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A Review of Designing, Installing and Evaluating Standalone Photovoltaic Power Systems

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Abstract: In this study a technical review of designing and installing the photovoltaic (PV) power system is proposed in order high light the optimum design and installing methods so as to optimize the photovoltaic system as much as can. The loads and the sun potential estimation methodologies have been proposed initially then the sizing methods of the PV system components; PV array, controller, batteries and inverter have mentioned. In the second part a recommended ways of interconnecting and installing the PV system have been introduced in order to reduce system faults and breaks consequently increase the system reliability. Finally an economic evaluation of the PV system using the present worth method is suggested in order to know how to evaluate the system feasibility and compare it with another alternative systems.

Key words: Photovoltaics, photovoltaic systems, optimizing PV systems, sizing PV systems

INTRODUCTION

The cost of energy produced by PV systems has dropped significantly since 1980. However, the cost of PV energy is still higher than energy bought from your local utility. Also, the initial cost of PV equipment is still higher than an engine generator. Yet, there are many applications where the low operation and maintenance cost of PV systems outweighs the low initial cost of the generator and makes PV the most cost effective long-term option, The number of installed PV systems increases each year because their many advantages make them the best option because of the following issues:

- **Fuel supply:** Supplying conventional fuel to the site and storing it can be much more expensive than the fuel itself. Solar energy is delivered free
- **Environment:** PV systems create no pollution and generate no waste products
- **Maintenance:** Any energy system requires maintenance but experience shows PV systems require less maintenance than other alternatives
- **Site access:** A well-designed PV system will operate unattended and requires minimum periodic maintenance. The savings in labor costs and travel expense can be significant
- **Durability:** Most PV modules available today are based on proven technology that has shown little degradation in over 15 years of operation
- **Cost:** For many applications, the advantages of PV systems offset their relatively high initial cost. For a growing number of users, PV is the clear choice (Thomas and Jones, 1988; Khatib *et al*., 2009a; Treble, 1993; Gavanidou and Bakirtzis, 1992; Hasti, 1994)

Typically, the standalone photovoltaic power system consists of solar array, controller with maximum power point tracker, batteries, inverter and loads. Since the solar array is a sole energy source, the power of the system will change significantly with the variation of solar radiation, temperature, load conditions and battery state of charge (SOC). Thus, it is very crucial to optimize sizes of solar array and battery to meet the load demand (or load profile) under the desired Loss of Power Supply Probability (LPSP) at minimum system cost (Shrestha and Goel, 1998).

In this review, designing and installing phases have been detailed in order to optimize the desired PV system as much as can. Moreover, an evaluating procedure using the present worth method has been proposed so as to state whatever the system is feasible or not.

LOAD ESTIMATION

An estimation of the energy demand of the load should be done firstly in designing the PV power system. This estimation is done by multiplying the power of each appliance by the average number of hours of use. Then a 20% might be added to allow for losses caused by wiring,

1 Load description	2 QTY	3 Load current (A)	4 Load voltage (V)	5A DC load power (W)	5B AC load power (W)	6 Daily duty cycle (HRS/DAY)	7 Weekly duty cycle (DAYS/WK)	8 Power conversion efficiency (DECIMAL) D	9 Nominal system voltage (V)	10 Amp-hour load (AH/DAY)
Lamp DC	/	x 2.0	x 12	= 24	N/A	x 2.9	x 7 ÷7	÷ /	÷ 12	= 5.8
Flasher DC	/	x 0.2	x 12	= 2.4	N/A	x 2.9	x 7 ÷7	÷ /	÷ 12	= 0.58
Surge current DC	/	x 0.4	x 12	= 4.8	N/A	x 0.29	x 7 ÷7	÷ /	÷ 12	= 0.12
DC		x	x	=	N/A	x	x 7 ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
11 Total load power (W)			DC 11A	31.5	AC 11B			12 Total Amp-hour load (AH/DAY)		6.5

13 Total DC load power (W) 11A	14 Total AC load Power (W) 11B	15 Nominal system voltage (V) g	16 Peak current draw (A)	17 Total amp-hour load (AH/DAY) 12	18 Wire efficiency factor (DECIMAL) D	19 Battery efficiency factor (DECIMAL) D	20 Corrected amp-hur load (AH/DAY)
31.2	+	÷ 12	= 2.6	6.5	÷ 0.98	÷ 0.9	= 7.4

Fig. 1: Load estimation work sheet

dc to ac conversion, dirty modules, etc. Loads whatever AC or DC loads should be described in a work sheet by load current, load voltage, daily duty cycle, weekly duty cycle, power conversion efficiency, nominal systems voltage and Amp-hour load. Figure 1 shows an example of a work sheet to estimate the load demand.

The designer should consider energy conserving substitutes for items that are used often. Identify large and/or variable loads and determine if they can be eliminated or changed to operate from another power source. Fluorescent lamps should be used in place of incandescent lamps. They provide the same light levels with much lower power demand. Consider using dc appliances to avoid the loss in the dc/ac power conversion process. DC lights and appliances usually cost more, but are more efficient and last longer. The number of ac appliances available is greater but efficiencies are usually lower because these appliances were designed for use on an infinite utility power supply (Celik, 2002; Khatib *et al*., 2010a; Protogeropoulos *et al*., 1997).

Table 1: Selecting system voltage

AC power demand (Watt)	Inverter input voltage (DC voltage)
<1500	12
1500-5000	24 or 48
>500	48 or 120

Voltage selection: The operating voltage selected for a stand-alone PV system depends on the voltage requirements of the loads and the total current. If the system voltage is set equal to the voltage of the largest load then these loads may be connected directly to the system output. However, it is recommended that the current in any source circuit be kept below 20 with a 100 amperes limit for any section of the system. Keeping the current below these recommended levels will allow use of standard and commonly available electrical hardware and wires. When loads require ac power, the dc system voltage should be selected after studying available inverter characteristics. Another consideration is the possible increase in the size of your system in the future. Table 1 shows the suitable voltage selection for PV system (Protogeropoulos *et al*., 1997).

DC loads usually operate at 12 volts or a multiple of 12-i.e., 24, 36 or 48 volts, etc. For dc systems, the system voltage should be that required by the largest loads. Most dc PV systems smaller than 1 kilowatt operate at 12 volts dc. If loads with different dc voltages must be supplied, the voltage of the PV system should be selected of the load with the highest current demand. Electronic dc-dc converters can be used to power loads at voltages different from the system voltage. If a lower voltage is required, it is sometimes possible to connect to only a portion of a series-connected battery string. This can cause problems with charging the batteries and should not be done without a charge equalizer if the current required at the lower voltage is more than 5% of the total current taken from the battery strings. A battery charge equalizer is an electronic device that keeps all batteries in a series string at the same voltage. Almost all ac loads for stand-alone PV systems will operate at 120 volts ac. The optimum selection of the inverter represented by choosing an inverter meets the load and keeps the dc current below 100 amperes.

Selection of an inverter is important and affects both the cost and performance of the system. Generally, the efficiency and power handling capability are better for units operating at higher dc voltages, i.e., a 48 volt unit is usually more efficient than a 12 volt unit. The designer should obtain information on specific inverters, their availability, cost and capabilities, from several manufacturers before making the decision on system voltage. Another fact to consider is the basic building block in the array and storage subsystems gets larger as the voltage increases. For example, a 48 volt system has four PV modules connected in series to form the basic building block. Fine tuning the design i.e., adding a little more current to the system, means buying four additional modules. However, the advantage of the higher operating voltage is the lower current required to produce the same power. High current means large wire size and expensive and hard to get fuses, switches and connectors. Again, a prior knowledge of the cost and availability of components and switchgear is critical to good system design (Celik, 2002; Protogeropoulos *et al.*, 1997; Borowy and Salameh, 1996).

CALCULATION OF THE SOLAR POTENTIAL

Solar irradiance is the amount of solar power striking a given area. It is a measure of the intensity of the sunshine and is given in units of watts (or kilowatts) per square meter (w m^{-2}). Insolation. is the amount of solar energy received on a given area measured in kilowatt-hours per square meter (kwh m^{-2})--this value is equivalent to peak sun hours.

A nearly constant 1.36 kw m^{-1} (the solar constant) of solar radiant power impinges on the earth's outer atmosphere. The extraterrestrial radiation spectrum is shown along with an estimate of the radiation spectrum at ground level. It is evident that the atmosphere is a powerful absorber and reduces the solar power reaching the earth, particularly at certain wavelengths. The part of the spectrum used by silicon PV modules is from 0.3 to 0.6 μm. These wavelengths encompass the highest energy region of the solar spectrum. On a sunny day the total irradiance striking the earth will be about 1,000 w m^{-2}.

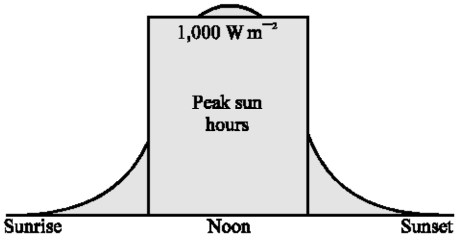
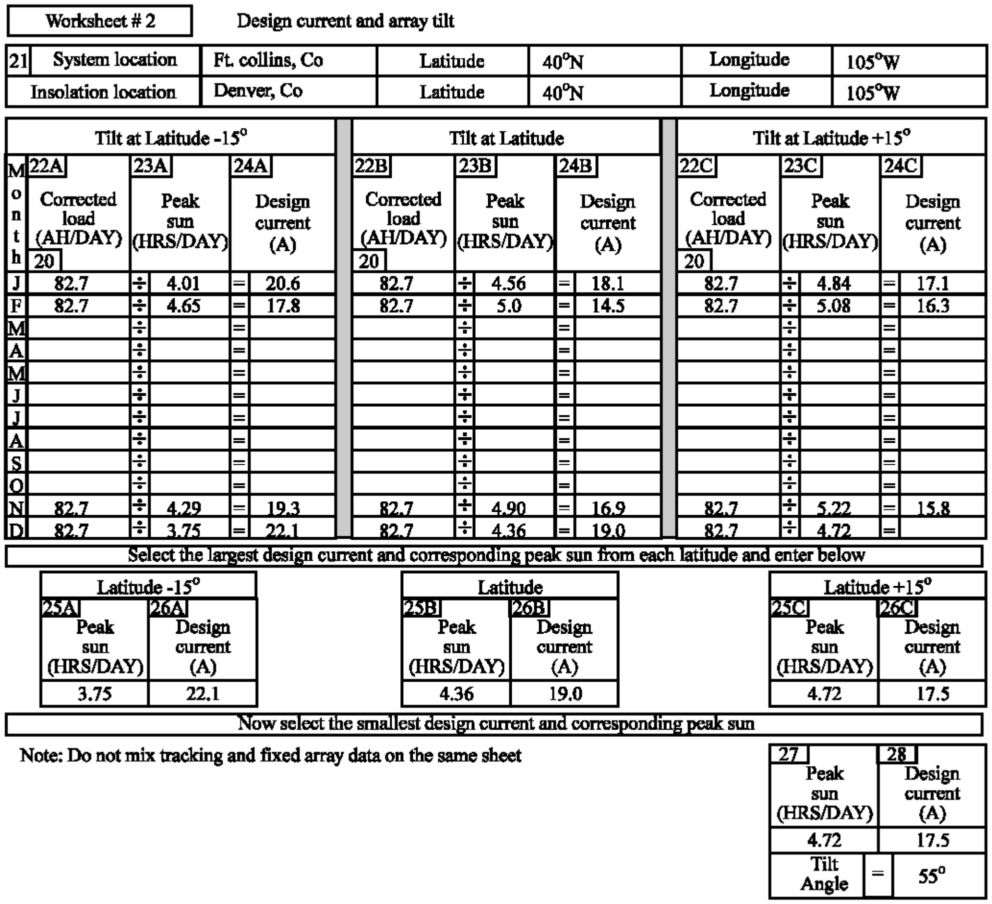


Fig. 2: The Definition of peak sun shine hours

Solar radiation data are often presented as an average daily for each month. Of course, on any given day the solar radiation varies continuously from sunup to sundown. The maximum irradiance is available at solar noon which is defined as the midpoint, in time, between sunrise and sunset. The term peak sun hours is defined as the equivalent number of hours per day, with solar irradiance equaling 1,000 w m^{-2}, that would give the same amount of energy (Fig. 2). Therefore, peak sun hours correspond directly to average daily insolation in kwh m^{-2}.

Insolation varies seasonally because of the changing relation of the earth to the sun. This change, both daily and annually, is the reason some 'systems use tracking arrays to keep the array pointed at the sun. For any location on earth the sun's elevation will change about 47° from winter solstice to summer solstice. Another way to picture the sun's movement is to understand the sun moves from 23.5° North of the equator on the summer solstice to 23.5° South of the equator on the winter solstice. On the equinoxes, March 21 and September 21, the sun circumnavigates the equator. At 40°N. latitude the sun paths for the solstices and equinoxes (Roger and Ventre, 2000; Kaye, 1994).

For any location the sun angle, at solar noon, will change 47° from winter to summer. The power output of a PV array is maximized by keeping the array pointed at the sun. Single-axis tracking of the array will increase the energy production in some locations by up to 50% for some months and as much as 35% over the course of a year. The most benefit comes in the early morning and late afternoon when the tracking array will be pointing more nearly at the sun than a fixed array. Generally, tracking is more beneficial at sites between ±30° latitude. For higher



Worksheet # 2 **Design current and array tilt**

21	System location	Ft. collins, Co	Latitude	40°N	Longitude	105°W
	Insolation location	Denver, Co	Latitude	40°N	Longitude	105°W

	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
Month	22A Corrected load (AH/DAY) 20		23A Peak sun (HRS/DAY)		24A Design current (A)	22B Corrected load (AH/DAY) 20		23B Peak sun (HRS/DAY)		24B Design current (A)	22C Corrected load (AH/DAY) 20		23C Peak sun (HRS/DAY)		24C Design current (A)
J	82.7	÷	4.01	=	20.6	82.7	÷	4.56	=	18.1	82.7	÷	4.84	=	17.1
F	82.7	÷	4.65	=	17.8	82.7	÷	5.0	=	14.5	82.7	÷	5.08	=	16.3
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N	82.7	÷	4.29	=	19.3	82.7	÷	4.90	=	16.9	82.7	÷	5.22	=	15.8
D	82.7	÷	3.75	=	22.1	82.7	÷	4.36	=	19.0	82.7	÷	4.72	=	

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak sun (HRS/DAY)	26A Design current (A)	25B Peak sun (HRS/DAY)	26B Design current (A)	25C Peak sun (HRS/DAY)	26C Design current (A)
3.75	22.1	4.36	19.0	4.72	17.5

Now select the smallest design current and corresponding peak sun

Note: Do not mix tracking and fixed array data on the same sheet

27 Peak sun (HRS/DAY)	28 Design current (A)
4.72	17.5
Tilt Angle =	55°

Fig. 3: Sun potential estimation work sheet

latitudes the benefit is less because the sun drops low on the horizon during winter months. Figure 3 shows sun estimation worksheet (Kaye, 1994).

BATTERIES

First, you must choose the amount of back-up energy you want to store for your application. This is usually expressed as a number of no sun days, in other words, for how many cloudy days must your system operate using energy stored in batteries. There is no right answer to this question. It depends on the application, the type of battery and the system availability desired. When specifying the amount of storage you must be aware of the difference between rated battery capacity and usable capacity. Battery manufacturers publish a rated battery capacity, the amount of energy that their battery will provide if discharged once under favorable conditions of temperature and discharge rate. This is much higher than the amount of energy you can take out of the battery repeatedly in a PV application. For some shallow-cycle, sealed batteries the usable capacity is only 20% of the rated capacity, i.e., taking more than 20 ampere-hours from a 100 ampere-hour battery will cause the battery to quickly fail. Other types of batteries designed for deep cycling will have usable capacities up to 80 percent of rated capacity. The best recommendation for the number of days of storage is to put in as much battery capacity as you can afford. Obviously, if you live in an area with extended periods of cloudiness you will need more storage capacity to keep the load going during these periods of inclement weather. Also, if it is critical that your load have power at all times, you will want to have a large battery capacity. A smaller battery size can be specified if you can live with some power outage. Figure 4 shows battery selection worksheet (Soras and Makios, 1988; Keller and Afolter, 1995).

Figure 5 shows a starting point for making your battery size selection using the design month peak sun hours for your site (Hill and McCarthy, 1991).

Worksheet # 3 **Calculate system battery size**

29 Corrected amp-hour (AH/DAY) 20		30 Storage days D		31 Maximum depth of discharge (DECIMAL) D		32 Derate for temperature (DECIMAL) D		33 Required battery capacity (AH)		34 Capacity of selected battery (AH)		35 Batteries in parallel
53.1	X	5	÷	0.5	÷	/	=	53 /	÷	90	=	6

Note: Block 35 round up for conservative design

36 Nominal system voltage (V) 9		37 Nominal battery voltage (V)		38 Batteries in series		39 Batteries in parallel 35		40 Total batteries
12	÷	12	=	/	X	6	=	6

Battery information		
Make	Johnson Controls	
Model	GC 12100 B	
Type	Gel aealed lead acid	
Nominal voltage (V)		12
Rated capacity (AH)		90

41 Batteries in parallel 35		42 Capacity of selected battery (AH) 34		43 System battery capacity (AH)		44 Maximum depth of dscharge (DECIMAL) 31		45 Usable battery capacity (AH)
6	X	90	=	540	X	0.5	=	270

Not: Use manufacturer's data to fill in battery information block

Fig. 4: Battery selection worksheet

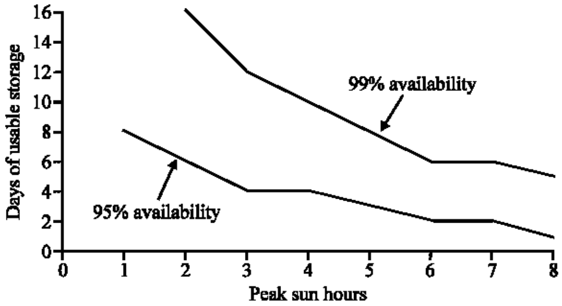


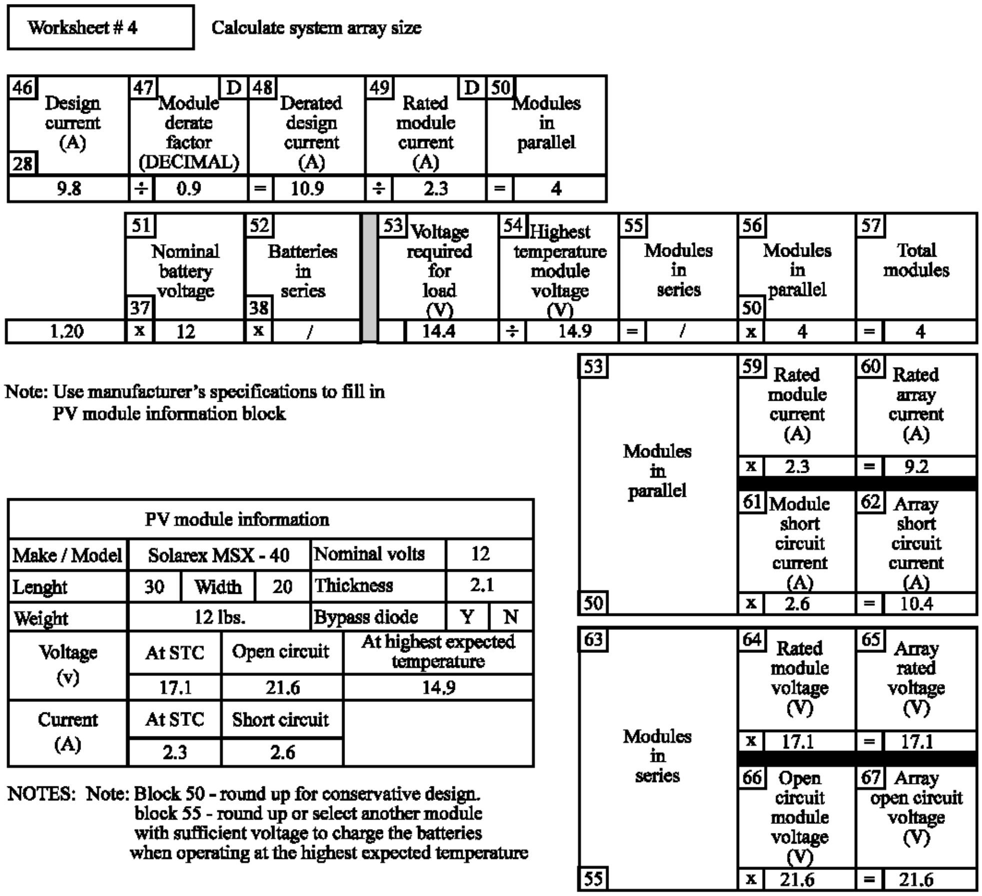
Fig. 5: Battery capacity needed verse the peak sun shine hours

PHOTOVOLTAIC ARRAY

This sizing technique is designed to generate enough energy during the design month to meet the load and cover all losses in the system. This means that in an average year the load will be met and the battery state of-charge will be the same on the last day of the design month as on the first day. The design method uses current (amperes) instead of power (watts) to describe the load requirement because it is easier to make a meaningful comparison of PV module performance, i.e., ask for PV modules that will produce 30 amperes at 12 volts and a specified operating temperature rather than try to compare 50 watt modules that may have different operating points. You should obtain module specifications for available modules so you can compare performance, physical size and cost (Khatib *et al*., 2010b; Groumpos and Papageorgious, 1987; Markvart *et al*., 2006).

In the PV modules data sheet the current values given are at short circuit, Isc and at the peak power point, Imp the value used in the worksheet for rated module current should be Imp. The voltage at the peak power point is usually stated. However, the operating voltage of a PV array is determined by the battery voltage. This varies over a narrow range depending on the battery state of charge and ambient temperature but is usually 1 to 4 volts.

Fortunately, the current changes little from the peak power voltage (17 volts for example) to normal system operating voltages (12 volts). For crystalline silicon modules, the operating voltage will decrease about one-half of one percent for each degree centigrade rise in temperature. For example if a PV module has a peak power voltage of 16 volts at 25°C. If this module operates at 50°C in a specific application, the peak power voltage would drop to about 14 volts. This is still adequate for use in a nominal 12-volt battery system, but the designer must make sure the current supplied by the module is adequate under the hottest expected conditions. Also, if a blocking diode is used between the module and the battery, this will cause a voltage drop of about 0.7 volts. The module must be able to sustain this drop plus any voltage drop caused by the wires and still supplies enough voltage to fully charge the battery. The module parameters at



Worksheet # 4 **Calculate system array size**

46 Design current (A) 28		47 Module derate factor (DECIMAL) D		48 Derated design current (A)		49 Rated module current (A) D		50 Modules in parallel
9.8	÷	0.9	=	10.9	÷	2.3	=	4

		51 Nominal battery voltage 37		52 Batteries in series 38	53 Voltage required for load (V)		54 Highest temperature module voltage (V)		55 Modules in series		56 Modules in parallel 50		57 Total modules
1.20	x	12	x	/	14.4	÷	14.9	=	/	x	4	=	4

53 Modules in parallel 50		59 Rated module current (A)		60 Rated array current (A)
	x	2.3	=	9.2
		61 Module short circuit current (A)		62 Array short circuit current (A)
	x	2.6	=	10.4

63 Modules in series 55		64 Rated module voltage (V)		65 Array rated voltage (V)
	x	17.1	=	17.1
		66 Open circuit module voltage (V)		67 Array open circuit voltage (V)
	x	21.6	=	21.6

Note: Use manufacturer's specifications to fill in PV module information block

PV module information						
Make / Model	Solarex MSX - 40		Nominal volts	12		
Lenght	30	Width	20	Thickness	2.1	
Weight	12 lbs.		Bypass diode	Y	N	
Voltage (v)	At STC	Open circuit	At highest expected temperature			
	17.1	21.6	14.9			
Current (A)	At STC	Short circuit				
	2.3	2.6				

NOTES: Note: **Block 50 - round up for conservative design.**
block 55 - round up or select another module with sufficient voltage to charge the batteries when operating at the highest expected temperature

Fig. 6: Selection of the PV array

standard test conditions and at the highest expected temperatures should be recorded in the space provided on the worksheet as shown in Fig. 6. The number of parallel connected modules required to produce the design current is rarely a whole number (Groumpos and Papageorgious, 1987; Markvart *et al*., 2006).

There are four factors that determine any photovoltaic module's output-load resistance, solar irradiance, cell temperature and efficiency of the photovoltaic cells. The output of a given module can be estimated by studying a family of current and voltage (I-V) curves. Three significant points of interest on the I-V curve are the maximum power point, the open-circuit voltage and the short circuit current. For a given solar cell area, the current is directly proportional to solar irradiance and is almost independent of temperature. Voltage and power decrease as temperature increases. The voltage of crystalline cells decreases about 0.5% per degree centigrade temperature per degree centigrade temperature increase. Therefore, arrays should be kept cool and mounted so air is not restricted from moving over and behind the array. Do not mount modules flush on a roof or support of Testing results show that modules mounted 3 inches above a roof will operate up to 15°C cooler than a directly mounted array a difference of 7.5% in power. No part of a PV array can be shaded. Unlike solar thermal collectors, the shading of small portions of a PV module may greatly reduce output from the entire array. PV modules connected in series must carry the same current. If some of the PV cells are shaded, they cannot produce current and will become reverse biased. This means the shaded cells will dissipate power as heat and over a period of time failure will occur. However, since it is impossible to prevent occasional shading, the use of by pass diodes around series connected modules is recommended. You do not need bypass diodes if all the modules are in parallel, i.e., a 12-volt array using 12-volt modules and many designers do not use them on 24-volt arrays. However for array voltages higher than 24 volts, bypass diodes should be used around each to solar irradiance and module to provide an alternative current path in case of shading. Figure 7 shows the use of bypass

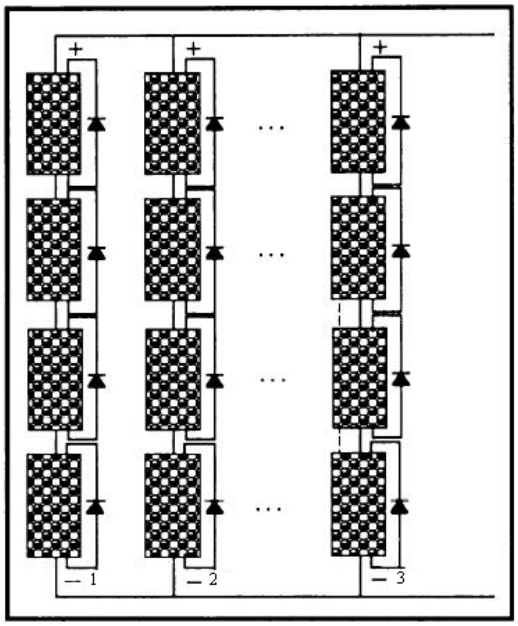


Fig. 7: Series string with bypass diodes

diodes on a 48-volt series string. Note the bypass diodes are reverse biased if all modules are operating properly. Many module manufacturers will provide modules with the bypass diodes integrated into the module junction box. It is important to check for potential shading before installing the PV array. Consider the seasonal changes in foliage and sun angle. After installation, the area must be maintained to prevent weeds or tree branches from shading the array (Groumpos and Papageorgious, 1987; Markvart *et al.*, 2006).

PV arrays include panels and source circuits. A panel is a group of PV modules packaged in a single name. Each panel should be sized for easy handling and mounting. A source circuit, sometimes called a string, may include any number of PV modules and panels connected in series to produce the system voltage. All PV modules should have durable connectors on the module. The connectors should be sturdy and the method of attaching the wire should be simple, yet provide a secure connection. Most modules have sealed junction boxes to protect the connections. Field testing experience shows that PV cells and connections between cells within the module laminate rarely fail. Most problems occur in the module junction box where the interconnections between modules are made. These can often be repaired in the field without replacing the module. Any stand-alone PV system should have a method to prevent reverse current flow from the battery to the array and/or to protect weak or failed strings. Individual blocking diodes are sometimes used for this purpose if the controller used does not contain this feature. Figure 8 shows the location of blocking diodes that can be installed in each parallel-connected string or in the main wire connecting the array to the controller. When multiple strings are connected in parallel, as in larger systems, it is recommended that blocking diodes be used in each string as shown on the left to prevent current flow from strong strings into weak strings (due to failures or shading). In small systems, a single diode in the main connection wire is sufficient. Do not use both. The voltage drop across each diode is 0.4-0.7 volt, represents about a 6 percent drop in a 12-volt system. A switch or circuit breaker should be installed to isolate the PV array during maintenance. This same recommendation applies to the battery circuit so another switch or circuit breaker is required. Also circuit breakers are normally installed to isolate each load. Fuses are used to protect any current carrying conductor. Fuses and cables in the array circuit should be sized to carry the maximum (Markvart *et al.*, 2006).

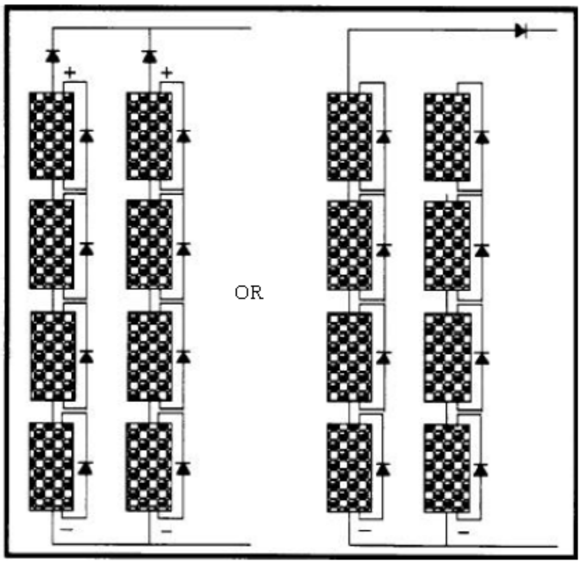


Fig. 8: PV array with blocking diodes

Current that could be produced by short-term cloud focusing of the sunlight-up to 1.5 times the short circuit current at 1,000 w m^{-2} irradiance. Slow-blow fuses are recommended. Only fuses rated for dc current should be used (Automotive fuses should not be used). All metal in a PV array should be grounded to help protect the array against lightning surges and as an added safety feature for personnel working on the system. The negative conductor on most PV systems is also grounded to the same grounding electrode used for the equipment ground (Groumpos and Papageorgious, 1987; Markvart *et al.*, 2006).

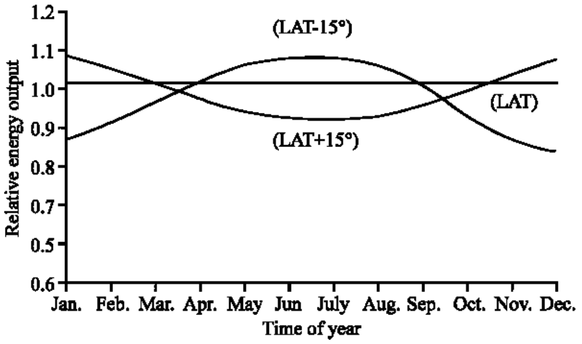


Fig. 9: Effect of array tilt angel on annual energy production

A photovoltaic array can be mounted at a fixed angle from the horizontal or on a sun-tracking mechanism. The preferred azimuth for arrays in the northern hemisphere is true south. The decrease in energy production for off-south arrays roughly follows a cosine function, so if the azimuth of the array is kept to ±20° of true south, annual energy production is not reduced significantly. Some arrays are sited west of south to skew the production toward an afternoon peak load demand. The effect of array tilt angle on annual energy production is shown in Fig. 9, for most locations, a tilt angle near the latitude angle will provide the most energy over a full year. Tilt angles of latitude ±15° will skew energy production toward winter or summer, respectively (Khatib *et al*., 2009b).

CONTROLLERS

Charge controllers are included in most photovoltaic systems to protect the batteries from overcharge or excessive discharge. Overcharging can boil the electrolyte from the battery and cause failure. Allowing the battery to be discharged too much will cause premature battery failure and possible damage to the load. The controller is a critical component in the PV system. Thousands of dollars of damage may occur if it does not function properly. In addition, all controllers cause some losses (tare loss) in the system. One minus these losses, expressed as a percentage, is the controller efficiency. A controller's function is to control the system depending on the battery state of charge (SOC). When t he battery nears full SOC the controller redirects or switches off all or part of the array current. When the battery is discharged below a preset level, some or the entire load is disconnected if the controller includes the Low Voltage Disconnect (LVD) capability. Most controllers use a measurement of battery voltage to estimate the state of charge. However, this does not give a precise indication because, as shown in Fig. 10, the voltage changes little until the battery nears the extremes of SOC. Battery temperature, age, type and rate of charge/discharge also affect this curve. Measuring battery temperature improves the SOC estimate and many controllers have a temperature probe for this purpose. These compensated controllers are recommended if the battery temperature is expected to vary more than ±5°C from ambient. The two voltage thresholds or activation set points, at which the controller will take action to protect the battery. Each threshold has a complementary-action set point. For instance, the array disconnect voltage is usually set near 14 volts for a nominal 12-volt battery. When the array is disconnected, the battery voltage will drop immediately to about 13 volts. The array reconnect voltage is usually set near 12.8 volts (Hill and McCarthy, 1991).

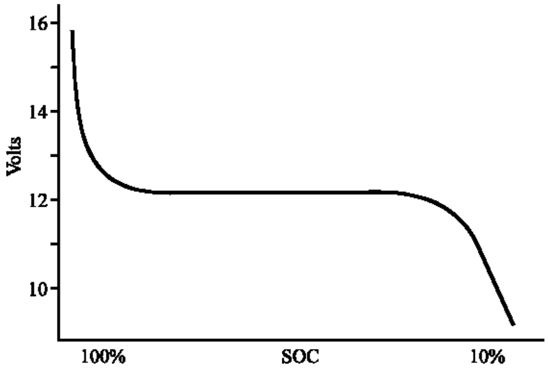


Fig. 10: Typical battery state of charge

Similarly, when the voltage reaches about 11.5 the load is disconnected and not re-connected until the voltage reaches about 12.4 volts. On some controllers these connect or disconnect voltages may be adjusted in the field. This is a good feature if you have ready access to your system and can monitor battery performance.

Reverse current protection is the prevention of current flow through the controller from the batteries to the PV array at night. Most controllers include a blocking diode or other mechanism that prevents this unwanted current. Also, most small controllers include built-in LVD capability to switch off the loads, activate lights or buzzers to alert users that action is required, or turn on a standby power supply (Hill and McCarthy, 1991).

INVERTER

Power conditioning units, commonly called inverters, are necessary in any stand-alone PV system with ac loads. The choice of inverter will be a factor in setting the dc operating voltage of your system. When specifying an inverter, it is necessary to consider requirements of both the dc input and the ac output. All requirements that the ac load will place on the inverter should be considered, not only how much power but what variation in voltage, frequency and waveform can be tolerated. On the input side, the dc voltage, surge capacity and acceptable voltage variation must be specified.

A study of many parameters listed by various inverter manufacturers should be done. Some parameters are listed on the specification sheet provided, a portion of which is shown in the inset. This sheet, located in also includes the specification for a dc to dc converter if one is needed to supply dc loads operating at different voltages. The choice of inverter will affect the performance, reliability and cost of your PV system. Usually, it is the third most expensive component after the array and battery.

Stand-alone inverters typically operate at 12, 24, 48 or 120 volts dc input and creates 120 or 240 volts ac at 50 or 60 hertz. The selection of the inverter input voltage is an important decision because it often dictates the system dc voltage. The shape of the output waveform is an important parameter. Inverters are often categorized according to the type of waveform produced; square wave, modified sine wave and sine wave. The output waveform depends on the conversion method and the filtering used on the output waveform to eliminate spikes and unwanted frequencies that result when the switching occurs. Square wave inverters are relatively inexpensive, have efficiencies above 90%, high harmonic frequency content and little output voltage regulation. They are suitable for resistive loads and incandescent lamps. Modified sine wave inverters offer improved voltage regulation by varying the duration of the pulse width in their output. Efficiencies can reach 90%. This type of inverter can be used to operate a wider variety of loads including lights, electronic equipment and most motors. However, these inverters will not operate a motor as efficiently as a sine wave inverter because the energy in the additional harmonics is dissipated in the motor windings. Sine wave inverters produce an ac waveform as well as that from most electric utilities. They can operate any ac appliance or motor within their power rating. In general, any inverter should be oversized 25% or more to increase reliability and lifetime. This also allows for modest growth in load demand. The efficiency of all inverters is lowest for small load demand and reach their nominal efficiency (around 90%) when the load demand is greater than about 50% of rated load (Barra *et al*., 1984).

INTERCONNECTING THE SYSTEM

Now that the major components have been sized and selected, it is time to consider how to interconnect everything as a working system. It is important to select wire, connectors and protection components such as switches and fuses that will last for twenty years or more. To obtain this long life, they must be sized correctly, rated for the application and installed carefully. Connections are particularly prone to failure unless they are made carefully and correctly. Obtain a quality crimp tool and ask an experienced electrician for advice on ways to make and protect long lasting connections. Remember the performance and reliability of the entire system depends on each connection. Selecting wire for your application may seem confusing because there are so many types of wire and insulation available. However, only a few types are popular with PV system installers. In most cases you don't need special (and therefore expensive) wire (Bucciarelli, 1984).

Wire type and size: In general copper conductors are recommended. Aluminum wire is less expensive, but can cause problems if used incorrectly. a wire with a covering that will withstand the worst-case conditions should be selected. It is mandatory that sunlight resistant wire be specified if the wire is to be exposed to the sun. If the wire is to be buried without conduit it must be rated for direct burial. For applications such as wiring to a submersible pump or for battery interconnections:

- **Underground Feeder (UF):** may be used for interconnecting balance-of-systems (BOS) but not recommended for use within battery enclosures; single conductor UF wire may be used to interconnect modules in the array but this type of wire is not widely available
- **Tray Cable (TC):** Multiconductor TC wire may be used for interconnecting BOS; TC has good resistance to sunlight but may not be marked as such
- **Service Entrance (SE):** May be used for interconnecting BOS
- **Underground Service Entrance (USE):** May be used for interconnecting modules or BOS; may be used within battery enclosures
- **THHN:** Indicates wire with heat resistant thermoplastic sheathing; it may be used for interconnecting BOS but must be installed in conduit either buried or above ground. It is resistant to moisture but should not be used in wet locations
- **TW:** Refers to moisture resistant thermoplastic sheathing; it may be used for interconnecting BOS but must be installed in conduit. May be used in wet locations. The use of NMB (Romex) is not recommended except for ac circuits as in typical residential wiring. Although commonly available, it will not withstand moisture or sunlight

Selecting the correct size and type of wire for the system will optimize performance and increase reliability. The size of the wire must be capable of carrying the current at the operating temperature without excessive losses. It is important to derate the current carrying capacity of the wire if high temperature operation is expected. A wire may be rated for high temperature installations (60-90°C) but this only means the insulation of the wire can withstand the rated temperature, it does not mean that ampacity is unaffected. The current carrying capability (ampacity) depends on the highest temperature to which the wires will be exposed when it is carrying the current. If the ampacity of the wire is exceeded, overheating, insulation break-down and fires may occur. Properly sized fuses are used to protect the conductors and prevent this kind of damage. Loss in a dc circuit is equal to I^2R where (I) is the current and R is the resistance of the wire. For 100 ampere current this means 10,000 times the loss in the circuit. It is easy to see why resistance must be kept small. Also, the voltage drop in the circuit is equal to IR. Voltage drop can cause problems, particularly in low voltage systems. For a 12-volt system, a one volt drop amounts to over 8% of the source voltage. Avoid long wire runs or use larger wire to keep resistance and voltage drop low. A portion of which is shown in the inset, provide a consistent way to record the minimum wire size for different subsystems (Bucciarelli, 1986).

Switches and fuses: Switches, circuit breakers and fuses are used to protect personnel and equipment. The switches provide the capability to manually interrupt power in case of emergency or for scheduled maintenance. The fuses provide over current protection of the conductors in case of system shorting or ground faults. Diodes are used to control the direction of current flow in the system. These protection components should be located throughout the stand-alone PV system. The largest current source in the system is the battery. A typical battery can provide over 6,000 amperes for a few milliseconds if faults occur and the battery is short circuited. These levels of current can destroy components and injure personnel so an in-line fuse should be installed in all battery circuits. The fuses must be rated for dc operation and have an Amperage Interrupt Capability (AIC) sufficient for these high currents. The NEC requires that there must be a method of disconnecting power from both sides of any installed fuse. This may require additional switches to be installed. Any switch used in a dc circuit should be specifically rated for dc operation, an ac switch may operate properly a few times, but it will probably fail when it is needed most. DC components are rated for voltage and current. Common voltage levels are 48, 125, 250 and 600 volts dc. Current ratings of 15, 30, 60, 100 and 200 amperes are common. The switch or breaker must be sized to handle the maximum possible current. This is the same current level used to specify the fuses. Fused disconnect switches with both devices incorporated into one assembly may be available. Using these will save on installation costs. DC rated circuit breakers can be used to replace both switches and fuses. They may be more difficult to find but the reliability is high and they are preferred by many system designers. The current produced by the PV array is limited, but the array short-circuit current, multiplied by a safety factor of 1.56, is commonly used to specify the size of a slow-blow fuse in the array output circuit. Should a ground fault occur in the array while the controller is engaged, this fuse will protect the array modules and the conductors from high battery current. In the load circuits a fuse or circuit breaker is usually installed for each significant load. Switches, fuses, blocking diodes, movistors and any sensors used for data acquisition are normally installed in a centrally located weather-proof junction box (J-box). The controller is often installed in the same J-box which may be referred to as the control center of the system. All negative wires should be attached to the negative buss and a solid copper wire used to connect this buss to the ground lug in the J-box. (The ground lug is connected to the common ground rod of the system). The positive leads are usually connected through a fuse to the positive buss. A surge protection device such as a movistor can be connected from each positive lead to ground (Buccuarelli, 1986).

SYSTEM INSTALLATION

Stand-alone PV systems will be reliable power producers for more than two decades if properly sized for the application, engineered well and installed carefully.

Array: PV arrays for stand-alone systems are installed in many unique and innovative ways, However, there are common issues involved in any installation, whether the array is fixed or tracking, mounted at ground level, or on a pole or building. The objective is a solidly mounted PV array that will last for many years and withstand all kinds of weather. Regardless of whether you buy or build the mounting structure make sure it is anchored and the modules are restrained. Many module manufacturers and distributors sell mounting hardware specifically designed for their modules. This hardware is intended for multiple applications and different mounting techniques and considerations like wind loading have been included in the design. Using this mounting hardware is the simplest and often the most cost effective. Customized array mounting structures can be expensive. Consider the characteristics of various mounting materials:

- **Aluminum:** Lightweight, strong and resistant to corrosion. Aluminum angle is an easy material to work with, holes can be drilled with commonly available tools and the material is compatible with many PV module frames. Aluminum is not easy to weld
- **Angle iron:** Easy to work with but corrodes rapidly. Galvanizing will slow corrosion but mounting brackets and bolts will still rust, particularly in a wet environment. The material is readily available and brackets can be welded easily
- **Stainless steel:** Expensive and difficult to work with but will last for decades. May be a good investment in salt spray environments
- **Wood:** Inexpensive, available and easy to work with but may not withstand the weather for many years even if treated with preservative. Attaching modules to a wooden frame requires battens or clips to hold them in place

Figure 11 shows one mounting technique that has been used for small PV systems, aluminum or galvanized angle can be used for the support struts, steel fence posts can be driven into the ground and the cross-beam can be made from treated wood, metal, or concrete. Galvanized Ubolts can be used to hold the crossbeams. Stainless steel bolts and nuts are recommended because they will not rust and portions of the array can be removed if future maintenance is required. The foundation for the array should be designed to meet the wind load requirements of the region. Wind load depends on the size of the array and the tilt angle (Chapman, 1987a, b).

Changing the tilt angle of an array to account for seasonal changes in sun altitude is not required. For mid latitude locations, a tilt angle change every three months is estimated to increase energy production about 5% on an annual basis. For most applications, the additional labor and the added complexity of the array mount does not justify the small increase in energy produced. If tracking of the flat-plate array is desired, the recommended trackers are single axis units that require little control or power. These are passive trackers driven by a closed Freon system that causes the tracker to follow the sun with adequate accuracy for flat-plate PV modules. In high wind areas a powered tracker may be preferred. Pole mounted trackers that support 4 to 12 PV modules are available and often used for small stand-alone systems, particularly water pumping applications. The tracker manufacturer will provide all the array mounting hardware and instructions for securely installing the tracker. The amount and type of foundation for the pole-mounted tracker depends on the size of the array being supported. Reinforced concrete with anchor bolts is recommended. The foundation and frame should be designed to withstand the worst case wind expected in the area. The movement of the array should be checked to make sure the path is clear of obstructions. In general, roof mounting of PV modules should be avoided. They are more difficult to install and maintain, particularly if the roof orientation and angle are not compatible with the optimum solar array tilt angle. Penetrating the roof seal is inevitable and leaks may occur. Also, it is important to achieve a firm and secure attachment of the array mounting brackets to the roof. Attaching the mounting brackets to the rafters will provide the best foundation, but this may be difficult because module size and rafter spacing are usually not compatible. If there is access to the underside of the roof, 2 x 6-inch blocks can be inserted between the rafters and the attachment made to the blocks. Attaching the array to the plywood sheathing of the roof may result in roof damage, particularly if high winds are likely. If a roof mount is required, be sure to allow a clear air flow path up

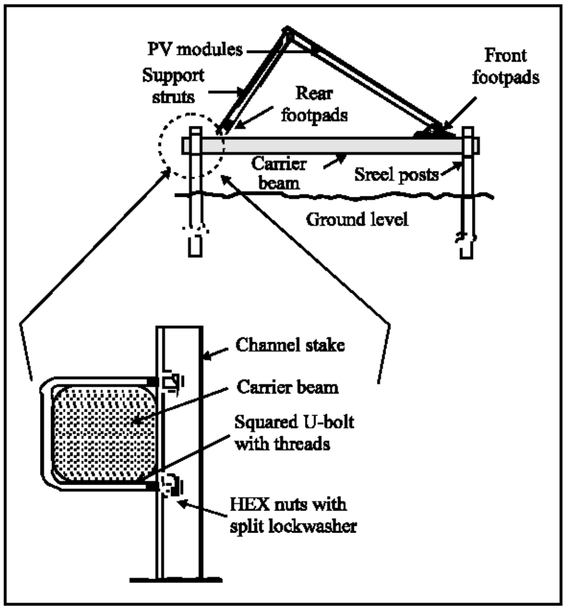


Fig. 11: Simple ground mount for a PV array

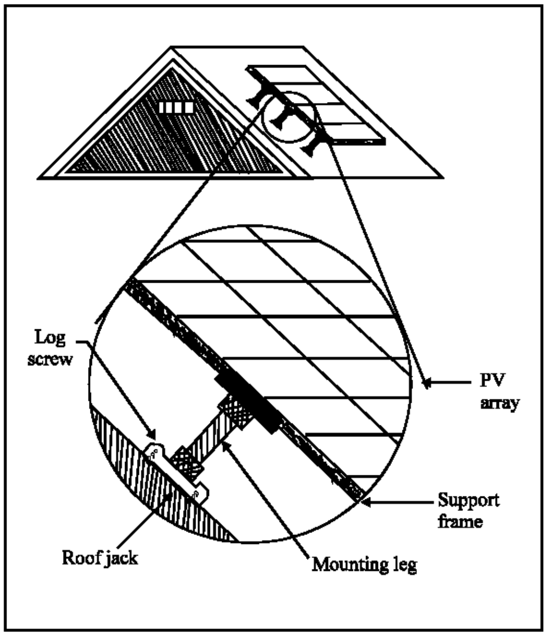


Fig. 12: Roof mount for a PV array

the roof under the array as shown in Fig. 12. The array will operate cooler and produce more energy if it stands off the roof at least 3 inches, Flush mounting PV modules to the roof of a building is not recommended (Chapman, 1987a, b; Egido and Lorenzo, 1992).

Control center: Electronic controllers, converters, or inverters are often installed in the control center along with switches, fuses and other BOS. Electronic components must be able to withstand expected temperature extremes in both operating and non-operating states. Any printed circuit boards in these units should be coated or sealed to protect the electronics from humidity and dust. Certified electrical service boxes should be used. Consult any electrical supply company to get advice about the type of box needed for a specific application. High temperatures will shorten the life of electronic equipment. Try to mount the boxes in a shaded area and/ or provide air circulation, particularly for inverters. Dust can be a problem in a well-vented enclosure. Some boxes have filters at the air access points. Filters require regular cleaning. Screen the inlets of the electrical boxes to prevent spiders, wasps and other insects from setting up residence. Finding wasps in the electrical box may not affect performance, but it will certainly make maintenance more exciting.

Grounding: A good ground will provide a well-defined, low-resistance path from the stand-alone PV system to earth ground. This path is expected to carry fault current if system malfunctions occur so the ground wire must be as large as the largest conductor in the system. Two types of grounding are needed in PV systems. For the system ground, one of the current carrying conductors, usually the negative, is grounded at a single point. This establishes the maximum voltage with respect to ground and also serves to discharge surge currents induced by lightning. Any exposed metal that might be touched by personnel should be grounded. This includes equipment boxes and array frames. This will limit the risk of electrical shock should a ground fault occur. A low-resistance earth ground requires good contact between the ground rod and earth. Subterranean water lowers the resistivity of the contact. If the system is in an area with rocky soil, a good ground may be difficult to achieve. Consult a local electrician for suggestions.

A PV array can attract lightning, especially if located at a high elevation relative to the surrounding terrain. In particular, water pumping systems may draw lightning because of the excellent ground path provided by the well casing. Current surges can be caused by a direct lightning hit or by electromagnetic coupling of energy into the PV system's conductors. There is little that can be done to protect the PV system equipment from a direct lightning strike. Surges caused by near strikes occur more frequently and the severity of possible damage depends on the distance from the strike to the array. Commercially available surge protection devices (movistors and silicon oxide varistors) are reasonably priced and their use is recommended. They are normally installed in the array output and at the dc input to any electronic device. If an inverter is used, surge protection devices should be installed at the ac output as well as the dc input. Installing the wiring in grounded, buried metallic conduit will decrease susceptibility to lightning (Chapman, 1987a, b).

Batteries: Batteries must be protected from the elements. If freezing temperatures are expected, the batteries can be buried below the frost line in a watertight enclosure or in a building where the temperature will remain above freezing. If the batteries are buried, a well-drained location should be selected and a drainhole provided in the battery enclosure. Batteries should not be set directly on concrete surfaces as self discharge will be increased (Hill and McCarthy, 1991).

System layout: Figure 13 shows an example of a PV system layout.

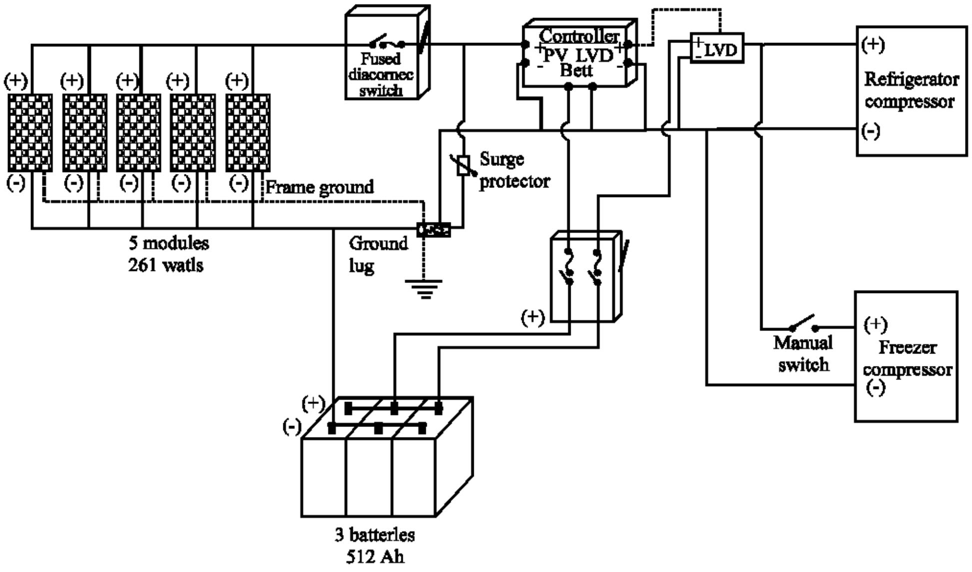


Fig. 13: Block diagram example of a PV system

MAINTENANCE

Periodic check: Preventive maintenance is the best maintenance, Periodic checks are recommended for any stand-alone PV system so that little problems can be found and corrected before they affect system operation. The system should be checked soon after installation when it is presumably operating well. Much of the checking can be done with only a voltmeter, a clamp on ammeter and some common sense. Many failures can be avoided if periodic checking is done and corrective action taken before the problems cause system failure. These recommended checks should be done regularly (Roger and Ventre, 2000):

- Check the tightness of all connections in the system. Battery connections should be cleaned and sealed with a corrosion inhibitor
- Check the electrolyte level and add clean (distilled) water as necessary. Do not overfill the batteries. Measure the specific gravity of each cell in the battery every year. The specific gravity is an indicator of the battery state-of charge but the measurements may be misleading if the electrolyte has stratified
- Check specific gravity from different levels in the cell to see if the electrolyte is stratified. If stratification is present, the battery should be charged vigorously to mix the electrolyte. If the specific gravity reading of any cell is different from the others by 0.050 it may indicate a weak cell. Monitor this cell's performance to see if replacement is required. With the battery under load, check the voltage of each battery cell and compare it to the average of all cell voltages. If the voltage of any cell differs by 0.05 volts from the others, it indicates a possible problem. Monitor this cell's performance to see if replacement is required
- Check the system wiring. If any wires are exposed, look for cracking or checking of the insulation. Inspect the entry and exit points from all junction boxes and look for breaks or cracks in the insulation. Replace wires if necessary. Do not rely on common black electrical tape for long-term repair of damaged insulation
- Check that all junction boxes are closed and sealed. Inspect for water damage or corrosion. If electronic components are mounted in junction boxes, check for ventilation in the box. Change or clean air filters. Inspect the array mounting frame or tracking mechanism. Maintain any tie-down anchors
- Check the operation of switches. Make sure the switch movement is solid. Look for corrosion or charring around contacts. Check fuses with a voltmeter. A good fuse will have almost no voltage drop when current is flowing. Look for discoloration at the fuse ends. The designer should provide specific instructions for maintaining the system. Following that advice, doing these simple checks and correcting any visible problem as soon as they appear will increase the system availability and extend its life

Troubleshooting: If a known or suspected problem has occurred, it can usually be located by following a logical progression of tests and analyzing the results. Basic tests can be completed with simple tools such as a voltmeter, clamp-on ammeter, hydrometer, pliers, screwdrivers and crescent wrenches.

Gloves, safety glasses, (for working around batteries) and rubber-soled shoes are recommended. Remove jewelry before testing any electrical circuits. Have two people working together to test the system. Before testing, make sure that both persons know where the power disconnect switches are and how to operate them. Safety first! Remember a PV array will produce power any time the sun is shining and any array that contains more than two modules can produce enough electricity to kill a human being under worst-case conditions. Always measure the voltage present before touching a wire or connector and never disconnect a wire before knowing what voltage and current are Fig. 14 gives some general guidance for finding problems in stand-alone PV systems with batteries. Check the simple things first. Look for blown fuses, tripped breakers, or bad connections. Repair as necessary. Check the status lights, if any, on the controller. Next, check the loads. The appliances or pumps, etc. may have blown a fuse or failed. Check to see if the correct voltage and current are present at the load input. If you have another load that can be plugged into that circuit see if it will work. If it does, the original appliance is suspect. If the correct voltage is not present, check the battery voltage. If the correct voltage is present at the output, check the circuit between the battery and the load. Recharge the battery if the battery voltage is low. You can also check the voltage and specific gravity of each cell and look for weak cells. If the battery voltage is low (less than 11.0 volts on a 12 volt system) the problem may be with the controller (Has the weather been

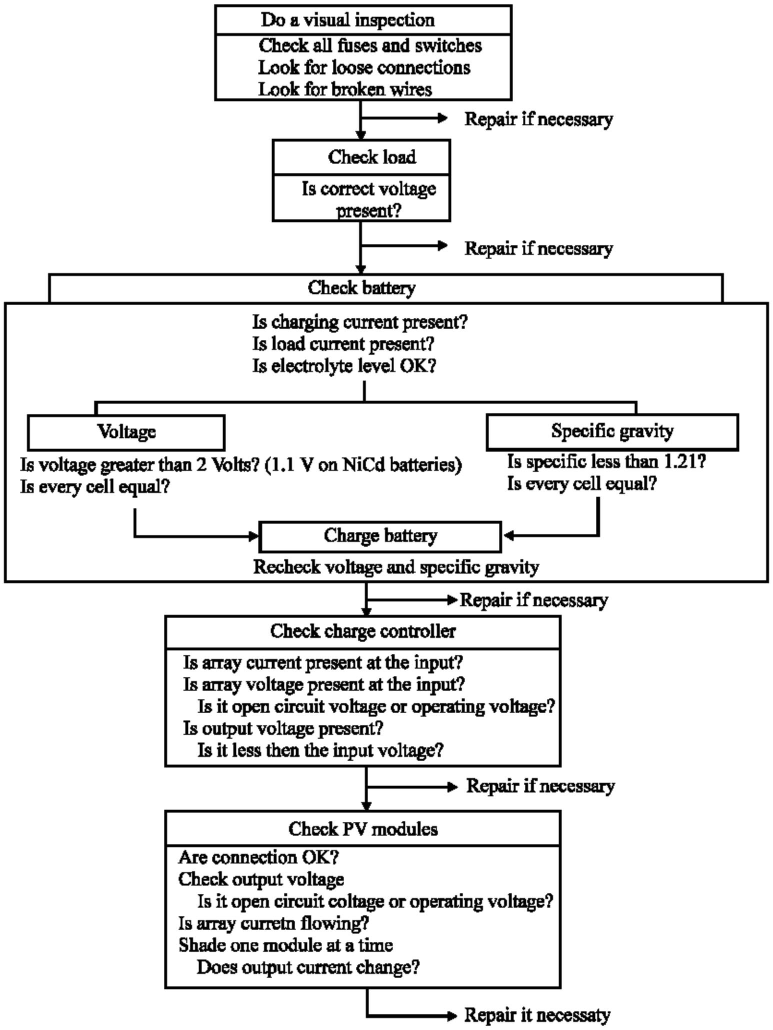


Fig. 14: Troubleshooting guide

cloudy for a long period-if so, there may be no system problem). Check the input voltage at the controller, Is it equal to the battery voltage? If so, the controller has the array connected to the battery, is a charging current flowing from the array? If yes, you may want to disconnect the load(s) and let the array charge the battery. If no current is flowing or if the voltage at the controller input equals the open circuit voltage of the array, the controller may have failed. If the controller is okay, test the array. Measure the voltage at the output. You may want to bypass the controller and connect the array directly to the battery-check for current. Shade each module in turn and see if the current changes. Be sure to return the system to its original configuration when you have finished troubleshooting. If the loads operate sometimes and you suspect the quantity of power being produced, the problem may be more difficult to locate. The power output of a stand-alone PV system varies with conditions and checking the system performance requires simultaneous measurement of the existing solar conditions, the temperature and the power output from the system. This may require specific test equipment and expertise that is not widely available (Roger and Ventre, 2000).

ECONOMIC EVALUATION

Description: Doing a life-cycle cost analysis (LCC) gives you the total cost of your PV system including all expenses incurred over the life of the system. There are two reasons to do an LCC analysis; to compare different power options and to determine the most cost-effective system designs. For some applications there are no options to small PV systems so comparison of other power supplies is not an issue. The PV system produces power where there was no power before. For these applications the initial cost of the system is the main concern. However, even if PV power is the only option, a life-cycle cost (LCC) analysis can be helpful for comparing costs of different designs and/or determining whether a hybrid system would be a cost-effective option. An LCC analysis allows the designer to study the effect of using different components with different reliabilities and lifetimes. For instance, a less expensive battery might be expected to last 4 years while a more expensive battery might last 7 years. Which battery is the best buy? This type of question can be answered with an LCC analysis. Some agencies might want to compare the cost of different power supply options such as photovoltaics, fueled generators, or extending utility power lines. The initial costs of these options will be different as will the costs of operation, maintenance and repair or replacement. A LCC analysis can help compare the power supply options. The LCC analysis consists of finding the present worth of any expense expected to occur over the reasonable life of the system. To be included in the LCC analysis, any item must be assigned a cost, even though there are considerations to which a monetary value is not easily attached. For instance, the cost of a gallon of diesel fuel may be known; the cost of storing the fuel at the site may be estimated with reasonable confidence; but, the cost of pollution caused by the generator may require an educated guess. Also, the competing power systems will differ in performance and reliability. To obtain a good comparison, the reliability and performance must be the same. This can be done by upgrading the design of the least reliable system to match the power availability of the best. In some cases, you may have to include the cost of redundant components to make the reliability of the two systems equal. For instance, if it takes one month to completely rebuild a diesel generator, you should include the cost of a replacement unit in the LCC calculation. A meaningful LCC comparison can only be made if each system can perform the same work with the same reliability (Protogeropoulos *et al*., 1997; Mahmoud and Ibrik, 2003).

LCC calculation: The life-cycle cost of a project can be calculated using the formula:

$$\mathrm{LCC} = \mathrm{C} + \mathrm{Mpw} + \mathrm{Epw} + \mathrm{Rpw} - \mathrm{Spw} \qquad (1)$$

where, the pw subscript indicates the present worth of each factor. The capital cost (C) of a project includes the initial capital expense for equipment, the system design, engineering and installation. This cost is always considered as a single payment occurring in the initial year of the project, regardless of how the project is financed. Maintenance (M) is the sum of all yearly scheduled operation and maintenance (O and M) costs. Fuel or equipment replacement costs are not included. O and M costs include such items as an operator’s salary, inspections, insurance, property tax and all scheduled maintenance. The energy cost (E) of a system is the sum of the yearly fuel cost. Energy cost is calculated separately from operation and maintenance costs, so that differential fuel inflation rates may be used. Replacement cost (R) is the sum of all repair and equipment replacement cost anticipated over the life of the system. The replacement of a battery is a good example of such a cost that may occur once or twice during the life of a PV system. Normally, these costs occur in specific years and the entire cost is included in those years. The salvage value (S) of a system is its net worth in the final year of the life-cycle period. It is common practice to assign a salvage value of 20% of original cost for mechanical equipment that can be moved. This rate can be modified depending on other factors such as obsolescence and condition of equipment. Future costs must be discounted because of the time value of money. One dollar received today is worth more than the promise of $1 next year, because the $1 today can be invested and earn interest. Future sums of money must also be discounted because of the inherent risk of future events not occurring as planned. Several factors should be considered when the period for an LCC analysis is chosen. First is the life span of the equipment. PV modules should operate for 20 years or more without failure. To analyze a PV system over a 5-year period would not give due credit to its durability and reliability. Twenty years is the normal period chosen to evaluate PV projects. However, most engine generators won't last 20 years so replacement costs for this option must be factored into the calculation if a comparison is to be made. To discount future costs, the multipliers presented in Tables. These Tables lists Single Present Worth factors. These are used to discount a cost expected to occur in a specific year, such as a battery replacement in year 10 of a project and Uniform Present Worth factors. These are used to discount annually recurring costs, such as the annual fuel cost of a generator. To use the tables, simply select the column under the appropriate discount rate and read the multiplier opposite the correct year or span of years. The discount rate selected for an LCC analysis has a large effect on the final results. It should reflect the potential earnings rate of the system owner. Whether the owner is a national government, small village, or an individual, money spent on a project could have been invested elsewhere and earned a certain rate of return. The nominal investment rate, however, is not an investor's real rate of return on money invested. Inflation, the tendency of prices to rise over time, will make future earnings worth less. Thus, inflation must be subtracted from an investor's nominal rate of return to get the net discount rate (or real opportunity cost of capital). For example, if the nominal investment rate was 7% and general inflation was assumed to be 2% over the LCC period, the net discount rate that should be used would be 5%. Different discount rates can be used for different commodities. For instance, fuel prices may be expected to rise faster than general inflation. In this case, a lower discount rate would be used when dealing with future fuel costs. In the example above the net discount rate was assumed to be 5%. If the cost of diesel fuel was expected to rise 1% faster than the general inflation rate, then a discount rate of 4% would be used for calculating the present worth of future fuel costs. Check with your local bank for their guess about future inflation rates for various goods and services. You have to make an estimate about future rates, realizing that an error in your guess can have a large affect on the LCC analysis results. If you use a discount rate that is too low, the future costs will be exaggerated; using a high discount rate does just the opposite, emphasizing initial costs over future costs. You may want to perform an LCC analysis with high, low and medium estimates on future rates to put bounds on the life-cycle cost of alternative systems (Mahmoud and Ibrik, 2003).

Technical notes: The formula for the single present worth (P) of a future sum of money (F) in a given year (N) at a given discount rate (I) is:

$$P = F/(1 + I)N \qquad (2)$$

The formula for the uniform present worth (P) of an annual sum (A) received over a period of years (N) at a given discount rate (I) is

$$P = A[1 - (1 + I)-N]/I \qquad (3)$$

The formula for the modified uniform present worth of an annual sum (A) that escalates at a rate (E) over a period of years (N) at a given discount rate (I) is The formula for the annual payment (A) on a loan whose principal is (P) at an interest rate (I) for a given period of years (N) is:

$$A = P\{I/[1 - (1 + I)-N]\} \qquad (4)$$

CONCLUSION

In this study methods for designing, installing and evaluating photovoltaic power systems have been reviewed, worksheets for designing phases have been provided. Moreover recommended installing methods have been mentioned so as to introduce a reliable photovoltaic system. Finally the present worth method is suggested to use to evaluate the feasibility of the photovoltaic system.

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