>94.5% Reduction in Grid-Buy Electricity and Elimination of AM & PM Energy Peaks/Spikes by Optimizing Energy Usage and Integration of Customer Self-Supply Rooftop Solar PV with Electrical & Thermal (Hot & Cold) Storage Batteries: A Case Study for Residential Hawaii

John Borland[1], Jay Moore[2], Corpuz Poncho[2], Takahiro Tanaka[3] and Harumi McClure[3]

[1]J.O.B. Technologies, 98-1204 Kuawa St, Aiea, Hawaii, 96701, USA
[2]Poncho's Solar, 650 Kakoi St., Honolulu, Hawaii, 96819, USA
[3]Tabuchi Electric America, 5225 Hellyer Ave, Suite 150, San Jose, California, 95138, USA

***Abstract---* We investigated the integration of customer self-supply rooftop solar PV system with electrical battery storage and hot & cold thermal storage for residential Hawaii. Optimizing time of use for key appliances and improvements to hardware and software control system, we reduced the average daily Grid-Buy from 48.7kWh/day in April 2016 to 2.7kWh/day in April 2017 and eliminated all AM and PM energy peaks. For 12 days in April we achieved 0.0kWh/day Grid-Buy.**

***Index Terms---* grid-buy, battery storage, thermal storage, hot thermal storage, cold thermal storage, solar PV, self-supply.**

I. INTRODUCTION

At the 43rd IEEE PVSC meeting in June 2016, Reindl gave the talk "LCOE reduction of PV electricity—does technology still matter?" based on end-users perspective the cost of PV generated electricity is not determined by the PV cell technology efficiency but rather dominated by climate and environmental energy yield effects [1]. This is especially true with the end of Net Energy Metering (NEM) and export/selling of excess rooftop solar PV generated energy back to the utility Grid as is the case for residential Hawaii when NEM ended in Oct 2015. This impact can be seen in the past year as the US solar PV market has grown 95% from 7.5GW in 2015 to 14.6GW in 2016 while Hawaii has fallen 31% from its peak of 130MW in 2013 to 99MW in 2016. Future growth in the residential solar market will no longer drive the solar industry to higher solar cell efficiency because this results in the loss of PV energy generation due to dumping/curtailment between 27-48% per month based on NREL's System Advisor Model for Honolulu [2]. For customer self-supply in a post-NEM world, lower price packaging of smaller solar-PV systems integrated with battery storage (electrical & thermal) and optimized energy usage of key household appliances will drive the next wave of residential solar deployment by maximizing the energy generation of smaller solar PV system and reducing utility Grid-Buy electricity to the best case of 0.0kWh/day. Therefore, we will report field data starting from the June 1, 2016 installation of the rooftop solar system + battery storage and steps we took to achieve the reduction in the daily utility Grid-Buy electricity going from a daily average of 48.7kWh/day for April 2016 to 2.7kWh/day for April 2017 as shown in Fig.1. Note that initially after the first month of solar PV + battery storage we only achieved a 53% reduction in Grid-Buy to 22kWh/day which was much less than expected. The Hawaii Energy website reports that the average Hawaii home with rooftop solar PV and NEM (the utility acts as a storage battery) sees a 56% reduction in utility bill from 537kWh/month to 234kWh/month [3].

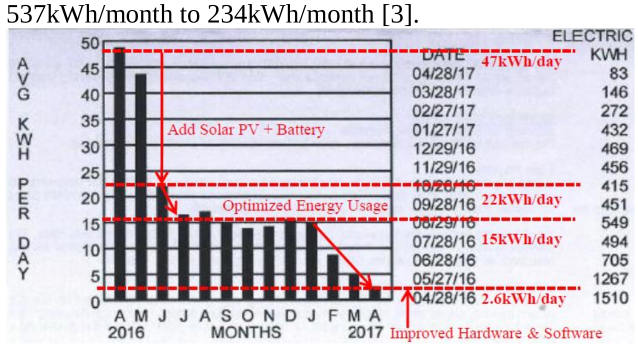

Fig.1. Hawaiian Electric April 2017 home utility bill.

II. EXPERIMENTATION

This residential Hawaii case study is for a Poncho's Solar installed 7kWh (27 cSi modules) rooftop solar PV + Panasonic 10kWh Li-ion battery for storage and a solar thermal hot water system as shown in Fig.2. The solar PV system is controlled by a Tabuchi Electric 5.5kWh inverter that is tied to the Grid in a customer self-supply mode with no export back to the Grid due to Hawaii's post-NEM. The solar thermal hot water heater has two solar panels, the 2nd panel was installed on Nov 3, 2016 to boost water heating temperature of the 80 gallon solar hot water storage tank to >170ºF (super-charged hot thermal storage battery) and on Jan 18, 2017 a 2nd hot water storage tank (40 gallons) was added in series to increase the hot thermal storage battery capacity from 80 to 120 gallons to provide a full day supply of hot water when fully thermally charged for the 4 baths/day each requiring 40 gallons of hot water. For cold thermal storage we used daytime solar PV generation to power the 3 to 7 portable air conditioning (AC) units around the house. This would chill selected rooms around the house from daytime high of >85ºF to <69ºF avoiding the need for running the AC after sunset or returning home after work.

Fig.2. Poncho's Solar installed 27 cSi solar PV modules and two solar thermal hot water panels.

III. RESULTS

A. Max Solar PV Energy Generation:

For post-NEM, the only way to monitor the solar PV system performance is by creating a total system load/demand >7.0kW/h with 1.5kW/h for maximum battery charging and 5.5kW/h for maximum inverter DC to AC energy conversion. This was achieved by running the clothes dryer around 12:30PM and the results for the past 11 months are shown in Fig.3. The peak solar PV energy generation varied from a high of ~6.6kW/h mid-Jan to mid-Oct to a lower high of 5.6kW/h for Nov and Dec, a 16.5% output difference. The reported yearly sun radiance variation for Honolulu Hawaii at 1PM is 0.6-1.1kW/m^2 or 45.5% difference as shown in the Fig.3 insert. The 16.5% shift we observed is less than sun radiance variation and since the panels were never cleaned this result also includes soiling effects.

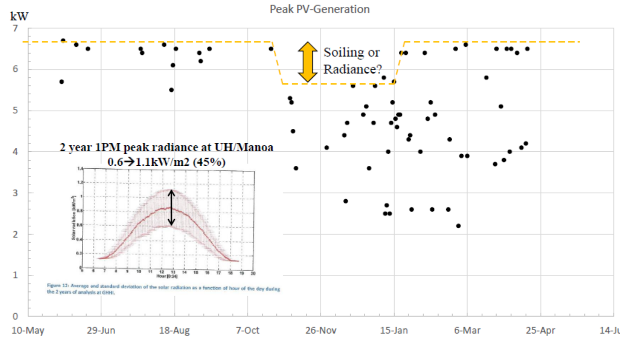

Fig.3. Past 11 months peak solar PV energy generation.

To determine the amount of solar PV generation dumping/loss and curtailment each month, we used the PVWATTS.NREL.GOV System Advisor Model simulation results based on data for Honolulu as shown in Fig.4 [2]. This shows a monthly average of ~30% solar PV energy dumping throughout the past year and the months with ~45% correspond to the 1+ week vacation mode out of town months (July, Sep, Oct & Dec).

Month	Solar Radiation (kWh / m^2 / day)		AC Energy (kWh)	Ene… Actual PV Results
January	4.52	=23.9kWH/Day	584	→383kWH (65.5%) =12.4kWH/Day
February	5.20	=27.7kWh/day	609	→374kWh (61.4%) =13.34kWh/day
March	5.74	=30.3kWh/day	738	→489kWh (66.2%) =15.8kWh/day
April	5.89	=31.2kWh/day	735	→512kWh (69.7%) =17.1kWh/day
May	6.32	=33.3kWh/day	811	→499kWh (61.5%) =16.1kWh/day
June	6.36	=33.4kWH/Day	786	→560kWH (71.2%) =18.6kWH/Day
July	6.41	=33.6kWH/Day	818	→461kWH (56.4%) =14.8kWH/Day
August	6.46	=33.7kWH/Day	820	→599kWH (73.0%) =19.3kWH/Day
September	6.32	=33.0kWH/Day	777	→452kWH (58.2%) =15.1kWH/Day
October	5.41	=28.6kWH/Day	697	→360kWH (51.6%) =11.6kWH/Day
November	4.71	=25.0kWH/Day	589	→368kWH (62.5%) =12.3kWH/Day
December	4.40	=23.3kWH/Day	568	→309kWH (54.4%) =10.0kWH/Day
Annual	5.65		8,532	

Fig.4. NREL solar PV generation simulation results for Honolulu.

B. Energy Usage Monitoring for Grid-Buy Reduction

The typical home energy usage for residential Honolulu as reported by Hawaiian Electric is #1 electrical water heater at 40%, #2 refrigerator/freezer at 15%, #3 air conditioner (AC) at 12%, tied for #4 are clothes dryer, cooking and lighting at 8% and #7 dishwasher at 3%. In order to reduce Grid-Buy energy usage, daily energy usage monitoring with 1 minute and not 1 hour data interval resolution is needed. Fig.5 shows the Tabuchi Electric remote wall solar system monitor in real-time with data refresh every 5 seconds for June 12, 2016. Energy demand usage at 1:16PM was 12.0kW/h with solar PV generation of 6.37kW/h, Grid-Buy electricity of 7.22kW/h and battery charge of 1.50kW/h. Fig.6 shows the web-link data using the Laplace software analysis in real-time with hourly updates and 1 hour data averaging.

The 1PM data shows demand was only 9kW/h with PV generation of <5kW/h which is much lower than the data in Fig.5. Also, the state of battery charge plot shows the 2nd battery discharge that occurs between 9AM and 11AM. Due to the poor resolution of hourly data monitoring no information for each critical household appliance energy usage can be determined. Therefore we used off-line Excel data analysis of the Laplace solar PV monitoring system that provides daily data with 1 minute interval resolution as shown in Fig.7. Now we can identify each energy usage spike including #1 clothes dryer at 6kW/h, #2 the 7 portable AC units at 5.5kW/h, #3 the electrical hot water heater at 4.5kW/h, #4 refrigerator/freezer at 300-800W/h, #5 pool pump at 200-2000W/h and cooking lunch/dinner at 4.5kW/h.

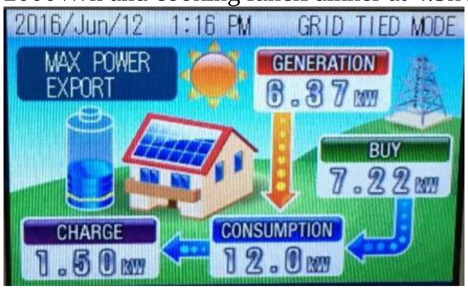

Fig.5. Tabuchi Electric remote wall solar system monitor in real-time with data refresh every 5 seconds.

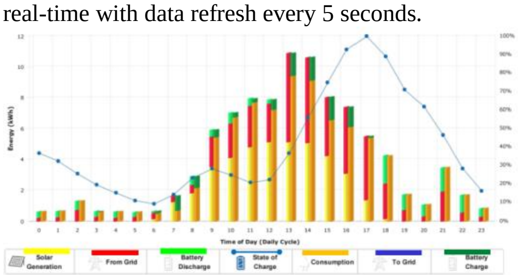

Fig.6. Laplace solar PV monitoring with 1 hour data resolution.

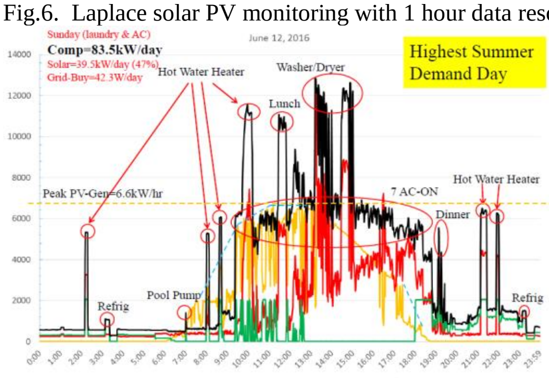

Fig.7. Off-line excel data analysis of the Laplace collected data with 1 minute resolution.

C. Hot Thermal Storage to Eliminate AM & PM Grid-Buy Energy Peaks/Spikes

The #1 dryer and #2 AC energy usage appliances can be scheduled so their time-of-use (TOU) coincides with the daytime peak solar PV energy generation as shown in Fig.7 leaving the #3 electrical hot water heater as the key contributor to the evening and morning Grid-Buy energy spikes and peaks. Results for rainy day Nov. 7, 2016 is shown in Fig.8 with a Grid-Buy of 21.0kWh/day and 5 hot water heater energy spikes throughout the day for heating the water from 110ºF to 135ºF at 5:30AM for the 1st morning shower/bath, again at 2:30PM because solar thermal heating was insufficent for heating water after the 2nd morning shower/bath above 105ºF requiring both Grid-Buy and battery discharge to reach 135ºF, again at 5:30PM, 7PM after the 1st evening bath/shower and 9:30PM after the 2nd evening bath/shower. Nov. 5 & 6, 2016 were sunny days and the solar thermal panels heated the water to >157ºF for full hot thermal charging (super charging) of the 80-gallon tank thermal storage battery so no Grid-Buy electricity was needed for morning and evening hot water heating for these 2 days as shown in Figs. 9 & 10 for Laplace and Bidgely monitoring systems. The Bidgely energy monitor is from Hawaii Blue Planet Foundation with real-time 5 minute interval energy usage collection and it also records the outside air temperature. Fig.11 shows the daily peak water temperature for the 80 gallon (up to 178ºF) and 40 gallon (up to 172ºF) hot thermal storage batteries and after the morning AM shower/bath (3rd hot water discharge). The 80 gallon tank drops by -35ºF and the 40 gallon tank by -45ºF.

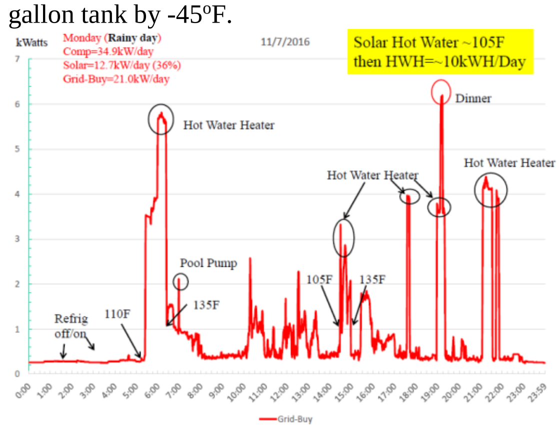

Fig.8. Laplace energy usage monitor for rainy day.

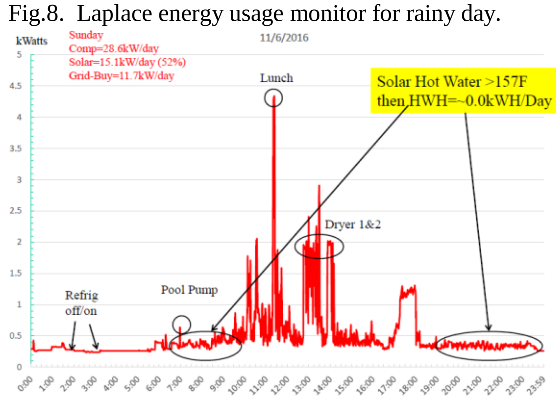

Fig.9. Laplace energy usage monitor for sunny day.

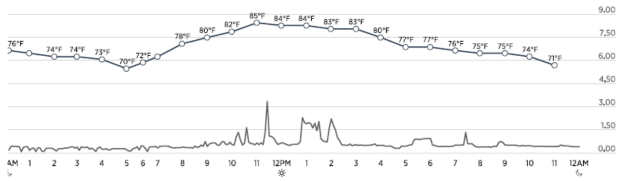

Fig.10. Bidgely energy usage monitor for sunny day.

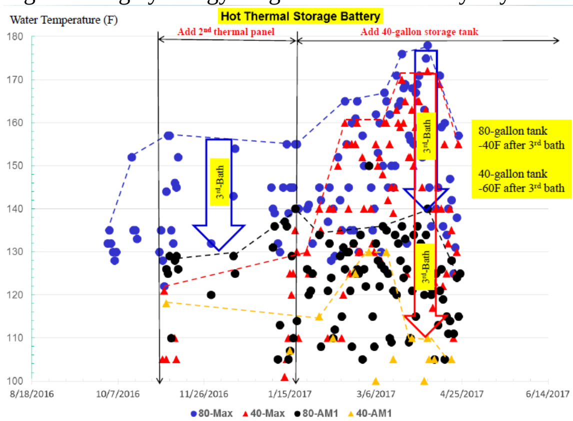

Fig. 11. Water temperature of Hot thermal storage battery.

D. Cold Thermal Storage to Eliminate PM Grid-Buy

Grid-Buy energy usage for room/house AC cooling for late afternoon or early evening especially after returning home from work can be significantly reduced or eliminated by using the daytime solar PV energy generation to power the room/house AC units during the day since this energy is free and not being exported back to the Grid it would reduce PV energy dumping/curtailment. This reduces the room temperature from a daytime high of >85°F to <69°F. Operating the solar control system in the Max Solar Energy Mode with all 7 portable AC units on for 6 hours resulted in a Grid-Buy of 5.1kWh/day as shown in Fig.12 but if the number of AC units on is reduced to 3 as shown in Fig.13 then Grid-Buy can be reduced to 0.0kWh/day. Fig.14 shows 12 days in April with 0.0kWh/day Grid-Buy.

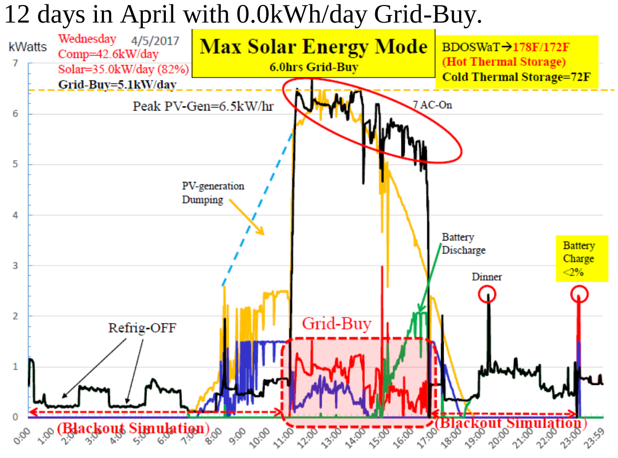

Fig.12. Max Solar Energy mode with 7 AC units on.

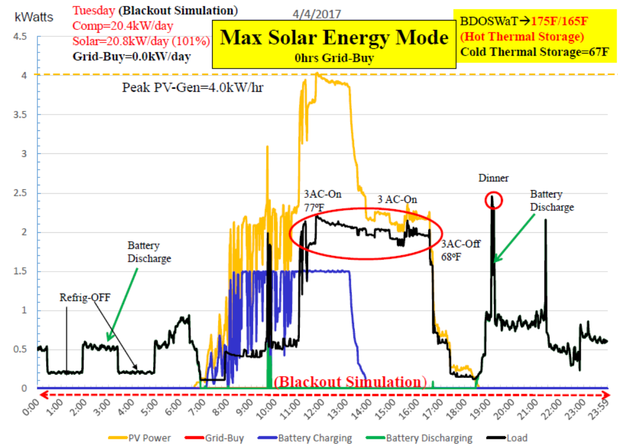

Fig.13. Max Solar Energy mode with 3 AC units on.

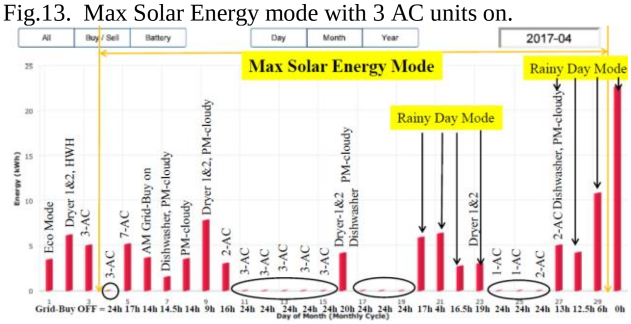

Fig.14. April 2017 Grid-Buy =0.0kWh/day for 12 days.

IV.SUMMARY

We investigated the integration of customer self-supply rooftop solar PV system with electrical battery storage and hot & cold thermal storage for post-NEM residential Hawaii. Optimizing time of use for key appliances and improvements to hardware and software control system we reduced the average daily Grid-Buy by >94.5% from 48.7kWh/day to 2.7kWh/day eliminating the AM and PM Grid-Buy energy peaks/spikes and also achieving 12 days in April with 0.0kWh/day Grid-Buy.

REFERENCES

[1] T. Reindl, "LCOE reduction of PV electricity—does technology still matter?", 43rd IEEE-PVSC 2016, area 8 plenary talk not published.

[2] www.pvwatts.nrel.gov website.

[3] www.Hawaiienergy.com website.