

MY SOLAR PLAYBOOK

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Operations & System Design Manual

Solar Photovoltaics

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Signature		

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1 Introduction

System design for Hawaii is relatively forgiving, in regards to grid interactive systems. The manufacturer's online calculators provide an excellent baseline for understanding, for example, how many solar panels of a specific manufacturer can be installed on a specific inverter model. This is for string types of inverters. As for the micro inverters, currently there are two flavors of them out there, but it is essentially very straightforward by following manufacturers recommendations on how many can be installed. Compatibility with the various solar panel products and their inverters is essential to understand in order to design and install a code compliant system that will have many years of useful service life.

As we go back to the site evaluation section, there will be some repeated lessons on system design, as we will build on the previous chapter's information that we acquired through the site evaluation.

This is to provide a general overview of the site conditions and site evaluation parameters necessary to facilitate a solar photovoltaic installation. By detailing a site feasibility study, this will allow the client and the company to develop a plan for success. Coupling this with the system design guide, will support a code compliant installation and create a higher level of harmony with the client and the company.

The topics covered under these guidelines will prepare anyone that is in the solar industry from a salesperson, to an engineer, to an operations person as well as an installer to understand how and why things are done in detailed steps.

Our industry is governed by the National Electrical Code (NEC), in regards to the electrical aspects of the work we perform. There is a strong emphasis in understanding Article 690 as it relates to solar photovoltaics. There are other sections in the code that are equally important that also need your familiarization. There are also numerous building codes that need to be adhered to as well.

The National Fire Protection Agency (NFPA 70) and a host of other industry standards from ASHRAE to structural engineering disciplines spanning many diverse aspects of solar photovoltaics that need to be understood as well.

There is the IEEE 929 & 1547 and the UL 1741, that have established benchmarks on the installation of inverters and their interconnection to the utilities infrastructure. There is also a strong emphasis on safety, as when we are working with electricity and the work is performed on roofs, these present additional hazards to our workforce that need to be discussed and understood fully. Fall protection is perhaps one of the most important aspects of safety, as roofing work is considered one of the most hazardous building trades, according to OSHA. Couple this with the confined spaces treatment of electrical work, and you can see why familiarizing yourself with these site conditions is essential.

It is also important to understand and follow manufacturer's recommendations, before installing any of their equipment. There are potential hazards to you, from electrical shock or to the possibility of damaging the equipment. This is why, if the manufacturer is offering any technical training, you should consider participation, as sometimes you can't absorb everything out of a manual.

There are some basic tenets to follow when working on electrical equipment, such as electrical panels to inverters:

1. Identify where your level of understanding of electrical systems and roof work are and don't enter into an electrical infrastructure without proper training. Also, don't go onto a roof if you are not wearing proper clothing, including wearing shoes on a roof.
2. Do not work on live electrical systems, unless you have the proper personal protective equipment- NFPA 70 and been trained.
3. Do not wear rings, necklaces when working in an electrical panel or an inverter- these can get in between busbars and other live equipment, potentially causing a shock or worse.
4. Wear ear, eye, head, fall protection and other OSHA related safety apparatus depending upon the site conditions.
5. If possible, do not walk on solar modules- while they may be able to support your weight, they tempered glass could fail by persistent people traffic on them.

6. If possible, don't drop tools or other objects on the surface of the solar panels, as this can also shatter the tempered glass, which renders the panel a hazard and it eventually will fail when water enters it.
7. Secure solar modules as you are working with them on a roof. In high wind conditions, which can occur, the ability of a solar panel to become a "kite" and fly off a roof or shatter after being blow over is a hazard that should be avoided.
8. Wiring or cords can become a trip hazard and should be secured.
9. Sharp edges of metal racking- wear protective gloves when working with these products.
10. Ladder safety- properly secure the ladders you are working on to prevent them from falling during the project.

Disclaimer of Liability

While we make every attempt to cover all of the relevant aspects of an installation from system design to a site evaluation to commissioning and servicing a system, SunHedge LLC indemnifies itself out of any claims to damages as a result of any errors in connection with the operations of your companies systems and best practices.

This guide is intended for Operations within an electrical contracting company who perform solar activities. It is not limited to operations, as many sales professionals would also benefit from the information contained within this manual as invariably, these questions come up. This guide is geared towards **Grid Interactive systems only** and does not cover any aspects of battery based systems.

System:	Details
Functions	System design-Feasibility-Conditions
Owner	Operations , Engineering & Sales
Name	Company

1.1 Guidelines for a System Design – Overview

The required information necessary to perform a photovoltaic (PV) system design (taken from the site evaluation manual), as the first steps to start the design.

1. A site visit would be the first recommended method for evaluation. As a preparation for the site visit, you could look at using tools like- google earth maps.google.com or maps.live.com. There will be more online tools to use in the future. Just because a client would like to have a system, it does not constitute their situation is an ideal location for a PV system.

Why? This will provide a starting point to begin the conversation with the client as well as your company. In order to facilitate any installation, this information must be culled. While this may seem obvious, a lot of sites are not ideal for a solar application, i.e.- the property has an obstruction that will prevent the installation, no roof space as it could either be too small of a roof or in a commercial application, the roof might have just enough space for HVAC equipment etc.

2. Basic diagram showing the solar panel configuration on the roof, conduit run, wiring, inverters, disconnects and POC (Point of Connection) to the utility as well as a general

site drawing, showing setbacks and property lines. This can also be culled online in most jurisdictions through the building departments archives.

Why? In order to communicate with your building department and your engineering department and operations in-house, you will need to have these baseline items in order to make the sale and sell it for the correct price to avoid a misunderstanding between the client, the company and the building department, in regards to what is possible. You might, for example, need to upgrade the electrical service to the premise, which could be a considerable cost, or need to consult a roofing company to verify the roofing material is ok to mount things to, or a structural engineer to verify the framing can handle the dead load to final permit closing to the project's completion. These are gating items in order to get a permit and can influence interconnection with the utility. (see drawing A1).

3. A detailed list of the components you will be using for the project. Solar panel, inverter, disconnect, combiner box, racking and mounting cut sheets.

Why? With the advent of so many new products on the market today, it is vital that the building department have the latest and most updated information in order to process and approve your permit. Help them, help you. While this might not be a gating item for the sale of a project, someone in the company will need to provide this information to the engineering department and operations of the company.

4. A copy of a current electricity bill from the client. This will outline their daily/monthly consumption for you to chart the trends in their usage and allow you to ask lifestyle questions.

Why? In order to provide a proposed system size, you will need to look at their energy demand and evaluate what sized system would benefit their situation. By looking deeper than the electricity bill, there are other ways to reduce demand, like energy efficiency. Do they have a solar hot water system? Do they have an 18 year old refrigerator that needs to be replaced?

5. The big “why” questions. By asking pertinent questions regarding why they are deciding to own and operate a mini power plant are always important as they leave clues for understanding the prospective buying drivers. Some reasons for making this type of purchase are:

- Reduce operating expenses- we are indexed to oil- as it goes up, so does the electric bill
- Environmentally driven- want to make a difference; drives a Prius
- State and federal credits and or programs to reduce the cost of the system- aka-buy down; municipal programs rebates; feed in tariff etc.
- Early adopters of technology

After receiving all of this relevant and pertinent information, we can now discuss the system design in more detail.

1.2 System Design- Grid Tied Inverters

There are many grid interactive inverters (without batteries) on the market today and they all have different characteristics in regards to the acceptable range of DC voltage input that they need to “wake up” in and continue to operate in, to produce power. This is another reason the site evaluation information is vital. If there is a tree in the way of the eighth panel, in a series string, for example, this will pull down the average string voltage and limiting the ability of the system to perform optimally.

For selection of a micro inverter, like Enphase Energy, this is less of an issue. However, proper sizing of the AC circuit is essential as well as the interconnection to the electrical infrastructure.

For more access to a host of programs California is embarking upon, please visit- <http://www.gosolarcalifornia.ca.gov/> There outline of STC to PTC is the industry standard in calculating actual values of a modules output and inverter output.

When designing a system, it is important to not exceed the amount of modules in series, as it will tip the inverter on the upper limit of its voltage window, and it will not optimize the array during peak times during the day. The same is true for putting too few modules on a series string, as the voltage window will only be optimized at the peak times of the day.

To determine the approximate maximum number of modules that can be connected to an inverter, divide the inverter maximum continuous ac output power by the CEC efficiency www.gosolarcalifornia.ca.gov/equipment/inverter.php to get the maximum continuous dc input power.

There is also the solar module list- <http://gosolarcalifornia.org/equipment/pvmodule.php>

You can also visit the solar inverter manufacturers website, as they all have calculators to determine how many solar modules you can connect to their products. www.sma-america.com and look at their solar design tools- http://www.sma-america.com/en_US/service/solar-design-tools.html Then divide by the module PTC power to get the approximate maximum quantity.

Using these values approximates for real world conditions.

1.3 System Design-Inverter and Panel details

As we talk about system design, we should also explain what a lot of the acronyms you see on inverter and solar panel literature are to help you understand system design.

Solar panel data- lets use the SunTech 175 watt module for our example

SunTech Solar Panel-Model # STP175S-24/Ab-1		
Open Circuit Voltage	Voc	44.2V
Optimum Operating Voltage	Vmp	35.2V
Short- Circuit Current	Isc	5.2A
Optimum Operating Current	Imp	4.95A
Maximum Power at STC	Pmax	175Wp
Operating temperature		-40°C to +85°C
Maximum System Voltage		600VDC
Maximum Series Fuse Rating		15 AMPS
Power Tolerance		+3%

Definitions:

Voc- Open Circuit Voltage- the maximum voltage possible under specific conditions. The lower right point on the curve where it intersects the horizontal axis. There is no current here, only voltage potential, so $\text{Power} + \text{Voc} \times \text{zero current} = \text{zero}$.

Vmp- Optimum Operating Voltage- the voltage at the point in which it produces the optimum (sometimes referred to as maximum voltage).

Isc- Short Circuit Current- The maximum current produced under specific conditions. The top point on the curve where it intersects the vertical axis. There is no voltage here, only current flowing, so, $\text{Power} = \text{zero voltage} \times \text{Isc} = \text{zero}$.

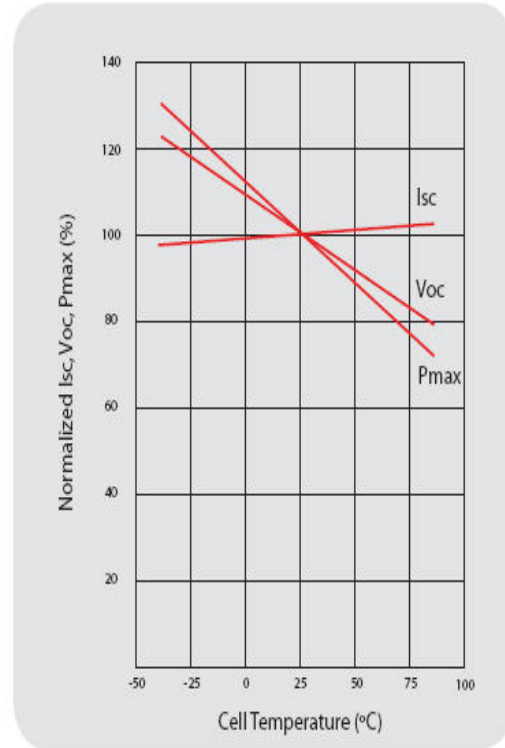
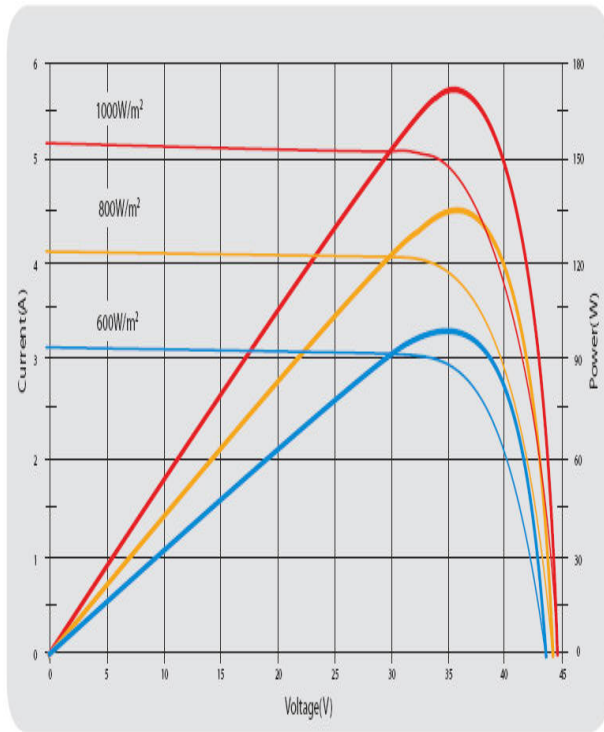
Imp- Maximum Power Current- The current at the point at which the panel produces maximum power. This is usually characterized at a point at the “knee” of the curve.

Pmax- Maximum Power at STC- STC is the standard test conditions in which modules are tested for output, at a module temperature of 25°C (77°F). The measurement is 1,000 watts per square meter solar irradiance, 1.5 air mass and the 25°C (77°F). This is a simulated indoor factory test condition. The module output is reduced with the rise in temperature, as the voltage goes down. The reverse is also true, as temperature drops, voltage rises. This is important in sizing a system, to understand the correlation of temperature has to a solar panel, which for all intents and purposes, is a computer chip that is sensitive to heat. This is why there are temperature coefficients published by the manufacturers and the data is important for calculations, more in colder climates than in Hawaii.

PTC- Here is one, that is not on the chart, but needs to be elucidated on further as it correlates to STC. PTC, stands for PV USA Test Conditions which were developed at the PV USA test site at Davis, CA. PTC are 1,000 watts per square meter solar irradiance, 1.5 air mass, and 20°C and ambient temperature at 10 meters above ground level and a wind speed of 1 meter per second. PTC is essentially translated into a more real world like conditions but does not factor in dust and dirt, module mismatch, DC and AC wire losses, actual inverter efficiency and if there is any, electrical storage efficiency (batteries).

Characteristics of the SunTech 175 Watt Module

Temperature Dependence of Isc, Voc, Pmax



1.4 Calculating System Size

In order to successfully design and install a system that will benefit the customer for years into the future. This includes a detailed analysis of their electrical service equipment, electrical service panel, routing of electrical infrastructure to the roof, the roof condition etc. For example, we don't want to put a system in front of a growing tree that in 1 year will shade the system. A feasibility study is important to determine if there is a fit- system to customer or having them invest in a system could be less desirable.

There is also a need to identify the customers' energy profile. For example, if they have a 15 year old refrigerator, it is advisable to have them look into purchasing a new refrigerator, to reduce the potential size of the PV system. This holds true for a survey of their total energy footprint. There could be a lot of phantom loads as well as inefficient use of energy that could be surveyed and evaluated to reduce the potential size of the system.

This would require you to ask through a survey of their electrical consumption (lifestyle questions). It is much easier to reduce load, as this is a less expensive option in the short and long run.

The necessity to have their current utility bill is essential combined with an energy analysis of their appliances is recommended as this can influence the system size as well.

One of the primary reasons customers decide to generate their own electricity, is to **reduce operating expenses** for their homes and businesses. With lucrative state and federal incentives, a customer's return on their investment adds additional benefits to incorporating a PV system into their home or business. Visit the DSIRE website, as it has information regarding renewable energy and energy efficiency around the country <http://www.dsireusa.org/> . Their site outlines the incentives from the state, federal and utility level that assist all of us in the decision making process.

1.5 Example Calculation

So, let's look at an example here in Hawaii and go through the steps to calculate a system size and an inverter selection. We will use the CEC rating- which is the California Energy Commissions calculations for inverter and module efficiencies. Note, this is the industry standard and accepted practice for system design and adopted in Hawaii.

Step # 1

$$\text{Maximum Total Modules} = \frac{\text{Inverter rated maximum continuous ac output power}}{\text{CEC Efficiency} \times \text{Module PTC Power}}$$

Step # 2

An SMA SB3000 240 Volt inverter has maximum output power rating of 3000 watts ac, and a CEC efficiency rating of 95.5%. What is the maximum number of SunTech Power Inc. 175 watt modules (157.8 PTC watts) that can be connected?

Step # 3

$$\text{Max Total Modules} = \frac{3000 \text{ watts}}{0.955 \times 157.8 \text{ PTC watts}} = 19.9$$

1.6 Series String Size

The final number will depend on the number of series strings and how many modules are in each string. This can be found quickly on the SMA website to determine the amount of modules in strings.

It is generally a wide band- from 7-12 modules for Hawaii. On their calculator, you will need to adjust the coldest temperature data to reflect this market. We rarely go below 59 degrees during the day (perhaps when the sun is cresting the horizon in the morning), at general altitudes- sea level to 2000 feet.

Rounding up yields an array that might produce more power than the rated value for the inverter. The excess power is only a small amount, and the inverter will not be damaged. The actual temperature at a location will most probably be slightly higher than that used to calculate the PTC rating and so the calculated peak power from the array might not even actually occur.

A slightly oversized array on paper will yield an installed system that will operate below the peak power of the inverter almost all of the time, with perhaps an occasional short period during a few days where there might be excess power potential. This is due to the edge of cloud effect where the 1000 W/M^2 is increased. The inverter will simply operate the array off of its maximum power point during that time to stay within its limits.

There are sometimes conflicts with the formula below and manufacturers recommended modules on their inverters. We like to ebb on being conservative and put fewer modules on any particular inverter to assist it in having a long service life.

1.7 Voltage Window

Grid connected inverters have a dc input “voltage window” within which they can safely and efficiently operate. The upper voltage window must not be exceeded or actual damage might occur to the input circuitry (over 600VDC). Since solar modules have more voltage potential when they are cold, the calculation for the maximum number of modules in series must take the coldest possible temperature conditions into account. We are fortunate in Hawaii that we generally don’t have to worry about this condition, as we rarely will experience temperatures below 59°, and if we do, it is at the crack of dawn or atop Haleakala.

The maximum dc voltage from an array is the number of modules in series times the Voc of a module at the lowest temperature.

The coldest temperature for the location can be obtained from various databases (e.g.: NREL) or from online sources (e.g.: www.weather.com , choose Averages, then Record Low). Use of the record low temperature for a site is the most conservative and safest approach, even though the array may not actually ever get to that temperature when the sun is out. Refer back to the manufacturer’s suggested design options for the criterion on string sizing and temperature coefficients. Their online calculators are generally conservative and a good guide.

The adjustment of Voc for cold temperature can be approached in two ways. The actual voltage temperature coefficient for the SunTech Power Inc. modules can be used.

1.8 Calculation using NEC 690.7

The second approach is to use the table in NEC 690.7.

Calculation using SunTech Power Inc. voltage temperature coefficient

Calculate the difference between the record low temperature and the STC rating temperature of 25°C, and then multiply this temperature delta by the coefficient for the module to determine the change in Voc above the STC value. Divide the adjusted cold Voc into the inverter upper voltage limit to determine the maximum number of modules in series. You must always round down for this calculation to stay within the limit.

$$\text{Maximum Series Modules} = \frac{\text{Inverter maximum dc input voltage}}{\text{Module Voc}_{@STC} + (25\text{-coldest temp})}$$

Example:

What is the maximum number of SunTech Power Inc. 175 watt modules that should be connected to an SMA-SB3000 inverter located in Honolulu, Hawaii using the SunTech Power Inc. temperature coefficient method?

$$\text{Record minimum ambient temperature} = *65^{\circ}\text{F}, 18.3^{\circ}\text{C}$$

(from www.weather.com)

$$\text{Inverter Vmax} = 600 \text{ volts}$$

$$\text{Module Voc (STC)} = 44.2 \text{ volts}$$

$$\text{Max \# of Series Modules} = \frac{600 \text{ volts max}}{44.2 + (25 - -18.3)}$$

$$= 12.8, \text{ round down to } 12$$

*Again, we can use the 59°F choice on the SMA tool on their website to come up with the same calculation.

The Calculation Using NEC Table

The NEC Section 690.7 defines how the maximum system voltage shall be determined.

A table has been created from generic module temperature data to account for the increase in Voc with cold temperature. You are to multiply the array Voc by the correction factor in the table from the temperature range for the location.

Table NEC 690.7

Ambient Temperature		NEC Correction Factor
°C	°F	
25 to 10	77 to 50	1.06
9 to 0	49 to 32	1.10
-1 to -10	31 to 14	1.13
-11 to -20	13 to -4	1.17
-21 to -40	-5 to -40	1.25

$$\text{Maximum Series Module} = \frac{\text{Inverter maximum dc input voltage}}{\text{Module Voc}_{@STC} \times \text{NEC Correction Factor}}$$

Example:

Determine the maximum number of SunTech-175 modules that should be connected to an SMA-SB3000 inverter located in Honolulu, Hawaii using the NEC Correction Factor method:

Record minimum ambient temperature = *65°F, 18.3°C
(from www.weather.com)

Inverter Vmax = 600 volts

Module Voc (STC) = 44.2 volts

Max Series Modules = $\frac{600 \text{ volts max}}{44.2 \times 1.06}$

= 12.8, round down to 12

*Again, we can use the 59°F choice on the SMA tool on their website to come up with the same calculation.

1.9 Why Manufacturers Data is Important

Ok, so here is the **challenge**- the SMA- SB3000, has a voltage window of 190- 450 volts DC. Therefore, you **can't** install **12** modules in series on this modeled inverter. Check their websites cut sheets for the SMA SB3000 and calculator for more clarity. The 4000, 5000, 6000, 7000 series have an upper voltage limit of 500 VDC and will accommodate up to 12 modules in series.

See the screen capture below of the SMA website to understand why it is important to not just do a calculation, but to look at the manufacturers specifications to determine system size options as it can be deceiving to use just the table in 690.7. Manufacturers design the products and most specifically the criteria in which they are to work in the field.

STRING SIZING PROGRAM

Further Instructions
 If you are having difficulty with the String Sizing Program, or it is not operating properly, see this [Read Me](#) file for the operating instructions and version history of the String Sizing Program.

By using this String Sizing Program you agree that this Program is for approximating PV module string sizes only. Further you agree that SMA America, Inc. makes no claim as to the actual performance of your system, including, but not limited to, the efficiency or power production of the inverter and PV modules based on the information from this Program. Additionally, you agree that it is the responsibility of the system design engineer to ensure that the PV module selection, array configuration, and associated wiring diagrams are appropriate for the system being considered.

NOTE:
 For an explanation of any particular [entry definition](#) click on the actual term for a glossary.

Design Options

Please Select an Inverter SB 3000US (240)	Please Select a PV Manufacturer SunTech	Please Select a PV Module STP175S-24/Ab-1
--	--	--

Inverter Data

Design Irradiance (W/m ²) 1000	P _{ac} 3000	P _{dcmax} 3500
I _{dc} Max 17	V _{dc} Max **** 500	V _{mp} Max 400
		V _{mp} Min 200
		V _{min} 200

Module Data

Module P _{nom} (W) 175 W	V _{oc} (V) 44.2 V	V _{mp} (V) 35.2 V	I _{sc} (A) 5.2 A	I _{mp} (A) 4.95 A
Temperature Coefficient of Voltage -0.34%	Temperature Coefficient of Current +0.017%	Temperature Coefficient of Power -0.48%		

Mounting Method

Please select the mounting method for the array: Mounted flat against the roof

Temperature Data

If you do not know the **hottest** and **coldest** ambient temperatures that you should select for your area please enter the 5-digit postal ZIP code of the address of the installation here: and then [Click Here](#)

Select the **coldest** record low ambient temperature when sunlight will be on the array:

Select the **hottest** average high ambient temperature when sunlight will be on the array:

Imperial units Metric units

Results

1 string configurations 7 in series 8 in series 9 in series 10 in series	2 string configurations 7 in series 8 in series 9 in series 10 in series	3 string configurations 7 in series
--	--	--

**** PV Array voltage may exceed 600 Vdc, please refer to NEC table 690.7 to calculate open circuit voltage at low temperature

Let's go back to the above example, using the **SMA SB4000** instead, and see how the previous calculation **will work**. If you recall, it was 12.8 modules in series that we dropped down to 12. Therefore, if you want to install more than 10 modules in series, you should install the larger inverter (SB4000).

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STRING SIZING PROGRAM

Further Instructions
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NOTE:
For an explanation of any particular [entry definition](#) click on the actual term for a glossary.

Design Options

Please Select an Inverter

Please Select a PV Manufacturer

Please Select a PV Module

Inverter Data

<small>Design Irradiance (W/m²)</small> <input style="width: 90%;" type="text" value="1000"/>	<small>P_{ac}</small> <input style="width: 90%;" type="text" value="4000"/>	<small>P_{dmax}</small> <input style="width: 90%;" type="text" value="4500"/>
<small>I_{dc} Max</small> <input style="width: 90%;" type="text" value="18"/>	<small>V_{dc} Max ****</small> <input style="width: 90%;" type="text" value="600"/>	<small>V_{mp} Max</small> <input style="width: 90%;" type="text" value="480"/>
	<small>V_{mp} Min</small> <input style="width: 90%;" type="text" value="250"/>	<small>V_{min}</small> <input style="width: 90%;" type="text" value="220"/>

Module Data

<small>Module P_{nom} (W)</small> <input style="width: 90%;" type="text" value="175 W"/>	<small>V_{oc} (V)</small> <input style="width: 90%;" type="text" value="44.2 V"/>	<small>V_{mp} (V)</small> <input style="width: 90%;" type="text" value="35.2 V"/>	<small>I_{sc} (A)</small> <input style="width: 90%;" type="text" value="5.2 A"/>	<small>I_{mp} (A)</small> <input style="width: 90%;" type="text" value="4.95 A"/>
<small>Temperature Coefficient of Voltage</small> <input style="width: 90%;" type="text" value="-0.34 %"/>	<small>Temperature Coefficient of Current</small> <input style="width: 90%;" type="text" value="+0.017 %"/>	<small>Temperature Coefficient of Power</small> <input style="width: 90%;" type="text" value="-0.48 %"/>		

Mounting Method

Please select the mounting method for the array:

Temperature Data

If you do not know the hottest and coldest ambient temperatures that you should select for your area please enter the 5-digit postal ZIP code of the address of the installation here: and then [Click Here](#)

Select the coldest record low ambient temperature when sunlight will be on the array

Select the hottest average high ambient temperature when sunlight will be on the array

Imperial units
 Metric units

Results

<p style="margin: 0;"><small>1 string configurations</small></p> <p style="margin: 0;">8 in series</p> <p style="margin: 0;">9 in series</p> <p style="margin: 0;">10 in series</p> <p style="margin: 0;">11 in series</p> <p style="margin: 0;">12 in series</p> <p style="margin: 0;">13 in series</p>	<p style="margin: 0;"><small>2 string configurations</small></p> <p style="margin: 0;">8 in series</p> <p style="margin: 0;">9 in series</p> <p style="margin: 0;">10 in series</p> <p style="margin: 0;">11 in series</p> <p style="margin: 0;">12 in series</p> <p style="margin: 0;">13 in series</p>	<p style="margin: 0;"><small>3 string configurations</small></p> <p style="margin: 0;">8 in series</p> <p style="margin: 0;">9 in series</p>
--	--	--

**** PV Array voltage may exceed 600 Vdc, please refer to NEC table 690.7 to calculate open circuit voltage at low temperature

Minimum number of modules in series

As opposed to cold temperatures raising the voltage of an array, as modules get hot during a day their voltage drops. If the array Vmp drops below the lower limit for maximum power point tracking (MPPT), then the inverter will no longer be able to extract maximum power from the array. The system will continue to operate, but not as effectively as it should. The array should be designed so that at typical hot conditions the array Vmp stays above the lower limit for MPPT.

Unlike the calculations for maximum voltage where damage could occur and therefore the record cold temperature was used to be safe, for this design consideration only the average high temperature needs to be considered. The inverter will not be damaged if the array V_{mp} drops below the lower limit to the MPPT.

When irradiance vs cell temperature rise above ambient in the that under the full 1000 W/m^2 irradiance the cell temperature in a module is approximately 30°C above ambient. So add this temperature rise to the average high temperature to estimate the cell temperature. Then subtract the STC temperature of 25°C from this cell temperature estimate to get the temperature change.

Multiply this temperature change by the temperature coefficient for the module to determine the change in V_{mp} below the STC value. Divide the adjusted hot V_{mp} into the inverter MPPT lower voltage limit to determine the minimum number of modules in series. You must always round **up** for this calculation to stay within the limit.

$$\text{Minimum Series Modules} = \frac{\text{Inverter minimum MPPT dc input voltage}}{\text{Module } V_{mp} @_{STC} - (\text{high avg. temp} + 30 - 25)}$$

Example:

What is the minimum number of SunTech 175 watt modules that should be connected to a SMA-SB3000 inverter located in Honolulu, Hawaii?

$$\text{Average max ambient temperature (August)} = 89^{\circ}\text{F}, 31.66^{\circ}\text{C}$$

(from www.weather.com)

$$\text{Inverter minimum MPPT voltage} = 200 \text{ volts (manufacturers information)}$$

$$\text{Module } V_{mp} \text{ (STC)} = 35.2 \text{ volts}$$

$$\text{Min Series Modules} = \frac{200}{35.2 - (66^{\circ} + 30^{\circ} - 25^{\circ})}$$

$$= 5.58, \text{ round up to } 6$$

2 Utility Bill & Site Feasibility

2.1 Utility Bill Assessment

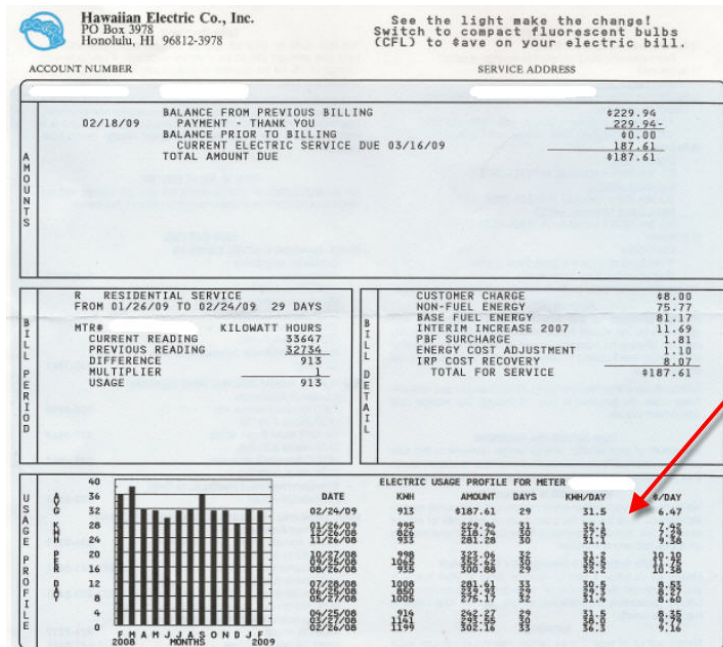
1. Ok, let's get started. You have contacted a customer and want to determine how you can assist them in reaching their goals of reducing demand through the installation of a PV system.
 - a) First, we will need a current copy of their utility bill.

In order to assist our clients in the education process, we need to explain to them, how to read their electric bill. Quite often, this is confusing and unclear, as there are a host of charges on the bill. On our bills here, there are 7 items in the bill detail section (see below). This can vary around the country, in regards to what these items mean and how they are calculated.

- b) For the sake of having a conversation, let's look at this bill below. A simple analysis of the kWh (kilowatt hour) consumed, per month, divided by the cost per kWh per month. Step # 1 and Step # 2 outline the simple analysis to determine what the client is being billed every month, per kW, for electricity. Every current utility bill will show the previous 12 months in the Usage Profile. This information is useful, as it can follow trends in their consumption, and sometimes, even the weather!

Depending upon the goals of the client and the laws governing interconnection standards in your area, will determine how large a system can be. We hope, from an industry perspective, that this will change in the future. So, in the design of a system can depend upon a host of variables, but most grid connected systems, we would like the utility company to be the "battery" and therefore, design a system to meet less than any peak months energy consumption.

The electric bill below represents what atypical HECO customer's bill looks like. We will use this as an example in our design of our basic system.



Step # 1
To determine the cost per kWh, we take the
\$/DAY / KWH/DAY
 $\$6.47/31.5 = \0.20 cents per kilowatt hour

Step # 2
31.5 kWh per day consumption
This is in a 5 hour "SunDay" in Honolulu
(5 avg hours of solar energy harvest)
So, in order to get close to eliminating the bill, they would need a
7kW DC PV system
 $7\text{kW} \times 5 \text{ hours/day(avg)} \times .77 \text{ (derate-DC-AC)} = 26.95 \text{ kWh's created in solar electricity per day}$

c) As you can see, this system would be large, for a residential system. It is a large home with eight people occupying the property. One of the ways we can assist the customer, is walk through the home and determine if we can offer any energy efficiency upgrades- solar hot water heating, refrigerator switched to an energy star appliance, energy efficient air conditioning etc. These energy conservation measures will lower their energy footprint, and consequentially, the size of the PV system. They can also check with the utility to see if they also have any energy efficiency rebates available for changing out old appliances. Their energy footprint, is surprisingly static through the year. This can vary from customer to customer, so checking their electric bill will show seasonal swings, for anything from air conditioning to house guests.

d) It is also important to discuss future plans with the customer. Are they adding an addition to the home- a second story? Planning on having in-laws move in/out? Are they putting a pool in the yard? Adding a refrigerator to the garage? All of these future lifestyle changes could swing the monthly utility bill, so please ask them as this is important in the system design and location of the solar panels and balance of system (BOS) components.

- e) Typical solar system output over a year will be lower in the winter and higher in the summer but typically in Hawaii is fairly consistent throughout the year (see PVWatts). The average annual harvest the PV system generates vs. the average annual consumption of the customer can vary. In hot areas in Hawaii, they could have a much larger AC load in the May-September time period, which could influence their utility bill. This coincides well with the production of the PV system and there is generally a match to load and energy production. Just as you looked at the electric bill above to correlate that we have inconsistencies in our daily/weekly and monthly energy footprint, we have the same relevancy for the energy the system creates.

- f) The customer must understand that there will be months when the solar system under-produces compared to their demand and other months when it will over-produce. The focus of energy assessment and system sizing should be on how much of the **total annual average** demand the solar system can satisfy, and not on any particular monthly match. We all know that in our own lives, our energy profile can change from month to month for a host of reasons.

- g) Whether it is the kids have started a sport at school, which in turn increases the family laundry schedule, or we have replaced an existing refrigerator with a more energy efficient one, we need to keep the PV system size in perspective. If a system is designed for the maximum demand, and the utility compensates you for an **annual true up** in the thirteenth month in Hawaii, it is best to not have a goal of independent power producer- aka, your own power plant manager. Let the utility be the battery until technology meets us with a low maintenance, high capacity solution.

- h) A rough estimation of solar system output can be made using the map on the next page. Local situations will vary of course, but the pictures below presents a rough guide for how much annual ac energy (kWh ac) can be expected from a 1kW dc of solar array in Honolulu. Assumptions have been made that may not apply to a particular installation (e.g.: the array tilt angle has been assumed to be the same as the latitude), so this guide is only for rough estimations and preliminary discussions with the customer. Even when you factor in variations- i.e. - a 3:12 pitched roof vs. a 4:12 pitch roof, we are blessed here with relatively consistent annualized averages.

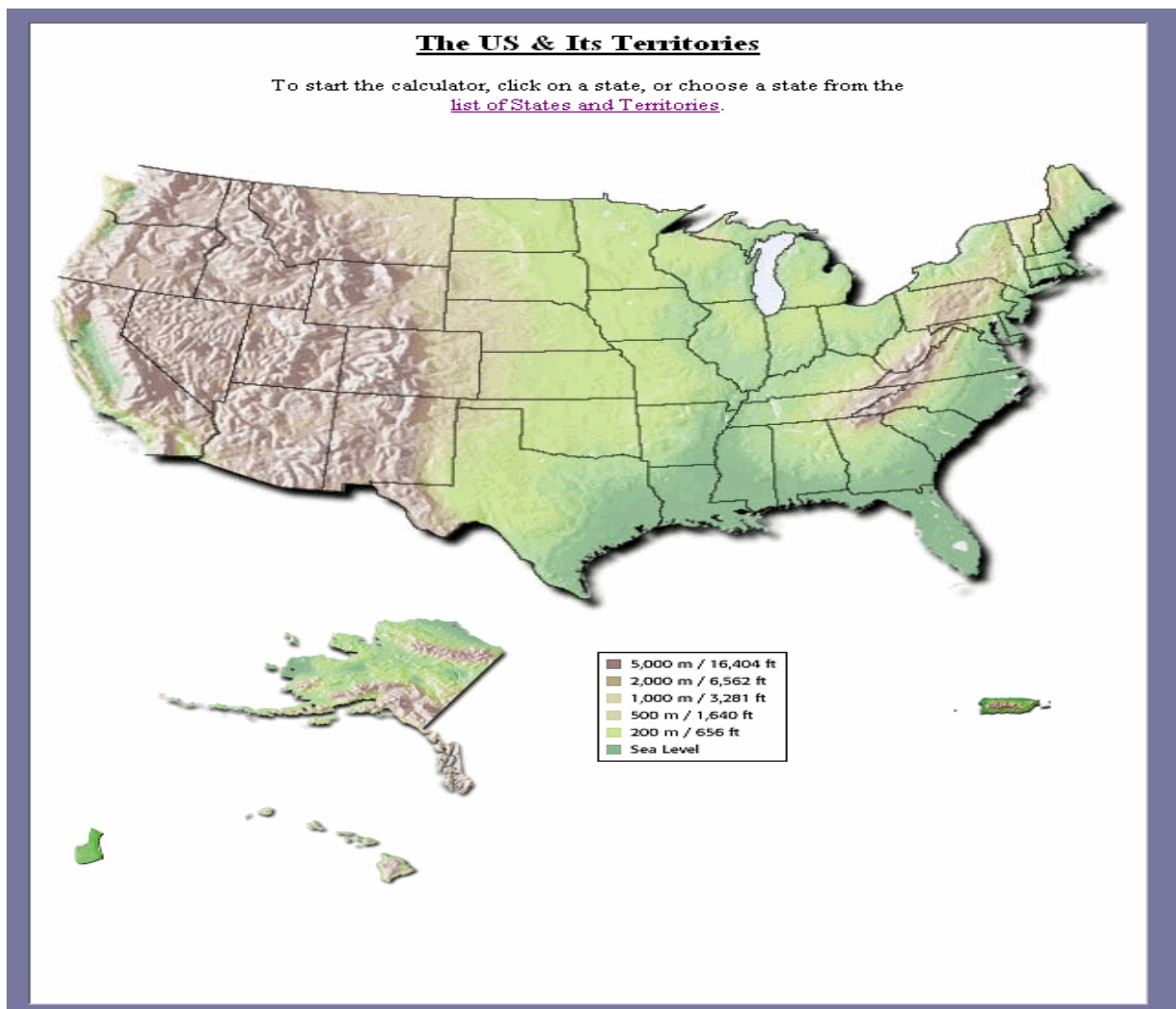
2.2 Design Tools

Here is the link to the map below and steps involved to determine the harvest:

http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/version1_index.html#map

Here are the steps to determine what a system will make in electricity in Honolulu Hawaii

Step # 1- Click on Hawaii



Step # 2 – Click on Honolulu



Click on the site where you want to use PVWATTS to calculate the electrical energy produced. Choose the site nearest to your location that has similar topography. If near a state border, you may wish to review site locations in the adjacent state.

Hawaii



Adjacent States:
None

Step # 3- Click in the DC rating box and put in for a 1kW system



Click on **Calculate** if default values are acceptable, or after selecting your system specifications. Click on **Help** for information about system specifications. To use a DC to AC derate factor other than the default, click on **Derate Factor Help** for information.

Station Identification:

WBAN Number: 22521
City: Honolulu
State: Hawaii

PV System Specifications:

DC Rating (kW):
DC to AC Derate Factor: **DERATE FACTOR HELP**
Array Type: Fixed Tilt
Fixed Tilt or 1-Axis Tracking System:
Array Tilt (degrees): (Default = Latitude)
Array Azimuth (degrees): (Default = South)

Energy Data:

Cost of Electricity (cents/kWh):

Step # 4- See the results



AC Energy
&
Cost Savings



Station Identification		Results			
City:	Honolulu	Month	Solar Radiation (kWh/m ² /day)	AC Energy (kWh)	Energy Value (\$)
State:	Hawaii	1	5.01	109	19.73
Latitude:	21.33° N	2	5.59	110	19.91
Longitude:	157.92° W	3	5.89	128	23.17
Elevation:	5 m	4	5.79	122	22.08
PV System Specifications		5	6.00	130	23.53
DC Rating:	1.0 kW	6	5.91	124	22.44
DC to AC Derate Factor:	0.770	7	6.02	130	23.53
AC Rating:	0.8 kW	8	6.25	135	24.44
Array Type:	Fixed Tilt	9	6.41	134	24.25
Array Tilt:	21.3°	10	5.72	124	22.44
Array Azimuth:	180.0°	11	5.16	109	19.73
Energy Specifications		12	4.92	106	19.19
Cost of Electricity:	18.1 ¢/kWh	Year	5.72	1460	264.26

[Output Hourly Performance Data](#)

[Output Results as Text](#)

[About the Hourly Performance Data](#)

[Saving Text from a Browser](#)

Notice that the default cost of electricity is 18.1 cents per kWh. You will need to go to the particular utility bill and snapshot that particular month. This is just a guide. So, you can see how much a 1kW system will make over the course of one year as well as the **average** “harvest” of **5.72** hours per year (solar radiation kWh/m²/day). We like to do an average annualized data projection of less than this, as we find most customers delighted that there systems performed more than projected. Again, we like to use averages, so we would generally look at the site

specific conditions and be conservative, perhaps **5.25** hours per day. Remember, most clients are enthused when their system actually makes more than estimated. Also, the 5.72 hours, is unique to Honolulu, and you need to compensate, if, for example, you are in the back of a valley and or other site specific obstructions to further reduce your harvest.

2. There may be constraints that will reduce the size of the solar system to smaller than that required to meet 100% of their average annual demand. Some of the factors that can influence the system size:
 - Customer budget may limit system size- this could make for a multi-year installation approach using multiple inverters (systems)
 - Available roof area may limit array size- if the south, south west/east roofs that are available aren't ideal and or if there are other obstructions- another homes shadowing; foliage, vent pipes, skylights etc., design considerations need to be discussed
 - Availability of products
 - Available rebates (coming Q3-Q4 2009)
 - Series/parallel limits into inverter may limit array configurations possible (example: SMA3000 has a smaller voltage window than the SMA4000-7000)
 - *An answer to multi roof/multi orientation installations- micro inverters. Currently Enphase Energy has them on the market and I envision we will see more manufacturers in the coming years. www.enphaseenergy.com

Let's do some simple math to understand the sizing of a system, based upon some generic assumptions. This will help familiarize yourself with the variables and generic costs.

A 2kW system- 10, 200 watt solar modules on a residence

200 watt panels x 10 panels	=	2000 watts
2000 watts x 5 Sun-Hours per day (Honolulu area average)	=	10,000 kW hours of power per day
10,000 kW hours x .77 (derate-DC-AC)	=	7700 kW hours per day
7700 kW hours x .20 cents per kWh (utility charge to you-variable and changes)	=	\$1.54 per day
\$1.54 per day x 30 days	=	\$46.20 per month in energy created
\$46.20 x 12 months	=	\$554.40
2kW system- Installed for \$14,000 (or \$7.00/per watt)		
\$14,000 x 35% (state of Hawaii tax credit)	=	\$4,900.00
\$14,000 x 30% (federal credit)	=	\$4,200.00
System cost- less credits \$14,000- \$9,100	=	\$4,900.00
Net system cost/ yearly production \$4,900/\$554.40	=	8.83 years to pay for the investment

While this is an example of what a system can cost there are many variables, like site conditions and electricity rates.

Discuss with the customer their budget and area restrictions. Perhaps they can begin with a smaller system and plan to add more solar modules and inverters as their budget allows or incentive programs improve. There could also be other options, such as going back to the lifestyle questions in the site evaluation and determine if there will be any additions or alterations planned in the future.




2.3 Site Conditions-Roof

The initial site evaluation must include recording of a variety of conditions at the site to ensure the system is designed and engineered appropriately and simultaneously we need to work to manage the expectations of the customer. These factors will be critical in estimating actual installation costs and designing a proper system. By not recording these items outlined in Section 1 and below, could **severely impact** the success of the project and the output of the system. At the end of this manual in the appendix, there is a site evaluation survey that needs to be filled out by the person who is performing the initial site visit. This information should be passed through the design department of the company as well as the installation team to verify the conditions and thoughts the team had for the project development.

- Design the system in compliance with all applicable building and electrical codes (especially article 690, 310, 250 of the NEC)
- Roof type, condition, and ease of access- can it handle the additional weight?
- Orientation and tilt angles of available roof areas- are there any obstructions?
- Approximate area dimensions for array(s)- module sq footage/ space
- Horizontal and or other shading
- Electrical service panel and electrical meter conditions
- Roof condition
- Ensure that the design meets the local utility interconnection requirements

Roof Types

Different types of roofing materials are more or less difficult to work on and will require different types of mounting hardware. Become familiar with the following typical roofing materials.

Roofing Material	Mounting Method	Installation
Asphalt shingle	Stanchion or hangar bolts (flushed appropriately)	
Spanish or curved concrete tile roof	Stanchion or hangar bolts (flushed appropriately- Lead Flashings)	
Standing seam metal roofing	S-5! Clamp	

<p>Flat- torch down brie roofing</p>	<p>Stanchion or hangar bolts (flushed appropriately-Chem curb)</p>	
<p>Wood shake</p>	<p>Stanchion or hangar bolts (flushed appropriately-Lead Flashings)</p>	
<p>Commercial Roof-Firestone/TPT/EPDM type of roofs</p>	<p>Stanchion or hangar bolts (flushed appropriately-Manufacturer specific)</p>	

Evaluate Roof Condition

Be sure to note the overall condition of the roof by taking pictures for dissemination amongst the engineering group for verification that a system can be installed on the respective roof. It is not recommended to install a solar array on a roof in poor condition but there are some options. With the advent of new roofing coatings, it is possible to extend the life of the roof, under the PV panels, with new rolled on types of elastomeric products. These increase the life of roofs and limit the degradation of the UV on the roof, which should extend the life of a questionable roof. We recommend establishing a relationship with a roofing contractor to assist you in evaluating the health of a roof, before committing to the installation. A poor roof condition may present dangers to installers in the form of slippery loose asphalt or dirt, or weak spots that might break through when stepped on due to termite damage or dry rot. A roof may have an uneven surface, making it very difficult to mount horizontal rails without laborious height adjustments. This will also make the solar installation look uneven, as it either tries to match the contour of the roof or deviate and look “level”, further drawing your eye to the project. An old roof might need replacement just a few years after installing the solar array which would mean a complete removal and reinstallation of the solar mounting system and modules. If the client still would like to proceed with the work, knowing there will be an installation and remove/reinstallation, make them aware of their choices. Quite often a re-roofing, removal of the system and reinstallation can take a day for most residential applications.

Older asphalt shingle roofs may be improved by simply having a new layer laid on top of the old by a roofing contractor. Typically, building departments allow a maximum of three layers of asphalt shingles. After that, the roof must be replaced. If the roof has one or two existing layers of asphalt shingle and is in need of re-roofing, perhaps, just another layer can be applied before installation of the solar array. Contact a roofer in your area to determine the suitability of the roof. Another option- obtain a letter of opinion from a roofing contractor, potentially offering a warranty on the roof, if possible, outlining the condition of the roof and their recommendations.

General guide for roof evaluation:

a. Asphalt shingles and wood shake roofs:

They are designed for a 20 year service life, so if the roof is 15-18 years old, it should be able to accept a solar system. This information is difficult to ascertain, as most homeowners don't keep records of their last roofing project and or the home might have been sold after a roof was replaced and this information was not passed on to the next homeowner. If the roof is older than 25-30 years of age, it is best to re-roof, before the installation occurs.

b. Ceramic tile roofs:

They are designed for a much longer service life, sometimes upwards of 50 years and care should be taken to walk on them, as they become fragile over time in the sun. It is good to check with the homeowner to see if they have spare tiles available as a replacement in the event their becomes a broken tile during walking on the roof or during the installation.

c. Metal Roof:

They are designed for a 20 year service life, so if the roof is 15-18 years old, it should be able to accept a solar system. This information is difficult to ascertain, as most homeowners don't keep records of their last roofing project and or the home might have been sold after a roof was replaced and this information was not passed on to the next homeowner. If the roof is older than 25-30 years of age, it is best to re-roof, before the installation occurs. There is also the propensity for the metal roof to be aged, from our salt environment, further accelerating the life of the roof. Visible wearing of the roof is noticeable in areas where there are connection points- rivets, screw attachments etc. Metal roofs can also suffer duress when in contact with dissimilar metals- copper to steel or aluminum to steel and rust stains can form. A consultation from a roofing contractor on their advice on the health and projected lifespan of the roof should be considered.

d. Commercial roofs:

Many commercial roofs today are segueing to membrane types of roofing materials from their pitch and gravel roofs of the past. These materials are high tech and proprietary- meaning, each manufacturer of these roofs has their own warranty and elects certain contractors to only work on these roofs after they have been formally trained. Any work that is done on these types of roofs warrants a consultation from a roofing company and or the manufacturer in the method of mounting things on the roof. There is even sensitivity by the roofing manufacturers to also wince at the notion of someone even walking on the roof. This is why you see walk pads, delineating where foot traffic should be on a roof, and this is generally focused on service and repair of AC equipment on the roof.

e. Torch down-rubberized asphalt/mechanically fastened:

This is another common roofing material for installations on flat roofs. It has an average lifespan of 15-20 years. Again, consult with a roofing specialist on the efficacy of installing a system on an existing roof.

2.4 Layout Options- Solar Array

There are essentially two ways to layout solar modules on a roof- either portrait or landscape. Certain roofs lend themselves to a lot of physical space while others are crowded with vent pipes, hips and other obstructions. Other design criteria would be the final look from the ground or the street of the layout and how symmetrical it looks. This design consideration is very important, as it will be on the roof for many years, and not thinking through symmetry of the solar array, could be visually unappealing.

There can also impacts in the cost of the racking materials associated with the layout. If you are designing in a landscape layout, you could end up using additional racking materials which will increase your costs which might not have been factored into the initial design & sales process.

Rectangular-Portrait

The most typical installation pattern is a rectangle, consisting usually of 1-“X” rows of modules in “portrait” mode with the long side of the module mounted vertically.



Figure 1 - Picture shown on a Spanish tile barrel roofing using lead flashings.

Triangular-Portrait

Another pleasant layout pattern is a triangle that tries to follow the angle of adjacent roof ridges.



Figure 2- Also referred to as the “Mayan” pyramid.

Staggered-Portrait or Landscape

If both sides of an array roof surface angle in the same direction then a staggered or stepped layout pattern will match. This situation arises out of the designs many architects make in visual appeal, but difficult to maximize the amount of solar array potential that could be installed on a roof. There are also factors, like skylights and roof vents that limit the layout as well.



Figure 3- Landscape layout, staggered to accommodate skylight

Multiple surfaces into multiple inverters

This can present itself often in Hawaii, as on many residential applications, we run into space constraints. So, if the desired amount of solar power cannot all fit on one roof surface, then multiple arrays (feeding multiple inverters) may be installed on several roof surfaces. They can face different directions because they are basically separate systems, so long as all the modules in each array are facing the same direction. While this statement is true for string type of inverters, a way to remedy this is to also consider micro inverters, as the orientation is not dependent on the multiple surfaces.

Multiple surfaces for the same array and the same inverter

Where there is not enough room for an entire array on one roof surface, the array may be installed in sections on several smaller surfaces, under the following conditions:

1. All of the modules in each series string must all be installed on surfaces that face the same direction. Meaning, if you have 8 panels on a south facing roof on the garage, you need to put the second string of 8 panels on another south facing roof on another surface of the roof that is identical, If one series string is installed with some modules facing one direction and the other modules facing another direction, then during a day some modules will always be getting less sunlight than the others and the entire string will be limited to the output from the lowest producing modules. By “pulling the strings down” to the lowest voltage available, you will restrict the amount of power being able to be extracted from the array and should be avoided.
2. A remedy to this situation is to go with a micro inverter, like Enphase Energy, which mitigates this situation, as there is an individual inverter on each panel.

An example of this would be a customer deciding to install solar panels on a roof of their detached garage, facing south, and also on a roof of their home facing south.

Modules in same series string should not face different directions

This is a situation that will not work as the inverter will have a difficult time trying to find the Multi Power Point Tracking (MPPT) in the optimization of the array and do a tug of war trying to find the optimum knee curve and be unsuccessful. Modules in the same series string on a single inverter need to face the same directions. The output of the entire string will be limited to the output of the lowest performing modules. This will keep the output of the entire string low all day long and defeat the purpose of adding additional strings of modules to the inverter.

An example of this would be a customer deciding to install solar panels on a roof of their detached garage, facing south, and also on a roof of their home, but they want to have this string facing east. It would be best to install a second inverter and have one string on one inverter and one string on the other.

Another remedy to a situation that has many small roof surfaces with different orientations is to go with a micro inverter, like Enphase Energy.

Complete series strings facing different directions – and **tilted** towards the same direction

Modules that are on roof surfaces facing different directions may be connected into the same inverter only if all the modules in each series string are all facing the same direction. One complete string can face one direction and another parallel string can face a different direction, so long as all the modules in each individual string are facing the same direction.

In this example there is one series string of 8 modules staggered on a roof surface facing south and another series string of 8 modules facing west. All the modules in each string however are facing the same direction- aka, they are tilted towards the south. These two strings can be connected into the same inverter. Their voltages will be nearly identical and the inverter will be able to operate them both properly. Their currents will just add.

While this is a solution, this occurs less often than desired, as most architecture of homes does not lend to this situation.

Another remedy to a situation that has many small roof surfaces with different orientations is to go with a micro inverter, like Enphase Energy.

And lastly-

Modules in same series string **should never** face different directions

This is a situation that is **not acceptable** - having modules in the same series string facing different directions and tilted in opposite directions- aka- one is facing south and tilted south and one is facing east and tilted east. The output of the entire string will be limited to the output of the lowest performing modules. This will keep the output of the entire string low all day long.

An example of this would be a customer deciding to install solar panels on a roof of their detached garage, facing south, and also on a roof of their home, but they want to have this string facing east. They don't want to tilt the modules to face the same direction.

This is a good application for using a micro inverter, like Enphase Energy.

2.5 Mounting Options- Roof

Rooftop Mounting Considerations

Dead Loading

The weight of a solar array and racking system will add to the overall weight of a roof but is spread out over a fairly large square foot area as a distributed load. When you consider the average weight of a system is 3 lbs per square foot, this is a lot less than an actual person standing in a 2 square foot area. There are two ways that this added weight should be checked. Both are considered "dead" weight, or just weight due to gravity without consideration for dynamic pressure from the wind.

Distributed Dead Loading

The goal of understanding if a roof can support the added weight of a solar photovoltaic system is often asked and sometimes misunderstood. The intent is to distribute the weight of the solar panels and the racking is distributed over a large square area and therefore, spreading the dead load appropriately.

Typical asphalt shingles are designed to support up to 7.5 psf and usually hover around 5 pfs as a rule of thumb. Shingles weigh approximately 2-2.4 lbs psf by themselves. This is why the building department allows for up to 3 layers of shingles maximum on a roof (please consult a licensed structural engineer to address your particular situation), before you are required to remove them off of the sheathings and start from the beginning.

When we look at the atypical solar photovoltaic system, we generally fall under 3 lbs per square foot. Couple this with the roofing materials, we are well under the acceptable dead loading requirements of the building department. There is actually more weight on the roof, when the roof and the solar system is being installed. Other factors, like wind loading are already factored into this equation. Hawaii has been blessed already by the early adoption of the solar hot water industry and they have been “educated” on additional roof weight and tilted racking as it pertains to wind loading.

The solar array weight can be compared to a layer of shingles. By contacting the local building department to determine the maximum layers of shingles allowed on a roof, the installer can verify if the local construction is suitable for supporting the added weight of solar panels.

Point Dead Loading

The other evaluation of dead loading is to realize that the entire weight of the array and mount is not distributed evenly over the area but presses on the roof at only the points of mounting. This method is most appropriate when considering the strength of the trusses and their ability to hold up to point pressure loading.

To calculate the point dead load, divide the total weight of the array and mounting system by the number of stanchions used for the project:

$$\text{Point Dead Loading} = \text{Total array + Mount weight} / \# \text{ stanchions}$$

The acceptability of this point pressure depends on the design of the roof trusses, and should be judged by a licensed structural engineer.

Pullout Strength Against Uplift Pressures

Another analysis of the mounting system is the pullout strength (or “withdraw resistance”) of the attachment hardware. Typically each stanchion is secured through the roof and into a rafter with a lag screw or a hangar bolt. The screw must have withdrawn resistance greater than the expected wind uplift force.

The Uniform Building Code defines several terrain “exposure zones” to describe local wind conditions for building design purposes:

- Exposure B has terrain with buildings, forest or surface irregularities, covering at least 20 percent of the ground level area extending 1 mile or more from the site.
- Exposure C has terrain that is flat and generally open, extending ½ mile or more from the site in any full quadrant.
- Exposure D represents the most severe exposure with terrain that is flat and unobstructed facing a large body of water with basic wind speeds of 80 mph or greater.

Calculations of uplift pressure depend on a variety of factors including the exact orientation of the roof surface to the wind direction, the height of the roof and the closeness of the array to the roof peak and edges. The following discussion is meant only to illustrate the principles involved. If official calculations are required by the building department, then a licensed structural engineer should be involved. The invitation of a structural engineer is generally not required for a residential application, and more for commercial applications.

This is especially relevant for systems that will either be tilt mounted, or ground mounted with a tilt, as these can become “sails”.

Typically Exposure C is the most severe terrain condition to which urban residential homes will be exposed. The basic wind speed that is specified by Honolulu, according to the building department, we are in the 90 mph zone. For a 2-story house in Exposure C terrain, this translates to approximately 30 lbs/sq ft of uplift pressure.

The total uplift force on the array from this pressure is calculated. The weight of the array and mount is subtracted to give the net upward force, and then divided by the number of footings to give the net uplift force per lag screw/hangar bolt. This is compared to the withdraw resistance of the lag screw in the wood of the rafter. The withdraw resistance is a function of (a) the density of the wood, (b) the diameter of the lag screw, and (c) the length of the screw thread imbedded in the wood (contact length). A typical 3" lag screw has only about 2" of contact length because it must first pass through the thickness of the stanchion plate, roofing asphalt shingles, and decking plywood.

Net Uplift force per footing < Withdraw force per footing

$$\frac{\text{Pressure X total array area} - \text{total weight}}{\text{Number of footings}} < \frac{\text{Resistance X contact length}}{\text{factor of thread}}$$

A table of some withdraw resistances for different types of wood is given below (from the NABCEP (North American board of certified energy practitioners) Study Guide). These are calculated for a 5/16" lag screw after an appropriate pilot hole has been drilled. The values also include a safety factor of four. This means that the values listed are four times greater than the actual resistance. This built-in safety margin is a common practice when working with the wide uncertainties of materials such as wood.

Withdraw Resistance for 5/16" Lag Screw

Type of Lumber	Specific Gravity	Withdraw Resistance (lb/in)
White Spruce	0.45	227
Douglas Fir	0.41	274
Southern Yellow Pine	0.58	332

Example:

Eight modules (SunTech 175's – 62.2" x 31.8" = 1977 Sq In/144= 13.72 Sq Ft x 8 panels =110 Sq Ft) are attached to a residential roof on a rail system supported by 12 stanchions (6 Stanchions, per 4 panels in a portrait layout- 3 stanchions per upper and lower rail). 3" lag screws are used, but only approximately 2" of threads actually penetrate into the rafters, which are Douglas Fir. The local building code specifies a basic wind pressure of 30 lbs/sq ft for the location.

$$\frac{\text{Pressure X area - total weight}}{\text{Number of stanchions}} < \frac{\text{Resistance X contact length}}{\text{factor of thread}}$$

$$\frac{30 \text{ lbs X } 110 \text{ sq ft} - 294 \text{ lbs}}{12 \text{ stanchions}} < 274 \text{ X } 2''$$

$$250 \text{ lbs per stanchions net uplift} < 548 \text{ lbs withdraw resistance}$$

The net uplift is less than the withdraw resistance, so the lag is sufficient to hold the array and mount system under the specified conditions of wind.

Pilot Holes for Mounting Lag Screws

It is recommended that pilot holes be drilled where the lag screws are to be inserted through the roof decking into rafters. This helps prevent splitting and ensures a better grip. The size of the pilot hole drill bit should be 60-75% of the screw diameter. For a 5/16" diameter lag screw, this would mean using from a 3/16" to 15/64" drill bit, nominally a 7/32" bit.

The diameter of a screw is its size number in 64ths. For example, a "#8" screw would have a diameter of 8 x 1/64", or 1/8".

Installation of lag screws/hangar bolts

It is recommended to use an impact gun or a cordless drill with the appropriate settings to drive the screw through the rafter and care should be taken that it is installed straight, as to ensure positive connection point to the structure. It is also advisable to apply a caulking adhesive to seal the penetration.

Row Spacing of Tilted Racks and other Obstructions

If rows of modules are being installed on tilted racks on a flat roof, the rows must be spaced so that there will not be any inter-row shading during hours of significant irradiance. This is generally avoided with manufactured racking solutions that have pre engineered. Even a few inches of shading spread across all the bottom cells of a module will effectively reduce the module output to near zero. A typical design target is to have no shading after 9 am on the winter solstice (December 21 in the northern hemisphere) when the sun is the lowest in the sky, casting the longest shadows. The relevant angles and distances for rack spacing are shown in the figure.



Figure 4-Shading of an array

The equation for row spacing is shown below. The values required are module vertical length (M), desired module tilt angle (T) (usually the site latitude), and the solar altitude angle (A) for the location at the desired time (usually 9 am).

Solar altitude angles are available from sun angle charts; or use the online calculator at www.susdesign.com/sunangle

$$D = M' + S = M \times \cos(T) + M \times \sin(T) / \tan(A)$$

Example:

A system is being installed on a flat residential roof in the Honolulu, HI area. What should be the minimum spacing between rows of tilted modules? Modules are in horizontal or landscape orientation and it is 1 row tall (note- you could mount multiple modules on racking, and tilt the 3-4 panels, but this is not the intent of this example).

Location: Honolulu Date: December 21

Latitude: 21.43°N Time: 9:00 am

Module length = 29.8" (SunTech-175 watt module- width)

Sun altitude angle = 39.05° (from susdesign.com)

Module tilt angle = 21° (latitude of site)

$$\begin{aligned} D &= 29.8'' \times \cos(21^\circ) + 29.8'' \times \sin(21^\circ)/\tan(39.05^\circ) \\ &= 29.8'' \times 0.933 + 29.8'' \times 0.358/0.821 \end{aligned}$$

$$= 40.78'' = 3.39 \text{ feet}$$

The above example gives a spacing distance between rows of approximately 1.35 times the length of the module. In general, we would like to keep the math simple and go for 1.5 times for Hawaii. If you are more comfortable with summertime maximization of the energy harvest, you can always lower the tilt angle to less than 21°, but will need to consider the potential of additional soiling in the dryer areas of the island, as the rain will not be available to “wash” the panels.

2.6 Layout Options- Electrical Equipment

There are many ways to layout your electrical equipment- inverters, disconnects etc. Most sites need to be looked at to see where it is feasible and Companysthetically pleasing to install the equipment. The equipment can be installed indoors or outdoors. Care should be taken in selecting either site for the following reasons

- If the equipment is installed indoors, proper ventilation is essential, as the equipment gives off heat in the transfer of DC to AC power
- If the equipment is installed indoors, the electronics in the inverters sometimes give off a high frequency noise, so care should be given to the location
- If it is installed indoors, a good location is a ventilated garage
- If the equipment is installed outdoors, proper ventilation is also important as well as keeping the equipment out of the sun for optimum performance
- If it is installed outdoors, a good location is under an eave or an equipment enclosure to protect it from the elements.

One Inverter

When just one inverter is installed, the equipment layout can be quite simple. If the inverter does not have any built-in dc or ac disconnects, then the conduit from the array runs directly into a dc disconnect switch and then on to the inverter. Conduit then leaves the inverter and goes into an ac disconnect switch and then on to the main service panel.



Figure 5-Single inverter with AC & DC disconnects as separate components

Hawaii utilities still require the external lockable ac disconnect switch at the main service panel or meter. Be sure to check with your local utility for their requirements and to see if there are any changes to their policies.



Figure 6

Single inverter with integral AC & DC Disconnects

Some inverters have an integral dc disconnect switch (and possibly ac as well) attached to the inverter unit. The conduit can pass uninterrupted from the array and connect directly into the inverter, unless an external dc disconnect is required. A redundant external lockable ac disconnect switch may still be required by the utility at the meter for verification the system will not backfeed in the event of a power failure and or when there are linemen working in the neighborhood.

Multiple Inverters

When multiple inverters are installed, conduit can be used from inverter to inverter, or a wiring gutter can be used. The wiring gutter allows for easy routing of dc wiring into and ac wiring out of the inverters, and also gives a common location for grounding. The inverters are shown mounted above a 6" wiring gutter with the dc disconnect switches and ac disconnect switches part of the inverter assembly. The array dc conductors enter the gutter on one side and the output ac conductors exit the gutter on either side, depending on the direction to the main electrical service panel. The ac conductors travel to breakers in an inverter subpanel where they are combined into a single conductor pair that continues on to the main service panel location. The breakers in the subpanel serve as the local ac disconnecting means. If this equipment were outside, then all conduit connections should be terminated with appropriate liquid-tight fittings and Meyers hubs.



Figure 7-Multiple inverters with built in AC & DC Disconnects, gutter and 200 amp Sub Panel

2.7 Disconnecting Means- AC & DC- ground work

2.7.1 Multiple disconnects may be required

A means of dc and ac disconnect must be present at the inverter location to allow for safe servicing. Duplicate disconnects may be required as well to comply with the NEC- 6 operations of the hand in NEC 230.26. So, if you have more than 6 inverters, you will want to combine them into a service panel, then upstream, you would install a disconnect to be able to shut down the 6 inverters.

2.7.2 AC disconnects

When there is a long distance between the inverter location and the service panel, or when there is a wall separating the two areas, then another ac disconnect switch will be required as well, per the NEC. Most utilities require a lockable mechanical disconnect switch with visible open blades near the meter, so that service personnel can have a visible and positive means of locking out any ac power from a solar system while they are working on the local grid. Some jurisdictions allow for the utility representatives to just remove the meter, as a means of disconnecting the inverter, in lieu of a mechanical disconnect. We hope in the future, all utilities drop this requirement, as the inverter manufacturers have verified they will disconnect from the grid in the event of a power failure, removing the concern about lineman's safety.

In the case of using a micro inverter, like Enphase, this can be considered a branch circuit and the circuit breaker will provide the means of disconnect as well as overcurrent protection. However, the utility still requires a lockable disconnect as of this publications writing.

2.7.3 DC disconnects

On the dc side, interpretation of the NEC may result in the requirement for duplicate dc disconnects. The 2005 NEC has a new exception in 690.14(C)(1) and a new section 690.31(E) that allows for the dc conductors from an array, if contained in metallic raceway, to run into a building and terminate at a readily accessible means of disconnect. However previous versions of the NEC do not have this explicit allowance, and the previous version of Section 690.14(C)(1) specifically requires a means of dc disconnect either on the outside of the building or inside nearest the point of entrance of the conductors. When the inverter is installed inside the building, this requirement usually results in a dc disconnect outside the building or inside nearest the point of entrance of the conductors. When the inverter is installed inside the building, this requirement usually results in a dc disconnect outside the building and another at the inverter location. While this is not common in a residential application it could be for a commercial situation.

This is not applicable if you are using a micro inverter, like Enphase, as the dc is "plugged in" on the roof.

2.8 Rooftop wiring-Residential

2.8.1 Array wiring to the junction box

This is where everything meets on the roof in the outdoor junction box. The negative and positive connectors from the end of each series string of modules connect to short leads that terminate in the box. For each series string, the pair of positive and negative leads from the solar array passes through a liquid-tight straight strain relief nylon dome fitting with a two-hole seal insert for residential applications. Another fitting with a single-hole seal insert can be used for the array from grounding conductor.

If you are using an micro inverter, like the Enphase product, you will just have AC wiring coming off of the roof and the above is not applicable. You would use the standard methodologies as you would with standard electrical wiring, except for the utility required disconnect. There will also be another requirement, based upon the size of the solar array as it pertains to NEC 690.64B, which will be discussed later in depth.

For commercial applications, this is usually transitioned from conduit through a bushing into the array.

The purpose of the fittings is to provide strain relief for the connections inside as well as provide a water-tight seal around the conductors entering the box. Be sure to tighten the connectors to minimize water infiltration.

If the array junction box is metallic, then there should be a lay-in lug connected to the inside of the box to allow the grounding conductor to bond with the box. The conductors leaving the box to connect to the disconnect should pass in the conduit. Due to the environmental conditions here, we recommend transitioning from metal conduit, if it is traversing through the attic or on the side of the home, to a flexible metallic conduit (Carflex or approved equal). This is to have more options, on where to mount the junction box on the racking as well as ease of installation.

2.8.2 Secure Conduit from the Junction Box to the Roof Penetration

Any conduit from the array junction box to the roof penetration must be secured per NEC requirements for the conduit used. If you are going to install EMT, refer to section 358.30 for the supporting requirements. The general rule is within 3 feet of an enclosure and every 10 feet. It is advisable to use stainless steel screws if available, as they will be the first items to rust and bleed down the side of a residence where they were installed. If this is an Enphase installation, it can be installed in PVC, as we are now in the low voltage category, or if applicable, transitioning in the attic to UV cable.

2.8.3 Conductor connections to the array wiring- transition

The short leads attach to regular conductors inside the array junction box using outdoor-rated connectors. You can utilize the type MC connectors as a disconnecting means and connector or utilize the new Gen 2 type of connectors. These are currently being sold by TYCO. Use insulated multi-cable connector blocks, like Polaris IPL or approved equal.

If this is an Enphase installation, it can be installed in PVC, as we are now in the low voltage category, or if applicable, transitioning in the attic to UV cable.

More than Three Series Strings requires a Fused Combiner Box- Example

Up to two series strings of modules can be connected in parallel in an array junction box without the need for individual fuses. This will allow one pair of larger sized DC conductors leaving the box in conduit to the inverter. While this might seem like a good practice, it is best to run individual home runs back to the inverter. In the case of using SMA, their built in combination switch comes with four fuses, so you can have four home runs run from the array back to the inverter. This is also helpful in commissioning the system as well as troubleshooting.

It is also notable, that you will always need to check the specific panel manufacturers spec sheets on fuse requirements, as this example above might not be as applicable.

2.8.4 Roof Penetration

The method to get from point A to point B will vary, depending upon site conditions to travel down to the dc disconnect/inverter area. If you are utilizing a micro inverter, like Enphase Energy, then you will still need to get the wiring from the roof to the electrical infrastructure. In either event, effectively sealing any roof penetrations is crucial to the longevity of the roof and anything that lives under it.

2.8.5 Roof Penetration Example

Here is an example of a roof penetration scenario below. In this instance, we had a comp shingle roof and utilized a flexible lead flashing product with a Geocel 2300 construction tripolymer sealant <http://www.geocelusa.com> (be sure to verify the type of roofing material you are working with to match the sealant to the application). The array junction box receives the string conductors and array frame grounding conductor through watertight fittings. The array junction box connects to a piece of flexible metallic conduit. The conduit has been run through the attic and there was a transition between the attic and the roof.



3 Wiring

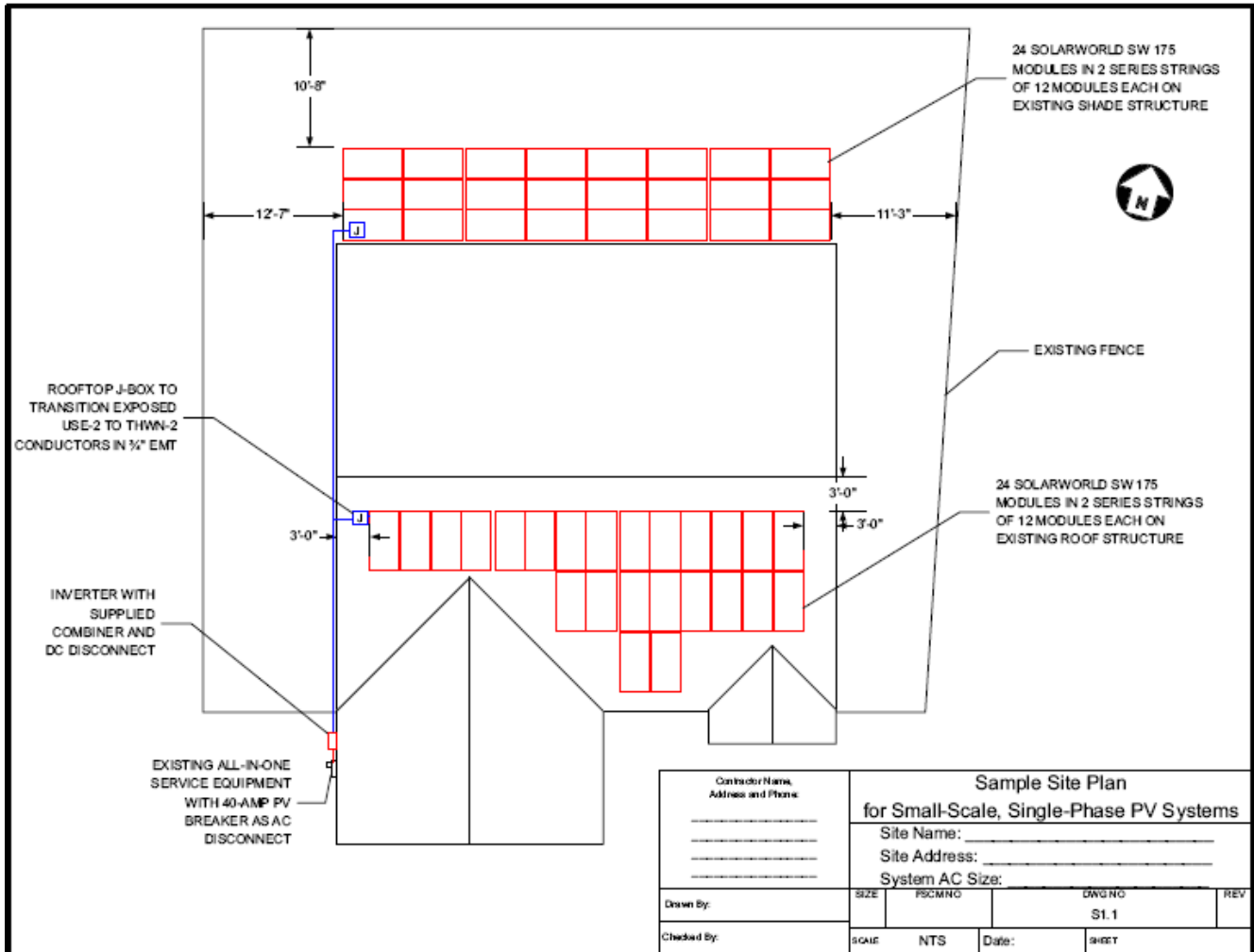
3.1 Typical wiring Diagram

There are a few different examples of wiring diagrams for solar photovoltaic systems. Depending upon whether it is a commercial or residential system, determines the likelihood that additional information is provided. This would be a typical commercial title page listing all of the information about the project. A residential plan would have a site plan, elevations, electrical notes, electrical plan, wiring schedule and sometimes this can all reside on one or two pages, whereas a commercial system would be on multiple pages.

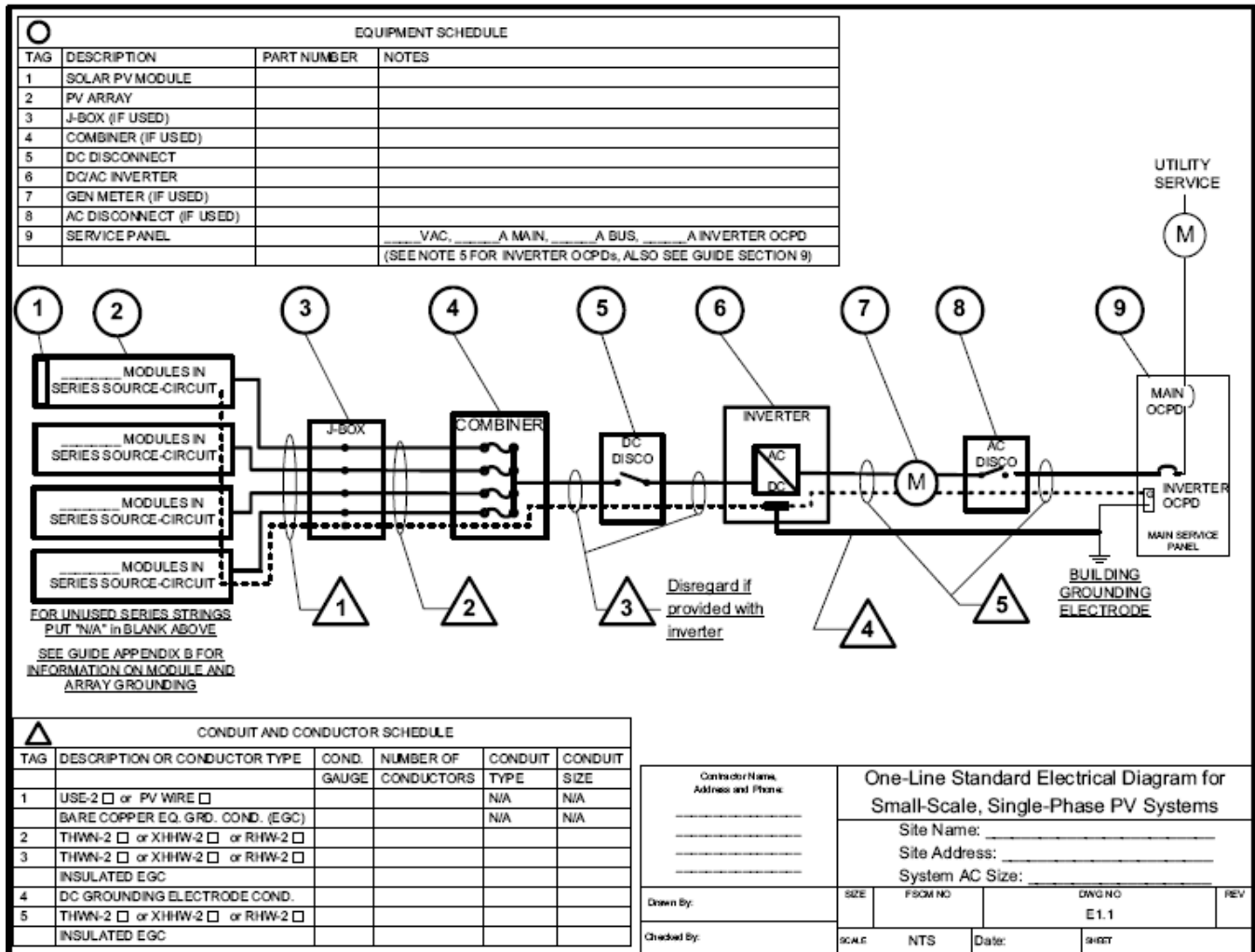
A	Title page
A.1	Site plan- overall
A.2	Roof plan
A.3	Enlarged floor plans
A.4	Elevations
E.1	Electrical notes
E.2	Electrical plan
E.3	Wiring schedule
E.4	Three line diagram
E.5	Labels and markings
E.6	Specifications
S.1	Details

On a residential set of drawings, you would see fewer details, in regards to some of the items above. You would see the site plan and the roof plan combined into one. The electrical plan, notes, wiring schedule, one line diagram with a combination of electrical notes and labels and markings can be on one to three pages. There would also be the submittals for the specifications on the equipment to be used- inverter and solar panels.

Site Drawing- Example



One line Drawing Example-



One line- Notes- Example

<p>PV MODULE RATINGS @ STC (Guide Section 5)</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>MODULE MAKE</td><td></td></tr> <tr><td>MODULE MODEL</td><td></td></tr> <tr><td>MAX POWER-POINT CURRENT (I_{MP})</td><td style="text-align: center;">A</td></tr> <tr><td>MAX POWER-POINT VOLTAGE (V_{MP})</td><td style="text-align: center;">V</td></tr> <tr><td>OPEN-CIRCUIT VOLTAGE (V_{OC})</td><td style="text-align: center;">V</td></tr> <tr><td>SHORT-CIRCUIT CURRENT (I_{SC})</td><td style="text-align: center;">A</td></tr> <tr><td>MAX SERIES FUSE (OCPD)</td><td style="text-align: center;">A</td></tr> <tr><td>MAXIMUM POWER (P_{MAX})</td><td style="text-align: center;">W</td></tr> <tr><td>MAX VOLTAGE (TYP $600V_{DC}$)</td><td style="text-align: center;">V</td></tr> <tr><td>VOC TEMP COEFF (mV/°C □ or %/°C □)</td><td></td></tr> <tr><td>IF COEFF SUPPLIED, CIRCLE UNITS</td><td></td></tr> </table>	MODULE MAKE		MODULE MODEL		MAX POWER-POINT CURRENT (I_{MP})	A	MAX POWER-POINT VOLTAGE (V_{MP})	V	OPEN-CIRCUIT VOLTAGE (V_{OC})	V	SHORT-CIRCUIT CURRENT (I_{SC})	A	MAX SERIES FUSE (OCPD)	A	MAXIMUM POWER (P_{MAX})	W	MAX VOLTAGE (TYP $600V_{DC}$)	V	VOC TEMP COEFF (mV/°C □ or %/°C □)		IF COEFF SUPPLIED, CIRCLE UNITS		<p>NOTES FOR ALL DRAWINGS:</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> <p>OCPD = OVERCURRENT PROTECTION DEVICE</p> <p>NATIONAL ELECTRICAL CODE® REFERENCES SHOWN AS (NEC XXXXX)</p> </div> <p>INVERTER RATINGS (Guide Section 4)</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>INVERTER MAKE</td><td></td></tr> <tr><td>INVERTER MODEL</td><td></td></tr> <tr><td>MAX DC VOLT RATING</td><td style="text-align: center;">V</td></tr> <tr><td>MAX POWER @ 40°C</td><td style="text-align: center;">W</td></tr> <tr><td>NOMINAL AC VOLTAGE</td><td style="text-align: center;">V</td></tr> <tr><td>MAX AC CURRENT</td><td style="text-align: center;">A</td></tr> <tr><td>MAX OCPD RATING</td><td style="text-align: center;">A</td></tr> </table>	INVERTER MAKE		INVERTER MODEL		MAX DC VOLT RATING	V	MAX POWER @ 40°C	W	NOMINAL AC VOLTAGE	V	MAX AC CURRENT	A	MAX OCPD RATING	A	<p>SIGNS-SEE GUIDE SECTION 7</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> <p>SIGN FOR DC DISCONNECT</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">PHOTOVOLTAIC POWER SOURCE</td></tr> <tr><td>RATED MPP CURRENT</td><td style="text-align: center;">A</td></tr> <tr><td>RATED MPP VOLTAGE</td><td style="text-align: center;">V</td></tr> <tr><td>MAX SYSTEM VOLTAGE</td><td style="text-align: center;">V</td></tr> <tr><td>MAX CIRCUIT CURRENT</td><td style="text-align: center;">A</td></tr> <tr><td colspan="2" style="text-align: center;">WARNING: ELECTRICAL SHOCK HAZARD-LINE AND LOAD MAY BE ENERGIZED IN OPEN POSITION</td></tr> </table> </div> <div style="border: 1px solid black; padding: 5px;"> <p>SIGN FOR INVERTER OCPD AND AC DISCONNECT (IF USED)</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">SOLAR PV SYSTEM AC POINT OF CONNECTION</td></tr> <tr><td>AC OUTPUT CURRENT</td><td style="text-align: center;">A</td></tr> <tr><td>NOMINAL AC VOLTAGE</td><td style="text-align: center;">V</td></tr> <tr><td colspan="2" style="text-align: center;">THIS PANEL FED BY MULTIPLE SOURCES (UTILITY AND SOLAR)</td></tr> </table> </div>	PHOTOVOLTAIC POWER SOURCE		RATED MPP CURRENT	A	RATED MPP VOLTAGE	V	MAX SYSTEM VOLTAGE	V	MAX CIRCUIT CURRENT	A	WARNING: ELECTRICAL SHOCK HAZARD-LINE AND LOAD MAY BE ENERGIZED IN OPEN POSITION		SOLAR PV SYSTEM AC POINT OF CONNECTION		AC OUTPUT CURRENT	A	NOMINAL AC VOLTAGE	V	THIS PANEL FED BY MULTIPLE SOURCES (UTILITY AND SOLAR)	
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AC OUTPUT CURRENT	A																																																									
NOMINAL AC VOLTAGE	V																																																									
THIS PANEL FED BY MULTIPLE SOURCES (UTILITY AND SOLAR)																																																										
<p>NOTES FOR ARRAY CIRCUIT WIRING (Guide Section 6 and 8 and Appendix D):</p> <div style="border: 1px solid black; padding: 5px;"> <p>1.) LOWEST EXPECT AMBIENT TEMPERATURE BASED ON ASHRAE MINIMUM MEAN EXTREME DRY BULB TEMPERATURE FOR ASHRAE LOCATION MOST SIMILAR TO INSTALLATION LOCATION. LOWEST EXPECTED AMBIENT TEMP _____°C</p> <p>2.) HIGHEST CONTINUOUS AMBIENT TEMPERATURE BASED ON ASHRAE HIGHEST MONTH 2% DRY BULB TEMPERATURE FOR ASHRAE LOCATION MOST SIMILAR TO INSTALLATION LOCATION. HIGHEST CONTINUOUS TEMPERATURE _____°C</p> <p>2.) 2005 ASHRAE FUNDAMENTALS 2% DESIGN TEMPERATURES DO NOT EXCEED 47°C IN THE UNITED STATES (PALM SPRINGS, CA IS 44.1°C). FOR LESS THAN 9 CURRENT-CARRYING CONDUCTORS IN ROOF-MOUNTED SUNLIT CONDUIT AT LEAST 0.5" ABOVE ROOF AND USING THE OUTDOOR DESIGN TEMPERATURE OF 47°C OR LESS (ALL OF UNITED STATES).</p> <p>a) 12 AWG, 90°C CONDUCTORS ARE GENERALLY ACCEPTABLE FOR MODULES WITH I_{sc} OF 7.68 AMPS OR LESS WHEN PROTECTED BY A 12-AMP OR SMALLER FUSE.</p> <p>b) 10 AWG, 90°C CONDUCTORS ARE GENERALLY ACCEPTABLE FOR MODULES WITH I_{sc} OF 9.6 AMPS OR LESS WHEN PROTECTED BY A 15-AMP OR SMALLER FUSE.</p> </div>	<p>NOTES FOR INVERTER CIRCUITS (Guide Section 8 and 9):</p> <div style="border: 1px solid black; padding: 5px;"> <p>1) IF UTILITY REQUIRES A VISIBLE-BREAK SWITCH, DOES THIS SWITCH MEET THE REQUIREMENT? YES <input type="checkbox"/> NO <input type="checkbox"/> N/A <input type="checkbox"/></p> <p>2) IF GENERATION METER REQUIRED, DOES THIS METER SOCKET MEET THE REQUIREMENT? YES <input type="checkbox"/> NO <input type="checkbox"/> N/A <input type="checkbox"/></p> <p>3) SIZE PHOTOVOLTAIC POWER SOURCE (DC) CONDUCTORS BASED ON MAX CURRENT ON NEC 690.53 SIGN OR OCPD RATING AT DISCONNECT</p> <p>4) SIZE INVERTER OUTPUT CIRCUIT (AC) CONDUCTORS ACCORDING TO INVERTER OCPD AMPERE RATING. (See Guide Section 9)</p> <p>5) TOTAL OF _____ INVERTER OCPD(s), ONE FOR EACH INVERTER. DOES TOTAL SUPPLY BREAKERS COMPLY WITH 120% BUSBAR EXCEPTION IN 690.64(B)(2)(a)? YES <input type="checkbox"/> NO <input type="checkbox"/></p> </div>																																																									
<div style="border: 1px solid black; padding: 5px;"> <p>Contractor Name, Address and Phone: _____ _____ _____</p> </div>		<p>Notes for One-Line Standard Electrical Diagram for Single-Phase PV Systems</p> <p>Site Name: _____</p> <p>Site Address: _____</p> <p>System AC Size: _____</p>																																																								
<p>Drawn By: _____</p> <p>Checked By: _____</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 15%;">SIZE</td> <td style="width: 15%;">FSCM NO</td> <td style="width: 15%;">DWG NO</td> <td style="width: 15%;">REV</td> </tr> <tr> <td></td> <td></td> <td style="text-align: center;">E1.2</td> <td></td> </tr> <tr> <td>SCALE</td> <td>NTS</td> <td>Date:</td> <td>SHEET</td> </tr> </table>	SIZE	FSCM NO	DWG NO	REV			E1.2		SCALE	NTS	Date:	SHEET																																													
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3.2 Sizing of Conductors

How do we size the conductors based upon ampacity?

If we look to NEC 690.8(A)(1) through (A)(4) states the maximum current shall be the sum of the parallel module rated short-circuit currents multiplied by 1.25%.

Why?

When we read 690.8(A)(1) it states the maximum current shall be the sum of parallel module rated short circuit currents multiplied by 125%.

PV output circuits can deliver output currents higher than the rated short circuit currents for more than three hours near solar noon. This 125% factor is in addition to the 125% factor required by 690.8 (B). This also takes into consideration, the phenomenon of the “edge of cloud effect”. When light hits the clouds, the actual irradiance can exceed 1000 W/m^2 . So, we are in essence in addition to 690.8(B)

This is also why we need to revisit 310.16 & 310.17 and have the ampacity of the wire corrected for the application as well.

So, the ampacity rating of a conductor is different for solar related work than most electrical applications due to the heating effect of wiring on roofs. This is sometimes brought up, but rarely, as standard electrical wiring is usually routed through a building, and then penetrated up to the roof for things like HVAC equipment. So, this safety component is essential as overheating of the conductors could create a hazard as well as reduced optimization of the solar system.

Here is an example below of how we determine the size of the wire using a SunTech 175 watt solar panel and an SMA4000 inverter.

Step # 1

A SunTech Power 175 watt solar panel is rated at 5.2 amps I_{sc} .(off of their spec sheet)

So, $5.2 \times 1.25 = 6.5$ amps

Step # 2

If we go to 690.8(A)(3), we need to determine the maximum rated output current of the inverter. We will be using the SMA SB4000. So, off of their spec sheet, we see a maximum AC current of 17 amps.

So, we need to calculate the minimum ampacity at least 125% greater than the maximum current for the circuit. This is where we actually multiply 1.25×1.25 as outlined in 690.8(B)(1) due to the *environmental conditions* of the conductors in a PV circuit.

Let's say we have 2 strings of SunTech 175 watt modules in parallel. What is going to be the smallest size conductor we can use?

The minimum ampacity is from above:

$$5.2 \text{ amps} \times 1.25 \times 1.25 \text{ (or } 5.2 \text{ amps} \times 1.56) = 8.12 \text{ amps}$$

$$2 \text{ strings of modules} = 8.12 \text{ amps} \times 2 = 16.24 \text{ amps}$$

If we look at the chart below, we can use a #14 THWN-2 conductor.

What is the minimum size conductors we should use from the electrical panel to the SMA SM4000 inverter?

$$17 \text{ amps} \times (1 \text{ inverter}) \times 1.25 = 21.25 \text{ amps}$$

If we look at the chart below (ampacity table), we can use a #12 THWN-2 conductor (90°C column)

3.3 Ampacity Tables

We have determined what the minimum ampacity is and now we can select a conductor to match our example above.

Once a minimum ampacity value has been determined, a conductor with that ampacity can be selected. The NEC has tables of ampacity for different conductors, depending on size and insulation. Standard ambient temperature is assumed to be 30°C. Table 310.16 is for conductors in conduit or earth. Table 310.17 is for conductors in free air (ex: battery cables; module wires to junction box). Some representative values from Table 310.16 are shown below.

Conductor Size (AWG)	60°C (140°F)	75°C (167°F)	90°C (194°F)
	Types UF	Types RHW, THHW, THWN, XHHW, USE	Types RHW-2, THHN, THHW, THWN-2, USE-2, XHHW, XHHW-2
14*	20	20	25
12*	25	25	30
10*	30	35	40
8	40	50	55
6	55	65	75
4	70	85	95
2	95	115	130
1	110	130	150
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260

*Limits to fuse size for 14, 12, 10 AWG wire [240.4 (D)]: 14 AWG, use max 15 A fuse; 12 AWG, use max 20 A fuse; 10 AWG, use max 30 A fuse.

3.4 Conduit Fill Derating

In the NEC-Article 110, the code outlines that if there are more than three current carrying conductors in a raceway or cable, the conductor ampacity must be derated.

Table 310-15 (B)(2)(a) gives the factors for derating. Some representative values from Table 310.15 are shown below.

Number of Current Carrying Conductors	Conductor Fill Derating Factor
4-6	0.80
7-9	0.70
10-20	0.50

So, let's go back to our example using the SunTech 175 panels and the SMA SB4000

There were 2 strings, so 4 conductors in the conduit. The ground wire is not counted in this calculation, per 310.15(B)(5).

The minimum ampacity for 2 conductors was 16.24 amps

We will need to derate to 80%, because we will have 2 strings of conductors.

So, 16.24 amps divided by .80 = 20.30 amps

We can see that we can still use a #14 wire, *right?* Read the next section on temperature derating

What about the temperature derating around the conductor? ***What about it?*** Read on!

3.5 Temperature Derate

Temperature Derating

If the ambient temperature around a conductor is above 30°C, the ampacity must be derated for such “conditions of use”. Higher temperature around the insulation will decrease its ability to dissipate the heat generated by the conductor itself, so less current is allowed to keep the internal temperature within the limits.

Table 310-16 and Table 310-17 give the factors for reductions. Some representative values from Table 310.16 are shown below that are applicable to solar and the roof environment and all of the tables variables are not represented here.

Ambient Temperature		60°C (140°F)	75°C (167°F)	90°C (194°F)
(C)	(F)	Types UF	Types RHW, THHW, THWN, XHHW, USE	Types RHW-2, THHN, THHW, THWN-2, USE-2, XHHW, XHHW-2
31-35	87-95	0.91	0.94	0.96
36-40	96-104	0.82	0.88	0.91
41-45	105-113	0.71	0.82	0.87
46-50	114-122	0.58	0.75	0.82
51-55	123-131	0.41	0.67	0.76
56-60	132-140	-	0.58	0.71
61-70	141-158	-	0.33	0.58
71-80	159-176	-	-	0.41

So, let's again go back to our example:

What would be the ambient temperature adjustment be for the #14 wire be for Hawaii if the conduit was 3" off of the roof? We need to determine a few things first. The maximum ambient temperature for Honolulu is 65°F, 18.3°C. So we would need to look at the chart below and add 22°C + the 18.3°C = 40.30°C as an ambient temperature correction. Since we are using a 90°C wire rating, we can see we will need to use a .91 adjustment factor.

In the 2008 code, it finally addresses this issue further, in 310.15(B)(2)(c) and they have created a table for the derating:

Ambient Temperature Adjustment for Conduits Exposed to sunlight On or Above Rooftops

Height Above Roof	Temperature Adjustment (rise above ambient)	
	(°C)	(°F)
0-½"	33	60
½"-3.5"	22	40
3.5"-12"	17	30
12"-36"	14	25

FPN to Table 310.15(B)(2)(c): the temperature adders in Table 310.15(B)(2)(c) are based on the results of averaging the ambient temperatures.

So, back to the example-

#14 THWN-2 = 25 amps

25 amps x .71 (derate chart for 40.30°C) = 17.75 amps.

This will be **not** acceptable, and you would need to up the wire size to #10 THWN-2.

#10 THNW-2 = 30 amps

30 amps x .71 = 21.30 amps

As we can see we need to compensate for the ambient air temperature, as the heat around the conductors in the conduit on a roof is higher than it would be in a building that is climate controlled or shaded by the sun. Please refer to the FPN in 310.10 No. 2 (2005 NEC) where it outlines that conductors in conduit exposed to direct sunlight can experience temperatures of 30°F/ 17°C above the ambient temperature on which the ampacity is based. This value is based upon elevating the conduit 3.5" to 12" above the roof surface.

3.6 Ampacity rating of the Overcurrent Device

Solar related circuitry:

If we look to 690.8(B)(1)- The circuit conductors and overcurrent devices shall be sized to carry not less than 125% of the maximum currents as calculated in 690.8(A). The rating or setting of the overcurrent devices shall be permitted in accordance with 240.4(B) and (C).

This is where we need to calculate the maximum circuit current @ the I_{sc} of the solar panel x 125%.

This is also where we would need to multiple the I_{sc} x 1.25 x 1.25 (or more simply- x 1.56).

This is most often misunderstood, as this is only applicable to solar related DC circuitry.

Again, as throughout this manual, this is only applicable to string type of inverters and not applicable to micro inverters, like Enphase Energy.

Non-solar related circuitry:

These are broken up into two segments. Most electricians are familiar with the 125% rule or .80 divisors for the standard fuse (circuit breaker) sizes. For example, the standard- 20 amp circuit breaker can handle up to 16 amps is something we have become accustomed to calculating from the beginning of our formal electrician training.

Standard Ampere Ratings in 240.6(A) and 690.9 (C) reference the standard sizes of overcurrent protection devices.

Round up to next standard fuse size: 1-15 in one amp increment, then 20, 25, 30, 35, 40, 45, 50, then 60, 70, 80, 90, 100, 110, then 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000 and 6000 amps.

In 690.9(A) exception- An overcurrent device shall not be required for circuit conductors sized in accordance with 690.8(B) and located where one of the following apply:

- a) There are no external sources such as parallel- connected source circuits, batteries, or backfed from inverters
- b) The short circuit currents from all sources do not exceed the ampacity of the conductors

As you read further on the FPN, you get a sense they encourage overcurrent protection, as the blocking diodes could possibly fail, furthering the argument of protection of the source circuits. This is also why most inverter manufacturers, like SMA, that incorporate a combination switch (AC & DC in one) , also provide fuses for up to four strings.

So, how do we match the conductor ampacity to the component?

Once a device is selected, or is specified as input protection to a component, the conductors into it must be checked for ampacity.

In 240.4 (D), Small Conductors- Unless specifically permitted in 240.4(E) or 240.4(G), the overcurrent protection shall not exceed 15 amps for #14, 20 amps for #12 and 30 amps for #10 AWG wire.

The ampacity of a conductor, reduced for conditions of use, must remain greater or equal to the overprotection device rating (otherwise the device will not protect the conductor). 240.4 (D)

3.7 Terminal Temperature Ratings and Ampacity

In the solar industry we use wires that have a higher temperature rating if they are run from the electrical infrastructure all the way to the roof. One of the overlooked aspects of the higher wire temperature ampacities, is this connection point to a terminal on a circuit breaker. These termination points are usually rated at 75°C and we generally run a 90°C wire to them. We don't want the ampacity of the wire and the respective load to overheat the terminals rating. Look at 310.16 and in conjunction with 110.14(C)(1) to cross reference for your particular application.

3.8 Sizing Conductors based on Voltage Drop

While it is the intent of this manual to give specificity on grid interactive solar systems, voltage drop does not tend to be an issue, unless it is a very unique installation environment where the inverter is further than 150 feet away from the solar array. As we also look to the manufacturers of the inverters, we also see general guides as to the recommended wire sizes to include the propensity for voltage drop. SMA, for example, has a VD calculator on their site which is useful in identifying variants in your specific situation. Also, when we are talking in general terms about voltage drop, this is geared towards the DC wiring, as it has the greatest susceptibility to voltage drop. This is another reason most electrical infrastructure around the country and world is done in AC, vs. DC.

To also understand, this is generally not applicable to the micro inverter subset of inverters, as they have AC coming off of the roof. It is essentially a 2P15 amp circuit, AC and the same design parameters you would use for AC wiring will apply.

In the NEC, Article 210.19(A) FPN No 4 states: Conductors for branch circuits as defined in Article 100, sized to prevent a voltage drop exceeding 3% at the farthest outlet of power, heating, lighting loads, or combinations of such loads, and where the maximum total voltage drop on both the feeders and branch circuits does not exceed 5%, provide reasonable efficiency of operations. See FPN No 2 of 215.2(A)(3) for voltage drop on feeder conductors.

In the photovoltaics industry, it is better to strive for more and shoot for a 1%-1.5% VD goal for DC wiring, especially since we can have swings in the current created on a DC circuit, due to edge of cloud effects and variations in temperature.

How do we determine the Voltage Drop in a DC circuit?

NEC handbook has a good guide- 215.2(A)(4)

$$VD = \frac{2 \times L \times R \times I}{1000}$$

Where:

VD- Voltage drop based upon conductor temperature of 75°C –expressed as a %

L- One way length of the circuit in feet (The voltage drop is calculated for the round-trip distance of the circuit)

R- Resistance in Ohms per 1000 feet- Chapter 9 Table 8

I- Load Current in amps, or in our example- current created- constant actual value

$$\frac{\% \text{ drop} \times V}{100} = \frac{(2 \times D)}{1000} \times I \times R$$

$$\% \text{ drop} = \frac{0.2 \times D \times I \times R}{V}$$

Wire Size AWG	DC Resistance (Ohms per 1000 feet)	AC Resistance (Ohms to neutral per 1000 feet)
14	3.14	3.1
12	1.98	2.0
10	1.24	1.2
8	0.778	0.78
6	0.491	0.49
4	0.308	0.31
2	0.194	0.20
1	0.154	0.16
1/0	0.122	0.13
2/0	0.0967	0.10
4/0	0.0608	0.067

NEC Chapter 9 Table 8 and 9, uncoated, 75°C

Example:

An array of 2 parallel X 8 series SunTech Power 175 watt modules is combined in an array junction box. The length of 10 AWG conductor run from the array to the dc disconnect is 100 feet. What is the voltage drop in the circuit?

$$\text{Circuit current (I)} = 2 \times 4.95 \text{ amps } I_{mp} = 9.9 \text{ amps}$$

$$\text{Circuit voltage (V)} = 8 \times 35.2 \text{ volts } V_{mp} = 281.6 \text{ volts}$$

$$\text{DC Resistance for 10 AWG} = 1.24 \text{ ohm/1000 ft (from the table above)}$$

$$\text{One-way distance (D)} = 100 \text{ ft}$$

$$\begin{aligned} \text{Percent voltage drop (10 AWG)} &= \frac{0.2 \times 100 \text{ ft} \times 9.9 \text{ amps} \times 1.24}{281.6 \text{ volts}} \\ &= \mathbf{1.14\%} \end{aligned}$$

3.9 Conductor Selection based on Voltage Drop

To choose a conductor size, given a distance and a desired maximum voltage drop, use the formula *in reverse* to calculate the resistance value. Choose the next lower resistance value in the table, which is the next larger conductor size.

Example:

An array of 2 parallel x 8 series SunTech 175 watt modules is combined in an array junction box. The length of conductor run from the array to the dc disconnect is 90 feet.

$$\text{Circuit current (I)} = 2 \times 4.95 \text{ amps } I_{mp} = 9.9 \text{ amps}$$

$$\text{Circuit voltage (V)} = 8 \times 35.2 \text{ volts } V_{mp} = 281.6 \text{ volts}$$

$$\text{One-way distance (D)} = 90 \text{ ft}$$

$$R = \frac{1 \times 281.6}{90 \times 9.9 \times 0.2} = 1.65 \text{ ohm/1000 ft}$$

The next lower value for dc resistance is 1.58, so use 10 AWG conductor. (Chapter 9 Table 8)

What is the Maximum Conductor Length

To determine the maximum one-way length (D) for a given conductor, use the formula in reverse again.

What is the maximum one-way distance of 10 AWG conductor for a combined circuit of 2 parallel x 8 series SunTech 175 watt modules?

$$D = \frac{1 \times 281.6}{1.58 \times 9.9 \times 0.2} = 90.25 \text{ feet one-way}$$

3.10 Parallel Strings- To fuse or to not?

Combining three array series strings in parallel requires a fused combiner, while two does not, right? Well, that is not completely accurate. All PV modules must be protected so that the maximum series fuse rating (the decal on the back of every module) is not exceeded. The word “fuse” is used, but the more applicable term would be overcurrent protection, as a fuse or a circuit breaker could be used to satisfy the requirement.

Why is this?

This is because the manufacturer has set the thresholds for its *specific* series fuse rating.

Up to two strings of SunTech Power 175 watt modules can be combined in parallel in the array junction box without the need for fuses to protect the conductors, but when three strings are combined, then a fused combiner must be used before the dc disconnect switch or utilize the fuses within the inverter in an example like the SMA type of inverters (if applicable). This is because this particular SunTech 175 watt module, as a 15 amp max fuse rating.

How can reverse current flow affect me with parallel series strings?

The concern with connecting series strings of modules in parallel has to do with reverse current flow. If a module in one string becomes damaged (eg: shorted bypass diode, shorted cell circuit) and the voltage of the string is not equal to the other parallel strings, then current from the other strings can be pushed in reverse down the damaged string. The concern is the ability of the module circuit to handle the reverse current. If the maximum current that could flow backwards is less than the rating of the module, then there is no need for protective fuses. If however the current from the other strings could exceed the limit for the module then protective fuses must be installed in each string.

Three Parallel Strings Need Fusing for SunTech 175 Watt modules- Example

So, how do we calculate the maximum number of series strings that we need before we need fusing?

A maximum of two series strings of SunTech Power 175 watt modules can be connected in parallel without needing individual fuses on each string. The possible fault current that could flow backwards through a series string from parallel strings is computed below.

Module fuse rating:	15 A	(STP-175 module)
Module Isc:	5.2 A	(STP-175 module)
Module maximum current:	Isc x 1.25	(per NEC 690.8 (A)(1))

With “X” amount of parallel strings, the number of strings that could push current backwards down a faulted string is the number of strings times X

$$\text{Possible fault current} = \# \times \text{max module current}$$

Possible fault current needs to be less than the module fuse rating (15 amps)

Example-three paralleled series strings:

$$3 \text{ strings} \times 5.2 \text{ A} \times 1.25 = 13 \text{ A} \text{ greater than } 15 \text{ A} \text{ (19.50 amps)}$$

This is not acceptable, as it is higher than the rated series fusing in parallel, and therefore we can only ***put 2 strings in series***.

By checking the specifications sheets of the panel manufacturers, you will be able to identify the parameters for fusing.

By installing more than 2 series strings in parallel, you could have a fault condition and the rating of the fusing would be exceeded.

Example-two paralleled series strings:

$$2 \text{ strings} \times 5.2 \text{ A} \times 1.25 = 13 \text{ A is less than } 15 \text{ A}$$

So, if an array of three parallel strings is to be connected to an inverter, then each string must be individually fused.

3.11 DC Disconnect

All systems must have means to disconnect all current carrying conductors of the solar power system from all other conductors per 690.13. If there are multiple inverters they must be grouped so that no more than six final disconnects or breakers must be opened to disconnect the entire solar power system from a building, 690.14 (C)(4) and 230.2 & 230.72 (6 operations of the hand).

Again, this is not applicable for the Enphase Inverters.

690.13:

No switch or breaker can be installed in the grounded conductor unless it is part of a ground fault detection system required by 690.5 and that a switch or circuit breaker is automatically opened and indicated as a normal function of the device in responding to ground faults.

FPN: The grounded conductor may have a bolted or terminal disconnecting means to allow maintenance or troubleshooting by qualified personnel.

Where is the DC disconnect supposed to be, geographically?

690.14(C)(1) Location

The photovoltaic disconnecting means shall be installed at a readily accessible location either on the outside of a building or structure or inside nearest the point of entrance of the system conductors.

The PV Disconnecting means shall not be installed in bathrooms.

These requirements generally prohibit long runs of PV source and output circuits inside a building before reaching the required PV disconnect. A short conductor run through a wall at the point of first penetration to reach a disconnect mounted inside the building is allowed. Section 690.31(E) permits these circuits to be run inside a building when installed in metal conduit from the point of entrance to the system disconnecting means.

Exception: Installations that comply with 690.31(E), shall be permitted to have the disconnecting means located remote from the point of entry of the system conductors.

1. Marking- Each photovoltaic system disconnecting means shall be permanently marked to identify it as a photovoltaic system disconnect.
2. Suitable for Use- Each photovoltaic system disconnect means shall be suitable to prevailing conditions. Equipment installed in hazardous (classified) locations shall comply with articles 500-517.
3. Maximum number of Disconnects- The photovoltaic system disconnecting means shall consist of no more than six switches or six circuit breakers mounted in a single enclosure, in a group of separate enclosures, or in or on a switchboard.
4. Grouping- The photovoltaic system disconnecting means shall be grouped with other disconnecting means for the system to comply with 690.14(C)(4). A photovoltaic disconnecting means shall not be required at the photovoltaic module or array location.

How do we make this look Companysthetically pleasing?

This topic comes up often, as we are now seeing conduit and a DC disconnect on the side of the home and we are trying to find ways to minimize the “look”. One method is to run everything in conduit in the home, or a metal raceway. This will address the code requirements and allow us to at least remedy one visual goal. The DC disconnect can also be eliminated, or incorporated into the inverter, again, minimizing the amount of equipment mounted on the side of the home.

What is the rating of the DC disconnect supposed to be for a series string inverter?

Standard or light duty disconnect switches are rated at 120 VAC and 240 VAC and are the standard ones you would see in a residential HVAC disconnect, like for a condensing unit that most electricians are familiar with. Heavy duty switches can be rated at 480 VAC and 600 VAC as well as 250 VDC and 600 VDC.

When we look to photovoltaics and series string inverters, we need to utilize a 600V rated disconnect. For example, the Square D HU361RB, would be used for a 30 amp DC rated input for a solar array. There are multiple types, based upon amperage of the load, so follow manufacturers recommendations for the type of disconnects they require, as these are generally called out in their specifications for their equipment.

One important note regarding the amperage rating- the HU361RB is rated for 15 amps @ 600VDC. So, how can we use it then on a 30 amp load?

This can be done, by installing a jumper wire on the two outside poles, in series, effectively breaking the DC load through 2 poles of the disconnect.

This was a quandary in the beginning of the solar revolution and how to effectively provide this disconnecting means, as Square D actually released, after testing through the UL to be in compliance with the ability of the switch to perform the function.

*The Square D HU361, 362 and 363 have been specifically re-rated and UL listed to allow the use of just one pole for 600 VDC operation. This means that up to three separate arrays and inverters can use the same 3-pole switch. This applies only to the Heavy Duty rated 30, 60 and 100 amp switches.

3.12 AC Disconnect

Where and why do we need to install an AC disconnect?

Each inverter needs a means of disconnecting the ac conductors between the inverter and the utility. Multiple inverters would generally be routed to a subpanel as the means of disconnect through individual circuit breakers. This disconnect and or subpanel should be located near, or within site of the inverter(s).

Do we need a utility disconnect as well as an AC disconnect?

The current climate for a utility disconnect is required although we look to the future and envision paralleling other states like California, which no longer require this for residential applications.

For commercial applications, it is still a requirement as well. The reason for this, is that you can't just "pull the meter", as most commercial meters are CT based, and will not provide a means of disconnect.

If a direct tap connection is installed between the service panel and the utility meter, this is considered another "service entrance". A fused ac disconnect switch with minimum ampacity 60 amps is required at that point.

What are the current ratings of the utility AC disconnect?

The size of the utility-required ac disconnect depends on the size and number of inverters supplying current. Use the inverter(s) maximum continuous output current times the NEC 125% safety factor to determine the single breaker that would be needed.

Example:

Three SMA 4000 inverters are installed and connected into a subpanel. (Max continuous output current = 18 amps per inverter). The combined output from the subpanel flows through a utility ac disconnect and then on to the service panel. What is the required rating of the ac disconnect switch?

$$3 \times 18 \text{ amps} \times 1.25 = 67.50 \text{ amps}$$

This would require you to install a 70 amp disconnect switch to meet this requirement.

What if we have multiple inverters?

If multiple inverters are being installed, then it is convenient to land the output of each inverter on a breaker in a subpanel and combine the ac output into just one conductor pair that will land on just one solar breaker in the main electrical service panel. You can use a subpanel with no main breaker. This disconnect and or subpanel should be located near, or within site of the inverter(s).

For example, the SMA-4000 inverter has a maximum continuous output rating of 18 amps. The breaker ampacity needed for this current level would be $18 \text{ amps} \times 1.25 = 22.50 \text{ amps}$. A 30 amp circuit breaker would be the next standard size available for each individual inverter.

Now if you have three, SMA-4000 inverters, this would be $18 \text{ amps} \times 1.25 = 22.50 \text{ amps}$.

$$22.50 \text{ amps} \times 3 \text{ inverters} = 67.50 \text{ amps.}$$

This would require 1- 100 amp rated subpanel.

Or does it?

As we look further, we need to take into consideration the size of the existing electrical service to determine if we have the correct size of the subpanel as well as the maximum size (or largest solar size) a system can be on the residence.

Let's look into this further:

If the system did have the three, SMA 4000 inverters on it, and the inverters were designed at their maximum, then we would need to recalculate. An SMA 4000, from the manufacturer's website, states it can be loaded to 5000 watts, @ 240 volts (15kW stc)

If this was a 200 amp service, with 225 amp busbar rating, then we could use the 70 amp PV breaker. This is because $225 \text{ amps} \times 1.2 (120\%) = 270 \text{ amps}$.

If this was a 200 amp service, with a 200 amp rated bus rating, then we would need to downgrade the main breaker to a 150 amp circuit breaker- $200 \text{ amps (bus)} \times 1.2 (120\%) = 170 \text{ amps}$.

We would then need to downgrade the 200 amp main circuit breaker to a 150 amp circuit breaker (next standard size). You will learn more about this in upcoming sections, but it is important to have this as a precursor for its direct correlation to the AC disconnect, as they are not mutually exclusive.

3.13 Utility Point of Connection

There are many rules and design issues that apply to the utility point of connection, usually the main electrical service panel of a residence or the meter main. This is usually where the connection takes place in some manner, either through the addition of a circuit breaker, circuit breaker panel or a tap.

The final connection to the utility is usually on the load side (customer side) of the main electrical service disconnecting means (usually the main breaker in the service panel). This allows for the solar generated power to flow into the house first and reduce the net consumption from the utility.

The final connection however may be made on the supply side (utility side) of the service disconnecting means. The power is effectively owned by the utility first, and the utility is basically just using the roof space to hold their generator. This application is generally for commercial type of applications as most residential situations don't allow for a supply side tap. On a residential application, this is not possible today, as the manufacturers have not made a way to allow us to tie into their system without voiding the warranty.

Backfed breakers

Since the solar breaker brings power into the service panel, it is considered a backfed breaker, and NEC 408.16(F) says that it should be clamped into the service panel. A new provision in the NEC 2005 takes precedence over this section of the code and allows for circuit breakers that are backfed from listed grid connected solar inverters to not be individually clamped to the busbars if a front panel cover is in place.

The traditional requirement for clamping backfed breakers arises from the fact that if they were backfeeding current from a source like a generator and if they were to come loose in their panel, they would continue to provide dangerous voltage. However grid connected solar inverters will shut off if their breaker becomes disconnected from utility ac power, so no dangerous voltage would be present, presenting a fundamentally different and less dangerous situation. 690.64(B)(5)

3.14 Size of Solar Circuit Breaker- Residential & Commercial

There is a limit on the electrical service as to the size of a photovoltaic system and how it interacts with the electrical infrastructure.

The sum of the ampere ratings of breakers supplying power to a service panel busbar shall not exceed 120% (residential) or 100% (commercial) of busbar rating (this did change in 2008 NEC to reflect the residential 120% rule). The breakers supplying power are the service panel main breaker and the solar breaker. 690.64(B)

The current rating of the solar breaker in the service panel should be the same as the rating selected for the utility ac disconnect described earlier.

$$\text{Solar Breaker (amps) + Main Breaker (amps) = 1.2 Busbar rating (amps)}$$

$$\text{Solar Breaker} = (1.2 \times \text{Busbar}) - \text{Main Breaker}$$

Residential Examples:

Example # 1

What is the largest rating of solar breaker that can be installed in a 100 residential service panel with a 100 amp main breaker with a 100 amp bus bar rating?

$$\text{Solar Breaker} = 1.2 \times 100 \text{ amp busbar} - 100 \text{ amp main breaker}$$

$$120 \text{ amps} - 100\text{amps} = 20 \text{ amps available for solar breaker}$$

Example # 2

What is the largest rating of solar breaker that can be installed in a 100 residential service panel with a 100 amp main breaker with a 125 amp bus bar rating?

$$\text{Solar Breaker} = 1.2 \times 125 \text{ amp busbar} - 100 \text{ amp main breaker}$$

$$150 \text{ amps} - 100\text{amps} = 50 \text{ amps available for solar breaker}$$

Example # 3

What is the largest rating of solar breaker that can be installed in a 200 residential service panel with a 200 amp main breaker with a 200 amp bus bar rating?

$$\text{Solar Breaker} = 1.2 \times 200 \text{ amp busbar} - 200 \text{ amp main breaker}$$

$$240 \text{ amps} - 200\text{amps} = 40 \text{ amps available for solar breaker}$$

Example # 4

What is the largest rating of solar breaker that can be installed in a 200 residential service panel with a 200 amp main breaker with a 225 amp bus bar rating?

$$\text{Solar Breaker} = 1.2 \times 225 \text{ amp busbar} - 200 \text{ amp main breaker}$$

$$270 \text{ amps} - 200\text{amps} = 70 \text{ amps available for solar breaker}$$

3.15 Options for System Integration to the Utility

What are the options for interconnection to the utility?

There are three scenarios that can be considered to allow for interconnection of a solar electric system to a residential service. These are reflected in the examples in 3.14 above.

1. Existing main breaker size allows for simple addition of solar breaker into the panel
2. Downsize main breaker to make room for addition of solar breaker
3. Replace existing service with larger size service and panel plus the main breaker

Simple Addition of a Circuit Breaker

The simplest solution is if the existing main breaker is large enough to allow for the addition of a solar breaker, to comply with the 120% rule of NEC 690.64. Even if there is no physical space for a new solar breaker, if the main is large enough then mini-breakers can be installed on existing circuits to free up enough space for a new solar breaker.

Downsize Main Breaker

If the main breaker is not large enough, then it may be possible to replace the existing main breaker with a slightly smaller main breaker that will allow for the desired solar breaker to fit. An electrician must calculate the typical load of the existing circuits to determine if a smaller main can be used. Reference the NEC 220.40 through 220.61. A smaller main breaker will allow for a large enough solar breaker, as shown in the example below.

Example of downsizing main breaker:

The existing main service panel has a 200 amp busbar and 200 amp main breaker. The maximum size solar breaker that can be installed is therefore 40 amps. (see 3.14 above)

The installer wants to install 2 x 4000 watt SMA inverters ($2 \times 18 \text{ amps} \times 1.25\% = 45 \text{ amps}$) which requires a 50 amp solar breaker. The installer replaces the 200 main breaker with a 150 amp main breaker. This allows enough room, per NEC 690.64, for the 50 amp solar breaker.

Service Panel Upgrade

If the main breaker cannot be downsized, then the installer can consider a service panel upgrade. The entire service panel is removed and replaced with a larger service and main breaker. The existing service panel may be too old and undersized for the current or future load demand as well as the ability to interconnect the solar or any additional loads as this could compromise the bus of the panel and create an overheating condition. A new service panel may not only allow for a larger main breaker and the interconnection of the desired solar system, but may result in more breaker spaces for new equipment. In Hawaii, the largest residential service available before a study has to be done on the load projections for your property is 320 amps.

3.16 AC Interconnection Quick Guide

	Maximum Inverter Current	Required Inverter OCPD Size	Minimum Conductor Size in Conduit	Minimum Busbar/Main Breaker Combinations (Busbar Amps/Main Amps)
1	64 Amps	80 Amps	4 AWG	400/400; 200/150
2	56 Amps	70 Amps	4 AWG	225/200; 250/225
3	48 Amps	60 Amps	6 AWG	300/300; 200/175
4	40 Amps	50 Amps	8 AWG	125/100; 150/125
5	32 Amps	40 Amps	8 AWG	225/225; 200/200; 150/125
6	24 Amps	30 Amps	10 AWG	150/150
7	16 Amps	20 Amps	12 AWG	100/100; 70/60
8	12 Amps	15 Amps	14 AWG	80/80

This quick guide will give the designer the combinations in a table format, to follow 690.64(B) and this is mostly to apply to a residential environment. Note- the 400 amp in row 1, is really 320 amps for rating purposes.

For example # 5- 32 amps for the max inverter current- this example provides the wide variety in determining which service configuration you could connect to, as well as the considerations for what would need to follow to do the interconnection and the possibility of downsizing the main breaker.

While a solution to downsize the main breaker could be an option, you will need to do a load calculation, to show that the load on the OCPD will not exceed 80% of its rating (NEC 220).

4 Grounding

4.1 Grounding the Solar Power System

The NEC 2005 & 2008 have extensive correlation to the proper grounding and bonding of a solar photovoltaic system as well as complimentary areas of the code, like 310 & 690

Areas in the code that are specifically applicable to solar and should be bookmarked:

- 250.21-27- The Exhibits (NEC Handbook)
- 690.41-47- specifics directly related to PV
- 690.43- equipment grounding
- 690.45- sizing of the equipment grounding conductor (ECD)
- 250.120(C)- Protected from physical damage
- 250.122 (B)- Increased ECD due to voltage drop calculations
- 250.130 (A)- ECD at the service panel (Drawing- Exhibit 250.48)
- 250.58- Grounded conductor- one point of connection
- 250.134(B) ex 2- Separation of DC conductors
- 250.126- Ground screw identification
- 250.136(A)-Effectively grounded-WEEB Clip application
- 250.118- Types of equipment grounding conductors-Conduit/MC cable
- 250.4(A)(4) –Grounded Systems- Bonding array equipments metal structure
- 250.50-60- Grounding Electrode- AC
- 250.166- Grounding Electrode- DC if grounded
- 250.169 Grounding Electrode- DC- if ungrounded
- 250.64- Grounding Electrode Conductor-Installation
- 250.97- Bonding over 250V- concentric knockouts-listed fittings
- 250.66-Size of the AC Grounding Electrode Conductor (GEC)- no smaller than a #8 copper wire
- 250.166- Size of the DC GEC
- 250-62- GEC-Material
- 250.64(B)-Installation-Securing-protection against physical damage
- 250.64(C) – Continuous- or irreversible crimp/exothermic welding
- 690.48- Continuity- removal for servicing equipment (inverter)

4.2 Grounding Terminology

Terminology- see article 250.21- 27 in the Handbook for diagrams as well as 690.41-47 on the specifics of grounding as it applies to solar photovoltaics.

- Grounded conductor – the neutral conductor in ac systems; for solar photovoltaic systems the negative dc conductor
- Equipment grounding conductor – the green or bare copper conductor linking exposed non-current-carrying metal parts of module frames, equipment and enclosures
- Grounding electrode conductor – the bare copper conductor connecting the system grounding bus to ground rod or earth
- Grounding electrode – the rod or other buried electrode in the earth
- Grounding electrode system – several grounding electrodes effectively bonded together

Always ground exposed metal parts (“equipment grounding”)

Exposed non-current-carrying metal parts of module frames, equipment and enclosures shall always be grounded, regardless of system voltage. 690.43

4.3 Sizing of the Equipment Grounding Conductor

The equipment grounding conductor is outlined extensively in 690.45. If the system is protected by a ground fault device (typical for grid connected inverters), size the equipment grounding conductor according to NEC 250.122. Typically this will mean size to the downstream overcurrent protection device. For the array this may be an input breaker to the inverter, which are now standard on most inverters. The grounding conductor does not have to be larger than the circuit conductors supplying the equipment. 690.45 and 250.122(A) if the system is not protected by a ground fault device, then the equipment grounding conductor should be sized to 125% of I_{sc} . - 690.45

While the code outlines that it can be permissible, based on the configuration and characteristics of a specific solar panel, that you could use a #14AWG-#10 AWG to ground the frames of the solar panels, protecting this wire from physical damage could be challenging. This generally occurs when you are transitioning from a roof area to another array, for example.

The application of this would generally be more applicable in a commercial environment, where panels are tilted up and there are spaces between the arrays for walking and servicing. In these types of instances, it is best to install the wiring in conduit. NEC 250-120 (C) addresses this in detail.

This same code section is applicable to the general environment electricians find themselves with installing a new residential electrical service. Even though a smaller gauge ground wire can be adequate, the cost to “protect from physical damage” clause in the code, can exceed the actual cost of running the next larger size wire.

If undergrounded conductors are increased in size to reduce voltage drop, then the equipment grounding conductor must be proportionally increased in size. Use the ratio of circular mils of the original and increased size conductors to ratio up the circular mils size of the grounding conductor. Use NEC Table 8 Conductor Properties to find sizes in circular mils. 250.122(B)

4.4 Methods of Equipment Grounding

Equipment grounding conductor connections at the source of separately derived systems shall be made in accordance with 250.30(A)(a). Equipment grounding conductor connections at the service equipment shall be made as indicated in 250.130(A)

For grounded systems- The connection shall be made by bonding the equipment grounding conductor to the grounded service conductor and the grounding electrode conductor. (see 250.48 for an illustration in the NEC 2005 Handbook).

So how does this apply to solar? Well, when we combine all of the grounding, it has to occur at the main electrical service where the grounded service conductor and the GEC meet. There should also be a main bonding jumper in place that ties together the equipment grounding conductor and bond it to the enclosure.

If separate grounding electrodes are used, they must be bonded together with jumper wire to create effectively one ground. 250.58

4.5 Separate Grounding Conductor from DC circuit Conductors

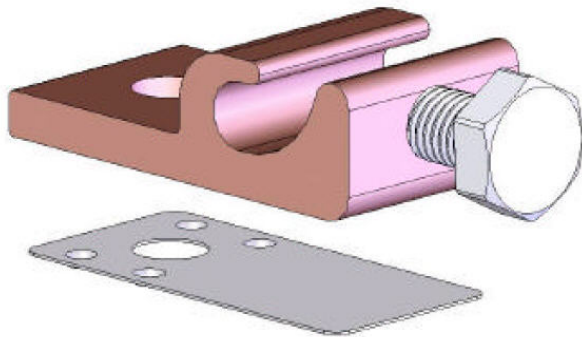
DC circuit equipment grounding conductors can be run separately from the dc circuit conductors.

In some cases, it may be necessary or desirable to run the grounding conductor in a separate path from the actual dc conductors. 250.134(B) Exception No 2.

The size of the equipment bonding jumper shall not be smaller than the system grounding electrode conductor specified in 250.166

4.6 Module Frame Grounding

This is a much debated topic as it has many implications to our industry. With the advent of the WEEB clip, by Wiley Electronics (pictured below), we can remedy a lot of the discussions around proper grounding of the panels and associated racking that supports them. This is the industry standard and should only be used.



The previous realm of installations revolved around just bolting things together- pieces of metal and this was the generally accepted practice. As further research and study evolved, the industry started to look at this more in depth and determined it was not sufficient as the frames of the solar panels and racking need to be “pierced” to ensure the module frame is effectively grounded. This piercing, breaches the physical metals of the aluminum frames of modules and the anodization of the racking to ensure a low resistance to ground. While it is unclear what the long term effects of grounding will be in Hawaii and our marine environment, this methodology will at least begin the process of improving the methodology of grounding of the solar arrays.

Solar module grounding “clips” or special “washers” have been developed that have several small sharp edges or “teeth” that cut through the anodization and make a gas-tight connection. If this method of grounding has achieved UL listing and is approved by the module manufacturer, then it can be an alternative for connecting equipment grounding conductors frame-to-frame.

4.7 Ground Fault Protection

Roof mounted arrays located on dwellings must have ground fault protection (GFP), or ground fault detection and interruption (GFDI). Currently all grid interactive inverters that are UL listed come equipped with GFDI protection to safeguard from a ground fault current greater than one amp. This is a standard from IEEE that is complied with by the inverter manufacturers.

4.8 Conduit as an Equipment Grounding Conductor

Conduit is allowed as an equipment grounding conductor, however, through research we have found it to be better to pull a ground and not solely rely on the conduit. This especially holds true on long conduit runs on the roof of a building where thermal expansion takes place. In the event of a ground fault, combined with a large swing in thermal expansion, the ability of a conduit to come loose could potentially remove the ground path.

UL listed flexible metal conduit that is not explicitly listed for grounding can be used as equipment grounding conductor under these conditions:

- Termination fittings are listed for grounding
- Circuit protection \leq 20 amp
- Combined length of all flexible conduits \leq 6 feet

MC cable can be used where listed and identified for grounding. 250.118

When installing solar modules on metal structures, such as a metallic trellis or metal standing seam roofing, the equipment grounding conductor used to ground the solar module frames should be extended or branched to include a connection to the metal structure. The conductor should be sized to handle the expected fault current from the array, per NEC 690.45. This will establish an effective ground-fault current path for the structure. 250.4(A)(4)

Grounding electrode “system” (general methods)

- For AC systems, follow NEC 250.50-60
- For DC systems, follow NEC 250.166 if grounded (250.169 if ungrounded)
- Install the grounding electrode conductor always per NEC 250.64

4.9 Ground Bonding at Concentric Knockouts

The use of bonding methods typically reserved for services is required for all circuits above 250 volts to ground NEC 250.97. This generally applies to all our DC conductors since the maximum voltage of our systems typically exceeds 250 VDC in string type of inverter environments. The DC aspect is not applicable when implementing a micro inverter, like the Enphase Energy type of inverter technology.

Threaded connectors and locknuts will generally meet these requirements. However if concentric knockouts are encountered (such as in DC disconnects and other enclosures), conduit or cable connectors must use an additional bonding jumper means such as a bonding bushing with an integral lug and jumper wire. This method will provide a continuous grounding path from the conduit to the grounding system without relying on the small tabs within the concentric knockout which could be weak and fail. 250.97

4.10 Dual Grounding Electrode Conductors

The grounding electrode conductor (GEC) is the conductor that actually makes the connection from the grounded (current carrying) conductor to the grounding electrode.

In typical grid connected solar electric power systems, there are two systems to be grounded—the AC system and the DC system.

The DC system is all the DC conductors and circuitry up to the transformer in the inverter.

The AC system is all the AC conductors past the transformer, exiting the inverter, passing through any ac disconnects and ending at the solar breaker in the service panel.

The point of DC system grounding typically is in the GFP device, as this is where the grounded conductor is connected to the earth (through the GFP fuse). This GFP device is typically inside the grid connected inverter enclosure.

So, how to we achieve this?

In 690.47 (C), it outlines the two ways in which the AC & DC grounding requirements are designed to function.

1. A GEC connects the identified DC system grounding point to a separate grounding electrode. This DC grounding electrode shall be bonded to the AC system grounding electrode to make a grounding electrode system according to 250.52 and 250.53. the bonding conductor shall be no smaller than the largest grounding electrode conductor either ac or dc.
2. The DC and AC GECs connect to a single grounding electrode. The separate grounding electrode conductors shall be sized as required by 250.66 (ac) and 250.166 (dc)

4.11 Sizing of Grounding Electrode Conductor

AC system: No smaller than 8 AWG copper, and proportionally larger if conductors larger than 2 AWG are used (per NEC table 250.66); that portion solely connected to the grounding electrode shall be no larger than 6 AWG copper (if electrode is rod, pipe, or plate); no larger than 4 AWG copper (if electrode is concrete encased). In grid connected systems, the ac grounding occurs at the meter main/ main electric panel. This is usually already in place, and we simply make use of the existing grounding electrode conductor to the existing ground rod, per 250.166 (ac)

DC system: No smaller than the largest conductor supplied by the system, and no smaller than 8 AWG copper. That portion solely connected to the grounding electrode shall be no larger than 6 AWG copper (if electrode is rod, pipe, or plate); no larger than 4 AWG copper (if electrode is concrete encased). 250.166 (dc)

4.12 Protection from Physical Damage

A grounding electrode conductor of size 4 AWG or larger does not need protection unless exposed to physical damage.

A GEC of size 6 AWG that is free from exposure to damage shall be permitted to run along a building surface where it is securely fastened to the surface; otherwise it shall be in RMC, IMC, rigid non-metallic conduit, EMT, or cable armor.

GEC of size 8 AWG or smaller shall be in RMC, IMC, rigid non-metallic conduit, EMT, or cable armor. 250.64(B)

4.13 Continuous GEC

GEC shall be installed in one continuous length without a splice or joint, unless the splice is made by irreversible compression-type connectors listed as grounding and bonding equipment. 250.64(C). This section is often misconstrued and a lot of installations end up using a split bolt or other mechanical means of connection, but fail to use irreversible compression-type connectors. This is perhaps in part to “thinking” like it is AC wiring, when in DC wiring, we need to use an irreversible connection.

4.14 Routing of the DC- GEC and Bonding for Multiple Inverters

If multiple inverters are installed, it may be possible to run a properly sized GEC from the first inverter to the grounding electrode (either the main ac electrode or a separate dc electrode) and then have each inverter tap into that GEC through an irreversible splice. The GECs must be sized and protected as described previously.

The example would be, you installed two inverters, and have a gutter underneath for wiring purposes. The DC GEC from the roof would pass through the gutter and irreversible spliced and tapped to a ground bar and then run to the grounding electrode.

4.15 Continuity of Equipment Grounding Electrode-690.48

If equipment is removed that interrupts the bonding between the equipment grounding conductor and exposed metal surfaces in the pv source or output circuit, then a bonding jumper shall be installed while the equipment is removed.

For example, if an inverter is *removed* (for service) and the module frame grounding conductor had landed on a jumper or busbar in the inverter, and therefore the continuity of the equipment grounding is now broken, a jumper shall be installed to reconnect the module frame grounding while the inverter is removed. This also means that if a module frame is integral to the array equipment grounding, as it is with the smart mount system, then a module can be removed for service but a bonding jumper must be installed to maintain continuity for the array. 690.48

5 Wiring Best Practices

What are wiring best practices? Well, Wikipedia describes it like this:

“Best practice asserts that there is a technique, method, process, activity, incentive or reward that is more effective at delivering a particular outcome than any other technique, method, process, etc. The idea is that with proper processes, checks, and testing, a desired outcome can be delivered with fewer problems and unforeseen complications. Best practices can also be defined as the most efficient (least amount of effort) and effective (best results) way of accomplishing a task, based on repeatable procedures that have proven themselves over time for large numbers of people.”

So, why do we need them in our solar field?

Well, how do we maintain standards in our wiring methodologies so that everyone who approaches a task, such as wire sizing, does it consistent within an organization? A well documented methodology assists our industry to improve the way in which we function daily in the design and installation of solar photovoltaic systems. This section outlines areas around methods and the NEC that are used frequently. See section 8 for more details.

5.1 Conductors for Outdoor Use

The best conductor insulation combination for exposed outdoor installations (not in conduit) is USE-2 / RHW-2 / XLP. You will see this often on solar array wiring as well as on overhead service entrance conductors from the utility.

USE has sunlight resistance; the “-2” rating raises the temperature rating to 90°C, needed for array wiring on hot roofs; RHW has flame retardant; and XLP means “cross linked polyethylene”. NEC 310.13 has definitions of wire types.

The best choices for outdoor use while in conduit are RHW-2, THWN-2, or XHHW-2. These all have -2 rating for high temperature and are resistant to moisture. We like to use THWN-2 in our conduits up to the roof for their high temperature rating characteristics and similar traits to their THHN cousins.

5.2 Design for the Full Rated Output of the Inverter

You might decide to design a solar system and read the literature from the manufacturer and design for less than the full rated output of the inverter. While this will address a short term solution, this can create a long term problem. Conductors should be sized based on 125% x full rated continuous output of a device or based on the size of the overcurrent protection device installed. We must design around the potential of the full rated output of the inverter, per 690.10(B) and protected from overcurrents in accordance with article 240.

For example, if a SMA 4000 watt rated inverter is connected to 10- 175 watt solar modules, the 1750 watt solar array, all conductors from the inverter should be sized based on it operating at its full rated 4000 watt output and not just at the level of the 1750 watt array initially installed.

5.3 DC & AC Circuitry in Same Enclosure

Can we install DC & AC circuits in the same enclosure? Yes, per Article 300.3(C)(1)- but we need to ensure that the insulation rating is the same or greater than the maximum voltage of any circuit. Normally this is not a problem, as most electricians use 600 volt rated wiring, but care should be taken when leaving the supplier or the shop, as to being prepared with the correct wire.

5.4 Combiner Box

String Combiner at the Array

One solution would be to use a fused string combiner box mounted near the array, either on the roof or under a nearby eave. Each array series string circuit lands separately on a 600 VDC rated fuse. The combined output is connected to a large gauge conductor pair that passes all the way to the DC disconnect and inverter location. Another option would be to limit the size of the arrays and spread the power across an additional inverter for a host of reasons.

This is based on 2005 NEC 310.10 FPN No.2 advising that the interior temperature of conduit exposed to the sun can be approximately 17°C greater than the outside ambient temperature.

String Combiner at the Inverter

Another approach would have the combiner mounted near the disconnect switch and inverter. Mounting the combiner at the inverter location might be more convenient for field testing of the strings and fuse replacement, but each string of modules would have to be run all the way down from the array to the combiner. A conduit running from an array to a single inverter would contain eight current-carrying conductors (one pair for each series string) plus an equipment grounding conductor. This would have to be calculated to ensure compliance with the # of conductors in the conduit, per the NEC 310.15(B)(2).

5.5 Conduit Sizing

The size of conduit to use depends on the type of conduit material as well as the number and size of conductors.

Maximum percent of conduit area available for conductors

NEC Chapter 9 Table 1 gives the percent of conduit area available for conductors. All conductors, including grounding conductors, must be counted. (Note that this is different from the conduit fill derating factor for reducing ampacity, where grounding conductors were not counted). These availability factors are used in all NEC tables for number of conductors in conduit.

Number of conductors in conduit	Percent of cross-section available
1	53%
2	31%
3 or more	40%

Conduit selection when conductors are *identical*:

The NEC Annex C Table C1-C12 gives the maximum number of conductors for twelve types of conduit when all conductors are the same size and type.

Example:

Four pairs of 8 AWG THWN-2 conductors, plus the same size equipment grounding conductor, are to be pulled in EMT conduit from an array to a combiner box. What size conduit is needed?

4 pairs x 2 conductors/pair + 1 grounding conductor = 9 conductors

Reading in the NEC Annex C, find Table C1 for EMT, find the section for THWN-2 conductor, and read across from size 8 AWG. Trade size 1 (1") can accommodate a maximum of nine conductors.

Conduit selection when conductors are ***different***:

NEC Chapter 9 Table 4 gives conduit area values, and Table 5 gives conductor area values. Use these tables when different size conductors are being installed.

First add up the total conductor area using Table 5, and then find the conduit that can accommodate that area in Table 4.

Example:

Four XHHW conductors, size 6 AWG, and one equipment grounding conductor, 8 AWG XHHW, along with four 10 AWG THHN conductors, must be pulled in flexible metal conduit (FMT). What size conduit should be used?

Use table 5 to determine the area of the conductors:

6 AWG XHHW conductor area	0.0590 in ²
8 AWG XHHW conductor area	0.0437 in ²
10 AWG THHN conductor area	0.0211 in ²

$$4 \times 0.0590 + 1 \times 0.0437 + 4 \times 0.0211 = 0.3641 \text{ in}^2 \text{ total conductor area}$$

Then use table 4 to determine the conduit that can accommodate that area. In table 4 for FMT, find the "Over 2 Wires" column, read down to find an area equal to or greater than the required 0.3641 in². Trade size 1 (1") is not quite large enough at 0.327 in², so the next

larger size, Trade size 1 ¼ (1 ¼”), must be used.

5.6 Equipment Clearances

Equipment clearance requirements

The working area in front of (depth) and around electrical equipment must be clear of obstructions as described below.

Depth of working area as defined in Article 110.26 (A)(1)

Nominal voltage to Ground	Minimum Clear Distance (Feet)		
	Condition 1	Condition 2	Condition 3
0-150 volts	3	3	3
151-600 volts	3	3.3	4

Condition 1- Exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides effectively guarded by insulating material. Insulated wire or insulated busbars operating at not over 300 volts are not considered live parts.

Condition 2- Exposed live parts on one side and grounded parts on the other side, concrete, brick or tile walls shall be considered as grounded.

Condition 3- Exposed live parts on both sides of the workspace (not guarded as provided in Condition 1) with the operator between.

The exception: 110.26(A)(1)(b) allows by special permission of the AHJ smaller working space of the voltage is less than 60 VDC.

Width of the working area:

Minimum width shall be at least 30 inches, or the width of the equipment if wider. The equipment does not need to be centered in the 30 inch allowance.

Height of the working area:

Minimum headroom shall be 6.5 feet (2.0 meters) or the height of the equipment if higher. [110.26(A) (3)]

Keeping clear:

Working space shall not be used for storage (kept clear at all times). [110.26 (B)]

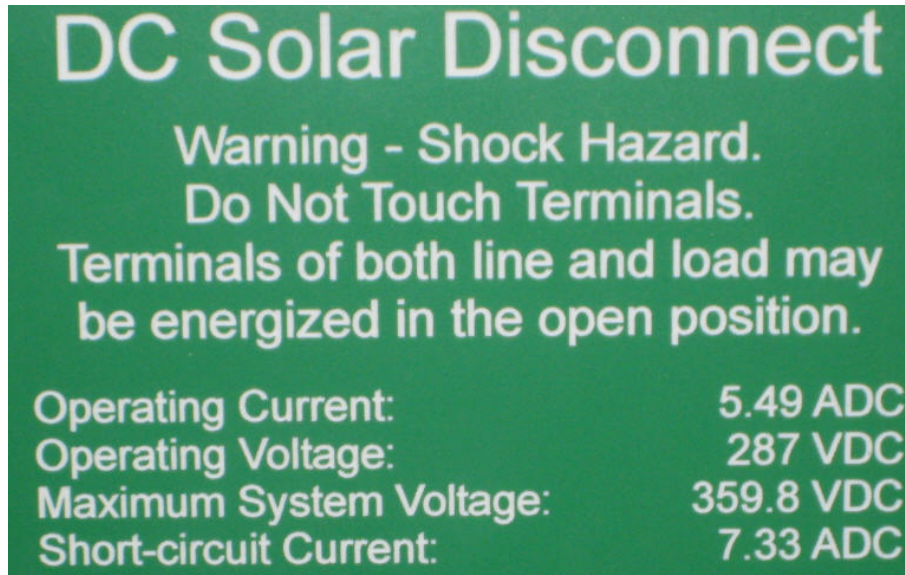
5.7 Labeling of Enclosures and Equipment

We have all come across a site where we have entered an electrical panel that has things either not labeled or mislabeled. In our industry, when we are mixing a host of AC & DC wiring as well as the propensity of high voltage and low voltage, labeling is a priority. NEC 690.14(C)2, 690.17, 690.53, 690.56(B).

The other areas that should be labeled- junction boxes, gutters and it is also desirable to label the wiring within an enclosure before the wire is terminated, using a label maker. This will assist your company in the future in the service and maintenance of the equipment and potentially expedite the troubleshooting process for your service team.

If we are working with series string inverters, we should look at labeling the DC disconnect, as outlined in 690.14(C)(2), 690.17 & 690.53. This label gives an overview of the system and a good indication of the parameters in which it was designed.

Here is an *example* below:



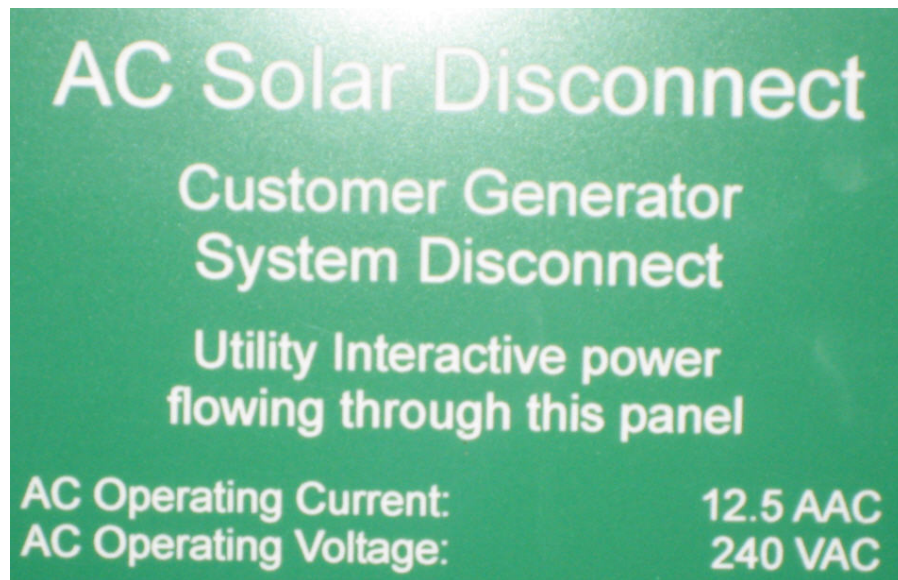
This is the information derived from the panel manufacturer specs for the panels and inverter for the operating characteristics of the system.

690.53:

1. Operating Current - I_{mp} of the array
2. Operating Voltage- V_{mp} of the array
3. Maximum system Voltage- V_{oc} of the array- Temp adjusted-lowest per 690.7
4. Short-Circuit Current- I_{sc} of the array

AC Disconnect – 690.14(C)(2) & 690.54

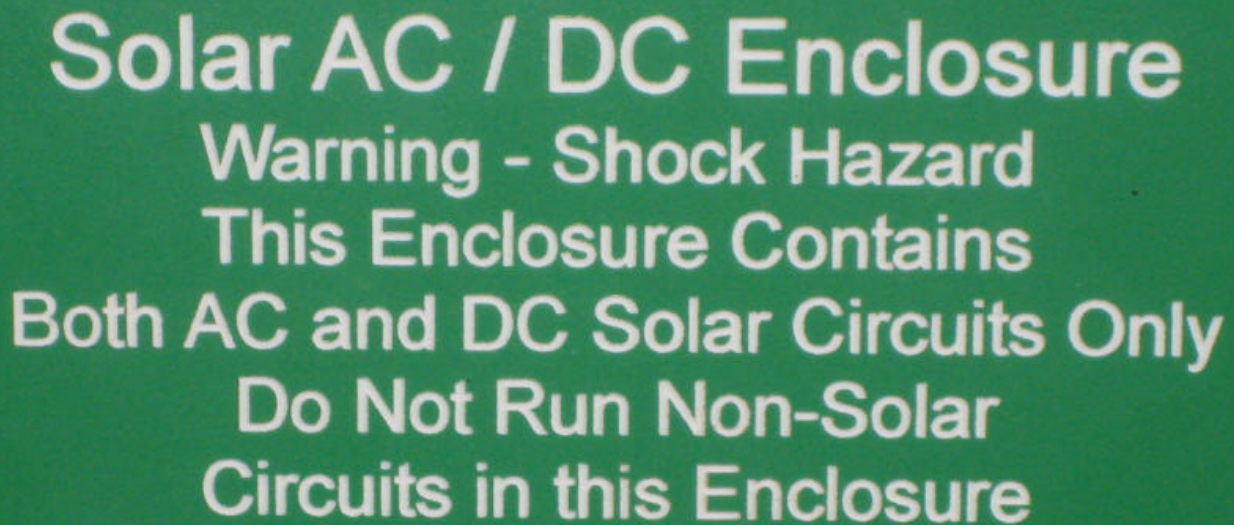
Here is an *example* below:



This is important, as it isolates the solar from any other sources of power on a property and clearly delineates what the intent is for. This label addresses two sections of the code simultaneously.

Subpanel & Enclosure labeling

Often when multiple inverters are going to be utilized on a project, an ac subpanel is installed to group the inverters outputs. This is also due to 690.64 in regards to the maximum amount of power, for example a 200 amp electrical service can accommodate- 40 amps. When we breach this or come close, we need to install a subpanel to address this issue. This is also why it is important to have this panel labeled and used exclusively for the solar inverters outputs only.



Solar AC / DC Enclosure
Warning - Shock Hazard
This Enclosure Contains
Both AC and DC Solar Circuits Only
Do Not Run Non-Solar
Circuits in this Enclosure

5.8 Micro Inverters

The recent introduction of the micro inverter, made by Enphase Energy will clearly spawn innovation and other advancements in system performance, monitoring and control.

Most of this manual is dedicated to string inverters, as these are currently the majority of offerings out in the community today. However, we believe we need to devote some best practices discussions to this product as its impact will be felt in many meaningful ways.

The premise that DC wiring will stop on the roof is encouraging from a DC design perspective, eliminating a lot of re-education for electrical designers and electricians. The plug and play nature of these “appliances” will further the adoption of them by companies and end users due to their simplicity and monitoring features, which will enable accountability from the panel manufacturers to the folks that do site feasibility studies and installations.

Some basic best practices:

1. Following manufacturers guidelines for the quantity of inverters on an AC circuit- in the future these will be not just 120/240 120/208, but 277/480.
2. Following the manufacturer’s guidelines for the panel selection, and match the inverter to the panel.
3. Following strict criteria outlined in this manual, in regards to the AC interconnection- most notably- 690.64(B) as the overloading of a service panel could occur.

5.9 Roof Penetrations

While wiring best practices and roof penetrations don’t seem to fit, they do have a corollary. When we are running conduit to the roof, most of the time we need to penetrate somewhere and ensure a weatherproof seal. This does not stop at the flashing, but also using the appropriate sealant to complement the penetration as well.

This is accomplished in multiple ways. We can use a lead flashing that is specifically designed for the diameter of the conduit we are running. We can also utilize a manufactured solution, like an Oatey roof flashing.

Each specific site condition will dictate the type of flashing necessary, which means different types of roof products require a different solution. A commercial roof will require a completely different methodology vs. a Spanish tile roof vs. a 3 tab shingle application.

Not to dismiss the electrical only aspect of this, we also need to be reminded of the larger quantity of penetrations- the racking/stanchion. A small leak can lead to property damage and a broken relationship.

6 System Output Projections

6.1 Determining the Harvest

How much will a system make in kWh's?

This is a very important consideration, as sizing a system that is too large for a customer, might not be beneficial for a host of reasons.

Typically there are three approaches to system sizing:

- Based on the load demand: begin with the percent of the customer's typical electrical demand that is to be reduced and arrive at an array size
- Based on the roof area or budget: begin with the maximum array size that will fit on the available roof surface, or the maximum size within their budget and arrive at an array size
- Build a system over multiple years using multiple inverters. This approach looks at maximizing government incentives.

The output estimation is made, as described in the early section of this manual, and we use annualized averages to calculate the total harvest.

The output from a system will rise and fall daily with the sun. Every area in the country has a certain amount of "Sun-Days". This is represented in peak sun hours per day.

The amount of energy harvested from a system will not be the STC rating of their array, as it is the DC to AC output is very different. The array STC power reflects dc power from a room temperature module under full sun for the industry to measure up against a standard test condition in a lab environment.

Actual system output power will reflect losses due to heating, dust, equipment efficiency and actual weather. Some typical sources of output derating are listed in the table below, with rough high and low estimates to the value of the derating. Overall, this is a widely accepted practice of "over derating", and enjoying the benefits of over production when the conditions are desirable. The information used below has historical basis through NOAA and used in the calculations of the PV Watts program.

6.2 Derating

How to we come up with the .77 from DC to AC to determine output?

PVWatts design program has default values built into their program.

System Output Derating Factors (per PVWatts)

	Derating Multiplier		
	Typical value	Low value	High value
Manufacturer nameplate variance	0.95	0.8	1.05
Module current mismatch	0.98	0.97	0.995
DC wiring	0.98	0.97	0.99
AC wiring	0.99	0.98	0.993
Dirt and dust on module	0.95	0.3	0.995
Inverter efficiency	0.92	0.88	0.96
Diodes and connections	0.995	0.99	0.995
System Availability	0.98	0	0.995
Shading	1	0.75	1
Ageing	1	0.7	1

The factors above are used by the online sizing program PVWatts to calculate system energy output over time. The product of all the typical values above is 0.77, the default derating factor used by the program. The top seven factors can be used to estimate instantaneous power at noon, while the bottom three factors are more involved in estimating energy output over time.

Each factor is briefly explained below.

Manufacturer nameplate variance	The variation that can occur from the “nominal” or nameplate power value of the module. Typical manufacturer allowance is +/- 5%, so modules may be installed from the -5% end of the allowed range.
Module current mismatch	All modules do not produce the exact same current, even if their output power rating is the same. Modules connected in series will be limited to the current output of the lowest module. A variation of 1-2% is common.
DC wiring	Power loss due to voltage drop and connections may be 1-3%.
AC wiring	Similar power losses in the ac wiring.
Dirt and dust on module	Soiling on the module glass will decrease the amount of sunlight getting through to the solar cells. Seasonal rains will clean off the modules but dust can build up, reducing output significantly.
Inverter efficiency	Conversion efficiency from input dc power to output ac power. Most good grid connected inverters today can operate at around 92-94% efficiency.
Diodes and connections	This small factor can arise when blocking diodes are used to prevent backflow from parallel strings. There is a small voltage drop across the blocking diodes in this case.
System Availability	This factor estimates the potential loss of energy due to the

	<p>entire system being off-line, perhaps due to utility outages or to equipment failures during the year. A factor of 0.98 means that 98% of the time the system was available, or 2% of the time the system was “down”. $0.98 \times 365 \text{ days} = 358 \text{ days available};$</p> <p>$0.02 \times 365 \text{ days} = 7 \text{ days off-line.}$</p>
Shading	This is the estimate of energy loss due to horizon shading by nearby objects or the distant horizon.
Ageing	Loss of output power due to weathering of the modules. This may be approximately 0.5-1% per year.

An estimate of the effect of heat on array output must be made. At full 1000 W/m^2 irradiation a module will heat up about 30°C above the ambient. If we estimate that more typical average peak irradiation will average around 850 W/m^2 then the heating difference will be more like 25°C . If we estimate an average daytime temperature of 30°C , then the estimated average peak temperature of a module will be $25^\circ\text{C} + 30^\circ\text{C} = 55^\circ\text{C}$. This is 30°C above its rating temperature of 25°C . Using the module temperature coefficient of power of $-0.38\%/^\circ\text{C}$, we estimate a power loss of $30^\circ\text{C} \times -0.38\%/^\circ\text{C} = 11.4\%$, which translates into a derating factor of $100 - 11.4 = 88.6\%$ or 0.886 .

6.3 Azimuth and tilt angle

The greatest energy is typically produced when an array is facing true south. There may be exceptions due to local microclimate conditions, such as morning fog in parts of California that might dictate an afternoon-facing or west-facing orientation. Also peak annual energy is typically produced when the array is tilted to the latitude angle. There may be reasons for deviating from this rule, for example having an array with a low tilt angle to produce the most energy in the summer months when it might be needed most to offset air conditioning loads. In Hawaii we are blessed with average daily and annual uniformity in regards to system performance which is much more predictable to estimate performance. When you look at the decrease in cost of solar modules, this argument is going to get harder to make, as making an adjustment for a 3:12 tilt, for example, is not going to be worth the added racking and labor costs.

Solar arrays are typically installed flush to an existing roof surface to give the highest Company aesthetic appeal, so a true-south azimuth is not always possible, and the tilt angle is the roof slope. It is not recommended to tilt modules on a tilted roof surface to try to achieve a better azimuth or tilt angle. The resulting look of the array is very unpleasant. An exception might be a flat roof where modules on tilted racks will not be too visible. In this instance, it might be just as desirable to go with a subtle 10 degree tilt, and increase the surface area of the potential energy harvest.

Adjustment to energy output due to azimuth and tilt angle cannot be easily calculated by hand from formulas, as the underlying math involves complex geometric formulas in 3-dimensions. Calculations have been made using computer models and summarized in the table below, averaging values from several cities across the US. The adjustment values are for annual energy production.

Orientation Adjustment Values

Pitch (tilt angle)	270° (west)	255°	240°	225°	210°	195°	180° (south)	165°	150°	135°	120°	105°	90° (east)
Flat (0°)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
4:12 (15°)	0.87	0.90	0.92	0.94	0.96	0.97	0.97	0.96	0.94	0.92	0.90	0.87	0.84
7:12 (30°)	0.83	0.88	0.92	0.96	0.99	1.00	1.00	0.98	0.96	0.92	0.88	0.84	0.78
12:12 (45°)	0.77	0.83	0.88	0.93	0.96	0.98	0.98	0.96	0.93	0.88	0.83	0.77	0.70
21:12 (60°)	0.68	0.75	0.81	0.86	0.89	0.90	0.91	0.88	0.85	0.80	0.75	0.69	0.62
45:12 (75°)	0.59	0.65	0.71	0.75	0.77	0.78	0.78	0.76	0.74	0.70	0.65	0.59	0.53
Vertical (90°)	0.49	0.54	0.59	0.61	0.62	0.62	0.61	0.60	0.59	0.57	0.54	0.49	0.44

The azimuth and tilt angle are entered into PVWatts as separate input factors, and the heating effect is calculated by the program. We make them explicit here to allow for estimation by hand.

Other derating factors that affect output

	Typical value	Derating Multiplier	
		Low value	High value
Azimuth and tilt angle (roof pitch)	1	0.83	1
Heating of module	0.886	0.83	0.92

Putting together the top factors used by PVWatts (except for inverter efficiency) and the estimate for heating factor, we get a combined derating factor of peak power of approximately 0.75.

Combined Peak Power Derating Factor = (Manufacturer nameplate variance) X (Module current mismatch) X (DC wiring) X (AC wiring) X (Dirt and dust on module) X (Diodes and connections) X (Heating of module)

$$= 0.75$$

Computer Based Output Estimation Using PVWatts

To dig deeper into the calculation to truly understand “why”, it is good to review the steps below to familiarize yourself with the process. Again, for the sake of brevity, and due to our relatively consistent solar environment, we can assume a lot more consistent outputs, compared to other areas of the country.

PVWatts v.1 uses hourly weather data from the 239-station TMY2 (Typical Meteorological Year) database (<http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/>) and a PV performance model based on Sandia National Laboratories’ PVFORM to estimate monthly and annual ac energy production (kWh) and cost savings for a crystalline silicon PV systems. PVWatts v.2 provides the same output as PVWatts v1, but incorporates the use of the NREL 40km resolution solar resource data to permit site-specific calculations down to specific zip codes.

Users have the option to change the following system parameters:

- Array STC dc power
- Dc-to-ac derating factor (default value is 0.77)
- Type of array mounting (fixed or sun-position tracking)
- Array tilt angle
- Array azimuth angle
- Local electric rate

Using the TMY2 weather data for the location selected, PVWatts calculates the solar radiation incident on the array and the cell temperature for each hour of the year. The dc energy for each hour is calculated from the PV system dc rating and the incident solar radiation, and then corrected for the cell temperature. The ac energy for each hour is calculated by multiplying the dc energy by the overall dc-ac derating factor and adjusting for inverter efficiency as a function

of load. Hourly values of ac energy are then summed to calculate monthly and annual ac energy production.

6.4 Site Evaluation Parameters

During the site evaluation, note any access issues that might affect the installation time, additional requirements for the crew and safety. Consider such factors as:

- Number of stories- how will they access the roof?
- Safety- determine what equipment will be needed to comply with OSHA standards regarding fall protection
- Length and number of ladders that will be needed- do you need a 24 foot extension ladder?
- Will you need a man lift?
- Is there pedestrian traffic you need to plan for?
- Condition of ground around roof for placement of ladders and equipment (gravel, shrubs, sloping ground)
- Access to attic space for verification of mounting hardware to the roof truss'
- Site access- are there times you can't gain access? Gated community? Locked electrical room?
- Pets- will we need to leash the Doberman?
- Parking- is there ample parking for the install team?
- Is the installation in a gated community that has CCR's and rules for installations look and appearance? Do they need approval prior to commencing work?
- Does a store manager need to allow you access?

There is a lot of pre-planning that goes into the site access that can greatly impact the successful outcome of the project, that should be a priority from day 1.

This step should not be under emphasized, as a poorly planned site evaluation will cause a ripple in the design and installation.

6.5 Roof Pitch Angle

The steepness or pitch of the roof will affect the ease and safety of working on the roof and should be noted on the initial evaluation. It will also influence computing expected system output of energy. It is also important to consider the safety and pre planning of the installation in terms man hours for a particular project. If you are doing an installation on a property that has a roof like a church, being prepared with a man lift or scaffolding is desirable or other arrangements will need to be made, such as having additional manpower on the site to assist with the installation.

Roof pitch is usually indicated by a “rise-over-run” ratio such as “4:12”, where there is a vertical rise of 4” over a horizontal run length of 12”. The equivalence between roof pitch and tilt angle is given below. Most residential roofs in Hawaii are between 0°-23°.

Roof Pitch	Equivalent Tilt Angle
Flat	0°
2:12	10°
3:12	14°
4:12	19°
5:12	23°
6:12	27°
7:12	30°
8:12	34°
9:12	37°

10:12	40°
11:12	43°
12:12	45°

1. The roof azimuth (east-west orientation)

The east-west orientation, or azimuth angle, must be noted for all roof surfaces where the solar array could be mounted. The azimuth angle will have an influence over the effect on the energy output from the system.

The optimum azimuth is due south in Hawaii. However an array mounted on a purely east or west facing roof surface produces approximately 85% of (south) orientation, so selecting non-south facing roof surfaces is quite acceptable. The sun does go north, for about 2 weeks in the summer time, but again, we are looking for average annualized harvested.

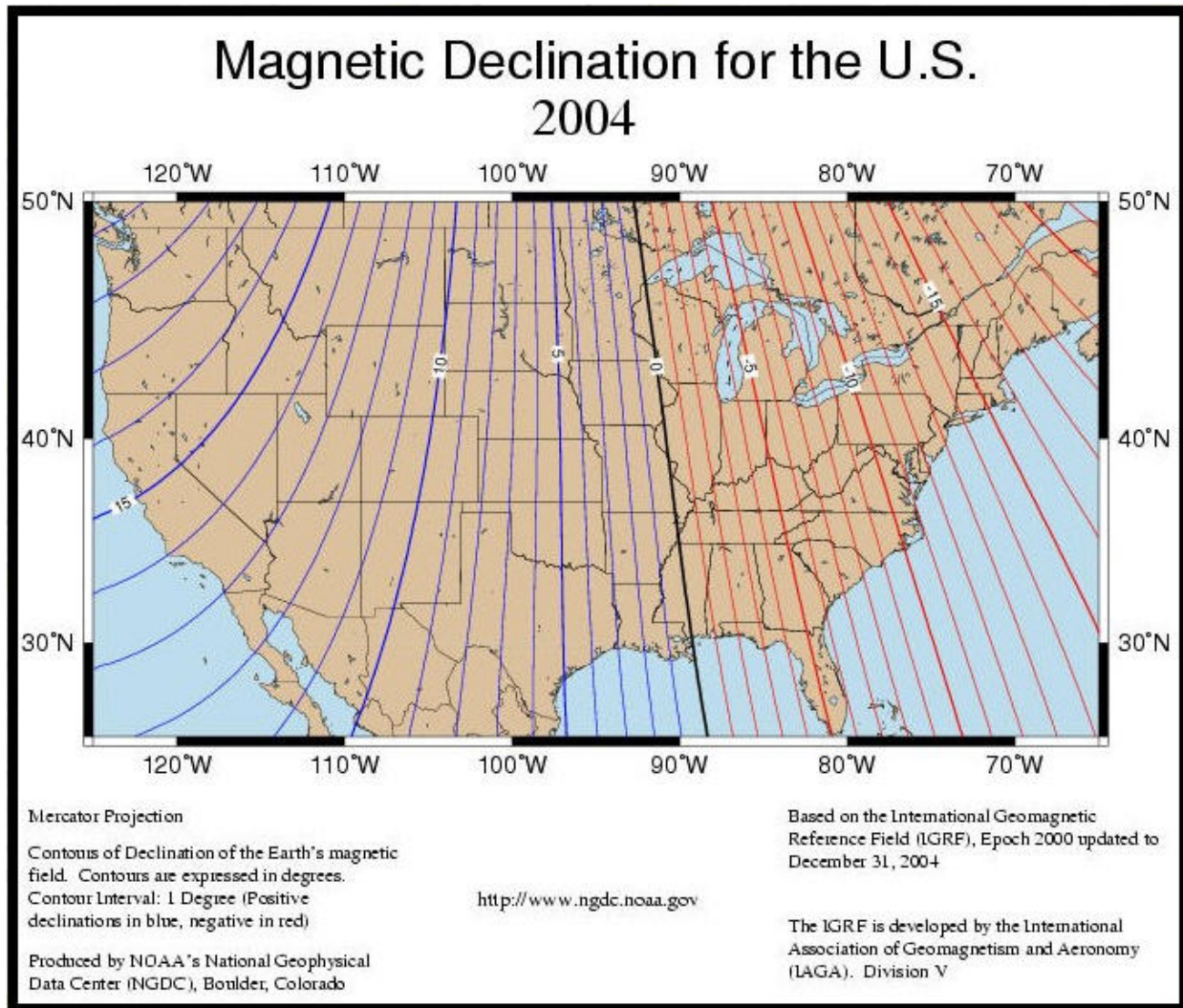
A compass should be used to determine the azimuth angle for various roof surfaces. A reading of zero degrees is associated with North and a reading of 180 degrees corresponds to South. East is at 90 degrees and West is at 270 degrees. Read below to understand why we need to make a correction for the magnetic declination.

6.6 Magnetic Declination Correction

1. Magnetic Declination Correction

A compass reading must be corrected for local magnetic declination, or deviation from “true north” reading. Large iron deposits in the Earth’s surface cause compass readings to deviate from pointing to the true solar, or rotational, North Pole. In the U.S., the compass North points to the east on the west coast, and points to the west on the east coast.

See this website for more information: <http://www.thecompassstore.com/decvar.html>



For Hawaii, we are +10°. The true azimuth will be found by adding 10° from the azimuth reading on a compass.

True Azimuth = Compass azimuth + declination value from map

7 Operations Overview

7.1 Solar Array Layout

1. How many solar modules can we install on a roof?

Use the guide below to estimate array sizes that could fit on the available roof surfaces. Modules are typically mounted in a portrait mode in horizontal rows across the roof.

This example, we will use a SunTech 175 watt module for illustrative purposes. The module dimensions are 62.1" x 31.8" x 1.4" or about 13.71 sq ft.

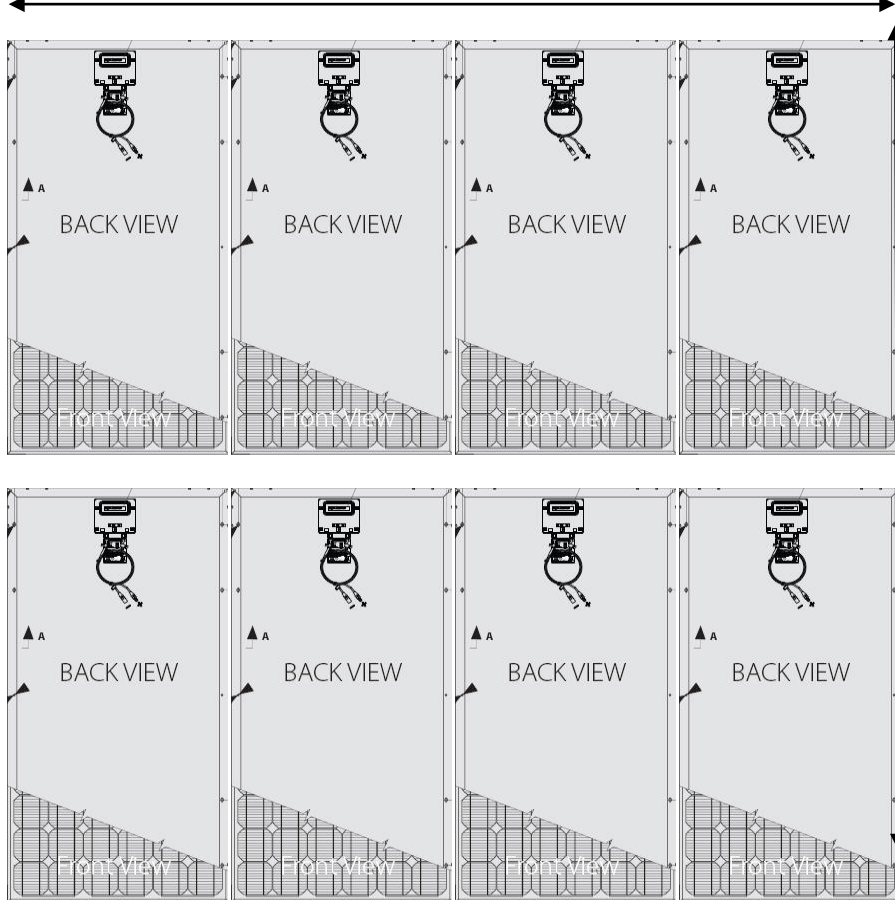
2. So, in order to fit an array of let's say, 8 panels, in a 4 panel wide x 2 rows, we will need a minimum of:

100 sq ft of space in the "portrait" layout as drawn in the example below.

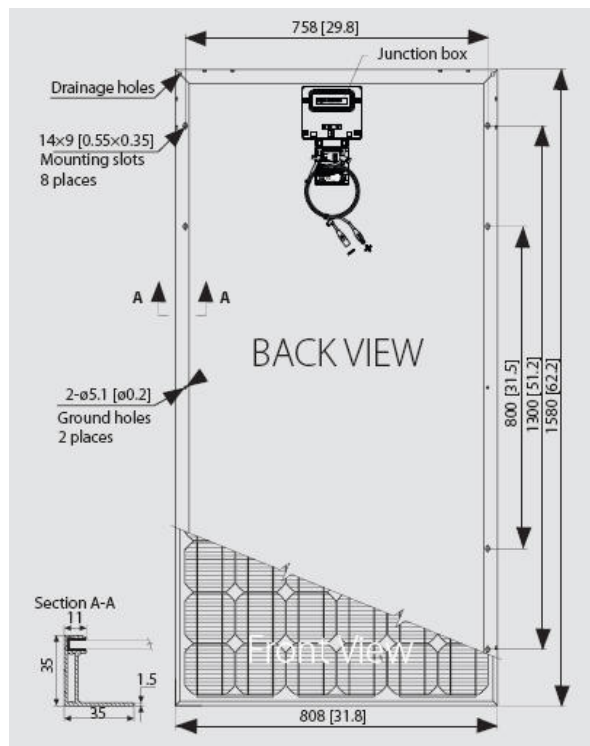
8 panels x 175 watts, 1400 watts. 1400 watts divided by the area consumed by the panels is approximately 10 watts per square foot. This is a standard rule of thumb in the industry as a guide for estimating space requirements.

This does not take into consideration the spacing that could be necessary for the racking either in the portrait or landscaping layout. Check with the manufacturer of the racking to determine the actual spacing requirements necessary.

10'6" Wide



10'3" Tall



SunTech 175 Cut Sheet

Back view showing the dimensions of the panel-

This module is 62.2" tall x 31.8" wide. Put another way, $1977 \text{ sq inches} / 144 = 13.73 \text{ sq ft}$.

$175 \text{ watts} / 13.73 \text{ sq ft} = 12.74 \text{ watts per sq ft}$.

As a rule of thumb, we can use 10 watts per sq ft in estimating the design of a solar system on a 3:12 pitched roof, for example. On a commercial flat roof, pitch angle will need to be taken into consideration and this will decrease the watts per sq ft.

7.2 Solar Array- Roof Location Selection

As we look at a particular site, we need to determine the feasibility of a "good" location, as all are not equal. When we look at the example above, we need to find 100 square feet to install our 8 solar panels and perhaps plan for more in the future.

So, what are some of the locations we should avoid?

1. Avoid shading of the solar array
2. Determine if this a partial shading during the day
3. If it is partial shading, can it be overcome- like moving a tree?
4. Can you go with a micro inverter to address the shading issue?

The solar modules must not be located in areas where hard shadows are cast by nearby objects. The output from shadowed solar modules is severely reduced. If shadows are observed, anticipate where they would be cast throughout the day and avoid the entire area swept by the expected shadow path. Examples of the typical sources of shading are shown below.

Examples of shading that will impact a systems performance:



Figure 8- Palm Tree Shading



Figure 9- More south facing roof-variable shading thru the day

3. Removing shading

There are specific actions that can be taken by either the installer or the customer to remove some sources of shading:

- Foliage can be trimmed or transplanted in a new location
- Vents can be moved for plumbing to another roof area.
- Satellite TV dishes can be relocated
- Relocate the proposed location of the solar modules to a more desirable location that will reduce or eliminate shading
- Be flexible with the location of the system- might need to go on the carport as opposed to the home

These actions should be discussed with the customer early in the sales process so that their importance can be emphasized and their cost can be estimated.

7.3 Estimating System Output

While our market in Hawaii generally has fewer obstructions than other areas around the country, we think having an understanding of how the pathfinder works is essential.

Our magnetic declination is 10 degrees.

There are a few tools available for our industry to assist us in making relatively good assumptions of system output.

You can also find your magnetic declination by visiting the compass store-

<http://www.thecompassstore.com/decvar.html> Click on Step 1 and enter in your zip code. This is a NOAA's, NGDC (national geophysical data center). This will fill in the latitude and longitude as well as today's date/month/year. Click on Compute Declination and the Declination will be produced in degrees.

An example would be- Kailua, Hawaii, 96734, it will be 9 degrees East, or to round up to 10 degrees.

7.4 Solar Pathfinder

The Solar Pathfinder works by showing a reflection of the surrounding horizon on a curved plastic dome. The horizon pattern can be traced onto a sun path sheet mounted below the dome that shows the path of the sun for all months and gives the amount of solar energy that would be blocked by any object.

Solar Pathfinder components

1. Dome
2. Tray that holds sun path sheet and compass
3. Base that allows for leveling of the tray
4. Sun path sheets printed with monthly solar paths for various latitude ranges
5. A bean bag is one of the best methods for placing the Solar Pathfinder on the sloped roof for stability and allows it to level

Their website <http://www.solarpathfinder.com/> contains a lot of great content and demo videos to assist you in understanding how to use the tool in less than 10 minutes. All you will need in addition to the pathfinder, is a bean bag to support the pathfinder on the roof and a digital camera to take a photo to input the snapshot data into their pathfinder assistant software!

You can also find your magnetic declination by visiting the compass store-

<http://www.thecompassstore.com/decvar.html> Click on Step 1 and enter in your zip code. This is a NOAA's, NGDC (national geophysical data center). This will fill in the latitude and longitude as well as today's date/month/year. Click on Compute Declination and the Declination will be produced in degrees.

So, the solar pathfinder tool essentially allows for the solar integrator to determine any shading issues and how that will influence the total energy harvest from a particular site.

The horizon seen from a roof surface may be partially blocked by distant objects which will reduce the annual solar energy available on that surface. These distant objects may include hills, distant trees and buildings. Using a tool called the Solar Pathfinder is the preferred method for estimating in a quantitative way the amount of solar energy that may be blocked by distant objects. It can also be used to find the least blocked location on a roof or yard that would be the best place for a solar array installation.

7.5 Solar Pathfinder- How do we use it?

1. The tool

Solar Pathfinder with case & tripod



The Solar Pathfinder™ gives an entire year's solar potential for a given site in just seconds. This non-electronic instrument is instantly ready to use.

This Unit Includes

Printed Manual (**online version** also available)

Sunpath Diagrams (latitude & application specific)

Angle estimator (for determining altitude & azimuth)

White marking pen with extra leads

Tool box specifically designed for the Pathfinder™

Tripod specifically designed for the Pathfinder™

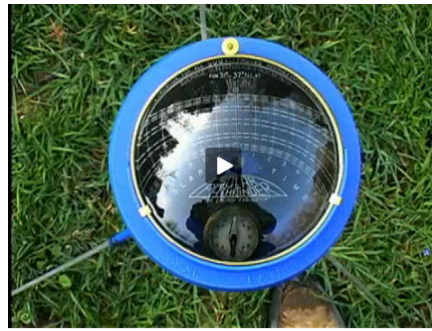
The Solar Pathfinder comes in a case with the exception of the tripod, which is sold separately as well as replacement Sunpath Diagrams for superimposing with the white marking pen, the outline of the obstructions.

2. Here are the steps for using the Solar Pathfinder:

Rotate the sun path sheet on the base to adjust for local magnetic declination. Align the white dot with the declination shown on the outer rim of the sheet to properly orient the compass. When this is done, then the compass can be pointed toward magnetic North but the sun path sheet will be properly oriented toward true North.



Solar Pathfinder Kit with Case



Top down view of the Pathfinder

Step # 1



Step #2



Set the pathfinder on the bean bag, if it is a roof application for solar and align the white dot for your declination- Hawaii is 10 degrees

Adjustments for Hawaii- 10 degree declination

Step # 3



Step # 4



Solar Pathfinder showing bubble level the unit is essential, before starting to take the survey

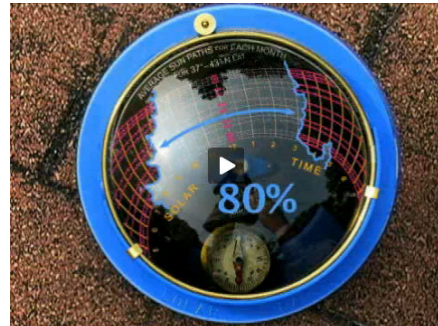
Confirm magnetic north

Step # 7



Example site showing 51% shading

Step # 8



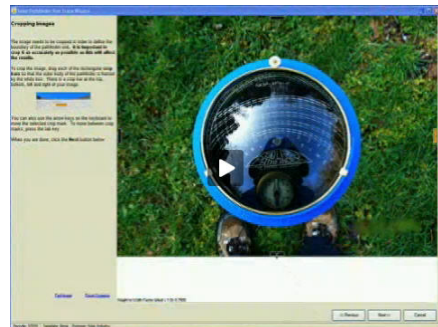
By relocating the solar array, we increased the site harvest to 80%

Step # 9



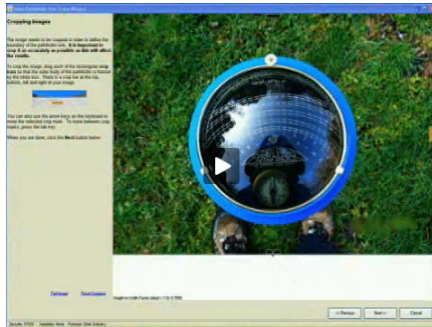
Utilizing a digital camera, you can take a photo in lieu of using the marking pen. Feed the photo into the Pathfinder Assistant software and get a detailed report of the site

Step # 10



Enter the photo into the software and crop the picture

Step # 11



Trace the points using your mouse and click, create a report

Step # 12



The report will output ideal vs actual monthly output for your analysis.

Step # 5



Solar pathfinder showing obstructions

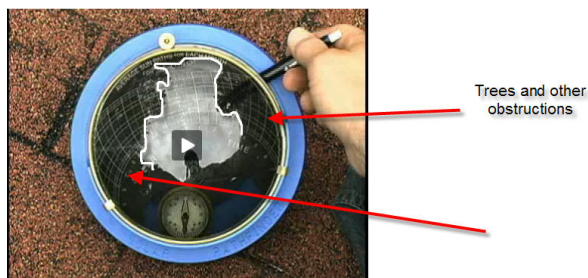
Step # 6



Sample showing only 51% annual solar radiation due to tree obstructions in red

3. For the manual drawing on the Solar Pathfinder sun path sheet

Place the Solar Pathfinder down on the roof and adjust so it is level and the compass is aligned to North as described in the examples above. (Placing the base on a pillow or bean bag allows for easy leveling). When looking straight down on the dome, the reflection of the surrounding horizon objects can be seen. Use the white pencil to trace the outline of the horizon objects onto the sun path sheet.



The tracing on the sun path sheet shows the outline of the horizon objects. Each hour of the day is indicated. The twelve smooth dashed lines on the sheet are the sun paths for each month. Every half-hour along each path, there is a small number that indicates the percentage of solar energy during a typical day in that month that would be blocked if a horizon object covered that segment of the line. By adding up the numbers obscured by distant objects, the amount of solar energy that will be blocked can be estimated for each month.

The above example is **severe** and would not be an acceptable location for an array. The Solar Pathfinder can be moved around on the roof or yard areas to find a location with minimal horizon obstruction.

4. Other Obstacles

The Solar Pathfinder should not be used to estimate the effect of nearby objects that will cast a moving shadow on an array surface. Nearby objects, such as tall narrow coconut trees, vent pipes, or telephone poles, will cast a shadow that will remain on the array as the sun moves, not simply block the sun. The loss of potential solar energy to the array will be much more than would be estimated by just adding up the numbers blocked on the sun path sheet. Any array should be located so that there is no shading by nearby objects that will cast a moving shadow on the array all day long whenever possible. Include this in your calculations regarding output of the system to assist in managing the expectations of the end user.

7.6 Google Sketch Up

1. Google Earth & Sketch Up

Google has a great tool to do shading analysis of a site as well as 3D modeling to develop a complimentary site evaluation as well. They offer a free version of the tool that is fairly intuitive to use and has import and export features into AutoCAD. You can also import photos and superimpose your solar array on the photo to provide a realistic model of what the completed project could look like.

There is also a 3D warehouse, training and a community area for people that use the product daily. For any size product, this can provide an additional competitive edge by creating a mock up of what will be offered and enhance the experience with an animation of what will be created for the end user. This can be a great sales and marketing tool as well.

7.7 Solmetric's- SunEye Tool

Another horizon analysis tool is the SunEye from Solmetric. This handheld measurement device represents the next generation of site assessment equipment and incorporates a digital camera and PDA together with software to do a detailed analysis of the horizon and shading influences on system output potential. Please visit their website to learn more. www.solmetric.com

The SunEye is a single unit with the camera, PDA calculator, compass and bubble level all built in. Some of the features are listed below.

6. Solar Panel System Design and Installation:

The Solmetric SunEye™ is the most important tool for the professional solar installer, saving time and money and helping to design the highest performance systems. It's equally useful for PV, passive hot water, roof mount or ground mounted systems.

Optimize new systems for maximum production. Analyze existing installations to solve problems of under production. Identify specific shade-causing obstructions such as trees or structures and know instantly how much additional energy would be produced if the obstruction were removed.

On-Site Data Collection and Analysis:

- Fish-eye lens and digital camera
- Sophisticated measurement software
- Simulates removal or addition of shading objects or structures
- Accommodates all panel orientations (tilt and azimuth)
- Accounts for panel tilt and orientation
- Multi-skyline averaging

That means:

- Easy measurements and instant feedback
- Fast estimates lead to quick sales and designs
- Data is automatically stored for later review



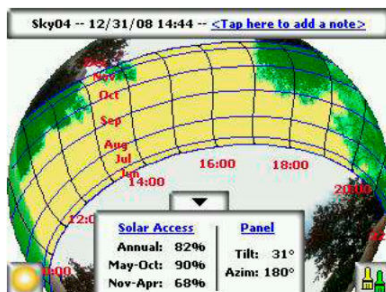
1	Fisheye lens and digital camera	7	Device/USB and charge port
2	Compass	8	5-way navigation button
3	Bubble level	9	Soft reset pin-hole
4	Power on/off button	10	Neck strap attachment points
5	Touch screen and LCD	11	Tripod mount
6	Protective cover		

Setting the unit on a tripod or use it handheld. Use the compass and the bubble level to orient it level and toward magnetic south. Then, press the button to take a picture of the horizon.

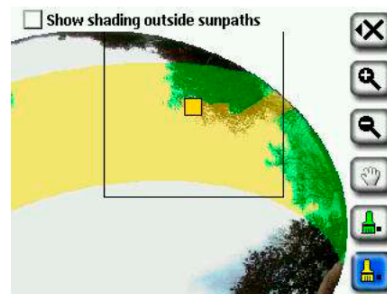
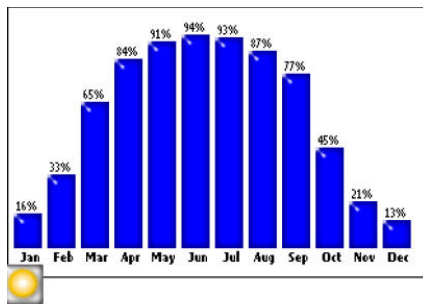


The SunEye does the following:

- Captures a fish-eye image
- Superimposes sunpaths based on latitude
- Adjusts for magnetic declination automatically, based upon the location you entered for the session
- Detects obstructions that could cause shading or sun blockage
- Accounts for solar module tilt and azimuth
- Calculates solar access percentages



The percent of unobstructed solar access can be presented graphically and on a monthly, seasonal or annual basis. Average access values can be calculated for multiple readings from various points on a large array. And objects can be added or removed graphically, to simulate tree trimming for example or the addition of a building. The software can then recalculate the solar access, for “what-if” analysis.



7.8 Actual site pictures- Roof

By taking digital photos of the site conditions of the roof, it is helpful for the company and all of the associated departments that will be working on the project to verify and lend some guidance. It is also helpful to have archived photos for the future, as this can be a great reference for maintenance and servicing the system.

Certain roofs could be considered marginally acceptable for an installation and could need remediation- re-roof to repair in order to install a system.

8 Utility Interconnection

8.1 Evaluation of the Electrical Service

Evaluation of existing utility interconnection equipment: Main electrical service usually in a residential application where the electrical meter is located and considered the Point of Connection. In a commercial application, this can vary, as an electrical meter could be stand alone and the point of connection could be elsewhere.

- a) Electrical service size and manufacturer of the equipment

The main electrical service panel for the house or business will contain the main solar breaker for the entire solar power system. The brand and size of service panel must be noted during site evaluation, as this will potentially limit the size of the system or require you to upgrade the existing electrical infrastructure to accommodate the solar system.

The solar breaker will have to match the manufacturer and model of the electrical panel to comply with the national electrical code (NEC) and the local electrical inspecting authority. On the inside front cover of most electrical equipment, or when the cover is removed, will be pertinent information regarding the make, model, voltage, amperage, voltage, busbar ratings of the equipment. You will need to write this down, in order to install compatible circuit breakers or the need to add additional equipment to satisfy the requirements of the NEC.

b) Main circuit breaker Information

The actual main breaker in the panel may be the same or smaller than the maximum indicated on the panel label. Usually, they ship from the manufacturers, for example- if it is labeled a 200 amp rated residential panel, it will have either, 1- 200 amp main breaker; 2- 100 amp main breakers. Make note of the amperage of the actual main breaker in the panel as this could need to be modified, depending upon the solar system size that is installed.

c) The maximum solar breaker size

The maximum size for a solar breaker in the house service panel is limited by NEC 690.64- (A) & (B). The supply side (A) is most applicable to commercial services, as there is not yet a method to tie into a residential service on the supply side via a manufactured means or by a utility method that is acceptable to them.

The Load Side (B) applies to both residential and commercial. For commercial applications, this can be an easier solution, as equipment manufacturers have made accommodations for such an application. In the 2008 NEC, they have changed the 100% of the service on a commercial application to reflect the same rules of engagement as the residential modeling of 120%.

For residential applications, there are fewer choices. The basic rule of thumb is outlined in the exception: For a dwelling unit, the sum of the ampere ratings of overcurrent devices shall not exceed 120 percent of the rating of the busbar or conductor.

As we have seen in our nascent industry, this has restricted the amount of solar photovoltaics, in wattage, we can install on a residence.

d) Evaluate the circuit breaker space available for the solar breaker

There must be physical room in the service panel for a new solar breaker. Sometimes all the breaker spaces are already occupied, and there appears to be no empty breaker spaces available for a new solar breaker. This must be noted in your site evaluation as it is a gating item for the installations field crew as well as the design considerations.

It may be possible to rewire some of the existing circuits in the panel or add a sub panel to accommodate the existing conditions. Some full size breakers may be replaced by mini or tandem circuit breakers that occupy a full breaker space but have two breakers. Be sure to not replace full sized breakers with a tandem breaker, if it is a multi wire branch circuit, as you will end up creating a code violation. NEC 210.4 speaks to multiwire branch circuits. There will also be a potential hazard by replacing a 2 pole circuit breaker with 1 mini/tandem breaker, as this can overload the neutral conductor.

e) Interconnection to the utility:

There are three baseline scenarios that can be considered to allow for interconnection of a solar electric system to a residential service. The commercial applications are broader in options and flexibility and should be looked at on a case by case basis.

- a) Existing main breaker size and service allows for the addition of solar breaker into panel (note- this would be 20 amps- for a 100 amp service (120%-NEC-690-64); 25 amps for a 125 amp service; 40 amps for a 200 amp residential service. Commercial installations require a further discussion, but generally have a lot more flexibility.
- b) Downsize the main breaker at the meter or circuit breaker panel to make room for the addition of solar breaker
- c) Replace existing service with larger size panel and main breaker

- f) This aspect of the installation process can be the most difficult, because of the varying degrees of existing installations combined with the increase in system sizes over the last few years. Before a project consultant that is performing the site evaluation provides a proposal, they should be familiar with the sites conditions, especially the electrical connection. By not having a complete understanding as to the “why” do we need to add an additional service panel (for example), can be costly and time consuming for the installation.

Some guidelines for addressing this in the site evaluation to system design phase:

- a) Company should have a documented “playbook” of previous installations as a guide and a point person directing the “what if” scenarios
- b) The guidebook should outline the challenge and the solution- in the written word, spoken word (video) and visually through pictures
- c) Verify the service size on the site evaluation form- document 101
- d) If in doubt, contact a qualified representative in the company to vet any concerns you have
- e) Open up the covers of the electrical panels and take notes and pictures of the wire sizes and the circuit breakers they are connected to
- f) If necessary involve the electrical inspectors or the utility representative- to ensure you will be able to get a final inspection and a net metering agreement executed

8.2 Existing Service can Accommodate Solar Interconnection

The simplest solution is if the existing main breaker is large enough to allow for the addition of a solar breaker, to comply with the 120% rule of NEC 690.64. Even if there no physical space for a new solar breaker, if the main is large enough then mini-breakers can be installed on existing circuits to free up enough space for a new solar breaker. Anything deviating from the simple solution should be reviewed with the appropriate personnel in the company.

8.3 Downsizing the Main Circuit Breaker

If the main breaker is not large enough, then it may be possible to replace the existing main breaker with a slightly smaller main breaker that will allow for the desired solar breaker to fit. A qualified electrician must calculate the typical load of the existing circuits to determine if a smaller main can be used. A smaller main breaker will allow for a large enough solar breaker, as shown in the example below.

The existing main service panel has a 200 amp busbar (verify with the manufacturer) and 200 amp main breaker. The maximum size solar breaker that can be installed is therefore 40 amps. The installer wants to install two paralleled inverters which will require a 60 amp solar breaker (example- 2- SMA 5000's). The installer replaces the 200 main breaker with a 150 amp main breaker. This allows enough room, per NEC 690.64, for the 60 amp solar breaker.

150 amp main + 60 amp solar = 210 amps.

So, $120\% \times 200$ amp busbar rating = 240 amps, which is permissible

There is one other option- some manufacturers make a 175 amp main breaker for their enclosures. This could be an intermediate point to address adding more solar for an ambitious homeowner to install a larger percentage of solar on their home.

You would need to coordinate with the utility to do a shutdown to remove the 200 amp breaker and install the 175 amp breaker under most conditions.

8.4 Service Upgrade

If the main breaker cannot be downsized, then the solar integrator can consider a service upgrade. For example, they can request through their utility, to upgrade from 100 amps to 200 amps for the residential service. In Hawaii, this would trigger procuring an electrical permit first, then contacting the utility with the permit # to commence the next step, which is providing the integrator with the costs and requirements the utility needs to perform the upgrade. Whether the service is fed from underground or overhead can influence and impact the price from the utility, the contractor and even a third party contractor who might be needed to do trenching work and tying into an electrical infrastructure in the sidewalk.

By having the entire service (meter, main disconnect, service cable from the main disconnect to the new electrical circuit breaker panel) is removed and replaced with a larger service and main breaker. This can be expensive, but may be a desirable improvement for the homeowner for a host of reasons. The existing service may be old and undersized for the current or future load demand as well as fatigued by overloading, system age (20 year plus) and environment (UV degradation). A new service may not only allow for a larger main breaker and the interconnection of the desired solar system, but may result in more breaker spaces for new equipment in the future, such as an addition to the home or an electric vehicle charging station.

Planning the upgrade is important, as the client could also have ambitious goals for adding to their systems over time. If you are just swapping out the 100 amp service with a 125 amp service, you might be overlooking some future needs of the client. It is generally advised to go to 200 amps and plan for the expansion and to have the bus rated at 225 amps. This could also benefit the future homeowner as well.

This will now lead us to identifying the feasibility of the conditions at the location, which are essential to a system design.

8.5 Site Map

We need to acquire this baseline information in order to provide an accurate proposal to the client as well as to get a permit for the project that will impact the logistics and cost of the installation.

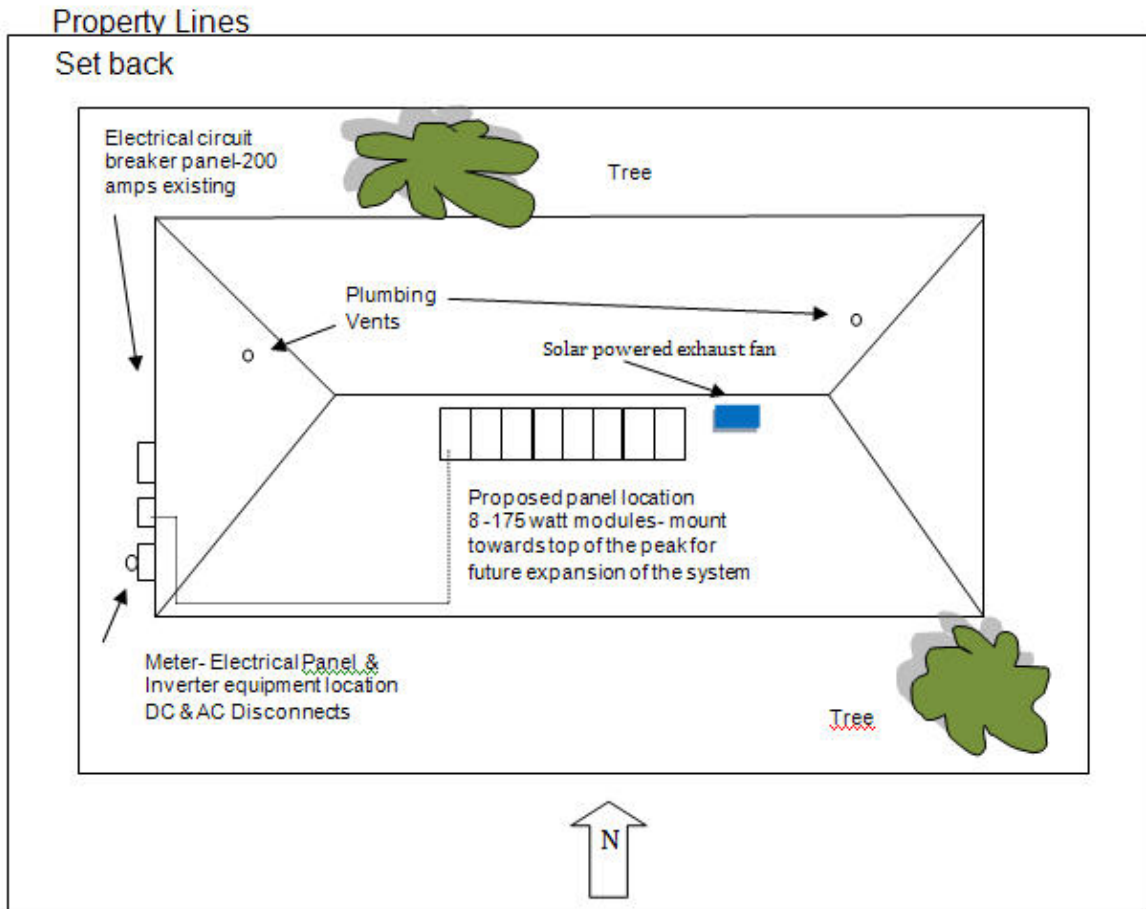
What information do we need?

- House outline showing roof surfaces
- Property lines and setbacks- this can also be obtained via GIS maps/building department and be verified by your engineering department
- North orientation- draw a letter N and an accompanying Arrow (all of this is also readily available via google earth, if the home is older than 5 years, if it is younger than 5 years, it might not show up on google earth, but could be on live.com)
- Trees or other objects or structures that could cast shadows on roof
- Fences or walls or other restrictions to movement and installation work

It is also important to denote the items that could cause shadowing as this will impact production of the system

- Shadows from roof/architectural feature- cupola, second floor eave etc.
- Chimneys
- Plumbing vents
- Satellite TV dish- while this is less common, this can impact a series string
- Gables, second storey additions, or other building surfaces

Drawing A1



Actual picture of a service and the solar equipment below: this is the “why” we need to cull this information on a site evaluation. This situation required additional requirements in order to successfully install the solar panels and inverters.

8.6 Actual Site Picture-Service

Actual picture of a service and the solar equipment below: this is the “why” we need to cull this information on a site evaluation. This situation required additional requirements in order to successfully install the solar panels and inverters.

This installation shows an existing 125 amp underground electrical service, where there was a need to install a 200 amp rated panel, due to the requirements outlined in 690.64B of the NEC. This requirement states that the sum of the ampere ratings of the breakers supplying power to a service panel busbar shall not exceed 120% (residential) and 100% (commercial) of the busbar rating. So, in this instance, if we wanted to install anything more than 25 amps of solar breakers, we would need to install the 200 amp rated panel. (pictured to the right of the inverters).



8.7 Site Service and Roof Details

In order to prepare a proposal for a system, a detailed analysis of the site service and roof is mandatory. These will be added to the site map and your evaluation checklist.

Existing electrical infrastructure:

- Utility meter and main circuit breaker combination- write down the information & take photos of the conditions- 100 amp, 125 amp, 200 amp, 325 amp, 400 amp etc.
- Electrical service panel and or any sub panels- make and model #
- Wire sizes to and from electric service panel and subpanels
- Are there any spaces available to tie in additional solar breakers?
- Do we need a dedicated solar panel?
- Take digital site photos of existing equipment- open the cover of the panel and meter for site verification

- Write down on your feasibility/evaluation form, all of the details: meter #, service size (size of the main circuit breaker), any additional circuit breaker information that you find on the site
- If the electric panel/service looks undersized, note this
- If the service looks corroded, note this and take pictures to share with your staff to evaluate whether or not an electrical service upgrade is warranted
- Check to see if the grounding is adequate- note the size of the grounding electrode conductor if it looks smaller than a #6 for a 100 amp service and a #4 for a 200 amp service
- Is there room for the solar equipment? Write down and take photos of proposed location(s)

Solar system equipment location:

- How many story's to the home- 1 or 2?
- Solar array, indicate number of modules and possible layout
- Roof penetration- will the conduit run inside/outside
- Roofing material- type- composition- 3 tab shingles, tile, metal
- Structural attachment- stanchions, hangar bolts, ribbing on standing seam metal- take photos- this is especially critical for mounting
- Structural- under the roofing materials- wood truss, metal purlins
- Combiner box (if proposing multiple parallel strings from array to the inverter(s))
- DC disconnect (if applicable- SMA and other manufacturers have theirs built in)
- Inverter(s)- Is there ample space? Is it out of the sun if possible? Measure the area for verification
- Will there be a future expansion of the system and are we providing adequate space?
- Inverter subpanel (if multiple inverters)
- Racking system- Comprail, S-5!, Unirac, Prosolar etc.
- AC utility disconnect near utility meter
- Routing of conduit- exposed- thru the attic etc
- Array to inverter- Conduit size anticipated- Owner OK with the location?
- Inverter to circuit breaker panel distance

8.8 Site Evaluation Checklist

The site evaluation checklist is a tool to insure that all major issues have been assessed during the site evaluation visit. It includes the site map as well as notes on equipment, logistics and conditions. By not acquiring this information, it is going to limit your ability to develop an accurate proposal to getting a final inspection from the building department, so take the time upfront to retrieve this information and save yourself multiple trips to the site.

See the end of this manual for a sample site evaluation checklist.

Site information:

a) Site mapping

- Lot and house outline with dimensions and North indicated
- Possible setback information, if there is any available
- Any obstructions or unique site characteristics- large tree that could shade array
- Estimated production- a 5 hour Sun-Day for example
- Existing electrical equipment components as described in the previous section

b) Planned location of the Solar Panels, Inverters, and Disconnects Etc.

- Layout array to avoid near object shading and other obstructions
- Roof penetration(s) for the mounting the racking and conduit to the junction/combiner box
- DC array disconnect(s)- if applicable and not utilizing micro inverters
- Inverter, insure adequate clearance distances, no direct sunlight if possible
- If an electrical service upgrade is required-for example, upgrade from 100 amps to 200 amps- allow for more space as the general rule is older service equipment was smaller in size and the new equipment has greater space within its enclosure
- If needed- a subpanel for a multiple inverter installation
- Utility AC disconnect- currently Hawaii still requires this- check with your utility as it can vary as they adopt new rules and regulations

c) Main electrical panel and service location

- Manufacturer, model and size of existing service panel (digital photo as part of the site evaluation)
- Confirm that existing service panel can accept inverter breaker (120% NEC 690.64)
- Need to upgrade panel? Call for pricing or have an associate with your organization provide the costs and requirements after consulting them or the utility company
- Need to downsize main breaker?
- Determine that panel has room to accept new solar breaker
- Need to re-wire circuits onto new mini-breakers to make room?

d) Roof conditions

- Describe condition of roof- worn out shingles, how many layers of shingles, uneven surface, dry rot, water damage, needs re-roofing
- Type of roofing material- shingle/ tile/ metal roof etc.
- Visible rafters to help with array attachment alignment under the eave?
- Roof pitch- 3:12, 4:12
- Height of roof off of the ground; second story installation? Access?
- Do you need a roofing company's evaluation of the roof condition?
- Is the client looking to install a new roof?

e) Conduit routing plan

- Plan routing of all conduit and conductors and note on the site evaluation
- Attic crawl space available?
- Do you need access to the attic?
- Exterior conduit routed discussed with the crew?
- Will the conduit look good after the installation?
- Need to paint exterior conduit?
- Using stainless steel hardware for longevity?

f) Customer's schedule

- Dates or days of week that customer does not want install crews working
- Time of day when customer or access is not available
- Clean up- will there be access to use a restroom?
- Rubbish removal?
- Electricity might need to be off- is customer aware or have critical items happening at home that this could disrupt?
- Pets- who will ensure they don't get out and if they do, who do we call?
- Is the permit available during the installation?

g) Clean up-create a plan

- Removal of all cardboard and shipping materials
- Pickup scrap wiring/metal/conduit/racking- dispose of properly
- Wash out gutters when completed- to avoid staining from the metals from working on the roof cutting and attaching racking etc.
- Broom finish clean up of the carport/hallway from the attic work
- Remove any lunch opala that could have migrated onto the property

9 The Design & Engineering

9.1 Gathering the Information

Ok, so this is the moment of truth where the design and engineering team have gathered all of the information and are ready to put the pieces together.

What do we have to take the project to the next level?

We will need all of the information, from the Site Evaluation/Feasibility study of the project to being putting the pieces together.

So, what do we have and what is the next step?

9.2 Site Evaluation Form

This form is going to need to be checked, soon after a project is sold or during the development process, for the non-standard types of installation. The project engineer/designer will need to verify all of the information on the form to ensure the project is feasible. If the project is complicated, meaning, it is not clear that there is an obstruction in the way or the electrical interconnection needs review/support, as site visit will be required and allow everyone to evaluate whether the project is a “go forward” based upon the information gathered.

For commercial systems, this will require a lot more scrutiny and more “eyes” on the project. This is from the electrical portion of the design as well as the roof/mechanical design. It could also mean inviting a utility representative out to the site for a consultation as well. It could also require an independent structural engineering evaluation of the buildings structure to ensure the roof can adequately handle the additional weight and dead loading.

9.3 System Design Stage

Now that we have completed the evaluation and determined that it is feasible to install a system at a particular location, the design begins. Many residential applications and design criteria can be generally “cookie cutter”, except for certain things like interconnection, but templates can be made to address a baseline system design using certain assumptions.

9.4 The Building Department

After the design has been verified and blessed in the company, this now gets sent to the building department for their review, which can take 3 weeks, depending upon their workload. If the site is unique, on a commercial perspective or the home is in a state historical area, this could take longer. The building department has been getting better as the stream of solar photovoltaic projects has grown, and their comfort is increasing, usually decreasing the amount of time a permit application flows through their departments.

It should be noted, that each island has their own criteria for the gating items they need for a solar photovoltaic system. On Oahu, there is no requirement for an electrical engineered stamped drawing for residential PV, whereas the neighbor islands require this. Also, Oahu, is on the 2005 code, where the Big Island is on the 2002 code. This can influence the design. An example of this would be the 2008 code- it states the 690.64(B)- residential and commercial are all sized at 120% of the service size, where the 2005 says commercial is only at 100%. This can cause designers to interpret different rules of engagement, depending upon the jurisdiction.

Once the plans are ready for pickup from the building department, the project can commence.

9.5 Design to Procurement

During the design process, we have worked closely with our procurement team and operations team to develop a bill of materials. This material list should be part of the site evaluation list that is developed on the site visit from everything from solar panels to conduit.

This materials takeoff is then staged, either at the warehouse or at a vendor for pickup. Having a baseline of long lead items or frequently used items are pivotal to the successful execution of the project as well as future projects in queue. This will keep the flow of materials and people in sync and allow everyone to perform at their most optimum state.

9.6 Procurement to Installation

Now that the design is complete, the materials procured and staged, we can give our field teams the resources they need to perform a successful installation. A recommendation for the field team to have prior to project commencement:

1. Access to the drawings and other related project information at least 1 day prior to the installation for review- and potentially a site visit if the location is close to a project they are working on
2. Any project related notes that are non standard for the project
3. A project manager/supervisor verifying the materials selected matches the projects drawings
4. Verification that their trucks will have all of the necessary tools required to perform the installation
5. Contact information for the client and any job specific things- like watch out for the “poodle” or you need 2 extension ladders etc.
6. System commissioning reporting forms- provided for the specific project to be returned to the office once the project is completed
7. Materials reordering forms- what do they need restocked or not?
8. Close out information- project completion information- ready for inspection?

9.7 Utility Documentation

Now that the project is completed, we can contact the utility and send in the executed Net Metering Agreement (NEM) for the project. This will occur only after the final inspection has been approved by the city and county, as the utility uses this as a gating item.

The utility will eventually send out a field team to replace the existing meter, with a digital meter and the customer will officially be on the “system” as a NEM participant!!

9.8 In House Closing Documentation

Now that the project is completed, a follow up call should occur within 6 weeks, which is enough time usually for the meter to be swapped out and the client to receive their first electric bill showing system performance. This is a great time to reconnect with the client and ask for a referral and also see if they are in need of any additional services.

You can now collect all of the pertinent documents for the project- from the original site evaluation forms, client contract, drawings, photos, NEM (copy) and any other related docs and file them in the cabinet. It is also helpful to have a software system to catalog all of your customers project related details, as this is helpful for future reference for service and repairs as well as any warranty related challenges.

10 Leadership Chart

From an operational standpoint, how do we assign responsibilities to the functions required to do a site feasibility study and the progression of steps to allow the work flow be successful to the design of the system, procurement of materials, installation, closing documentation and future service of the project?

Similar to an organization chart, the structure of the workflow and roles are paralleled. The reporting relationship and the requisite “information” handoff is critical to a successful outcome. Identifying key elements of the process encourages continuity.

10.1 Key Roles & Responsibilities

Identify key roles and responsibilities within your team. Specify expectations as this section is essentially about team expectations.

Role	Name	Organization	Responsibility
Operations Manager		COMPANY	Has overall responsibility and accountability from sales to service.
Sales Manager		COMPANY	Has overall responsibility and accountability for sales numbers, goals and projections
Project Manager		COMPANY	Has overall responsibility and accountability for installation teams metrics-KPI's
Sales person- Project consultant		Independent Contractor/ in house reps	Has overall responsibility and accountability for accurate site evaluation, some system design criteria, contract execution

Role	Name	Organization	Responsibility
Installation team		COMPANY	Has overall responsibility and accountability to follow design and uphold safety and code related activities as well as system commissioning completion
Engineering		COMPANY	Has overall responsibility and accountability to design and engineer systems to specifications as well as provide accurate checklists for the sales team as well as the installation team and clearly outline the expectations
Administration		COMPANY	Has overall responsibility and accountability to keep the paperwork flow from scheduling sales activities to customer service
Accounting		COMPANY	Has overall responsibility and accountability to ensure vendors are paid and maximize cash flow and keep score on profitability and to report this to the operation manager before the 10 th of every month
Purchasing		COMPANY	Has overall responsibility and accountability to seek to find the best products and the best terms for the products as well as logistics

Role	Name	Organization	Responsibility
Warehouse		COMPANY	Has overall responsibility and accountability to make sure tools, materials and any prefabrication can be done to maximize the efficiencies of the operations

10.2 Anticipated Change

As the ramp up occurs and most specifically we live within a Q3-Q4 expansion, it will be the goals of the organization to effectively manage the projects and allocate resources accordingly.

There is also a lot of change that occurs when people leave an organization, so having systems in place to ensure consistency is paramount.

11 Operations Schedule

Tasks can generally grouped into daily, weekly and monthly schedules.

Depending on the circumstances, additional administrative tasks may need to be implemented, and some tasks may occur more or less often or not at all. Other tasks should be reviewed periodically, especially when personnel changes occur as this causes disruptions in the flow of information.

11.1 Daily Tasks

Perform these tasks on a daily basis:

Task #	Description	Schedule
1	Sales- meet new clients and keep score thru a CRM to identify who is working on what projects to minimize confusion and overlap. Have pricing and contracts always available as well as a support structure to communicate variations in site conditions and have access to these resources	Daily
2	Project managers- prepare projects in queue daily and keep in contact with field teams to keep projects on schedule	Daily
3	Administration-Customer Service- work with project managers to parallel the work flow and support the field operations as well as address changes in personnel	Daily
4	Installation team- report on progress on projects and keep the management up to date on anticipated completion dates vs actuals. Give feedback on procurement challenges, design obstacles and communicate the conditions	Daily
5	Engineering- receive updated site information on pipeline related projects and work with the field teams to ensure proper installation best practices. Coordinate building department related activities	Daily

6	Accounting- daily deposits of checks for transactions for cash flow purposes	Daily
7	Purchasing- ensure just in time delivery of products and anticipate trends	Daily
8	Warehouse- keep up with the demands of purchasing and the field teams as well as pre fabricate as much as possible	

11.2 Weekly Tasks

Perform these tasks on a weekly basis:

Task #	Description	Schedule
1	Operation Manager- update project in the queue and make adjustments to the work flow	Friday or Monday
2	Sales Manger- forecast sales for the coming week and communicate this to operations	Friday or Monday
3	Accounting Manager- check and verify outstanding receivables	Friday or Monday

11.3 Monthly Tasks

Perform these tasks on a monthly basis:

Task #	Description	Schedule
1	Operations- forecast the coming month/quarters pipeline and plan accordingly with sales and the support team	First week- Month
2	Sales- Review what was sold the previous month and check in with sales team to determine where they see the coming month	First week- Month

3	Accounting- AR-AP and job cost- require other departments to provide their information into the computer system to keep score	First week- Month
4	Purchasing- check with sales to verify products are paralleling pipeline	First week- Month but can be more often as we have 10 days on a boat for float time
5	Department reporting to senior management to make future planning decisions	First week- Month

12 System Design to System Installation

Now that we have an understanding of the steps involved in the design, we need to pass the torch to the system installation criteria. Below is a transitional area on managing the workflow as well as some suggestions as to have a 360 degree improvement process.

12.1 Managing workflow

Task #	Description
Schedule	Daily, Weekly, or Monthly
Purpose	Purpose of each activity
Related activities	Descriptions of all activities
Initiation	Method of initiation (on request, initiation by another activity, predetermined time)
Task time	Estimated activity time
Turnaround time	Required turnaround time
Reports	Requirements and procedure for report generation and reproduction
Activity Checkpoints	
Identify and describe the activities and verification of the results through the benchmarks and standards defined by the company's best practices	
#	Action
1	Sales cycle- from training a new sales representative (1-2 weeks of training) to "ride along program" with other sales reps to understand the process of information flow

2	Engineering cycle- from receiving the information from sales to doing a site walk thru to ensure design criteria is in alignment with the sales template
3	Operations cycle- managing the workflow- from sales contract, procurement, engineering, scheduling installation, administrating process to close out documents- all related file activities end up in the job folder for ease of verification and predefined checklists
4	Accounting cycle- manage cash flow through sequencing purchasing of a majority of the components and decrease the AR time between projects

Related Activities, Initiation & Task Time	
Review activity, initiation and task time and how it correlates to resource planning	
#	Action
1	Sales- their activity and access to their pipeline is critical in the work flow, as things need to be sold, in order to orchestrate the rest of the events. Their task time, per se is not quantifiable, in so much as time allocated, but results oriented. They sales departments close ration and pipeline directly impact and influence the resource planning. For residential solar sales, the time from first contact to executing a contract can be 2 days to 2 weeks, depending upon the situation and a much longer horizon for commercial sales.
2	Engineering- their activity is closely tied to sales and the second step after sales, validating site information and equipment to work within their design parameters. The task time can be improved by developing some baseline templates for the projects and adjust them for field conditions and product availability. This execution of this role is essential to permitting and procurement of the projects preliminary functionality and further influences the resource planning of the installation team.

Related Activities, Initiation & Task Time	
3	Operations- this by far is the most instrumental in the symphony of activities as so many departments are influenced. If the previous 2 action items are not working in tandem, it limits the effectiveness of this departments ability to forecast task time to a project and makes planning resources, highly susceptible to scheduling slippages.
4	Accounting- the function and role of cash flow is critical in the hierarchy of things, as not having adequate resources to fund a project to pay vendors and payroll can hamper all of the organizations efforts. When factoring in 70-80% of a solar project is material intensive, AP & AR and the cash flow equation are pivotal to the success

Turn Around Time & Reporting	
How do we optimize turnaround time and reporting functions to accelerate productivity?	
#	Action
1	Sales- their ability to close deals and deliver deposits is only part of the equation. They need to be technically trained to limit the inconsistencies in varying site conditions and manage this more effectively to optimize engineering's resource base and productivity. This will further managements reporting of pipeline and reduce training time for sales representatives.

Turn Around Time & Reporting	
2	Engineering- by having a well trained staff that has some background in solar design and some field experience will greatly improve turnaround time for site evaluations and vetting unique site conditions. They also need to work closely with sales to ensure their design criteria are being adhered to and incorporated into their proposals. From a reporting perspective, you should be seeing a decrease in man hours allocated to designing projects. There will need to be a person assigned to QC to go to the field and determine if things are being built to the design.
3	Operations- their turnaround time to deliver and execute again is weighed heavily on sales and engineering for their deliverables to allow ops to set the stage for success. Depending upon the workload, from sales to engineering to operations, a standard residential system should be able to be installed in approximately 2 weeks. The reporting function with a software package capable of delivering desired metrics can report on a project by project basis, weekly or monthly.
4	Accounting- if they are provided with all of the details and there is a rigorous system in place for receiving receipts, invoices from vendors, the processing time to deliver reports that business decisions can be made on, is relatively easy with cooperation. Ideally, reporting would be before the 10 th of the following month.

12.2 Areas of improvement

Review- Determine areas of improvement	
Provide the department and activity that is in process and polish the event and look for ways to optimize- discuss with stakeholders.	
#	Action
1	Operations- develop clearly defined processes for reducing costs and increasing man hours per kW installed metrics
2	Sales- clearer checklists for developing one off projects and make them normalized through standardization of field manuals of case studies of similar projects
3	Installation team- provide them with detailed systems- from daily checklists on items used in the field as a requirement from a job description to ensure the availability of materials for the next projects activities. Record materials used and make them available and replenished daily thru a parts runner to maximize efficiencies
4	Accounting- how can we get better terms from our vendors to JIT delivery options to balance the cash flow needs of the projects?

12.3 Error enhancement

Error enhancement		
List all errors that occur through the process and look for ways to improve the roles, processes and people skills.		
#	Error	Corrective Procedure
1	Sales to Engineering to Field- sometime inaccurate information is not updated from the inception, pushing the design changes up to the hour before the installation begins	Standardization and systems to minimize confusion
2	Warehousing- not having the requisite \$10 part that stalls a crew of 4 people for 3 hours	Having a detailed list of frequently used items stocked on the trucks and a system to replenish used stock
3	Purchasing- missed delivery date to get product on the ship from the west coast	Work closely with operation and sales on anticipated pipeline and if stock is not available from the vendor, look to other resources

12.4 Procedure review process

Review Procedures	
Describe the baseline procedures that staff is currently following- chunk it down, step by step	
#	Action/activity
1	Weekly review of installation teams needs and benchmark averages for kW installed compared to the site conditions and evaluate missing steps in the process
2	Weekly review of supporting the field crews to enable them to effectively perform their roles the most effectively
3	Weekly review of sales teams technical understanding of a site evaluation thru testing and or ride along program to verify a high level of understanding of the processes to develop a project
4	Weekly or monthly review of utility standards and disseminate this with the organization
5	Monthly training- from sales to safety

13 Operational Workflow

13.1 Procedures and process

Describe the steps with operations in the following scenarios.

13.2 Sales workflow

#1	Steps- Sales
1	Sales person is trained on the how solar works and the technical aspects of an installation as well as the financial incentives for the client. They have been trained in the paper flow from the office and how the timeline works for scheduling the installation. They are also familiar with the gating items to get paid and the steps involve to turn in their paperwork.
2	Sales person gets signed contract, deposit and contacts the company to schedule the installation. Generally installations are 3 weeks from contract signing to installation
3	Sales person contacts the client with an estimated installation date and verifies it is ok to have the company do the installation
4	Sales person/manager starts the dialog with engineering and operations for commencement

13.3 Operations workflow

#2	Steps- Operation
1	They receive executed contract documents from the sales team and review for accuracy.
2	Paperwork for the project is disseminated to the following groups-engineering to schedule a site visit to evaluate the feasibility of the project and check for discrepancies in the site evaluation. Once this is done, the documents are handed back to operations.
3	Simultaneously, operations starts the process of communicating with purchasing/warehouse team to see what materials are needed and prepare for the completion of the bill of materials and any other items associated with the installation lead times.
4.	Administration- they begin the process of procuring the permit and work with engineering to provide submittals and relevant supporting documents. They also being any related utility required paperwork for the project. They also consult with the operations manager to glimpse into scheduling the field team for the installation.
5.	Field team goes to the warehouse and or vendors to pickup materials and paperwork for the project and load in the vehicle or coordinates delivery from the warehouse team. Field team commences the installation and follows startup procedures as well as commissioning documents and turns in this paperwork for closeout of the project.
6	Accounting works with operations/sales for final billing and any other execution related documentation for final release of funds for the project.
7	Customer service/admin- contacts the client for follow up regarding the overall experience and process and asks for feedback and other potential offers from the company.

8	Warehousing-purchasing- receives from the field team, the list of items used on a project and the items they want/need restocked are ordered and setup for the next project.
9	In one-two months after the system is installed, check in with the client to verify they are content and satisfied with the systems performance. Ask for a referral.
10	Job well done, let's do it again, better and more efficiently!

As you can see, there are a lot of stakeholders involved in the successful outcome of a relatively simple solar PV installation. Coordinating all of these events is critical and even more so as the business grows.

By keeping score and setting action items and turnaround times, you can improve the overall task time to execute and installation. Everyone wins- the customer, the employee and the company. All of the stakeholders have something to gain and more often than not, a lot to lose if a high level of systems and communications are not implemented.

14 Appendix

14.1 Site Evaluation Form

In order to gain knowledge and extract the correct amount of information on the initial site visit, a site evaluation form is necessary for the project consultant to fill out.

Below is a sample form for a residential system

PV System Site Evaluation Checklist

Client Information

Name _____ Date _____

Address _____

City _____ State _____ Zip _____

Tel _____ Cell _____

Work _____ Fax _____

Email _____ Website _____

Project Consultant _____

Point of Contact at the Company _____

Utility Bill Information

Name utility bill is in _____

Utility Company _____ Average Monthly Usage _____ kWh's

Account # _____ Peak Monthly Usage _____ kWh's

Meter # _____ Current cost per kWh _____ kW
(\$/DAY/kWH/DAY off of the bill)

Proposed System Information

Proposal: (circle one) Standard Custom

Inverter: (circle one) Series String: Brand _____ Micro: Enphase

of inverters _____

Circle one: Grid Tie Grid Tie with Battery backup Number of Batteries _____

Brand of Modules : _____ **Quantity:** _____

Electrical Service- Existing (circle one)

Residential 100 amps 125 amps 200 amps 325 amps other _____

Commercial _____

Roof Type (circle one)

3 tab shingle Wood Shake Barrel Tile Monir Tile Metal standing seam (rib for S-5)

Metal corrugated-Mayan Pyramid Torch Down Other _____

Commercial Roofing- EPDM TPT Firestone Other _____

Flashing method (circle one)

Stanchion Oatey Roof Flashing Lead Flashing Metal Roof Flashing Other _____

Attachment System (circle one)

Stanchion S-5 Other _____

Racking System (circle one)

Comprail S-5 Unirac Prosolar Other _____

Installation Information

Electrical service size _____	Make & Model _____
Space in Service for Solar Breaker Yes No	Do we need 200 amp Panel for Solar Circuits Only? Yes No
Proposed tie in location (circle one) Main electric service Panel in the home	Need to upgrade service (circle one) Yes No Explain _____
Distance from Solar Array to Inverter – DC run (if _____ String _____ Inverter) _____ Feet	Conduit Route (ex- roof thru attic, down side of the house) Exposed? Yes No Cleared with Client? Yes No
# of Strings from the roof to the inverter _____	Future expansion- # of strings _____
If Micro Inverter- AC run from Solar Array to Main electrical area/Utility Disconnect ___ Feet	
If ground mount or to detached building- Trenching required? Yes No Explain Distance _____ Obstructions (circle) Concrete Trees Other _____	
Home (circle one) 1 Story 2 Story Other _____	Location of Solar Array : Front Back Right Left
Compass reading _____	Solar Array Location: South South West South East
Roof Pitch: (ex: 3:12) _____ Need to Tilt? Yes No	Obstructions? (ex-vent pipe, skylight, tree, satellite dish) _____
Pictures Required: Proposed- Roof Location; Tie in Location; Conduit Runs on the home or underground, Electrical Panel (open cover), Electrical Service (open cover)	

Place roof pic here	Place conduit run pic here
Place electrical panel pic here	Place electrical service pic here
Other pics	Other pics

Proposed system cost # 1 \$ _____	Proposed system cost # 2 (Option) \$ _____
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