Guidelines for High reliability Remote Power System Design

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When designing high reliability power systems for critical loads at remote sites, a variety of considerations must come into play during the design process.

The purpose of this class is to familiarize participants with the key issues affecting reliability. The process starts with the simple, but often overlooked gathering of accurate load information, how to accurately size a solar system and elect the proper solar array and battery bank, how to select reliable components, how to minimize field and installation errors, efficiently use materials, basics on DC-UPS systems, hazardous locations and vendor selection.

The discussion also covers common myths and misconceptions in the marketplace, and closes with the "Ten Commandments" of good solar design, a slightly humorous set of guidelines to follow when designing a solar power system.

LOAD PROFILES: Accurate load information is essential for proper design and reliable operation. Most information is available today at the manufacturers website. When in doubt, measure the current of the device you intend to power with a digital amp meter. For communication systems, always consider the Transmit/Receive duty cycle, as most communication devices consume quite a bit more power in Transmit mode than Receive or Standby mode. For systems with mixed voltages, 12V and 24V for example, the dominant, or heavier load will determine the system voltage. The smaller load should be run through a DC/DC converter, and assume 80% efficiency even though it may be higher. DC/DC converters lose efficiency when in a hot outdoor enclosure. Do not "center tap" 24V batteries to power a 12V load, this leads to mismatched batteries and can lead to early failure of the battery powering both loads. For relatively heavy loads, it is acceptable to build the system with two independent solar arrays and battery banks, one for each voltage, operating independently of each other.

For AC loads, always consider the quiescent (no load) current draw of the 120V AC inverter, which can be considerable. 700mA is not uncommon for 120V pure sine wave inverters. When using a "wall wart" transformer to step the 120V down to a lower voltage, 24VAC is common, consider the inverter and transformer efficiencies combined, and pay close attention to the loss of inverter efficiency at higher temperatures found inside an enclosure sitting in the sun. It is not uncommon for inverters to drop to 60-70% efficiency, and if the transformer is 85% efficient, the overall system efficiency may be as low as 50%. The good news is that when the inverter loses efficiency, typically during the hot summer months, the solar resource is greater and makes up for the inverter losses.

For 24VAC loads, common in the security, HVAC and telephone industries, a single, high efficiency 12-24VDC to 24VAC inverter is the most efficient and preferred solution, resulting in a much higher system efficiency, and often a smaller solar system.

SOLAR INSOLATION/WEATHER DATA: We use NREL (National Renewable Energy laboratory) weather data from the 30 year period between 1961 and 1990. This weather data base, which is available online, http://www.osti.gov/bridge/servlets/purl/10169141-YmPrJc/webviewable/10169141.pdf , will show the worst months weather over the full 30 years. Use the worst month of the worst year for solar sizing purposes, do not use average insolation values. This practice is used by some solar companies because using average values will always result in a smaller, less costly system. This may be useful in winning price based business, but makes for an unreliable system design. Consider that many oil and gas companies deploy hundreds of systems, often at each wellhead. If a bad year occurs, they may suffer numerous simultaneous system failures, resulting in a loss of revenue, and customer goodwill. For international applications, use www.gaisma.com to view weather data.

Solar radiation is expressed in peak sun hours, equal to 1000W per square meter, or roughly the equivalent of the sun at noon on the Fourth of July. All solar panels are rated at this insolation level, and geographic locations also use this value to express how much sunlight is available for each month.

SOLAR SYSTEM ENGINEERING: The peak sun hours for a given month is how a solar (photovoltaic) module's output is rated. To determine the solar module output for a given month, multiply the peak sun hours times the module current. For example, if a site has 3.0 peak sun hours per day in December that means a 50W solar panel will NOT produce 150 watt hours of energy per day, but will produce the module's rated current times 3. This is important because solar modules are rated at peak power point, usually about 17V for 12V system and 34V for 24V systems. Since it is very unlikely the system will be operating at this high voltage, it is better to use the module current rating instead of the wattage.

Thus a 50W panel, rated at 3.0A will produce 9.0 amp hours (Ah) per day. If the battery voltage averages 13V, then the net output will actually be 117 watt hours. The usable power will be this value multiplied by .8 to take into consideration the overall system and battery charging efficiency. Thus, a 3.0A panel in a 3.0 peak sun hour regime will produce (3.0) x (3.0) x .8= 7.2Ah per day, or a 300mA continuous load. Never divide the solar module wattage by 12V to determine the current.

Please note that this is only the first step in sizing the system, safety factors, or "head room" are not yet taken into consideration.

For purposes of discussion, we are considering all of the loads to be critical. Again, using the Oil and Gas example, a failed system can result in lost revenues. The natural gas will continue to flow, but if the system is down, it can't be accounted for, and the customer usually gets pretty annoyed when this happens. If the site happens to be an offshore platform the cost of sending a technician out in a helicopter to replace the batteries can be very expensive., and any monies saved in the initial cost of the system is wiped out several times over. When designing a system always consider the “cost of failure”: lost revenues, compromised security, lost service, damaged reputation for you and your customer, the cost of deploying a security guard or technician, transportation, possible danger to the public and resulting outcry.

When sizing batteries for a solar system, keep in mind that the recommended battery capacity for a give system is inversely proportional to the peak sun hours. So a system in sunny Arizona probably only needs 7-9 days autonomy, but a system in Seattle, WA should have about 30 because of the long cloudy periods in a typical winter.

When in doubt, always err on the side of reliability. Also consider possible weather extremes, hurricanes or high winds; wind driven rain; cold temperatures; ice and snow formation; high water; blowing sand and intense sunlight.

CONSERVATIVE DESIGN APPROACH: Never size a system to do just what the load requires, always allow a safety factor for several reasons: Most solar system will very slowly degrade over time due to aging batteries, minor dirt or dust accumulation on the solar modules, and other factors, such as less than perfect site conditions, occasional shading by antenna’s or vegetation, possible inaccurate load information or a change in the load profile itself. Since a solar system can last for 30 years or more, it’s not realistic to expect it to operate as efficiently at its’ end of life. Most solar module manufacturers offer 20 – 25 year warranties, however, these warranties usually only warrant the output of the solar module to be 80% of it’s initial power rating.

Batteries should be derated for cold temperatures and gradual loss of capacity due to aging, especially in hot climates. Battery capacity and age is always rated at 25C or 75F. For every 10C or 15F in average annual battery temperature over that temperature, the battery life is cut in half. Thus, a 5 year battery in an average temperature of 90 degrees will last 2-3 years. In cold climates batteries should be insulated, their own thermal mass will help prevent them form undergoing wide temperature swings. Don’t skimp on batteries, they are cheap insurance. For some reason, when trying to keep costs down, a lot of people are inclined to reduce the battery capacity even though they are the heart of the system. Remember, solar systems do not run on solar power, but battery power. We simply use solar to recharge them.

The other consideration for not sizing the system too tight is the simple fact that if you have an extended cloudy period and the batteries are deeply discharged, the solar system needs extra capacity to simultaneously recharge the batteries while running the load. If there is not sufficient capacity to do this, then the batteries will linger at a low state of charge, causing sulfation, an irreversible condition that causes them to lose capacity and require replacement. This extra solar capacity can be considered “head room”, and I recommend a 20% safety factor; that is, the solar array should be capable of providing 120% of the load during the worst month of the year.

COMPONENT SELECTION: Design for long life with exposure to 30 years of weather including extremes.

For solar modules, I prefer crystalline solar cells over thin films. They have a proven track record going back 50 years, and are not subject to gradual degradation that some tin film modules experience. Believe it or not, some inferior solar modules degrade in sunlight, and their lower efficiency will result in a physically larger solar array, using more materials and additional wind loading. All industrial grade solar modules will feature tempered glass designed to take the impact of a 1" hailstone at terminal velocity, approx. 63 MPH; have anodized aluminum frames for maximum corrosion resistance; a polymer back sheet and a waterproof Nema 4X/IP66 junction box that will accept conduit or waterproof cable glands. All cables must be rated for weather and sunlight resistance. Do not confuse consumer grade solar modules, commonly found in catalogs, for industrial grade ones. If the cost is low, the quality is likely to be low also.

The batteries generally preferred for industrial solar systems are low maintenance gel or AGM type. Although these batteries are commonly referred to as "sealed", in fact, they can vent gases under certain conditions, and therefore should not be placed in a sealed enclosure. The correct term is VRLA, or Valve Regulated Lead Acid, and both the battery manufacturers and the National Electric Code (NEC) advise to NEVER put them in a sealed enclosure.
"Wet" batteries are sometimes used, and though they require periodic maintenance, they can last very long in hot climates, as long as 15 years. For larger battery banks, over 1000Ah, telecom batteries are often used. Since they are very expensive, they should be kept in a conditioned enclosure, especially in hot climates, in order to get the rated 15-20 year life. In cyclic applications, a 10 year life is realistic.
In hot climates, utilize sun shades on the exterior of the enclosure to essentially put it in the shade and reduce solar heating of the batteries and electronics, extending their life.

The voltage regulator should be temperature compensated, that is, it adjusts the battery voltage set points based on temperature, lowering it in summer to prevent overcharging and drying the batteries out, and higher in winter, when the batteries need higher voltage to bring them to full 100% state of charge (SOC). I do not recommend the voltage regulators that mount in the junction box of the solar module, they have no way of knowing the battery temperature.
Digital display is a very good idea on the voltage regulator, it makes it very easy to verify system performance and trouble shoot when there is a problem. They're just downright convenient! A Low Voltage Disconnect (LVD) type voltage regulator is also recommended, so in the unlikely event of a system failure, the LVD circuit will disconnect the batteries when they are almost fully discharged, and reconnects them when they reach a 50% state of recharge, preventing damaging sulfation which we mentioned earlier.

Enclosures should be selected for long life and corrosion resistance, such as powder coated aluminum. Although aluminum is corrosion resistant, by powder coating them bright white you will minimize the solar heating of the batteries in summer because of the highly reflective finish. The array structure should also be fabricated from aluminum or hot dipped galvanized steel. Painted finish is only recommended in very arid climates where corrosion is not an issue.

DESIGN FOR LONG LIFE: High quality solar modules and key components; copper conductors with soldered lugs and adhesive lined heat shrink tubing to protect from corrosion; corrosion resistant enclosures, array structures, mounting brackets with stainless steel fasteners and hardware. Consider any threat from theft and vandalism by using special locks, tamper-proof fasteners, key locks instead of padlocks; and "hardened" padlocks with a protected shackle. Again, if the solar modules will last 30 years, so should the rest of the system. In remote areas frequented by rednecks, consider heavy gauge steel enclosures to provide bullet resistance.

If you buy your components from Radio Shack, expect problems.

PREASSEMBLY AND TESTING: Assures minimal installation time and trouble, even if the system has to be partially broken down for shipping. Preassembly allows performance verification, and also allows you to provide a value added service. By fully assembling the system, you are assuring the end user that everything fits and works as planned, and there should be nothing missing at the installation. We preassemble and test everything, and experience very few warranty claims even with a 5 year warranty. It just makes sense if you are building for quality and reliability.

SYSTEM INTEGRATION: By combining the power equipment with the electronics, you improve system efficiency and material utilization, reduce installation time, costs and materials, and allow complete system testing and FAT (Factory Acceptance Testing). Batteries should not be placed in an airtight enclosure (Nema 4, 4X, 12 and 13) with the electronics, as they may vent explosive gases. Proper battery ventilation is required by the National Electric Code (NEC) and all battery manufacturers recommendations. Even "sealed" batteries can vent explosive gases, as they are not really sealed, but have small vents that will "burp" if the internal pressure builds up to over 2 PSI. The internal pressure is necessary for the recombination of hydrogen and oxygen inside the battery, these gases are given off during charging, and when contained inside the battery, allow it to be relatively maintenance free, requiring no added water during its life.
"Wet" batteries are much worse, you can count on them gassing both explosive and corrosive gases, and their use requires a much different system design. They do have their advantages in hot climates, they will greatly outlast VRLA batteries, offering up to 15 years of life, but they do require semi-annual maintenance of adding water and probably removing corrosion from the terminals.
(Accompanying slides show good examples of efficient system integration)

When done properly, a well integrated system will use one large enclosure instead of 3-4 smaller ones, with the accompanying rack and conduit interconnecting the various enclosures. Cost savings can reach 50%, and the design is much cleaner.

INSTALLATION CONSIDERATIONS: Where is it going? How will it be mounted and to what? Pole-what size? Tower-what model? Wall or rack? Handrail? Concrete pad? Wooden Pole? What is the skill level of the installation crew? Do they have a compass?

Sometimes manpower is limited, and the batteries are very heavy. These questions should be answered before shipping the system in order to avoid installation problems that can cost your customer a lot of money if he is not prepared, or the system is not. If manpower is limited, then mounting brackets and installation aids can be supplied to allow one person to install the system safely.

Check for shading by an antenna, fence, heli-deck or other nearby structures. If there is vegetation nearby, especially tall trees, the solar day may be shorter than you think. Remember that safety factor or "head room"? It's not a perfect world out there. Keep in mind that most electricians are used to high voltage AC, and a completely different set of rules apply to low voltage DC installations. Electricians are not prone to asking questions, and many a Master electrician has screwed up a solar installation. Make sure the installation manual is well written with lots of pictures. Hand puppets can be a useful training aid. (Just kidding!)

Our company has special heavy duty pallets built because we have learned that when shipping heavy, valuable cargo, a regular pallet does not offer adequate strength or protection in transit. We think a $50 pallet is good insurance, and we experience very little freight damage as a result. This is a lesson we leaned the hard way.

Never underestimate the power of an incompetent freight handler, forklift driver or lazy trucker. They can destroy in minutes a system designed to last 30 years. And you can count on them denying it and refusing your freight claim. I had one trucking company insist I had shipped the system damaged.

DC-UPS SIZING GUIDELINES: Begin with the same step as solar, gather accurate load information. Determine average load current and the customer's desired run time without power. Allow enough extra capacity on the DC-UPS power supply to both run the load and recharge low batteries simultaneously. Always consider battery capacity as a function of the rate of discharge, the lower the discharge rate relative to the battery capacity, the greater the capacity. Battery capacity at the 8 hour rate is always much less than the 100 hour rate. Allow for battery aging, especially in hot climates, and try to design the system so it still meets spec when the batteries are due for replacement and have lost some of their capacity.

Use sun shades in hot climates and insulation in cold ones. Other packaging considerations are the same as solar, know what type of power input you have. For example, may municipal Wi-Fi applications are powered from street lights that only have power at night. In these cases, consider the summer solistice, when the night is shortest, day longest, and the system has to replace the maximum amount of power during the shortest night of the year. For cyclic applications such as this, size the battery for a 20% Daily Depth of Discharge (DOD), this will give you between 1000 and 1500 cycles in a mild climate.

In a hot climate, the battery life is shortened. As we discussed earlier, Gel and AGM batteries lose life in hot climates, so for DC-UPS applications where there is line power consider a small air conditioner or air to air heat exchanger to keep the batteries cooler in summer. Both allow cooling without introducing outside air, especially important in dusty desert environments, or humid, salt laden coastal or offshore sites.

HAZARDOUS LOCATIONS: Class 1 Division 2, Groups C and D are the most common, usually on natural gas pipelines, refineries, chemical plants, grain or fuel terminals, well heads and offshore platforms. There are some standard, pre-approved systems, but for large projects or OEM equipment, it is recommended that the complete system, including the load electronics, be approved by one of the major testing laboratories, such as UL, FM or ETL. Class 1 Div 1 is very difficult, and usually limited to very small systems, with small solar/battery combinations, and utilizing explosion proof enclosures and components.

Non certified systems near hazardous areas are usually located at least 15 feet from the pipeline or other explosive gases source. The NEC must be followed, usually using intrinsic safety barriers, OEM approved interface electronics, and by using rigid metallic conduit or armored cable that is completely sealed internally to prevent the migration of explosive gases into the non-hazardous power system. Simply using Class 1 Div 2 components DOES NOT mean the system is legal, however, the NEC is somewhat vague in this area, and an experienced electrical engineer does have the power to approve such a system if he believes it fully complies with the NEC. An example would be an offshore production platform that is les than 30' across. In this case, it is physically impossible to locate the equipment, such as navigation aids, the required 15' away.

WARRANTY: I recommend a 1 year minimum, and a 5 year is desired. Batteries are always pro-rated, just as when you buy or replace a car battery. Beware of long, lengthy warranties written by lawyers, they are likely not very good, for you anyway.. A simple, no hassle warranty is best, and the vendor should offer to replace whatever is needed without delay, sorting out the claim is secondary to getting your equipment back up and running as quickly as possible. If you have done your homework and designed the system properly, and it is pre-tested before shipping, then the warranty shouldn't be an issue. Keep in mind that customers who might have hundreds of systems deployed cannot afford warranty issues of any kind. Acts of God, nature and man are usually not covered by a warranty, so you should not expect a system that has been struck by lightning to be covered under warranty. Solar modules generally carry a 20-25 year performance warranty, they are guaranteed to produce at least 80% of the original power spec after that time. My experience shows that a good module will degrade very little over time.

VENDOR REPUTATION AND SELECTION: How do they present themselves and their products? Lowest cost or highest quality? You can't buy the best equipment for the lowest cost, in spite of what you may be told. Again, consider the consequences of failure, a small cost savings can be quickly wiped out with a poor quality system prone to problems or failure.

Check their website-how do their products look? Is the information complete, or vague?

I’ve seen some websites that show the exact same picture for 20 different products. What is the warranty, and the warranty caveats or conditions? Dig deeper- how do they honor their warranties? Check references, especially within your industry. Are they local or out of state? Do they have a local rep? If they are out of state, and have a electronic switchboard instead of a real person answering the phone, then you may be on your own.

TEN COMMANDMENTS of GOOD SOLAR DESIGN: This is a slightly humorous set of guidelines I wrote for my customers, who are usually smarter and better educated than I am. I can’t lecture them, but if I can make them smile, then they might just listen.

I Thou shalt clearly and accurately define thy load, and add no additional loads in the future.
II Thou shalt know thy site, especially in winter, and avoid obstructions to the heavenly rays of sustenance.
III Thou shalt be prepared for the attack of the heathen, the thieves, the vandals and those coveting thy goods.
IV Thou shalt not be guilty of using too few batteries, for batteries are cheap insurance, and the heart of thy system.
V Thou shalt honor thy controls, for they are the soul of the system, and must be temperature compensated.
VI Thou shalt always ground thy system, for when the heavens open up, lightning shall quickly find thy system and destroy it.
VII Thou shalt check thy system regularly, for the ravages of time can be insidious.
VIII Thou shalt consider the worst case scenario, for it is written that this shall occur.
IX Thou shalt build to last, and by seeking value, thou shalt be held in high esteem by thy peers.
X Thou shalt know thy vendor, for one day thy salvation may lie in his hands.