Troubleshooting a Photovoltaic System

From Appropedia

Contents

Problem Definition

Phil Lucas, a student in Lonny's Engr. 305 class, carried out a project that involved troubleshooting, repairing, testing and maintaining a preexisting off-grid photovoltaic system located at the Arcata Educational Farm, on Old Arcata road, Arcata, CA. This project was carried out over the 2009 spring semester. The goal of the project is to provide AEF with a renewable source of off-grid electricity. The electricity powers an answering machine and a portable stereo system for the enjoyment of the farmers. The AEF provided a binder full of literature on the photovoltaic system; including operating manuals for the inverter, charge controller, and answering machine, as well as troubleshooting guidelines and performance monitoring checklists. These papers as well as additional technical literature provided the basis for the troubleshooting process. The previous system used a single panel and powered both the answering machine, and a fan for the disassembled compost toilet. This project involved adding an additional panel in parallel to the original system, providing additional power. This Project Involves

- Determine how AEF would best benefit from Photovoltaic Power.
- Research into literature regarding sizing and design, components, installation, testing and maintenance of the photovoltaic system
- Testing of panels to determine the current-voltage curve using a rheostat and two millimeters.
- Use a compass and an azimuth chart to determine the direction of true south
- determine insolaton, using peak hours for Arcata to estimate the power produced by system.
- Follow a troubleshooting process to identify which components of the system are not working
- Replace all malfunctioning parts with appropriate replacements
- Wire additional panels in parallel to the existing system
- Build upon the preexisting mounting system so it can support an additional panel
- Carry out monitoring and testing to determine system performance.

Literature Review

follow link for literature review

Criteria

table 1: project criteria

Critera	Constraint	Success
Cost	Under $200	yes
Sustainable	provide an off-grid source of electricity	yes
Renewable	the sun provides a renewable source of energy	yes
Educational	the system is an example of a photovoltaic application and parallel wiring	yes
User friendly	the system comes with troubleshooting guide and component manuals	yes
Appropriate	the system provides electricity to an off grid location and powers useful appliances	yes

Timeline

table 2: project timeline

task	deadline	on time
Visit Arcata Educational Farm and assess project, make materials list	February 26	yes
Carry out testing with amp/voltmeter and other tools to determine problem	March 15th	yes
Test panels, acquire needed parts	March 27th	yes
Attach additional panel, make mounting structure	April 7th	yes
test complete system	April 20th	yes

Research

Problem Assessment

The first step was to collect as much information as possible about the preexisting system from AEF. This includes manuals for system components, individual opinions about could be wrong with the system, as well as any existing literature written on by other students who had previously worked on the photovoltaic system.

System Wiring

- The panels of the system provide direct current (DC) power to the inverter. DC systems use lower voltage and the current flows only in one direction.
- The inverter supplies alternating current(AC), which is used by household appliances.
- Working on a photovoltaic system requires the use of a multi-meter to check continuity, current, and voltage, for both AC and DC parts of the circuit.

Table 3: Color Coding of Wires

Alternating Current (AC) Wiring		Direct Current (DC) Wiring	
Color	**Application**	**Color**	**Application**
Black	Hot	Red	Positive
White	Neutral Ground	Black	Negative
Green or bare	Equipment Ground	Green or Bare	Equipment Ground
Red	Ungrounded Hot		

Safety

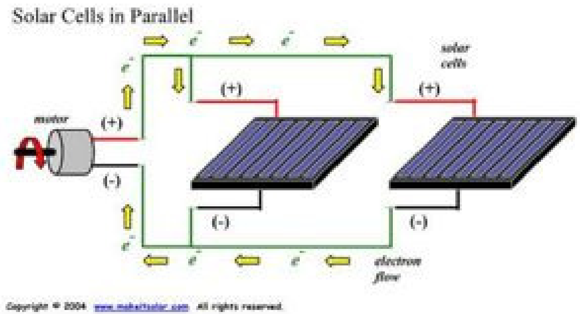
Safety is a crucial aspect of working on electrical systems. The following precautions were taken while working on the photovoltaic system.

- Always wear safety glasses when working with electrical circuitry

- Do not work alone on electrical circuits
- do not handle the instrument, its test leads, or the circuitry while high voltage is being applied
- Turn off the power and discharge any capacitors in the circuit before connecting to or disconnecting from the circuit.
- Do not change switch settings or test lead connections while the circuit is energized.
- Locate all voltage sources and accessible current paths before making connections.
- Check and double check switch positions and jack connections before applying power to instrument
- Make certain that the equipment you are working with is properly grounded and fuses are of the proper type and rating

Parallel Wiring

By adding an additional panel, the system provides more power and is useable for a wider array of applications. By having two panels in parallel, their output voltage remains equal, however the current is the sum of both the panels' individual currents.



Solar Site Analysis

- Solar insolation is solar radiation striking the earth's surface at a particular time and place. On a clear day, solar insolation is equal to 1000 watts/ square meter of surface.
- Peak sun hours are the number of hours per day where the solar insolation is equal to 1000 watts/square meter (A watt is equal to a Joule per second)

It is important to remember that magnetic south is not the same as true south. A compass aligns with the earth's magnetic field, which is not necessarily aligned with the earth's rotational axis. This magnetic declination from true south is known as the azimuth, and varies depending on specific location. The optimal tilt occurs when the panels are oriented perpendicular to the suns rays. The highest average insolation will fall on a panel with a tilt angle equal to the latitude of that specific area. (Arcata has a latitude and longitude of 40.98 by 124.1.) By using the chart below, the best orientation the panels is determined to be about 17 degrees east of magnetic south, with a 41 degree tilt. (year round loads should have a tilt angle equal to the latitude of that location.)

System Components

The main parts of the photovoltaic system include the charge controller, circuit breaker, inverter, and battery. The operating manuals of inverter, charge controller, and answering machine provide more specific information such as performance limits which are used to size the

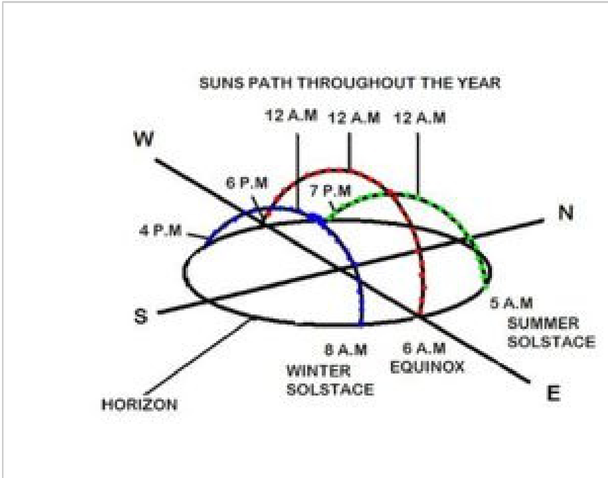


Fig.2 daily path of sun

system.

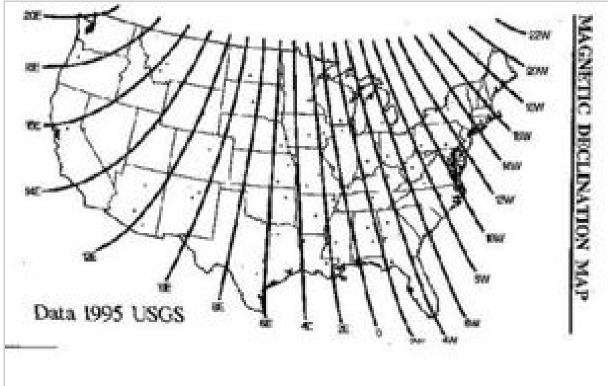


Fig.3 Source: http://users.netonecom.net/~s

Charge Controller

The photovoltaic control is a voltage regulator.

- The primary function of a controller is to prevent the battery from being overcharged by the array.
- Many PV controls also protect a battery from being overly discharged by the load.
- The charge controller used in this system is a Sun Saver-10 by Morningstar Corporation with the specifications shown on the table below.

Table 4: Technical Specifications of Charge Controller

System Volts	(V)	12
Maximum PV Volts	(V)	25
Rated PV Input	(A)	10
Rated Load	(A)	10
Maximum Array Short Circuit Current	(A)	12.5
Setpoint for Sealed PWM Batt.	(V)	14.1
Setpoint for Flooded PWM Batt.	(V)	14.4
Low Voltage Disconnect (LVD)	(V)	11.5
LVD Reconnect	(V)	12.6
Ambient Temp. Range	Deg.C	(-40 to 60)
Temp Compensation	mV/Deg.C	(-28)

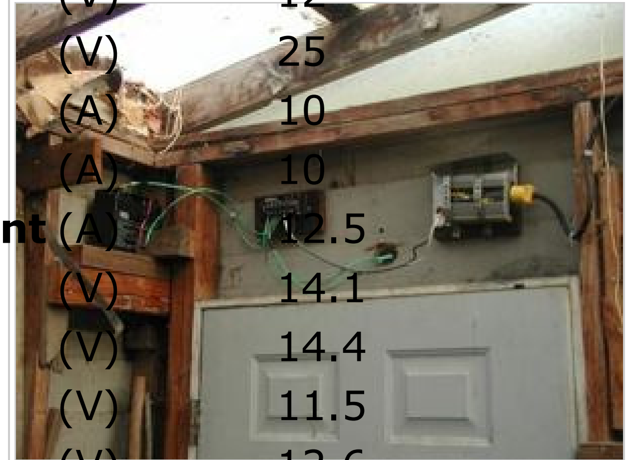


Fig 4 from left to right: battery, charge controller, inverter

Battery

Batteries store direct current electrical energy in chemical form for later use. In a photovoltaic system, the energy is used at night or during cloudy or rainy weather.

- This system uses a Power Patrol absorbed glass mat (AGM) 12 volt 18 amp-hour battery.

- AGM batteries are sealed saturated absorbent glass (boron silicate) mats between the plates instead of an electrolyte fluid. This makes them resistant to freezing and leaking.

Fig.5 charge controller

Inverter

Inverters take DC current electricity and convert it to the AC electricity commonly used by appliances.

- In principle, inverters use transistors to abruptly switch the polarity of the direct current electricity from positive to negative at a very vast rate. This creates a sine wave form.
- A transformer is then used to step up the voltage for AC appliances.
- Modern inverters use sophisticated multi step process variable timing cycles to create AC voltage.

Fig.6 Power Patrol 18AH battery

Below is a table of the Xantrex Xpower400 inverter Inverters technical specifications.

Table 5: Technical Specifications of Inverter

AC output voltage	(V)	120
DC output voltage	(V)	10-15
Continuous AC output power	(W)	320
5 minutes AC output power	(W)	400
Max.AC output surge power	(W)	600
AC output frequency	(Hz)	56-64
AC output waveform	Modified sine wave	
Batt. drain with no load	(A)	0.2
Efficiency	%	90
Low battery alarm	(V)	10.7
Low battery shut down	(V)	10
High battery shut down	(V)	15

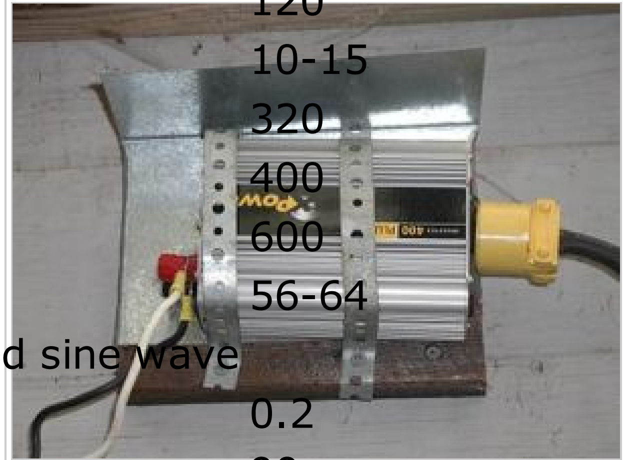


Fig.7 Xantrex Xpower400 inverter

Solar Panels

Photovoltaic panels consist of semiconductor wafers beneath a sheet of glass. The panels in this system were manufactured by Solar International Inc. They were originally rated at 20 watts, and due to wear and tear they now produce around 18.5 watts.

Fig.8 2 solar International panels in parallel

- photons in the light pass through glass and hit semi conductive PV cells
- Electrons are released and absorbed by the silicon material which allows electron flow in one direction
- The parallel arranged cells within the module provide DC power

Design

System Sizing

The previous photovoltaic system powered an answering machine and a fan for the composting toilet, however the compost toilet is no longer in use. After asking various people involved with the AEF what electrical appliances would be most useful on the farm they mentioned the need for a radio.

- In addition to a radio, the system can charge cell phones, provide lighting and supply power tools.
- The system must provide a constant small amount of power for the answering machine and large amounts of power over a short time for other appliances.
- By adding an additional panel, the system can recharge the battery faster during the daytime when the sun is shining and appliances are most likely to be used.

The battery is more likely to be fully charged when the sun goes down and power must be provided throughout the night for the answering machine.

- According to the charge controller owner’s manual, the maximum allowable array voltage is 25 volts. By wiring a second panel of the same model in parallel the overall panel output is below 25 volts while amperage output is doubled, providing enough power for more energy demanding appliances.

To size the photovoltaic system requires these basic steps:

1. Estimating the electrical load
2. Design current and array tilt
3. Sizing and specifying batteries
4. sizing and specifying array

It is important to note that while this approach sizes the system around the energy demand of the loads, the sizing of the AEF system was constrained within the parameters of the pre existing components of the system. The cost of having AEF buy completely new components to get optimum system performance would outweigh the overall benefit of the project. Actual performance of the system is found in the testing & infrastructure section.

Sizing Worksheets

Fig.9: worksheet 1. This is the estimated weekly usage of the syster

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21	System Location	Arcata, CA	Latitude	40.98	Longitude	124.1
	Insolation Location		Latitude		Longitude	

Tilt at Latitude -15°

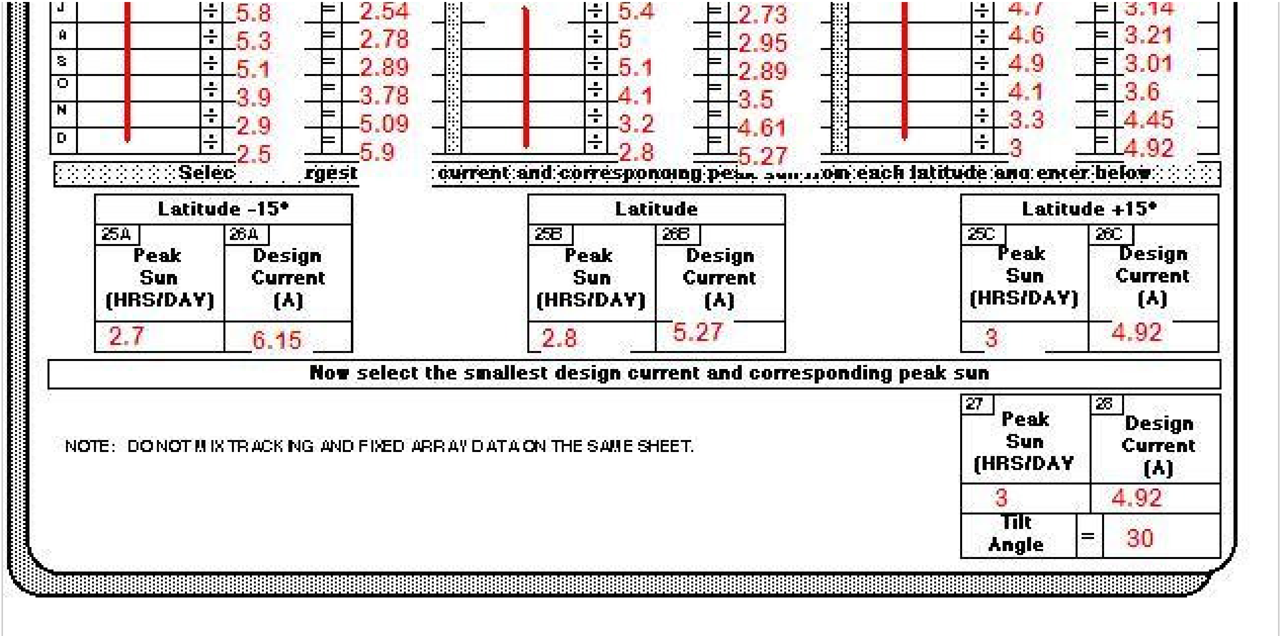
MONTH	22A Corrected Load (AH/DAY)	23A Peak Sun (HRS/DAY)	24A Design Current (A)
	20		
J		÷ 2.7	= 6.15
F		÷ 3.3	= 4.47
M		÷ 4.3	= 3.43
A		÷ 5.4	= 2.73
M	14.75	÷ 5.9	= 2.5
J		÷ 5.9	= 2.5

Tilt at Latitude

MONTH	22B Corrected Load (AH/DAY)	23B Peak Sun (HRS/DAY)	24B Design Current (A)
	20		
J		÷ 3	= 4.92
F		÷ 3.5	= 4.21
M		÷ 4.4	= 3.35
A		÷ 5.3	= 2.78
M		÷ 5.5	= 2.68
J	14.75	÷ 5.4	= 2.73

Tilt at Latitude +15°

MONTH	22C Corrected Load (AH/DAY)	23C Peak Sun (HRS/DAY)	24C Design Current (A)
	20		
J		÷ 3.2	= 4.61
F		÷ 3.6	= 4.1
M		÷ 4.3	= 3.43
A		÷ 4.9	= 3.01
M		÷ 4.9	= 3.01
J	14.75	÷ 4.7	= 3.14



Month		Latitude −15°			Latitude			Latitude +15°
J	÷ 5.8	= 2.54		÷ 5.4	= 2.73		÷ 4.7	= 3.14
A	÷ 5.3	= 2.78		÷ 5	= 2.95		÷ 4.6	= 3.21
S	÷ 5.1	= 2.89		÷ 5.1	= 2.89		÷ 4.9	= 3.01
O	÷ 3.9	= 3.78		÷ 4.1	= 3.5		÷ 4.1	= 3.6
N	÷ 2.9	= 5.09		÷ 3.2	= 4.61		÷ 3.3	= 4.45
D	÷ 2.5	= 5.9		÷ 2.8	= 5.27		÷ 3	= 4.92

Selec… rgest current and corresponding pea… on 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)
2.7	6.15	2.8	5.27	3	4.92

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)
3	4.92
Tilt Angle =	30

Fig.10: worksheet 2.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

28 Corrected Amp-Hour Load (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
14.75	X	1	÷	.82	÷	1	=	17.98	÷	18	=	1

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN

36 Nominal System Voltage (V) (8)		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel (35)		40 Total Batteries
12	÷	12	=	1	X	1	=	1

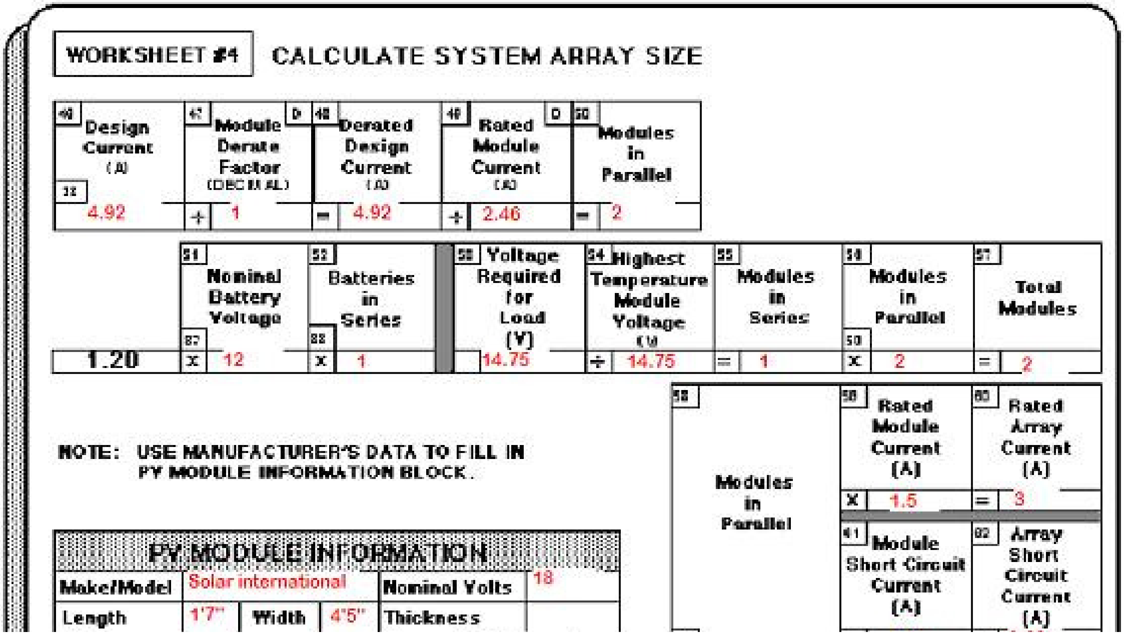
BATTERY INFORMATION	
Make	Power Patrol
Model	12V18A
Type	sealed AGM
Nominal Voltage (V)	12
Rated Capacity (AH)	18

41 Batteries in Parallel (35)		42 Capacity of Selected Battery (AH) (34)		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) (31)		45 Usable Battery Capacity (AH)
1	X	18	=	18	X	.82	=	14.74

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

Fig.11: worksheet 3. This section was filled out by working backwards with using one battery. In reality the low voltage

disconnect of the charge controller causes the battery to have a max. discharge depth of 20%. battery life under the given loads was determined by finding the difference between fully charged battery and low voltage disconnect, dividing the difference by daily amp-hours of loads and multiplying the dividend by 24



WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A)	47 Module Derate Factor (DECIMAL)	48 Derated Design Current (A)	49 Rated Module Current (A)	50 Modules in Parallel
4.92	÷ 1	= 4.92	÷ 2.46	= 2

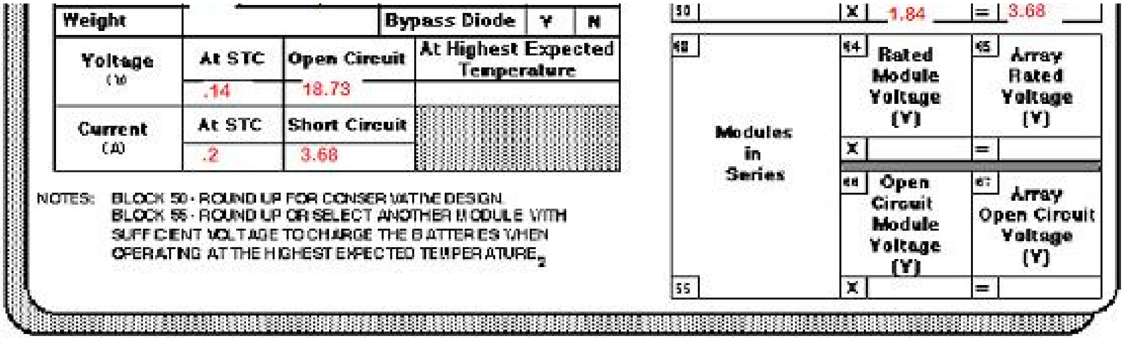
51 Nominal Battery Voltage	52 Batteries in Series	53 Voltage Required for Load (V)	54 Highest Temperature Module Voltage (V)	55 Modules in Series	56 Modules in Parallel	57 Total Modules
1.20 x 12	x 1	14.75	÷ 14.75	= 1	x 2	= 2

NOTE: USE MANUFACTURER'S DATA TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel	59 Rated Module Current (A)	60 Rated Array Current (A)
	x 1.5	= 3
	61 Module Short Circuit Current (A)	62 Array Short Circuit Current (A)

PV MODULE INFORMATION

Make/Model	Solar international			Nominal Volts	18
Length	1'7"	Width	4'5"	Thickness	



Weight		Bypass Diode	Y	N
Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature	
	.14	18.73		
Current (A)	At STC	Short Circuit		
	.2	3.68		

50 X 1.84 = 3.68

53 Modules in Series	54 Rated Module Voltage (V)	45 Array Rated Voltage (V)
	X	=
	66 Open Circuit Module Voltage (V)	67 Array Open Circuit Voltage (V)
55	X	=

NOTES: 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.12: worksheet 4. This section was filled out working backwards with 2 panels. Due to wear and tear the panels do not have exactly the same output current or voltage.

Construction

- The first task to be completed was to determine what was wrong with the system. Initially I was under the impression that the battery was the major cause of the problem. However when I measured it on the site it had a charge of a little over 12 volts. Later on it was charged from an ac source with a trickle charger up to a voltage of 12.8 volts and used again in the system.
- When connecting the panels to the system, voltage appeared at the terminals of the charge controller. After hooking up the test battery directly to the charge controller, bypassing the fuse on the positive battery wire, the charge controller and inverter seemed to work fine. However in my own folly I overlooked the importance of having a fuse in front of the battery. By accidentally having the wires touching the battery terminals to their opposite ends, causing the system to reverse polarize and destroying the inverter.
- The next step was to buy some replacement fuses, wire splice caps, a new ac power outlet, electrical tape and a new inverter. I found a newer model of the same inverter on eBay. Once the

replacement inverter and the new power outlet were installed, the system seemed to operate.

- Now that a new panel was part of the system, it was necessary to find a way to secure it to the building. The only reasonable way to connect it to the other panel in parallel without long unnecessary wiring was to integrate it into the preexisting mounting structure for the PV system. This was accomplished by using lumber found on site at the AEF to extend the beams from the house and secure it to the upper part of the building. Some metal bracing also found on site was used to reinforce the structure to the frame of

the shed.

Materials and Cost list

Table 6:Materials List

Amount	Item	Cost
1x	Xantrex 400 inverter	$60
1x	12V 15AH test battery	Borrowed

Fig.13 PV system mounting structure

1x	AT&T answering machine	on site
1x	electrical outlet	$2.50
2x	multi-meters	borrowed
1x	roll of 10 gauge wiring	donated by AEF
1x	wire splicer	borrowed
1x	box of galvanized 1.25"wood screws	$1.50
1x	hammer	borrowed
4x	2x4" beams of wood	donated by AEF
2x	solar panels	donated by CCAT
1x	12V 18AH AGM Battery	on site
1x	Sunsaver charge controller	on site
1x	portable radio	donated by AEF
1x	rheostat	borrowed
1x	roll of Romex wiring	on site
1x	Roll of 12 gauge wiring	on site

1x	screwdriver	borrowed
6x	wire splice caps	$1.50
1x	box of galvanized 2" nails	$2.50
1x	hand saw	borrowed
1x	box of assorted fuses	$6.35
2x	2x2" beams of wood	donated by AEF
1x	battery tester	borrowed
total cost	$74.35	

Troubleshooting

Routine Maintenance

1. Test system meters using a device where you know the voltage and verify it is working and correct
2. Test array/panel voltage with a multi-meter to measure the voltage/amperage(in full sun) in an array/panel and record
3. Measure battery voltage before and after connecting array and

record
4. Check status indicators on charge controller and inverter if available
5. Check all wiring to see if any is live by testing voltage and/or current at all points before and after a component
6. Check all terminals and wires for loose, broken, corroded or burnt connections or components
7. Test system under full sun and re-test each point and component for common voltage/amperage

Troubleshoot individual components

- Battery

If trouble occurs, turn off then back on. If problem persists, take home to try in different outlet. For programming, see enclosed user manual.

- Charge Controller

For hook up and wiring instructions, please see enclosed diagram. For basic troubleshooting, test all three connection points with a voltmeter. If they are bad, it may need replacement. If they are good (have all the same voltage), the problem is most likely something else.

- Battery

Check all points for corrosion and test each terminal with a voltmeter. If the voltage is below 12 volts and/or the Low Voltage Disconnect light is lit on the Charge Controller, unplug the answering machine and wait until you have two hours of full sun, then re-test. If not charging, the battery may be bad.

- Inverter

Using a voltmeter, test points on both sides of the inverter(one is AC and the other DC), during full sun if possible. For more troubleshooting, see the enclosed manual.

- Panel

Test panel by disconnecting from charge controller during full sun and using a voltmeter to test the voltage. It should be around 18 volts DC. The chart on the following page is a table of common faults and possible remedies.

Troubleshooting Table

table 7: troubleshooting table

Battery is not charging	Measure PV array open circuit voltage and confirm it is within normal limits. If voltage is low or zero, check the connections at the PV array itself. Disconnect the PV from the controller when working on the PV system. Measure PV voltage and battery voltage at charge controller terminals if voltage at the terminals is the same the PV array is charging the battery. If PV voltage is close to open circuit voltage of the panels and the battery voltage is low, the controller is not charging the batteries and may be damaged.

Battery voltage is too high	Disconnect PV array, disconnect lead from the battery positive terminal and leave PV array disconnected. The green charging light on charge controller should not be lit. Measure the voltage at the solar panel terminals of the charge controller. If green light is on, or battery voltage is measured at the terminals the controller may be damaged.
Load not operating properly	Check that no fuses are defective or circuit breakers have been tripped.
Low voltage shutdown	Shorten cables or use heavier cables, recharge battery, allow unit to cool, improve air circulation, locate unit to cooler environment.
Fault light on, AC load not working	AC products connected are rated at more than the inverters power rating, overload shutdown has occurred The AC products connected are rated at less than the inverters continuous power rating. The product

	exceeds the inverters surge capacity.
Reverse Polarity connection on inverter	Check connection to battery, the inverter has likely been damaged and needs to be replaced.
Loads disconnecting improperly	controller not receiving proper battery voltage, check battery connection. Adjustable low voltage disconnect is set too high. Reset Adjustable low voltage disconnect using a variable power supply
Array fuse blows	Array short circuit test performed with battery connected. Disconnect battery to perform test. Array exceeds rating of controller, add another controller in parallel if appropriate or replace with controller of greater capacity.

Testing & Infastructure

testing

It is important to test the performance of the panels so that the system power output can be calculated. The performance of a photovoltaic panel are measured by its short circuit current, its open circuit voltage, and the maximum power point, all of which are expressed by graphing the panels current against its voltage, known as an I-V curve. To determine the current-voltage curves, it was necessary to learn how to configure multi-meters, a rheostat, and photovoltaic panels in a way such that current and voltage readings can be taken incrementally as the rheostat is adjusted.

recording data for each individual panel and both panels wired in parallel, Minitab software was used to create a graph of the current-voltage curve.

A battery tester was used to determine that the battery was functional.

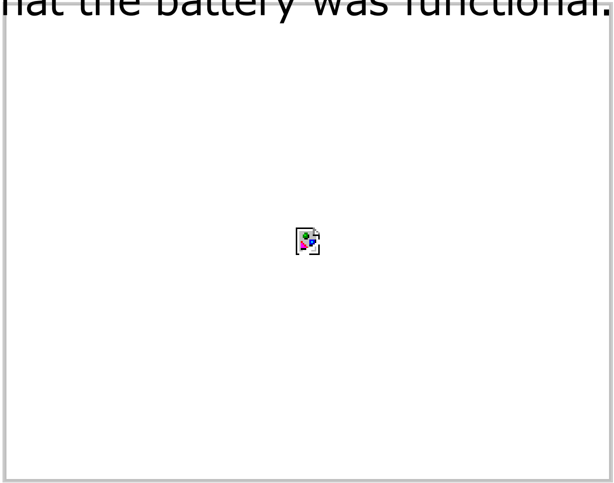


Fig.14 layout of circuit for finding IV curve

- The battery was charged to 14.4 volts and attached through spark plug and allowed to discharge the battery fully. the answering machine stayed on for almost 2 whole days
- When the battery was hooked up to the answering machine through the inverter which only lets the battery charge drop to 10.7 before sounding an alarm. the answering machine stayed on for about 10 hours before being disconnected by the inverter.
- When the charge controller is hooked up to both the battery and the answering machine, the fully charged battery lasts 9 hours

before being disconnected by the inverter

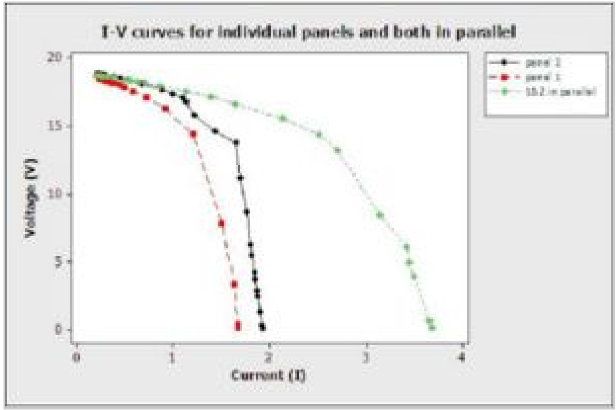


Fig.15 When the two panels are put in parallel their current becomes the sum of their individual currents, as evident in the graph.

infrastructure

To prevent damage to the system, a sign is posted stating the following information

- Always refer to troubleshooting guides, operating manuals before taking apart or maintaining system
- Always turn off inverter before disconnecting battery or any other components of system.
- when reattaching components to the charge controller use the following order, with negative first:

1. battery
2. PV array
3. load

- do not attach anything to the last screw
- the inverter cannot recharge nickel-cadmium batteries or rechargeable tool batteries
- Never attach black wires to red terminal or vice versa

Fig.16 To test the draining abilites of the battery, the 4 watt answering machine as a test load

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