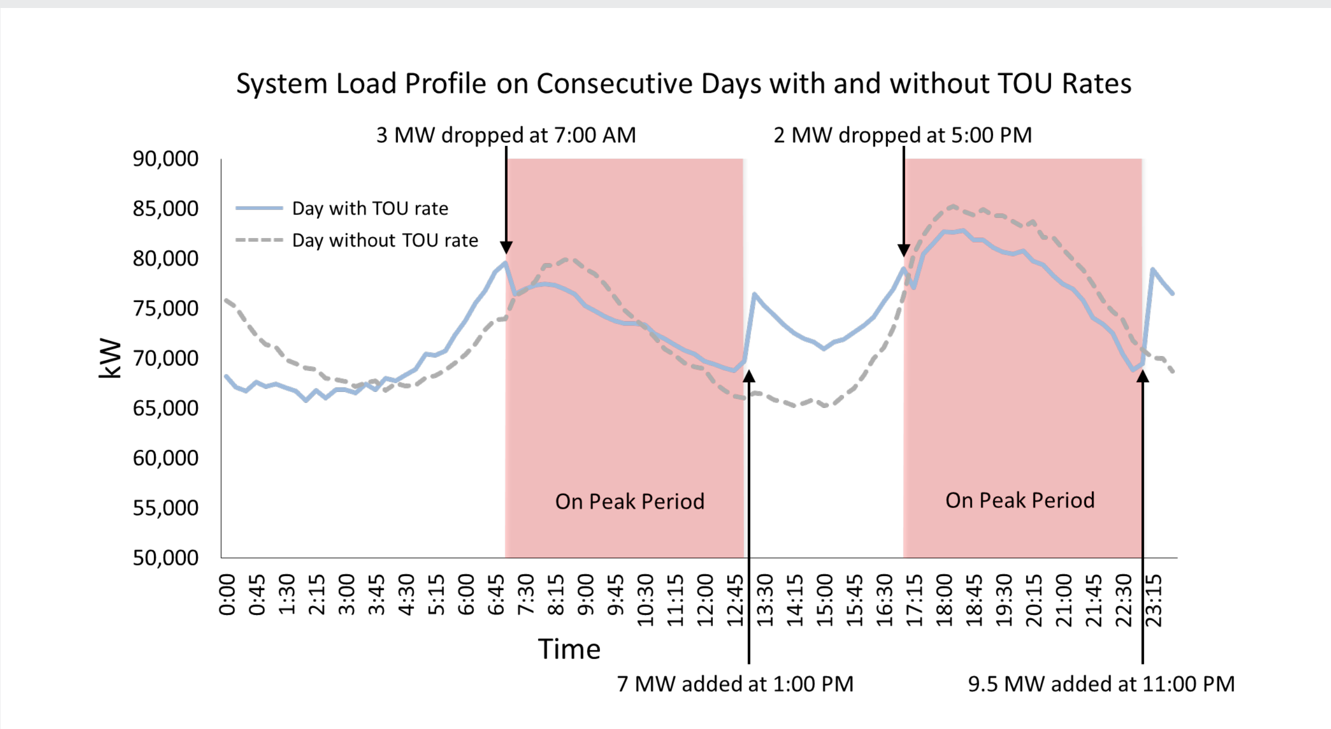


FIGURE 5 - La Plata Electric Cooperative reduced peak power consumption with its time-of-use (TOU) program but had to develop strategies to address the large ramp rates occurring at the end-of-the-peak billing period when thermal storage units all switch on. SOURCE: Modified from Ron Meier, La Plata Electric Association, "Time-of-Use Rates: The Policy, Economics, and Physics," presentation to the workshop, February 8, 2016..

[3] *D. Cardwell, "Solar Power Battle Puts Hawaii at Forefront of Worldwide Changes," New York Times, April 18, 2015, http://www.nytimes.com/2015/04/19/business/energy-environment/solar-power-battle-puts-hawaii-at-forefront-of-worldwide-changes.html?_r=0.*

withstand minor system disturbances. Thus, electricity systems serving Alaskan cities and rural villages typically combine traditional diesel generators, renewables, and energy storage, which in turn require more sophisticated controls. Such control systems require robust communications infrastructure, and several speakers agreed that this is a critical barrier to reducing fuel consumption costs and modernizing electricity systems both in Alaska and throughout the rural continental United States. However, the large distances and remote settings of many villages makes laying fiber optic cable impossible, and improved communications infrastructure will likely come from a less conventional technology.

MICROGRIDS OFFER AN ALTERNATIVE SERVICE DELIVERY MODEL FOR ISOLATED AND REMOTE AREAS

A definition of a microgrid is a group of interconnected loads and distributed energy resources within a clearly defined boundary that acts as a single controllable entity and is able to connect and disconnect from the electricity grid to allow the area to operate in both grid-connected and islanded modes.[4] Steven Rowe from General Electric said that microgrids can improve reliability and resiliency as well as reduce electricity costs in places with high reliance on diesel generators by better utilizing renewable resources. Microgrid installations are becoming more common in remote and islanded locations with high fuel costs, on military installations that require energy assurance, and on some college campuses as a technique to optimize energy use, explained Tom Bialek of San Diego Gas and Electric, a Sempra Utility. He described the components and operational experience at the Borrego Springs microgrid, which is one of only a few utility-owned microgrids serving rate-paying customers in the continental United States. The single transmission line serving the Borrego Springs community is vulnerable, and the microgrid can sustain a fraction of the community's load if service is disrupted—for example, as shown in Figure 7 after severe storms damaged 9 transmission towers, necessitating 25 hours of repairs. Andrew Merton of Spirae, LLC, described an ongoing project upgrading an isolated grid on a Caribbean island with the principal objective to reduce diesel consumption through incorporation of wind power, solar photovoltaics, battery storage, and demand response, while meeting system constraints related to minimum loading and run time for diesel generators.

ROBUST COMMUNICATIONS INFRASTRUCTURE IS A CRITICAL BARRIER FOR MODERNIZING REMOTE ELECTRICITY SYSTEMS

Realizing the full benefits of intelligent devices such as advanced metering infrastructure, distributed sensors, and automated fault restoration on the electric grid requires access to high-bandwidth communications infrastructure to transfer increasingly larger volumes of data. However, isolated communities in Alaska and many rural areas in the

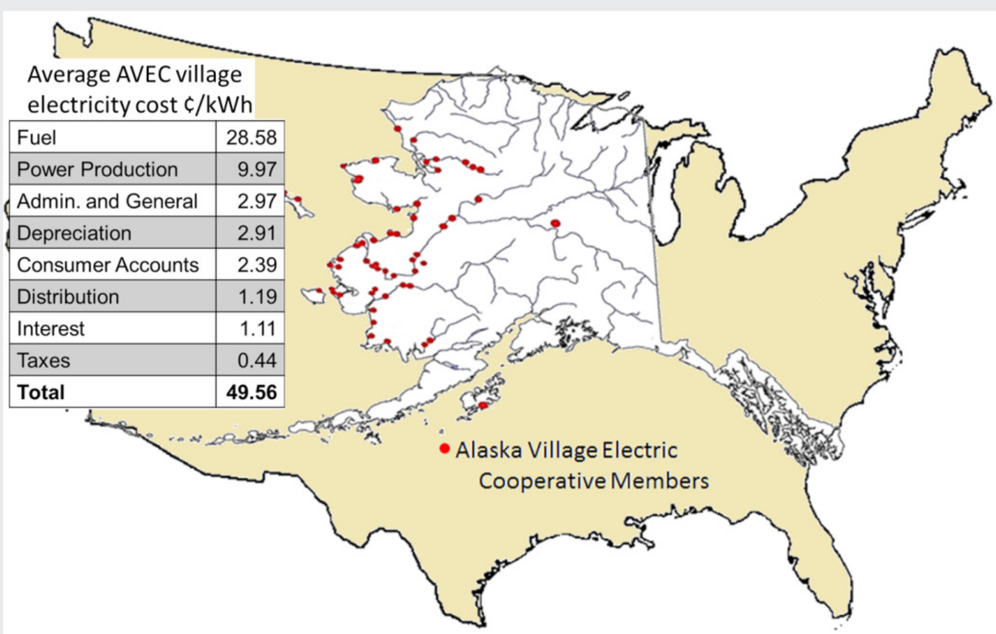


FIGURE 6 - As of 2015, the Alaska Village Electric Cooperative serves more than 50 small communities dispersed across large distances and in remote regions with harsh climatic conditions. All of these factors contribute to average electricity prices approximately 5 times the U.S. national average. SOURCE: Modified from Meera Kohler, Alaska Village Electric Cooperative, "Alaska Village Electric Cooperative," presentation to the workshop, February 8, 2016.

[4] *Lawrence Berkeley National Laboratory, 2016, "Microgrid Definitions: U.S. Department of Energy Microgrid Exchange Group." https://building-microgrid.lbl.gov/microgrid-definitions.*

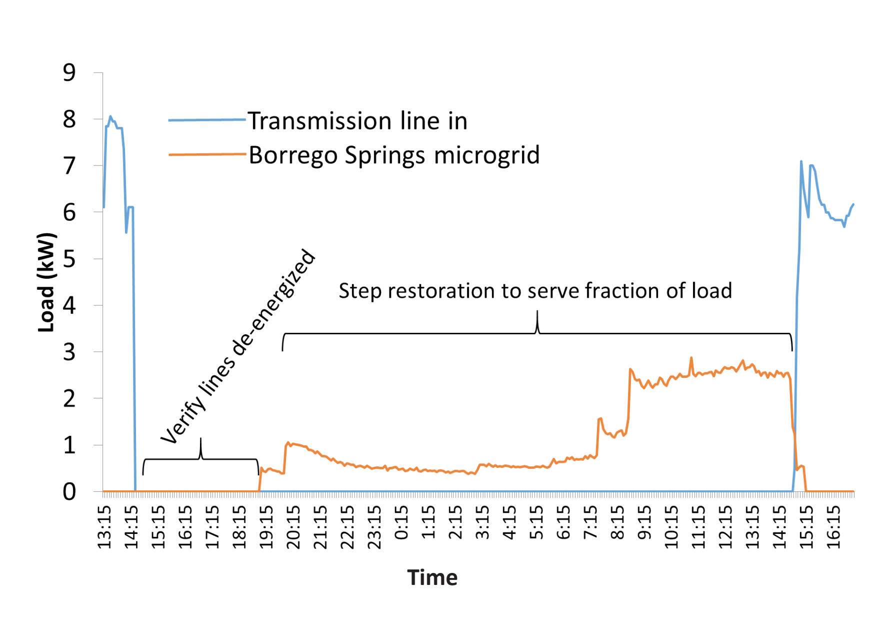


FIGURE 7 - After a severe storm knocked out bulk grid service (blue line), the Borrego Springs microgrid was able to provide power for a fraction of community load in a step restoration process (orange line). From the initial loss of power (14:35) it took approximately 4 hours to access the area and verify that lines were de-energized, at which point (18:35) the microgrid began powering affected customers. SOURCE: Tom Bialek, San Diego Gas and Electric, a Sempra Utility, "Utility Role in Microgrids," presentation to the workshop, February 9, 2016.

continental United States have limited or no coverage from large commercial high-speed internet providers, in part due to lower population densities, topological constraints, and large geographical distances. Several presenters including Meera Kohler of the Alaska Village Electric Cooperative and Curtis Wynn of Roanoke Electric Cooperative identified the lack of communications infrastructure in rural areas as a critical barrier to improving electricity system resilience, reliability, and efficiency. Chris McLean, Assistant Administrator of the United States Department of Agriculture Rural Utility Service Electric Program, explained that low-interest loans made available through his organization must be for electricity system improvements and not solely for providing communications infrastructure. However, as electricity infrastructure becomes increasingly dependent on high-speed communications, promoting wider adoption of smart grid technologies in rural and isolated areas becomes more important, and there are opportunities to improve coordination between communications and electricity providers as well as between groups that finance rural development. Some rural cooperatives are on the leading edge of smart grid technology adoption already, said McLean, in part because of access to low-interest capital from the U.S. Department of Agriculture Rural Utility Service—a resource that is unique to rural communities.

SUPPORT NEEDED FOR DEVELOPMENT OF STANDARDS AND PROTOCOLS FOR EASY INTEROPERABILITY

The growth of distributed energy resources such as solar photovoltaics, batteries, and smart inverters, as well as deployment of advanced metering infrastructure, distributed sensors, and controls on the grid and in customers' homes, imply a critical need to develop common standards and communications protocols for grid-connected intelligent devices. Many components currently rely on distinct communications protocols, and combining devices from different manufacturers into functioning, controllable systems can require multiple communication protocol conversions. For example, Richard Rocheleau of the Hawaii Natural Energy Institute commented on the large amount of time and resources his team must invest simply to get different components to communicate properly and work together. Rocheleau and other speakers encouraged the Department of Energy and professional societies such as the Institute of Electrical and Electronics Engineers to take an active role in developing common communications protocols and standards for equipment that will be connected to transmission and distribution circuits. James Connaughton commented that although the federal government is doing important work in this area, it will take a larger concerted effort on the parts of both component manufacturers and users to move toward common standards for data exchange in the context of grid modernization.

THERE MAY BE A ROLE FOR DISTRIBUTION SYSTEM OPERATORS

Several presenters suggested that, as distributed energy resources and customer demand response play an increasingly important role in electricity systems, there will be a growing need for aggregation and management of two-way power flows on and between individual distribution circuits. Joe Brannan, North Carolina Electric Membership Corporation, said that today's distribution systems were not designed for this, as they serve only as wires to deliver power to consumers. He suggested there is significant value to be created for customers through creation of distribution system operators that aggregate and manage bi-directional power flows on this small scale. Richard Silkman, of Grid Solar, LLC, discussed a pilot project in the area surrounding Boothbay, Maine, in which Grid Solar actively manages distributed solar, demand response, diesel generators, and a battery to meet variable load in times of high transmission congestion. In this capacity, Grid Solar is acting as an independent entity that procures and manages, but does not own, assets on the distribution level, and Silkman suggested the practice should become more widespread. Analogous to the independent system operators of the transmission system that emerged following electricity market deregulation, these independent distribution system operators would provide unbiased access to distribution infrastructure for small-scale generation and load-controlling assets, said Silkman.

SPEAKERS: Tom Bialek, San Diego Gas and Electric, a Sempra Utility; Joe Brannan, North Carolina Electric Membership Corporation; Ken Colburn, New Hampshire Electric Cooperative; James Connaughton, C3IoT; Gary Connett, Great River Energy; Henri Dale, H Dale, LLC and retired from Golden Valley Electric Association; David Dunn, Green Mountain Power; R. Neal Elliott, American Council for an Energy-Efficient Economy; Aloke Gupta, Imergy Power Systems; Kerrick Johnson, Vermont Electric Power Company; Meera Kohler, Alaska Village Electric Cooperative; Chris McLean, U.S. Department of Agriculture; Ron Meier, La Plata Electric Association; Andrew Merton, Spirae, LLC; Marc Mueller-Stoffels, Alaska Center for Energy and Power; Richard Rocheleau, Hawaii Natural Energy Institute; Steven Rowe, General Electric; Richard Silkman, Grid Solar, LLC; Jennie C. Stephens, University of Vermont; Terry Surles, Hawaii Natural Energy Institute; David Wade, Electric Power Board Chattanooga; Karen Wayland, U.S. Department of Energy; Curtis Wynn, Roanoke Electric Cooperative; Chris Yunker, Hawaii State Energy Office

PLANNING COMMITTEE: Tom Bialek, San Diego Gas and Electric, a Sempra Utility; Michael Dworkin, Vermont Law School; Mark Glick, Hawaii State Energy Office; John Kassakian, Massachusetts Institute of Technology; Meera Kohler, Alaska Village Electric Cooperative; Pam Silberstein, National Rural Electric Cooperative Association

STAFF: Linda Casola, Senior Program Assistant; Elizabeth Euller, Senior Program Assistant; K. John Holmes, Associate Board Director/Scholar, Study Director; Ben A. Wender, Associate Program Officer; E. Jonathan Yanger, Research Associate; James J. Zucchetto, Board Director, Board on Energy and Environmental Systems

DISCLAIMER: This Workshop Highlights was prepared by Ben Wender of the Board on Energy and Environmental Systems as a factual summary of what occurred at the meeting. The committee's role was limited to planning the event. The statements made are those of the individual workshop participants and do not necessarily represent the views of all participants, the planning committee, the board, of the National Academies. The full proceedings is available for download at http://nap.edu/23539.

Division on Engineering and Physical Sciences

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people's lives worldwide.
www.national-academies.org