The Good, The Bad, and The Ugly

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In the last two months I have been involved in two aspects of PV power systems that have created conflicting emotions. First, I had an opportunity to visit and inspect a number of PV systems that have been installed within the last year in the Southwest. After seeing these systems, I was ashamed to be a part of the PV Industry. More on those systems later. Second, I attended a facilitated discussion with other members of the PV industry. The results from this conference will evolve into a PV system procurement manual for municipalities and counties. The members of the PV industry that participated in this all-day discussion and the results left me with very warm feelings about the future of PV.

Inspection of Southwest PV Sites

First the bad news. A large southwest utility had purchased the systems at the sites I visited via competitively bid contracts. In some cases the specifications were tight, in others quite loose. The largest installation, a 100 KW utility-interactive system was sold, designed, and installed by a small company specializing in large-scale PV systems. Another small PV systems house sold and designed other grid-connected systems. Local electricians did those installations, using kits supplied by the design firm.

A company that sells PV-powered hydro pumps had sold, designed, and installed a water pumping system to run sprinklers for an athletic field. I also inspected a lighting system designed by a major PV distributor and sold and installed by a regional PV dealer. Another regional PV dealer had designed and installed PV lighting.

These systems were not as good or as safe as they could have been. Some of the systems had failed after only a year.

Grid Connected 100 KW System

For the most part, this system was a delight to inspect and test. The installers has used high-quality components and workmanship. Although the inverter was experiencing some operational problems, the manufacturer quickly identified and remedied them. Only in one area did I see a need for additional safety features. The main number 4 AWG conductors from the row-combining boxes to the inverter were not protected from faults. I recommended that fuses be added at the inverter to protect these cables.

Grid Connected 2.5 KW System

The installation used 16 AWG conductors to connect the modules to the inverter. The cables were held in a tray and were rated for 8 amps (NEC Section 340-7 and Table 402-5). The 15 amp fuses at the DC disconnect did not provide overcurrent protection for this cable.

The modules had a rated short-circuit current of about 7 amps, but short currents could be higher on clear days near solar noon. When the inverter was off-line or detected a ground fault, it automatically shorted the array, subjecting the cables to overheating. An 8-10 amp fuse should be installed in the string junction box to protect these cables. An 8 amp fuse meets the NEC cable ampacity requirements, but the high operating currents exceeds this.

The use of 2000 volt cable used in this system was an excellent choice since the operating voltage is near or over 600 volts. I noted some cable damage caused by sharp conduit edges.

Cable under-sizing was also a problem. The 10 AWG ac output cable only handled 30 amps; however the inverter output circuit was rated for 34 amps (4KW). The inverters internal 50-amp fuse did nothing to protect the undersized cable. Although the inverter can’t deliver more than 34 amps of current when connected to the 2.5 KW array, the output cable should be 8 AWG, rated for at least 42.5 amps.

Disconnect switches were mounted high on a wall, out of reach.

Suggestions:

1. Change and fuse module conductors to handle the larger 12–13 amp current seen at peak power operation.
2. Replace the present unfused ac disconnect with a fused ac disconnect. Identify the circuit breaker in the building’s ac load center for back-feeding. Secure it to the load center enclosure with additional mechanical fasteners.
3. Protect all metal conduit and fittings with insulating

bushings to prevent cable damage on sharp metal edges. Replace the Bussmann NOS DC input fuses (which have only a factory DC rating) with Littlefuse IDSR fuses which are UL-Listed for use at 600 Volts DC.

4. Mount disconnect switches so that the handles are no higher than 6.5 feet above the floor.

Grid Connected 2 KW System
The comments on the preceding installation apply to this one, even though the inverter had been removed when inspected.

The ambient-air temperature sensor was mislocated. It should have been mounted outside, exposed to the same air temperature as the modules.

PV Powered Sprinkler System
This system pumped water up from a well to supply sprinklers on an athletic field. The site was a hazardous nightmare. To start off, I could find no equipment or system ground, ground rod, or surge protection!

The system had other major mechanical and electrical safety problems caused by poor workmanship. The well pump motor shaft was left exposed. The enclosure containing the sprinkler pumps and controls was crowded and lacked enough space to work safety.

I found electrical junction boxes mounted at or slightly above ground level. They were already corroding. The installers had put a load center designed for indoor use in an exposed outdoor location. An open right-angle pull box held cable splices.

They had used hugely oversized 100 amp fuses to protect very small conductors. Wires and cables lacked any labels indicating wire size or routing. Battery cables were not protected from fault currents. Circuit breakers were used as disconnects with no fault current protection. Charge controllers were mounted in outdoor locations where dirt and moisture would cause the mechanical relays to fail prematurely.

Battery water levels had fallen below the tops of the plates, indicating possible battery damage. The charge controllers were cycling and the battery voltage was 28.2. The batteries were not insulated and their performance suffered in cold weather. The system failed to include compensation during charge. The builders installed multiple battery charge controllers instead of a single large one. Battery terminals were not sealed and had already begun to corrode.

Every aspect of the system was sloppy. The designer had ignored row-to-row module shading at low sun angles during the winter. This caused unnecessary and annoying reductions in power output.

Major inefficiencies marred system performance. Multiple small pumps were operating in parallel when a single large DC motor connected to a single sprinkler pump would have wasted less energy. Use of battery storage severely affected water pumping efficiency. Possibly 50% or more of the PV energy was being lost in battery charging/discharging! To avoid these losses, PV systems for water pumping usually omit batteries and feed energy directly to the load. The sprinklers did not appear to be designed for athletic field use. They didn't have provisions for contact from above and were eroding nearby soil. The low-quality externally mounted sprinkler timer mechanism was already rusting.

Suggestions:
Safety
1. First and foremost, GROUND THE SYSTEM! Don't even think of operating it before this is done.
2. Have a qualified electrician rewire the system using the proper cables, overcurrent devices, disconnects and enclosures.
3. Add surge protection on the PV and motor conductors.

Function
1. Redesign the entire system. Increase the north-south spacing between rows of modules to reduce winter shading.
2. Eliminate the batteries except for a small one to power any timers or control devices. Operate the pumps in the daytime only, connect the PV array directly to the well pump to fill the tank. Reconnect the PV array directly to a large sprinkler pump with zone valves to water the field.
3. Use a linear current booster to get better early morning and late afternoon performance.
4. Use full-tank and empty-tank switches to control the charge between well pump and sprinkler pump operation.
5. Use a simple timer to control and operate the zone valves. This may require a small battery system and an inverter. Timer operation may not be accurate with devices that sync off the 60 Hz powerline frequency. Radio Shack has 120 volt ac timers that generate their own reference frequency and are accurate even if the inverter's frequency output varies.
6. Use a day-of-the-week timer or manual override switch to avoid watering the grass on game days.

Lighting System
This installation had only one module powering an 18-watt lamp and probably couldn't procure much light on cold, short winter days. It also had functional and safety problems.

Safety was badly neglected. The system was not grounded and had no surge protection devices. It lacked any disconnect for the PV or the batteries. No properly rated overcurrent devices were installed to protect array or battery wiring. Exposed battery terminals represented a safety hazard for service personnel and had no anti-corrosion protection.

The batteries were located in the same compartment as electrical devices; a major mistake. Even with catalytic recombiner caps, batteries produce corrosive gases and hydrogen gas. Even sealed batteries may vent explosive gas under some conditions. Enclosures should be partitioned with hermetic seals and be well vented. Batteries should be mounted above electrical components to allow hydrogen gas to escape upward and be mounted in acid-proof containers to avoid corroding metal surfaces.

The rest wasn't much better. Battery water was low, but still above the plates. There was insufficient space to properly water the batteries or service the system. Batteries were not insulated against cold weather and the charge controller lacked any temperature compensation or regulation. The timing device appeared overly complicated and inappropriate for this environment. It had already failed.

Suggestions
Modify the system, in order of priority, as follows:

1. Ground the pole, all equipment cases, and the negative conductor of the system (if allowed by the lighting fixture design). Add surge arrestors on cables to PV modules and lamp.
2. Add pull-out fuse holder/disconnects with appropriately rated DC fuses for PV and battery conductors.
3. Seal off the battery compartment and vent it outside.
4. Spray battery terminals with Permatex battery-terminal fluid after installation. Cover exposed battery terminals.
5. Replace the separate charge and lighting controllers with a combined PV lighting/charge controller.

Flashing Lights - Pedestrian Crossing
This system had a sufficient number of modules and sealed batteries to perform well. Safety-wise it had major deficits, including no apparent system ground. One of the brackets holding the flashing light was cracked open.

All of my preceding comments about battery safety apply here, with one important addition. The system is located near the roadway where passing vehicles could strike the battery enclosure. If one did, the battery terminals could contact the metal enclosure—with possibly explosive results.

Suggestions:
1. Ground the pole, the equipment and the negative conductor unless there are equipment restrictions to the contrary. Add surge suppression to the PV and lighting circuits.
2. Add the fused disconnect previously described.
3. Fully insulate and protect the battery terminals and surrounding metal surfaces.
4. Consider enclosing the base of the lights with protective barricades.
5. Insulate the battery compartment.
6. Repair or replace the broken bracket.

Specifications and Bids
The results of my inspection were disheartening. The PV industry can do and has done better. I have seen systems that are well designed, safe, and performed as specified without unexpected failures. To some extent the problem lies with the purchaser, who writes loose specifications and then goes looking for the lowest bidder. As in all other endeavors, you get what you pay for. Low bid, loosely-specified PV systems usually turn out to be unsafe and give less than optimum performance.

When purchasers get tired of poorly performing PV systems, they will start tightening contract performance specifications and demanding warranties. In future contracts, PV purchasers will examine a company's past performance and history of customer satisfaction.

To help prospective PV purchasers and encourage higher standards in the PV industry, I have begun developing a PV procurement manual. Parts of this are outlined below. It is intended for municipalities, utilities, and other agencies. The PV industry must look at these requirements and use them to design, bid, and install better systems.

Photovoltaic Power Systems: Specifying and Verifying Performance
Photovoltaic (PV) Power Systems are a relatively new technology. Few systems are available off-the-shelf for any particular application or level of power output. PVs initial cost is often higher than the cost of other non-renewable power systems. Reliability has been a problem; prospective PV buyers cannot always assume long-term, maintenance-free performance. Cost and reliability issues create a dilemma for those who want PV.

Although it is not legally mandated in every jurisdiction, the National Electrical Code (NEC) contains a comprehensive set of requirements and good engineering practices that can ensure a safe and durable PV installation. The NEC should be called out as a basic requirement in any system.

The following spectrum of procurement styles and performance assessments cover the range of PV purchases.

Minimum Technical Expertise
1. Procure a Turn Key installed system with performance specifications.
2. Write performance guarantees and warrantees into the contract. A maintenance contract will usually be required. Penalties are required for delays in delivery and poor performance.
3. Performance is assessed by easily observable or measurable output quantities. The quantities may be directly observed or read from standard meters. For instance: A PV-powered light must produce usable illumination from dusk to dawn, 365 days per year for five years. A specified amount and quality of AC energy in kilowatt hours is to be produced each month for ten years.

The vendor is fully contractually responsible for the initial and long-term performance of the system.

Moderate Technical Expertise
1. Determine the required performance specifications.
2. Initiate bids for a system that meets those specifications.
3. Require the following milestones in the contract.
A. Review and acceptance of system sizing and performance design calculations.
B. Safety review of electrical and mechanical design.
C. Inspection of electrical and mechanical installation.
D. Performance testing of the installed system.
E. Require long term performance and maintenance warranties as needed.
F. Perform periodic testing if output not easily observable.

If not otherwise specifically contracted, initial and long term performance of the system is the responsibility of the owner.

Expansion of the milestone tasks in this section is presented in the Milestone Section that follows.

Substantial Technical Expertise
1. Design the system with in-house personnel, specify components, procure material, build system, and install system.
2. Set up a maintenance program, if required.
3. Test and evaluate installed system at time of installation and yearly thereafter. Install monitoring hardware if necessary (larger systems) and monitor system performance.

There are no system performance warranties. The individual components have factory warranties.

System Contract Milestones
Write contracts so that each of the following milestones are reviewed and approved by the purchaser before moving on to the next. The contract should require timely submission of data necessary to evaluate these milestones. State that the vendor must implement any required changes to the design, material, or installation before approval will be granted.

Make it clear that purchaser approval of any or all of these milestones does not relieve the vendor from meeting any system performance or warrantee contractual requirements.

System Sizing Review
The vendor must furnish all information and calculations used to size the array, inverter, and storage system (if any). They should also provide sources of data or actual data for solar insolation and weather used in these calculations. The vendor should give the efficiencies of components such as charge controllers, inverters, and other electronic devices.

System Safety Review
The vendor and purchaser will review the detailed electrical and mechanical design for safe engineering practices. This review shall be made early in the contract before any equipment is purchased.

The review should examine the electrical design for compliance with the requirements of the National Electrical Code (NEC) in the following areas:

1. Short-circuit currents in all conductors.
2. Conductor voltage and ampacity ratings.
3. Overcurrent device ratings and locations.
4. Disconnect ratings and locations.

The vendor will furnish full and complete electrical specifications for each component used. These include manufacturer's specification and ratings and any equations or tables (NEC) used in the electrical design. The vendor must also use UL-Listed (or equivalent) components where possible.

Qualified civil engineers will examine the mechanical design for compliance with applicable building codes. Emphasis will be placed on wind and snow loadings and other factors affecting the durability and safety of the exposed systems.

The planned battery storage installation should provide the necessary degree of safety for operating and maintenance personnel.

System Installation Inspection
After the system has been installed, inspect to determine if the equipment in the electrical and mechanical design is installed safely and durable.

Conduct the following tests:

1. Perform dry and wet insulation tests on the conductors and PV array.
2. Verify the mechanical and electrical integrity of electrical connections.
3. Assess the mechanical operation of disconnects and overcurrent devices.
4. Verify the installation of a grounding system and equipment grounds.
5. Perform appropriate mechanical inspections as required.
6. Verify the performance of the module/array tracking system (if used).

System Performance Testing
Use the following electrical tests to determine the performance of the system immediately after installation. Perform only the measurements needed to verify contracted performance specifications.

1. Perform I-V Curve Tests on modules, strings, or array.
2. Rate the DC array output at standard test conditions (STC).
3. Measure the efficiency of the inverter.
4. Measure the storage system capacity.
5. Measure the power produced by the system under STC.
6. Measure the AC voltage, current and harmonic distortion produced.
7. Measure the frequency stability.

Continuing System Evaluation
If the output of the system is not readily observable, or the output decreases over time, it may be necessary to perform some or all of the tests listed under "System Performance Testing" on a periodic basis. The test results might be used to establish the need for system or component maintenance. They could also be used to identify trends in system performance that could be used to prevent system failures.

Access
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