Renewable Energy Services, Inc.
Generating Sustainable Power for Hawaii Since 1990
Solar Power Systems Contractor License # C-27865

HPA ENERGY LAB PV SYSTEMS COMMISSIONING DECEMBER 2009

THEORY OF OPERATION

The HPA ENERGY LAB PV systems consist of two different models of Sanyo PV modules, located on the two south facing roofs and the shade awning on the south end of the building. The PV modules, totaling 25.41 kW, are connected in various quantities to three SMA single phase, “string” inverters and 48 Enphase three phase “module” or micro inverters. The output of all inverters is combined in a three phase 208 VAC panel labeled “LDCTR NETMETER 1” located in the building electrical equipment room. The combined output of all inverters is routed outside of the building to the HELCO MAIN DISCONNECT SWITCH and then back into the electrical room where it is terminated in the main distribution panel at a 3P-200 amp circuit breaker labeled “ MAIN SOLAR (PV) SYSTEM POINT OF INTERCONNECT”.

The combined power from the PV systems enters the building at the main distribution panel and is distributed to the various building loads as needed. Should PV power be less than the total requirement of the building, the additional power required by the load will flow from the utility automatically. Should PV power exceed the building loads, the excess PV power will be exported from the Energy Lab to be consumed by other loads within the HPA campus. It is not expected that PV energy exported by the Energy Lab will ever exceed the campus loads and be exported to the utility. Whenever utility power fails to meet voltage and frequency specification or drops out entirely, the PV inverters will disconnect from the line and wait for the utility to return to proper operation. When utility power returns, the inverters resume normal operation automatically.

DESCRIPTION OF THE PV SYSTEMS

Each PV system consists of strings of Sanyo 210 watt or Sanyo 195 watt PV modules (sub arrays) or individual modules connected to an inverter(s). There are two types of inverters installed at the Energy Lab. There are three SMA string type inverters labeled Inverter #s 1,2 & 3. The modules connected to each string inverter are listed below.

INVERTER # 1
SMA SB6000US, 6.0 kW
3 series strings of 10 Sanyo 210 watt modules each, total of 30. Name plate 6.3 kW.

INVERTER # 2
SMA SB6000US, 6.0 kW
3 series strings of 10 Sanyo 210 watt modules each, total of 30. Name plate 6.3 kW.

INVERTER # 3
SMA SB4000US, 4.0 kW
2 series strings of 7 Sanyo 195 watt Bi-facial modules each, total of 14. Name plate 2.70 kW.

ENPHASE INVERTERS
There are 48, Sanyo 210 watt modules connected to 48 individual 210 watt Enphase inverters. The inverters are mounted under each PV module on the roof. The inverters are grouped in three circuits of 16 module/inverters each.

PERFORMANCE VERIFICATION

PV module nameplate ratings are based on tests performed in the factory under standard conditions. "Standard Test Conditions" are defined as an irradiance of 1,000 watts / square meter, Atmospheric factor of 1.5 (typical atmosphere at sea level) and a cell temperature of 25º C. Because the voltage and power produced by a PV module decreases as the temperature of the module increases and because the actual operating temperature of a PV module on a roof, in the sun will be as high as 50º C, the temperature of the PV array as well as the amount of sunlight falling on the array have a large impact on the power produced. Temperature and irradiance are dynamic and highly variable and must be measured in real time in order to calculate the power an array should produce.

However, the voltage of a sub array string of modules while affected by temperature is much less effected by irradiance, so string voltage can be tested and verified statically without integrating irradiance.

PRE-FUNCTIONAL ASSURANCE TEST

PV modules are connected in series to build up the DC voltage to a level that matches the inverters input specifications. The open circuit voltage (Voc) of a module, corrected for temperature and multiplied by the number of modules in the series string will predict the voltage that should be present at the fuses located in the DC disconnect associated with each inverter. Open circuit voltage measurements outside of the predicted design voltage indicate a problem with the circuit being tested. After a visual inspection of the PV array, this open circuit voltage test of each series string sub array is the best means of performing a pre-functional assurance test of the PV system.

SMA inverters # 1 & 2 have 3 strings of 10 each of the Sanyo 210 watt module connected. The open circuit voltage of the Sanyo 210 is 50.9 VDC and the temperature coefficient is -0.142 V per degree C above the test cell temperature of 25ºC. Assuming (actual cell temperature were not measured) a typical cell temperature of 40º C, the predicted open circuit voltage per string will be:

40º - 25º = 15 X -.142V = -2.13V   50.9 Voc -2.13 = 48.77 x 10 = **487.7 Voc per string.**

Actual measurements made during installation were between 496 and 500 VDC. The measured Voc is higher than predicted due to cell temperatures lower than the assumption. Note: Due to the Energy Lab being at 2,500 ASL, ambient temperatures and therefore cell temperatures will be lower than those found at sea level.

SMA inverter # 3 has two strings of 7 each of the Sanyo195 watt bi-facial module connected. The Voc for the 195 is 68.7 VDC and the temperature coefficient is -.172 VDC per ºC above 25ºC. Again assume (actual cell temperature not measured) a typical cell temperature of 40ºC.
40º - 25º = 15º X -.172 = -2.58 V   68.7 Voc -2.58 = 66.12 X 7 = **462.8 Voc per string.**

Actual measurements during installation were 478 Voc. Note: Because the Bi-facial modules are installed as an awning with good air circulation around all sides they will operate cooler than modules mounted flat against a roof. Additionally, Bi-facial modules produce voltage and power from sunlight reflecting onto the underside of the module. This explains the abnormally high Voc.

All series string voltage measurements for the SMA inverters exceeded the predicted voltage.

Enphase micro inverters condition the PV modules DC voltage underneath the modules where the inverter is mounted, so DC voltage measurements are not available. As such, there are no static, pre-functional assurance tests to be performed for the Enphase systems.

FUNCTIONAL TESTS

SMA INVERTERS

In order to accurately predict the power a PV system should produce, the “name plate rating” of an array of modules must be adjusted to all of the real world conditions present at the time of the test.   Verifying instantaneous output power of the SMA inverter arrays requires taking three main readings: inverter output power, cell temperature and irradiance (brightness of the sun). Other factors affecting the real world output of a PV system also include the power tolerance of the module, soiling of the module surface, small voltage mismatches from module to module, diode losses, wiring losses, age of the array and the efficiency of the inverter.

Aside from inverter power, cell temperature and irradiance, the smaller, systemic conditions listed above are difficult to measure but have generally accepted ranges in a properly designed system. The generally accepted derating factors for the small systemic system losses are listed below:

PV Module power tolerance (Sanyo is -0%+10%)	1.05
Inverter	.96
Module Mismatch	.95
Diodes & connections	.995
DC wiring	.99
AC wiring	.99
Soiling	.99
Shading	1.00
Age	1.00
Overall DC to AC derate factor	**.948**

In addition to the systemic derate factor of .948, the cell temperature and irradiance at the time of the test need to be measured. Cell temperature will be measured with a non contact infra red temperature probe (Fluke model 62) and irradiance in watts per square meter will be measured by a Daystar hand held pyranometer held in the plane of the array. Cell temperature will be used to calculate the power derating of the array according to the power coefficient listed for the PV module (array) under test.

The Sanyo 210 watt modules Power/Temperature coefficient is -.336%/ºC above 25ºC.
The Sanyo 195 watt modules Power/Temperature coefficient is -0.29%/ºC above 25ºC.

The decimal equivalent Power/temperature derating factor can be found by subtracting (total percent of power lost due to temperature divided by 100) from 1.00.

Output power, as measured and displayed by the inverter is directly proportional to the intensity of sunlight striking the array. Because the nameplate power of the array is rated at 1,000 watts per square meter, a reading of 1,000 watts will equal 100%. A reading of 830 watts per square meter will mean the array should operate at 83% of nameplate before temperature derating.

Example for Inverter # 1, Total 30 Sanyo 210, Total array name plate rating = 6,300 watts (6.30 kW)

Assuming a 40ºC cell temperature the Power/temperature derating factor is:

40ºC - 25º = 15 X -.336% = 5.04%   1.00 - .0504 = **.9496**

Assuming an irradiance of 830 watts per square meter the Irradiance factor will be **.830**

After converting the three individual derate values to decimal equivalents, they are multiplied together for total instantaneous system derating:

Systemic system losses factor	.948
Temperature derating factor	.9496
Irradiance derating factor	.830
Total derating factor	**.7472**

Therefore under the conditions of a cell temperature of 40ºC and a sunlight level of 830 watts per square meter, Inverter # 1 with 6,300 watts of PV connected should produce:

6,300 X .7472 = 4,707 watts.

An acceptable range of variation is -5%/+5%

ENPHASE INVERTERS

Output power of the individual Enphase inverters/modules can be seen on the Enphase web site for the Energy Lab. Additionally, the total power output of the 48 Inverter/modules is indicated on the Enphase Envoy Communications Gateway located in the mechanical room next to the electrical room

Temperature and irradiance derating are applied to the total array nameplate rating and an inverter efficiency of .95

At 40ºC cell temperature the derating factor of .9496 is the same because the modules connected to the Enphase system are the same, Sanyo 210.

Example:

At 830 watts per square meter irradiance each inverter/module should produce:
210 watts X .9496 (Temp.) X .830 (Sunlight) X .95 (Inverter efficiency) = 157.2 watts per ininverter/module or 157.2 X 48 = 7,545.6 watts for the entire Enphase array.

Once again an acceptable range of variation is +/- 5%.