Distributed Energy System Validation, Commissioning and Qualification Test Report

Prepared for the

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Report on Energy Storage Systems

Prepared by

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This overall report on Storage Technology Subscale Testing consists of two parts. Part I covers the validation and commissioning aspects and Part II covers the qualification testing. Part I begins on page 1 and Part II begins on page 15. The four appendices for Part I are presented after the last page of Part II (page 25).

UNIVERSITY OF HAWAII
HAWAII NATURAL ENERGY INSTITUTE

Storage Technology Subscale Testing Part I Validation and Commissioning Report

September 20, 2012
Revision 6.0

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APPENDIX D: Modified One-line Diagram (Two PV Inverters)

1 INTRODUCTION

Over the next decade, it is estimated that 150 to 300 GW-Hr of Distributed Energy Storage (DES) capacity will be required to help support the modernization of our nation's electrical grid. The rapid growth of wind and solar power that the Hawaiian Islands have experienced is a key driver to improve the development and deployment of community-scale DES. A properly implemented DES co-located with solar photovoltaic (PV) power generation can significantly improve power quality at the point of connection, and even increase the value of the energy generated. Variable power output by a PV system can be stored by a battery system and delivered to the grid at fixed rates and at specific times.

Currently HNU Energy is developing DES technologies (Figure 1) to address issues related to un-firm power from individual renewable sources. HNU Energy has a grid-tied test bed site to demonstrate various renewable technologies. HNU Energy has integrated solar PV and energy storage at the residential level by storing the energy and then deploying the energy to the grid at prescribed times. This report describes this system (the inverter and battery) as well as how it is integrated into the test bed site. This report also discusses how the DES was validated and commissioned.

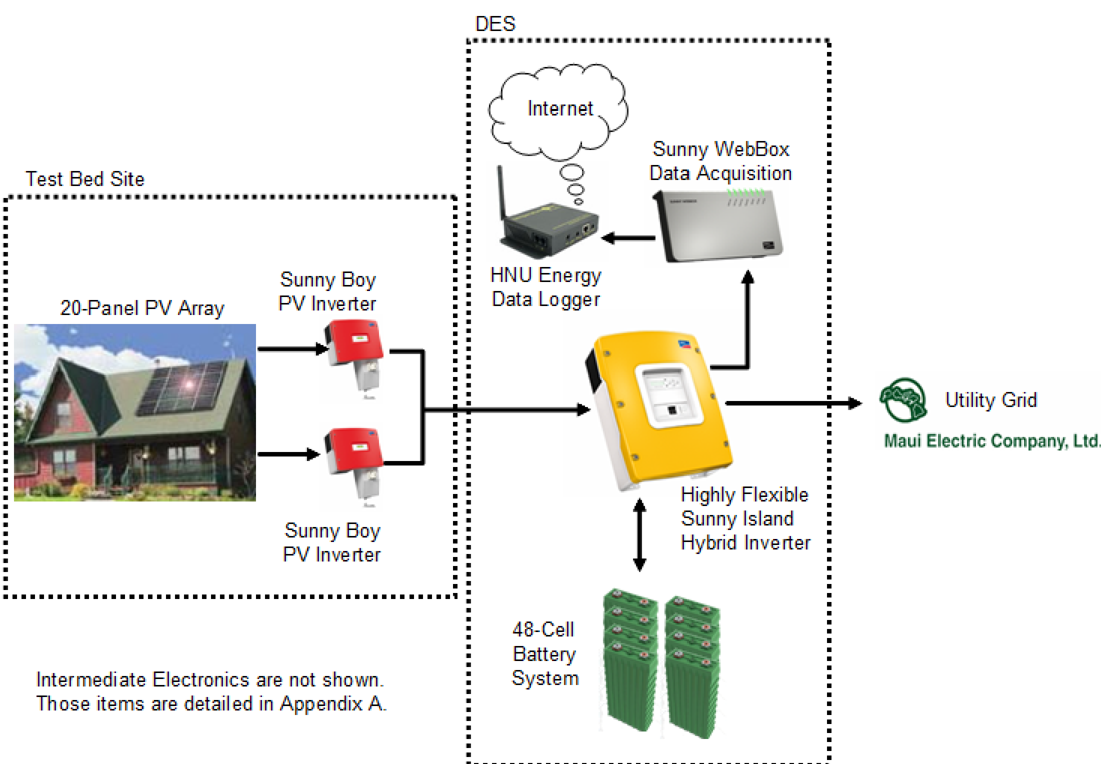

Figure 1: DES System Demonstration.

2 COMPONENTS AND SPECIFICATIONS

The primary components of the DES are; (1) a programmable Sunny Island inverter, (2) a battery system manufactured by International Batteries Inc., (3) a data acquisition system (the Sunny WebBox), and (4) a data logging system developed by HNU Photonics LLC. However, since this research project is scoped to detail the integration of the DES into our test bed site, the balance of system components DES are also discussed in detail.

2.1 PV Array

The PV array consists of 20 Sun-Power Serengeti (SER-228P) panels. The specifications for each panel are tabulated in Table 1.

Table 1: PV Panel Specification

Specification	Value
Power [Wmpp]	228
Voltage [Vmpp]	29.6
Current [Ampp]	7.7
Open Circuit Voltage [Voc]	37.8
Short Circuit Current [Asc]	8.3
Wind Tolerance [MPH]	150

Note: the wind tolerance specification applies to the entire PV array and is certified by HNU Energy.

2.2 Sunny Boy PV Inverter System

The PV inverter system consists of two Sunny Boy 3000-US central inverters (Figure 2). Each inverter is connected to ten PV panels - this is a modification to Appendix A that is captured in Appendix D.

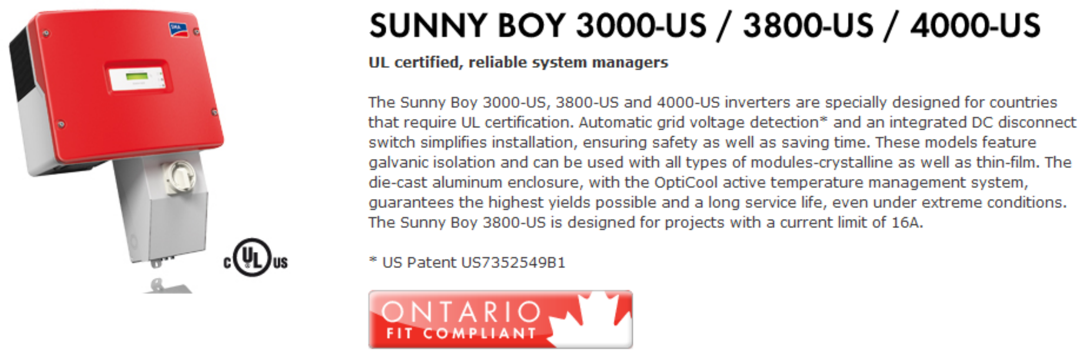

Figure 2: Sunny Boy 3000-US PV Inverter.

The specifications for the inverter are shown in Table 2.

Table 2: PV Inverter Specifications

Item	Input (DC)	Specification	Notes
1	Max PV Power	3750W	Recommended @ Module STC
2	Max DC Power	3200W	@ Cosine psi = 1
3	Max DC Voltage	500V	
4	Nominal DC Voltage	250V	
5	MPP Voltage Range	175-400V	
6	Min DC Voltage	175V	
7	Start Voltage	228V	
8	Max Input Current	17A	36A @ Combined Terminal
	Output (AC)		
9	AC Nominal Power	3000W	
10	Max AC Apparent Power	3000VA	
11	Nominal AC Voltage 1	208V	Adjustable
12	Nominal AC Voltage 2	240V	Adjustable
13	AC Voltage Range 1	183-229V	
14	AC Voltage Range 2	211-264V	
15	AC Grid Frequency	60Hz	
16	Frequency Range	59.3-60,5Hz	
17	Max Output Current	15A, 13A	
	Efficiency		
18	Max Efficiency 1	96.00%	
19	Max Efficiency 2	96.50%	
20	CEC Efficiency 1	95.00%	
21	CEC Efficiency 2	95.50%	

Note: Items 13, 14, 18, and 19 contain the markings "1" and "2". These are dependent upon the selection of the adjustable parameters 11 and 12. Also, Item 7, the maximum output current is 15 A when mode 1 is selected and 13 A when mode 2 is selected.

2.3 PV Sub-Panel

The new 240V PV sub-panel houses a 20 A breaker for each of the two Sunny Boy inverters. This sub-panel isolates the residence from the PV system in the event of a trip. The manufacturer of this component is Siemens. The model number is W0204ML1060U.

2.4 Isolation Transformer

The isolation transformer is a 5 kW Federal Pacific (model number SE2N5FS) 240/120 V single phase transformer. This component is UL listed for indoor and outdoor use. The maximum operating temperature is 115 °C. This transformer (1) isolates the PV array and inverter from the residence, and (2) steps the voltage down from 240 V to 120 V. Other specifications can be found at http://www.temcoindustrialpower.com/products/Transformers_-_General/FT2070.html.

2.5 Single Breaker Enclosure

The new single breaker enclosure houses a 120 V, 50 A breaker manufactured by Siemens. This breaker isolates the residence from the transformer. The model number is W0204ML1060U.

2.6 Sunny Island Hybrid Inverter

Because the Sunny Island Hybrid Inverter (Figure 3) is programmable, it is a highly flexible device. It was intended to develop an isolated AC grid that is not necessarily connected to a utility grid system. It is being used in the DES to (1) automatically balance AC and DC sources, (2) feed power to the MECO grid, and (3) manage the battery (optimizing battery life). Some modification was performed on the software in this unit so that it could be used to sell battery-only power to the utility grid. This required special permission from MECO.

SUNNY ISLAND 5048 / 5048-US

The Island Manager

The Sunny Island 5048 makes commissioning within minutes possible. All required operational settings can be made quickly and easily in just a few steps. The Sunny Island 5048 is versatile, extendable and takes on all control processes. Its first-class battery management ensures maximum battery life. It also features impressive efficiency, a rugged die-cast aluminum enclosure and the OptiCool active cooling system. The Sunny Island is also available in a UL-compliant 5048-US version with an output rating of 120 V and 60 Hz for the North American market.

Figure 3: Sunny Island Inverter System

The specifications for this inverter are listed in Table 3.

Table 3: Sunny Island Inverter Specifications

AC Output (Loads)		**Battery DC Input**	
Nominal AC Voltage (Adjustable)	120V (105-132V)	Battery Voltage Range	48V (41-63V)
Nominal Frequency (Adjustable)	60Hz (55-65Hz)	Max Battery Charging Current	120A
Continuous AC Power at 25 Degrees C	5000W	Continuous Charging Current at 25 Deg. C	100A
Continuous AC Power at 45 Degrees C	4000W	Battery Type	Lead, NiCh
AC Power at 25 Degrees C for 30 Min.	6500W	Battery Capacity Range	100-10000A-Hr
AC Power at 25 Degrees C for 1 Min.	8400W	Charge Control	IUoU Process
AC Power at 25 Degrees C for 3 Sec.	11000W		
Nominal AC Current	41.7A	**Efficiency / Operating Consumption**	
Max AC Current	180A for 60ms	Max Efficiency	95%
		Internal Consumption with no Load	25W
AC Input (Generator or Grid)		Standby Internal Consuption	4W
AC Input Voltage Range	120V (80-150V)		
AC Input Freq. Range	60Hz (54-66Hz)	**Protection Devices**	
Max Input Current (Adjustable)	56A (0-56A)	DC Reverse Polarity Protection	Yes
Max Input Power	6.7kW	DC Fuse	Yes
		AC Short-Circuit	Yes
General Data		Overtemperature	Yes
Dimensions (W / H / D) inches	18 / 24 / 9	Excessive Battery Discharge	Yes
Weight [lbs]	139		
Operating Temperature Range	-25 Through +50 Deg. C		
Protection Rating (IEC 60529)	Indoors (NEMA 1)		

2.7 Battery

The lithium-ion battery consists of 48 LiFePo cells (Figure 4) manufactured by International Battery (model number IB-B-FHE-160). Each cell has a rating of 160 A-Hr (0.5 kW) for a total of 24 kW-Hr of storage.

High Energy Large Prismatic Rechargeable Cell

Lithium-Iron Phosphate Cells (LiFePO4)

International Battery, Inc.'s Iron Phosphate rechargeable cells are available in a rugged prismatic format in capacities ranging from 40 - 160Ah. LiFePO4 is an intrinsically safe cathode material. LiFePO4 cells do not incinerate or explode under extreme conditions. LiFePO4 cells have a high discharge current, are not toxic and have a high cycle life. The specific geometries of these cells allow for even electrode utilization, good heat dissipation and efficient packaging. IB's cells offer a low self-discharge rate and have excellent operating temperature characteristics. The excellent thermal stability and safety performance of the Lithium Iron Phosphate electrochemical system is well suited for variety of commercial, military and industrial applications.

Figure 4: International Battery (one cell shown)

The specifications for the battery are listed in Table 4.

Table 4: Battery specification

Specification	Condition	Value
Nominal Voltage	(C/3)	3.2V
Nominal Capacity	(C/3)	160A-Hr
Nominal Energy	(C/3)	512W-Hr
Specific Energy	(C/3)	94W-Hr/Kg
Peak Power (60% DOD)	30 Sec, 2/3 OCV, 60%	3000W (555W/Kg)
Peak Power (60% DOD)	30 Sec, 2/3 OCV, 60%, Active Cooling	4200W (778W/Kg)
DC Pulse Resistance	10 Sec, 5C, 60% DOD	0.75 mOhm
Self-Discharge Rate	Monthly RT	<3%
Cycle Life @ 25 Deg C	100% DOD	>2000 Cycles
Cycle Life @ 55 Deg C	100% DOD, 1C, Active Cooling	>1000 Cycles
Cell Weight	Integrated Cell	5.4kg
Rec. Cutoff Voltage	Charge	3.6V
Rec. Cutoff Voltage	Discharge	2.5V
Safe Operating Ranges	Max	3.6V
Safe Operating Ranges	Min	2.5V
Max Pulse Current (< 30 Sec)	>2.5V	800A (5C)
Max Pulse Current (< 30 Sec)	>2.5V, Active Cooling	1120A (7C)
Max Con't Charge Current	100% DOD	80A (C/2)
Max Con't Charge Current	100% DOD, Active Cooling	160A (C)
Max Con't Discharge Current	10% - 90% DOD	160A (C)
Max Con't Discharge Current	10% - 90% DOD, Active Cooling	480A (3C)
Charging Efficiency	100% DOC @ C/3	90%
Charging Efficiency	10% - 90% DOC @ C/3	98%
Operating Temperature	Charge	0 to 50 Deg C
Operating Temperature	Discharge	-20 to 55 Deg C
Storage Temperature		-30 to 60 Deg C
Calendar Life		10 Years

2.8 Residential Specifications

The test site is based on a standard grid interconnection on Maui. There are no special transformers needed to support this research.

3 ELECTRICAL CONNECTIONS

All electrical connections are specified in Appendix A. The only wiring items that were not specified are the DC connections between the Sunny Island inverter and the battery. Those are all 1/O cables. Note that the feed to the MECO grid is single phase AC.

3.1 PV System to Sunny Boy Inverter

The wiring between the PV panels and the two PV inverters is shown in Appendix A. All wires are 10-gauge, with two wires per panel (positive and negative).

3.2 Sunny Boy Inverter to PV Sub-panel

The connections between the Sunny Boy inverter (PV inverter) and the PV sub-panel are made with two 10 gauge wires (20 A, 240 V).

3.3 PV Sub-panel to Isolation Transformer

The connections between the PV sub-panel and the isolation transformer are made with two 10-gauge wires (20 A, 240 V).

3.4 Isolation Transformer to Single Breaker Enclosure

The connections between the isolation transformer and single breaker enclosure are made with two 10-gauge wires (30 A, 120 V).

3.5 Single Breaker Enclosure to Sunny Island Battery Inverter

The connections between the single breaker enclosure and Sunny Island inverter are made with two 10-gauge wires (30 A, 120 V).

3.6 Sunny Island Battery Inverter to International Battery System

The connections between the Sunny Island Inverter and the battery are made with 1/O, 600 volt battery cable.

3.7 Sunny Island Battery Inverter to Existing Distribution Panel

The connections between the Sunny Island Inverter and the existing distribution panel are made with two 8-gauge wires (50 A, 120 V).

3.8 Existing Distribution Panel to New AC Disconnect

The connections between the existing distribution panel and the new AC disconnect are made with 100 A standard service aluminum cable.

3.9 New AC Disconnect to Existing Main Load Center

The connections between the new AC disconnect and the existing main load distribution center is made with 100 A standard service aluminum cable.

4 COMMUNICATIONS AND DATA LOGGING

A Sunny WebBox is used as an interface for a user to communicate with the two inverters. A data logger, custom built by HNU Energy, provides the access to this data (web interface) for analysis or visualization.

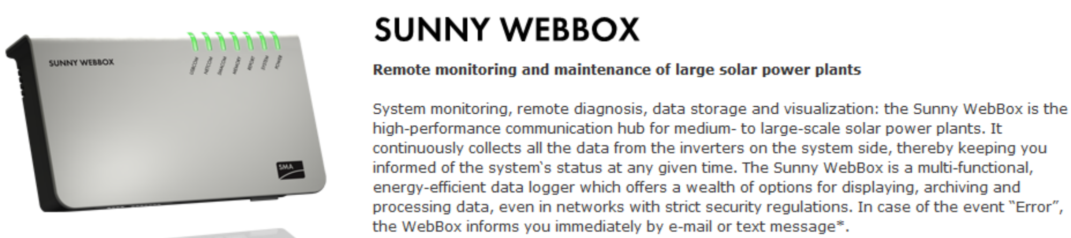

Figure 5: Sunny WebBox

4.1 Communications Connections

The Sunny Island inverter is connected to the Sunny WebBox using a RS-485 cable. The WebBox is connected to the Internet through an Ethernet cable. The HNU Energy Data Logger is also connected to the Internet via Ethernet.

4.2 Data Logging

The HNU Energy Data Logger can sample at a maximum rate of 1 sample per second. This sub-system logs a time stamp, voltage, and current into and out-of the Sunny Island inverter. This is to monitor AC power generated by the PV array, and the AC power generated by the battery (both going to the MECO grid).

4.3 Software Setup

No software setup is required since both the WebBox and HNU Energy Data Logger are equipped with embedded firmware.

4.4 Data Access

The data can be accessed from http://cray36.mauibuilt.com using the Microsoft Internet Explorer version 8.0 or above. See Figure 6 for the initial portion of the Data Access list.

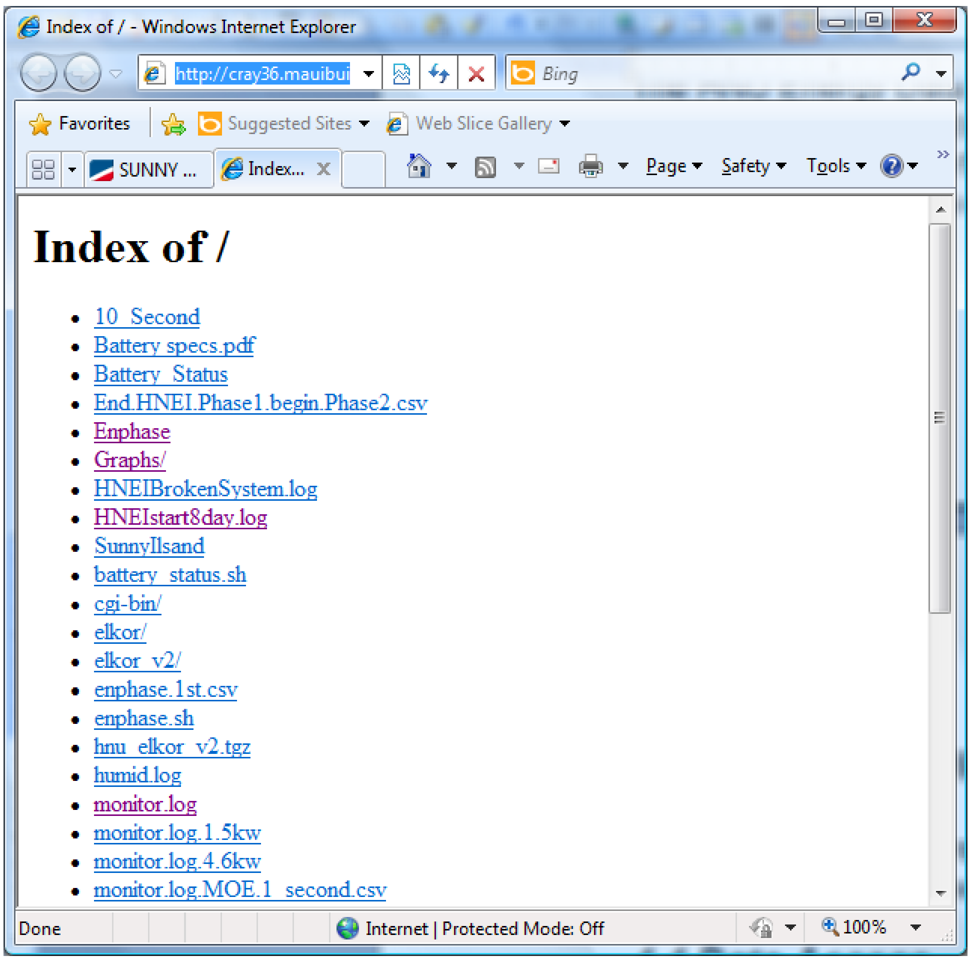

Figure 6: Data access

The procedure to access the data is as follows:

1. Right-click the file "monitor.log" to execute a context menu.
2. Left-click the "save-as" item in the context menu. This launches a "Save As" dialog box.
3. Change the name from "monitor.log" to "monitor.csv".

4. Locate the folder location where the file was saved (named in the "Save As" dialog box.
5. If Microsoft Excel is installed, double-clicking this file will display the contents of the file.

The CSV file contains the following data:

1. Date
2. Time
3. Total Energy Consumption
4. Total Real Power(W)
5. Total Reactive Power(VAR)
6. Total Apparent Power(VA)
7. Average Voltage (L-N)(Volts)
8. Average Voltage (L-L)(Volts)
9. Average Current(Amps)
10. Total (System)
11. Power Factor()
12. Frequency(Hz)
13. Sliding Window Real Power Demand (Total of phases)(kW)
14. Voltage A-N(Volts)
15. Voltage B-N(Volts)
16. Voltage C-N(Volts)
17. Voltage A-B(Volts)
18. Voltage B-C(Volts)
19. Voltage A-C(Volts)
20. Current A(Amps)
21. Current B(Amps)
22. Current C(Amps)
23. Real Power A(kW)
24. Real Power B(kW)
25. Real Power C(kW)
26. Reactive Power A(kVAR)
27. Reactive Power B(kVAR)
28. Reactive Power C(kVAR)
29. Apparent Power A(kVA)
30. Apparent Power B(kVA)
31. Apparent Power C(kVA)
32. Power Factor A()
33. Power Factor B()
34. Power Factor C()
35. Software Version()
36. Import Energy (+) A(KWh)
37. Import Energy (+) B(KWh)
38. Import Energy (+) C(KWh)
39. Total Import Energy (+) A+B+C(KWh)
40. Export Energy (-) A(KWh)

41. Export Energy (-) B(KWh)
42. Export Energy (-) C(KWh)
43. Total Export Energy (-) A+B+C(KWh)
44. Total Energy (+/-) A(KWh)
45. Total Energy (+/-) B(KWh)
46. Total Energy (+/-) C(KWh)
47. Total Energy (+/-) A+B+C(KWh)
48. Inductive Energy (+) A(KVARh)
49. Inductive Energy (+) B(KVARh)
50. Inductive Energy (+) C(KVARh)
51. Total Inductive Energy (+) A+B+C(KVARh)
52. Capacitive Energy (-) A(KVARh)
53. Capacitive Energy (-) B(KVARh)
54. Capacitive Energy (-) C(KVARh)
55. Total Capacitive Energy (-) A+B+C(KVARh)
56. Total VARh (+/-) A(KVARh)
57. Total VARh (+/-) B(KVARh)
58. Total VARh (+/-) C(KVARh)
59. Total VARh (+/-) A+B+C(KVARh)
60. Total VAh A(KVAh)
61. Total VAh B(KVAh)
62. Total VAh C(KVAh)
63. Total VAh (A+B+C)(KVAh)

Since the demonstration system is a single phase system, the phases A, B, and C do not have their usual meaning. Instead, phase A is ignored, phase B contains raw data from the PV array, and phase C contains data from the battery.

5 VALIDATION AND COMMISSIONING

The DES system was designed by HNU Energy and inspected by county inspectors as well as the local utility (MECO). System verified and turned on by qualified electrician.

5.1 Component Testing

Standard testing of all AC and DC components were verified and tested with a Fluke 376 multi-meter. This was performed by a certified electrician.

5.2 Electrical Connection Testing Procedure

Standard testing of all AC/DC circuits were verified and tested with a Fluke 376 multi-meter. For key components, such as the battery, these values were also compared against data from the HNU Energy Data Logger.

5.3 Communications Testing Procedure

Performed the procedure described in Section 4.4.

5.4 System Start-up

The system start-up procedure is as follows:
1. All voltage and wiring are verified before start up.
2. DC from all panels are turned on first.
3. The DC from the battery bank to Sunny Island is asserted.
4. All A/C circuits are turned on (including the grid).

5.5 Data Access Testing

Performed the procedure described in Section 4.4.

5.6 System Shut-down

The system shut-down procedure is as follows:
1. Disconnect or turn off all AC circuits (including the grid),
2. Turn off, or disconnect the DC between the Sunny Island inverter and the battery
3. Turn off all DC panels.

6 CONCLUSION

The system was commissioned by the action of granting the permit (Appendix C) issued by MECO. The system was validated by the certified electrician (Appendix B).

A follow-on report titled "Distributed Energy System - Qualification and Testing Report" is presented beginning on page 15, following this report, and it documents long periods of operation with that resulted in a highly favorable outcome.

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APPENDIX E: Data Delivery (Filename: Appendix E - Data Delivery.zip)
APPENDIX F: MATLAB Plotting Script (Filename: AppendixF_Plots.txt)

These appendices are not presented in this report but are available from HNEI on request.

1 INTRODUCTION

This document is the Qualification Test Report supporting the Distributed Energy System (DES) Commissioning and Validation report presented beginning on page 1, which describes the components and connections of the Distributed Energy Storage (DES) system in detail. This report discusses the performance results of the DES as implemented in its test bed site. This report covers the first two weeks of operation.

The DES and its test bed site were discussed in detail in [1]. The site and the DES are briefly reviewed in Figure 7 for convenience. The utility grid is supplied energy from a battery and inverter instead of directly from the photovoltaic (PV) array. Figure 7 is a simplified illustration of the test bed site and how it is connected to the DES.

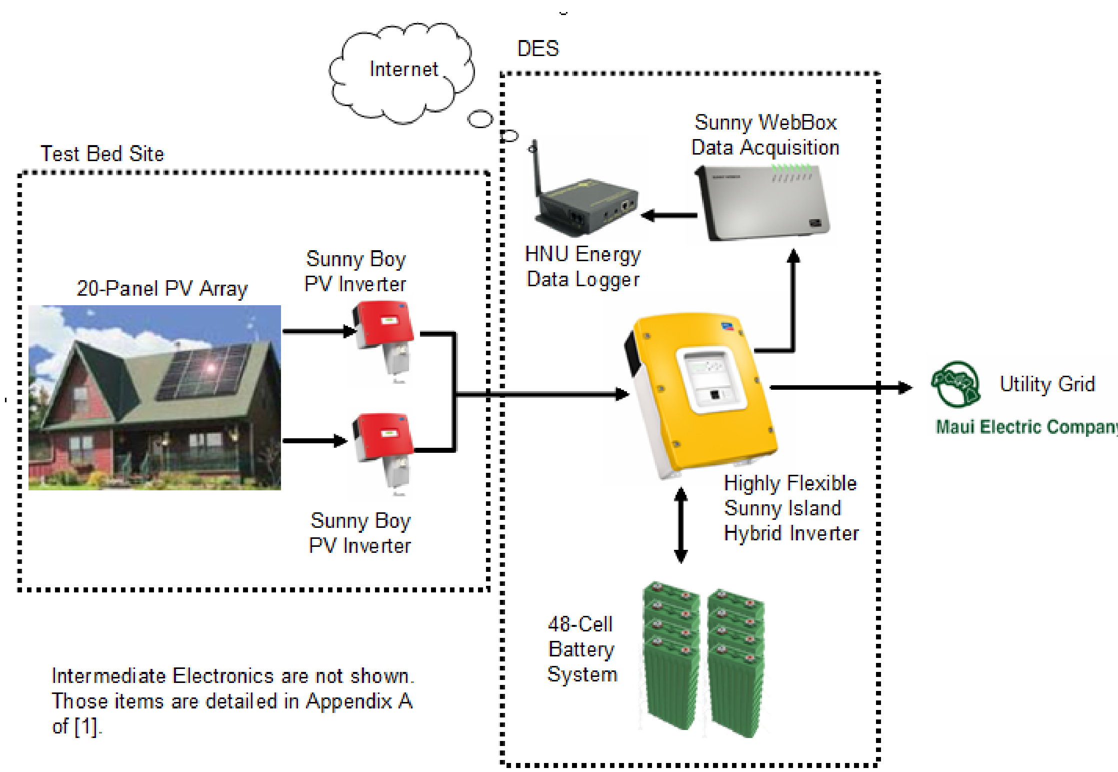


Figure 7: DES System Demonstration.

2 OBJECTIVES

The objective of the DES demonstration is to deploy a sub-scale DES system at an existing PV test bed site that is grid-connected to the MECO electricity grid. This test bed site will provide an opportunity to record and analyze detailed datasets on the performance, reliability, and durability of the energy storage device and its ability to respond to changes in load and variable output of the PV system. Reliability is demonstrated by running the system over a period of 23 days sampling power data once every 30 seconds. The low variability is studied by observing two days of data sampled at 1 sample per second.

3 DATA ACCESS PROCEDURE

The following procedure is intended for a Microsoft Windows (Version XP or later) computer equipped with MATLAB 7.0 or newer.

The data has been formatted so that it can be accessed from MATLAB. The procedure is as follows:

1. Rename the file (APPENDIX F) "AppendixF_Plots.txt" to "AppendixF_Plots.m". It is possible that the target system "hides" filename extensions for known file types. If the filename appears to be "AppendixF_Plots" with no extension, following the following sub-procedure:
    - Open a Windows Explorer window by holding the "windows" key on the keyboard, and clicking "E".
    - Click the menu item "Tools", then "Folder Options".
    - Click the "View" tab.
    - Un-check the option "Hide Extensions for Known File Types".
    - Click "Ok".
2. Move or copy "AppendixF_Plots.m" to any folder that is on the MATLAB path or the current MATLAB directory (See Figure 8).
3. Create a new directory called "Xfer" in the root drive (i.e., c:\).
4. Extract the contents of "Appendix E - Data Delivery.zip" into c:\Xfer.
5. At the MATLAB command prompt, type: AppendixF_Plots

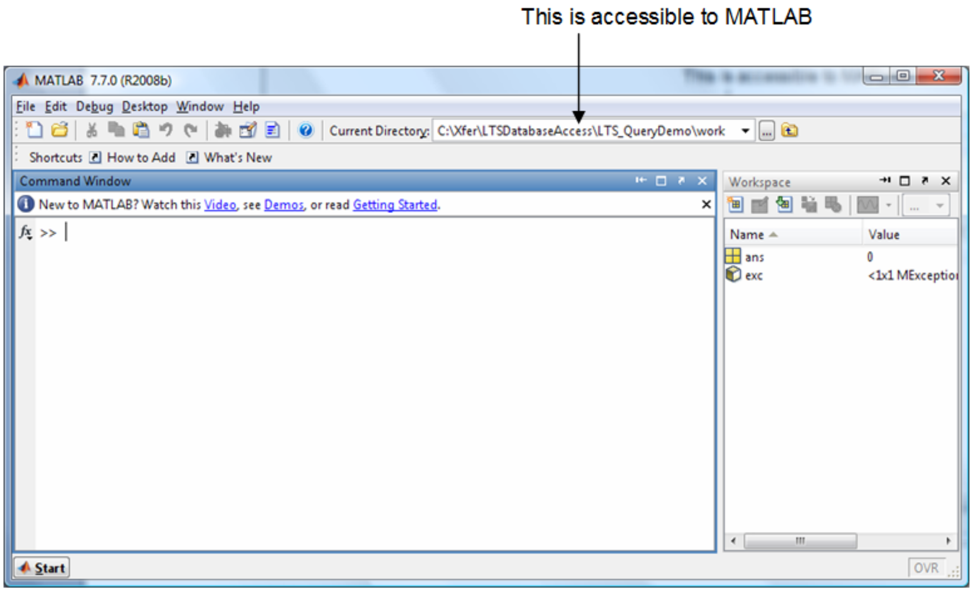


Figure 8: MATLAB directory setting.

The procedure above generates a plot and creates a variable "M" in the MATLAB workspace. This M is a matrix that has 58267 rows and 61 columns. Column 1 contains relative timestamps. Column 22 contains raw PV power. Column 23 contains the DES power. These three columns are the only valid columns in this dataset. Work is currently underway to add more detailed information, such as individual battery cell voltages.

4 RESULTS

The system logged AC power from the isolation transformer (raw PV power), and the DES output (AC power from the Sunny Island battery inverter). This was sufficient to measure reliability and variability.

The system did not log the cell-level DC voltages. The DC voltage data sets would support an analysis of the long-term cell health and any degradation in performance. Future funding under a separate grant will develop the capability to measure cell-level DC voltages.

4.1 Reliability

Figure 9 shows the results of a 23-day test period at a rate of one sample every 30 seconds.

There are nine periods when the battery was fully discharged, resulting in DES output drop-outs. The flat-top effect in Region A of Figure 9 (expanded in Figure 10) is not understood. However, this effect occurred during the first two days of operation; a period in which the operator was actively tuning the entire system (test bed and DES).

There was also a period in which the DES output was switching between outputting power, and not outputting power. This was also a part of the tuning period. The Sunny Island inverter was developed to be used in conjunction with a lead-acid battery. A threshold voltage adjustment was required so that the battery could be used with a lithium ion battery. The switching anomaly occurred during this period of adjustment. See the red line near day 2, shown in Figure 10.

Eight days of uninterrupted power is shown in Figure 11. During this period, the PV system provided the DES with enough power to maintain an adequate state-of-charge in the battery system.

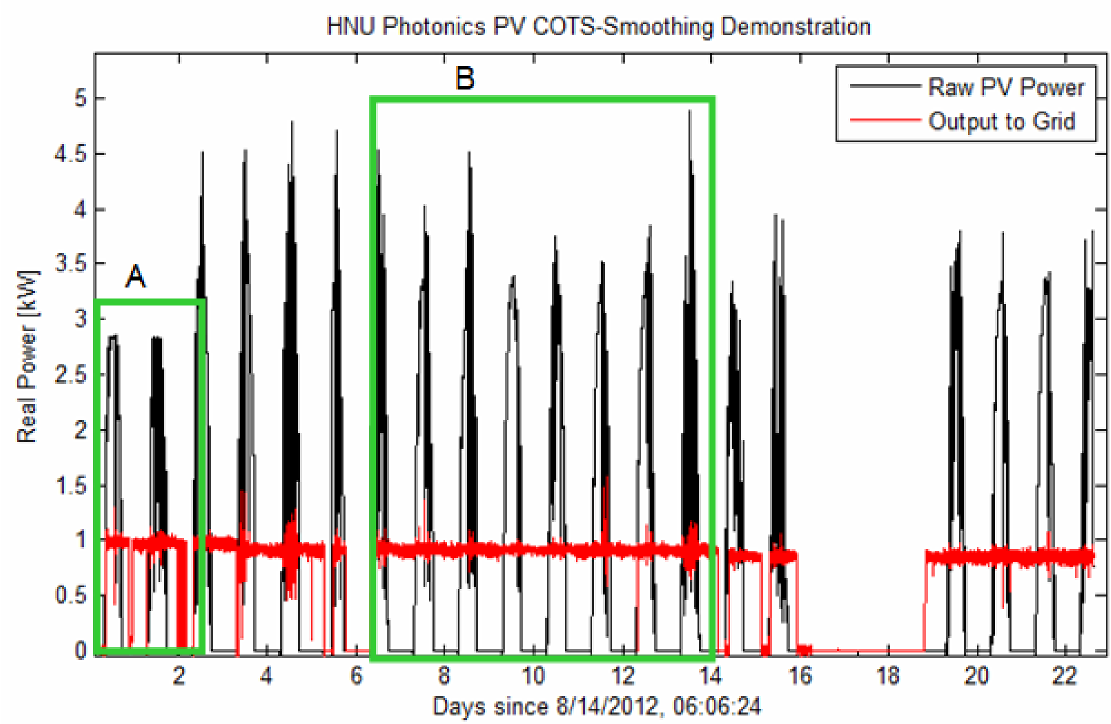


Figure 9: Raw and DES output to grid for 23 days.

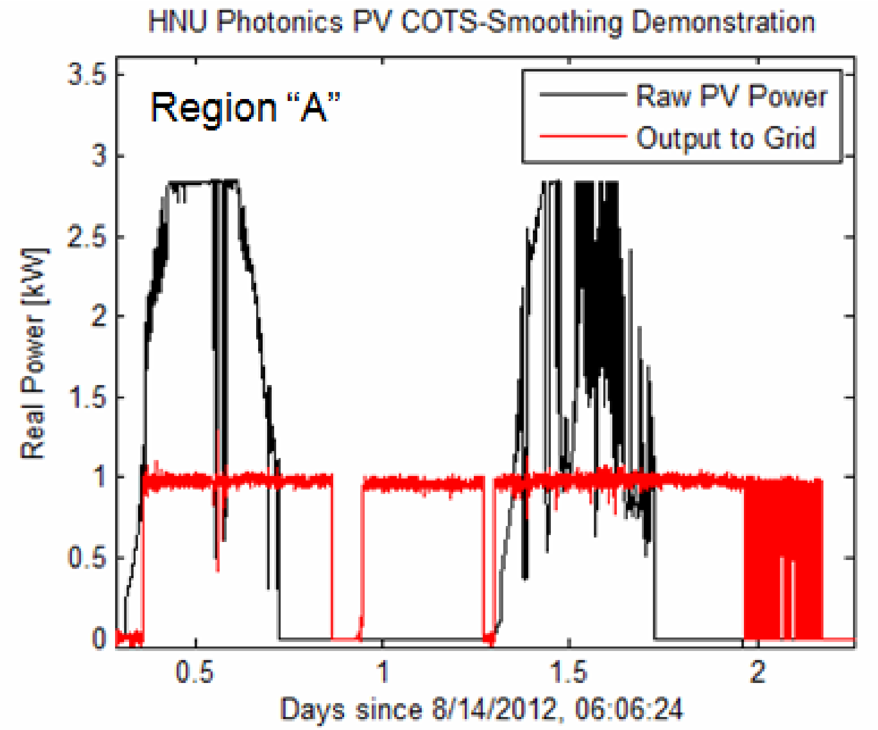


Figure 10: Region "A" from Figure 9. Shown are two dropouts, flat-top maximum PV power, and DES switching between ON and OFF states.

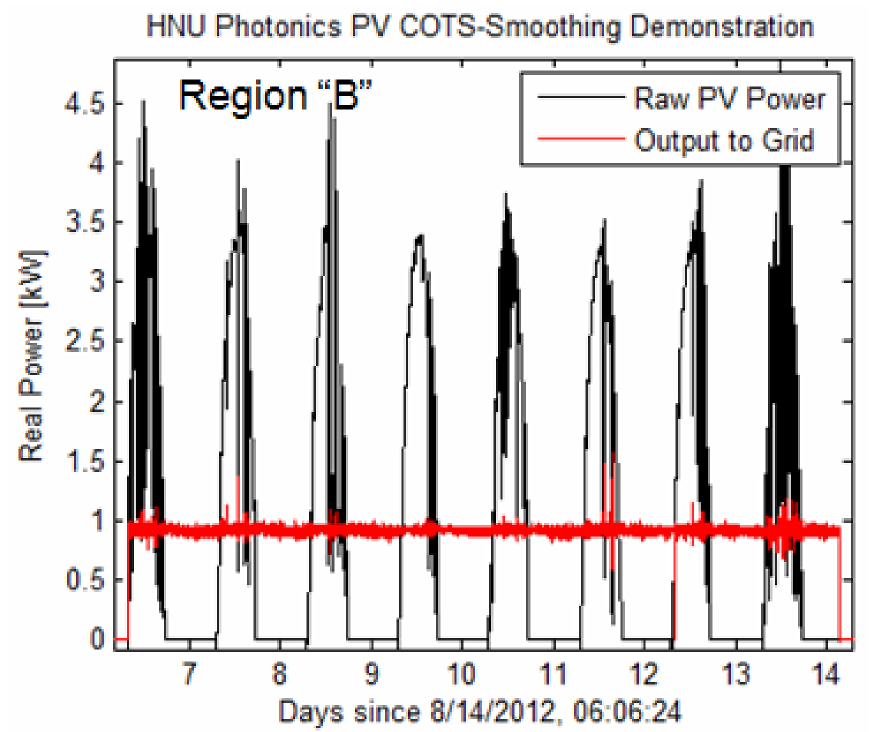


Figure 11: Region "B" in Figure 9. Eight days without DES power drop-outs.

Figure 12 shows an expansion of the ON/OFF anomaly in Figure 10.

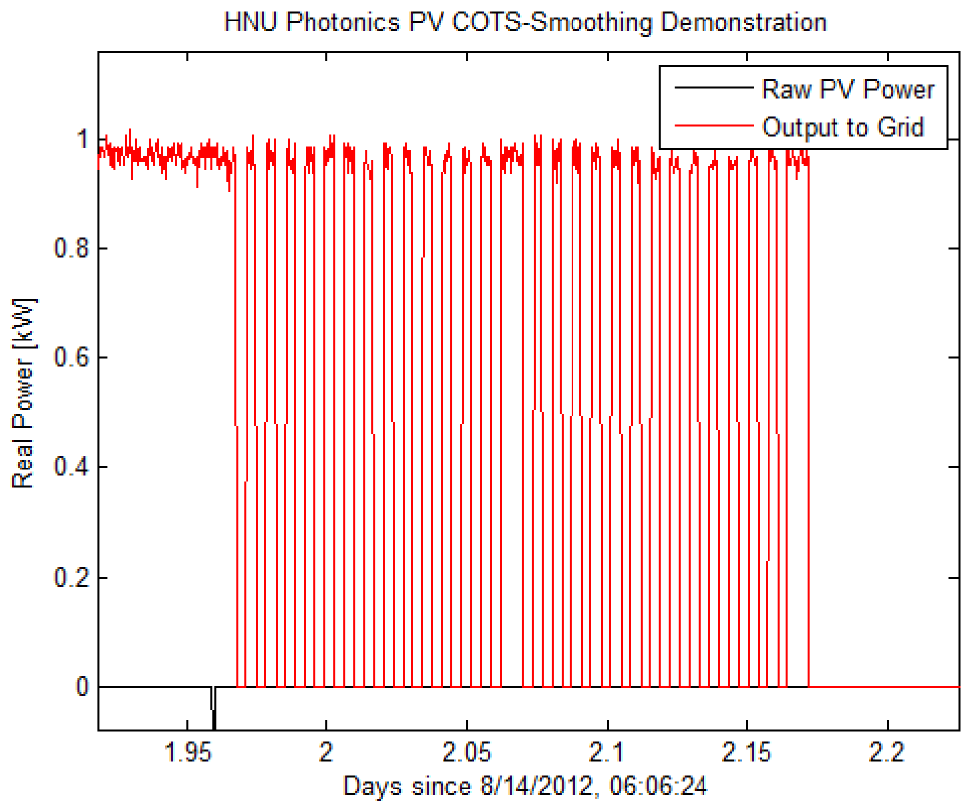


Figure 12: Expansion near day 2.

4.2 Variability

The high-rate data was run for two days to capture relatively high-resolution data sets at a sampling rate of 1Hz. This sample rate was sufficient to capture data to quantify the improvement in the AC power output to the grid. Figure 13 shows this data. The raw PV power (black) would have been fed to the MECO grid. The DES power (red) was actually fed to the grid instead. The DES power is nearly constant would be uncorrelated with other DES systems, while the raw PV power is highly variable and highly correlated with other PV systems in a geographically isolated community. Variability was quantified using one of three methods often defined in a "power purchase agreement" between a utility company and a vendor of renewable energy. Here, a 2-minute kernel was used. The minimum power was subtracted from the maximum power within this kernel. If the maximum value occurred before the minimum value, a negative sign was assigned to the metric. This kernel is then stepped by one time sample at-a-time, recalculating maximum and minimum values. This variability is shown in the two right-hand plots of Figure 13. It is clear that the variability from the DES is much less than the variability that would have come from the raw PV power.

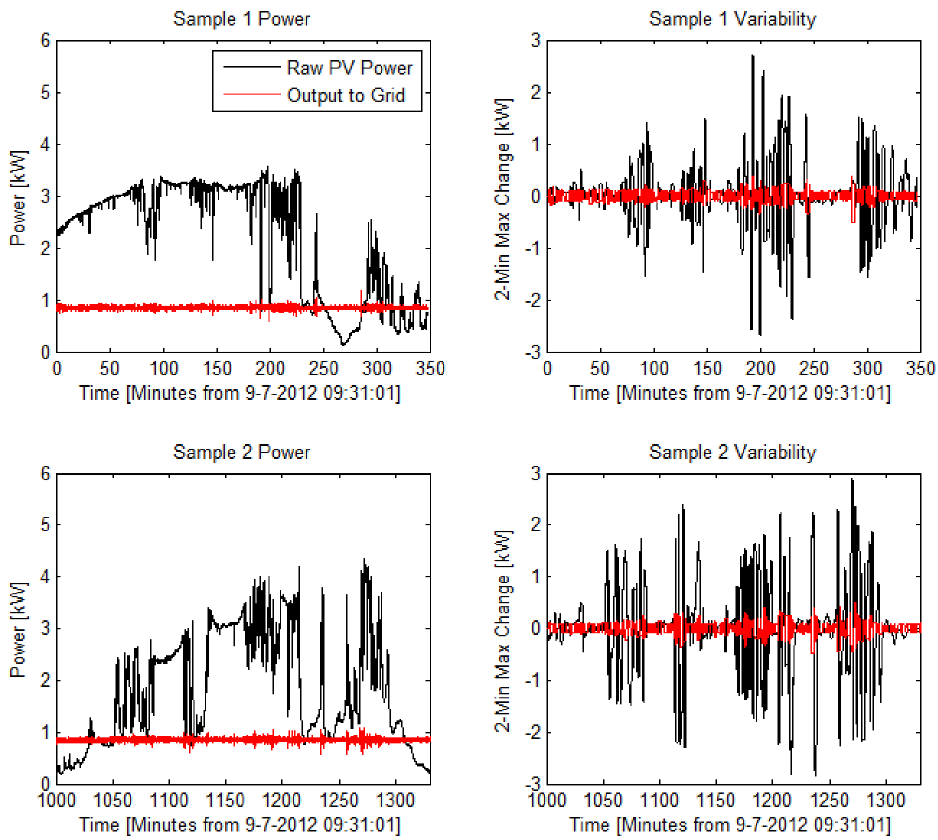


Figure 13: (Left Plots) Two days of PV power. (Right Plots) Comparison of variability for 2-minute periods.

A comparison of the DES and raw variability is presented in Figure 14. The red line bounds the maximum and minimum values for both samples. For Sample 1, the ratio of the width to height is 6.1. For Sample 2, this ratio is 5.8. This suggests an improvement in a 2-minute maximum variability of nearly a factor of six.

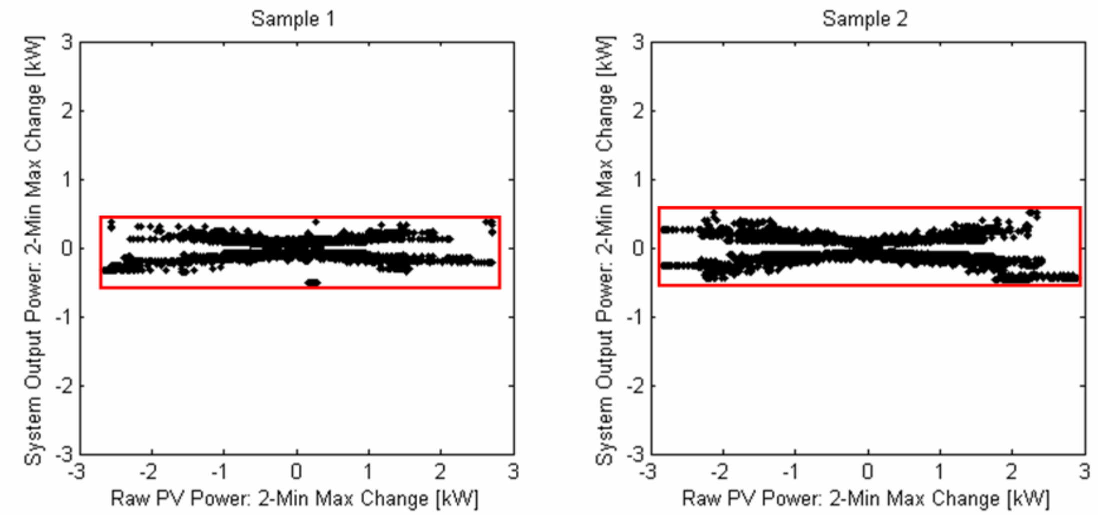


Figure 14: Comparison of variability.

It should be noted that there are no sophisticated "smoothing" or SOC management algorithms being employed. The results would likely be even more demonstrative if such an algorithm was used.

5 CONCLUSION

The DES provided output power continuously for eight days with no interruptions. There were nine periods in 23 days when the battery was fully discharged. This could be addressed with a software modification to manage the battery's state-of-charge (i.e., slowly reduce the DES output when the state-of-charge is low).

The data also showed that the current Sunny Island based DES reduced the variability of the power output by nearly a factor of six.

The data are included in a massive Microsoft Excel document as APPENDIX E. A script used to create the plot in Figure 9 is also included as APPENDIX F. Neither of these appendices is given in this report, but both of them are available from HNEI.

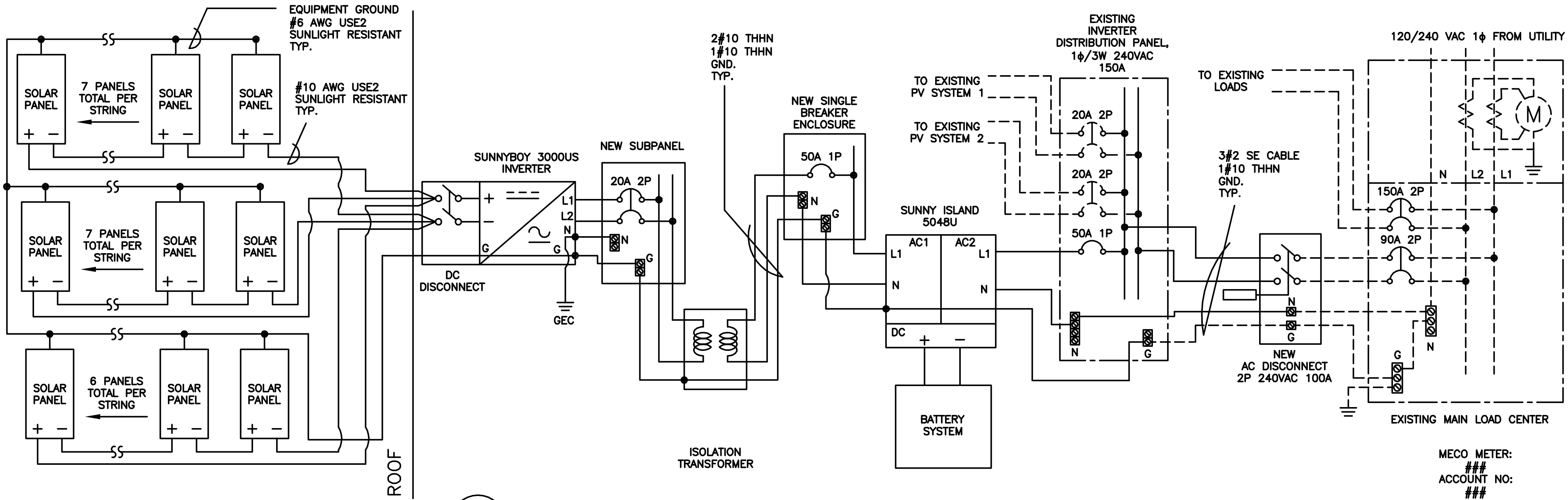
Future funding under a separate grant may be utilized to continue testing and analyzing the performance of the system for approximately three months. The data sets will be analyzed to assess performance characteristics of significance for future grid integration.

6 REFERENCES

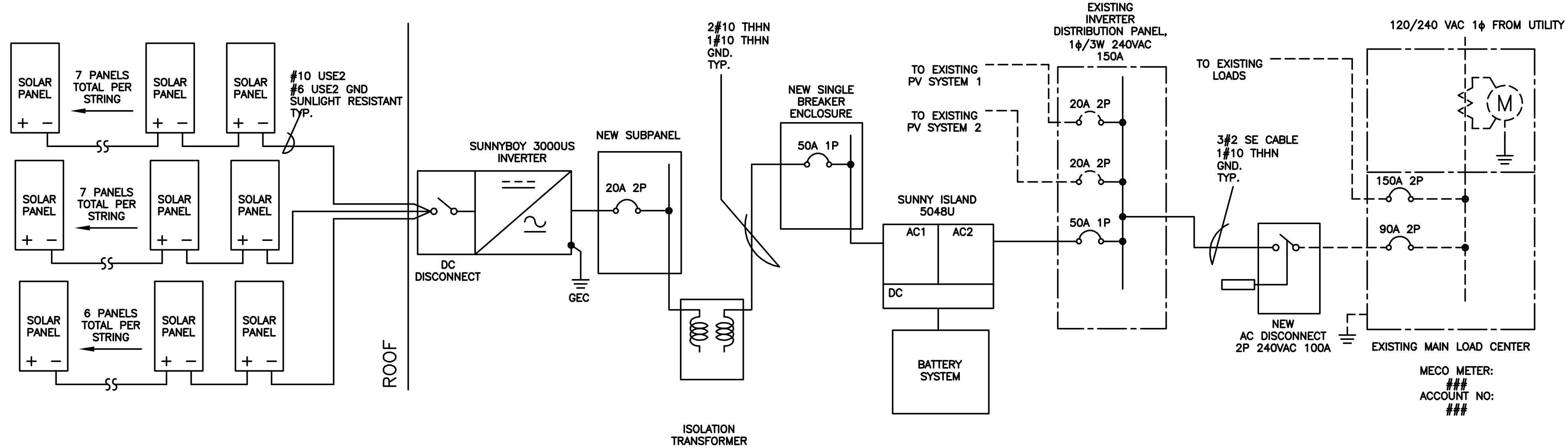
[1] R. Puga, M. Tun, "Distributed Energy System: Validation and Commissioning Report", Revision 6, September 2012. Delivered to the US Department of Energy by HNEI under Subtask 11.2, in October 2012.

APPENDIX A

This appendix consists of the following one page only.



1 PV ROOF MOUNTED SOLAR SYSTEM THREE–LINE DIAGRAM
SCALE: NONE



2 PV ROOF MOUNTED SOLAR SYSTEM SINGLE–LINE DIAGRAM
SCALE: NONE

*UNDER ANTICIPATED CONDITIONS

SYSTEM	PANEL TYPE	PANEL SPECIFICATIONS	NUM. MODULES	INVERTER TYPE	SYSTEM POWER* (KWDC)	SYSTEM POWER* (KWAC)
PV	SERENGETI SER–228P	228Wmpp (STC) 29.6Vmpp 7.70Impp 37.8Voc 8.30Isc	20	SUNNY ISLAND 5048U	BATTERY	5.00

HNU-ENERGY
Harnessing the Power of Light

1765 WILI PA LP
WAILUKU, HI 96753
(808) 244–7844
LIC# C–30247

PROJECT
ELECTRICAL SCHEMATICS
PV ROOF MOUNTED SOLAR SYSTEM
Puga, Richard
(TMK: (3)–9–027–013)
50 KAHELE ST.
KIHEI, HI 96753
(808) ###

VIEW	DWG BY	REV
SCHEMATIC	MOWENS	A

SCALE	DATE	SHEET
NONE	2/17/2012	1 OF 1

APPENDIX B

This appendix consists of the following seven pages.

APPENDIX I

NET ENERGY METERING AGREEMENT
10 kW or Less

Section 1. Applicant Information

Customer-Generator

Name: Richard Puga

Mailing Address: 50 Kahele Pl

City/State: Kihei / HI , Zip Code: 96753

Generating Facility Location (if different from above)/Tax map key 390270130000

Daytime Phone #: (808) 879-6538 Evening/Cell Phone #: ____

Electric Service Account #: ____

Owner of Generating Facility (if different from Customer-Generator)

Name: ____

Mailing Address: ____

City/State: ____ , Zip Code: ____

Daytime Phone #: ____ Evening/Cell Phone #: ____

Operator of Generating Facility (if different from Customer-Generator)

Name: ____

Mailing Address: ____

City/State: ____ , Zip Code: ____

Daytime Phone #: ____ Evening/Cell Phone #: ____

Section 2. Generating Facility Information		**Power Conditioning Equipment**	**Energy Storage**
Solar:	Rated generator capacity in kW 5 AC	Generator/Inverter Make/Model Sunny Island .	5048U kWh.
	Rated photovoltaic module capacity in kW_{DC} 20 x Serengeti SER-228P		
Wind:	Rated generator capacity in kW ____	Generator/Inverter Make/Model ____ .	____ kWh.
Biomass:	Rated generator capacity in kW ____	Generator/Inverter Make/Model ____ .	____ kWh.
Hydro:	Rated generator capacity in kW ____	Generator/Inverter Make/Model ____ .	____ kWh.
Hybrid:	Rated generator capacity in kW ____	Generator/Inverter Make/Model ____ .	____ kWh.
	Total rated capacity in kW ____	(Shall not exceed 10 kW) Attach specification sheet if available.	

Generating System Building Permit # (Certificate of Completion or Notice of Electrical Inspection?): ____

Is system self-excited with potential to island: Yes ☐ No ☒

Please submit a single line diagram. Submitted: Yes ☒ No ☐

Section 3. Certification by Licensed Electrical Contractor:
Generating and interconnection systems must be compliant with all applicable safety and performance standards of the National Electrical Code (NEC), Institute of Electrical and Electronic Engineers (IEEE), and accredited testing laboratories such as the Underwriters Laboratories (UL), and where applicable, the rules of the Public Utilities Commission of the State of Hawaii ("Commission"), or other applicable governmental laws and regulations, and the Electric Company's (Company) interconnection requirements, in effect at the time of signing this agreement. The following certifies that the installed generating system meets all preceding requirement(s).

Signed (Licensed Electrical Contractor): ____________________ Date: __________

License Holder (printed) Derrick Makekau of HNU Energy Hawaii License #C: C-30247

Mail Address: 1765 Wili Pa Loop

City: Wailuku , Hawaii, Zip Code: 96793

Daytime Phone #: 808-244-7844 Installation date: __________

Section 4. Installation: Design, installation, operation and maintenance of the Generating Facility shall include appropriate control and protection equipment and a manual load-break disconnect device lockable in the open position and accessible by the Company, as a means of electrically isolating the Generating Facility from the Company's system, and to establish working clearance for maintenance and repair work in accordance with the Company's safety rules and practices. This load-break disconnect device shall be furnished and installed by the Customer-Generator and is to be connected between the Generating Facility and the Company's electric system. The disconnect device shall preferably be located in the immediate vicinity of the electric meter serving the Customer-Generator. With permission of the Company, the disconnect device may be located at an alternate location which is accessible to utility company personnel on a 24-hour basis. The Customer-Generator and/or Owner/Operator grants access to the Company to utilize the disconnect device, if needed. The Customer-Generator shall obtain the authorization from the owner and/or occupant of the premises where the Generating Facility is located that allows the Company access to the Generating Facility for the purposes specified in this Agreement. The disconnect device shall be clearly labeled "Customer-Generator System Disconnect".
Location of lockable disconnect device, adjacent to meter? ☒ yes

If not, please describe location: ____________________

Section 5. Notice: A Customer-Generator shall provide the Company with an advance 30-day written notice of any proposed material changes made to the Generating Facility, for example, a change in ownership or an increase in capacity. In no event may the rated generator capacity of the Generating Facility exceed 10 kW. If a Generating Facility changes ownership, the Company may require the new owner to complete a new Net Energy Metering Agreement.

Section 6. Permits and Licenses: The Customer-Generator shall obtain, at its expense, any and all authorizations, permits and licenses required for the construction and operation of its facility.

Section 7. Metering: The Company will supply, own, and maintain all necessary meters and associated equipment utilized for billing. The meters will be tested and read in accordance with the rules of the Commission and the Company. The Customer-Generator shall supply, at no expense to the Company, a suitable location for meters and associated equipment used for billing and in accordance with the Company's tariffs. The Customer-Generator shall, at its expense, provide, install and maintain all conductors, service switches, fuses, meter sockets, meter instrument transformer housing and mountings, switchboard meter test buses, meter panels and similar devices required for service connection and meter installations on the Customer-Generator's premises in accordance with the Company's Rule 14, Section A.2.

Section 8. Indemnification: Each party as indemnitor shall hold harmless and indemnify the other party and the directors, officers, authorized agents, and employees of such other party against and from any and all loss and liability for injuries to persons including employees and authorized agents of either party, and damages, including property of either party, resulting from or arising out of (i) the engineering, design, construction, maintenance, or operation of, or (ii) the making of replacements, additions, or betterments to the indemnitor's facilities which are required for the interconnection and parallel operation of the Generating Facility with the Company's electric system and the generation of energy by the Generating Facility. Neither party shall be indemnified for liability or loss resulting from its sole negligence or willful misconduct. Nothing in this agreement shall create any duty to, any standard of care with reference to, or any liability to any person not a party to it.

Provided, however, where the Customer-Generator is an agency of the United States, the United States understands that it may be held liable for loss, damages expense and liability to third persons and injury to or death of persons or injury to property caused by the United States in its engineering design, construction ownership or operations of, or the making of replacements, additions betterment to, or by failure of, any of such party's works or facilities used in connection with this Agreement to the extent allowed by the Federal Tort Claims Act 28 U.S.C. § 2671 et seq. and the Contract Disputes Act of 1978, 41 U.S.C. §§ 601-613.

Company shall be responsible for damages or injury caused by Company, Company's agents, officers, and employees in the course of their employment to the extent permitted by law.

Provided, however, where the Customer-Generator is an agency of the State of Hawaii (the "State"), the State shall be responsible for damages or injury caused by the State's agents, officers, and employees in the course of their employment to the extent that the State's liability for such damage or injury has been determined by a court or otherwise agreed to by the State. The State shall pay for such damage and injury to the extent permitted by law. The State shall use reasonable good faith efforts to pursue any approvals from the Legislature and the Governor that may be required to obtain the funding necessary to enable the State to perform its obligations or cover its liabilities hereunder. The State shall not request Company to indemnify the State for, or hold the State harmless from, any claims for such damages or injury.

Company shall be responsible for damages or injury caused by Company, Company's agents, officers, and employees in the course of their employment to the extent that Company's liability for such damage or injury has been determined by a court or otherwise agreed to by Company, and Company shall pay for such damage and injury to the extent permitted by law. Company shall not request the State to indemnify Company for, or hold Company harmless from, any claims for such damages or injury.

[FOR OWNER / OPERATOR OTHER THAN STATE AGENCY]
The Owner/Operator shall indemnify, defend and hold harmless the Company and its officers, directors, agents and employees, from and against all liabilities, damages, losses, fines, penalties, claims, demands, suits, costs and expenses (including reasonable attorney's fees and expenses) to or by third persons, including the Company's employees or subcontractors, for injury or death, or for injury to property, arising out of the actions or inactions of the Owner/Operator (or those of anyone under their control or on their behalf) with respect to their obligations under this Agreement, and/or arising out of the installation, operation and maintenance of the Facility and/or the Facility Parties Interconnection Facilities, except to the extent that such injury, death or damage is attributable to the gross negligence or intentional act or omission of the Company or its officers, directors, agents or employees.

Section 9. Continuity of Service: The Company may require that the Generating Facility be temporarily curtailed, interrupted or deliveries of energy reduced: (a) when necessary in order for the Company to construct, install, maintain, repair, replace, remove, investigate or inspect any of its equipment or any part of its system; or (b) if the Company determines that such curtailment, interruption or reduction is necessary because of a system emergency, forced outage, or compliance with good engineering practices. Whenever feasible, Company shall give Customer-Generator reasonable notice of the possibility that interruption or reduction of deliveries may be required. In any such event, the Company shall not be obligated to accept any energy from the Generating Facility except for such energy that the Company notifies the Customer-Generator that it is able to take during this period due to the aforesaid circumstances. The Company shall take all reasonable steps to minimize the number and duration of interruptions, curtailments or reductions.

Section 10. Personnel and System Safety: If at any time the Company determines that the continued operation of the Generating Facility may endanger any person or property, the Company's electric system, or have an adverse effect on the safety or power quality of other customers, the Company shall have the right to disconnect the Generating Facility from the Company's electric system. The Generating Facility shall remain disconnected until such time as the Company is satisfied that the endangering or power quality condition(s) has been corrected, and the Company shall not be obligated to accept any energy from the Generating Facility during such period. The Company shall not be liable directly or indirectly for permitting or continuing to allow an attachment of a net metering facility or for the acts or omissions of the Customer-Generator that cause loss or injury, including death, to any third party.

Section 11. Additional Information: The Company reserves the right to require additional information, where necessary, to serve the Customer-Generator under net energy metering service.

Section 12. Term: This agreement shall become effective upon execution by the Customer-Generator and the Company and shall continue in effect on a month-to-month basis. The Customer-Generator may terminate the agreement at any time. Company may terminate the agreement at any time if the Customer-Generator fails to comply with the terms of this agreement or meet the definition of Eligible Customer-Generator under the Company's Rule 18 relating to Net Energy Metering.

Section 13. Net Energy Metering and Billing:

A. General:

(1) The net energy metering and billing arrangement covered by the Net Energy Metering Agreement shall be governed by the Company's Rule 18, as may be amended, revised and/or updated from time to time. If there is a conflict between any provision in the Net Energy Metering Agreement and the Company's Rule 18, as may be amended, revised and/or updated, the provisions of the Company's Rule 18 shall control.

(2) Customer-Generator's with Net Energy Metering service, pursuant to the Company's Rule 18, shall be billed monthly for the billing period, in accordance with the Company's Rule 8. Every 12 months, a reconciliation of the Customer-Generator's net energy consumption supplied by the Company with the net energy produced by the Generating Facility for that 12-month period will be performed as described in Section C.5. of the Company's Rule 18.

(3) For Customer-Generators with existing Net Energy Metering service, the measurement of kilowatthours supplied by the Company and the kilowatthours produced by the Customer-Generator for the first bill of the initial 12-month period under 2005 Haw. Sess. Laws Act 104 (effective July 1, 2005) shall begin at the start date of the billing period following the effective date of the Company's Rule 18. For all other Customer-Generators requesting Net Energy Metering service, the measurement of kilowatthours supplied by the Company and the kilowatthours produced by the Customer-Generator for the first bill of the initial 12-month period shall begin on the start date of the first billing period after the installation of the required meter(s).

B. Net Electricity Producer:

(1) When the electricity produced by the Generating Facility during a billing period exceeds the electricity supplied by the Company for the same period, the Customer-Generator is deemed to be a net electricity producer.

(2) In a billing period when the Customer-Generator is deemed to be a net electricity producer, the Customer-Generator will not be billed for the kilowatthours supplied by the Company during that billing period. For billing purposes, the Customer-Generator shall instead be charged the Minimum Charge provided in the applicable rate schedule in effect during the billing period.

(3) The excess kilowatthours produced by the Customer-Generator in each billing period, shall be carried over to the next billing period(s) within the current 12-month period, as a monetary credit and applied only to the Energy Charge, plus adjustments applicable to the Energy Charge, as well as adjustments based on kWh consumption, if any, for the Customer-Generator's net kilowatthour consumption in the succeeding billing period within the current 12-month period. Adjustments applicable to the Energy Charge include the Power Factor Adjustment, the Supply Voltage Delivery Adjustment, the IRP Cost Recovery Adjustment, the Firm Capacity Surcharge, the Firm Capacity Surcharge Adjustment and other similar adjustments applicable to the Energy Charge that are in effect. Adjustments based on kWh consumption include the Energy Cost Adjustment, the Residential DSM Adjustment, the Commercial & Industrial DSM Adjustment, and other similar adjustments based on kWh consumption that are in effect. When the Customer-Generator is billed the Minimum Charge in any billing period, the Customer-Generator's cumulative net monetary credit shall not be applied to the Minimum Charge.

(4) The Customer-Generator's cumulative net monetary credit shall also not be applied to the Demand Charge, Customer Charge, adjustments applicable to the Demand and Customer Charges and other similar rate adjustments applicable to the Demand and Customer Charges that are in effect. See Section C.3. (a-e) of the Company's Rule 18 for the determination of monetary credit as applicable to the Customer-Generator's rate schedule.

C. Net Electricity Consumer:

(1) When the electricity supplied by the Company to the Customer-Generator during a billing period exceeds the electricity produced by the Generating Facility for the same period, and also exceeds any unused cumulative credits for excess electricity supplied by the Customer-Generator carried over from the prior months since the last 12-month reconciliation period, the Customer-Generator is deemed to be a net electricity consumer.

(2) For billing purposes, the Customer-Generator shall be charged for the excess kilowatthours supplied by the Company based on the applicable rate schedule in effect during the billing period. The payment for excess kilowatthours supplied by the Company, however, will take into consideration any unused cumulative credits to the extent provided for in Section C.3. of the Company's Rule 18.

(3) In a billing period in which the Customer-Generator is deemed to be a net electricity consumer, the Customer-Generator will also be billed for other applicable charges, base rate adjustments and non-base rate adjustments, to the extent the amount exceeds the Minimum Charge; if such amount does not exceed the Minimum Charge, the Customer-Generator will be billed the Minimum Charge, plus any rate adjustment that may apply to the Minimum Charge.

(4) The kilowatthours supplied by the Company and the kilowatthours produced by the Customer-Generator for each billing period shall be recorded in each billing period of the 12-month period. Coincident with the last bill of the 12-month period following the start date of the Customer-Generator's billing under the Net Energy Metering contract, and for each 12-month period thereafter, the (i) Energy Charge plus adjustments applicable to the Energy Charge and adjustments based on kWh consumption, less any monetary credits applied during the 12-month period for net kilowatthours produced by the Customer-Generator ("Remaining Energy Charge Balance"), and (ii) the available cumulative credit balance (i.e., cumulative net monetary credit for net kilowatthours produced by the Customer-Generator for the 12-month period remaining after the subtraction of the monetary credits previously credited to the Customer-Generator during the 12-month period for net kilowatthours produced by the Customer-Generator) will be compared to determine whether the Customer-Generator is entitled to a refund of remaining Energy Charges plus adjustments applicable to the Energy Charge and adjustments based on kWh consumption. If the available cumulative credit balance equals, or exceeds the Remaining Energy Charge Balance, the Remaining Energy Charge Balance will be refunded. If the Remaining Energy Charge Balance is greater than the available cumulative credit balance at the end of the 12-month period, the amount of the refund will be capped at the available cumulative credit balance.

(5) The Energy Charge shall include the Customer-Generator's Energy Charge for each billing period within the 12-month period, plus adjustments applicable to the Energy Charge and adjustments based on kWh consumption, except for those billing periods when the Customer-Generator was billed the Minimum Charge provided in the applicable rate schedule. Any monetary credits for excess kilowatthours produced by the Customer-Generator that remain unused at the end of each 12-month period shall expire and not be carried over to the next 12-month period. The Customer-Generator shall not be compensated for such excess kilowatthours produced by the Customer-Generator unless the Company enters into a purchase power agreement with the Customer-Generator.

D. Other:

(1) If a Customer-Generator terminates its Net Energy Metering service under Rule 18 prior to the end of any 12-month period, the Company shall reconcile the Energy Charge, plus adjustments applicable to the Energy Charge and adjustments based on kWh consumption, less monetary credits previously applied, to the cumulative credit balance at the end of the billing period when service was terminated, similar to the reconciliation that would have been performed at the end of the normal 12-month period.

(2) The kilowatthours supplied by the Company and, if any, the kilowatthours produced by the Customer-Generator, including an accounting of the cumulative monetary credits for the excess kilowatthours produced by the Customer-Generator since the last 12-month period reconciliation, the credits applied in each billing period of the current 12-month period and the remaining unused credits, if any, will be included in the Customer-Generator's regular billing statement.

Section 14. Customer-Generator (and/or Owner/Operator) Signature: I agree to be bound by the terms of this Net Energy Metering Agreement, and I understand that all aspects of billing for electric service will conform with existing Company Rules, the Commission's general orders, and the applicable provisions of Hawaii Revised Statutes, Chapter 269, Part VI. I also certify that, to the best of my knowledge, all the information provided in this agreement, is true and correct.

Customer-Generator ______________________________ Date ________________

Owner/Operator of Generating Facility ______________________ Date ________________

Section 15. Company Signature:
I hereby acknowledge receipt and completeness of the Net Energy Metering Agreement.

Company ______________________________ By ________________________

Title ____________________________________ Date ________________

APPENDIX C

This appendix consists of the following one page only.

ELECTRICAL PERMIT

COUNTY OF MAUI
DEPARTMENT OF PUBLIC WORKS
DEVELOPMENT SERVICES ADMINISTRATION

ELECTRICAL PERMIT NO.:	**E 20120567**	**DATE ISSUED:**	**March 8, 2012**
PROPERTY OWNER:	**Puga,Richard A**	**LESSEE/ TENANT:**	
PROJECT ADDRESS:	**50 Kahele St , Kihei HI 96753**	**TMK:**	**(2) 3-9-027:013-0000**
ELECTRICAL CONTRACTOR:	**H NU SOLAR LLC**	**LICENSE NO.**	**(C13) 0030247**
PROJECT LEAD ELECTRICIAN:	**DERRICK S MAKEKAU**	**LICENSE NO.**	**(EJ) 0008972**

Project: RICHARD PUGA
Scope: NEW OFF GRID PHOTOVOLTAIC SOLAR POWER SYSTEM WHICH CONSIST OF 1 ARRAY FOR A TOTAL OF 20-228 WATT SERENGETI SOLAR MODULES IN SERIES OF (3) STRINGS WITH 1-SUNNYBOY 3000US INVERTER.
PANELS MOUNTED ON ROOFTOP OF EXISTING 3 BEDROOM/3 BATH DWELLING BUILT IN 1971. INVERTER MOUNTED NEXT TO METER MAIN ON THIS SAME STRUCTURE.
Fee Summary: 1 feeder not over 100A, (1)Renewable Energy System

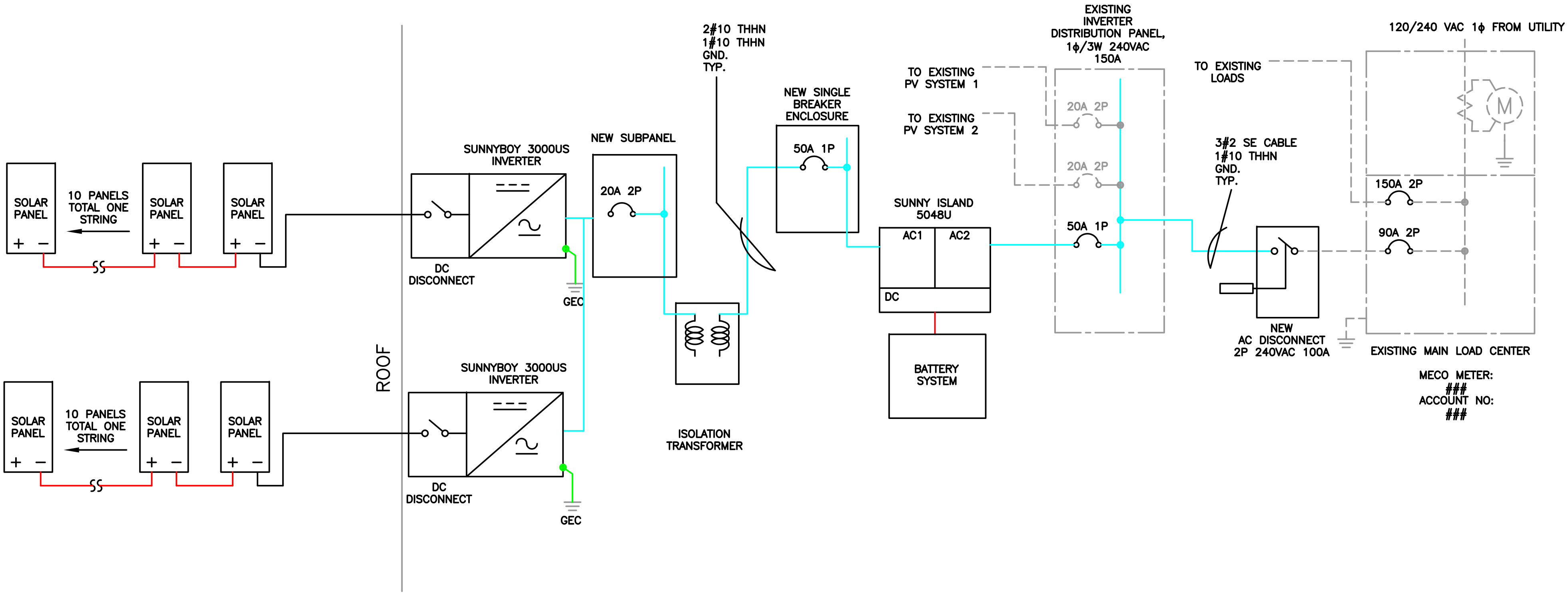
THIS PERMIT SHALL EXPIRE AND BECOME NULL AND VOID IF WORK AUTHORIZED UNDER THIS PERMIT IS NOT STARTED AND THE INITIAL INSPECTION IS NOT APPROVED WITHIN 1 YEAR FROM DATE OF ISSUANCE. ONCE THE INITIAL INSPECTION IS APPROVED, THIS PERMIT SHALL REMAIN ACTIVE UNTIL THE FINAL INSPECTION IS APPROVED, OR UP TO A MAXIMUM OF 5 YEARS FROM THE DATE OF ISSUANCE.

Riley Sardinha
FOR DIRECTOR

05/11

APPENDIX D

This appendix consists of the following one page only.



2 PV ROOF MOUNTED SOLAR SYSTEM SINGLE-LINE DIAGRAM

SCALE: NONE

*UNDER ANTICIPATED CONDITIONS

SYSTEM	PANEL TYPE	PANEL SPECIFICATIONS	NUM. MODULES	INVERTER TYPE	SYSTEM POWER* (KWDC)	SYSTEM POWER* (KWAC)
PV	SERENGETI SER-228P	228Wmpp (STC) 29.6Vmpp 7.70Impp 37.8Voc 8.30Isc	20	SUNNY ISLAND 5048U	BATTERY	5.00

HNU-ENERGY
Harnessing the Power of Light

1765 WILI PA LP
WAILUKU, HI 96753
(808) 244-7844
LIC# C-30247

PROJECT

ELECTRICAL SCHEMATICS
PV ROOF MOUNTED SOLAR SYSTEM
Puga, Richard
(TMK: (3)-9-027-013)
50 KAHELE ST.
KIHEI, HI 96753
(808) ###

VIEW	DWG BY	REV
SCHEMATIC	MOWENS	A

SCALE	DATE	SHEET
NONE	2/17/2012	1 OF 1