The Montana Consumer Guide to Grid-Interactive Solar Photovoltaic Systems

☼ Capturing Solar Energy

☼ Converting and Directing Power

☼ Utilizing Produced Electricity

☼ Making a Good PV Choice

☼ Consumer Resources

The Montana Consumer Guide to Grid-Interactive Solar Photovoltaics

Incorporating On-site PV Electricity Generation for Residential and Small-Business Consumers

Thank you for your interest in solar photovoltaic (PV) technology and for taking the time to read this publication. The information is a primary resource and practical guide for consumers who are considering a solar PV system. The publication is focused on grid-interactive solar PV systems and has three principal sections with information crucial to understanding solar PV. They are; capturing the sunlight, directing and transferring the produced PV electricity, and utilizing the electricity within a grid-interactive framework. This consumer guide is not a technical manual, instead, it represents the factors, options, and decision steps essential to purchasing and installing a safe and productive PV system.

Developed by:
Highmark Media

With Support, Input, and Review by:
Solid State Educators
Montana Electrical Joint Apprenticeship Training Center (MEJATC)

Acknowledgments:
Funding for the printing of this publication has been provided through Universal Systems Benefits (USB) funds collected from NorthWestern Energy electric customers in Montana.
The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of funders or any state agency.

Cover and Inset Photos:
Bridger Bowl - Bozeman, MT

Printed May 2021

Table of Contents

The History and Science of Photovoltaic Power

Photovoltaic Power and How it Works....2

Building Blocks of a PV System....2

The Three Objectives of a PV System....3

Capturing the Sunlight (Cell, Modules, Arrays, Mounting and Racks)

Crystalline Solar Cells and Montana Performance.... 3-4

Thin Film Modules and New Technologies....4

Mounting and Mount Types.... 4-6

Racks, Structural Attachments, and Rack Variables.... 6-7

Tracking Systems....7

Siting the System, Contractor Site Assessment.... 7-8

Converting and Directing PV Produced Power (Inverter, Wiring, Energy Storage)

Balance of System (BOS) Components.... 8-9

Inverters and Inverter Types.... 9-10

AC Modules, Power Optimizers, Inverter Comparisons....10

Wiring, Rapid System Shutdown....11

Energy Storage Systems....12

Utilizing the Produced Electricity (Net Metering, Energy Efficiency)

Net Metering....12

Energy Efficiency....13

Making a Good Choice (Analysis Steps and Formulas)

Analysis Overview....13

Step One - Determining the Electricity Use and Desired Offset.... 13-14

Step Two - Sizing the System Based on Site Characteristics....14

Step Three - Determining the System Cost, Available Incentives and Payback.... 14-15

Resources and Important Information to Know

Solar PV and Applicable Electrical Definitions....16

System Warranties (Modules, Inverters, Energy Storage Systems).... 16-17

Interconnection and Consumer Safety Considerations.... 17-18

Solar PV Internet Resources....18

NorthWestern Energy Contact Information....19

The History and Science of Solar Photovoltaic Power

Photovoltaic (PV) Power

In 1839, French physicist Edmund Becquerel found that exposure of certain materials to sunlight resulted in a small electrical current. Albert Einstein described the science of this interaction - for that, he won the Nobel Prize for Physics. His research and writings on the “photoelectric effect” form the basis of modern photovoltaics.

Bell Laboratories built the first photovoltaic (PV) module, and NASA used the technology in the 1960s space programs. Land-based, structural PV prototypes followed, and systems became available to consumers. The cost of the first PV modules was high, but due to incentives, market transformation, and production improvements, the price for PV systems steadily dropped.

Today’s prices for PV modules are approximately 30-50% of those ten years ago. To a lesser degree, component costs have also decreased. Montana has an established, reputable solar contractor community- the number of solar (only) and general electrical contractors who perform and maintain PV systems has steadily increased and serves most of the State’s geographic areas.

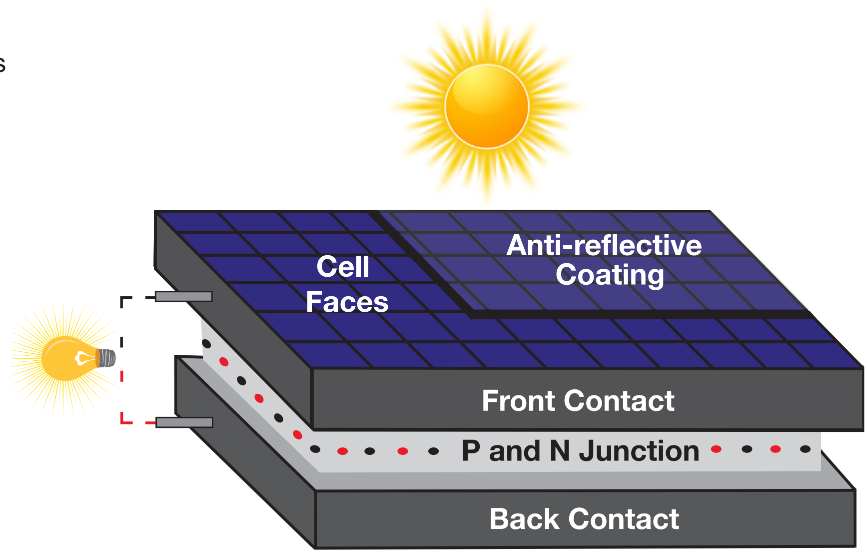
How PV Works

As described by Einstein, sunlight contains energy. When it contacts the PV cell, integrated materials within the cell (typically silicon) enable the light energy to produce an electrical field near the top surface of the cell. This electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the cell connects to an electrical load.

Solar PV Building Blocks (Cell, Module, Array)

There are between 60 and 72 solar cells in a residential or small commercial solar module (also called a panel). Residential modules are usually 60 cell designs.

Each cell has a voltage of between 0.5 and 0.6 volts and produces approximately 200 to 250 mA (milliamps) per square inch. The cells electrically connect and form the solar module, and modules wired together comprise the solar array.



Solar Photovoltaic Process
60-Cell Solar Module (Expanded View)

The modules used for non-utility applications are rectangular with outside dimensions of approximately 39” x 65” for a 60 cell module and 39” x 78” for a 72 cell module.

The average weight of a 60 cell module is between 40-50 pounds, and 72 cell modules weigh between 50-65 pounds each. Based on the cell composition, design, and cell count, the electrical output per module is between 175-450 watts.

The solar array is the entire cluster of modules grouped on the roof of a structure or a ground-mounted pole. The array has a maximum system power capacity rating, listed in watts or kilowatts (one thousand watts). This rating is also called the “peak output.”

The maximum capacity rating is the production benchmark. This figure represents the output of the array when operating at full power. Production is highest when the sun is providing the greatest amount of light. When the sun is blocked or not directly striking the panels or in conditions such as extreme temperature, the system’s output will not reach rated capacity.

The Three Objectives of a PV System

(Capture, Direct and Utilize Produced Power)

The three principal objectives of a grid-interactive photovoltaic system are to capture, direct and use generated power safely and efficiently. For the consumer, there are many variables and options within a PV system. These begin with the type of solar cell used, system components, and DC/AC conversion designs and devices. All are integral to one or more of the three objectives.

This publication addresses the key components, variables, and options that impact each objective. In this framework, solar PV system design and installation are easier to understand.

Capturing the Sunlight

Cells, Modules, Arrays, Mounting, and Racks

Crystalline Silicon Solar Cells

Approximately 95% of residential and small-scale commercial PV systems use modules that contain silicon. The most common silicon module has recently transitioned from monocrystalline (mono) to polycrystalline (poly). The longevity and performance characteristics of the two silicon types have narrowed to the point where features such as cost, warranties, and aesthetics are factors in choosing a specific product. Following is a general overview of crystalline modules. Consumers should examine module specification sheets in detail before deciding on which type they select.

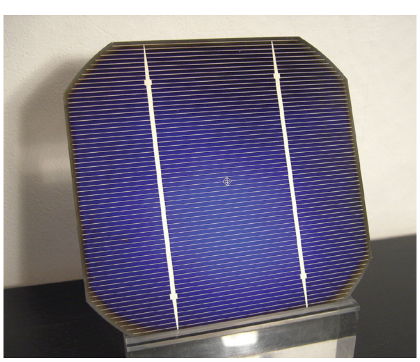
Monocrystalline cells typically have the highest efficiency rates (15-20%), and they are the most space-efficient per produced watt. They are manufactured using single-crystal, high purity silicon formed into an ingot and then cut into wafers (which results in minor silicon waste).

Monocrystalline cells have a black hue and rounded edges. Research shows that mono modules outperform poly modules in higher temperatures and low-light conditions. The primary disadvantage of them is a higher cost per module. There are available premium mono panels with field-tested efficiency rates in the 21-23% range.

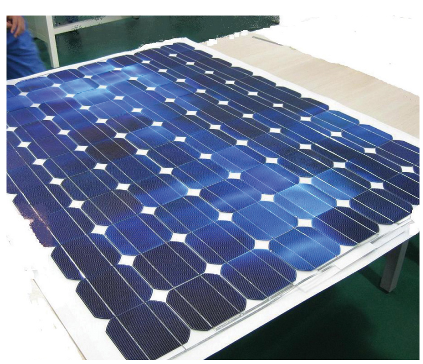
Polycrystalline cells are between 14-19% efficient, which translates into higher space requirements than a monocrystalline array of the same capacity. They are manufactured through pouring raw silicon into a square mold and then cutting the silicon into square wafers. This process is more straightforward and less costly than the method used to produce monocrystalline cells.

Polycrystalline cells have a blue tint, sometimes striated face, and square cells. They usually cost less than mono, and there are premium poly panels available with field-tested efficiency rates between 18-20%.

Solar dealers and contractors typically offer both types of crystalline modules. Depending on the specific installation, a contractor might recommend either type. From a performance perspective, the critical factors are the output and efficiency ratings. High-quality UL® listed panels include ratings based on real-world conditions. These ratings account for fluctuating ambient temperatures and panel aging.



Cell



Module

Array

Crystalline Module Performance in Montana's Environment

In Montana, where the PV industry has been viable for approximately 20 years, the most frequent system problems and warranty replacements involve faulty electronic components and issues such as wiring degradation within the array. PV module defects and breakage issues are rare.

Montana solar contractors report that crystalline modules have demonstrated the ability to withstand the State's weather patterns, including "four seasons" extremes, as well as hail and heavy snow episodes. The most common damage to modules is from ice and snow buildup at the bottom of an array, where freeze/thaw cycles can cause module cracks and breakage.

Amorphous (Thin Film) Modules

Thin-film (amorphous) modules make up between 3-5% of the solar PV market in the United States. Sales are hard to quantify because the thin-film label also identifies crystalline-based products with a compact or non-traditional design or composition.

Thin-film modules are manufactured through a process whereby the photovoltaic elements of the module are adhered to a substrate such as glass, instead of using the complex methods used to manufacture crystalline modules.

The efficiency ratings of thin-film technologies are between 6-9% (or roughly 30-50% of crystalline modules). This efficiency factor translates into the need for two to three times the roof space to produce a similar amount of power compared to a crystalline array.

A survey of thin-film modules also suggests shorter warranty periods and less favorable performance curves as the modules age. There are also amorphous designs that do not have traditional frames around the outside of the module, leading to extra costs when customizing the required support structure.

On the plus side, thin-film modules work well in niche designs and applications and perform well in higher temperatures and low light conditions. In Montana, thin-film modules exist on several small commercial jobs and show favorable performance results.

Thin-film is a technology that continues to evolve, and it has steady support from the solar industry. Some professionals consider new coatings that use proprietary photovoltaic compounds as the next breakthrough in the industry.

New Technologies

The solar PV industry continuously works on solar PV cell and module efficiencies. In the last five years, the average power capacity of a conventional 60 cell residential module has increased from approximately 250 to 335 watts.

At the forefront of the new, more powerful modules are Passivated Emitter and Rear Cell (PERC) modules and bi-facial designs, which capture direct sunlight and ambient and reflected light. The latest "premium" and "premium plus" modules combine higher quality components and metals. They improve efficiency by minimizing cell shading and maximizing available light through proprietary design and construction.

The majority of Montana solar PV contractors are knowledgeable about contemporary solar products and system components. Guidance on the advantages of one module type and design over another for a particular installation is a service a contractor should provide to consumers.

Array Mounting

It's not acceptable to attach solar modules directly to a structure without proper racking, or worse, to lean them on the side of a building or place them on the ground. Appropriate mounting components and techniques are essential for production, structural integrity, and safety.

Engineered module racking is designed to match the structure or pole it attaches to. Racking functions as the structural "backbone" of the array and is crucial to the system's electrical safety.

This section of the publication will address the three options for mounting (roof, ground, pole) and then overview array racks and variables.

Roof Mounts

Modules do not attach directly to the roof surface; instead, the contractor first attaches the array framework or "racking" to the structure. The modules are then attached to the racking.

The National Electrical Code (NEC) and State of Montana building codes govern the regulations for placing the racking and modules. These standards ensure the array's electrical and mechanical compliance and allow for proper airflow and temperature regulation. Modules require roof clearance to prevent high heat conditions that can cause decreased production and lead to electrical failures.

In most cases, the solar contractor mounts the racking and modules with a minor offset but at an equal angle with the roof. There are engineered systems that change the angle or orientation of the modules compared to the roof. These are reliable and can boost performance but add cost to the system.

When considering a roof mount, there are some essential factors that the consumer should analyze. They are:

1. **What is the condition of the roof? The module lifespan will likely exceed that of most roof coverings. How will this impact future re-roofing? If the roof covering needs repair or replacement, should this be completed before the installation?**
2. **What is the composition of the roof covering? As a general rule, wood shake or tile roofs are harder to mount racking on and seal. If the existing roof covering is suspect, consult with a roofing contractor familiar with solar PV mounts.**
3. **What are the tilt angle and orientation of the roof? Also, is there available space for the desired system size?**
4. **Are there existing obstructions impacting the roof that will result in shading? Inventory vent pipes, chimneys, adjacent trees and structures, and wires. Can obstacles be moved or, in the case of trees, be trimmed?**
5. **Can the structure support the load increases of the array? The building permit process includes roof load calculations.**
6. **Can the system be installed and maintained safely? Is there adequate access to and around the proposed array? Does the system allow for access around the modules in the event of an emergency? Building and fire codes require access for emergencies.**
7. **Are there zoning requirements that could influence a rooftop installation? Evaluate adjacent properties and their impact on the system. Include trees that could affect PV production as they grow. Some jurisdictions have solar access statutes that address inter-neighborhood regulations.**

Ground Mounts

Ground-mounted arrays have rows of single height modules, with secure foundations. They are popular in rural residences, agriculture, and dedicated commercial assemblies - or other locations with minimal shade and open space.

An advantage of ground-mounted systems is their design, which allows optimal tilt and orientation. Also, they have adequate airflow and accessible components for installation and maintenance.

In urban areas, public accessibility and vandalism can be a problem. Other challenges are overgrown vegetation, drifting snow, and inter-row shading when there is more than one module row.

The National Electrical Code has regulations for the bulk of safety concerns. The solar contractor must comply with the Code standards, including the security of electrical wiring and components. Compliant ground-mounted arrays safeguard humans, pets, and livestock.

Single Pole Mounts

A single-pole system regularly includes a large diameter (6”-8”) steel pole, engineered for mounting at a considerable depth in the ground, with concrete footings.

In a single-pole system, the entire array attaches to the pole at the desired tilt angle and orientation. The pole can be quite tall, especially when adding ground and safety clearances required in the NEC.

Single-pole systems take up less square footage than ground mounts. As a result, they work in both urban and rural settings. Some designs also include a tilt mechanism that allows for seasonal modifications based on the sun’s altitude.

The cost of the pole, excavation, and footings add to the overall cost of the system. Often a crane or lift is required to place the pole. Maintenance of single-pole systems can be problematic in some cases. The height of the array can require a mechanical lift and the associated rental costs.

Like ground-mounts, achieving optimum tilt and orientation and avoiding shading will optimize production. Some single-pole systems incorporate unique designs that owners find pleasing.

When considering a ground or pole mount, there are some factors that the consumer should deliberate. They are:

1. **What is the likelihood of vandalism or access by children, pets, and livestock?**
2. **What are the additional costs of the ground or pole mount footings, materials, and labor? How will the solar contractor assure cost-effective maintenance?**
3. **Will the ground or pole mount be installed in a location where there could be future modifications, such as outbuildings or roads?**
3. **Is it feasible to connect the PV electricity to existing electrical circuitry?**
4. **Are there zoning or subdivision requirements that affect the installation? Check restrictions relative to “edge of property” rules.**
5. **Can trimming of vegetation and environmental factors such as drifting snow and flooding be resolved?**

Mounting Racks

Just as there are options for solar modules, the racking attached to the roof or pole is available in various designs, materials, and mounting choices.

The primary factor a consumer should examine with the solar contractor is the rack’s compatibility with the modules. Essential elements include the roof or pole type, rack composition, NEC compliance, and aesthetics. The contractor should also offer a warranty for both materials and workmanship.

Array Standoffs Attached to the Roof’s Substructure

Structural Attachments

The racking attaches directly to the roof or pole. The attachment method and hardware varies based on the roof covering or substructure type. One of the severe failure points can be a roof leak due to faulty penetrations. Building inspectors in Montana are diligent regarding structural loading requirements for solar PV systems. In most cases, roof-mounting issues are workable; however, consumers shouldn’t expect a rubber stamp when permitting the array.

Rails/Racking Attached to the Standoffs

Fixed Versus Adjustable Racks

Modules Attached to the Racking

Fixed racks are permanently mounted to a structure or pole framework and are stationary. Most contractors use what is called a “top-down” rail system. This design contains four components:

1. **Feet, called “standoffs” mounted to the roof’s substructure (Customarily, the rafter system).**
2. **Aluminum rails fastened to the standoffs.**
3. **End clips that secure the modules to the racking.**
4. **Junction or mid-clips that join two modules to the mounting rail.**

Top-down systems come in various designs and mount at the same pitch as the roof, with a gap between the racking/module and the roof’s surface. The primary problem with top-down systems is the limited airflow underneath the array and limited access to the rear of the modules. Accessible quick-connect electrical links minimize access problems.

When solar modules cost more, contractors commonly employed components, including manually adjustable racks, to increase the production and ROI of arrays. Today, adjustable racks are used less – instead, contractors recommend fixed arrays containing more modules.

Adjustable racks are still available to consumers, and they will increase production and provide maintenance access and optimal airflow. They are ideal for awning-type installations. The racking can be difficult to install – with smaller tolerances for rafter spacing and layout options. Seasonal adjustments require contractor labor costs, reducing the extra production benefits resulting from the adjusted array.

Tracking Systems

Solar tracking systems, similar to manually adjustable racking, were popular when solar modules were high priced. These trackers, designed for pole and ground mounts, through passive or electrically powered technology, allow the array to track the sun’s path. Manufacturers advertise a 10-25% increase in production over fixed systems.

There are two types of solar PV trackers. The most popular trackers for non-utility applications are single-axis units aligned at a static position north and south but track the sun from east to west (sunrise to sunset).

As the name suggests, dual-axis trackers have mechanisms to allow the solar modules to move in both an east-west and north-south pattern as the day progresses. Dual-axis trackers work well in northern locations where the sun is low in the winter sky and higher during the summer months.

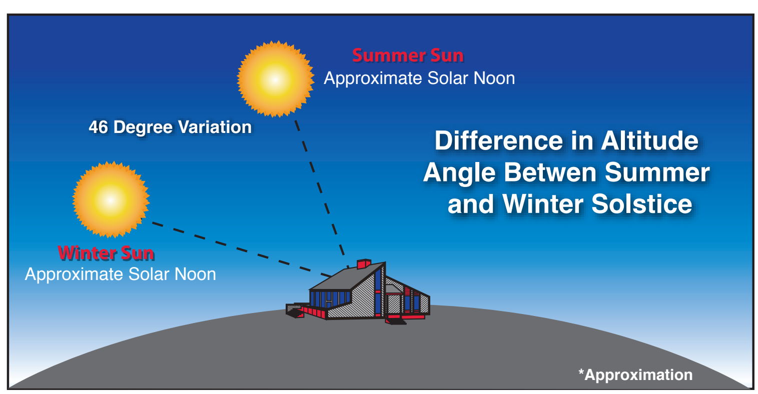
Passive trackers rely on chemicals that move the tracker based on thermal reactions, but consumers have experienced problems with adjustments and performance. Active trackers use motors, gears, and hydraulics, which need maintenance.

Residential tracker performance has improved, and several consumer models are available. In some applications, they remain popular, most notably in utility-scale or off-grid systems. Also, some consumers enjoy watching the array track the sun throughout the day. Consumers should be aware that not all contractors are familiar with tracking system installation and service. A performance and maintenance warranty is a critical request when purchasing trackers.

Capturing the Available Power - “Siting” the PV System

For the consumer, determining where to mount a PV array is as crucial as the system components. Without adequate sunlight, even the most efficient and expensive array will not perform up to expectations.

The main goal of the system mounting (commonly called siting) is to have the array positioned to capture the maximum amount of light energy throughout the day. When the sun’s rays are perpendicular to the array, power production is best. Excluding obstructions, the two factors that impact the percentage of sunlight that hits the modules’ front surface are orientation and angle (tilt).



The direction and angle of the PV array directly relate to the sun's position in the sky and rely upon the sun's azimuth and altitude.

Azimuth is the sun's location on a horizontal plane, east to west, as it moves throughout the day. Altitude is the height of the sun in the sky. Azimuth changes throughout the day, and as important, is seasonal, which accounts for the longest day of the year on June 21st (summer solstice) and the shortest day on December 21st (winter solstice).

Orientation (the direction the array points) corresponds to the azimuth. The optimum orientation is "solar south," which has an azimuth of zero degrees, but this is not always possible. The good news is that an array mounted within 30 degrees of solar south still produces about 90% of an array mounted directly at solar south. On some installations, modules are purposely sited on southeast and southwest surfaces to complement a south-facing array.

The tilt or angle of the array depends on a location's specific latitude. Montana's average latitude is 47 degrees North, which roughly splits the State in half. The northern border is at 49 degrees North, and most of the State's southern border is at 45 degrees North.

In theory, the desired angle or tilt of the array for year-round production will match the latitude at the installation site. A steeper angle would favor winter production (because the sun is lower on the horizon), and a flatter angle would increase summer production.

Most residential roofs have between a 4/12 and 8/12 pitch, or equal to a tilt angle of between 18 and 35 degrees. As discussed earlier, when modules were costly, adjustable racking (roof) or trackers (ground or pole mounts) were popular, but now the standard practice is to use additional modules.

Finally, relative to the sun's azimuth and altitude, the term "solar window" is helpful to understand. This term defines the optimal hours for the production of a southerly facing array. Adjusted for the four seasons, the hours from 9:00 am. - 3:00 pm. represent the ideal year-round time for solar production.

Contractor Solar Site Assessment

Shading impacts many residential sites, and evaluation by sight alone requires observation over an entire year. Fortunately, reputable solar contractors will provide the consumer with an accurate site analysis using equipment and software designed for PV installations.

There are several proprietary site analysis instruments that solar PV contractors use for site assessments. These devices can determine the impacts of shading and potential gains if obstacles are removed or minimized. They also provide projected monthly power output data and other relevant information.

Professionals recommend that consumers request a site assessment that is more than a walk-through or general production estimate. Solar PV systems are a valuable investment, and a realistic production appraisal is essential to the purchase and installation processes.

Converting and Directing PV Produced Power

Inverters, Wiring, Batteries

Balance of System (BOS) Components

Photovoltaic cells produce direct current (DC). With a grid-interactive system, the conversion to alternating current (AC) occurs between the module or array's output circuit and structure's electrical service. An electronic device called an inverter performs this. There can be other electrical interactions within the system; for example, a system with energy storage that channels some of the DC electricity to the batteries.

The industry term for the wiring and components supporting the PV array is the balance of system (BOS). Depending on the specific design, the BOS components can include; wiring, connectors, combiner boxes, disconnects, rapid shutdown devices, and the system inverter(s). If installing a system on NorthWestern Energy's distribution system, an external disconnect switch (EDS) is required for utility personnels' safety.

An understanding of inverter types, functions, and applicability to siting variables is essential for the consumer. In the complete PV system, inverters are second only to modules in cost, and incorrect selection and installation of an inverter can lead to production and safety impacts.

What are Inverters?

America's electrical infrastructure relies on 60-Hertz (Hz) alternating current (AC) power. This hertz value includes the power delivered via the utility grid and the electrical parameters of appliances, lights, and other loads used by consumers.

Because solar cells produce DC power, conversion from DC to AC, called "inversion" in proper electrical terms, is required for grid-interactive systems.

In a grid-interactive system, the essential component in the PV system is the inverter(s). Inverter sizing must meet or exceed the peak output of the array in a string or central inverter system or the production of one or two individual modules in a micro-inverter design.

For use in a grid-interactive system, the inverter must be listed for grid-interactive use. Grid-interactive inverters have supplementary functions, including the integration of utility and solar electricity. NorthWestern Energy requires consumers to use UL® listed, IEEE compliant inverters to ensure the reliability of the electrical grid and safety of utility workers.

There are two distinct types of grid-interactive inverters used in the PV industry - string and micro-inverters. Both apply to residential and small commercial installations.

String Inverters

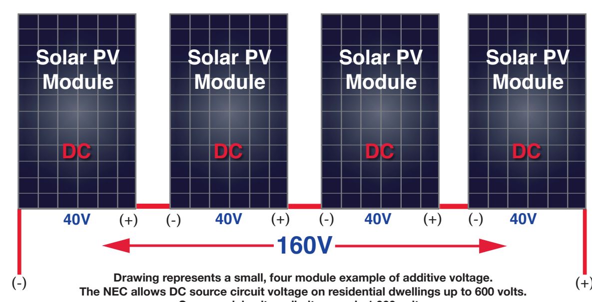
In small-scale applications, the most common inverter type used is a string inverter. Modules connect in a series configuration, and the DC power produced by the modules flows into the inverter at a single point. In a series wiring design, voltages are additive, resulting in up to the NEC threshold of 600 volts direct current (Vdc) voltage to the inverter (residential systems). After conversion, the output to the structure or grid is usually 120/240 volts alternating current (Vac.)

The advantages of string inverter systems are the cost and single component to operate and service. There are various inverter sizes to match the power rating between the array and inverter. The percentage of systems that use string inverters in Montana is approximately 80%.

In a string inverter configuration, the primary disadvantage is that the poorest performing module directly impacts overall system performance. Several factors can contribute to decreased system performance, including; a manufacturing defect in a single module or partial shading from nearby structures, trees, or snow on the array.

PV String Inverter System (Grid Interactive)

Additive Voltage (Series Wiring)



Drawing represents a small, four module example of additive voltage.
The NEC allows DC source circuit voltage on residential dwellings up to 600 volts.
Commercial voltage limit exceeds 1,000 volts.

Micro-inverters

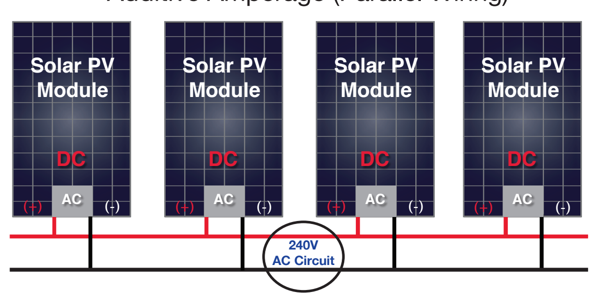
Micro-inverters are distinct from string inverters. They perform the DC-AC conversion at or "attached" to the module and have a parallel wiring design. The voltage remains constant, but the amperage (current) increases as each module connects within the array. AC flows from the array to the PV electrical components and utility point of connection.

The primary benefit of micro-inverter systems is that poor performance in a single module (due to module failure or shading) does not impact the array's production to the same degree that occurs in a string inverter system.

Manufacturers suggest that using a micro-inverter can increase annual electricity production between 10-30%, depending on the site. Micro-inverters are popular with some home and business owners because the addition of modules at a later date is possible without the need to buy additional, expensive equipment. The primary disadvantage with them is a higher initial cost, and in some cases, access for repairs and maintenance can be difficult.

PV Micro-Inverter System (Grid Interactive)

Additive Amperage (Parallel Wiring)



Drawing represents a small, four module example with micro-inverters.
With this type of grid-interactive system, the amperage from module to module is additive and the voltage remains constant.

AC Modules

Modules that have pre-installed micro-inverters are known as AC modules. These modules prevent the installer from performing two separate mechanical and electrical tasks when installing and wiring the module and micro-inverter. Manufacturers of AC modules suggest a 20-40% time-savings for the array module installation.

Several reputable module manufacturers now offer AC modules. They are advertised as a “plug and play” component; however, a licensed electrician must complete portions of the installation, including wiring the AC circuit and connecting to the consumer’s electrical system.

Some manufacturers label AC modules, with integrated micro-inverters, as “smart modules.” Simultaneously, other manufacturers who produce modules with built-in DC optimizers also use the same smart module classification for their products.

Consumers should consult the module specifications for a particular product. The term smart module is a marketing rather than a technical designation.

DC Power Optimizers

DC power optimizers are relatively new to the market, and some contractors recommend them as an alternative to micro-inverters. Unlike micro-inverters, which do not require a string inverter, power optimizers are paired with a string inverter but operate at the module level. When modules produce electricity, the optimizers isolate and condition the voltage at each module before directing the power to the string inverter.

Optimizers minimize string power loss due to shading or other problems. Without them, the connected modules can only produce electricity at the level of the lowest output module on the string.

Solar PV contractors favor using power optimizers when designing systems where not all modules are on the same roof plane or face the same direction. This use allows for increased productivity throughout the day as the sun tracks across the sky.

As a rule, power optimizers cost approximately 50-60% of micro-inverters. A primary disadvantage with power optimizers, compared to micro-inverters, is if the consumer wanted to increase the size of their array in the future, the inverter might require upgrading.

String Inverters (Positive Comparisons to Micro-Inverters)

1. **String inverters cost less per total array capacity.**
2. **String inverters have been tested and improved. Common failure points have been fixed.**
3. **A string inverter mounts at ground level (usually next to the main electrical supply), supporting operation and maintenance.**
4. **String inverter systems typically have lower voltage loss due to the wire and component size.**
5. **There are various string inverter designs and features available to consumers, including system monitoring and feedback.**

Micro-inverters (Positive Comparisons to String Inverters)

1. **Failure of one micro-inverter only impacts the module it services. A string inverter failure affects the entire system. Likewise, shading or damage to a single module in a micro-inverter array has a minimal overall impact.**
2. **For non-conventional applications where modules are placed on surfaces with different orientations, micro-inverter modules are more productive and can be orientated individually, rather than collectively.**
3. **It’s common to add future modules without the cost of purchasing a larger-sized, costly inverter.**
4. **Individual power point tracking assures the optimum performance of each panel. With a string inverter, this is a more difficult task and can add high costs if done at the module level.**
5. **Micro-inverters shut the system down at module level in an emergency or utility disruption. String inverters need additional electrical safeguards to offer the same level of safety.**

A Note on Wiring

Depending on whether the consumer decides on a string inverter or micro-inverter system, the array's wiring scheme varies. Compliant wiring methods are essential for safety purposes - PV systems have high voltages.

Grid-interactive string inverters connect in a series configuration. The positive wire from one module connects to the next negative lead until they combine at the inverter. DC voltages exist up to the NEC limit of 600 Vdc (at the inverter) on residential installations. The NEC allows up to 1,000 Vdc for roof-mounted commercial systems.

Grid interactive micro-inverters or AC modules connect in a parallel configuration. The positive wire from each module connects to the next module's positive lead. Amperage increases with each module's connection, but the voltage remains constant.

Rapid System Shutdown (RSS)

Solar PV systems are power production units regulated by the National Electrical Code (NEC). The State of Montana adopts the NEC and enforces the Code through both local and State compliance networks.

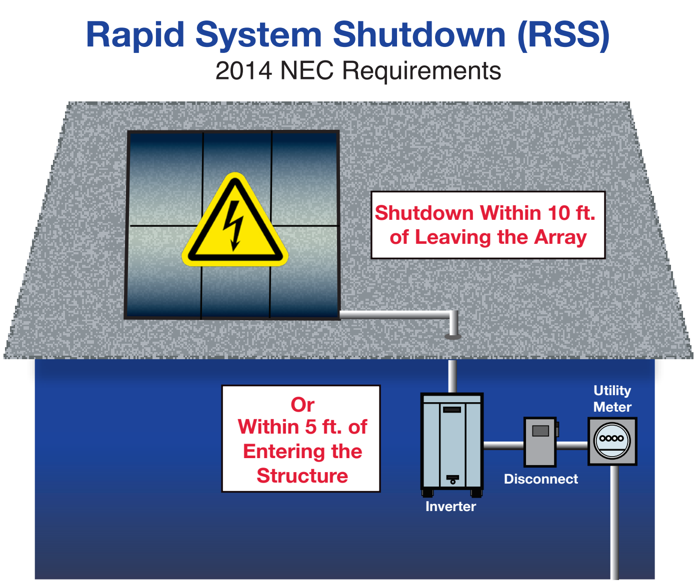
Beginning in the 2014 edition, the NEC placed requirements in the Code for the rapid shutdown of PV systems in the event of an emergency. Without a rapid system shutdown (RSS) mechanism in place, even if the utility electricity is disconnected, energized circuits from the PV array are possible.

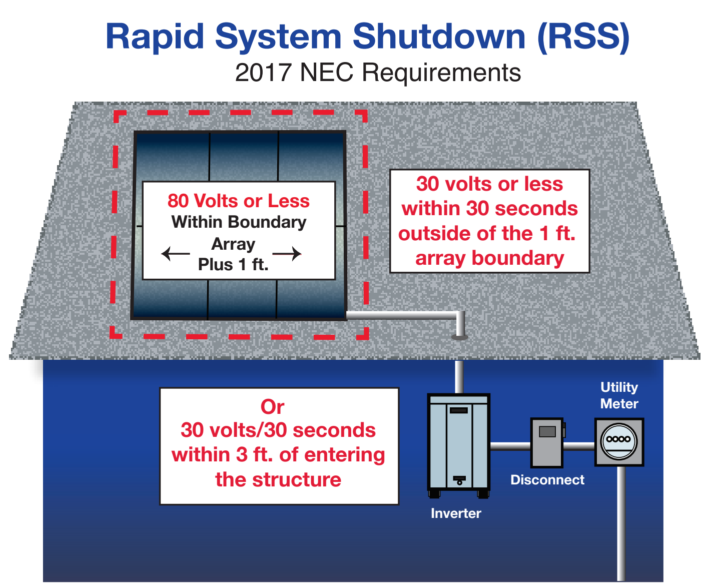
The NEC doesn't require RSS for ground or pole mount systems. Also, arrays with either micro-inverters or power optimizers meet the requirements for rapid shutdown without supplemental controls.

The NEC further modified RSS parameters in the 2017 NEC - with criteria for a more stringent shutdown. Different geographic areas and jurisdictions within the State will enforce either the 2014 or 2017 RSS standards.

It's necessary to ensure the solar contractor includes RSS in the design and bid for a system. RSS components can add cost and should be included upfront in contractor bids.

The specifics of RSS are beyond this publication; however, the two illustrations below highlight the 2014 and 2017 NEC rules.





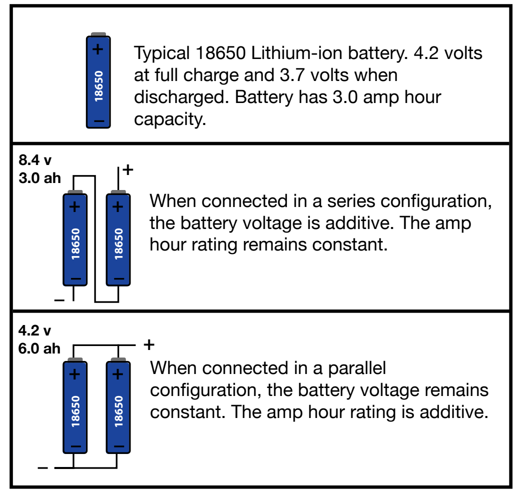
Energy Storage Systems (ESS)

A small percentage of consumers include battery or generator backup for their grid-interactive PV systems. The majority of existing energy storage installations incorporate lead-acid batteries. In Montana, energy storage systems are regulated by; the National Electrical Code (NEC), the International Fire Code (IFC), and International Building Code (IBC). These Codes include both structural and electrical requirements for ESS installations.

Battery systems usually service critical devices in the event of a grid power outage. The PV system might not be able to produce enough electricity, or the outage can occur at night or during a storm, therefore the system includes storage batteries.

The cost and complexity of designing and installing the energy storage system depends on the loads to be serviced and other factors. In many cases, battery storage costs can be high.

Lithium-ion Battery and Connections
The Building Blocks Behind Battery Banks



New to the solar PV market are lithium-ion storage batteries. These can be pre-engineered, pre-packaged products matched to the output of the PV array, or systems that use separate components designed, installed, and connected per NEC regulations. Lithium-ion based energy storage represents one of the renewable energy areas where solar PV professionals expect the most immediate improvement and growth. Expected advancements include technological and safety upgrades, as well as projected cost reductions.

Utilizing the Produced Electricity

Net Metering, Energy Efficiency

The final factor for a successful PV system is the productive use of electricity. For the consumer, this includes understanding the net-metering framework and integrating energy efficiency and conservation measures.

Net Metering

A net metered PV system can either use the electricity from the PV array or the utility and transfer unused PV power back to the utility distribution lines.

Net metering allows the homeowner to self-generate electricity without the expense of energy storage systems or generators; when not utilizing the power from the PV system, it transfers to the grid, and the consumer receives a kilowatt-hour (kWh) credit. Conversely, when the consumer requires utility power, it is provided, and the utility charges for it. To accomplish this, NorthWestern Energy technicians install a net meter. The meter has bi-directional instrumentation that accurately reflects both the consumer's PV production and utility use.

At the end of the monthly billing cycle, if the consumer has generated more power than what they used, the utility provides kWh credits. If the consumer uses more kWh than they produce, the utility collects the difference.

The accounting cycle for NorthWestern Energy net metered consumers extends for twelve months and then starts over - if the consumer has excess credit at the end of the period, it transfers to NorthWestern Energy without compensation.

Consumers can designate the beginning date of their cycle, choosing among January, April, July, or October 1st. This choice enables consumers to select a cycle date based on seasonal usage and their particular system's estimated production pattern. NorthWestern Energy allows consumers to change their cycle date one time after the system is installed.

Before installing the PV system, the consumer must contact NorthWestern Energy and request an interconnection to the utility grid. The interconnection application and process are formal and require the submission of relevant documents from the consumer. The agreement includes technical and safety requirements ensuring utility and public safety and the integrity of the electrical grid.

Energy Efficiency

The complements of producing PV electricity are energy efficiency and conservation. Consumers who combine efficiency and conservation with renewable production have more satisfaction with their PV system performance and total energy "footprint." Energy conservation and efficiency both work to minimize the amount of loss (and waste) from electricity generation to the end-use task. Although the terms are sometimes interchanged, there is a difference.

Energy efficiency is the capability to provide the same level of energy output using less input. For example, if a lamp's output (light) is 75 watts, 100% efficiency would mean that 75 watts of electricity would be required to power the lamp at its rated wattage. However, an incandescent bulb, as an example, might take 150 watts of power input to provide 75 watts of output (light). The lamp would be considered 50% efficient.

A compact fluorescent or LED bulb would satisfy the same wattage requirements at a higher efficiency.

Energy conservation focuses on reducing the use or instances of the need for energy services. Conservation is the result of behavior changes or choices. The term energy conservation was widespread in the late 1970s and early 1980s and was identified with activities like turning down thermostats or shutting off lights. Energy conservation is still a valid control mechanism – what has changed is the ability to mesh efficiency and conservation with updated technology.

From an economic perspective, conservation and efficiency rank high. Professionals estimate that one dollar spent on conservation or efficiency has the same value as three to five dollars spent on alternative electricity production.

There are various efficiency and conservation programs and services for Montana residential and business consumers. These are searchable at the Database of State Incentives for Renewables and Efficiency (DSIRE).

Making A Good Choice

Analysis Steps and Formulas

The preceding pages overview the technical components, site considerations, and available options for PV systems. The capture, transfer and conversion, and efficient use of PV power are the elements of a productive system. Ultimately, the consumer must decide the type, size, and features of the PV system.

Following is a general guide to help in that process.

There are three steps in the decision-making process. 1) determining the electricity use and percentage of the load the consumer wants the PV system to offset 2) analyzing the space requirements for the PV system, and other siting factors 3) calculating the cost of the system.

Step One (Three Parts) - Determining Electricity Use and Desired Offset

Part A - Determine electricity use

The average Montana consumer uses approximately 9,000 kWh of electricity per year. To determine individual home energy use and patterns, review electricity consumption for a one-two year period.

NorthWestern Energy consumers can access two years of electrical usage data by registering for a My Energy Account at northwesternenergy.com.

Part B – Evaluate potential efficiency and conservation measures

Inventory lights and appliances to determine where efficiency measures are feasible (i.e., changing to efficient lighting) and conservation measures such as a family "lights on/off policy."

Part C – Choose the desired system size

Based on the data from parts A and B, determine the average yearly amount of electricity to be offset. Research estimates that most net-metered consumers try to offset between 25-75% of their annual electrical use.

Example

A consumer uses 11,700 kWh of electricity per year, which was determined by reviewing electrical usage for two years. **(Part A)** The consumer also completed an energy audit and calculated that by retrofitting lights and removing several consumptive devices, they could reduce annual electricity consumption by 1,000 kWh per year. **(Part B)**

The estimated electrical use, with the efficiency measures included, is reduced to 10,700 kWh annually. The consumer would like to offset 50% of that usage. 10,700 kWh x 50% equals 5,350 kWh per year. This kWh number represents the required annual output of the PV system. **(Part C)**

Step Two (Two Parts) - Sizing the System Based on Site Characteristics

Siting factors and options are highlighted in the prior sections. Step two takes these into account and helps combine objectivity and sound science with the decision process. For many consumers, characteristics such as available roof space determine the system's size and location. Disregard of planning stage limitations or impediments will lead to problems.

Square footage requirements depend on the rated output (listed in watts) of each module. For crystalline arrays, it is prudent to allow between 100-150 square feet of roof space for each kilowatt of rated output (this also applies to crystalline array ground and pole mounts). Thin-film arrays require between 150-300 square feet for each kilowatt of rated output.

Solar module manufacturers understand space concerns and continue to develop modules that increase production per square foot. In general, modules that have a higher power rating are more expensive.

When considering the variables, it is essential to understand the siting considerations and limitations for a specific location and the options and remedies. A reputable solar contractor should provide these for the consumer during the assessment and bid steps.

Part A – Determine the system size based on Montana's average production per rated kW. For a standard fixed-mount PV system in Montana, the formula used to estimate annual output is; one kilowatt of installed solar produces about 1,300 kWh of electricity per year. The estimate accounts for environmental, seasonal, and time of day factors - however, it is a generalization. For a more accurate estimate, there are online estimators such as PVWatts®. The PVWatts estimate is usually compatible with the kWh output provided by the solar contractor after the site evaluation.

Part B – Analyze space requirements and other siting considerations. After choosing the system size, the next task for the consumer is to evaluate the physical siting factors and constraints.

For some consumers, conditions such as available roof space or obstructions that can't be relocated or removed will determine the size and design of the array.

Example

The consumer wants to offset 5,350 kWh per year. Using the one kilowatt expected annual output of 1,300 kWh, the required system size is determined by taking the desired output (5,350 kWh) and dividing it by 1,300 kWh. (5,350/1,300) or 4.115. The size of the array would be approximately 4.1 kilowatts. **(Part A)**

There is ample, south-facing roof space with adequate square footage to install a 4.1 kW system. The problem is that there is a tree in the front of the yard that will shade sections of the array to different degrees on a seasonable basis. The solutions could include downsizing the system, trimming part of the tree, or installing a micro-inverter or power optimizer system to minimize production losses.

The consumer also has an unused, obstruction-free space that used to be a garden. There is an option to split the system - with a smaller array on the roof and pole mount in the former garden space. Due to the consumer's uncertainty, they will contact several solar contractors to complete a site assessment and provide recommendations. **(Part B)**

Step Three (Five Parts) – Determining the System Cost, Available Incentives, and Payback

Montana consumers regularly consider the economic value of installing a system as one of the principal decision factors. Other reasons influencing the choice are: environmental considerations, the necessity for power during utility outages, and a general interest in solar technology.

Step Three concentrates on the economic value of the system. There are several accounting formulas used in the solar industry relative to solar payback. For this document, calculations use simple payback on non-borrowed funding. Other methods include multipliers for factors such as the predicted increase in energy commodity prices - while others center on valuations such as internal rate of return. Whatever the formula, the consumer should understand the incorporated projections and math.

Part A – Determine the total system cost before tax credits

Although it might seem straightforward and easy, determining the total system cost (TSC) sometimes reveals unforeseen expenses. When working with contractors, consumers should request a complete, detailed bid and specification sheet before the installation begins. (This is a standard offering from quality contractors).

The bid should include the costs for system components, design, permits, labor, maintenance contract fees, excavation or modifications to the structure, and other supplementary costs.

Part B – Research the available tax credits and calculate the net cost of the system.

State and Federal Solar PV tax credits and/or exemptions are currently available for select PV systems – for up-to-date information, consult the State of Montana Department of Environmental Quality (deq.mt.gov) and the Internal Revenue Service (irs.gov).

Part C – Determine the adjusted or net system cost.

Calculate the Net System Cost (NSC) by subtracting tax credits or exemptions from the Total System Cost (TSC).

Part D – Calculate the annual production value of the PV produced electricity

The current NorthWestern Energy kWh price for residential and general service (demand and non demand) electricity is available by calling NorthWestern Energy Customer Service at (888) 467-2669. To determine the PV system's annual production value (APV), the calculation is estimated annual production output (APO) in kWh multiplied by the NorthWestern Energy kWh price.

Part E – Determine the simple payback

Divide the Net System Cost (NSC) by the Annual Production Value (APV) to determine the simple payback (in years).

Example

The consumer estimates an annual production factor of 15% for their 4.15-kilowatt array. The total system cost is $14,525. They are eligible for both a $1,000 State of Montana Tax Credit and a 26% Federal Solar Tax Credit. **(Parts A and B)**

The Completed Simple Payback Calculations

NSC - Net System Cost (Part C)
1. 14,525 (TSC) minus -1,000 (State Tax Credit) = $13,525
2. 13,525 x .26 (26% Federal Tax Credit) = $3,517
3. 13,525 – 3,517 = **$10,008 (NSC)**

APO - Annual Production Output (Part D)
4.15 kW array size x 15% production factor x 24 hours per day x 365 days per year = **5,453 kWh (APO)**

APV - Annual Production Value (Part D)
Annual production output (5,453 kWh) x NorthWestern Energy kWh price of 11.5 cents per kWh) = **$627.10 (APV)**

Simple Payback
10,008 (NSC) divided by $627 (APV) = **15.96 years (SP)**

*** PV system cost is estimated at $3.50 per installed watt (3.50 x 4,150 = $14,525)**
*** Both the Federal Solar Tax Credit and State of Montana Tax Credit figures in the above calculation are subject to change and included for example purposes only.**
*** The 11.5 cents per kWh in the above calculation is for example purposes only. Consumers should contact NorthWestern Energy for current electrical service rates.**

Resources and Important Things to Know

Definitions, Websites, Warranties, Safety

The following definitions and resources help to answer common questions and concerns about PV systems. When having a system installed, the first objective for the consumer is to establish a trusting relationship with the solar contractor. Reputable contractors welcome consumers who ask questions and take the time to learn about solar PV.

Solar PV and Applicable Electrical Definitions

Alternating Current (AC) - The flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that changes direction at a rate of 60 times per second.

Ampere (Amp) - The unit of measure that indicates how much electricity flows through a conductor. For example, a 1,200-watt, 120-volt hair dryer uses 10 amperes of electric current (amps = watts/volts).

Circuit - One or more conductors through which electricity flows.

Direct Current (DC)- The flow of electricity that flows continuously in one direction. Solar PV produced electricity is DC at the cell level.

Interconnection - The linkage of electrical lines between two utilities, or between a utility and an end-user, enabling power to be moved in either direction.

Insolation - The solar power density incident on a surface of stated area and orientation. It is commonly expressed as average irradiance in watts per square meter (W/m2) or kilowatt-hours per square meter per day (kWh/m2/day).

Inverter - A device that converts direct current electricity to alternating current either for customer consumption or to supply power to an electricity grid.

Irradiance - The direct, diffuse, and reflected solar radiation that strikes a surface. Usually expressed in kilowatts per square meter. Irradiance multiplied by time equals insolation.

Kilowatt (kW) - 1,000 watts - A unit of measure of the amount of electricity needed to operate given equipment. For example, a one kW system provides enough power to illuminate 10 light bulbs at 100 watts each. (volts x amps = watts)

Kilowatt-hour (kWh) - The amount of kW produced over a period of time, or one kilowatt of electricity supplied for one hour. For example, a one kW system, if operating at full capacity for 5 hours, will produce 5 kWh of electricity.

Maximum Power Point (MPP) - The point on the current-voltage (I-V) curve of a module, under illumination, where the product of current (amperage) and voltage is maximum.

National Electrical Code (NEC) - Contains guidelines for all types of electrical installations. The 1984 and later editions of the NEC contain Article 690, "Solar Photovoltaic Systems" which should be followed when installing a PV system.

The NEC is adopted by the State of Montana under the Department of Labor and Industry.

Peak Sun Hours - The equivalent number of hours per day when solar irradiance averages 1,000 w/m2. For example, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the irradiance for six hours been 1,000 w/m2.

Solar Resource - The amount of solar insolation a site receives, usually measured in kWh/m2/day, which is equivalent to the number of peak sun hours.

String - A number of photovoltaic modules or panels interconnected electrically in series to produce the operating voltage required by the load.

Utility Grid - The interconnection of electricity generation plants through the transmission and distribution lines to customers. The grid also refers to the interconnection of utilities through the electric transmission and distribution systems.

Utility Interactive Inverter – An inverter that can function only when tied to the utility grid, and uses the prevailing line-voltage frequency on the utility line as a control parameter to ensure that the PV systems output is fully synchronized with the utility power

Volt (V) - The amount of force required to drive a steady current of one ampere through a resistance of one ohm. Electrical systems in most homes and offices use 120 volts. (volts = watts/amps) (volts = amperes x resistance)

Watt (W) - Electric measurement of power at a single point in time, as either capacity or demand. For example, light bulbs are classified by wattage.

System Warranties

The PV system warranty is all-important, can be challenging to understand, and might contain fine print. The system's primary components (modules, inverter, etc.) have separate warranties, and the contractor's installation warranty, if offered, is independent of the manufacturer.

At the contractor level, there usually is a one-two year warranty on parts and labor. In this case, even if the manufacturer's component failure is covered, the contractor will often repair or replace the component with no labor charge. After the contractor's "parts and labor" contract expires, the manufacturer component warranty doesn't always include labor charges. A survey of manufacturer component warranties follows.

Modules Warranties

Most UL® listed modules have a warranty of between 20-25 years. The warranty is based on power output (customarily 80% output for the life of the warranty or pro-rated per year of the warranty).

Module warranties cover electrical performance and damage from normal environmental conditions but do not cover vandalism or misuse. Module failure is rare because there are no moving parts in the design; however, electrical circuitry problems can happen.

Consumers opting for micro-inverters or AC panels should research the details of the module warranty. Because some modules have integral micro-inverters, there can be coverage variables.

Inverter Warranties

Surveyed Montana solar contractors agree the point of failure in a grid-interactive PV system is often the inverter. Inverters have electronics and complex circuitry susceptible to failure. A broken or defective inverter can be both a performance issue and a safety concern.

String (central) inverters are usually warrantied from 5-10 years, although manufacturers suggest that a well-installed inverter has a life expectancy of up to 20 years.

Various manufacturers advertise micro-inverter warranties at 25 years. Some solar professionals question this and believe there is incomplete historical data to justify the warranty period. However, to date, contractors report few problems with the micro-inverter manufacturers when fulfilling warranty responsibilities.

Energy Storage System and Battery Warranties

Battery warranties vary between manufacturers and are often limited or pro-rated. Limited warranties are not due to unethical manufacturers or contractors; instead, they are based on variables such as charge/discharge cycles (use patterns) and factors including compliance with manufacturer ESS installation protocol.

Reputable companies will provide some level of warranty protection for the initial years of battery life - principally to cover manufacturing defects.

Questions to Ask the Contractor Relative to Warranties (All Components)

1. Does the installation contract include a parts and labor warranty from the contractor separate from the manufacturer warranty?
2. In the case of a component failure, is the consumer "on their own" after the contractor's parts and labor warranty expires (but while still under manufacturer warranties)?
3. For manufacturer warranties, what is covered, and to what degree? Examples include; troubleshooting, removing, and replacing components and shipping costs.
4. What guarantee is available if the manufacturer discontinues the component while the warranty is in place?

Assuring Interconnection Safety - NWE's Required External Disconnect (EDS)

A grid-interactive PV system connected to NorthWestern Energy's grid requires a lockable, accessible external disconnect switch (EDS). The EDS must be within ten feet of the utility meter and marked as the utility disconnect.

The EDS's primary purpose is to prevent back-feeding to the utility grid when NorthWestern Energy personnel need to provide emergency services or perform maintenance to the distribution lines connected to a consumer's PV system.

NorthWestern Energy service workers can manually activate and place a lock on the disconnect device. The EDS is supplemental to the preventative controls designed within the inverter and required NEC disconnects.

If the system design includes locating the EDS farther than ten feet away from the utility meter, prior permission from NorthWestern Energy is required. If the utility grants an alternative EDS placement, a weather-resistant placard at the meter, indicating the EDS location, is necessary.

Consumer Safety Considerations

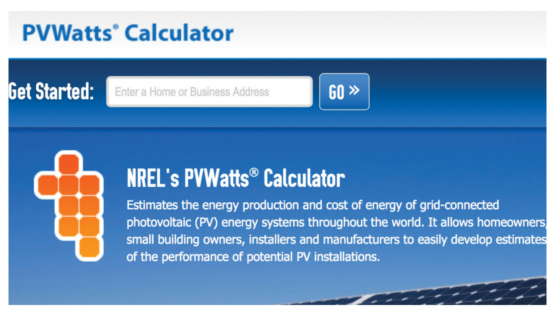
Even smaller PV systems have the potential to cause serious injury to people or structures if installed improperly. The DC voltage "on the roof" to the inverter is often three-five times 120 Vac household voltage. Other components and connections, if not designed and installed correctly, can be hazardous.

Montana Statute requires a licensed electrician to perform the work on circuits that are 90 volts and above; thus, all grid-interactive systems require State licensed electricians. Some established, reputable solar contractors in Montana do not have an electrician on staff but sub-contract the electrical part of the installation to a licensed electrician.

When in operation, the consumer is liable for their PV system's safety and integrity - until then, the contractor is primarily responsible for the crew and public safety. Before hiring a solar contractor, the consumer should request proof of liability insurance, workmen's compensation insurance (for employees), and copies of structural and electrical permits. If in doubt, consumer protection groups suggest contacting insurance providers to ensure the contractor's proof of insurance is valid.

Two Useful Solar PV Internet Resources

PVWatts® and DSIRE™ are two useful PV internet resources. Both receive funding from the United States Department of Energy and provide objective information. The PVWatts® Calculator is helpful in system planning and production estimates, and DSIRE™ is a clearinghouse for renewable energy and energy efficiency incentives and tax information.



The PVWatts® Calculator

The PVWatts® Calculator is a useful and simple online tool to estimate the production of a solar PV system. The user inputs the array's location, design parameters, and economic data. PVWatts® then calculates the output and monetary value of the produced electricity. The application assigns standard production losses to factors such as shading and inverter efficiency.

The calculator provides consumers the ability to quickly look at performance based on different options and sizes and provides a baseline production estimate prior to a physical site assessment from a solar contractor. This baseline information can prevent contractors from overselling based on unrealistic production or unneeded features.

The PVWatts® Calculator is accessible at pvwatts.nrel.gov. To begin, type in the address and zip code (or geographic location) for the system. The application guides consumers through the remaining steps.

Established in 1995 and operated by North Carolina State University, DSIRE™ is the go-to internet source for the range of renewable energy and efficiency incentives and tax credits.

DSIRE™ has tools to help understand the specifics of various tax credits/deductions, incentives, and loans. The site is written and organized in a practical format and provides links to resources with more detailed information. DSIRE™ is accessible at dsireusa.org. Consumers can access Montana incentives and tax credits by clicking on the "MT" section on the site's home map.

NorthWestern Energy Resources

Interconnection Department (Interconnection and Net Metering)

Phone: (406) 497-4165

E-mail: northwesternenergynetmeter@northwestern.com

NorthWestern Energy E+ Energy Efficiency, Renewable Energy and Qualified PV Installer Information

Phone: (800) 823-5995

E-mail: e+programs@northwestern.com

Web Address: northwesternenergy.com/eplus

NorthWestern Energy Customer Service

Phone: (888) 467-2669

Web Address: contactus.northwesternenergy.com