SIZING A SOLAR PHOTOVOLTAIC SYSTEM

The photovoltaic power system is being used in an increasing number of applications. Although the dollar per watt is still too high to justify its use in most locations where regular commercial power is available, it is becoming very easy to justify in remote areas.

With normal utility line construction costs of $10-30.00 per foot, the installation of a solar photovoltaic powered control system is usually an ideal way to go if existing utility power is not already at the site and if the power needed is relatively small. This is not to imply that solar powered systems in the kilowatt, and in fact a few in the megawatt range, have not been completed in recent years. It is just to admit that there needs to be other reasons than merely "installed cost" to justify these large power solar electric systems today.

For relative low voltage (12-48 VDC) systems with continuous current drains of under 2 amps, the solar cell is hard to beat.

The phenomenon that photovoltaic cells convert sunlight into electricity was first observed and documented by a French physicist in 1839. It wasn't until the 1950's, however, that this phenomenon was made into a workable system. Even at that time it was very expensive (approximately $1,000.00 per peak watt). Through the 1960's and early 1970's, the solar cell was primarily a power source for the space industry. With the initiation of rapidly increasing utility and utility line construction costs, the solar cell began to receive more interest by the traditional systems engineer.

Today, with the total system cost many times under $20.00 per peak watt, it is no longer a question of "Can I justify it?" Today the most often heard question is "Why didn't it perform in real life like it did on paper?"
Many times the solar powered control system being installed is the initial experience the specific control design engineer has had with solar power, and in many cases, the initial experience his company has had. Without a base of experience to draw from, the systems engineer must attempt to gather engineering data from various sources, including potential suppliers with whom, in many instances, he is also unfamiliar.

In spite of the fact that the various manufacturers of solar cells are spending large sums of money on research and development, they are many times less application oriented than would be desired. The manufacturers have been very effective in improving the efficiency of their units and providing improved and less expensive encapsulation of their arrays. The dollar per peak watt has dropped by more than 20:1 in the last thirty years. The bulk of their attention, however, remains in the areas of dollars/watt. The industry is working hard to achieve their $1.00 per peak watt goal that is felt necessary to appreciably tap the potential consumer product market.

Because the cost of the solar array is going to be a hurdle at best, there is many times a tendency to take a few short cuts. These short cuts usually show up as:

1. Less expensive batteries
2. No or inadequate charging control
3. Less days of autonomy
4. Less array power

More attention has been given to whether the battery is lead acid or nickel cadmium than to what type of lead or nickel battery is used. Briefly stated, a properly sized system will have longer life and lower maintenance with nickel cadmium cells than with lead acid cells. The initial battery costs will, however, be two to four times as expensive with nickel cadmium.

The typical battery problems will be better understood with a brief description of battery float and recharge considerations regardless of what power source is available. There is a voltage for any electrochemical couple where optimum charge retention and minimum water loss is achieved. This is typically 2.2 v/c for lead calcium and lead selenium, 2.18 v/c for pure lead, and 1.42 v/c for nickel cadmium. There is also another voltage approximately 10-15% higher for the most efficient recharge of the cell.

With conventional utility powered battery chargers, the recharge (equalize) voltage is maintained for 24-72 hours to assure the cells are fully recharged after a discharge period. With a solar photovoltaic charging system we know we are, at best, less than 12 hours from "charger failure" unless we happen to be geographically near one of the poles. Then we know when it does "fail" it will be "off" for months. This presents unique battery problems because the battery may remain less than fully charged for extended periods of time.

On the other hand, if during ideal weather conditions the battery is fully charged and the full array voltage (typically 16-20 volts for 12 volt systems) is connected across the battery, excessive heating, water loss and reduced battery life will result.

The battery for solar applications should, therefore, have very low self discharge. This typically means thick plates with more than normal space between positive and negative plates. Also, for lead acid batteries, plate types with known sulfation problems should be avoided. Very heavy, pure lead positives with little or no antimony in the negative or thick plate (deep discharge) lead calcium seem to function the best. For nickel cadmium batteries, low discharge pocket plate construction offers the best results.

These low discharge rate batteries do not usually present a problem because most of the time when solar photovoltaic power is being considered, the application does not have high current rapid discharge loads.

To protect against overcharge and yet allow minimum recharge time, it would be desired to apply full array voltage across the battery and load unless and until the battery is fully recharged. Note: It may be necessary to use a CEMF circuit to protect voltage sensitive loads during recharge. When the sensing circuit has determined the battery is fully recharged, the controller should reduce the charging voltage across the battery to near the ideal battery float voltage.

A common practice in recent years has been to use a simple shunt regulator for charge control. The very real problems this causes the battery are interesting.

If we assume for a moment that at noon on a bright sunny day in June, the battery is 100% charged and is connected across a properly sized array through a shunt regulator, we will see the problem very quickly. Because the battery is fully charged, the array will raise the DC voltage to the maximum allowed by the regulator. The regulator will then disconnect the array from the battery, and the load will draw power from the battery for a minute or two while the voltage drops to the point where the regulator again connects the array to the battery. Since only a small amount of energy was removed from the battery in its 1-2 minute discharge while the regulator had been removed, it will only take another minute or so for the array to again raise the battery voltage to the maximum allowed by the regulator.

It is not uncommon for this cyclical on and off condition to continue on a 1-2 minute duty cycle for the rest of the day.

If a battery is discharged at a few milliamps and then charged at a few milliamps on a 1-2 minute duty cycle all afternoon, it will and the day with less total energy in the battery than there was at noon.

We then go into the night period and discharge the battery more, only to restart our cyclical on and off charging mode again tomorrow.

Many times at the end of the summer months, when we have just finished our best season for solar charging, the battery has less actual capacity than it had at the start of the summer.

We recommend the solar controller be a high efficiency DC/DC converter which will provide regular “float” and “recharge” voltages similar to conventional AC powered battery chargers. The primary difference is, of course, that you are going to experience a “charger failure” at sundown.

It must be remembered the solar array is drawing energy from the sun and is, therefore, following a 24 hour cycle which is itself riding on a seasonal cycle, both of which are periodically interrupted by specific weather conditions.

A very common problem is the result of installing a battery which is initially less than fully charged, into a system in the fall of the year and then using more than normal power during the period of system check-out and commissioning. In this condition the system may be "in trouble" from day one and premature battery failure could be experienced during the first year.

It may be desirable to provide a portable charger at the site for startup to accomplish a full recharging of the battery at the end of commissioning of the system.

The United States, and in fact to a less precise extent, the entire surface (land and sea) of the earth has been mapped to provide data for determining the size of array and orientation for optimum photovoltaic efficiency.

The array must be directed in a specific direction and at a precise angle in order to achieve optimum results for each specific location. Without violating this requirement, however, attention should be given to assure the following areas of concern are addressed:

1. The array is not shaded at certain times of the day or year
2. The array is above the reach of land animals and dust splatter
3. It should be improbable that a nearby tree limb (etc.) would break and fall across the system
4. Under normal snow conditions, drifts would not collect on the array face
5. If solar reflectors are desired, these same conditions must be met for them
6. Should the battery be installed underground or should some other method of heat retention be utilized
7. Is a battery watering manifold desired

<u>System Maintenance</u>

In properly sized and installed systems, very little maintenance is required. The battery should not require appreciably more water than its conventionally charged counterpart in the same ambient conditions.

If for any reason (i.e., load malfunction) the battery should become severely discharged, it will probably be desired to either bring a portable battery charger to the site (i.e. portable generator set) or replace the battery with a spare and return the original one to the base station for recharge.

<u>AC Power</u>

If the system should require AC power, a solid state inverter would be sized and applied in the same manner that it would for a typical in-plant installation.

<u>Interconnect</u>

Because of the relatively low output power from the solar array, special care should be taken to guard against terminal corrosion. Special greases and fungus proofing are available to aid in this.

<u>Sizing Calculations</u>

For optimum system reliability and battery life, the system should be sized to provide a fully charged battery at the end of any normal sun day. This means that under normal solar conditions, the array will replace to the battery all energy removed the night before, plus all battery recharge losses.

A typical scenario of how the solar array and battery operate is as follows:

<u>Approximately two hours before sundown:</u>

The sun is at such a low angle that virtually no energy is being derived from the array and the battery begins powering the load.

<u>Approximately two hours after sun up:</u>

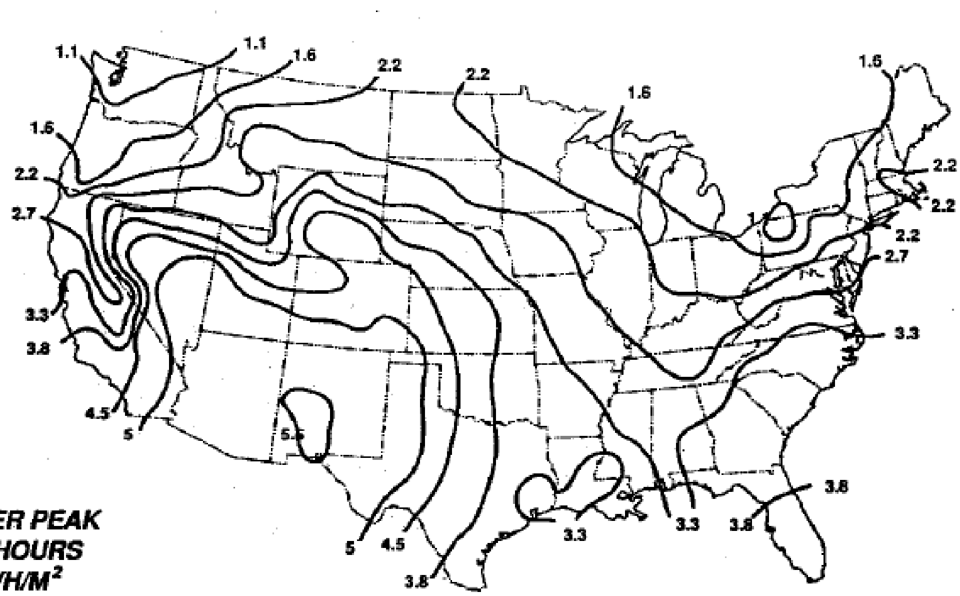
The sun has risen sufficiently that a normally sized array will probably be providing sufficient energy to take over powering the load. However, the energy level from the array will not yet be adequate to have much effect towards recharging the battery. It has just stopped allowing the battery to be further discharged.

<u>Peak Sun Hours:</u>

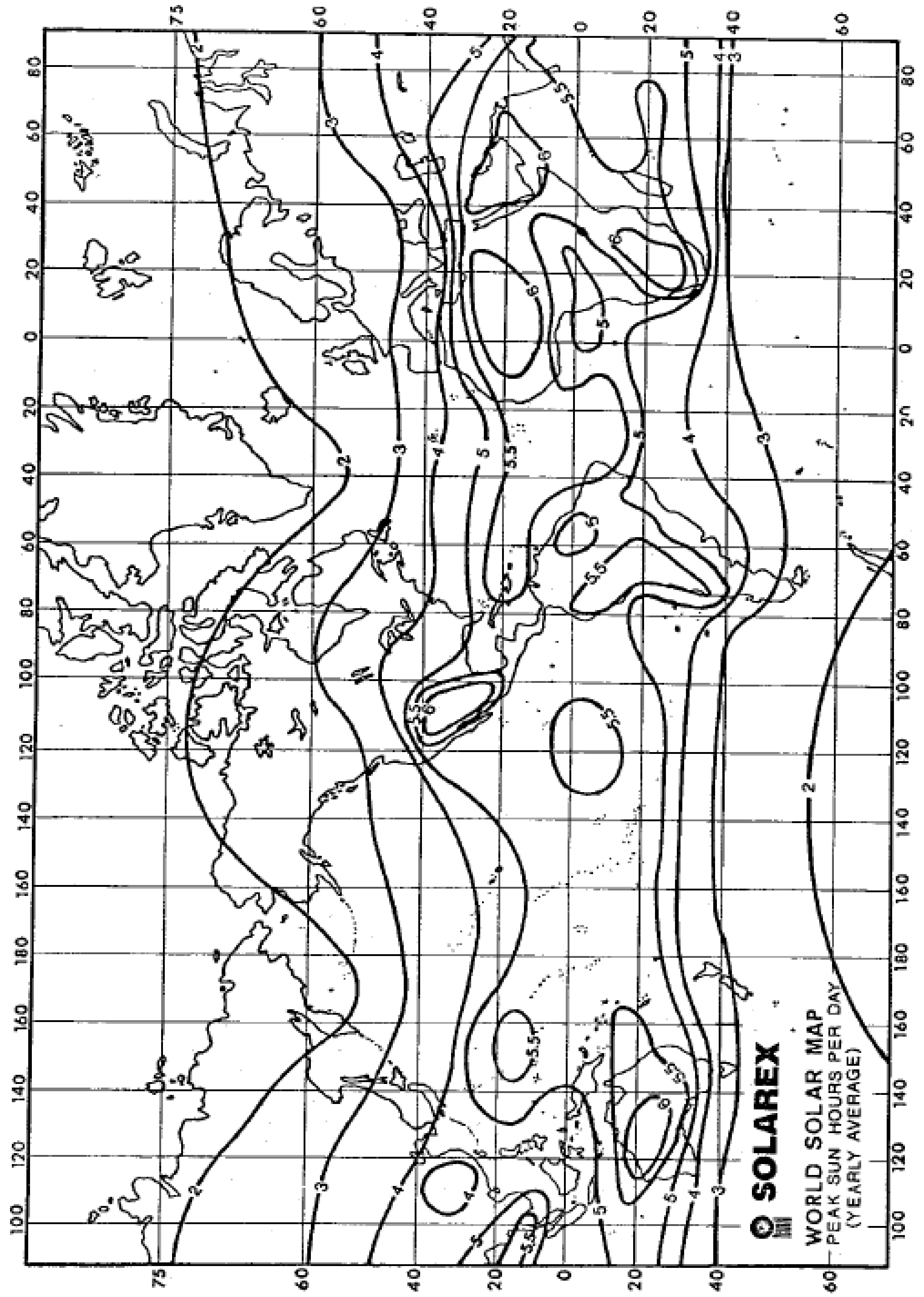
During the period of peak sun hours, sufficient energy is available to perform the recharging of the battery. Therefore, the array must be sized to recharge the battery during this peak sun period

The following maps are provided for ascertaining the minimum (winter) peak sun hours for various locations.

(Source: Solar Energy Research Institute)



WINTER PEAK SUN HOURS KWH/M²


SOLAREX
WORLD SOLAR MAP
PEAK SUN HOURS PER DAY
(YEARLY AVERAGE)

Battery Sizing

AH = (1 load) (Hr/Day) (Days Aut.) (Temp De-rate) (EDL De-rate)

AH = Amp Hour of required battery

1 load = Load current

Hr/Day = Hours/Day the load is powered

Days Aut. = Days of autonomy the battery is desired to power the load without benefit of the sun

Temp De-rate = The battery de-rating factor if the battery temperature will be less than 77˚F (see Section 20, Page 2.)

EDL De-rate = End of life de-rate (See Section 14, Page 18, Note 2.)

Array Sizing

$$\text{1 peak} = \frac{\text{(1 load) (Hr/Day)}}{\text{(Battery Recharge Efficiency) (Peak Sun Hours)}} + \text{1 load}$$

1 peak = Solar Array Peak Charging Current

For battery recharge efficiency see Section 15, Page 9.

The optimum array tilt angle is the array latitude plus 15˚

Array tilt angle = latitude = 15˚

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