SunWize Tech Notes Compendium: Volume1

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Battery Temperature Compensation

The following is a discussion on battery temperature and the effects of warm and cold weather on battery charging setpoints. If your batteries are exposed to warm or cold weather, it's important that your battery charger has temperature compensation in order to maximize the life of the batteries by assuring that they're receiving the proper voltage in all weather conditions.

What is Battery Temperature Compensation and why is it Needed

The chemistry in lead-acid batteries causes energy to flow more easily in warm temperatures and less easily in cold temperatures. This affects how much energy a battery can absorb during the recharge process. Most charger voltage setpoints are set for room temperature, 25°C [77°F], so if that setpoint is not adjusted for temperature then the battery might get overcharged and gas when it's too warm, or undercharge and sulfate when it's too cold. The end result of either scenario is a battery with a shortened lifespan, sometimes significantly if exposed to extreme conditions.

By adjusting the charge voltages for temperature, the battery can be properly charged in warm and cold weather year round. Some chargers have an internal temperature sensor and some have remote temperature sensors. If the battery charger is in the same enclosure with the batteries and the internal temperature is about the same than an internal sensor is fine. If the charger and batteries are in separate enclosures, then a remote temperature sensor would be more appropriate.

Some chargers have a fixed temperature compensation voltage (e.g. -5mV/°C/cell) and others might have an adjustable setpoint. An adjustable setpoint might be advantageous as different battery manufactures might recommend different temperature compensation values. (e.g. Deka battery recommends -3mV/°C/cell, Concorde recommends -4mV/°C/cell, Crown recommends -3mV/°C/cell, and Rolls recommends -4mV/°C/cell)

How to Calculate the Charge Voltage with Temperature Compensation

In order to find your new temperature corrected charge voltage you need to know 4 things:
1. your nominal system voltage
2. your charge voltage at 25°C [77°F]
3. your temperature compensation value
4. the temperature

Example 1: let's use a 24V system, with a charge voltage of 28.6V, a temperature compensation value of -5mV/°C/cell, and a battery temperature of 40°C.

From the system voltage, there are 12 battery cells (24V / 2V per cell).

-0.005V/°C/cell x 12 cells = -0.06V/°C.

The temperature compensation value is from 25°C, so 40°C-25°C = 15°C x -0.06V/°C = -0.9V + 28.6V = 27.7V.

So the battery charge voltage at 40°C would be **27.7V.**

Example 2: let's use a 12V system, with a charge voltage of 14.1V, a temperature compensation value of -3mV/°C/cell, and a battery temperature of 5°C.

From the system voltage, there are 6 battery cells (12V / 2V per cell).

-0.003V/°C/cell x 6 cells = -0.018V/°C.

The temperature compensation value is from 25°C, so 5°C-25°C = -20°C x -0.018V/°C = 0.36V + 14.1V = 14.46V. So the battery charge voltage at 5°C would be **~14.4V.**

Don't leave your batteries out in the cold without battery charging temperature compensation!

Gel vs AGM Batteries – Which to Choose?

The following is a discussion on some general guidelines and considerations when deciding whether to purchase a Gel or AGM VRLA Battery! While each battery does have certain advantages, for solar applications in general, the quality of the manufacturer and specific battery is usually more important than a Gel vs AGM distinction.

Valve Regulated Lead-Acid (VLRA) batteries come in one of two technology types: Gel (also known as "starved electrolyte") or Absorbed Glass Mat (AGM) (also known as "absorbed electrolyte"). Which is better depends on the manufacturer, the battery specification, and the application. Note the below are generalizations and may depend heavily on the manufacturer. E.g. Deka states their Gel battery is better for deep discharge than AGM, Concorde states the opposite for their AGM battery.

CYCLE LIFE

The cycle life of the battery is dependent on the manufacturer and battery model. As an example: a Deka 8G Gel battery has a cycle life of approximately 1000 cycles to 50% Depth of Discharge (DOD), whereas their 8A AGM battery only has 500 cycles to 50% DOD. Compare this to the Concorde Sun Xtender AGM battery, which is rated to 1000 cycles to 50% DOD. Universal Power Group (UPG) Gel and AGM batteries are both rated for 500 cycles to 50% DOD. In backup power Uninterruptible Power Supply (UPS) applications this is an inconsequential difference, as the battery is almost always floating at a full state of charge and may only cycle a few times a year. However, in solar power system applications, batteries are cycled to some depth of discharge daily, so a higher battery cycle life rating is beneficial.

TEMPERATURE

Most manufacturers agree that AGM batteries operate better in colder climates (below 32°F [0°C]). While it is true that many AGM batteries are able to deliver a higher percentage of rated capacity at lower temperature, Gel batteries are quite capable at lower temperature and many are rated to operate at temperatures as low as -76°F (-60°C). Therefore, what's important is to size the battery appropriately so it can deliver the required amount of energy while operating at lower temperature and to ensure the electrolyte does not freeze.

DISCHARGE RATES

Generally, AGM batteries allow higher discharge rates than Gel batteries. Manufacturers of AGM batteries frequently provide Cold Cranking Amps (CCA) ratings on battery spec sheets. The CCA rating is applicable to powering high current motors to start engines and is not applicable in most solar or UPS applications. Although some solar systems may start motor loads and other surge loads, these surge loads are typically inconsequential to selection of the battery technology.

VRLA BATTERIES ARE NOT SEALED

A lot of people refer to VRLA batteries as sealed, but they are not actually sealed; they are valve-regulated. They contain a pressure relief valve that opens when the internal battery pressure becomes too high, as a result of overcharging. Some smaller AGM and Gel batteries, typically less than 36AH, are truly sealed and have no valve. Both batteries are similar in this regard, so this feature is not a factor in technology selection.
Note: when the valve opens and the gas is released, the gas is gone and cannot be used in the recombination process of recharging the battery, essentially reducing the capacity of the battery. Therefore, it is important to minimize the overcharging and gassing of VRLA batteries.

PRICE

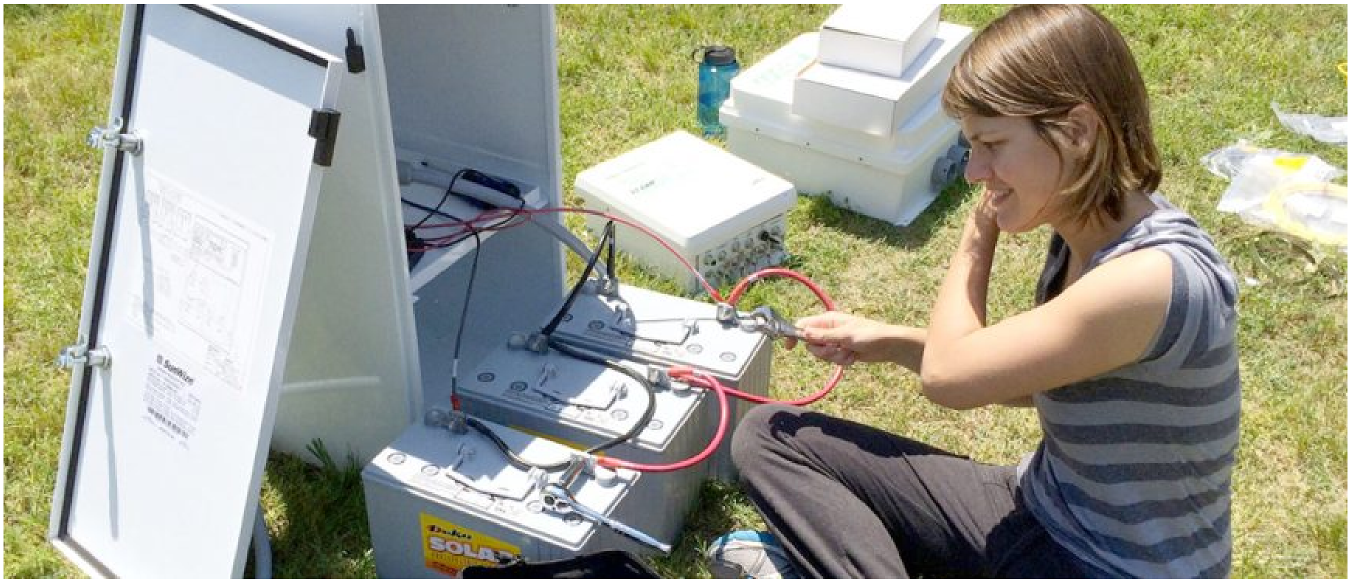
AGM and Gel batteries are competitively priced for a given Amp-hour capacity and cycle life specification. The largest factor influencing the battery price is the life cycle rating of the battery. For example, batteries rated for 1000 cycles at 50% DOD will be higher priced than batteries rated for 500 cycles at 50% DOD.

IN SUMMARY

While each battery technology has advantages for certain solar and UPS applications, in general the battery specifications as evidenced by the battery specification sheet, as well as the experience of the manufacturer, are typically more important than a Gel vs AGM distinction. Given the electrical load and the charging sources, if the battery is sized suitably to deliver the expected design life in consideration of the application operating temperature range, then either Gel or AGM batteries will provide excellent performance. If the application is intended to be in service only a few years, then it may be suitable to select a battery with a lower cycle life rating and to design for higher depth of discharge. On the other hand, to maximize the service life of the battery the battery should be size for shallower average depth of discharge and a battery with a higher cycle life rating should be chosen.

Solar Battery Basics

The following is a discussion on the fundamentals of Valve Regulated Lead Acid (VRLA) batteries in solar applications. There are many important considerations when designing, installing, and maintaining a solar-battery system that should be adhered to in order to maximize the life of your batteries.



INTRODUCTION TO SOLAR BATTERY BASICS

SunWize has been designing and building reliable solar and battery backup systems for leading governments and industrial customers for over 25 years. Our experience working with demanding mission critical applications and harsh conditions gives us unique insight into what it takes to successfully design, build, and maintain solar and battery backup based systems that will work and last!

Topics Overview:

1. Battery Safety
2. Terminology
3. Series vs Parallel
4. VRLA vs Lithium
5. Charging Parameters
6. Cycle Life
7. Temperature Effects
8. Logistics

Want Even More In-Depth Information on VRLA Batteries?

SunWize suggests reviewing the below technical manuals from these leading VRLA battery manufacturers!

- MK Deka – Technical Manual for Sealed Valve Regulated (SVR) Gelled Electrolyte Lead-Acid Batteries
- Concorde – Technical Manual for Sun Xtender Batteries
- Rolls Battery – Rolls Battery Engineering User Manual

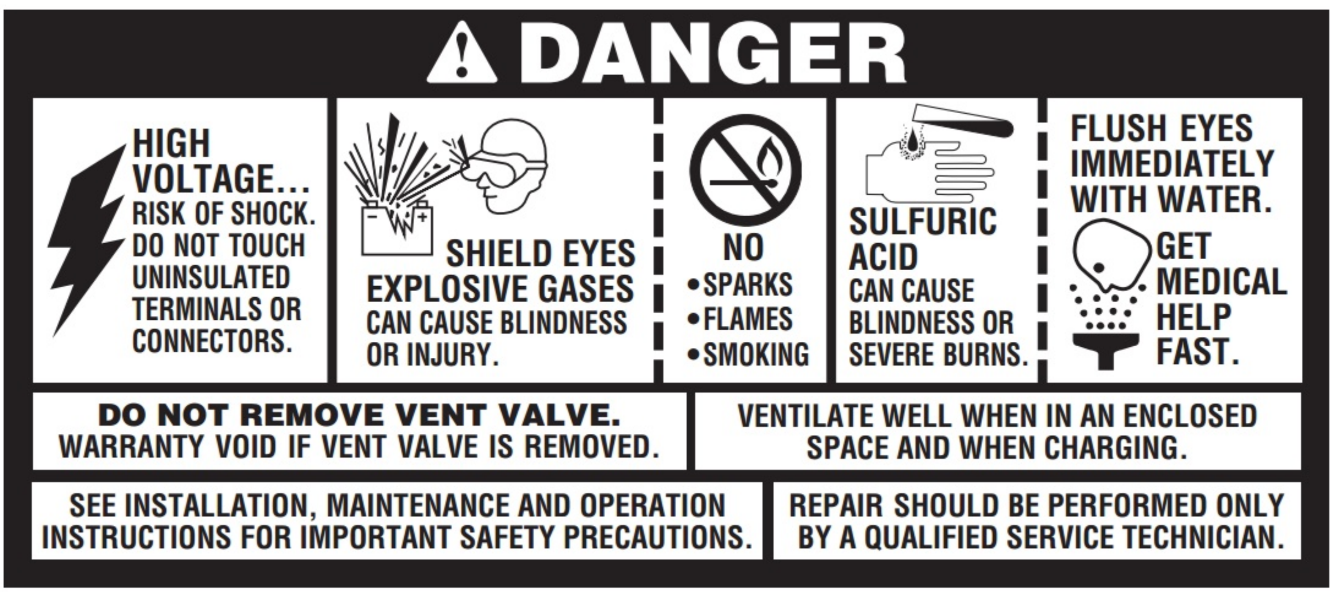
1. Intro to Solar Battery Basics

The first and most important consideration when working with batteries is always safety, as even sealed batteries can have the potential to be harmful, or even deadly, if not treated with proper care.

For a more comprehensive overview of battery safety we suggest reviewing both of the below:

IEEE 937-2007 Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems – Available for Purchase Here

MK Deka – Safety Precautions Section of the Guide to VRLA Batteries



Below Per Excerpts From IEEE 937

Battery Safety Overview
The guidelines discussed below should be followed anytime you're working on or around batteries. Work performed on batteries should be performed with proper protective equipment and tools. Battery installation should only be performed by personnel knowledgeable on required safety precautions.

Safety Gear
The following equipment is recommended for safer handling of lead-acid batteries and protection of personnel:

- Goggles, safety glasses, or other suitable eye protection
- Insulated Grip Tools
- Protective clothing and overshoes, preferably with gloves, that leaves no exposed skin
- Eye-wash stations
- Baking Soda or other acid neutralizer
- Forklift or other lifting device if batteries are very heavy
- Fire extinguisher

Safety procedures
The below are all risks associated with handling batteries. Follow the guidelines below to minimize safety hazards.

Electrical Safety Tips
Electrical shock can occur from batteries if they are short circuited. Use care when handling or in potential contact with battery terminals. Always follow these procedures:

- Do not wear any metallic objects while working with batteries, as these may cause unintended short circuits
- Don't use any metal tools without insulated handles
- Rubber or plastic protective gear can help minimize risk to electrical shock
- Check if battery is unintentionally grounded
- Make sure all loads and charging sources are de-energized before working on batteries

Electrolyte Safety Tips
The electrolyte used in batteries is made of sulfuric-acid liquid. The electrolyte can not only conduct electricity but is extremely toxic. Always follow these procedures:

- Use proper protection for clothing and eye wear
- If electrolyte solutions is exposed to skin, immediately wash it off
- If electrolyte solution is exposed to the eyes, use eye wash station to thoroughly rinse eyes, then reach out for professional medical help
- Always neutralize any spilled electrolyte, using Baking Soda or similar
- Spilled battery acid is a hazardous waste if not properly disposed of
- Any containers that have been in contact with battery electrolyte also need to be properly disposed

Fire Safety Tips
VRLA batteries produce hydrogen gas through a process known as off gassing. Because of this, there is a fire present danger from igniting the hydrogen gas. Always follow these procedures:

- Never put a battery in a completely sealed environment
- Do not smoke near batteries
- Do not have any open flames near batteries
- Touch a grounded metal surface before working with batteries to discharge any static electricity

Handling Safety Tips
Batteries can be extremely heavy. Use appropriate care when lifting and moving batteries by following these steps:

- Verify any lifting devices are adequately rated and functioning properly
- If storing on shelves or racks, make sure they are secure
- Do not drop batteries or allow any significant impacts to battery
- Keep batteries upright

General
Always follow these general tips as well:

- Verify there is clear exit path from battery area
- Keep unauthorized people out of the battery area
- Do not ever place any objects on the top of the batteries (near terminals)

2. Terminology

- ***Ah Charge Efficiency:*** *Ah charge efficiency is calculated by dividing the Ah discharged by the required Ah charged to maintain battery capacity under specific cycle and charging conditions.*
- ***Autonomy:*** *The amount of time a fully charged battery can satisfy the load with no contribution from the photovoltaic array or auxiliary power source.* ***See also:*** *Days of Battery Reserve.*
- ***Battery Conditioning:*** *Battery conditioning charges a battery to its full capacity after performing multiple cycles. Battery conditioning is designed specifically for obtaining maximum new battery capacity.*
- ***Battery Group Size:*** *Most VRLA batteries fall into the internationally adopted Battery Council International (BCI) group's size definitions, such as group numbers 24, 27, 31, 4D, 8D, L16, etc.*
- ***Capacity (C)****: Generally, the total number of ampere-hours that can be withdrawn from a fully charged battery at a specific discharge rate and electrolyte temperature, and to a specific cutoff voltage.*
- ***Charge Controller****: An electrical control device that regulates battery charging by voltage control and/or other means. The charge controller may also incorporate one or more of the following functions: discharge termination, regulation voltage temperature compensation, load control, and status indication.*
- ***Cycle Life:*** *The number of cycles (discharges and recharges), under specified conditions, that a battery can undergo before failing to meet its specified end of life capacity.*
- ***Days of Battery Reserve:*** *The number of days a fully charged battery can satisfy the load with no contribution from the photovoltaic array or auxiliary power source.* ***See also:*** *Autonomy.*
- ***Depth of Discharge (DOD):*** *The ampere hours removed from a fully charged battery, expressed as a percentage of its rated capacity at the applicable discharge rate.*
- ***Discharge Rate:*** *The rate, in amperes, at which current is delivered by a battery.* ***See also:*** *hour rate.*
- ***Dry-Charged Cell:*** *A cell that does not contain electrolyte for ease in shipping or storage, or both.*
- ***End-of-Discharge Voltage:*** *The battery voltage just prior to load termination. EODV will be the minimum voltage for the given discharge cycle.*
- ***Energy Capacity:*** *The energy, usually expressed in watt hours (Wh), that a fully charged battery can deliver under specified conditions.*
- ***Equalizing Voltage:*** *The voltage, higher than float, applied to a battery to correct inequalities among battery cells (voltage or specific gravity) that may develop in service.*
- ***Freshening Charge:*** *The charging of batteries to assure that they are maintained "fresh" in a near-maximum state of charge, and to assure that there is no deterioration of the battery plates due to self-discharge and resulting sulfation. Freshening charges*

are usually performed using the manufacturer's recommended equalization or cycle-service charging voltage.

- ***Hour Rate:*** *The discharge rate of a battery expressed in terms of the length of time a fully charged battery can be discharged at a specific current before reaching a specified end-of discharge voltage.*
- ***Low Voltage Disconnect (LVD):*** *The battery voltage at which the load is disconnected to prevent over discharge. The LVD is the determining factor for the actual maximum allowable depth of discharge and available battery capacity in a PV system.*
- ***Life:*** *The period during which a fully charged battery is capable of delivering at least a specified percentage of its capacity, generally 80%.*
- ***Overcharge:*** *The number of ampere-hours charged divided by the number of ampere-hours discharged times 100. Typical overcharge values are between 105 and 130%.*
- ***Pilot Cell(s):*** *One or more cells chosen for monitoring the operating parameters, e.g., cell voltage, specific gravity and temperature, of the entire battery.*
- ***PV Array to Load Ratio (ALR or A:L):*** *The photovoltaic (PV) array Ah to load Ah ratio is the monthly daily average PV ampere-hours available divided by the monthly daily average load ampere-hours. Average daily PV ampere-hours are calculated by taking the daily average solar resource for each month in kWh/m2 times the PV array current at its maximum power point (Imp) at standard test conditions (STC). Array to load ratios can also be calculated in terms of their respective Watt-hour parameters.*
- ***Rated Capacity (C):*** *The capacity, in ampere hours (Ah), assigned to a cell by its manufacturer for a given constant-current discharge rate, with a given discharge time, at a specified electrolyte temperature and specific gravity, to a specific endof-discharge voltage.*
- ***Regulation Voltage:*** *The maximum voltage that a charge controller will allow the battery to reach under charging conditions. At this point the charge controller will either discontinue charging or begin to taper the charging current to the battery.*
- ***Self Discharge:*** *The process by which the available capacity of a battery is reduced by internal chemical reactions (local action).*
- ***Self Discharge Rate:*** *The amount of capacity reduction in a battery occurring per unit of time as the result of self discharge.*
- ***Standard Test Conditions (STC):*** *The accepted conditions under which PV devices are commonly rated: 1000 W/m2 irradiance at a spectral distribution of airmass (AM) 1.5 and a 25°C PV cell temperature.*
- ***String:*** *Refers to a group of batteries wired together in series to some nominal voltage (usually 12, 24, or 48V). Can also be referred to as a group of solar modules wired in series.*
- ***Vented Battery:*** *A battery in which the products of electrolysis and evaporation are allowed to escape freely to the atmosphere. These batteries are commonly referred to as "flooded."*
- ***Valve-Regulated Lead-Acid cell (VRLA):*** *A lead-acid cell that is sealed, with the exception of a valve that opens to the atmosphere when the internal gas pressure in the cell exceeds the atmospheric pressure by a preselected amount. Valve-regulated cells*

provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption.

3. Series vs Parallel

Wiring solar batteries into the proper configuration is relatively straightforward if you know the rules! When batteries are wired together in Series their voltage is increased but their capacity (Ah) remains the same. When batteries are wired in parallel their voltages remain the same but their capacity (Ah) is increased.

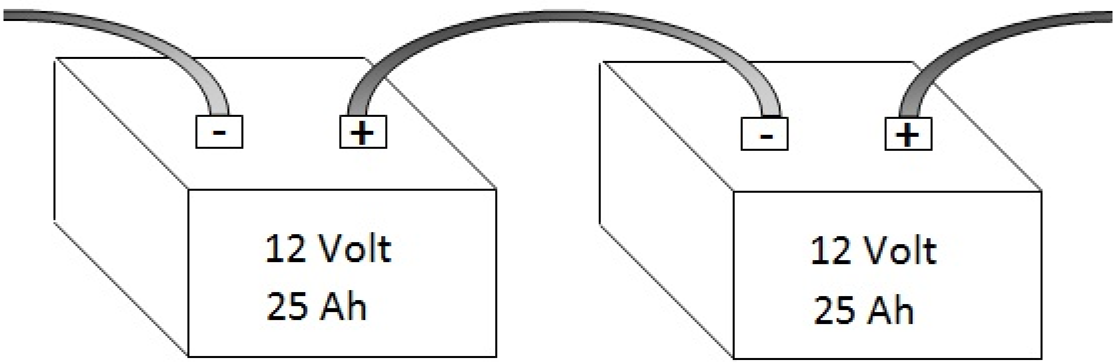
By wiring batteries together in different Series and Parallel combinations, you can achieve a battery bank that gives the appropriate rating (accomplished through wiring strings of batteries together in parallel) at the appropriate voltage (accomplished through wiring your batteries together in strings to the desired design voltage).

Generally, battery banks are wired in nominal 12V, 24V, or 48VDC configurations. In addition, batteries are usually limited to (4) or less strings in parallel (for battery performance and reliability).

Batteries Joined in Series

Connecting batteries in Series will increase the voltage of the battery "string", but will not increase its capacity. For example, two 12V batteries rated for 25 Ah wired together in series will produce a battery string rated for 25 Ah at 24V.

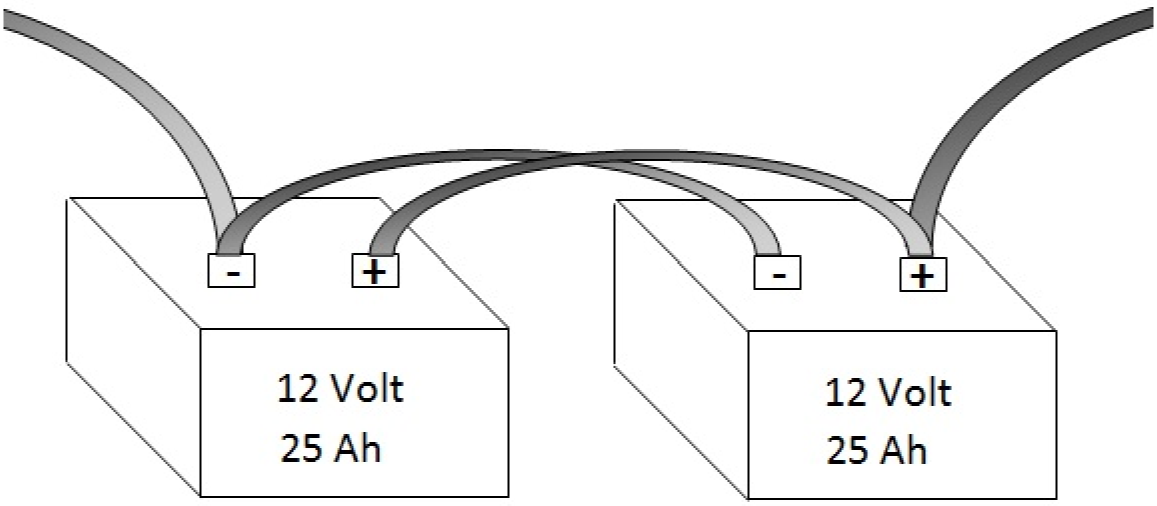
(X2) 12V BATTERIES RATED AT 25AH WIRED IN SERIES = 25AH AT 24V



Batteries Joined in Parallel

Connecting batteries in Parallel will increase the capacity of the battery bank, but will not increase its voltage. For example, two 12V batteries rated for 25 Ah wired together in parallel will produce a battery string rated for 50 Ah at 12V.

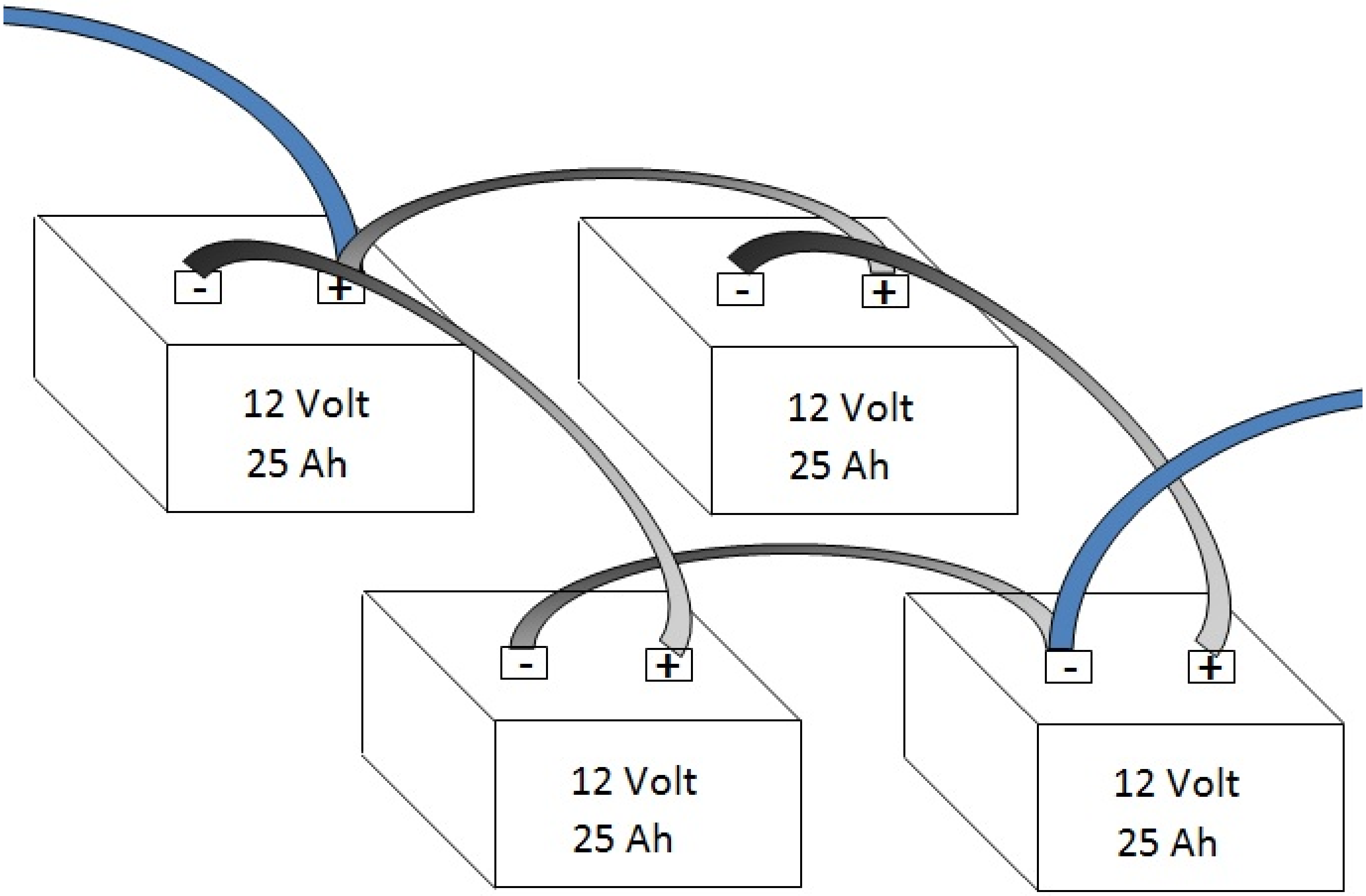
(X2) 12V BATTERIES RATED AT 25AH WIRED IN PARALLEL = 50AH AT 12V



Batteries Joined in Series & Parallel Together

Using the above rules for connecting batteries in series and parallel, batteries can be wired together to form whatever rated capacity the system design dictates. For example, if your design required 50Ah of energy storage at 24VDC, then one possible solution would be (x2) strings of batteries rated at 25Ah each.

(X4) 12V BATTERIES RATED AT 25AH WIRED SERIES (24V) AND IN PARALLEL (50AH) = 50AH AT 24V



Other Wiring Considerations

In general, it’s not recommended to have more than 4 strings of batteries in parallel together. The reason is that internal resistance from wire, connections, etc. can create imbalances in the way currents are shared between batteries. Over time, this causes some batteries or strings to get used more than others and causes them to fail prematurely.

As more batteries are wired in parallel the risk increases for failed connections or batteries. Always remember to use the same wire size and length between batteries, even if it’s possible to use shorter lengths. Keeping the lengths consistent will keep your battery bank charges evenly distributed among strings and batteries! Always make sure your battery connections are clean of debris and corrosion!

When using multiple batteries, it's important to not mix and match different batteries, even if they appear similar! If possible, do not mix new and used batteries either. Any small differences in battery health, chemistry, or target voltages can result in poor performance, failure, or become a safety concern.

4. VRLA vs Lithium

By now nearly everyone is familiar with Lithium Ion Battery Technology and its different variants for consumer technologies. What people are less familiar with are lithium batteries for industrial energy storage applications. Specifically, SunWize receives many questions on the differences between "lead-acid" or "VRLA" batteries and Lithium based batteries, including Lithium Ion (Li) and Lithium Iron Phosphate (LFP). Customers that are exploring these new technologies often want to know if their applications are a good fit for some of these advanced batteries and what the hurdles are.

Morningstar recently released a white paper detailing functionality and settings for using their charge controllers with NEC Energy ALM series advanced Lithium Batteries! We suggest reading this white paper if you're interested in using Lithium batteries in solar applications!

PRELIMINARY CONSIDERATIONS

Whether a traditional VRLA battery or an advanced chemistry battery is right for your application depends on a host of factors. While the below are not exhaustive by any means, we suggest starting here.

LENGTH OF PROJECT

Projects that have intended lives well in excess of typical VRLA battery lifespans are good candidates for advanced battery technology. When factoring in the total lifetime cost of replacing batteries (labor, travel expenses, future batteries), investing in the extra longevity of some advanced chemistry batteries may result in overall cost savings during the life of the project.

COST OF BATTERY REPLACEMENTS

When factoring in the total life cost of a system, remember that there may be unforeseen failures and/or battery replacements beyond just the scheduled replacement interval. If the project is in a particularly hard to reach location, the travel expenditures of replacing a set of batteries may be thousands of dollars for the batteries alone. For projects that involve high cost of travel to the system, spending additional money up-front on longer lasting batteries may save money in the long run!

EXTREME ENVIRONMENTS

Many VRLA batteries are built to withstand extremely harsh conditions. However, the limitations of the battery chemistry mean that in extremely cold and warm environments VRLA batteries have major drawbacks. At extremely cold temperatures (in excess of -15°C) VRLA batteries can and will freeze if experiencing particularly cold temperatures at low state's of charge (SoC). At sustained high temperatures, the life span of VRLA batteries can be significantly reduced. In these extreme temperature conditions, there are some advanced batteries with design temperature ratings well outside of VRLA battery capabilities!

SPACE LIMITATIONS

Sometimes projects or applications are overly constrained with regards to space requirements. In cases where there simply is not room to scale or add additional batteries, going with high power density batteries may be the only way to achieve the required design.

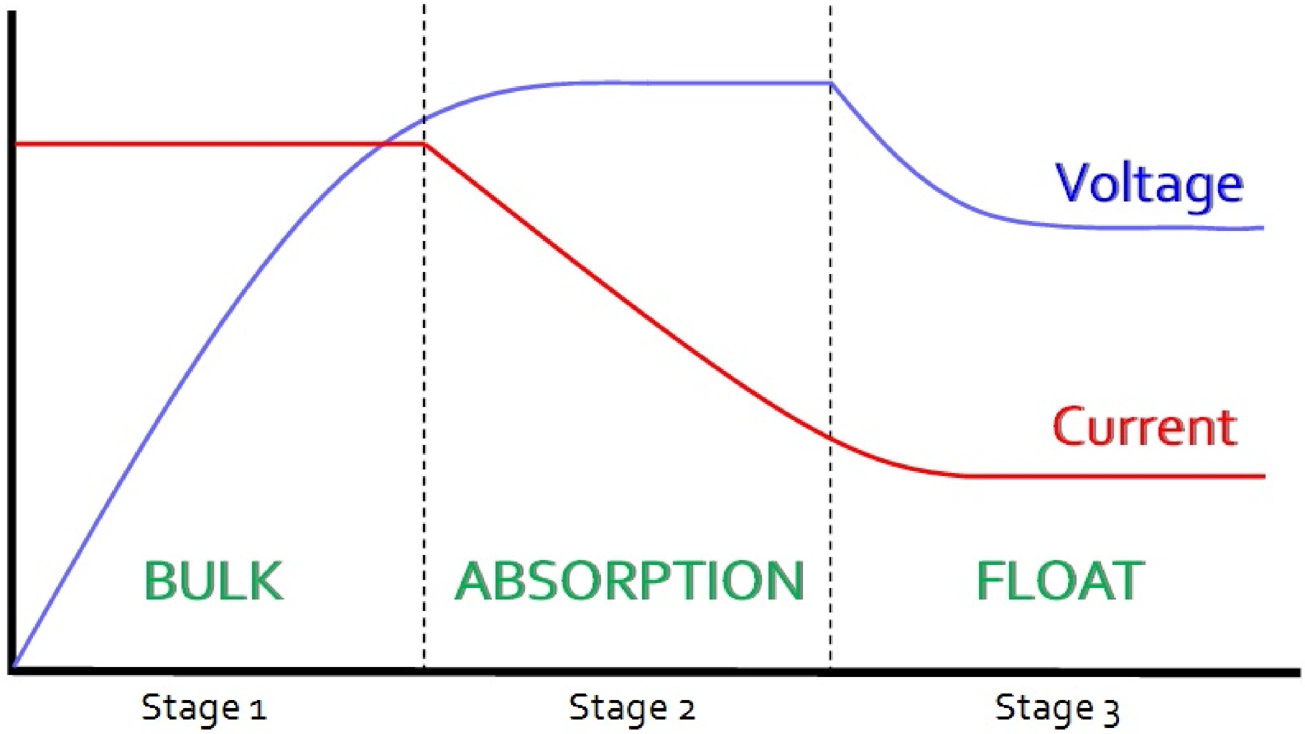
POWER REQUIREMENTS

In certain specialty applications there may be exceptional power input or output requirements for the batteries. For instance, if an exceptionally fast recharge time is required there are many advanced batteries capable of receiving many times the amount of energy as VRLA batteries during charging. Similar, if very fast power discharge is required, while AGM batteries can perform very well at this task, they still will not compare to the power density output capabilities of some advanced batteries.

5. Charging Parameters

Most solar charge controllers and battery chargers operate in 3-stages. These are known as the Bulk, Absorb, and Float stages. Sometimes it's important to understand what the various specific charging characteristics are for individual batteries, how to find that in the manufacturer's literature, and then how to apply that to your system design!

3 Stages of Battery Charging



STAGE 1 – BULK CHARGING

Bulk charging is the first stage of battery charging and occurs when a mostly or completely drained battery begins to get charged. The charging source could be a solar charge controller, a dedicated battery charger, or an inverter-charger in charge mode. In this bulk charging phase the charger is giving the batteries a constant amount of current (shown as the red line on the above chart). As current (amps) flows into the battery over time (horizontal axis), the voltage on the battery begins to rise (blue line).

In Bulk charging the current to the batteries is constant, while the voltage of the batteries Increases. The majority of energy delivered to the battery occurs during bulk charging stage, as the battery is able to receive energy easily when fully discharged. When the battery voltage reaches a sufficient value, the charger moves from Stage 1 Bulk charging into stage 2 Absorption charging.

STAGE 2 – ABSORPTION CHARGING

The second stage of battery charging is Absorption charging. In this stage, the battery voltage essentially stays constant (blue line) while the amount of current (red line) feeding into the battery decreases. At the end of the absorption stage a battery will be fully charged.

While bulk charging is responsible for bringing the battery to 80%-90% of its energy capacity, the remaining 10%-20% is extremely important for the long-term health of the battery in order to prevent sulfur build-up on the battery plates, which significantly affects battery performance and life.

STAGE 3 – FLOAT CHARGING

The third stage of battery charging is float charging. In this stage, the battery has reached a state of full charge and begins to maintain a constant voltage and current in order to keep the battery at the optimized voltage and current for maximum battery longevity.

Charging Times

Many people incorrectly assume that because a battery shows a certain voltage during charging that it must be full! This is incorrect as the voltage on the battery will be affected by the charging source! Only batteries that have been at “rest”, no charging or discharging, for quite some time (several hours to a full day) display a correct voltage.

Typical battery recharge times from an empty state of charge to a full state of charge, when the charging source has unlimited power, are roughly at least 5-7 hours or longer. During this time period the battery frequently reaches 90% state of charge after roughly half the recharge time, and takes the entire other half to gain the remaining 10%. However, as we mention above, this last 10% is extremely important so do not remove the charging source prematurely!

Voltage Setpoints

While most solar and battery charging products will have a default setting for VRLA batteries that should work with your batteries out of the box, sometimes it’s important to understand what the voltage set points are and how they’re used. In cases of custom programming, or unusual temperature environments, it is necessary to understand what the optimal charging set points are for your specific battery. This can be found on either the battery data sheet, or the technical manual for the battery manufacturer. If you’re unsure, we recommend using the set points provide by one of the manufacturer technical manuals at the top of the page. These Gel and AGM settings will work with most Gel and AGM products.

Table 5-1 below from the Concorde Technical Manual lists typical Absorption and Float voltage setpoints for the Sun Xtender line of AGM batteries.

Table 5-1 Recommended Charge Voltage Settings

	Absorption Voltage at 25°C (77°F)	Float Voltage at 25°C (77°F)
Volts per Cell	2.37 - 2.40V	2.20 - 2.23V
For 12V System	14.2 - 14.4V	13.2 - 13.4V
For 24V System	28.4 - 28.8V	26.4 - 26.8V
For 48V System	56.8 – 57.6V	52.8 – 53.6V

The below table from the official MK Deka Charging Parameters document illustrates detailed set point information for Gel batteries.

		Monobloc			2-Volt Cells		
		GEL	AGM	FLOODED	GEL	AGM	FLOODED
Bulk Charge Stage							
Max. Current		30% of $C_{20}^{1.75\ vpc}$ or 6 times $I_{20}^{1.75vpc}$		30% of $C_{20}^{1.75\ vpc}$ or 6 times $I_{20}^{1.75vpc}$	15% of $C_{20}^{1.75\ vpc}$ or 3 times $I_{20}^{1.75vpc}$	15% of $C_{20}^{1.75\ vpc}$ or 3 times $I_{20}^{1.75vpc}$	20% of $C_{20}^{1.75\ vpc}$ or 4 times $I_{20}^{1.75vpc}$
End Condition		**Max Time (Hr) = Ah_r x 1.2 / Avg. Current (A) - Voltage limit equal to "Absorption (Regulation) Stage" limit**					
Absorption (Regulation) Stage							
Constant Voltage		**2.35 - 2.40 vpc**		**2.40 - 2.45 vpc**	**2.37 - 2.42 vpc**	**2.35- -2.40 vpc**	**2.40 - 2.45 vpc**
	12V	14.10V - 14.40V		14.40V - 14.70V	14.22V - 14.52V	14.10V - 14.40V	14.40V - 14.70V
	24V	28.20V - 28.80V		28.80V - 29.40V	28.44V - 29.04V	28.20V - 28.80V	28.80V - 29.40V
	48V	56.40V - 57.60V		57.60V - 58.80V	56.88V - 58.08V	56.40V - 57.60V	57.60V - 58.80V
End Condition		**Charge until change in current < 0.10A per Hr / Max Time: 12Hr**					
Float Charge							
Constant Voltage		**2.24 - 2.26 vpc**		**2.30 - 2.35 vpc**	**2.25 - 2.30 vpc**	**2.24 - 2.26 vpc**	**2.30 - 2.35 vpc**
	12V	13.44V - 13.56V		13.80V - 14.10V	13.50V - 13.80V	13.44V - 13.56V	13.80V - 14.10V
	24V	26.88V - 27.12V		27.60V - 28.20V	27.00V - 27.60V	26.88V - 27.12V	27.60V - 28.20V
	48V	53.76V - 54.24V		55.20V - 56.40V	54.00V - 55.20V	53.76V - 54.24V	55.20V - 56.40V
End Condition		**No Time Limit**					
Equalize Charge							
Constant Voltage		**2.40 - 2.43 vpc**		**2.50 - 2.55 vpc**	**2.43 - 2.48 vpc**	**2.40 - 2.43 vpc**	**2.50 - 2.55 vpc**
	12V	14.40V - 14.60V		15.00V - 15.30V	14.58V - 14.88V	14.40V - 14.60V	15.00V - 15.30V
	24V	28.80V - 29.20V		30.00V - 30.60V	29.16V - 29.76V	28.80V - 29.20V	30.00V - 30.60V
	48V	57.60V - 58.40V		60.00V - 61.20V	58.32V - 59.52V	57.60V - 58.40V	60.00V - 61.20V
End Condition		**Charge until change in current < 0.10A per Hr / Max Time: 12Hr**					
Temperature							
Temperature Coefficient		**-3 mV / cell / °C[1]**					

Are My Batteries Charged?

The below table from the MK Deka Technical Manual helps to easily illustrate corresponding State of Charge (SOC) values, or how much energy is in the battery, with the battery voltage. In summary, battery voltages that are between 12.6V to 12.8V are at or near full state of charge. Batteries that are between 11.8V to 12.0V are at or near an empty state of charge.

Note the manufacturer recommends leaving the batteries "at rest", no charging or discharging, for a full 24-hours before testing the battery voltage!

Open Circuit Voltage vs. State of Charge Comparison*

% Charge	Open Circuit Voltage Flooded	Gel	Absorbed
100	12.70-12.60	12.80-12.70	12.90-12.80
75	12.40	12.50	12.60
50	12.20	12.20	12.30
25	12.00	12.00	12.00
0	11.80	11.80	11.80

NOTE: Divide values in half for 6-volt batteries.

** The "true" O.C.V. of a battery can only be determined after the battery has been removed from the load (charge or discharge) for 24 hours.*

6. Cycle Life

The most defining characteristic of a solar battery is its cycle life. The "Cycle Life" of a battery refers to the number of times a battery can go through a full charge discharge cycle, *to a specific discharge level*. The last part is particularly important as batteries have different cycle life's depending on how deeply they're discharged! A battery that is always discharged to 80% Depth of Discharge (DOD) during each cycle will last much less time than a battery that is only discharged to 20% Depth of Discharge (DOD) each cycle. Of course, the battery that's discharged to 80% will give you significantly more energy than the battery discharged to 20%!

The reason Cycle Life is so important to solar battery systems is that solar battery systems cycle daily (during night when the sun goes down and during extended periods of cloud cover).

In contrast, batteries in many other applications, such as those attached to the grid, may only cycle very infrequently, such as when there's a power outage.

Therefore, if using batteries in a solar powered application, make sure they're designed specifically for solar applications and list a Cycle Life rating. If the battery does not have a Cycle Life rating, it is likely not designed for solar applications and will fail prematurely compared to a battery that is designed for cycling applications.

High quality solar batteries that are designed and operated properly should expect lifespans between 5-8 years. If your batteries are lasting significantly less than this it's usually because of some combination of:

- Low quality battery or not designed for solar applications
- System not properly designed resulting in over discharged battery
- Not properly maintaining battery health, such as quickly recharging to full health after a low voltage disconnect (LVD) event.

Premium VRLA batteries often are rated for 1,000 Cycles or more at a 50% Depth of Discharge rating. Some advanced VRLA batteries are higher than this, but it's generally not by a tremendous amount, Other advanced chemistry batteries, such as Lithium Ion or LFP, on the other hand, may have Cycle Life ratings as high as 10,000 cycles or more.

7. Temperature Effects

Temperature has a major effect on battery performance. Both low temperatures and high temperatures can significantly impact battery performance, both in the short term, as well as, the long term. Extreme temperature's, if not properly designed for, will almost certainly result in battery failures.

In addition to the general effects of extreme cold and warm weather on batteries, charging devices may have additional temperature compensation features that should be set. To see detailed information on this, review our Battery Temperature Compensation Tech Note.

Cold Weather

Cold temperatures primarily affect batteries by limiting the amount of energy that is able to be released. While a typical battery may have 50 Ah of usable energy at room temperature, that same battery may only have 25 Ah of usable energy at -15°C. Therefore, if installing batteries in climates where extended temperatures are significantly below ambient, it's important to apply a proper temperature de-rate to the battery so that, even in the coldest weather, you have the appropriately designed amount of energy storage available. If the system requires 200 Ah of usable energy storage to operate properly, but you install it in an environment that de-rates that battery energy in winter from 200 Ah to 100 Ah, then you only have half the required energy in your system design!

The below Table 6-3 from the Concorde Technical Manual illustrates temperature de-rates for AGM batteries. Note that in addition to cold temperature de-rate affects, batteries can also “freeze” if discharged too far in cold weather. Therefore, when designing batteries in extremely cold weather, take into account both the freezing point and the appropriate de-rate values!

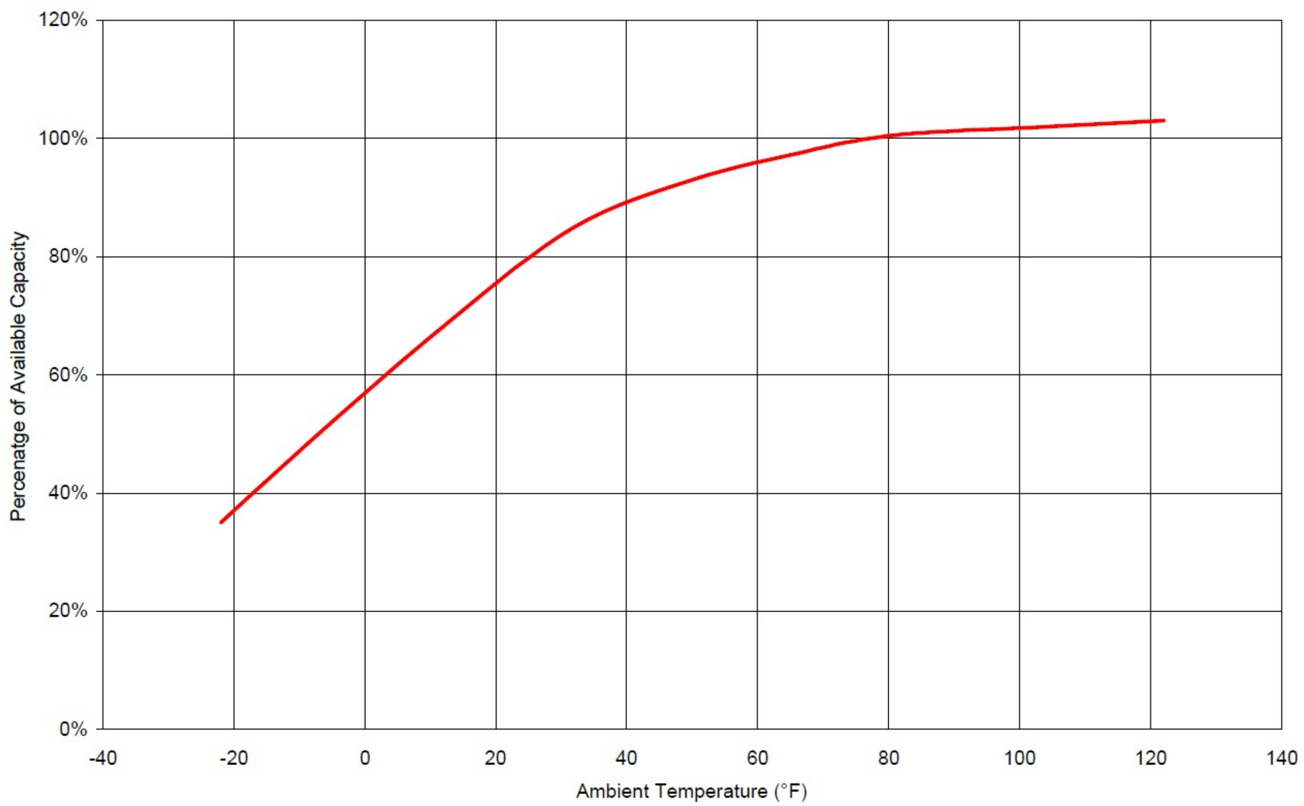
Table 6-3. Recommended Design Factors for Battery Sizing

Lowest Battery Temperature Averaged over 24 Hours		Design Factor for 80% End of Life	Design Factor for 50% End of Life
Degrees C	Degrees F		
25 or above	77 or above	1.25	2.00
20 to 24	68 to 76	1.39	2.22
10 to 19	50 to 67	1.43	2.29
0 to 9	32 to 49	1.60	2.56
-10 to -1	14 to 31	1.84	2.94
-20 to -11	-4 to 13	2.23	3.57
-30 to -21	-22 to -5	2.84	4.54
-40 to -31	-40 to -23	4.17	6.67

The below chart from MK Deka illustrates the same information as Table 6-3, but gives the de-rate values rather than the design factor values (simply the inverse of eachother). Table 6-3 is an excellent reference point for AGM batteries while the below chart from MK Deka is a great reference point for Gel batteries.

Example: at -15°C the de rate value according to MK Deka is ~50%, therefore you would need 2x the rated battery capacity at these temperatures (rated capacity divided by 50% = 2). According to Table 6-5, between -11°C and -20°C (roughly the same temperature), the design factor is 2.23x, or very close to the 2x value for the Gel battery.

Capacity vs Operating Temperature Gel Batteries



Hot Weather

Hot temperatures primarily affect batteries by decreasing the overall lifespan of the battery. In general, for every 13°F above ambient, a battery will experience a 50% total loss of lifespan. Therefore, at sustained temperatures of 107°F (30°F above ambient of 77°F) a battery will last only 25% of its rated life!

In addition, off gassing, thermal runaway, and other issues related to extreme warm climates also exist. In these cases, the batteries are generally actively cooled or buried underground for passive cooling.

8. Logistics

For information related to packaging and shipping VRLA batteries, see our Solar Battery Recycling & Storage page for more info!

Solar Charge Controller Types

This page will provide an overview of different charge controller types and their uses. Knowing what type of charge controller you have and how it operates can help you to troubleshoot and understand if your controller is functioning correctly.

PRIMARY FUNCTION

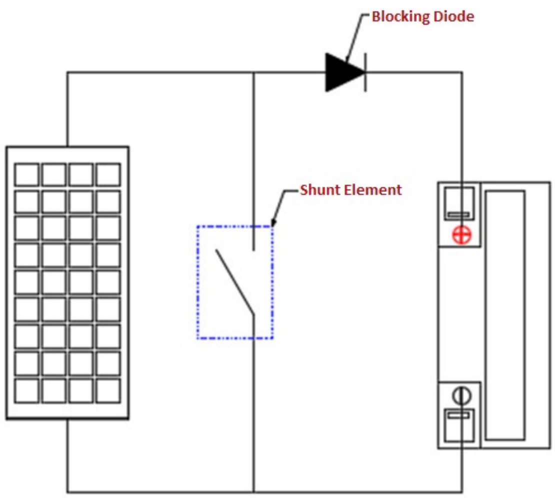
The primary function of a solar charge controller is to prevent the battery from being over/under charged by the solar array. Most charge controllers have various setpoint points for regulation based on battery voltages; these setpoints can be fixed or variable. Variable setpoints can be adjusted by potentiometers, dipswitches, jumpers, displays, computers, and other means. The charge setpoints should be adjusted for temperature with either a local or remote temperature probe.

MOST CHARGE CONTROLLERS ARE A VARIATION OF ONE OF THESE FOUR BASIC TYPES:

- Shunt Regulator
- Series Regulator
- PWM Regulator
- MPPT Charge Controller

SHUNT REGULATORS

Shunt regulators function by short circuiting the solar array when the battery reaches a set voltage. When the battery voltage drops, the array is un-shorted and current is allowed to flow to the battery again. This is also sometimes referred to as a pulse regulator, since the current can be "pulsed" to the battery as the array current is regulated. As the charge regulation is either on or off, it's simply a single stage charge controller. As the regulator sees the full current from the array during regulation, the shunt regulators get hot and are generally only used for small arrays.



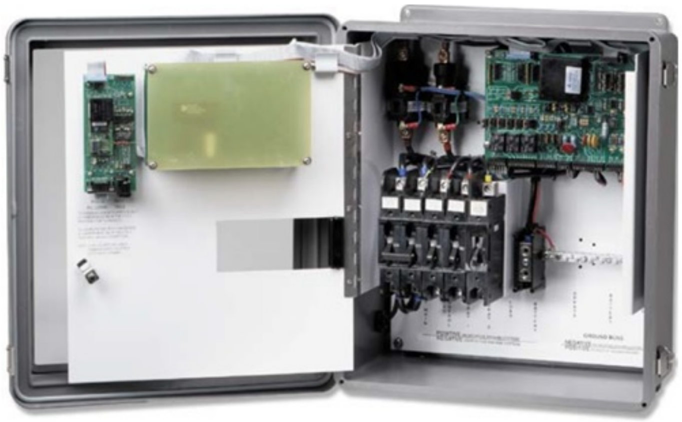
Shunt regulators function by short circuiting the solar array when the battery reaches a set voltage. When the battery voltage drops, the array is un-shorted and current is allowed to flow to the battery again.
This is also sometimes referred to as a pulse regulator, since the current can be "pulsed" to the battery as the array current is regulated. As the charge regulation is either on or off, it's simply a single stage charge controller.

As the regulator sees the full current from the solar array during regulation, the shunt regulators get hot and are generally only used for small solar arrays.
Shunt regulators are on/off type controllers. This means the solar array is either on or off; the battery sees the full charge current available or none. The regulator allows current from the array to flow to the battery until the disconnect voltage is reached, at which time the solar array is shorted, preventing any further current to flow to the battery. Without any charge current, the battery voltage will drop until the reconnect voltage is reached at which time the regulator will allow current to flow to the battery again. The battery voltage will rise and the cycle will repeat.

When the shunt regulator shorts the array during regulation, measuring the array voltage during this time will yield an array voltage that should be less than 1V. During normal charging, the array voltage should be slightly higher than the battery voltage (battery voltage + the voltage drop from diodes or transistors). If array open circuit voltage was ever measured during normal operation, this would indicate a problem.

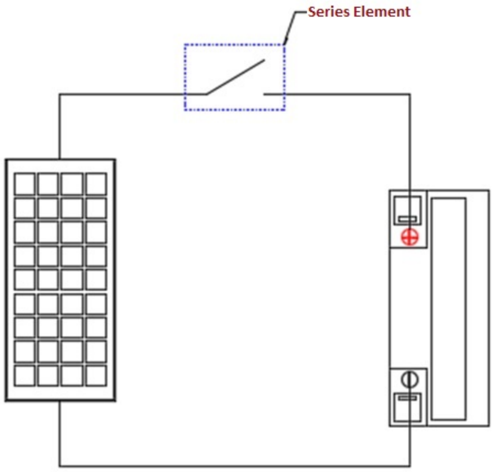
SERIES REGULATORS

Series regulators function by open circuiting the solar array when the battery reaches a set voltage. When the battery voltage drops, the array is reconnected and current is allowed to flow to the battery again.Series regulators generally use a relay or transistor to connect and disconnect the solar array.



As the relay (or transistor) can be placed in either the positive or negative line, Series regulators can be used in positive and negative ground systems.
Series regulators (similarly to shunt regulators) are on/off type controllers. The solar array is either on/off, so the battery sees the full charge current or none. The regulator allows the

current from the array to flow to the battery until the disconnect voltage is reached, at which time the solar array is disconnected (open circuited) and prevents any further current to flow to the battery.



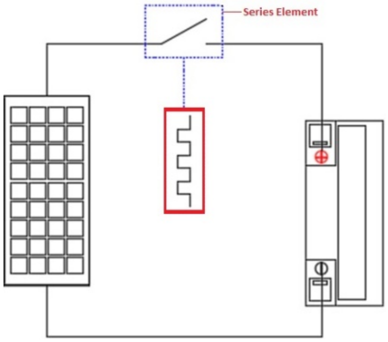
Without any charge current, battery voltage will drop until the reconnect voltage is reached, at which time the regulator will allow current to flow to the battery again. The battery voltage will rise, and the cycle will repeat. It is sometimes referred to as a pulse regulator, since the current can be “pulsed” to the battery as the array current is regulated. The duration of the pulses can be from hours to seconds depending on: battery SOC & health, load current, temp., etc.

Unlike shunt regulators, some series regulators can control multiple relays (or transistors), allowing for multiple disconnect/reconnect set points and stepped charge current. If the series regulator has a single relay, it is simply a single stage charge controller. Additional relays with different set points can make the regulator a multi-stage controller.As the regulator opens the solar array to regulate the battery voltage, series regulators run much cooler than shunt regulators (especially if a relay is used instead of a transistor). For this reason, series regulators are well suited for large solar arrays.

When the series regulator opens the array during regulation, measuring the array voltage during this time will yield an array voltage that should be close to the open circuit value. During normal charging, the array voltage should be slightly higher than the battery voltage (battery voltage + the voltage drop from diodes or transistors). If an array voltage value is less than the battery voltage was ever measured during normal operation, this would indicate a problem.

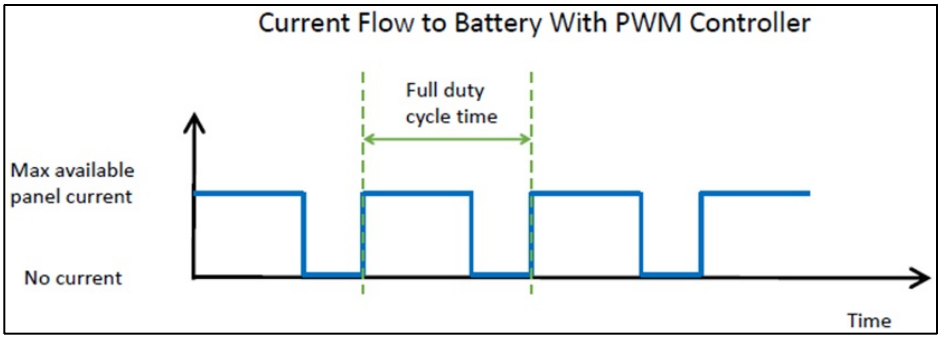
PULSE WIDTH MODULATION (PWM) REGULATOR

PWM regulators are similar to series regulators, but they use a transistor instead of a relay to open the array. By switching the transistor at high frequency with various modulated widths, a constant voltage can be maintained. The PWM regulator self-adjusts by varying the widths (lengths) and speed of the pulses sent to the battery. Unlike the on/off charge controllers which instantaneously cut off the power transfer to minimize battery overcharging, PWM regulators act like a rapid on/off controller constantly.



When the width is at 100%, the transistor is at full ON, allowing the solar array to bulk charge the battery. When the width is at 0% the transistor is OFF, open circuiting the array preventing any current from flowing to the battery when the battery is fully charged.

Like the series regulator, the transistor can be placed in either the positive or negative line, allowing the regulator to be used in positive and negative ground systems.The difference between the series regulator and the PWM regulator is the PWM of the transistor. When the modulation width is at 100% or 0%, the regulator is essentially a series regulator, it is that modulation width variation that allows the PWM regulator to create a constant voltage to the battery as opposed to the on/off of the series regulator. The below figure shows an example of a PWM regulator regulating with a 70% on 30% off duty cycle.



Some PWM regulators have provisions for converting to a series (on/off) regulator. This could be needed for sensitive loads that have an issue with the noise created by the frequency of the PWM. Some PWM regulators have provisions for converting to a series (on/off) regulator. This could be needed for sensitive loads that have an issue with the noise created by the frequency of the PWM. Because PWM charge controllers require transistors, they are always solid-state; this means heat dissipation can become a problem, especially in larger solar arrays.

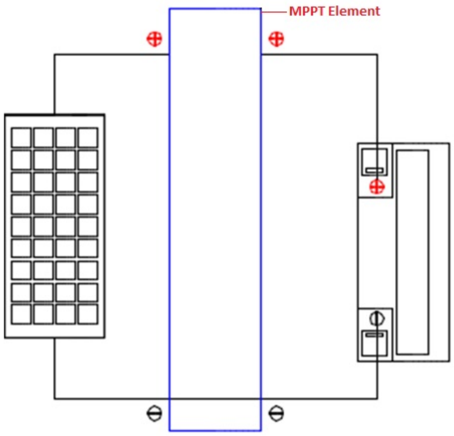
As with series regulators, because the PWM regulator regulates by opening the array during regulation (at high frequency), if you were to measure the array voltage during this time, the array voltage can be anywhere between battery voltage and open circuit voltage depending on the regulator’s charging stage. If an array voltage value less than the battery voltage was ever measured during normal operation, this would indicate a problem.

MPPT CHARGE CONTROLLER

The Maximum Power Point Tracking (MPPT) charge controller takes the PWM to the next level, by allowing the array voltage to vary from the battery voltage. By varying the array input, the charge controller can find the point at which the solar array produces the maximum power.

The MPPT process works like this. Imagine having a battery that is low, at 12 V. A MPPT takes a voltage of 17.6 volts at 7.4 amps and converts it down, so that what the battery gets is now 10.8 amps at 12 volts.

MPPT controllers takes the DC input from the solar panels, convert it to high frequency AC, and then change it once again to a different DC voltage and current. The point is the voltage will exactly adhere to the requirements of the battery. As the MPPT charge controller uses the negative line as a reference and then switches the positive line, they can be used in negative ground systems only. It is crucial to understand that voltage is a potential difference; the 'difference' refers to the difference between ground potential and some potential. This means that the starting point is below zero, but this is only used as a reference point.



Since MPPT charge controllers can vary the charge current to the battery, the regulator can be a multi-stage charger with bulk, absorption, and float settings. They are always solid state; this means heat dissipation can become a problem, especially in larger solar arrays. MPPT controllers are typically step-down converters, so the array voltage always needs to be higher than the battery voltage. Therefore, an array voltage value less than the battery voltage during normal operation would indicate a problem.

CONCLUSION

Charge controllers are arguably the most important components of off-grid solar systems. Without them, batteries would be overwhelmed and unable to keep up with the dynamic changes in energy that come from solar panels. When choosing the correct charge controller, it is important to keep in mind the specifics of the project at hand; each controller is applicable for various scenarios and like most things in life requires trade-offs.

Power over Ethernet

The following is an overview of the components of Power over Ethernet and ensuing complications associated with Power Sourcing Equipment.

INTRODUCTION

Power over Ethernet (PoE) describes standardized systems which pass electrical power and data along twisted pair Ethernet cabling. PoE-enabled devises allow for a single connection that provides both data connection and electrical power, instead of the traditional power connection and separate network connection.

COMPONENTS OF POWER OVER ETHERNET SYSTEMS

1 INJECTORS

PoE injectors supply data and up to 30 watts of power to PoE-enabled devices such as network cameras and wireless access points.

2 SWITCHES

PoE switches are network switches with a PoE injector built-in and are designed to expand the network created by a router.

3 EXTENDERS

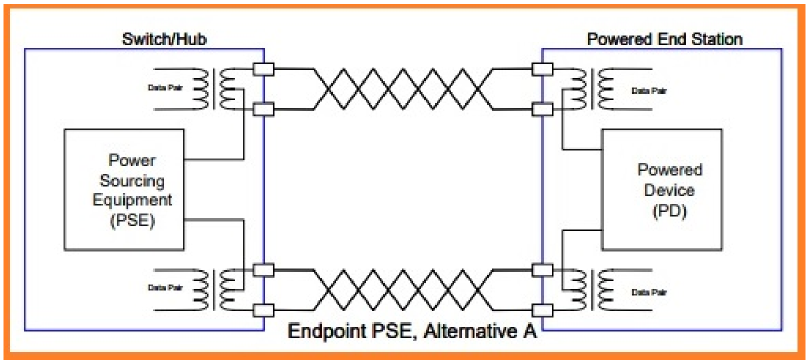
PoE extenders can extend the distance for PoE-Powered network devices

COMPLICATIONS WITH POE POWERED DEVICES AND POWER SOURCING EQUIPMENT (PSE)

A common issue experienced by users revolves around the complications with PoE powered devices and PSE. It is first important to understand that there are several standards for injecting power: two sub-standards associated with 10 Base T and 100 Base TX being IEEE 802.3af Alternative A and Alternative B.

ALTERNATIVE A

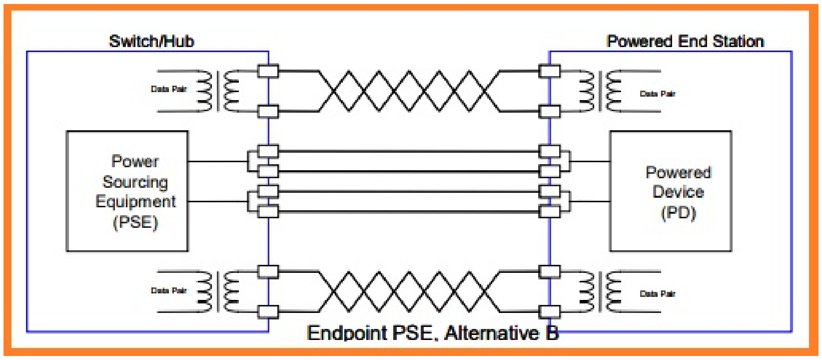
- Runs power on the same wires as data–power may be transmitted on the data conductors by applying a common voltage to each pair
- Positive voltage runs on pins 1 and 2
- Negative voltage runs on pins 3 and 6



~Using a technique similar to the phantom method, Alternative A uses the same wires to transmit both data and power. Due to this process, Alternative A is also known as common-mode data pair power.

ALTERNATIVE B

- Separates the data and power conductors
- Positive voltage runs on pins 4 and 5
- Negative voltage runs on pins 7 and 8



~Alternative B clearly depicts the distinct wires for both data and power. This method of connection between PSE and the PD leads to Alternative B also being known as the spare-pair data pair power.

THE ORIGINAL POE STANDARD AND POE+

IEEE 802.3AF

- Developed in 2003, the PoE standard provided up to 15.4W of DC power (minimum 44VDC and 350mA) on each port

THE UPDATED IEEE 802.3AF (a.k.a PoE+)

- Revised in 2009, the IEEE 802.3af, also known as PoE+, provides up to 25.5W of power for “Type 2” devices.

CONSIDERATIONS FOR SOLAR

Although Power over Ethernet injectors can provide up to 30W per channel, that does not mean the device is consuming 30W. The solar system should be sized based upon the device consumption and any losses or inefficiency of the injector itself. Typical PoE injectors have a 24VDC or 48VDC input; selecting an injector with a wide voltage input will eliminate the need for an additional DC/DC converter. Additionally, using a switch with a built-in injector might be more efficient than using separate devices.

60-Cell Solar Modules & Off-Grid Applications

The following is a discussion on the best practices of 60-Cell Photovoltaic modules in off-grid applications using batteries. SunWize recommends always using MPPT controllers when charging batteries using 60-cell Modules.

CHARGING BATTERIES WITH 60-CELL SOLAR MODULES IN OFF-GRID APPLICATIONS

Traditional 36-Cell (nominal 12V) and 72-Cell (nominal 24V) solar modules work well in battery charging applications using traditional PWM charge controllers as long as the nominal voltage of the array and battery bank matches. For example, two 36-Cell modules wired in series (nominal 24V) will properly charge two 12V solar batteries wired in series (nominal 24V).

The actual solar module voltage is somewhat higher on 36-Cell (12V nominal) and 72-Cell modules (24V nominal) than the nominal voltage nameplate rating, for instance the max power voltage, Vmp, of a typical 320W “24V” solar module is actually 36.8V. The difference between the higher voltage solar module (36.8V) and battery bank (approximately 24V-28V) creates a voltage differential, allowing current to flow from the solar array to the battery bank, thus charging your battery banks with energy!

With the introduction and popularity of 60-Cell modules in many applications (both on-grid and off-grid), it’s important to know there are critical differences between module types. Solar applications that utilize batteries need to be aware that 60-Cell solar modules do NOT have sufficiently high voltages to properly charge batteries using PWM charge controllers, which will result in damaged batteries and greatly reduced battery life.

SunWize strongly recommends that when using 60-Cell solar modules in battery applications to ***ALWAYS*** use MPPT charge controllers so that there is sufficient voltage to fully charge your batteries, which will help prevent premature battery failure.

Rather than go into this topic in great detail, we suggest reading Morningstar Corporation’s white paper on this topic, which covers it thoroughly.

Morningstar 60-Cell Module Reference White Paper

http://support.morningstarcorp.com/wp-content/uploads/2014/07/tech-tip-60-cell-PV-module-sizing.pdf

Online String Sizing Tools

Another indispensable tool when sizing and designing solar arrays and charge controllers are online String Sizing tools. Many charge controller manufacturers have their own string designing tools on their websites. Morningstar Corporation has an excellent string sizing guide we recommend using.

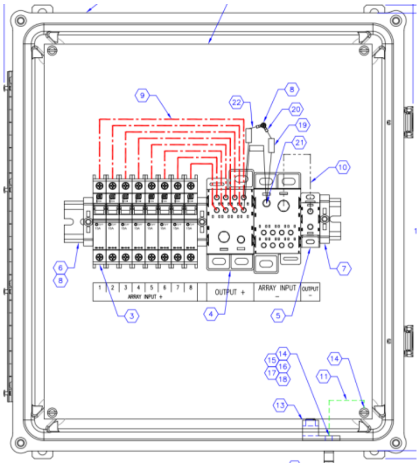
Morningstar String Sizing Guide

http://string-calculator.morningstarcorp.com/

Combiner Box Requirements

The following is a discussion on the requirements for combining multiple solar array strings using a combiner box.

NEC Article 690.9(A) states the following exception with regards to solar module overcurrent protection:



"An overcurrent device shall not be required for PV modules or PV source circuit conductors sized in accordance with 690.8(B) where one of the following applies:

(a) There are no external sources such as parallel-connected source circuits, batteries, or backfeed from inverters.

(b) The short-circuit currents from all sources do not exceed the ampacity of the conductors or the maximum overcurrent protection device size specified on the PV module nameplate."

What this means is if you have more than 1 string of PV modules in parallel and the combined short circuit current (Isc) times 1.56 exceeds the maximum fuse rating on the solar module, then overcurrent protection is required (fuse or circuit breaker). As an example; if you have a 190W module with an Isc of 5.8A and a maximum series fuse rating of 10A, and you want to parallel modules, overcurrent protection will be required for each string as the output of 2 modules would be 11.6A exceeding the maximum rating of 10A. However, if the maximum series fuse rating was 20A, then you can parallel 2 modules as 5.8A X 2 X 1.56 = 18A which would be less than the 20A maximum rating.

This means overcurrent protection is still required; however, the protection could be located at the solar array or at the controller. This is a preference and may depend upon the site and application. If you have multiple outputs from the solar array, having a single combiner box at the array with a single output to the controller might be a cleaner solution; however, if you only have 1 or 2 outputs, it might make more sense to just combine them at the controller.

Often times when combining solar arrays stand-alone enclosures to house the breakers, din rail, terminal blocks, wire, etc. are used. Below is an example of what combiner boxes may look like.

Shading Effects on Photovoltaic Modules

The following discussion on the shading effects of Photovoltaic modules applies only to single and multi-crystalline silicone modules, and does not apply to thin-film modules.

Many people may not understand that, due to the way that solar modules work, covering even a small portion of the solar module (compared to the overall area) can have a profound impact, up to reducing your total solar panel energy down to zero! It's important to understand solar modules are comprised of much smaller solar cells (usually 36 or 72 of them), and covering or impacting the performance of one cell will impact the performance of the entire module!

PV BASICS

Photovoltaic modules consist of a number of photovoltaic cells wired in series. Typically there are 36 cells for a nominal 12VDC module and 72 cells for a 24VDC module.

Each photovoltaic cell produces approximately 0.5VDC. So a 36 cell module will produce approximately 18VDC at peak power as all of the 36 cells are wired in series.

In electrical systems, wiring devices in series increases the voltage. The voltages are added while current remains the same.

Conversely, wiring devices in parallel increases the current. The currents are added while the voltage remains the same

Therefore, wiring photovoltaic modules in series increases the output voltage and wiring them in parallel increases the output current. The output voltage of a module varies little in sunlight conditions. If there is sufficient sunlight there is an output voltage, and it varies little with sunlight intensity. However, the photovoltaic module output current is completely dependent on the amount of sunlight the surface of the solar module is receiving. Because of these factors, and the way solar modules are wired, shading on individual solar cells has a profound impact on performance – something that can have a major adverse effect your project if you're not designing and installing your array correctly.

PV SHADING

Because the photovoltaic module output current is completely dependent on the amount of sunlight and varies linearly with the sunlight conditions available, shading considerations are extremely important when designing and siting the location of your array installation.

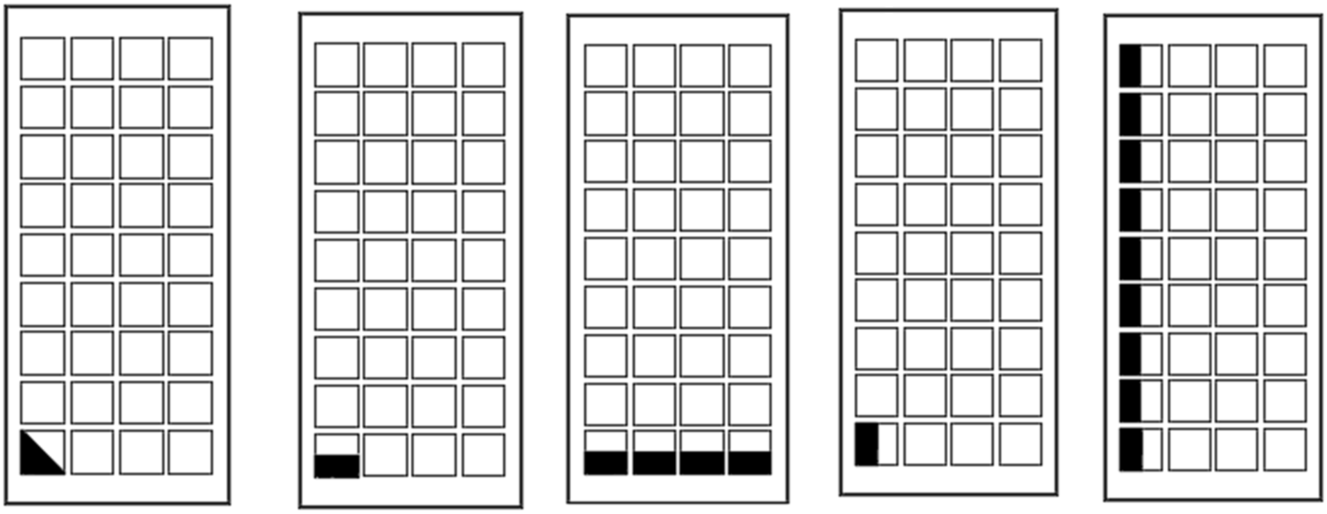
As an example: if a solar module produces 8 Amps of current under STC [Standard Test Condition: Irradiance 1000 W/m², Module Temperature 25 °C, AM 1.5], it will produce 4 Amps current with an irradiance of 500 W/m².

Because the cells of a solar module are wired in series, the maximum output current is dependent on the weakest cell, as the current is the same through each cell. The module maximum output current is dependent on the maximum current available from the weakest cell. Therefore, if a single cell in a photovoltaic module is shaded, the output current from the entire module goes to zero.

If any part of cell is shaded, the output current from the photovoltaic module is reduced by the proportional amount that the cell is shaded.

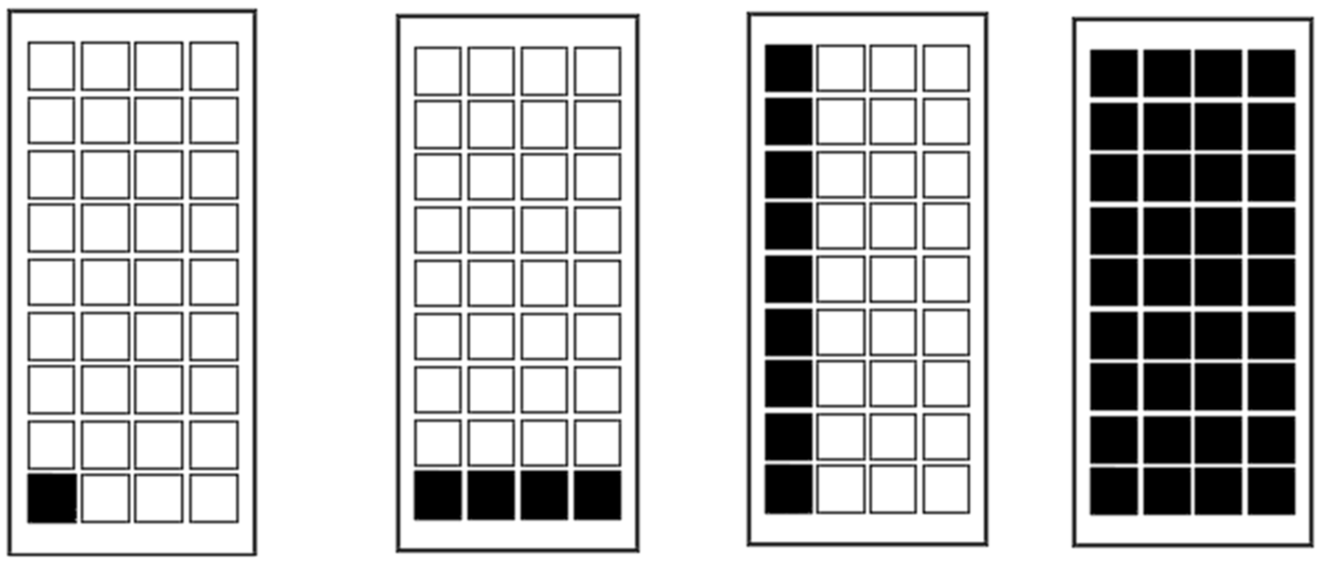
PV SHADING EFFECTS EXAMPLE – 50% REDUCTION

Below are examples of shading that will reduce the module output current by 50%



PV SHADING EFFECTS EXAMPLE – 100% REDUCTION

Below are examples of shading that will reduce the module output current by 100%



IN SUMMARY

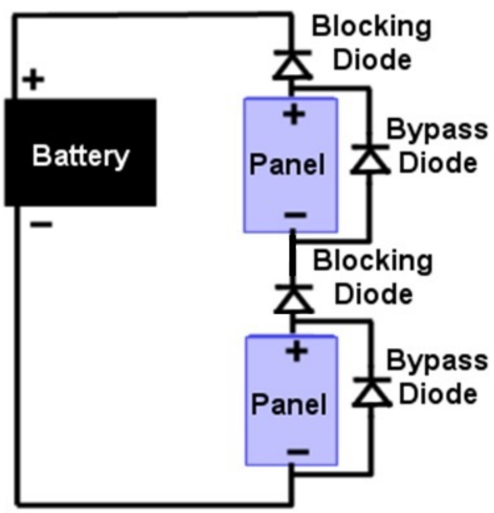
When installing your solar module, pay special attention to the site layout, geography, and nearby structures, including signs, trees, masts, posts, buildings, etc. Sometimes it's helpful or necessary to note during different times of day and different seasons what the shading conditions will be. If possible, you should minimize shading as much as possible. Always take into account proper shading and size for an extra array string if it's known that one string will have some shading but that it is unavoidable.

PV Module Bypass Diodes

The following is a discussion on the main functions, operations, and limitations related to PV Module Bypass Diodes. SunWize also provides considerations when using Bypass Diodes.

INTRODUCTION

Bypass Diodes, also known as free-wheeling diodes, are wired within the PV module and provide an alternate current when a cell or panel becomes shaded or faulty. Diodes themselves are simply devices which enable current to flow in a single direction. Bypass diodes then are exactly as they sound: devices for channeling current by bypassing the solar panel itself.



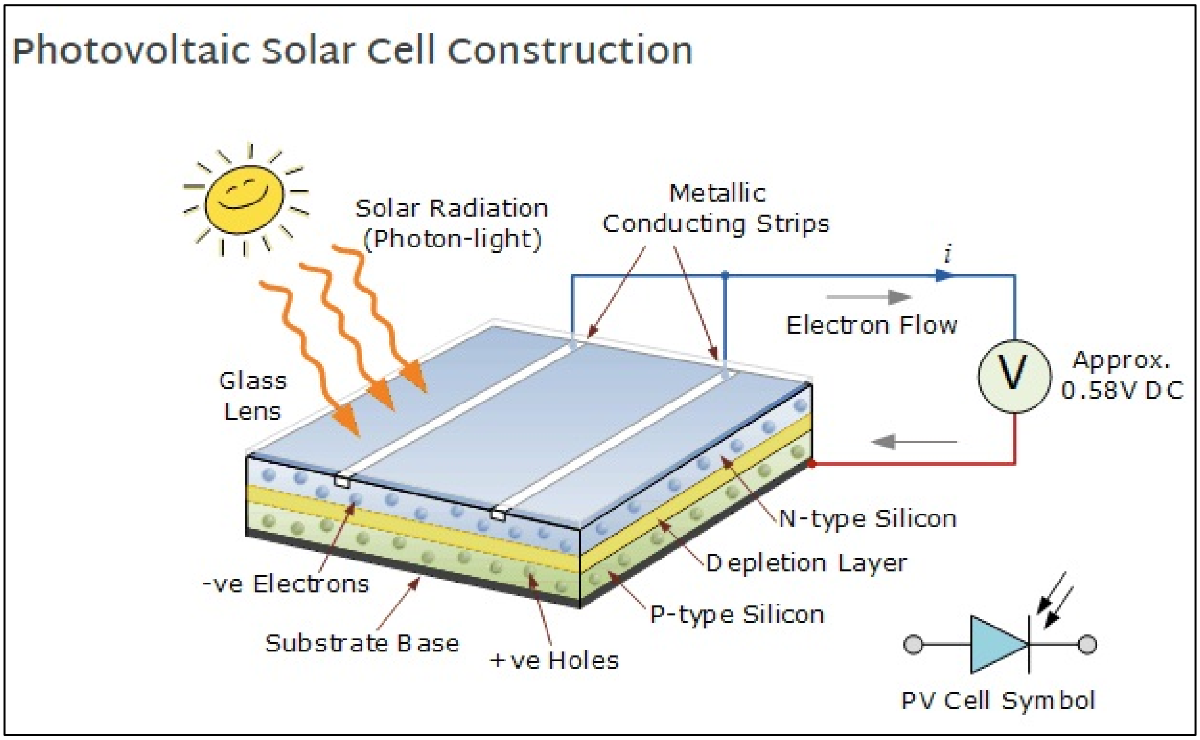
They typically come installed in the PV module from the module manufacturer, and are generally placed every 18-24 cells. You will typically find 2 sets in nominal 12VDC modules and 3 sets in nominal 24VDC modules. They can be installed in the module junction box or integrated into the module itself. While physically similar to blocking diodes, bypass diodes are wired in parallel with the solar cell or panel, which is in contrast to series-connected blocking diodes.

MAIN FUNCTIONS

- **Safety Purposes:** The bypass diode prevents "hot spots" by regulating the current from the sunlight
- **Increased Power Production:** When used with an MPPT charge controller, a bypass diode can increase power production under shady conditions in certain situations.

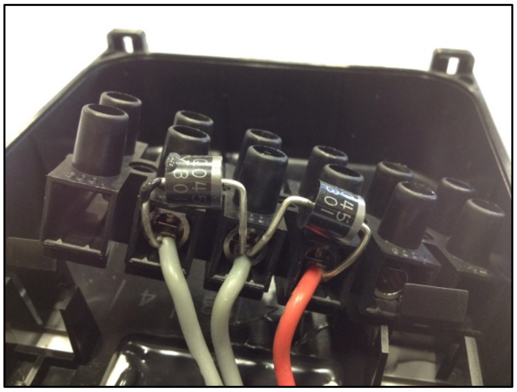
HOW DOES THE BYPASS DIODE WORK?

To understand bypass diodes, you first have to understand what a solar cell is and how it works. The image below depicts a basic solar cell construction. The simplest way to think of a PV cell is an LED (Light Emitting Diode) in reverse. When you run current through an LED it produces light; a solar cell works in the exact opposite way: you put light on it and it produces current. So when light is taken away from the solar cell (either at night, shading, etc.) it actually consumes power instead of producing it. The bypass diode works to regulate the current and works within the array.



Note: The flat line represents the blocking of current flow, the triangle represents the flow of current through the diode

~One important thing to note on Bypass Diodes is that the flat line of the diode symbol that touches the triangle (see figure above) corresponds to the physical colored line on the actual diode itself (see picture below). This is helpful because you know which way to install the physical diode in the circuit.



WHY ISN'T A BLOCKING DIODE SUFFICIENT?

A blocking diode can be used to prevent the current from flowing from a battery back through the array. This is typically built into the charge controller and can be done using diodes, transistors, or other method. A blocking diode is fine for a string or an array, but does not work internally. So when shading occurs, current is being produced by cells that are in the sunlight and being consumed by ones that are being shaded. This can create a "hot spot" and literally cause damage to the module. Bypass diodes allow the current from the sunlight cells to go around "bypass" the shaded cells preventing the "hot spot" from occurring.

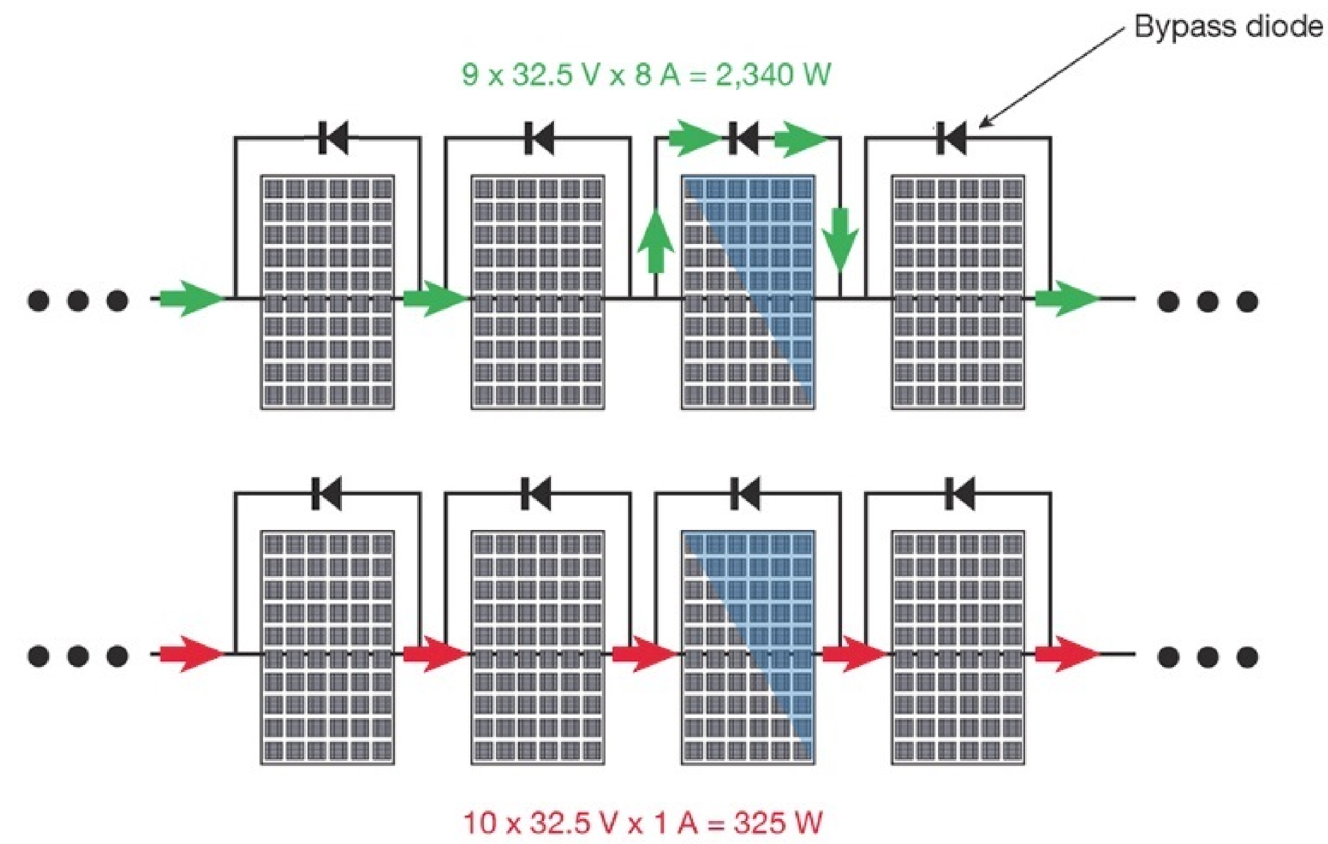


Figure 1 Bypassing a shaded module in a PV string (top) can lead to significantly higher total output power compared to forcing the string to operate at the low-current level of the shaded module (bottom).

CONSIDERATIONS FOR USING BYPASS DIODES

Reduced Total Output Voltage: increased safety requires some form of a cost and with bypass diodes it is found within the output voltage of the PV module.

- The VOC for a 36-cell module is around 22VDC, however with a bypass diode engaged it is reduced to 11VDC.
- For a 72-cell module, the VOC is around 44VDC, and with a bypass diode engaged it is reduced to 30VDC.

As the voltage has been reduced, it is no longer high enough for battery charging using a PWM charge controller; however, if the array has been wired for a high voltage and an MPPT charge controller has been used, battery charging may continue at a reduced rate. This allows the shaded portion of the module or array to be removed while still allowing the remaining unshaded portion to continue charging the battery.

FINAL NOTES

When troubleshooting PV modules, the discrepancy in VOC may help to determine if the module is being shaded, if diodes have gone bad, or if the module is missing wire.

Understanding Temperature Effects on Crystalline PV Modules

The following is a discussion on temperature and how it affects solar module voltages and power output. This is particularly important in solar-battery applications because not properly accounting for temperature effects may leave your modules with insufficient voltage to properly charge the batteries. This will result in costly and premature battery failures.

While the output current from a Photovoltaic (PV) Module is directly related to the amount of sunlight striking the surface, the output voltage is fairly consistent under most sunlight conditions. The voltage is, however, affected by temperature. Understanding this effect will help ensure your battery is being properly charged and that the solar module selected correctly matches the required charging voltage of the battery.

Battery Charging

The first thing to understand in this discussion is that lead acid batteries are charged by current, not voltage. The voltage of the solar array only needs to be high enough to allow current to flow, any extra voltage is power that is left unused in the solar array. A Maximum Power Point Tracker (MPPT) controller extracts this extra power from the solar array and converts it to additional current to charge the battery (this will be addressed in greater detail further in this document). If the voltage from the solar array is not sufficiently high compared to the battery voltage, current will not flow and the battery will not get fully charged.

Leaving a lead acid battery at a low state of charge for an extended period of time will cause sulfate crystals to form on the plates and will reduce the capacity of the battery causing the battery to fail prematurely.

Voltage Between Array & Battery

Second, you need to understand why the Maximum Power Voltage (Vmp) of a solar module is so much higher than the battery voltage. Most nominal 12V PV modules have a Vmp of 17-19VDC at Standard Test Conditions (STC) and consist of 36 solar cells wired in series. Most nominal 12V Valve Regulated Lead Acid (VRLA) batteries have a charge voltage of 14.1-14.4VDC.

There are three main reasons for voltage drop:

• Line loss (voltage drop in wires). 5% in a 12VDC system is 0.6VDC.

• Controller loss (voltage drop in diodes and transistors). 0.5 to 1.2VDC depending on the controller.

• Module voltage loss due to temperature. Up to 4VDC at 50°C (depending on voltage & temperature coefficient of specific solar module).

If you add up the voltage losses, they range from 1VDC to over 5VDC (depending on temperature and charge controller used). If the module Vmp is 18VDC and the total voltage loss is 4VDC, only 14VDC is left to charge the battery. The minimum charge voltage for a 12VDC VRLA battery is 14VDC.

With the module voltage loss from temperature being the single largest loss in the calculations, it's important to understand this loss and how it effects the solar system and battery charging.

STC vs NOTC

Third, you need to understand how modules are rated and the difference between STC and NOCT.

• **STC** = Standard Test Conditions: irradiance of 1000 W/m2, spectrum AM 1.5 and cell temperature of 25°C

• **NOCT** = Nominal Operating Cell Temperature: Irradiance of 800 W/m2, spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s

STC is more of a lab created scenario; whereas, NOCT is closer to reality. Note two main items:

1) STC is at 1000 W/m2 and NOCT is at 800 W/m2. This is the amount of sunlight that strikes the surface of the solar module and represents a 20% reduction in power just based on this one variable.

2) STC is rated at cell temperature and NOCT is rated at ambient temperature. This is important to note as it has a direct impact on the output voltage and power and will be discussed further in the following paragraphs.

Electrical Characteristics	
Max power(Pm)	140W
Maximum power voltage(Vpm)	18.3V
Maximum power current (Ipm)	7.8A
Short circuit current (Isc)	8.24A
Open circuit voltage (Voc)	22.2V
Module efficiency	13.47%
Tolerance	±5%
Nominal Voltage	12V
Temperature coefficient of Voc	-0.36%/K
Temperature coefficient of Pm	-0.46%/K
Temperature coefficient of Isc	0.05%/K
NOCT	48℃±2℃
Maximum series fuse rating	12A
Maximum system voltage	1000V

Using the Solartech SPM140P-F as an example:

- **Voc = 22.2VDC at STC**

- **Vmp = 18.3VDC at STC**

- **Temp. coefficient of Voc = -0.36%/°C at STC**

- **NOCT = 48°C +/-2°C**

So based on the NOCT number above, there is a 28°C difference ambient and cell temperature (48°C-20°C=28°C). If you applied that to a cell temperature of 25°C (STC rating) that would equate to an ambient temperature of -3°C. Not a very real world situation, as in most locations and year round the average daytime ambient temperature is going to be greater than 0°C. This, along with the 20% reduction in irradiance, constitutes most of the reason array output production more closely approximates NOCT and not STC. This is one of the reasons NOCT ratings were developed, to more closely approximate real world variables.

Temperature Compensation Calculations

To better understand the impact, lets run through some calculations using the above numbers.

22.2Voc x -0.36%/°C= **-0.07992V/°C.**

At an ambient temperature of 50°C the cell temperature is 78°C.

78°C – 25°C (STC) = 53°C x -0.07992V/°C = **-4.23V.**

This would reduce the module Vmp to approximately 14V (18.3-4.23=14.07V), and Voc to 18V (remember Voc is at 0A, no current). Note this is before any additional losses of voltage drop in the wires or charge controller!

MPPT and PWM Examples

Now referring back to the MPPT controller mentioned earlier, in this example there is no extra voltage to extract power from the module, so the MPPT would be of little or no benefit. However, this example is at an extreme temperature of 50°C, so what happens at more normal operating temperatures.

For the following example, let's use the Canadian Solar CS6X-320P PV module, whose data sheet vales for temperature characteristics, STC, and NOTC are shown below.

ELECTRICAL DATA / NOCT*

CS6X	310P	315P	320P	325P
Nominal Max. Power (Pmax)	225 W	228 W	232 W	236 W
Opt. Operating Voltage (Vmp)	33.2 V	33.4 V	33.6 V	33.7 V
Opt. Operating Current (Imp)	6.77 A	6.84 A	6.91 A	6.98 A
Open Circuit Voltage (Voc)	41.3 V	41.5 V	41.6 V	41.8 V
Short Circuit Current (Isc)	7.36 A	7.44 A	7.50 A	7.57 A

* Under Nominal Operating Cell Temperature (NOCT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temp. Coefficient (Pmax)	-0.41 % / °C
Temp. Coefficient (Voc)	-0.31 % / °C
Temp. Coefficient (Isc)	0.053 % / °C
Nominal Operating Cell Temperature	45±2 °C

ELECTRICAL DATA / STC*

CS6X	310P	315P	320P	325P
Nominal Max. Power (Pmax)	310 W	315 W	320 W	325 W
Opt. Operating Voltage (Vmp)	36.4 V	36.6 V	36.8 V	37.0 V
Opt. Operating Current (Imp)	8.52 A	8.61 A	8.69 A	8.78 A
Open Circuit Voltage (Voc)	44.9 V	45.1 V	45.3 V	45.5 V
Short Circuit Current (Isc)	9.08 A	9.18 A	9.26 A	9.34 A
Module Efficiency	16.16%	16.42%	16.68%	16.94%
Operating Temperature	-40°C ~ +85°C			
Max. System Voltage	1000 V (IEC) or 1000 V (UL)			
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)			
Max. Series Fuse Rating	15 A			
Application Classification	Class A			
Power Tolerance	0 ~ + 5 W			

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

MPPT EXAMPLE

As the MPPT controller is trying to extract power from the module let's begin with those calculations and let's use an ambient temperature of 25°C, which is fairly close to normal operation.

320W x -0.41%/°C = **-1.312W/°C**

At an ambient temperature of 25°C the cell temperature is 50°C.

50°C – 25°C (STC) = 25°C x -1.312W/°C = **-32.8W**

320W-32.8W = **287.2W**

The typical battery charge voltage of a 24V nominal VRLA battery is 28.56VDC

287.2W/28.56VDC = **10.0A** of charge current from an MPPT controller.

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PWM EXAMPLE

A PWM charge controller would just pass through the maximum current available, which could be up to 9.26A (Isc value of the 320W module from the STC datasheet above).

10.0A – 9.26A = **0.74A**, which is a 7% increase in output current from the MPPT charge controller over the PWM controller.

Conclusion

The temperature has a large impact on the output voltage and power from a crystalline PV module. This impact is linear and increases with temperature. In high temperatures, modules with insufficient voltage may be unable to fully charge a lead acid battery.

As additional unused power in PV modules is reduced in high temperature, so is the advantage of MPPT charge controllers. Therefore, even at normal operating temperatures, the additional extracted power of an MPPT charge controller compared to a PWM controller can be minimal.

Use the knowledge in this Tech-Note to:

- Calculate what the expected power output and voltages are of modules under various temperature conditions.
- Determine whether your batteries will get sufficiently charged in these conditions.
- Compare the potential advantages of an MPPT controller over a PWM controller by calculating the expected power output of both and comparing them.

Testing PV Modules

The following is a discussion on the best practices for testing a PV Module to determine whether or not it's functioning properly. The simplest way to test whether a module is working is to perform an Open Circuit Voltage test (Voc). This test can be performed at different locations within the system to troubleshoot different potential problems.

Basic Photovoltaic (PV) Module Testing

The best, quickest, and easiest way to test a solar module is to check both the open circuit voltage (Voc) and short circuit current (Isc).

Depending on the reason for testing; the test can be done:

- at the controller
- at the combiner box (if present)
- at the solar module
- can also be done on a string (2 or more modules wired in series)

The test needs to be performed with the module(s) isolated from the rest of the system, and is best done in full sunlight conditions. For this reason, having an array disconnect for maintenance and troubleshooting purposes can be advantageous, otherwise the array wires will need to be disconnected from the system.

Getting Started

The first thing we'll need before we get started is the manufacturer's data sheet for the module we'd like to test and a multi-meter capable of reading DC Voltage and Current! This information is important as it will give us the electrical specifications that we'll be using to validate whether the module is working properly or not.

Specifically, we're looking for the values for Open-Circuit Voltage (Voc) and Short-Circuit Current (Isc) for the specific rating of module. The purpose of our test is to determine whether the module is working, not if it's performing to factory specifications. Therefore, values from either the Standard Test Conditions (STC) table, or Nominal Operating Cell Temperature (NOCT) table should work.

ELECTRICAL PERFORMANCE

Electrical parameters at Standard Test Conditions (STC)				
Module type			YL320P-35b	YL315P-35b
Power output	P_{max}	W	320	315
Power output tolerances	ΔP_{max}	%		
Module efficiency	η_m	%	16.5	16.2
Voltage at P_{max}	V_{mpp}	V	37.0	36.8
Current at P_{max}	I_{mpp}	A	8.64	8.56
Open-circuit voltage	V_{oc}	V	46.0	45.7
Short-circuit current	I_{sc}	A	9.18	9.12

STC: 1000W/m² irradiance, 25°C cell temperature, AM 1.5G spectrum according to EN 60904-3.

Electrical parameters at Nominal Operating Cell Temperature (NOCT)				
Power output	P_{max}	W	233.4	229.8
Voltage at P_{max}	V_{mpp}	V	33.8	33.6
Current at P_{max}	I_{mpp}	A	6.91	6.85
Open-circuit voltage	V_{oc}	V	42.5	42.2
Short-circuit current	I_{sc}	A	7.42	7.37

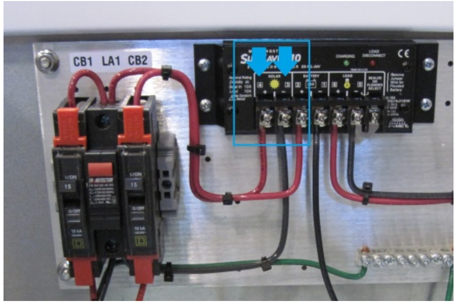
NOCT: open-circuit module operation temperature at 800W/m² irradiance, 20°C ambient temperature, 1m/s wind speed.

Open-Circuit Voltage (Voc) Test

To perform the Voc Test, simply measure the voltage between the positive and negative terminals. This voltage should be within **~10%** of the rating on the data sheet under most sunlight conditions.

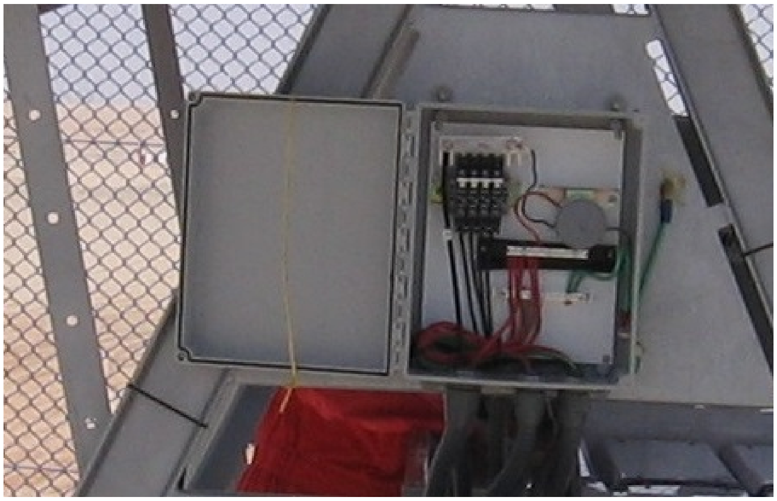
TESTING AT CONTROLLER

- Reverse polarity
- Wiring open/short circuit
- Incorrect array wiring



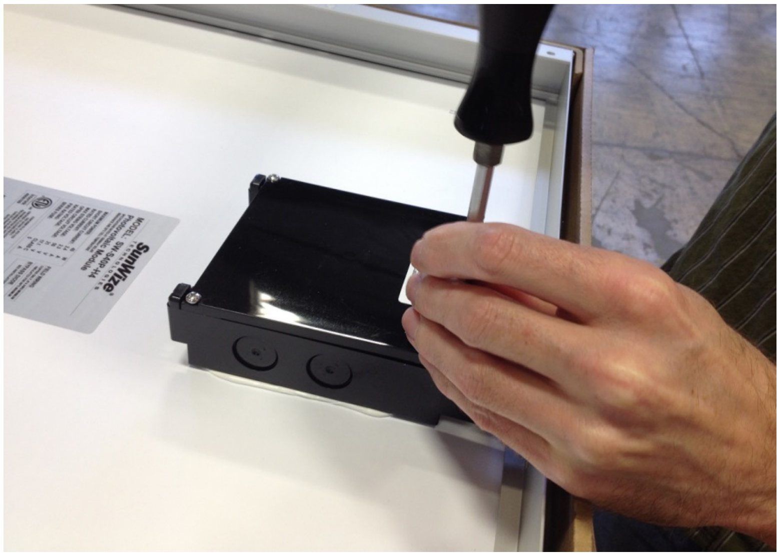
TESTING AT COMBINER BOX

- Reverse polarity
- Wiring open/short circuit
- Incorrect array wiring



TESTING AT MODULE

- Failed bypass diode
- Incorrect/Loose wiring
- Failed module



Testing Voc at Controller or Combiner Box (if present)

Reverse Polarity

Sign: A negative voltage number would indicate a reverse polarity of the wiring.

Cause: Positive and Negative wiring leads are reversed between Module, Controller, or Combiner Box (if present).

Solution: Reverse plus and minus on wiring between each connection point for correct polarity reading. Re-test to confirm correct polarity after changing.

Wiring Open/Short Circuit

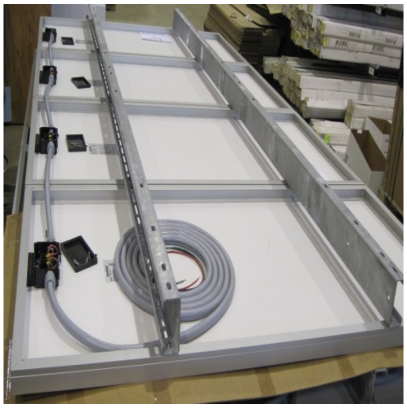
Sign: A voltage number near zero would indicate either an open circuit in the wiring or a short circuit in the wiring.

Cause: Bad or loose connections within module junction box, or between module, combiner box (if present), or charge controller.

Solution: Trace wires to find open or short circuit.
Correct problem (tighten or repairing wire) between bad connection points.

Incorrect Array Wiring

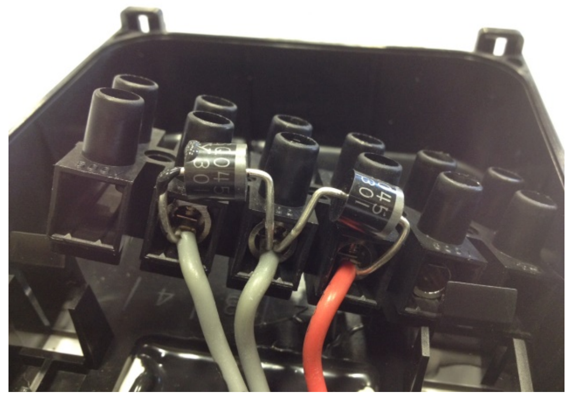
Sign: A voltage number that is higher or lower than expected.



Cause: Too many modules wired together in series will result in a Voc number that is too high. Too few modules wired in series will result in a Voc number that is too low. Remember to add the Voc values together for as many modules as you have wired in series (see ohm's power law)!

Solution: Check system design and voltage drop calculations to verify enough voltage is passing through from the array to the controller or combiner box and that the voltage matches expected values.

Testing Voc at Module



Failed Bypass Diode

Sign: A voltage number that is half the expected value.

Cause: Incorrect diode orientation, diode damage, or diode failure is most likely. Also check any wiring, if present, to make sure it's actually the diodes that are the issue.

Solution: Confirm diode orientation or replace diode in module. If accessible, you will need to remove the Junction Box cover on the back of the solar module.

Incorrect/Loose Wiring

Sign: A voltage number that is lower than the expected value.

Cause: Check any wiring, if present, to make sure there are no wiring mistakes or bad connections. Tighten all screws and gently pull wires to make sure they're secured. Check for corrosion on wires if in a humid environment.

Solution: Fix wiring mistake or loose/bad connection issues. Confirm connection to the correct terminals in the module junction box (confirm with voltmeter).

Failed Module

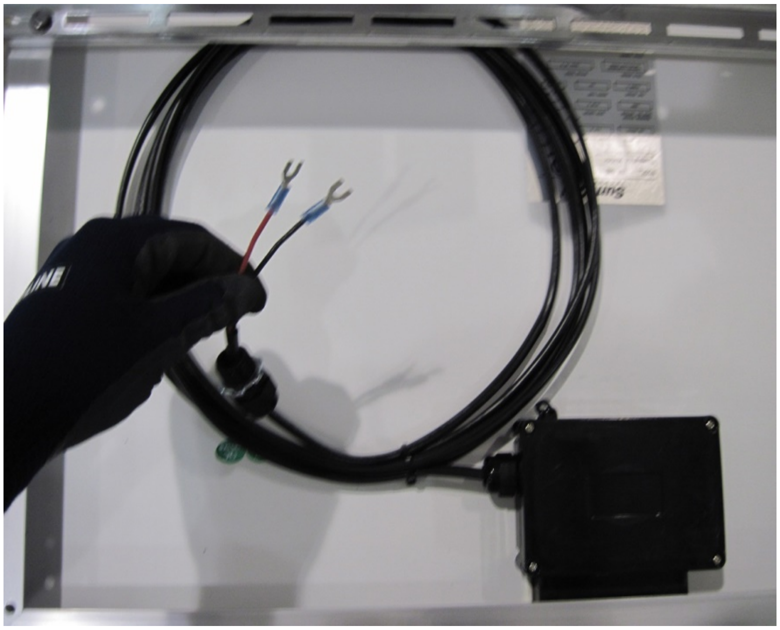
Sign: A voltage number that is lower than the expected value.

Cause: Check any wiring, if present, to make sure there are no wiring mistakes or bad connections. Tighten all screws and gently pull wires to make sure they're secured. Check for corrosion on wires if in a humid environment. If all of this is ruled out, then the module may be failing.

Solution: Fix wiring mistake or loose/bad connection issues. If you are still experiencing a lower voltage number than expected, you may need to replace the solar module by contacting the module manufacturer.

Short-Circuit Current (Isc) Test

Caution: when performing the Isc test confirm the maximum current being measured is less than maximum meter rating. An arc is very common when breaking the connection, therefor it should be done quickly.



Although the Voc Test is a good troubleshooting technique to detect many common array and module issues, the Isc Test can be used to find additional problems.

The Isc Test should be done on the **module** or **string** level, as the currents should be kept to **10A or less**.

The test should be done on a sunny day, and the measured value should be linear with the sunlight conditions available. An insolation or solar radiation meter can be very helpful in determining the sunlight conditions.

To perform the test using an inline ammeter, place the positive lead on the positive module terminal and the negative lead on the module negative terminal.

The measured value should be within 20% of the module rating adjusted for sunlight conditions. E.g. on a partly sunny day if the sunlight conditions are about half, then the Isc current will be about half.

No Current

Sign: No current is measured.

Cause: Open circuit in the wiring, a bad or loose connection, incorrect wiring, or an internal problem with the solar module. It's possible the connection point is sufficient enough for full voltage reading, but limited current.

Solution: Fix wiring mistake or loose/bad connection issues.

Less Than Expected Current

Sign: Measured Short-Circuit Current (Isc) value is less than expected.

Cause: Solar modules degrade by approximately 1% per year; however, if the measured current is less than 20% of the expected value after adjusting for sunlight conditions then the module maybe failing.

Solution: Determine whether current loss is appropriate with age of module. If it's not, then the module may be prematurely failing. Consult power performance warranty from module manufacture.

Conclusion

A couple of simple measurements are a great way to quickly troubleshoot and isolate possible problems in a solar array.

Grounding in Off-Grid Solar Systems

The following is an introduction of the concept of 'Grounding' in off-grid solar systems. We explore the definitions of each type of ground and also give recommendations when dealing with grounding in general.

GROUNDING BASICS

There are three main reasons for grounding in an off-grid power system: safety, voltage transients, and the sheer fact that they are required for some loads**.** But before we address each of these, it's important to understand the actual definition of 'ground'. There are two types of ground: chassis (or mechanical) and electrical. Both are completely different grounds and must be understood correctly. 'Ground' is just a reference point; it does not always mean neutral.

DEFINITIONS

CHASSIS GROUND

– The bonding of all exposed non-current carrying metallic objects (solar module frame, battery enclosure, backplate, array mounting structure, etc) together and eventually to the actual earth.

Chassis grounds are done primarily for safety reasons. This prevents any possible potential buildup on the metal object that could cause a shock when there is contact with the metal. Remember! Voltage is just the potential difference between ground potential and some potential. Having your system mechanically ground would get rid of the difference.

ELECTRICAL GROUND

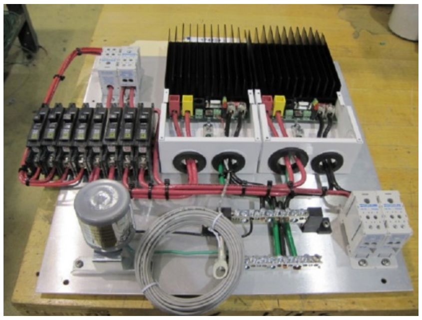
– the connection of one of the current-carrying conductors to the equipment grounding system and to the actual earth. In a battery based system, it is recommended to connect one of the current-carrying conductors as close to the battery as possible, as the battery is typically the greatest DC source of power.

As with chassis grounds, one reason to ground the electrical system is for safety; however, electrical transients are another major reason.

ELECTRICAL GROUNDS AND CHARGE CONTROLLERS

Many charge controllers and other electrical devices in off-grid systems have transient protection that require a grounded conductor for them to function correctly. What that means is both lines must be connected properly in order for the system to work correctly. Surge arrestors are devices that protect the system from over-voltage transients caused by external events, such as lightning. Many of these devices use a grounded conductor to function; without the grounded conductor, there is nowhere to shunt, or divert, the transient. This greatly limits the effectiveness of the surge protector. Additionally, the grounded conductor causes most controllers to be labeled as either negative or positive ground. Switches, fuses, and circuit breakers should not be used in grounded conductors, as this could potentially break the conductors ground. That being said, there is one exception, which leads us on to the next topic.

ELECTRICAL GROUNDS AND MOBILE SYSTEMS



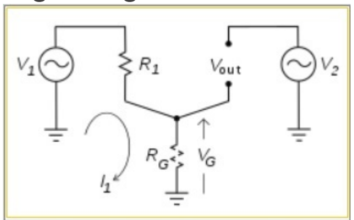
Switches, fuses, and circuit breakers can be used with electrical grounds in the case of mobile systems. Due to the nature of the requirements of the system, a floating ground is used in both off-shore platforms and mobile systems. In mobile applications, it is still advisable to have a common (grounded) conductor that is connected to the actual earth. For this reason, the chassis of the vehicle (car, truck, RV, etc) will typically be used as the electrical ground. Although it is not as ideal as an actual earth ground, it does provide a measure of safety. In off-shore platforms, it gets a bit trickier, as you can create a galvanized corrosion reaction between the electrical and chassis ground. In order to prevent this from occurring, these systems are typically truly floating and use two-pole breakers to switch both the positive and negative lines at the same time.

ELECTRICAL GROUNDS AND LOAD REQUIREMENTS

The last reason for electrical grounds is the load requirements. This is obvious in some loads, like cathodic protection systems, where a reverse process is used through impress current to defeat the naturally occurring ground voltage in the area of the pipeline. An electrical ground is required in this reversal process and is absolutely critical to the longevity of a system. If there is too much earth voltage on the pipeline, there will be irreversible damage to the pipe coatings. Understanding what an electrical ground is and how it properly protects vulnerable metal elements like this, helps to cement the difference between an electrical ground and a chassis ground. It should be noted that some loads may connect both the electrical and chassis grounds together within the device-lack of proper care when overseeing these situations can lead to major problems.

A FEW THINGS TO KEEP IN MIND

>>Ground Loops Should be Avoided: The electrical ground should be connected to the system/earth ground at one point and only one point. Multiple grounds can cause the system and electrical equipment to function incorrectly. This is especially true with charge controllers, as ground loops can create additional paths for current to flow when the controller is trying to regulate.



The above diagram shows an electrical ground loop. We can see a common wire connecting two circuits to the ground (R). In cases where (R ≠0) R and R will form a voltage divider, meaning the current I flows through R and a voltage drop of V = I R flows across R. This results in the ground connection of both circuits no longer being the actual ground potential. They are no longer isolated, and as a result, can cause interference.

>>Connection to both a System Ground and Earth: An earth ground can be created by a ground rod, copper wire in the ground (known as a ground ring), and by other means. A mounting pole can be used as the ground, if installed correctly. However, an earth resistance meter should be used to measure the resistance from the system ground to the actual earth. It is recommended that the ground system have a resistance less than 5Ω to ground.

Note: Depending on the soil and site conditions, multiple ground rods may be required to achieve the required resistance.

>>Different Grounds means using an isolated DC/DC converter: Operating loads with different grounding requirements within the same system can be done using an isolated DC/DC converter. The load can still be grounded; the isolated DC/DC just allows the voltage to be inverted from other loads and systems as well. These types of converters are usually used to improve basic safety, enhance noise immunity, generate dual-polarity rails, and provide galvanic isolation and are used in a broad range of applications.

>> Connection - Chassis and Electrical: The connection from chasis grounds to the earth or system ground should be done by copper wire and ground lugs with bonding wires or self-tapping screws, as required. The electrical ground, on the other hand, can simply be made by connecting the grounded conductor to the earth or system ground. Refer to the National Electric Code (NEC) for grounding requirements.

CONCLUSION

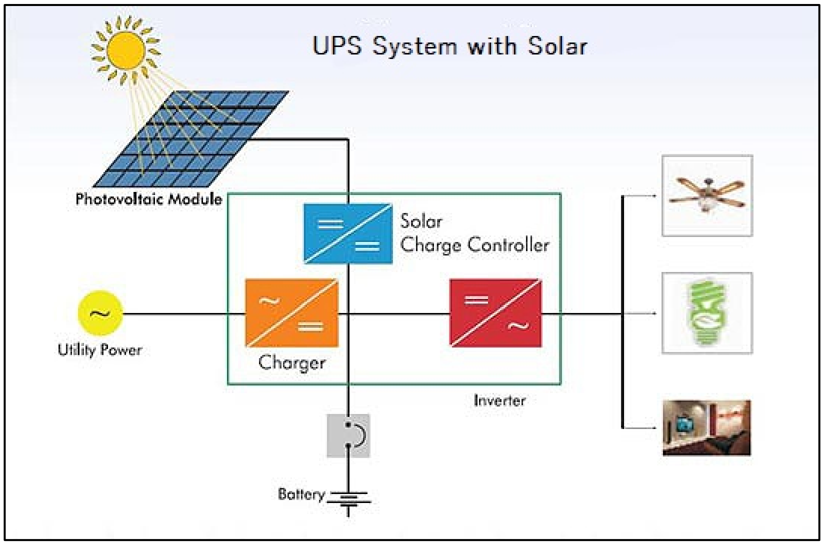
Understanding the difference between a chassis ground and an electrical ground allows you to maintain an efficient and long-lasting system. While understanding exactly how much current voltage is required in an electrical ground to offset the natural earth voltage is complex, when done correctly, it can prevent corrosion before it becomes visible. Grounding improves the safety in an off-grid system and allows the transient protection to function properly.

Should I Add Solar to my UPS System?

The following is a discussion on the complications and considerations that go into adding solar into a UPS System.

BRIEF OVERVIEW OF UPS SYSTEMS

A UPS system, or uninterruptible power supply system, is an electrical aid that assists in power fails. A UPS system runs for only a short time, but it is sufficient enough to either turn on and protect the equipment or start a standby power source. The power comes from battery-stored energy and is used mostly in computers, telecommunication equipment, and electrical equipment. The UPS system helps to avert otherwise disastrous situations which can be life-threatening.

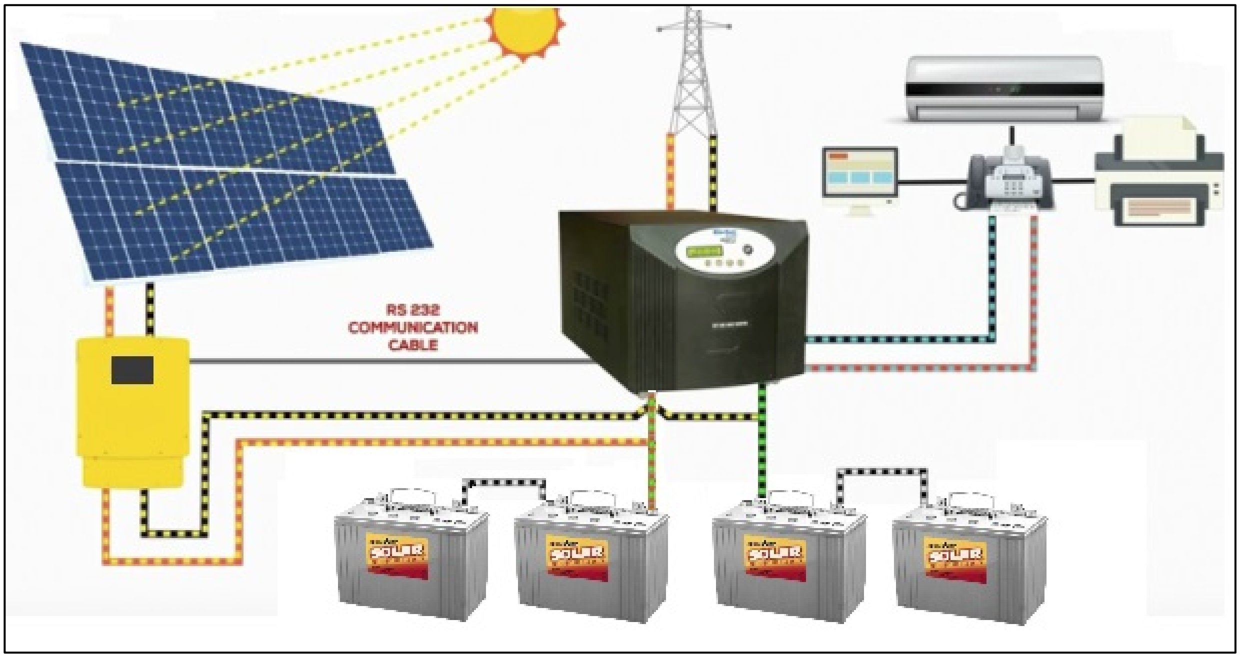


SHOULD I ADD SOLAR TO MY UPS SYSTEM?

The answer depends! If you are trying to reduce the energy consumed from the utility, then yes, add as much solar as necessary to offset the utility. However, if you are trying to add a backup to the backup, then things get a bit more complicated.

THE COMPLICATIONS

Adding solar only makes sense if it's enough to be a stand-alone system. If the solar added is not enough to be a stand-alone system, then it makes less sense to use it since the solar would only be enough to run for a few hours while the sun was available. To function properly, the system must essentially become a solar system with a utility backup. To be a true backup, the solar has to be big enough to power the load and recharge the battery enough to support the load at night when the sunsets, and the solar array has to do all of this in the few hours that the sun is available.



FINAL VERDICT

Solar can be added to your UPS system and still run separate and autonomous from each other. However, the benefit depends on how large the solar array is and what goal is trying to be achieved.

Solar Sizing - IEEE 1562:2007

The IEEE standard 1562:2007 is a comprehensive overview on the sizing of array and batteries in stand-alone PhotoVoltaic ("PV") systems. These off-grid solar systems are considered to have PV as their only incoming power source while using the batteries to store the energy produced by the solar panels.

Below are highlights of IEEE 1562. The complete standard can be purchased from IEEE at https://standards.ieee.org/findstds/standard/1562-2007.html

- IEEE 1562:2007 is the only industry standard for sizing a photovoltaic array and batteries in a system where the solar array is the only charging source.
- Peak sun-hours are to be used for the array power production calculations.
- Calculations should be based on the month with the lowest solar insolation and highest load demand.
- The calculations and system performance are only as accurate as the solar insolation & load data used.
- The sizing methodology does not take into account the use of Maximum Power Point Trackers (MPPTs). This means extra energy produced by the MPPT controller is considered a safety factor.
- As MPPT controllers are not considered in the calculations, the calculations should be done using nominal 12VDC PV modules (36 cells). Nominal 24VDC PV modules [72 cells] OK for 24VDC systems
- The calculations are based on amps and amp hours, as the solar array is sized to recharge the battery as the load consumes energy from the battery.
- Section 6 states the minimum battery autonomy should be 5-7 days for non-critical loads and areas for high solar insolation, and 7-14 days for critical loads or areas with low solar insolation.
- Typical losses used in the solar calculations are 10-20% (section 9.2).
- Section 9.4 states the minimum Array-to-Load Ratio ("ALR") should be 1.1-1.2 for non-critical loads and areas for high solar insolation, and 1.3-1.4 for critical loads or areas with low solar insolation.
- A worksheet is included in the standard for manual calculations.
- A computer simulation is recommended for design verification (Section 10). SunWize has access to several design tools that we use to design and verify all of our solar systems. "An overcurrent device shall not be required for PV modules or PV source circuit conductors sized in accordance with 690.8(B) where one of the following applies:

Troubleshooting Tips for Stand-Alone PV Systems

Diagnosing a solar system that is experiencing issues can be challenging if you're not familiar with the appropriate methodology and tools. This page is meant to help guide technicians and users in quickly identifying the issues & implementing the appropriate solution.

INTRODUCTION

Well-designed off-grid solar systems should be able to operate reliably in all but the most extraordinary weather events.

Well maintained & high quality VRLA solar batteries should last approximately 5-7 years before needing replacement. Non-battery components in a well-designed system should last 20 years or more.

Despite this, components do fail, technicians occasionally accidentally leave breakers in the off position, and there are many other issues that can require system diagnosis.

This page is meant to help users quickly identify the source of problems in an off-grid system design using thorough guidelines.

MAJOR SYSTEM COMPONENTS

Major Off-Grid System Components Include:

- **PV Modules** – Input Power Source
- **Charge Controller** – Solar Charge Regulation
- **Batteries** – Energy Storage.

*To protect batteries from becoming permanently damaged, systems will disconnect the load using a Low Voltage Disconnect "LVD" if battery energy ("State of Charge" or "SOC") drops below 20%!

Minimum Suggested Equipment

Required for any field troubleshooting:

1. Multi-meter for measuring DC voltage, current, and AC voltage (if necessary)

2. Insulated screw drivers

3. Wrenches for battery terminals

Additional Helpful Equipment

Recommended for any field troubleshooting:

1. Wire stripper/crimper

2. Extra wire for replacements

3. Electrical tape

4. Fresh batteries for measurement / replacement

5. Spare 150VDC breakers

6. Field capable battery charging device

PRELIMINARY CONSIDERATIONS

Before beginning actual technical troubleshooting, take notes on several pieces of important information that may help you resolve system performance issues without needing to take electrical measurements!

1. Visual Inspection – Before opening the control and battery enclosures walk around the system and look at the array, the wiring from the array to the combiner, the control enclosure and the battery enclosure. Note any damage or changes to the systems appearance.
2. Verify Installation – Compare the installation to the factory requirements, has the system been installed correctly, mechanically as well as in relation to the sun.
3. Load Verification – Verify that the load being consumed by the system is consistent with the original design expectations. If the current load is larger than what was designed for, re-evaluate your design. Visit our IEEE 1562 Sizing tech-note page for details on appropriate design considerations.
4. Shading Considerations – Make sure the solar array is in full sun exposure throughout day and is not shaded at all. If unfamiliar with shading effects for solar arrays, please read our tech notes page.
5. Breaker Settings – Make sure that all appropriate circuit breakers are in the "on" position.
6. Weather – Has there been an abnormally long period of cloud cover at the site? Recent weather history may give clues to system performance or failures.
7. Temperature Compensation – For best system performance, we strongly recommend all charge controllers should have temperature compensation included.
8. Battery Quality – Solar batteries are primarily measured in cycles, between 500-1000 cycles at 50% Depth of Discharge (DoD) is the typical range for VRLA batteries. If your batteries are failing prematurely, make sure you're using quality deep cycle batteries and keeping them properly charged.
9. Array Positioning – For systems in North America, solar arrays should always be pointed due south. Solar arrays should be tilted at between approximate 45° and 65° depending on your exact latitude.

TROUBLESHOOTING

Once you have addressed the above considerations and feel confident that the system is designed well, installed correctly, and positioned properly, but still failing, follow these steps:

1. **Open the control, combiner and battery enclosures –**

    - Inspect the interior of these enclosures for any damage or potential issues.
    - Check the circuit breakers are not tripped.
    - Locate the Charge and Load controllers and confirm their operational status via the meter or the LED displays on the front of each unit.

2. **Check Wiring Terminations –**

    - Ensure that all wire terminations are tight.
    - Make sure no corrosion is present.
    - Make sure wires are not chaffed.

3. **Load Verification –** Is there a voltage at the load? If there is no voltage, measure voltage on each piece of equipment leading back to the solar array until you find where the voltage and/or current drops.
4. **Batteries –** We'll be releasing a detailed troubleshooting guide specifically for batteries, stay tuned!

    - Check and record each individual battery voltage. Large deltas between batteries or cells can indicate a problem. Replace or recharge problem batteries.
    - Verify all interconnections between the batteries are tight & corrosion free.
    - If the battery voltage is between 11.5V and 12.6V (23.0V and 25.2V for a 24V system), check the LVD controller battery status LEDs. If LED is red, load has been disconnected to protect battery.
    - Consult the charge controller manual for other LED colors or flashing sequences.
    - Check for any signs of swelling, shrinkage, or case cracks, these may indicate battery damage.
    - If the batteries are not damaged, but are at a low state of charge (indicated by a low voltage measurement), then the system may simply need to have the batteries recharged. This can be done by charging batteries in the field using a portable battery charging unit or swapping the batteries out while they're charged off-site. Batteries can take 24 hours to fully recharge.

5. **Solar Array –** The two most important numbers when troubleshooting the array are the Short Circuit current (Isc) and Open Circuit voltage (Voc). Refer to module data sheet for both values.

    - **Voc** – The Voc should be fairly consistent between each module in your array and should be around 20-22VDC for a 12V nominal array and 40-44DC for a 24V nominal array. The voltage is minimally affected by sunlight conditions.
    - **Isc** – The short circuit current (Isc) should ideally be tested on a sunny day around solar noon. It will be linear with the sunlight conditions. So if only 50% of irradiance is available, then the current will be reduced by 50%. If an irradiance

meter is not available, and you have multiple strings, a comparison between the strings can indicate a problem.

- All electrical measurements for the solar array should be taken at both the individual module, as well as, the individual array string level. Discrepancies between module or array measurements may help to indicate problems.

6. **Using a Multimeter –** Once all the above issues and concerns have been addressed, it's time to begin measuring electrical parameters (voltage and current) on each side of our electrical devices to look for any faulty components. With all components on, we will attempt to trace the voltage from the load to the solar array, through each electrical device.

   - Check voltage on load side and battery side of Load Controller
   - Check voltage of battery bank
   - Check voltage on either side of any load breakers
   - Check voltage on either side of any battery breakers
   - Check voltage on battery side of charge controller
   - Check voltage on either side of any array breakers
   - Check voltage on array side of charge controller
   - Check voltage at the individual module and array string levels (check combiner box if present).
   - Check any other power electronics that may be in circuit, such as DC-DC Converters or AC Inverters.

SUMMARY

After recording voltage and current for each device through the system (refer to wiring diagram if available) it should be apparent if there are any faulty devices. Typically there will be valid input voltage or current into one side of the device (input), but nothing or bad values coming out of the other end of the device (output). Refer to the instruction manuals for appropriate input/output voltage values for each device. An input voltage on one device may exceed the equipment specifications (perhaps due to unexpectedly hot temperatures) and therefore may be failing even though the device is not faulty).

Example – there may be appropriate voltages all the way through the circuit from the solar array to the input side of the battery breaker, but no output voltage at this breaker. This would indicate a faulty or broken breaker, and we would recommend replacing that breaker to see if it resolves the issue.

Understanding Loads

The following is a discussion on understanding and calculating off-grid loads. Loads in off-grid applications should be converted to Amp-Hours/day at the nominal voltage of the system battery bank. Understanding your loads is extremely important because it's the first step in designing a reliable off-grid solar power system!

Off-Grid Solar Load Calculations

In solar terminology, the term "load" refers to the power consumption of the device(s) that are being used in the system. Understanding your loads is critical to maintaining a well functioning power system, as we will explain in this article. *Many of the customer issues SunWize sees are not because of anything to do with the power system itself, but because customer's don't understand their own loads!!*

For example, an off-grid solar system may power a security camera, a radio, or both! The power being consumed by these devices are the system's "loads". The security camera may consume 10W of power, while the radio may consume 12W of power, resulting in a total continuous load of 22W, if using both simultaneously, which of course is very straightforward!

Now – what if your load only runs 4 hours a day, only has power consumption information in amps, and has efficiency losses which must be accounted for? What if you have multiple loads at different voltages with different use profiles? What if your loads change? If you're unsure of the answers to these types of questions, read on to learn how your business will use and deploy off-grid solar and battery backup systems more effectively when you properly understand your loads and how they relate to system functionality and limitations!

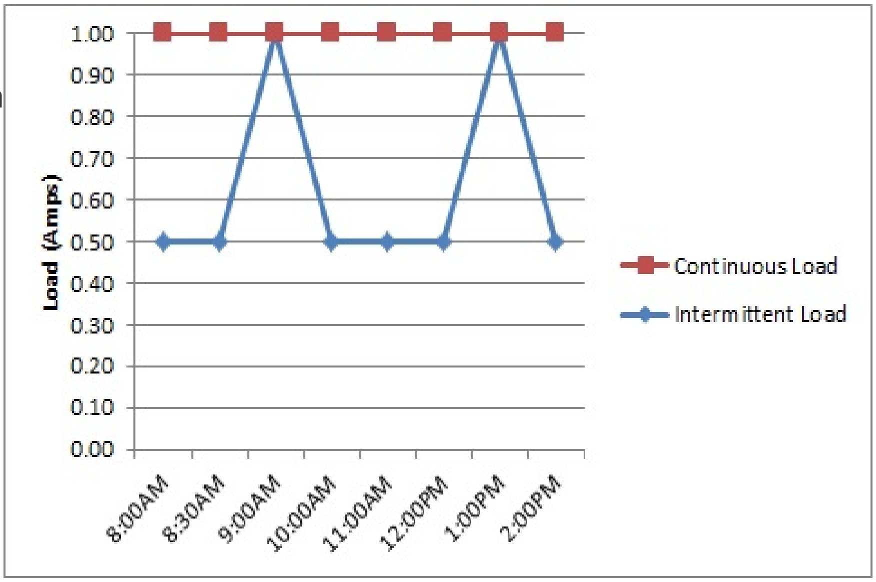
Reasons a 100W module cannot run a 100W load:

6. The module rating is lab created
5. Storms happen
4. Season effective disorder (there is less sun light in the winter)
3. Night comes every day

2. If it did you wouldn't need batteries for storage
1. Because it just doesn't work

Types of Loads

Properly calculating load consumption is a critical step in properly sizing an off-grid power system. As most off-grid systems are dependent on batteries to store energy, and these battery capacities are sized based on amp hours, the load needs to be calculated in amp hours in order to properly size the system. You can learn more about this in our [basic system sizing webinar!]



In this Tech-Note we'll cover several different types of loads and how to properly convert them into amp hours. All loads can be defined as the following:

- continuous or non-continuous
- at system voltage or at non-system voltage.

Continuous is defined as 24 hours a day, 7 days a week. Non-continuous, also referred to as intermittent, defines a load that operates for a portion of a day, or has different consumption at different times of the day. Typical non-continuous loads are lighting, radios on transmit, valves or actuators, pumps or motors, gate openers, etc.

Temperature Compensation

Because off-grid systems typically use lead-acid batteries as a storage mechanism, the system voltage can vary from -10% to 20% of its nominal value. As an example, a nominal 24VDC system can vary from 21.6VDC to 28.8VDC or even higher in colder climates with temperature compensation. It is important to understand this operating voltage is for the health of the battery and ***NOT*** for the load.

- Although the minimum system voltage can be adjusted higher this will prevent the system from being able to utilize the full capacity of the battery.
- Adjusting the minimum system voltage lower will cause the battery to be over-discharged and possibly damaged.
- The maximum system voltage is set to properly recharge the battery, adjusting this voltage higherwill over-charge the battery causing a VRLA to gas and reduce its capacity.
- Adjusting the maximum system voltage lower will cause the battery to not be fully charged. If a lead-acid battery is not periodically fully charged, sulfation crystals will form on the plates causing the battery to lose capacity and fail prematurely.

Note: the maximum system voltage is further adjusted for temperature, higher in temperatures below 25°C and lower in temperatures above 25°C. This is referred to as temperature compensation and is important for the battery to be properly charged. For more information on temperature compensation refer to the tech note by clicking here.

Load Calculation Guidelines

Now that we understand a little bit about the range and limitations of what “nominal battery voltage” means, how does that relate to our loads?

If the load cannot operate within the voltage tolerance of the system, then power conditioning equipment will be required. Typical power conditioning equipment would be a DC to AC inverter for AC loads, or a DC to DC converter for DC loads. Power conditioning equipment contains losses that need to be included in the load calculation. Typical efficiencies are 85-95% for inverters and 80-90% for converters.

Loads can be expressed in any of the formats listed below:

- current (amps[A])
- power (watts[W], kilowatts[kW])
- energy (amp hours[Ah], watthours[Wh], or kilowatthours[kWh]).

Notice, most utility bills are based on kWh, so this is a common unit for AC loads. Regardless of how the load is expressed, it will need to be converted to Ah for system sizing calculations. Recall from the power equations [Power(W) = Current(A)*Voltage(V)] we can convert from Watts to Amps by dividing power by nominal voltage [Power(W)/Voltage(V) = Current(A)].

Some load calculations will be simpler than others depending on the type of load and application. Ultimately, all answers will be expressed in the total amount of Amp-Hours consumed over a full day (24-hour period), for a given nominal voltage (Ah at 12V vs Ah at 24V are different things).

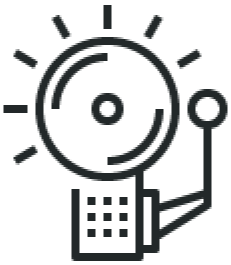
Load Calculation Examples

Let's begin with the <u>simplest</u> example:
The simplest load is one that is:

- expressed in amps and
- is continuous and
- will operate within system voltage.

To calculate the load in this example you simply multiply the amps by 24 hours (the number of hours in a day) to get the daily load in Amp-Hours, often abbreviated "Ah".

Example 1:
0.5A, 12VDC nominal continuous load
0.5A x 24h/day = **12Ah/day @ 12VDC**

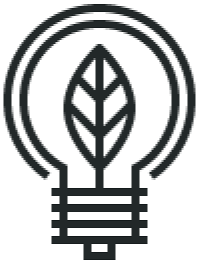


If that same load were expressed in watts instead of amps, we would just convert it to amps by dividing power(W) by nominal voltage (V) and follow the same procedure.

Example 2:
6W, 12VDC nominal continuous load
6W/12VDC = 0.5A x 24h/day = **12Ah/day @ 12VDC**

If the load is non-continuous, we simply multiply it by the number of hours per day it is active rather than by 24.

Example 3:
8W, 12VDC LED light that operates only at night.

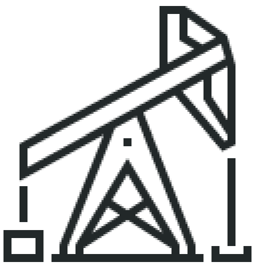


Let's assume worse case the light will operate for 16 hours in the winter.

8W/12VDC = 0.67A x 16h/day = **10.67Ah/day @12VDC**

Example 4:
A 12VDC radio that is 1A in standby and 10A in transmit. The radio transmits for 1 hour per day.
10A x 1h/day + 1A x 23h/day = 10Ah/day + 23Ah/day = **33Ah/day @12VDC**

Example 5:
A 10A, 24VDC valve that operates for 15 minutes a day and a 20W, 24VDC continuous controller.
10A x 0.25h/day + 20W/24VDC x 24h/day = 2.5Ah/day + 20Ah/day
= **22.5Ah/day @ 24VDC**



If the load is at voltage other than the system voltage then the losses of the conversion equipment need to be included in the calculations.

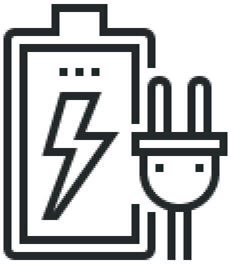
Example 6:
8W, 120VAC LED light that operates only at night.

Let's assume worse case the light will operate for 16 hours in the winter.

Let's also assume a system voltage of 12VDC and a power conversion efficiency of 90%.

8W/90%/12VDC = 0.74A x 16h/day = **11.85Ah/day @ 12VDC**

Example 7:
5W, 24VDC continuous sensors with a voltage tolerance of +/-10%.



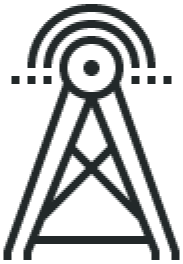
As the load has a small voltage tolerance, a DC/DC converter will be required, as 24V +-2.4V is much narrower than the 21.6V to 28.8V we determined at the beginning may be present from a nominal 24V battery voltage.

Let's assume the converter efficiency is 80% and the system voltage will be 24VDC.

5W/80%/24VDC = 0.26A x 24h/day = **6.25Ah/day @ 24VDC**

If there are multiple loads, they can be calculated separately and then summed together to get the total load.

Example 8:
Telecommunications tower with a 500W, 48VDC continuous communication load and 50W 24VDC nighttime obstruction lighting load.



Again, let's assume the worst case for the lighting load is 16 hours in the winter. We'll also assume a DC:DC Converter will be required for the 24VDC load, with an efficiency of 85%.

Load1
500W/48VDC x 24h/day = 250Ah/day

Load2
50W/85%/48VDC x 16h/day = 19.6Ah/day

Total Load = 250Ah/day + 19.6Ah/day = **269.6Ah/day** @ **48VDC**

Summary

Some more complicated sites may have multiple combinations of the above examples. If necessary, calculate each load individually and then combine them to calculate the total load for the site. If necessary, a spreadsheet can help to keep track of the loads and the calculations.

It's usually most efficient to choose your nominal battery voltage based off which voltage you have the largest loads at (in example 8, that would be 48VDC since the 500W load is substantially larger than the 50W load), and then use power conversion devices for all other required voltages.

Choosing a Battery Enclosure

The following is a discussion on selecting and protecting the correct battery enclosure.

WHAT IS A BATTERY ENCLOSURE?

A battery enclosure is a box designed to protect batteries from potential weather and battery mishaps. They can be designed for indoor or outdoor use, and may include room for electronics. Specific designs allow for pole, wall, or ground mounted systems.

WHY DO I NEED A BATTERY ENCLOSURE?

Battery enclosures are essential components of off-grid solar systems for a number of reasons including: physical protection from outside elements including people and weather patterns, maintaining consistent temperatures, and meeting the requirements of the National Electric Manufacturer's Association (NEMA).

WHICH TYPE IS RIGHT FOR ME?

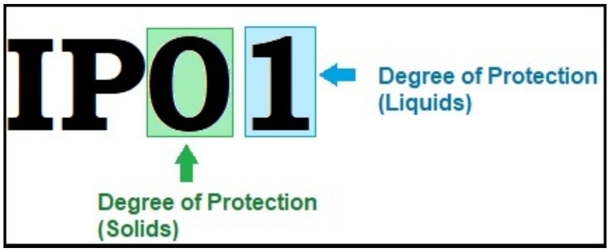
The specific type of battery enclosure design is different given the application and requirements of the project. The features and functions differ depending on the location and needs of the system. In general, all battery enclosures should be vented. This includes VRLA batteries, as hydrogen gas could potentially build up in a fault condition (e.g. controller failure). Passive venting should be adequate and active venting, like a fan, should only be required in rare cases. NEMA provides a rating scheme for consumers to easily decipher the correct number associated with his/her needs.

RATING SCHEMES

Two common methods of measuring the quality of protection offered by battery enclosures are the Ingress Protection Rating and the NEMA rating. IP and NEMA ratings are similar yet different; the NEMA code of protection can be said to be equivalent to the IP rating, but the same does not hold true for the IP rating.

INGRESS PROTECTION RATING

The IP rating is a standard evaluation of battery enclosures common in Europe. The given value contains 2-3 numbers to depict the level of protection from solid foreign objects and water.



NEMA RATING

The NEMA rating on the other hand is commonly used in North America. It considers the IP rating as well as other specifiers such as corrosion and construction details. The scale ranges from 1-13 with 7-10 being designed for Hazardous Locations and 1-6, 11-13 designed for Non-Hazardous Locations. These are types of NEMA enclosure ratings, and their various forms of protection in outdoor nonhazardous locations. All SunWize enclosures are designed to NEMA3R, which provides a high degree of protection from the elements in rugged and exposed outdoor locations.

Table 2
[From NEMA 250-2003]
Comparison of Specific Applications of Enclosures
for Outdoor Nonhazardous Locations

Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	3	3X	3R*	3RX*	3S	3SX	4	4X	6	6P
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of water (Rain, snow, and sleet **)	X	X	X	X	X	X	X	X	X	X
Sleet ***	...	...	...	...	X	X	...	...	...	...
Ingress of solid foreign objects (Windblown dust, lint, fibers, and flyings)	X	X	...	...	X	X	X	X	X	X
Ingress of water (Hosedown)	...	...	...	...	...	...	X	X	X	X
Corrosive agents	...	X	...	X	...	X	...	X	...	X
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	...	...	...	X	X
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	...	...	...	X

* These enclosures may be ventilated.
** External operating mechanisms are not required to be operable when the enclosure is ice covered.
*** External operating mechanisms are operable when the enclosure is ice covered.

INDOOR ENCLOSURES

Indoor enclosures may not have complex designs. Due to the simple features required of an indoor enclosure, it may only be composed of a battery rack with panels attached to it. In most cases, the indoor enclosure only needs to prevent things from falling onto the battery, so typically a Nema 1 rating is fine. The enclosure may need to be externally vented depending on the building requirements that house the battery. In most industrial applications, if the batteries are installed in a dedicated space, a separate enclosure is not required.

OUTDOOR ENCLOSURES

Outdoor enclosures should be rated Nema 3R to prevent water intrusion into the enclosure. Filters and screens can be added to prevent dust and insect intrusion. Powder-coated enclosures fabricated from aluminum can help prevent corrosion, further lengthening the battery's lifespan. Nema 4X enclosures should only be used in extremely corrosive environments. Although breather vents can be added to the Nema 4X enclosures to allow venting and still maintain the Nema 4X rating, they are restrictive and may not allow the gas to flow as freely.

SIDE OF POLE ENCLOSURES

Smaller battery enclosures can be mounted on a pole or a wall. Usually up to 300-400 lbs, larger enclosures are placed on the ground, slab, or foundation. Practical limitations usually prevent too many batteries or too much weight from being installed on the pole or wall. Larger ground mount enclosures usually do not have any limits.

CONCLUSION

Battery enclosures come in all shapes, sizes, materials, and ratings; choosing the best one that works for the application and requirements is a simple, yet crucial process. For more information on finding the perfect enclosure for your business needs, give SunWize a call or click on the button below to view enclosures online!

Considerations for Solar in Tiny Houses

The following is a discussion on the best practices and guidelines for integrating solar within a tiny house.

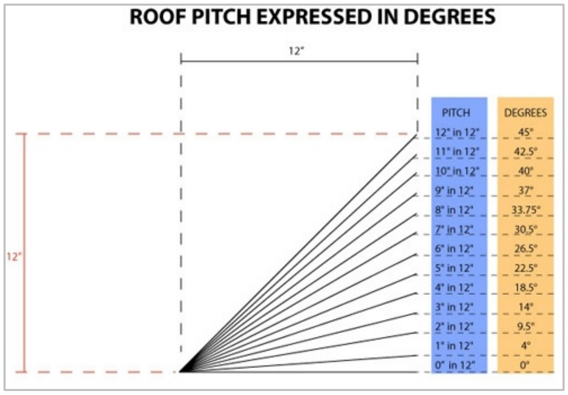
INTRODUCTION

Renewed interest in environmental concerns has resulted in many varied approaches to individual impact on the environment including, but not limited to, Tiny Houses. For others, Tiny Houses simply mean living independently. Regardless of the motivations surrounding them, Tiny Houses mean having the opportunity to work with solar. If possible, it is best to integrate solar into the home during the planning process of the building. It is always best to take into account potential complications and limitations of solar when deciding to incorporate solar into your home; this page attempts to give a brief overview of Tiny Houses.

LOOKING AT THE SPECIFICS

THE ROOF

The roof should be designed to have the solar modules mounted to it, so it should be preferably at an angle 35°-45° and reinforced to support the weight and wind load of the solar modules (including when the house is mobile).



STORAGE BATTERIES

As the storage batteries can be quite heavy, it is best to place them near the axle; if possible, they could be recessed in the floor to save space and lower the center of gravity. Extra space should also be given for the electronics: inverter, charge controller, etc. Generally, this should be installed as close to the batteries as possible to minimize the length of the DC wires.

POTENTIAL COMPLICATIONS AND LIMITATIONS

- Occasionally, it will not be possible to integrate the solar system into the house due to design complications and/or space issues. In this case, a separate area will need to be created for the solar array; the solar array will need to be anchored down, so that it does not blow over in the wind.

- To prevent potential weather damage to the system, it is crucial that a weatherproof enclosure be used to hold the batteries and miscellaneous electronics. Additionally, thought should be taken as to how to dissemble and pack the system for transport. Click on the text to view our custom enclosures!

- Due to the unique energy needs and available space, potential limitations of using solar revolve around power output. This simply requires a little thinking about consumption needs and means using propane loads for the stove/oven, heating, hot water, and refrigeration. While this may not necessarily be the case for every user, it is a potential limitation which should be considered.

FINAL CONSIDERATIONS

Whether the solar system is integrated or separate, care should be taken to ensure the solar modules are facing south and free of shade. While it may seem complicated, with careful consideration and planning, adding solar to a tiny home is a wonderful way to make a positive environmental impact and a move towards greater independence.

Looking For More In-Depth Resources?

SunWize provides two other distinct avenues for learning: Webinars and Engineering Bulletins

Webinars

Batteries

- Batteries and Enclosures-From Installation to Maintenance
- Solar Battery Fundamentals – Presented by MK-DEKA & SunWize

Charge Controllers

- Are All Charge Controllers Created Equal?
- Charge Controller Types & Sizing
- PWM vs MPPT Charge Controllers 60 Cell Modules

Communication

- Intro to Remote Communication

Modules

- (Almost) Everything you Need to Know About Solar Modules

Systems

- Advanced Solutions for Off-grid Industrial Solar Systems
- Battery Based Systems for Lighting Applications
- Basic Stand-Alone PV System Sizing
- Basic System Troubleshooting Learn Where to Begin
- Intro to Power Ready Express

Mounts & Enclosures

- Solar Module Mounts & Battery Enclosures

Other

- Electrical 101 for Solar Applications
- Primus Wind Power Introduction to Wind and Hybrid Power
- SunWize Connect 3.0 Overview

Engineering Bulletins

Solar – A Reliable Power Source

- Better Backup Power for Outdoor Equipment
- When a Solar System Makes Sense for Remote Site Power
- Solar Electric Systems and Power Reliability

The Science of PV Systems

- Are Solar Modules Economically Efficient
- How Long Does it Take to Recharge Solar Batteries
- How Tough Are Solar Modules
- Power vs. Energy
- PV Module Efficiency
- Why Isn't a 12V Module Really 12V?

PV System Design

- What's so Special About a Solar Battery?
- PV Array Sizing
- Load Voltages & Efficiency
- Loss of Load Probability
- Seven Benefits of Solar Hybrid Systems
- Snowed In
- Solar Radiation and System Design
- Guidelines for Choosing a SunWize Power System

Site Logistics

- Cut Down on Generator Fuel Costs with Solar
- Difficult Site Challenges
- Logistical Considerations
- SunWize System Design Protects Your Investment