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CASE STUDY

Kauai Island Utility Cooperative: *The Impact of Extensive PV Penetration*

BY TOM LOVAS
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ARTICLE SNAPSHOT:

What has changed in the industry?
Solar energy has become of significant interest to cooperatives as a viable option for both on-site and utility-scale applications of renewable energy. As the availability and cost of solar systems have provided for greater applicability, cooperatives may encounter unprecedented expansion of this distributed energy resource.

What is the impact on electric cooperatives?
Cooperatives faced with the potential of increasing deployment of solar energy systems may be unprepared for the administrative and operating conditions that arise from increasing deployment of solar as a share of the renewable energy portfolio.

What do cooperatives need to know or do about it?
Co-ops can use the lessons learned from the experience of a cooperative that has seen dramatic growth in solar photovoltaic systems to understand the issues and be prepared as solar PV grows in importance for both on-site energy supply and as a shared resource.

EXECUTIVE SUMMARY

Around the country, electric cooperatives are experiencing an increasing rate in the development of on-site and community solar installations. A significant share of the nationwide growth in solar installations has occurred on the Hawaiian Islands, as solar facilities have become increasing cost-effective in tropical locations with high electricity costs. Kauai Island Utility Cooperative (KIUC) has been a leader in solar deployments, for both on-site solar installations by consumers and utility-scale systems. By 2016, Kauai will be obtaining over 17 percent of its annual electricity from solar generation. Under clear sun conditions, around 80 to 95 percent of the daytime demand will be met by the installed solar capacity.

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The challenge faced by KIUC will be in maximizing the contribution of low-cost solar and other valuable renewable resources while operating conventional generation to maintain grid reliability and frequency control. The experience of KIUC from this rapid growth of photovoltaic (PV) solar power on Kauai Island provides a rich source of reference material on the impact of extensive PV penetration. The lessons learned from the KIUC experience with rapid and extensive solar penetration can help guide other cooperatives as solar development becomes an increasingly significant contributor to the power supply portfolio.

INTRODUCTION: THE KIUC SYSTEM

Kauai Island Utility Cooperative is the exclusive provider of utility electric service to the residences and businesses on the island of Kauai, the fourth largest island of the state of Hawaii. KIUC's system is vertically integrated, providing all of the facilities, equipment, and personnel to provide power generation, transmission, and retail distribution. There are no interconnections to other electrical systems or other islands.

KIUC provides electricity to more than 28,000 residential consumers, 4,600 commercial consumers and 130 large power consumers. In addition, KIUC supplies three irrigation consumers and the island's public street and highway lighting. The utility operates 121.3 Megawatts (MW) of generating capacity at two locations—93.8 MW at Port Allen and 27.5 MW at Kapaia. Two hydroelectric facilities are currently in use at the Waiahi Power Station, providing an additional 1.3 MW of power, for a total of 122.6 MW of traditional generation facilities. Additional power supply is provided by three agricultural producers and three classes of solar photovoltaic sources that provide energy on an "as-available" basis.

FIGURE 1: Communities—Kauai Island

The KIUC system all-time coincident peak load was 78 MW in 2007. The 2014 system energy sales of 429,925 MWh was delivered via 171 miles of transmission circuit, 1,006 miles of overhead distribution circuit, and 304 miles of underground distribution. KIUC operates seven transmission switchyards and five primary distribution substations. The system's current load profile varies from a low of 30 MW to a daytime peak of around 73 MW, with a daytime average of between 60 MW and 65 MW. The system peak for KIUC typically occurs in early evening. In 2014, the system peak of 72.9 MW occurred at 7:52 PM on a Sunday evening at the end of September.

Consumer density varies across the island, with dense populations located at major communities, lower density throughout the agricultural areas, and significant portions of uninhabited space, primarily mauka (inland) from the coastline and on the western shore. Major population locations are identified in Figure 1, and the associated generation and transmission facilities of KIUC are shown on **Figure 2**.

KIUC rates and tariffs are regulated by the Hawaii Public Utility Commission (HPUC). The HPUC has also established certain operational criteria that apply to the planning and operating of the electrical system. These include specific requirements for the level of capability required of the system (i.e., capacity margin to

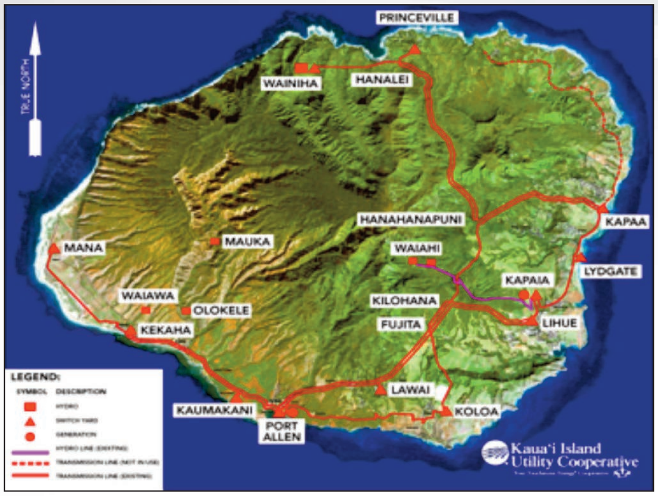

FIGURE 2: KIUC Generation and Transmission

The regulatory conditions for KIUC include HPUC's requirement for Integrated Resource Plans and mandate of renewable energy goals.

ensure adequate installed reserve), provisions for public review of transmission construction plans for circuits of 45 kilovolts (kV) and above, and construction in excess of $2.5 million (HPUC General Order No. 7).

The regulatory conditions for KIUC include the HPUC's requirement that KIUC prepare Integrated Resource Plans (IRPs) for a 20-year planning horizon. The HPUC's IRP framework for electric utilities specifies that:

> *"The goal of integrated resource planning is to develop an Action Plan that governs how the utility will meet energy objectives and consumer energy needs consistent with state energy policies and goals, while providing safe and reliable utility service at reasonable cost, through the development of Resource Plans and Scenarios of possible futures that provide a broader long-term perspective."*

Beyond the IRP requirements, the State of Hawaii has mandated certain renewable energy goals for electric utilities. In particular, the Hawaii Renewable Portfolio Standard (RPS) mandates 10 percent renewable net electricity sales by 2010, 15 percent by 2015, 25 percent by 2020, and 40 percent by 2030.[1] Hawaii also has enacted Greenhouse Gas legislation requiring a reduction in greenhouse gas emissions to 1990 levels by 2020, and is undertaking a Clean Energy Initiative that targets 70 percent clean energy by 2030 (40 percent renewable energy) to which KIUC voluntarily participates with an aggressive target to reach 50 percent renewable energy.

An underlying consideration for KIUC is the unique circumstances of a true island grid and limited power supply options. The traditional source of power supply has been facilities in two locations operating on fossil fuels—diesel and naptha—with the retail residential rates ranging between 22¢/kWh and 49¢/kWh, varying over time in direct relation to the cost of fuel for energy production. The rate profile for representative consumers throughout the most recent calendar year is described in Table 1.

Table 1: KIUC Average Rates by Class of Service

Class of Service	Average Retail Rate 2014, ¢/kWh
Residential	43.0
General Lighting Service	42.5
Large Power[2]	39.2
Streetlights	57.6
Irrigation	31.1

Due to recent reductions in the cost of fuel, however, the energy component of the retail rates has fallen, reducing the residential rate to about 36.5¢/kWh, with commensurate reductions in the energy component of other rate classes.

[1] On May 5, 2015, the Hawaii Legislature passed, and Governor subsequently signed on June 10th, House Bill 623 into law (Act 97, 2015 Session Laws), accelerating the mandate to 30 percent by 2020, 70 percent by 2040, and 100 percent by 2045.

[2] Customers served under the Large Power rate schedules are large commercial customers such as resorts, shopping centers, hospitals, and other facilities.

Efforts have been underway at KIUC, in accordance with the intent of the KIUC board and management, to move to a system of 50 percent renewable energy sources.

Unique circumstances arise from the terrestrial nesting on Kauai of the threatened Newell's Shearwater and endangered Hawaiian Petrel seabirds. During their fledgling period, these birds seek their way out to sea and may collide with manmade structures. As a result, wind turbine generation is not an option for KIUC, although a wind resource is available. KIUC instead has participated extensively in the Save our Shearwaters (SOS) program on Kauai and its Habitat Conservation Plan, including active monitoring of the flight patterns and flight corridors of the seabirds, and has focused on development of solar and hydroelectric renewable resource alternatives.[3]

THE KIUC RENEWABLE PORTFOLIO

Efforts have been underway at KIUC, in accordance with the intent of the KIUC board and management, to move to a system of 50 percent renewable energy sources. The Renewable Portfolio Summary, Table 2, provides the

TABLE 2: KIUC Renewable Portfolio Summary

Active In Use	Type	MW	% of Sales
KIUC, Koloa	Solar	12.0	5.5%
KIUC, Anahola (on-line 2nd qtr. 2015)	Solar	12.0	5.5%
Green Energy Team (on-line 2nd qtr. 2015)	Biomass	7.5	12.4%
McBryde, Port Allen	Solar	6.0	2.9%
McBryde, Wainiha	Hydro	4.0	3.6%
KIUC Waiahi	Hydro	1.3	1.4%
McBryde, Kalaheo	Hydro	1.0	0.9%
Gay & Robinson, Olokele	Hydro	1.3	0.8%
KAA, Waimea/Kekaha	Hydro	1.5	0.8%
Pioneer, Waimea	Solar	0.3	0.1%
Kapaa Solar	Solar	1.0	0.4%
MP2, Omao	Solar	0.3	0.1%
Customer Solar	**Solar**	**17.3**	**2.2%**
Total		**65.5**	**36.6%**
UNDER CONSTRUCTION/PERMITTING			
Gay & Robinson, Olokele	Hydro	6.0	4.2%
Customer Solar	**Solar**	**6.6**	**1.0%**
Total		**12.6**	**5.2%**
UNDER CONSIDERATION			
Puu Opae, Kekaha	Hydro	8.3	9.1%
Menehune Ditch, Kekaha	Hydro	1.5	1.5%
Wailua River/Kalepa	Hydro	4.0	5.2%
West Side Pumped Storage	Solar/Hydro	20.0	-.--
Total		**33.8**	**15.8%**
POTENTIAL RENEWABLE RESOURCE		**111.9**	**57.6%**

[3] Involved in the program since the late-1990's, KIUC has been the primary funding source since 2003, and has extensive programs to protect endangered wildlife including power line and lighting reconfiguration, habitat restoration and predator control, research, and injured bird rehabilitation.

PREVIOUS VIEW

perspective of currently available renewable resources, resources under construction, and resources under consideration. Overall, the Portfolio Summary recognizes a renewable resource potential on Kauai of 111.9 MW of hydroelectric and solar power facilities that could provide for up to 57.6 percent of KIUC's annual energy sales.

The effect of the growth in renewable energy sources for KIUC is dramatically reflected in a comparison of the percentage growth in renewable energy sources since 2007 and the reduction in kWh sales of the cooperative. Although a portion of the decline in energy sales between 2007 and 2009 was attributable to the economic recession, the growth in renewable energy sources clearly reflects the self-generation aspect of customer-supplied energy, even during the periods of economic recovery on the island since the economic recession. Figure 3 provides a comparison of the growth in KIUC's renewable energy sources and the system change in sales between 2007 and 2014.

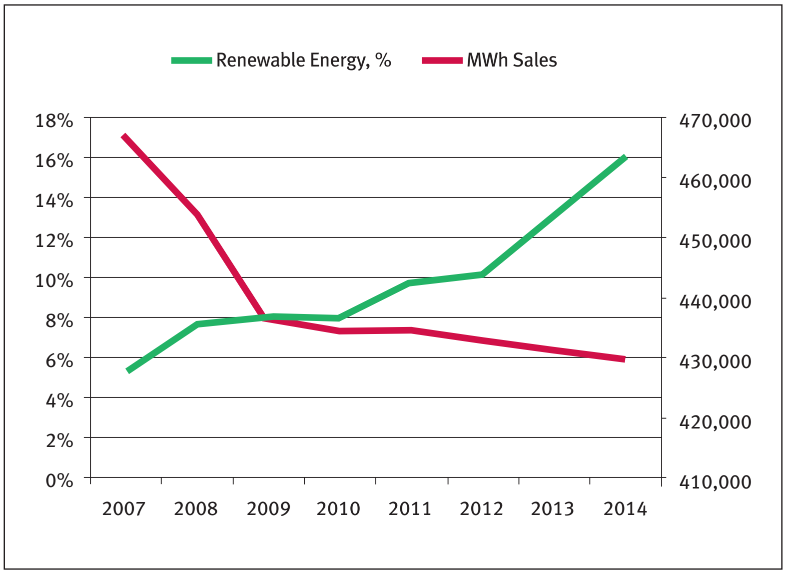

FIGURE 3: KIUC Renewables Growth and Energy Sales, 2007-2014

In April 2015, KIUC was honored by the Solar Electric Power Association (SEPA) as one of the nation's Top 10 utilities for delivery of solar energy to its customers, and was ranked No. 4 on the list of electric utilities in 2014 that added the most new solar power to their systems on a watts-per-customer basis. The cooperative was ranked sixth among all utilities for the cumulative watts installed per customer. With the addition of about 500 customer-sited photovoltaic systems in 2014 and its own 12 MW array in Koloa, KIUC had added 503 watts of solar per customer on the grid. By the end of 2014, KIUC had nearly 37 megawatts of solar and about 2,400 PV systems on its grid, more than any other utility cooperative in the U.S.[4] The ranking, which identified the companies that are most quickly integrating solar into the nation's power grid, is part of the eighth annual Utility Solar Rankings report issued by SEPA. KIUC has been listed among SEPA's Top 10 for solar integration since the rankings began.

With nearly 37 MW of solar PV currently in service, solar contributes as much as two-thirds of Kauai's daytime demand during periods of clear sun, and provides for about 11.2 percent of the annual energy sales. The customer-owned PV resource on-line and operational reached 17.3 MW as of year-end 2014. After providing for on-site requirements, the customer-owned PV contributes energy for about 2.2 percent of those annual sales. KIUC continues to offer programs that enable residential and commercial members to install solar systems, and as of early 2015, there is another 6.6 MW in the interconnection queue that is expected to increase the customer-owned surplus solar energy contribution to 3.2 percent of the co-op's energy sales. In addition, KIUC is completing construction of a second 12 MW utility-scale solar project that is scheduled to come online mid-year 2015.

[4] Press release: *For 8th Year, KIUC Ranks Among Top Utilities for Solar Integration*, April 29, 2015.

THE GROWTH OF NON-UTILITY PV AT KIUC

The growth of consumer-owned and operated PV has been dramatic at KIUC. Although a few PV systems were installed prior to 2005, the rate of increase since has been extraordinary, and under current circumstances likely to continue on a significant trajectory.

There are four categories of consumer-owned renewable or PV installations at KIUC under the four tariff provisions approved by the HPUC. The four categories, described in more detail on the following pages, are:

1. Net Energy Metering (or NEM),
2. NEM "Pilot,"
3. Schedule Q, and
4. Large Customer.

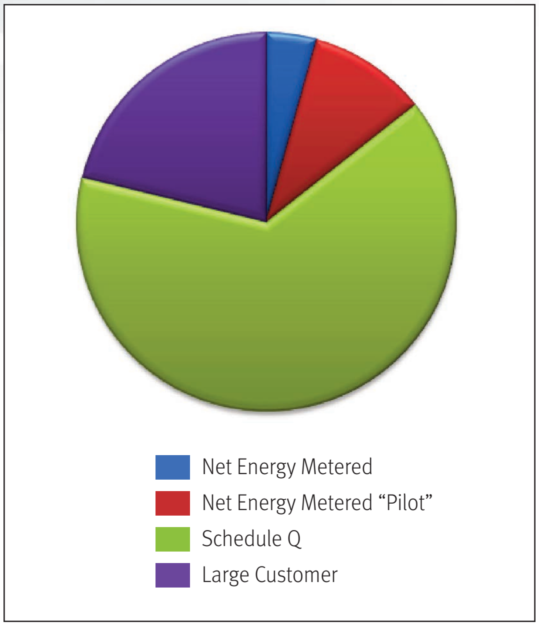

FIGURE 4: Consumer-owned Renewable Resources, % by Tariff 2014

All installations are required to enter into an interconnection agreement with KIUC that specifies the installation and operating guidelines to ensure safe operation. The relative share of each category of PV installation under the tariff provisions is depicted in Figure 4 with Schedule Q installations providing the preponderance of the installed capacity.

Net Energy Metering

The NEM category of renewable energy installations includes those residential and commercial installations of no more than 50 kWac that are installed and operated under an HPUC-initiated net metering program. While offered to any renewable energy system, virtually all subscribers have been PV systems. Starting in 2005, these installations were eligible to operate in parallel with the KIUC system such that any energy not otherwise required by the host facility would be allowed to flow into the KIUC system to serve other customers. Surplus energy is thus acquired and compensated by KIUC at the retail rate in effect at the time of the delivery (33¢/kWh as of April 2015). Effectively, the host facility is compensated by a direct reduction in the monthly electricity bill. The subscription to the NEM program was limited by directive to not more than one percent of the peak load of KIUC at the time of system installation.

YEAR	2005	2006	2007	2008	2009–12	2013–14
Cumulative Installed kW	87	118	291	656	783	739
Annual Production, kWh	152,298	206,680	510,407	1,148,835	1,371,830	1,295,583

TABLE 3: Net Energy Metering Program Renewables Installations, 2005–2014

The PV contribution offered under the HPUC-initiated NEM program was fully subscribed by the year 2009. The KIUC system peak had reached 78 MW in 2008, providing the opportunity for a just a few more additions. Immediately thereafter, however, as a result of recessionary pressures and reductions in economic activity, the peak system load fell by about 3 MW. For a few years, 2009–2012, the program was slightly oversubscribed. By 2013, however, some of the initial NEM subscribers had converted to an alternative compensation offering (Schedule Q, described below) for which they were eligible. By the end of that year and through 2014, the program subscription aligned more closely with limitation based on the KIUC system peak load. Of the total annual energy production, the coop received 524,334 kWh for serving other loads.

The NEM "Pilot"

The NEM "Pilot" program was initiated in June, 2011, to allow current and prospective permanent customers of KIUC who own (or lease from a third party) and operate (or contract to operate with a third party) a solar, wind turbine, biomass, or hydroelectric energy generating facility, or a hybrid system consisting of two (2) or more of these facilities, with a total capacity of not more than 200 kWac that is located on the customer-generator's premises; is operated in parallel with the Company's transmission and distribution facilities; and intended primarily to offset part or all of the customer-generator's own electrical requirements. The offering was provided under a priority queuing system whereby participants in other acquisition programs could transfer to the "Pilot".

The advantage to the participant of the NEM "Pilot" was, and is, the provision of a fixed rate of 20 ¢/kWh over a 20-year period for all energy that is surplus to the customer's own requirements and provided to KIUC.

The advantage to the participant of the NEM "Pilot" was, and is, the provision of a fixed rate of 20¢/kWh over a 20-year period for all energy that is surplus to the customer's own requirements and provided to KIUC. A three-year sign-up period was provided, through June 2014 with a maximum allowed subscription of 3 MWac of installed capacity. The maximum capacity was established with consideration of the size of the subscribing facilities in anticipation of potential impacts on the electrical system. For installations of between 50 kW and 200 kW, the maximum allowable in the aggregate was 2 MW. For installations of between 10 kW and 50 kW, the aggregate allowed was 0.5 MW, as was the cap for an aggregate of subscriptions of systems up to 10 kW. The program included transfers into the fixed payment program from other offerings, new PV capacity additions, and planned construction. In calendar 2014, the NEM "Pilot" program provided 1,039,833 kWh for enegy sales to others.

Schedule Q

The KIUC tariff includes the provisions of Schedule Q, an offering to acquire energy from renewable energy installations of up to 100 kW located at residences or commercial facilities. The offering has no cap to the aggregate capacity that may be installed. Schedule Q was first offered in the year 2008, and has seen a dramatic growth in installed capacity in recent years. Ranging upwards from single panels of about 1 kW, Schedule Q participation includes PV systems installations of as much as 88 kW, with a cumulative installed capacity over 11 MW since inception. Of the estimated annual production of Schedule Q facilities, about 53 percent

YEAR	2011	2012	2013	2014
Cumulative Installed kW	39	239	811	1,750
Annual Production, kWh	67,978	418,378	1,421,461	3,066,683

TABLE 4: Net Energy Metering "Pilot" Renewables Installations, 2011–2014

(10,286,248 kWh in 2014) is exported to the utility.

The existence of the Schedule Q buy-back tariff in Hawaii has its roots in the Public Utilities Regulatory Policies Act (PURPA) passed by Congress in 1978, requiring utilities to purchase energy from qualifying systems at a nondiscriminatory, just, and reasonable rate that does not exceed the purchasing utility's avoided cost. The energy provided to KIUC by Schedule Q installations—that is, the energy that flows into the KIUC system that is in excess of the on-site energy requirements—is paid an avoided cost rate that has been established by HPUC. Facilities under the Schedule Q tariff must operate in parallel with the KIUC system and, in addition to a signed interconnection agreement, the customer must enter into a contract with KIUC that will specify whether the customer will purchase its net energy requirements from KIUC, or will sell the energy produced by the facility in excess of the customer's total load and purchase from KIUC its net load requirements at the rate schedule applicable to the type of customer.

Under the Schedule Q tariff, an energy credit or payment from KIUC to the Schedule Q customer for energy delivered to KIUC is posted on the KIUC website and filed with the Commission. A base Schedule Q rate (annual rate) is determined for each calendar year based on KIUC's cost of fuel and a budget heat rate, as filed with the HPUC in December. The annual rate for 2014 was established at 23.61¢/kWh, a relatively high buy-back rate as a result of the reliance on fossil fuel and the high cost of fuel delivered to the island. By the end of 2014, however, fuel costs had declined such that the annual rate for 2015 was set at 13.66¢/kWh. On the first day of each month, an adjustment is made to the base payment rate to reflect composite fuel costs on file with the HPUC using on-peak and off-peak heat rates. The avoided cost rate in April 2015 for power delivered to KIUC in March was 13.48¢/kWh, reflecting the impact of continuing reductions in the cost of production fuels.

Large Customer

The final category of PV installations at KIUC is the Large Customer group that includes individually negotiated agreements among large commercial customers such as resorts, shopping centers, hospitals, and other facilities that are served under Large Power rate schedules. These interconnected facilities provide for a portion of their electric load with installed PV systems (and, in some cases, fossil-fueled

YEAR	2008–9	2010	2011	2012	2013	2014
Cumulative Installed kW	435	946	1,975	4,354	7,496	11,171
Annual Production, kWh	761,349	1,657,707	3,459,906	7,628,653	13,133,286	19,572,443

TABLE 5: Schedule Q Renewables Installations, 2008–2014

YEAR	By 2009	2010	2011	2012	2013	2014
Cumulative Installed kW	1,753	1,974	2,545	2,797	3,279	3,678
Annual Production, kWh	3,071,640	3,457,980	4,459,395	4,900,899	5,744,943	6,444,630

TABLE 6: Large-Customer Renewables Installations, 2008–2014

Potentially, with the retention of the Schedule Q payment structure, the total amount of customer-sited solar could reach around 40 MW.

Third-party developments are common, with lease arrangements over extended periods of time, typically 15 to 20 years.

combined heat and power equipment). These customer-sited generation systems have not entered into a power purchase agreement with KIUC. The PV systems either do not export any energy to KIUC, or provide energy for system purposes without compensation.

While no surplus energy is purchased by KIUC, these facilities with PV capacity ranging from 8 kW to 717 kW are served by KIUC for that portion of the electric load not met by the on-site systems.

EXPECTATIONS FOR CONTINUED GROWTH IN SOLAR INSTALLATIONS

The rapid decline in the cost of solar equipment, the variety of alternative acquisition options available to both residential and commercial customers, the relatively high retail electricity rates, and a generous pricing structure for surplus energy provided to the system suggest that solar additions will continue to proliferate at KIUC. Recently, Black & Veatch estimated that with the continuation of the current Schedule Q payment structure, the number of participants in the solar provisions of Schedule Q will increase over three-fold from year-end 2012 and may reach a level of installed capacity of 25.8 MW, capable of providing 45,275,212 kWh, more than twice the amount of energy currently produced for on-site service and export into the grid. Potentially, with the retention of the Schedule Q payment structure, the total amount of customer-sited solar could reach around 40 MW. In combination with solar capacity from power purchase agreements and utility-owned facilities, the daytime solar capacity could well exceed the average daytime load, perhaps by as much as 10 MW.

Estimates of residential PV installations in Hawaii range from $15,000 to $25,000 per installation (assuming $4 per Watt). Depending on every individual tax situation, installations may take advantage of the federal Investment Tax Credit to deduct 30 percent of the cost of a solar system from federal income taxes. In addition, Hawaii has adopted a tax credit incentive to enhance the affordability of the different types of solar products for homes and business. For solar panel systems, a Hawaii tax credit of 35 percent of project costs or $5,000 (whichever is less) is available for single family residences. For multifamily residences, a Hawaii tax credit is available for 35 percent of project costs or $350 per unit (whichever is less). For commercial properties, the tax credit provided is 35 percent of system cost or $500,000 per system (whichever is less). Third-party developments are common, with lease arrangements over extended periods of time, typically 15 to 20 years.

ADMINISTRATIVE, TECHNICAL AND FINANCIAL CHALLENGES OF HIGH SOLAR PENETRATION AT KIUC

The challenges have been multiple to KIUC as a result of the dramatic growth in solar penetration within just a few short years. Some of the technical issues that arose from installations of early systems have been resolved, such that with greater understanding of the operational characteristics of the installed systems, and from working through issues with vendors, more recent installations have become somewhat of a routine matter. Other technical challenges remain, such as effectively operating the system into the future to maintain stability and reliability with increasing solar penetration. As noted, relatively high electric system rates as a result of the continued contribution of fossil energy to meet a significant portion of the total energy requirements, and the avoided cost offering related to fossil energy for Schedule Q installations, will serve to prolong the incentives for further PV penetration.

A relatively unique circumstance for KIUC relative to most cooperatives is that KIUC is a fully-integrated utility, providing generation, transmission, and distribution services. As both a supplier of electricity and a distributor of electricity, KIUC experienced the full range of impacts associated with the development of grid-connected PV systems.

Administrative Impacts at KIUC:

- *Processing Requests*

  As had been the case for any operating utility subject to PURPA in the 1980s, interconnection guidelines were established and tariffs developed for non-utility generation facilities at KIUC, either as directed by the HPUC or prepared by KIUC for approval by the HPUC. In the initial years of implementing the Net Energy Metering tariff for renewable energy sources, KIUC primarily handled requests for interconnection at the engineering level. The initial interconnection guidelines and tariff offerings were the purview of a group of dedicated Energy Services employees that handled requests for interconnection and coordinated with engineering personnel for recommendations, as needed, on the interconnection standards and equipment requirements.

- *Communications*

  As solar costs continued to drop, more and more requests for information came to the cooperative, suggesting additional effort on educating the membership on the how and why of solar, and how to gain the most benefit of solar applications. The KIUC website and periodic publications to the membership became an invaluable tool in providing solar development information. The materials provided included both background information for those planning or evaluating acquisition of PV systems and the conditions under which the solar installations would be integrated. More recently, as a result of the aggressive marketing of solar systems, KIUC has distributed "straight talk" messages to the membership. A handout and corresponding web page provided to the membership entitled **"Straight talk from your co-op on rooftop solar"** provides information to help cooperative members make informed decisions about their energy use. The message addresses energy load shifting to meet solar production, the sizing of PV systems, minimum bills and cost recovery, the impact and risks of leasing, the potential variability in the buy-back rate for PV generation, potential curtailments, and the possibility of changes in rates as a result of renewables integration.

- *Realignment of Staff*

  As time went on and requests for PV interconnection soared, significant backlogs developed in the review process. It became apparent to KIUC that formalized procedures and a structured approach was required to efficiently accommodate the accelerating rate of interconnection applications.

  The result was that certain staff and responsibilities were realigned between the Members Services group and the Engineering/Energy Services personnel, but not specifically requiring additional personnel. Applications for small installations, 10 kW and less, were directed to the Member Services staff, while all applications for larger installations were referred directly to the Engineering Department. Details of the interconnection process were formally entered in the cooper-

To address the significant backlogs in PV interconnection requests, certain staff and responsibilities were realigned between KIUC's Member Services and Engineering groups.

The viability and potential for PV varies across the island and can be affected by a number of factors including sunlight incidence, shadowing, residential and commercial facility density, and other factors.

ative's tariff as Tariff No. 2 *Distributed Generation—Interconnection Policies and Procedures* and easily accessible on the KIUC website.[5] Even then, after initial review by Member Services personnel and if required, an application may be referred to Engineering. The Engineering staff provides feeder and transformer analysis and identification of any upgrade requirements, or other costs imposed on the utility to accommodate the interconnection that would need to be paid by the applicant.

- *Documentation*
  The cooperative maintains clarity of the progress of an application for interconnection through use of an interconnection process checklist that fully documents those necessary steps to ensure all administrative oversight. The process checklist serves to accomplish a safe and fully-coordinated interconnection that will ultimately operate in parallel with the KIUC distribution system.[6] Quite often, PV system vendors or PV system installation contractors initiate and coordinate the application on behalf of the members acquiring the PV systems.

Distribution System Impacts on KIUC

Feeder level challenges from extensive solar penetration have been evident on the KIUC system. The rapid growth of residential and commercial PV during the early years of the solar power development required close monitoring and active recommendations by KIUC to prospective PV applicants. The growing incidence of distributed generation, and the movement of the KIUC distribution network from the traditional model of radial feeders with one-way power delivery to a framework of expanded distributed generation, demanded new focus on distribution system characteristics. Of particular interest was the growing feeder penetration associated with the rapid growth, which called for careful review of the technical characteristics of the equipment proposed for on-site installation.

The viability and potential for PV varies across the island and can be affected by a number of factors including sunlight incidence, shadowing, residential and commercial facility density, and other factors. The size of the PV system or systems relative to the feeder load, for example, varies dramatically across the KIUC system.

Figure 5 describes the varying impact of PV development and penetration across the KIUC system. KIUC's Feeder 1231, for example, reflects 685 kW of PV capacity connected on the southwest portion of the island of Kauai relative to a daily load of 895 kW. Generally considered the dry, sunny region of Kauai, the feeder reflects a high PV penetration portion of the island. The 80+ percentage on Feeder 2132 on southwest Kauai includes the interconnection of 300 kW of utility-scale PV in addition to other installed systems. On the more eastern side of Kauai, the Kapaa substation Feeder 3415 represents another high PV penetration location, in part from the location of the 1 MW Kapaa Solar that also provides energy to KIUC under a purchase power arrangement.

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5 **Tariff Information | Kauai Island Utility Cooperative**. Detailed criteria are spelled out in KIUC's Interconnection Policies and Procedures that allow for inverter-based systems of less than 10 KW to be treated in a more routine fashion, while larger systems and systems with characteristics that warrant additional equipment or protections schemes are fully reviewed for compliance with engineering standards or the need to reconfigure feeders accordingly, generally at the expense of the PV system applicant.

6 Of note is that the interconnection requirements have served KIUC well in maintaining safe operating conditions for utility field personnel.

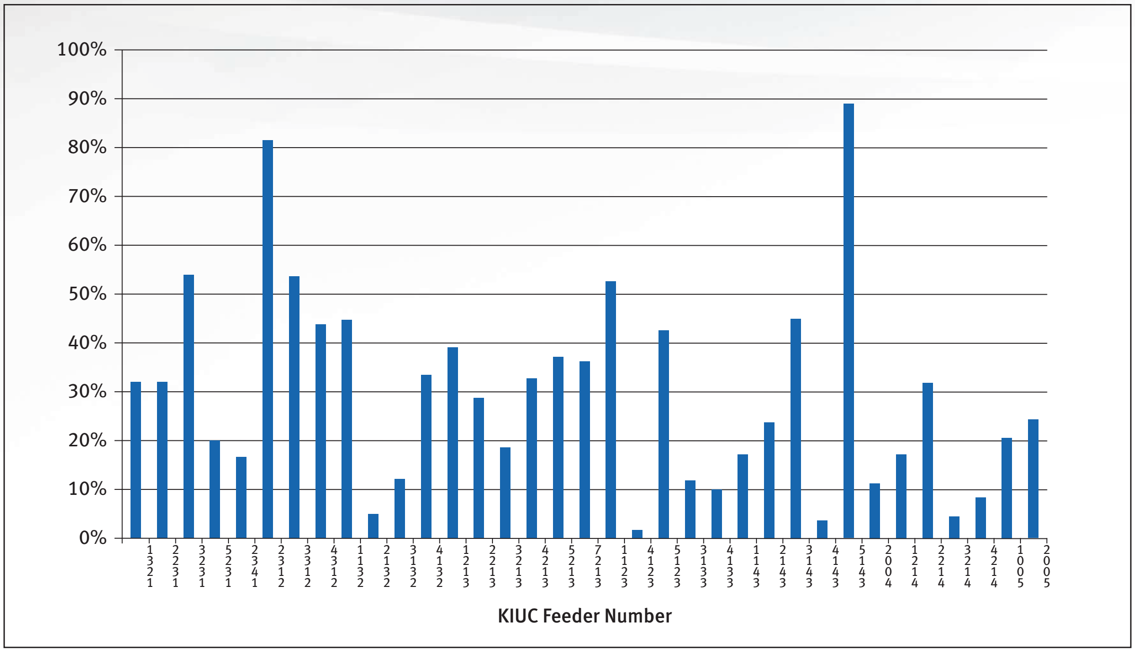

FIGURE 5: PV Penetration by KIUC Feeder, Percent

Various conditions exist under the Interconnection Policies and Procedures to ensure that small generator installations are properly evaluated for impacts on the feeder and the generation and transmission system.

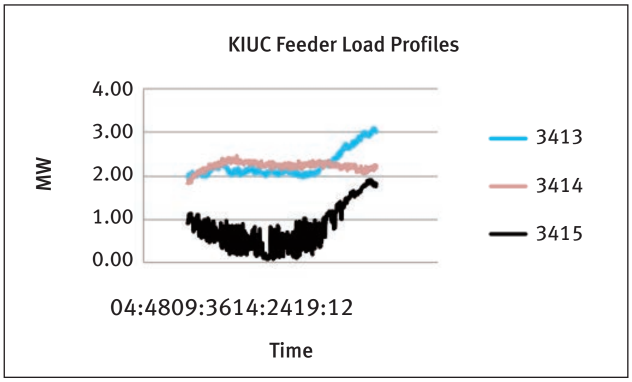

FIGURE 6: Example KIUC Feeder Load Profiles, Time-of-Day

The impact of a high penetration feeder load[7] may be seen in Figure 6, with comparison of the load profile of three feeders at the Kapaa substation. The feeders are metered at the low-side bus. Feeder 3413 reflects a relatively modest penetration of PV seen above. The load is fairly stable throughout the day, but increases late in the day into the early evening hours, increasing throughout the early evening to the typical evening peak of the KIUC system, indicative of a relatively modest PV penetration. Feeder 3414 with modest PV contribution, on the other hand, represents a relatively stable load throughout the daytime period, while 3415, with the highest PV penetration, exhibits a common characteristic droop during the sunlight hours corresponding to the highest level of PV energy production. The variability and

[7] A worthwhile reference on feeder impacts of high PV penetration may be found in a study completed by NREL, *Analysis of High-Penetration Levels of Photovoltaics into the Distribution Grid* on Oahu, Hawaii Detailed Analysis of HECO Feeder WF1, Subcontract Report NREL/SR-5500-54494, May 2013

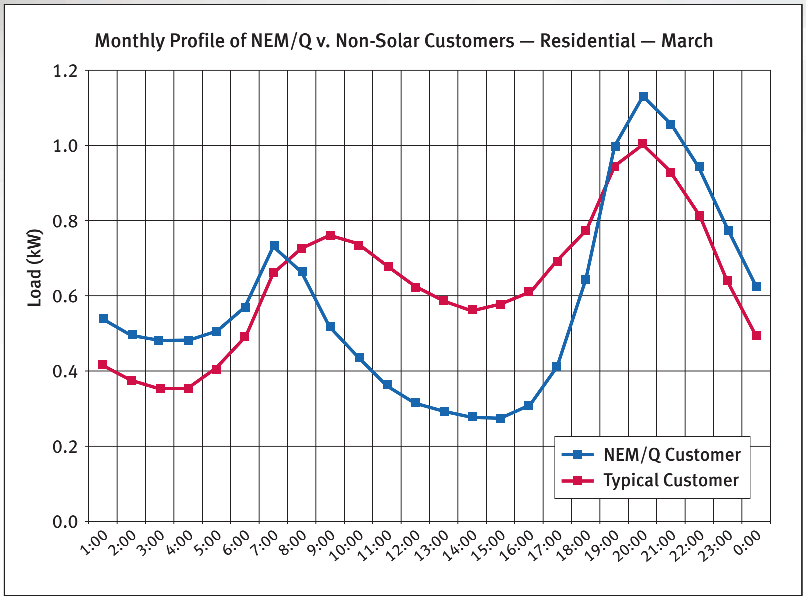

FIGURE 7: Residential Load Profile Comparison, March

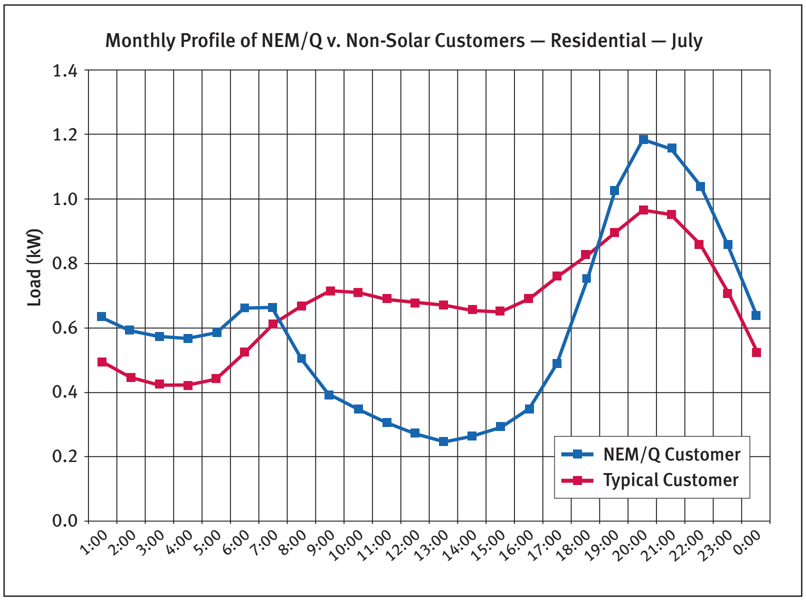

FIGURE 8: Residential Load Profile Comparison, July

intermittency of the PV impact may also be observed from the feeder load profile.

Recent load research undertaken at KIUC following the installation of the Advanced Metering Infrastructure (AMI) and data gathering system[8] has provided additional information with regard to the incidence of PV installations of the residential and commercial consumers of KIUC. The load research is the first fully-documented load study for the KIUC system and was undertaken to support cost-of-service and rate design, load forecasting, and demand-side management planning. In so gathering data from the interval metering and communications technology, detailed class load profiles were developed that identify the differences in load characteristics for those consumers with PV systems (the NEM/Q customers) and those without. Figure 7 and Figure 8 show the residential profiles with and without PV installations for two reference months, March and July.[9]

The slightly higher load (observed by the difference between the starting and ending points of each profile) of the typical NEM/Q residential customer of KIUC probably reflects that larger homes, or the more electric intensive homes, on the distribution system are more likely to have PV installed.

[8] The installation of the AMI system was supported in part by NRECA/CRN through the Smart Grid Demonstration Project, Department of Energy OE-DE10000222.

[9] AMI-Based Load Research—KIUC Demonstration: *Confirming the Value of AMI,* May 2014. Available at **NRECA Smart Grid Demonstration Project—NRECA**.

An even more dramatic evidence of the impact of a high penetration of PV on the KIUC system is demonstrated in Figures 9 and 10, which compare small commercial customers with and small commercial customers without PV installations during the months of July and December. Although perhaps small in number, the small commercial load shape provides evidence of the significance of the small commercial load to the feeder penetration level.

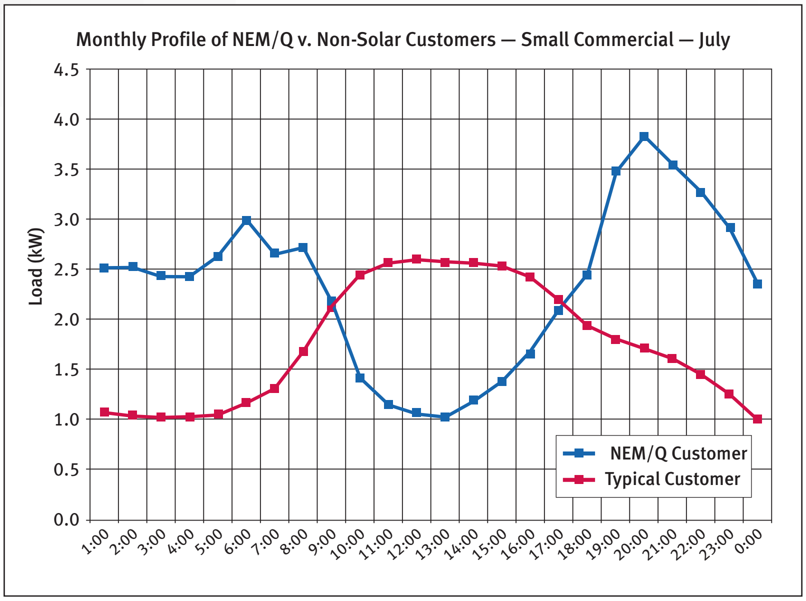

FIGURE 9: Small Commercial Load Profile Comparison, July

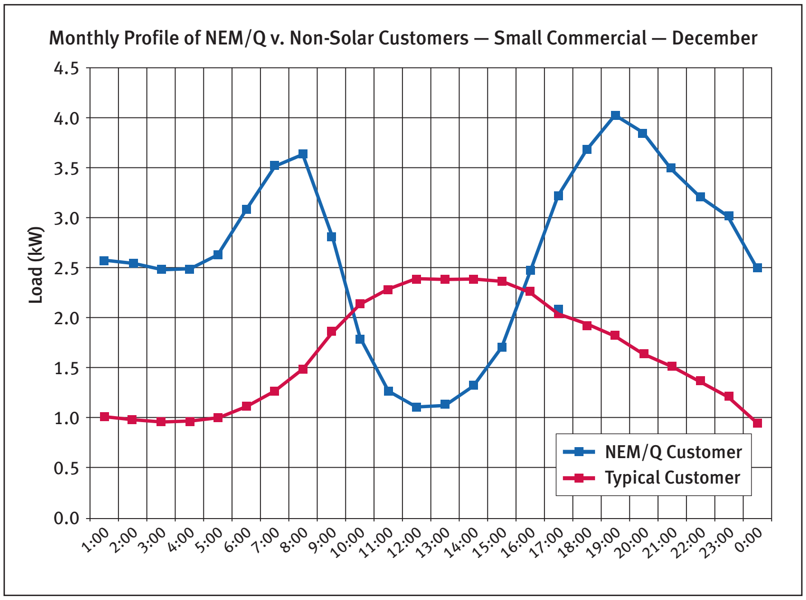

FIGURE 10: Small Commercial Load Profile Comparison, December

Generation & Transmission System Impacts on KIUC

While efforts have been on-going to offset the high cost of fossil fuel generation with renewable resources, and KIUC continues to move to a renewable future, the growing prevalence of PV has introduced other impacts. Some of the technical issues of the generation and transmission grid include coordination of the PV installations with the system protection under a variety of scenarios. Legacy PV inverters, for example, had very narrow voltage ranges (0.9 per unit [p.u.[10]] for 0.1 second, for example). With increasing penetration of solar, KIUC sought full ride-through of frequency excursions, in keeping with the needs of both anti-islanding and protection of the island grid. Initially, KIUC received pushback from the inverter providers, but prevailed to the benefit of the system overall. Provisions are available for drop-out of the smallest systems, but larger systems are protected through reverse power relays.

A snapshot of the KIUC system frequency response under the current level of PV penetration has been provided by the KIUC SCADA system in **Figure 11.** This is a steady-state 15 minute snapshot showing the range of a typical operating time period with PV contributing to the system. The frequency within that time frame ranges between 59.5 Hz and 60.1 Hz, with excursions beyond 59.85 Hz and 60.15 Hz.

[10] "p.u." is a contraction of the term per-unit that expresses the electrical system condition relative to a reference level.

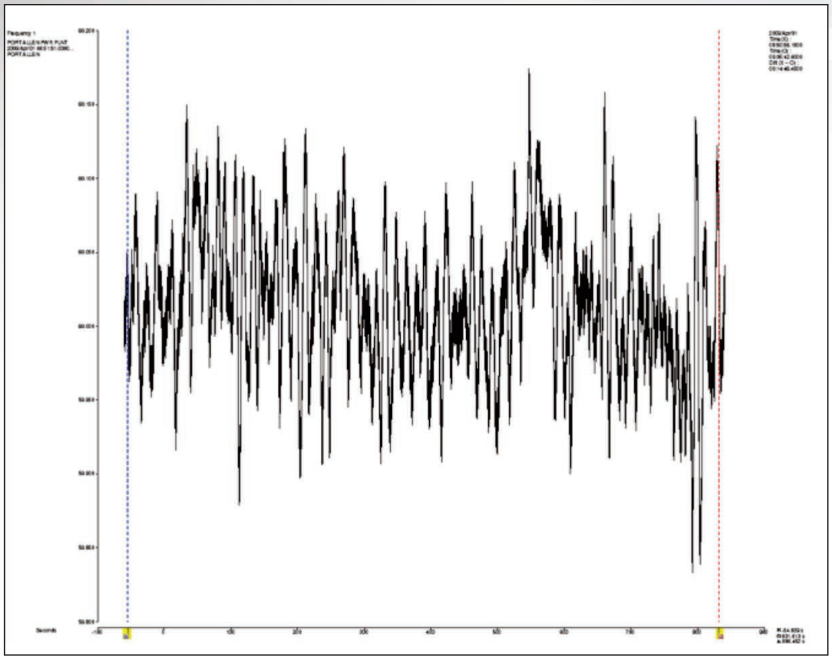

FIGURE 11: PV Impact on Frequency Response – 15 Minute, KIUC Port Allen Power Plant

KIUC's interconnection requirements are very explicit with regard to system requirements and inverter set points, in order to effectively accommodate the high level of penetration without introducing instabilities on the system. They are referenced at Section 2.2 of the Interconnection Agreement required under Tariff 2 (referenced above). The applicable operation requirements and operational test criteria of KIUC are required to be listed in an exhibit to the Agreement. Exhibit 5 of the Agreement provides the Cooperative's specific requirements that must be met prior to initiating parallel operations and the operational test criteria after connecting. They are:

1. Interconnecting Customer's standard operating procedures shall be subject to the Cooperative's review and approval.
2. Interconnecting Customer shall not alter, modify, or otherwise change any protective relay or control characteristics of the facility without KIUC approval.
3. Testing of operational criteria before and after parallel operation will be done in accordance with Good Utility Practice.
4. Inverter under frequency set points must be adjustable down to 57.0 Hz, 3 seconds and over frequency set points must be adjustable up to 62.5 Hz, 3 seconds.
5. Inverter overvoltage fast settings must be adjustable to 1.2 p.u.,[11] 0.16 sec. and the overvoltage slow settings must be adjustable to 1.19 p.u., 1.00 sec.
6. Inverter undervoltage fast settings must be adjustable to 0.5 p.u., 0.16 sec. and the undervoltage slow settings must be adjustable to 0.51 p.u., 2.0 sec.
7. Interconnecting Customer must be willing and able to adjust the inverter trip settings given by KIUC as to preserve grid stability. These inverter requirements will have to be reviewed and approved with KIUC Engineering during the commissioning phase before interconnection to the grid is allowed.
8. Interconnecting Customer shall not alter, modify, or otherwise change any inverter settings without KIUC approval.
9. Interconnecting Customer must be willing and able to generate report of inverter activities based on request by KIUC within 30 days of request.
10. System shall not exceed IEEE 519 Standard Practices and Requirements for Harmonic Control in Electric Power Systems.

As a result, under a variety of conditions, the system may remain stable on unit trips with first-stage load shedding. Had the inverters remained at 59.2 Hz, the system would likely go into second-stage load shed upon an event.

[11] In this case, p.u. refers to the nominal voltage level.

Under clear sun conditions, around 80 to 95 percent of the daytime demand will be met by the solar systems' installed capacity, once KIUC begins commercial operation of its second utility-owned PV installation of 12 MW at Anahola.

Figure 12 provides evidence of the expected system response to a trip of a generating unit with PV on the system. The unit trip is of D-7 (a 7.5 MW diesel unit) and the system response is tested under various conditions of on-line PV, as well as available spinning reserve, and an additional generating unit (S-1, a 10 MW steam turbine).

The engineering analysis shows that under identical generation loss scenarios, the different levels of low-inertial PV will have an impact on how far and how fast system frequency decays. Additionally, it shows that the amount of on-line spinning reserve has an impact, as does the addition of the high-inertia S-1 unit.

Considering further the impact of high penetration PV on the generation and transmission facilities, when commercial operation begins at the second utility-owned PV installation of 12 MW at Anahola, now scheduled to begin production mid-year 2015, Kauai will be getting nearly 17 percent of its annual electricity from solar. Under clear sun conditions, around 80 to 95 percent of the daytime demand will be met by the solar systems' installed capacity. This will create the challenge of maximizing the contribution of low-cost solar, maintaining the ability to take output from existing energy-only renewable energy PPAs, and keeping the absolute minimum conventional generation online in order to maintain grid reliability, specifically frequency control.

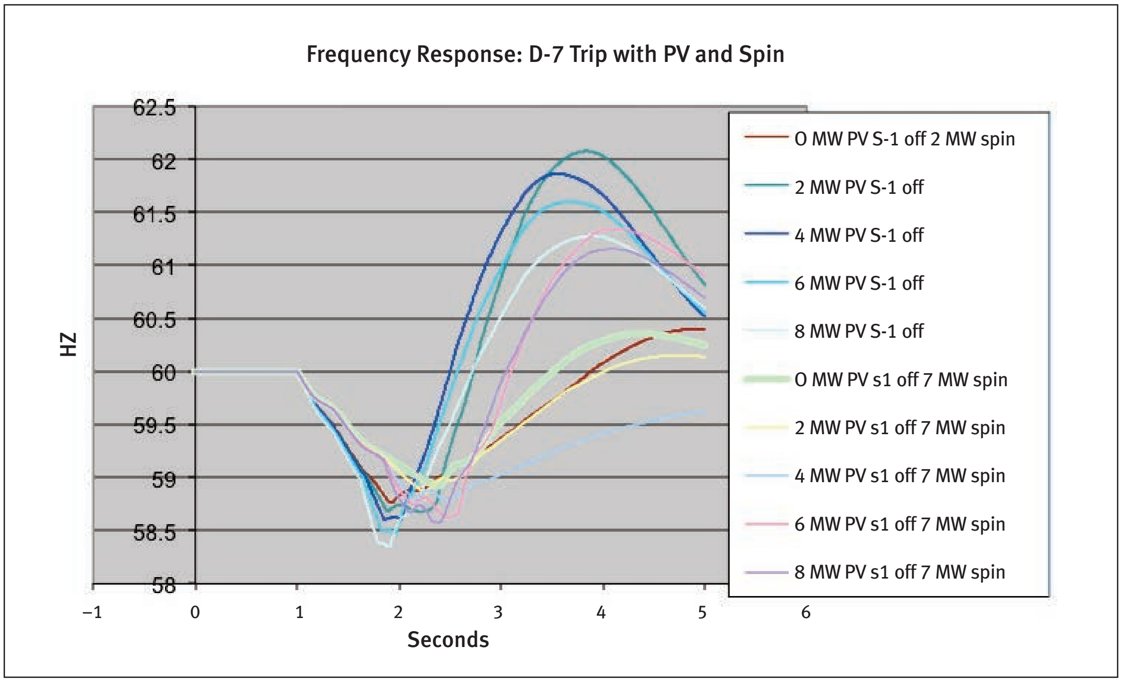

FIGURE 12: Frequency Response from Unit Trip—Impact of PV and Level of Spinning Reserve

FIGURE 13: Port Allen 6 MW PV, on-line Dec. 2012

FIGURE 14: Koloa “KRS2” 12 MW, on-line July 2014

FIGURE 15: Anahola “KRS1” 12 MW, under construction, expected in-service July, 2015

FIGURE 16: Anahola “KRS1” substation under construction, with 6 MW BESS on the right

The most difficult portion of this situation to manage is the midday segment since the net electrical demand during clear sun times ranges between 10 and 20 MW.

Another challenge for KIUC as result of high PV penetration is the high variability of solar.

Looking ahead to the near future with the combination of customer and utility PV penetration, Figure 187 shows how solar has impacted KIUC's typical low-load day curve for select recent years, and the expectation for the balance of 2014 and the forecast year 2015. The low-load day, Sunday, reaches a system demand of approximately 55 MW as opposed to 65 MW for a high-load day, which may occur any day of the week. Year 2014 and earlier reflect actual data, and year 2015 reflects forecast data that includes the effect of the completion of the two utility-owned 12 MWac projects. The chart is intended to display demand situations on an hourly basis, and not solar variability, as the data resolution is only once every 15 minutes.

As more and more low-capacity factor solar generation is added, no demand reduction is affected at night, while some demand reduction is created during the morning peak (9:00–11:00 a.m.). A significant demand reduction occurs through midday, but there is no demand reduction during the evening peak period (6:00 p.m.–9:00 p.m.). The most difficult portion of this situation to manage is the midday segment. The net electrical demand (i.e., the net generation requirement AFTER the aggregate solar generation) during the clear sun times ranges between 10 and 20 MW. KIUC's current minimum conventional generation limit is about 10 MW, and the minimum take from KIUC's energy-only PPAs is about 9 MW. Either generation assets will have to be curtailed (solar being the likely candidate since its low capacity factor is causing the situation), electrical demand will have to increase, or significant storage assets will be required to store excess generation and provide confidence that conventional units can be de-committed.

A related but technically different issue for KIUC as a result of the high PV penetration is the high variability of solar. Although Kauai is blessed with plenty of sun, it is often partly cloudy. When clouds pass over a PV system, it decreases output significantly—as much as 90 percent, depending on the severity of the cloud cover. This change can occur in less than one minute and can occur many times throughout the day, as shown by the one-minute data capture from the existing 6.0 MWac Port Allen project shown on Figure 19. When this happens, other grid assets must be able to react in the opposite direction of the solar farm in order to maintain grid reliability, specifically frequency and voltage support.

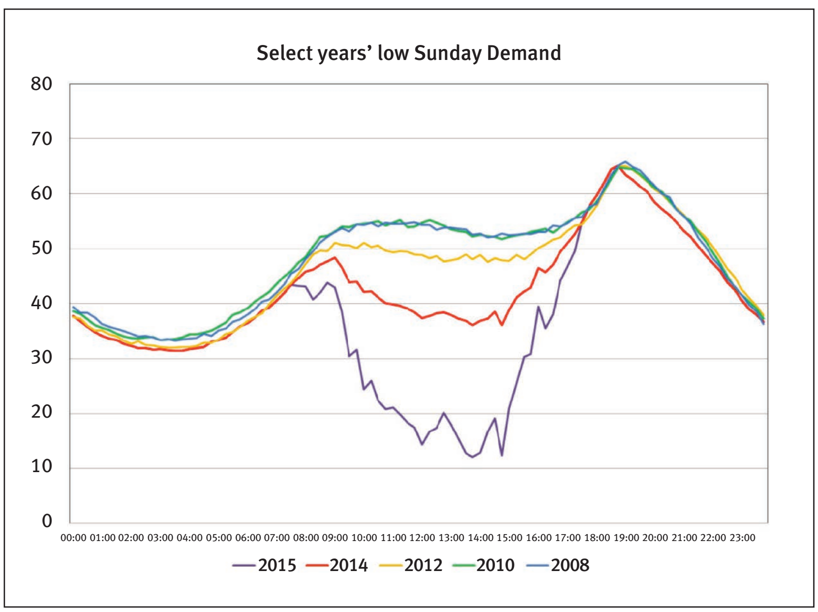

FIGURE 17: 2014 and earlier is actual MW load data, 2015 is forecast (15 min. resolution)

The data shown in Figure 18 is for one day only; as more days are considered, the day-to-day random variability is noticeable, but the granularity is lost. An example is shown in Figure 20, which shows one weeks' worth of data from the same 6 MWac project. The second solar day from the left on Figure 19 is the same day as shown in Figure 18.

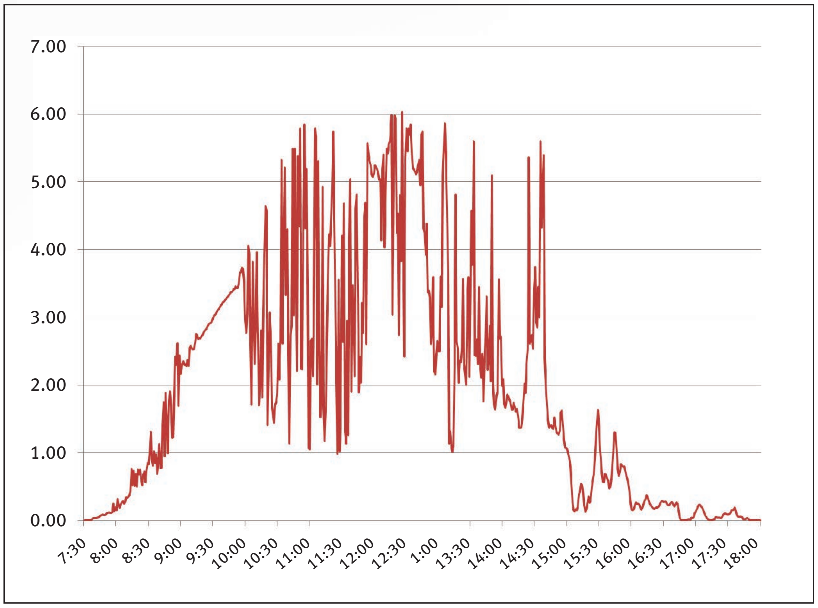

FIGURE 18: Port Allen PV System—Single Day Hourly Output, Max. 6 MW

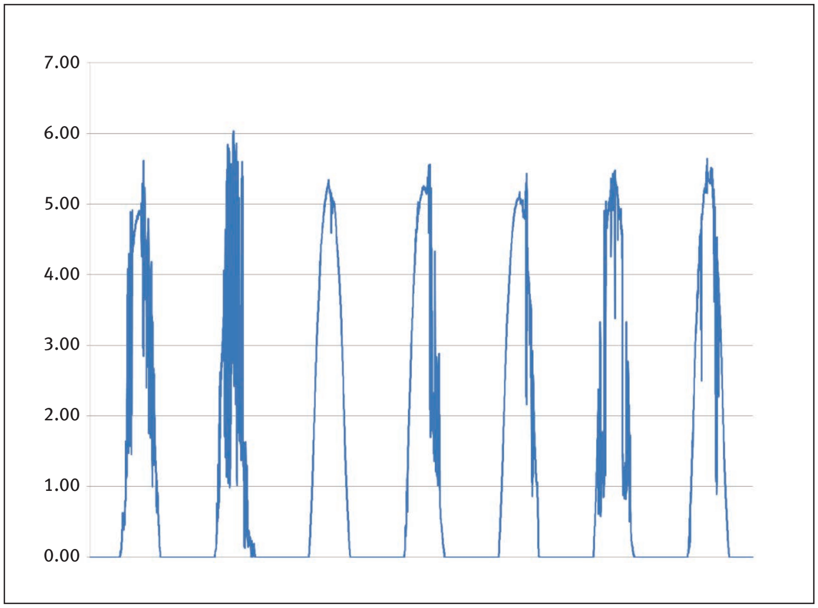

FIGURE 19: Port Allen PV System—One Week Output, Max. 6 MW

Managing Variability

It is important to note that differing solar installations impact KIUC's grid reliability in different ways. For the most part, residential and commercial solar systems cause more localized, feeder-level concerns (as discussed earlier) and do not cause significant grid-level reliability issues. Even some of the smaller utility-scale systems (i.e. those rated at less than 10 percent of system load) do not cause significant impacts to grid frequency during periods of variability. Solar systems that are 10 percent of system load and above, such as the 6 MWac project and the two 12 MWac projects, do cause significant frequency deviations during extreme ramp events, if left unmitigated. KIUC has measured ramp events from the existing 6 MWac solar project to be as high as 10 MW/minute (i.e. 5 MW over a 30 second period), and expects similar ramp events from the two 12 MWac solar projects that will soon come online.

KIUC is currently using a combination of batteries and conventional generating units to mitigate the high variability caused by existing solar systems. Specifically, KIUC uses a base load gas turbine (GE LM2500) in combination with four cycling marine diesels (Wartsila TM620) in droop control to respond to the majority of ramp events. KIUC also uses three 1.5 MW/1.0 MWh battery systems to handle the most extreme ramp events. The batteries operate in frequency and voltage droop control and are not currently used to limit ramp rates coming out of the 6 MWac solar project. In other words, the full, unmitigated output of the 6 MWac solar project is fed directly into the KIUC grid, the gas turbine and diesels complement the ramp events, and the batteries only respond during the most severe ramp events. Each of these assets has its place—the conventional units are slower to react than the batteries, but they can provide a much longer response.

The primary financial issue is the loss of contribution toward the fixed costs of the system by those customers that install PV equipment.

The cost of utility-owned large scale solar is significantly less than that of small, disaggregated systems.

The batteries can perform the smoothing function quite well, but the more cycles they are called upon to provide, the less overall life they have.

Based on the experience gained to date, KIUC is continuing to add batteries, including 6 MW at the Anahola PV site scheduled to be on-line mid-year 2015 to provide for frequency control and stability enhancement, but also is actively investigating new battery technologies with long-period discharge, pumped storage options and other storage hydro opportunities available on the island.[12] A recent development has been consideration of equitable curtailments of PV installations to achieve the best possible operating conditions.

Consideration is underway, for example, of installing controllable AMI meters on PV systems that are oversized and thereby have generation capability in excess of the on-site energy requirements. The purpose would be to implement a curtailment system among producers that would limit PV production when the peak solar production exceeds demand and threatens the integrity of the KIUC system. KIUC hopes, however, to avoid curtailments by encouraging customers to install "right-sized" rooftop PV systems.

FINANCIAL IMPACTS AND CONSIDERATIONS OF HIGH PV PENETRATION

The advent of renewable resources has provided a significant opportunity for KIUC to reduce the cooperative's reliance on high cost naptha and diesel fuel. The cost of fuel at KIUC has comprised over 50 percent of the retail rates; consequently, reduced fossil fuel generation from the addition of solar saves fuel cost, but only that portion of the cost of electric service. The Schedule Q rate, for example, is based in large part on the level and rate of change in fossil fuel used in the generation facilities. All solar energy provided to the system effectively reduces the requirement to consume diesel fuel at the generation facilities.

The primary financial issue, therefore, is the loss of contribution toward the fixed costs of the system by those customers that install PV equipment. Those with PV installations, particularly the net metered customers and the large commercial providers that install PV systems, no longer contribute through the electric rates for those costs in excess of the marginal cost of fuel and O&M to meet the needs of the system. In addition, the utility remains obligated to have on-hand and in operation adequate other capacity to meet the system peak load once the solar systems are no longer producing—after sunset or during periods of limited clear sky.

Furthermore, the cost of utility-owned large scale solar is significantly less than that of small, disaggregated systems. The new 12 MW systems constructed by KIUC at Koloa and Anahola are expected to produce energy for the system at an average cost of less than 13¢/kWh, well below the marginal cost of generation and the rate paid under Schedule Q. While the value of the solar systems prevails in reducing the reliance on high cost fossil fuels, significant rate disparity exists among those customers with and without solar installations in terms of the coverage of the non-fuel costs of maintaining and operating an adequate supply of on-peak generation, and the transmission and distribution facilities to meet the need of the island.

To respond to the rate issues, KIUC has submitted a proposed revision to the Schedule Q rate, such that rather than a preponderance of reliance on the cost of fuel for generation, the rate is based on the utility-owned resource

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[12] See, for example, the resources under consideration on **Table 2**.

alternative that provides scale economies and serves any and all load placed on the system. Secondarily, the cooperative is investigating alternative rate structures, including time-of-use rates that provide incentives for daytime load (i.e., peak shifting to the extent able), and restructured stand-by rates for those facilities that rely on KIUC to meet loads not otherwise met by on-site systems (which may include combined heat and power facilities, such as currently installed at some of the island resorts).

LESSONS LEARNED FROM THE HIGH PENETRATION OF PV ON KAUAI

The experience of KIUC with the high penetration of solar over a relatively short period of time has provided some practical lessons for those cooperatives expecting or currently experiencing rapid deployment of solar facilities, and particularly non-utility solar systems. Those lessons learned include:

Expand Member Services:

- Actively strengthen the Member Services functions and training for responsiveness to solar deployment questions from the membership, sales representatives, and installation contractors.
- Identify and allocate personnel resources well in advance of initiating the application processes, and be prepared to provide for the additional time and effort in dealing with solar issues.
- Be mindful that the interconnection relationship is between the cooperative and the member being served. An installation contractor may serve as the technical representative of the member, but the ultimate responsibility lies with the consumer, and tariff conditions are established for safe and reliable service.

Communicate Fully and Effectively:

- Provide carefully drawn talking points to educate and share with consumers the characteristics of solar installations and the effects of interconnection to the cooperative's system.
- Use the cooperative's website extensively, shine a light on the issues involved in high penetration of solar installations, and bolster communications efforts on all fronts.
- Maintain watch on the expectations of savings of the cooperative membership and individual consumers considering solar installations, and caution the membership with regard to sizing and acquiring rooftop systems and the expectation of savings.

Provide Essential Information:

- Acquire and use Advanced Metering Infrastructure equipment, as the availability of the AMI data will help in determining the appropriate size of residential PV installations. The AMI information will help consumers to correctly size their panels and help protect against non-economic investments, such as north-facing or otherwise shadowed panels. AMI equipment may also be used to affect curtailment, as may be required for prevention of adverse system impacts.
- Have clear interconnection guidelines. Mandate proper inverter settings, have a way to verify those settings, and establish stiff penalties if settings are found to be changed after the interconnection inspection and approval to interconnect.

Set Appropriate Rates:

- Consider minimum charges, and fixed fees for on-site facilities.
- Plan the rate structures in advance and anticipate the requirements. Establish the appropriate rates early.

- If you are unable to initially implement an appropriate buy-back rate (due to regulatory lag, net metering requirements, or other reasons) communicate clearly what the cooperative believes the rates should be. Consumers will then be able to make long-term investment decisions on sound information provided by the cooperative, rather than from a third-party solar provider.

Carefully Monitor Deployments:

- Establish a database of the installed systems as soon as possible, so that one can track system details individually and in the aggregate. Knowing the capacity of each system will enable the utility to calculate the on-site solar contribution to system requirements.

- Consider methods to limit on-site solar installations to the maximum peak demand of the location, to avoid over-sizing or over-building in anticipation of additional revenue. In the absence of excess feeder capability and large-scale energy storage, over-sizing by some reduces the opportunity for other members to acquire cost-effective solar systems.

Be Ready to Respond:

- Watch out for crisis communications as issues evolve.

BUSINESS AND TECHNOLOGY STRATEGIES
RENEWABLES AND DISTRIBUTED GENERATION WORKGROUP

The Renewables and Distributed Generation Work Group, part of NRECA's **Business and Technology Strategies** department, is focused on identifying the opportunities and challenges presented by the continued evolution of renewable energy resources. This article is part of efforts to examine various aspects of solar technology, including market status, related policies and regulations, and business models. For more information about renewable energy, please visit **cooperative.com**, and to see the current portfolio of work by NRECA's Business and Technology Strategies, please visit **www.nreca.coop/what-we-do/bts**.

About the Author

Tom Lovas is a Senior Program Manager (Contractor) of the Business and Technology Strategies department of NRECA. As the principal consultant of Energy & Resource Economics, Mr. Lovas has also supported KIUC in load forecasting and system planning activities, including preparation of planning studies in support of Rural Utilities Service financial assistance.

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Questions or Comments

• Andrew Cotter, Program Manager, Renewables and Distributed Generation Work Group, NRECA Business and Technology Strategies: **Andrew.Cotter@nreca.coop**

• Tom Lovas, Senior Program Manager, Business and Technology Strategies: **Tom.Lovas-contractor@nreca.coop**

• CRN online **feedback form**.

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