A “Green” Approach to Power Supply for Remote Systems

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ABSTRACT

Photovoltaic power systems have the potential to drastically affect power design for remote applications. Rising energy costs coupled with rising construction costs are making it less economical to run power lines from a distant utility source to a remote site, particularly when the load at the site is relatively small. As current technologies improve and new technologies arrive, it will become more feasible, as well as cost-effective, to pursue photovoltaic power options when designing remote sites.

Photovoltaic power systems are driven by an array of photovoltaic cells that harness the sun’s energy and convert it to useful electric power in the form of a DC voltage. Several design factors can contribute to the required size of the array, including system voltage, the desired reliability, the amount of “quality” sunlight available (particularly during the month with the fewest average hours of sunlight), and the use of tracking versus non-tracking arrays. The system also includes a battery bank to provide power backup for times when solar energy is not available. Battery type and cost is largely affected by the battery bank’s housing, as well as routine battery maintenance. Typically, the photovoltaic array feeds into a battery charger that regulates the energy required to charge the batteries, which are connected to the load in parallel with the array to ensure backup capabilities. The need for ancillary equipment, such as power inverters, transfer switches, and backup generators, is dictated by the load being served.

This paper discusses a recently designed project that fits this very scenario. The site contains the following equipment: three valves, a small pump system, instrumentation, and a small building that houses control panels and a remote terminal unit (RTU). The total connected load for the system is approximately 3 kilowatts. However, the site is 15 miles away from the nearest available utility connection point, so running power lines does not make economic sense for such a small load. Instead, a small array of 24VDC panels and a battery bank, along with a backup generator, will be installed to power the site. This approach will keep construction costs significantly lower than those associated with the construction of power lines.

As a growing technology, photovoltaic systems are becoming more common in water applications. In situations where the economic feasibility of constructing power lines to feed a small metering or pump site is not very high, a photovoltaic system can provide a clean, neat, and reliable method of providing power. Combine this with the fact that

initial capital required for installation can be offset by low-maintenance requirements, energy savings, and possible tax credits, and it is easy to see that the advantages of using a photovoltaic system are growing as fast as the technology itself.

KEYWORDS

Photovoltaic, solar, renewable, green energy, remote site, power distribution

INTRODUCTION

In the past few years, the steady climb of costs associated with traditional power distribution equipment, including construction, materials, and maintenance, has been far from unnoticeable. As this trend continues, owners of small remote systems are seeking ways to generate and distribute power within the site by means other than long, costly runs of utility lines. While some owners choose to install a bank of engine generators to serve this purpose, others are seeking cleaner, more modern approaches.

One method being considered in these applications is the installation of photovoltaic systems. Currently, the technologies associated with photovoltaic systems are developing at a rate similar to that of the computer in the 1980s and 1990s. Solar panels are in constant demand, and energy conversion and delivery efficiencies are increasing. As energy costs continue to rise (coupled with a growing interest in “green energy” research), photovoltaic systems will find themselves to be much less of an “idea” and much more a common reality, particularly in small, manageable applications.

SYSTEM COMPONENTS

In its simplest form, a photovoltaic system can be broken down into two basic components: a solar array (consisting of a number of photovoltaic cells connected in parallel) and a battery bank. The solar array captures solar energy that is emitted in the form of sunlight and converts it to useful electrical energy (in the form of a DC voltage). The array is connected to the system's load in parallel with a battery bank that serves as a storage device to provide “backup” power during times of low solar energy. Typically, a charge controller is used to regulate the feeder connection from the solar array to the batteries, and a power inverter will be required if there are AC loads present. **Figure 1** shows the block diagram that was used in this study and has been attached to the end of this paper.

Solar Installation

Photovoltaic cells are currently available in three types of technologies, or “generations.” The first generation cell is essentially a single layer semiconductor diode. These cells are constructed from a silicon wafer and are the most common type of cell in today's market. The second generation cell expands on the use of a diode with the use of thin-film deposits of semiconductors. Due to recently declining costs of the materials required for construction of second generation cells, these cells can be found at a lower cost per watt than silicon wafer based cells. However, it should be noted that conversion efficiencies are also lower. The third generation cell, still a new technology in relation to the other two, does not rely on the semiconductor diode.

In order to most efficiently capture the available solar energy, one of the first things to consider in the system design is the angle at which the array of cells will be tilted toward the sun. The orientation of the array relative to the local horizontal (in most cases the earth) greatly affects the required size of the array. The three common tilt angles that are used are 0°, +15°, and -15° (all with respect to the latitude of the location). For example, a tilt angle of +15° at a location with a latitude of +35° would require the array be oriented at +50° to the horizontal (earth). Generally, a 0° tilt will provide a fairly evenly distributed energy output throughout the year. Tilting the array at +15° will bias the output to be higher during the winter, and tilting at -15° will bias to the summer. For this design, a tilt of +15° was chosen to ensure maximum output during the winter months, when sunlight is more likely to be unavailable.

The sizing of the array, while mostly affected by peak-sun-hours and load size, is also affected by the choice of a tracking or non-tracking array. A tracking array is mounted in such a way that the array follows the path of the sun throughout the day, always orienting itself to capture the maximum amount of sunlight available at that time. This tracking is achieved by using optical sensors to determine the amount of sun available. The sensors feed this information to a controller that then rotates the array to an angle set to match the information provided. This method allows for a smaller number of panels to be used in the array because the constant optimum orientation of the panels makes more efficient use of the available sunlight. A non-tracking array is just the opposite. It remains in a fixed position, with that position being optimized to capture the energy available during the peak-sun-hours of each day. This type of array requires more panels than a tracking array. However, because there is no complex sensing and motor controlling involved, the mounting of a non-tracking array can be achieved at a lower cost than a tracking array. **Table 1** lists various advantages and disadvantages of both tracking and non-tracking arrays**.** Due to the high number of peak-sun-hours available for the design being studied, the array was designed to be non-tracking.

Array Type	Advantages	Disadvantages
Tracking	Optimizes available sunlight through focused tracking	Higher Costs, more complex system (increased maintenance), increased chance of array failure
Non-tracking	Simple array, less expensive, does not require automation	“Peak” sunlight hours are limited by climate and season

Table 1

Battery Bank

The required size of the battery bank is largely driven by the amount of electrical storage capacity desired. In many instances, the “design month” (defined as the month with the fewest peak sun hours per day) is the primary criteria for designing the battery bank. Ideally, the battery bank will have enough storage capacity to provide power for the entire load demand for a duration that is at least equal to the longest number of consecutive days that the site will not receive quality sunlight. In the case of the design being studied, January was chosen to be the “design month” for which the battery band was designed. January provided a peak-sun-hours range of 4.49 hours (at -15°) to 5.74 hours (at +15°). As was mentioned before, a tilt of +15° was chosen in order to maximize the peak-sun-hours.

Over the course of a photovoltaic system design, battery type and cost will have a large effect on the total cost of the project. **Table 2** lists various advantages and disadvantages of three commonly used battery types. This system design is based on a nickel cadmium (NiCd) battery. The parallel installation of the batteries and power sources requires the batteries to be resistant to voltage depression, more commonly known as “battery memory.” Voltage depression occurs when a rechargeable battery is not fully discharged before being recharged. Over time, the battery’s full capacity slowly drops to lower levels that approximate the level of discharge that is achieved before recharging. NiCd batteries do not build up a “battery memory” over time, and can, therefore, be exposed to a period of constant charging. NiCd batteries also offer low maintenance requirements, high durability, and tolerance of extreme hot or cold temperatures.

Battery Type	Advantages	Disadvantages
Lead Acid	Low-cost, long-life cycle, operates well under a variety of conditions	Risk of leakage, not tolerant to extreme temperatures
NiCd	Long-life expectancy, low-maintenance requirements, tolerance of extreme hot/cold temperatures, tolerance of complete discharge	Cost, cannot mix with other battery types
Lithium Ion	High-energy density, long-life expectancy	Risk of leakage, life-cycle is dependent upon time from manufacturing and not charge/discharge cycles

Table 2

DESIGN CONSIDERATIONS

Photovoltaic system design can be approached from several starting points. Factors such as system availability, back-up capabilities, land area required, and cost all contribute to the desired final design. Like other designs, however, there is often a trade-off between the various design factors. For example, system availability and cost are particularly intertwined, as increasing availability in a photovoltaic system affects cost a great deal. **Chart 1** reflects this relationship.

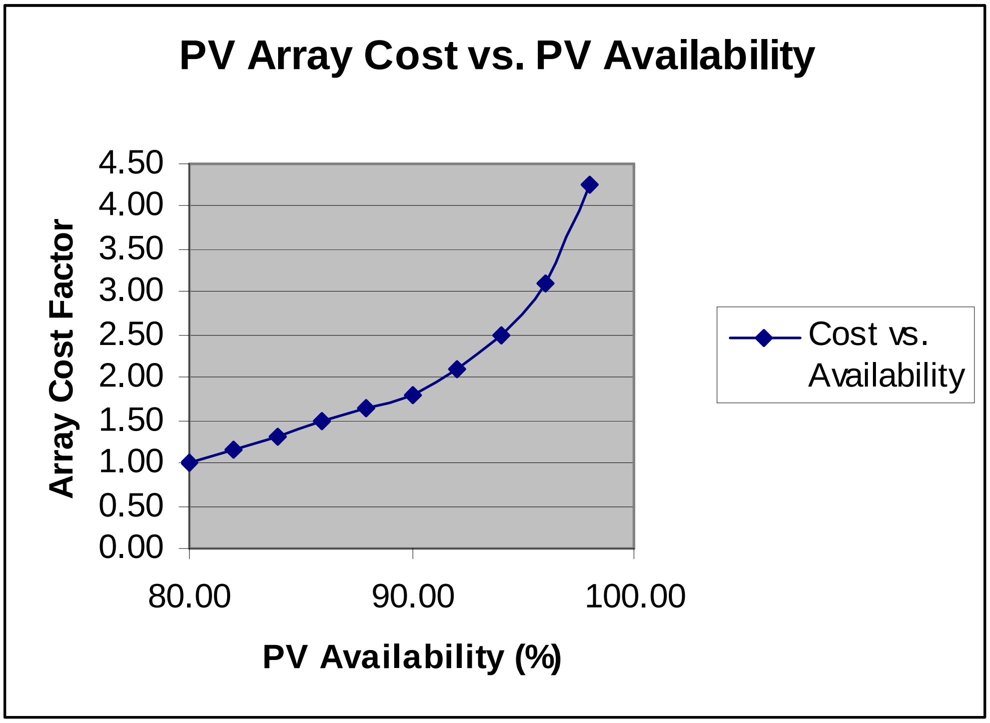

Chart 1

System availability is best defined as the number of hours annually that a photovoltaic system is capable of meeting load demands. For example, an installed system that has an availability of 95 percent would be capable of meeting load demands 8,322 hours during the average year (8,760 hours annually multiplied by the availability factor, in this case 0.95). System availability is driven by any cost ceiling associated with the design, as well as any sort of back-up system that will be installed.

Photovoltaic modules are presently available at a cost of approximately $5 per watt. Miscellaneous equipment (power inverters, mounting brackets and channels, wiring, etc.) will cost an additional $4 per watt, and a professional installation might run between $5 and $10 per watt. The battery bank that will be required will also add to the cost of the system.

As the desired availability of the system being installed increases, the land area required will also increase. Battery banks that provide storage capacity will become larger, and the number of panels installed will increase, requiring a larger expanse of open area around the perimeter of the panel area to ensure that shadows are not cast onto the array.

The two main considerations taken into account for this study were cost and system availability. The project's location and associated climate provided for a very high availability of sunlight throughout the year. Solar data shows that the longest average absence of quality sunlight is less than 5 days. The system was designed around an availability of 90 percent due to the favorable solar conditions and the fact that an emergency generator was being installed. In this case, the generator provides backup power to drive the load and charge the batteries. The generator is called to start and stop by the battery charger, which detects the charge of the battery bank. This configuration keeps generator run-time (and associated fuel costs) at a minimum, as once the batteries have charged to satisfactory levels, the charger will call the generator to stop.

The other consideration for this design was the amount of land area that each solar installation will require. The 90 percent reliability for which this installation was designed kept the solar array from becoming unnecessarily expansive. The remaining electrical items (generator and pre-fabricated building for the battery bank) take up small amounts of land area, so the cost of real estate was minimized.

ECONOMIC INCENTIVES

A driving factor in the push to increase renewable energy use is the economic benefit that can be realized. Currently, the Texas state government has various tax benefits in place to serve as incentives in the decision to use a renewable energy system. Section 11.27 of the State Property Tax Code specifically outlines what exemptions can be taken in the appraisal of property values, and Section 171.107 of the State Taxation Code outlines exemptions available on capital purchases that fall under the renewable energy device definitions (these definitions are also outlined in the tax codes).

CONCLUDING THOUGHTS

As renewable energy research and development continues to gain funding and interest, the associated technologies are becoming more developed, more reliable, and more available for common use. At the same time, rising energy costs are driving customers to seek alternative solutions to running costly power lines over an extreme distance for loads that seem too small to warrant the construction costs. As this search develops momentum, photovoltaic systems, previously a thought for the future, are finding themselves to be a "tangible" discussion item, providing a clean, efficient, and incentive-laced alternative to the common power generation systems of previous days.

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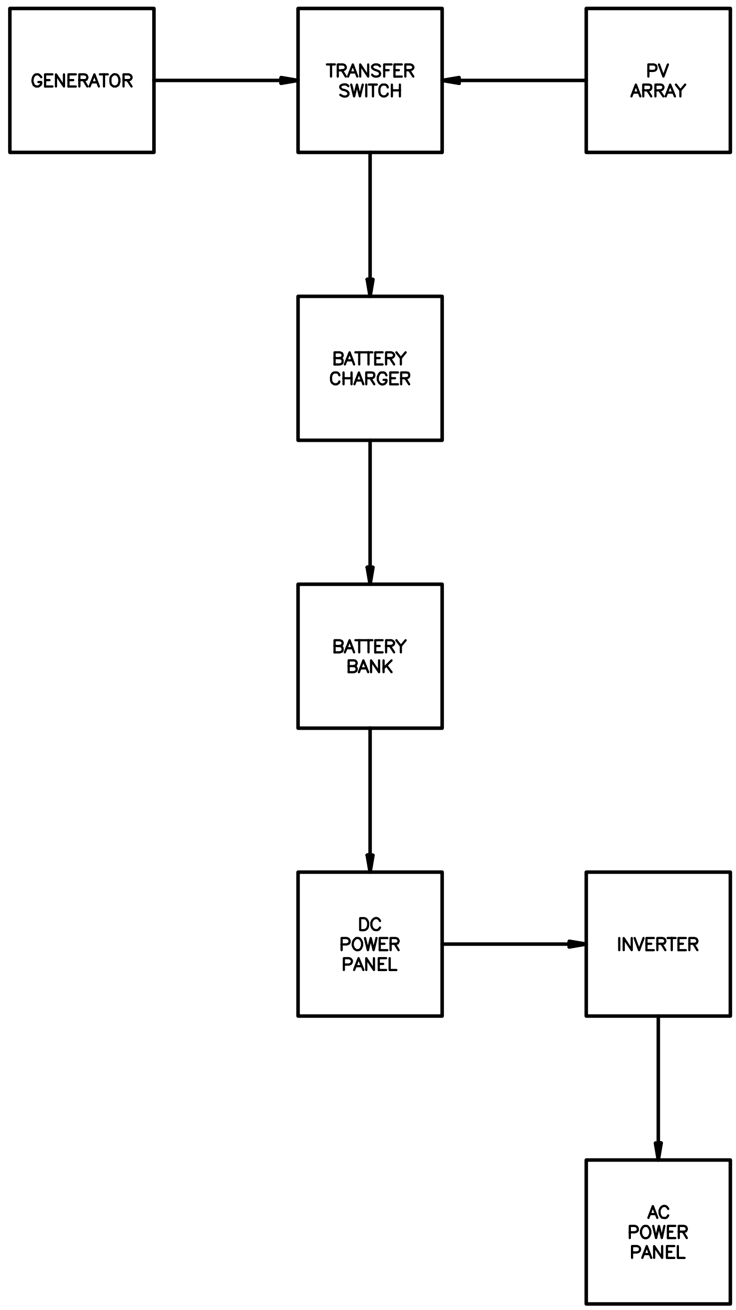
GENERATOR
TRANSFER SWITCH
PV ARRAY
BATTERY CHARGER
BATTERY BANK
DC POWER PANEL
INVERTER
AC POWER PANEL

FIGURE 1