

Tucson Solar Test Yard

Student Employee Manual

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Spring 2009

Introduction

This manual is designed to give student employees a basic understanding of the Tucson Solar Test Yard. This is by no means an exhaustive description of all aspects of the facility as there are many nuances that can only be learned through hands on experience as well as some more technical aspects such as the programming of the data loggers that are best taught by those who are experts with that particular aspect. This manual will give a brief outline of the history of the facility and how Dr. Cronin and the University of Arizona became responsible for the research. It will also outline the equipment presently located at the facility and give a detailed descriptions of the data calibration techniques. Finally, the manual will briefly discuss safety issues, public relations responsibilities, and some future research goals.

Background Information

The Tucson Solar Test Yard is the property of Tucson Electric Power. Much of the equipment at the yard is approximately three to five years old. The facility was built to study the efficiencies of various types of photo voltaic panels in Tucson, Arizona in order to provide information to members of the public interested in installing PV systems on their homes. However, after the completion of the construction of the yard the research was not pursued. In the fall of 2008 Dr. Cronin organized a relationship with Tucson Electric Power that allowed him to take over the research responsibilities as a teaching opportunity for students at the University of Arizona. The funding for the facility is made available by grants from Tucson Electric Power, the Arizona Research Institute for Solar Energy, and the National Renewable Energy Laboratory. There are approximately 650 panels organized in to 22 separate stings. A string is a complete power production and data monitoring system consisting of PV panels, a DC sensors box, an AC power meter, an inverter, a thermocouple, and a data logger card. The total cost of the equipment at the yard is approximately \$ 1 million, and the total cost including upkeep is approximately \$ 3 million for a three year period.

Photo Voltaic and Inverter Specifications

The following pages contain tables of the information for each PV string and inverter. Most of the information comes directly from the manufacturer's label located on the back of the panel or the side of the inverter. Some entries in the tables are blank as those particular devices did not contain the information on their sticker. In addition to the information from the manufacturers, the theoretical efficiency of each panel is listed based on its active surface area and the theoretical value of 1000 watts per meter squared solar irradiance.

System Calibration

The current and voltage for each system must be calibrated separately as each hall probe has a different start value and each voltage divider has a slightly different resistance. If at any point a change is made to a string, such as the addition or the replacement of any piece of equipment, the string should be recalibrated to ensure the most accurate data possible. In most cases such a change will likely not change the calibration equations by much, but it is possible that the change will be significant enough to affect the accuracy of the data. For instance, after adding a diode to the DC current sensors, the intercept of each current calibration equation changed by approximately a factor of two. Without recalibration, this would lead to a significant difference in the calculated current for each string.

DC Voltage Calibration

An external voltage supply must be used in the calibration of the DC voltage. Before beginning calibration, be sure to disconnect the panels and use a digital multimeter (DMM) to ensure there is no longer a voltage difference inside the DC sensors box. Some inverters have built in capacitors so it may take a minute or two for the voltage on the string to decrease to safe levels. Once you are certain the system is safe connect the positive and negative leads from the voltage source to the location on the voltage divider of the corresponding PV voltage lines. Use a DMM to measure the voltage from the supply and the output voltage from the divider. Record this information in a spreadsheet application such as Excel. Use a laptop

System number	Model Type	Number of panels	Inverter	Maximum Power (W)	Open Circuit Voltage (V)
1	Sharp NE-Q5E2U	18	Aurora	165	43.10
2	Kyocera KC150G-A	9	Xantrex 1500	150	28.50
3	BP3150U	10	Xantrex 1500	150	43.50
4	Uni-Solar 64W	24	Fronius IG	64	23.80
5	Sanyo 167W	8	SunnyBoy 1800	167	64.90
6	BP MST50	30	Xantrex 1500	50	102.00
7	ASE 300-DGF/17	4	Xantrex 1500	300	20.00
8	BP SX140S	10	Xantrex 1500	140	42.80
9	ASE 300-DGF/50	4	SunnyBoy 1800	300	60.00
10	GSE GG-112	32	Xantrex 1500	45	49.00
11	Shell ST40	38	Xantrex 2500	40	23.30
12	Sanyo HIP-J54BA2	8	Fronius IG	180	66.40
13	BP MST50	30	Sharp Sunvista	50	102.00
14	BP MST50	150	Beacon Power	50	102.00
15	Shell SQ150-PC	20	Star Inverter	150	43.40
16	Astro Api-MCB	9	Xantrex 1500	165	32.00
17	Solarex MST-43	60	Solectria	43	98.00
18	ASE DGF50	9	Soleil 2000	300	60.00
19	ASE 300	75	Three Phase	300	20.00
20	GSE SL-62W	24	Xantrex 1500	62	57.00
21	BP 4170S	18	Xantrex Utility	170	44.00
22	ASE 300-DFG/17	75	None	300	20.00

System number	Open Circuit Voltage (V)	Short Circuit Current (A)	Maximum Power Voltage (V)	Maximum Power Current (I)	Maximum System Voltage (V)
1	43.10	5.46	34.60	4.77	600
2	28.50	7.26	22.50	6.67	600
3	43.50	4.75	34.50	4.35	600
4	23.80	4.80	16.50	3.88	600
5	64.90	3.63	51.40	3.25	600
6	102.00	0.79	78.00	0.64	600
7	20.00	19.10	17.20	17.4	600
8	42.80	4.50	34.00	4.11	600
9	60.00	6.50	51.00	5.9	600
10	49.00	2.00	34.00	1.3	600
11	23.30	2.68	16.60	2.41	600
12	66.40	3.65	54.00	3.33	600
13	102.00	0.79	78.00	0.64	600
14	102.00	0.79	78.00	0.64	600
15	43.40	4.80	34.00	4.4	600
16	32.00	7.40	25.00	6.6	600
17	98.00	0.84	73.00	0.589	600
18	60.00	6.50	51.00	5.9	600
19	20.00	19.10	17.20	17.4	600
20	57.00	2.10	36.50	1.7	600
21	44.00	5.40	34.70	4.9	600
22	20.00	19.10	17.20	17.4	600

System number	Minimum Bypass Diode (A)	Fuse Rating (A)	Fire Rating	Approximate Active Surface Area (m ²)	total power at yard	panel efficiency (%)
1		10	Class C	1.17	2970	14.1
2				1.18	1350	12.7
3	8	20		1.16	1500	12.9
4	8	8	Class C	0.93	1536	6.9
5		15		1.07	1336	15.6
6	6	15	Class B	0.78	1500	6.4
7		30	Class A	2.25	1200	13.3
8	8	15	Class C	1.16	1400	12.1
9		10	Class A	2.25	1200	13.3
10	3	3		0.78	1440	5.8
11		5	Class C	0.36	1520	11.1
12	6	1.5	Class C	1.06	1440	17.0
13	6	15	Class B	0.78	1500	6.4
14	6	15	Class B	0.78	7500	6.4
15		15	Class C	1.16	3000	12.9
16	18	15	Class C	1.33	1485	12.4
17	3	3	Class C	0.78	2580	5.5
18		10	Class A	2.25	2700	13.3
19		30	Class A	2.25	22500	13.3
20	3	3		0.71	1488	8.7
21	8	15	Class C	1.16	3060	14.7
22		30	Class A	2.25	22500	13.3

Model	Maximum System Voltage (V)	Range of Operating DC Voltage (V)	Maximum Operating DC Current (A)	Maximum Array Short Circuit DC	Maximum Utility Backfeed	Operating AC Voltage Range (V)
Aurora PVI-3000	600	150-580	10	12	20	211-264
Xantrex STXR1500	120	52-85	60	75	0.05	211-264
Xantrex STXR2500	120	52-75	60	75	0.05	211-264
Froinus IG 2000	450	150-450	13.6			212-264
Sunny Boy	400	156-400	12	18	20	106-132
Sharp Sunvista	380	110-350	22.5	10		211-264
Soleil 2000-120	450	200-360	15			106-132
Xantrex GT	600	195-550	16.6	19	20	211-264
	AC Output Voltage (V)	AC Output Frequency (Hz)	Max Continuous Output Current (A)	Max Continuous Output Power (W)	Max Output Fault Current (A)	Output Overcurrent Protection (A)
Aurora PVI-3000	240	60	13	3000	17.0	20
Xantrex STXR1500	240	60	6.3	1500	6.3	15
Xantrex STXR2500	240	60	10.5	2500	10.5	15
Froinus IG 2000	240	60	8.35	1800	16.0	15
Sunny Boy	120	60	16	1800	20.0	20
Sharp Sunvista	240	60	15	3500		
Soleil 2000-120	120	60	18	2000		
Xantrex GT	240	60	14.2	3000	288 Apk	20

to check the digital reading (channel 1) from the data logger. This digital reading will likely fluctuate so it is beneficial to take an average of at least ten measurements over a period of approximately a minute. Vary the output voltage from zero to the maximum value the voltage supply is capable of creating repeating this process for each voltage. To obtain the calibration equation, make a linear fit of the data points using the average digital measurement from the loggers as your x value and the DMM reading of the high voltage from the source as your y value. The voltage range used for the present calibrations was zero to 30 V. In order to increase accuracy, the calibrations may need to be redone using a supply capable of producing a higher maximum voltage as many of the strings operate at significantly higher values. Below are the voltage calibration equations for each string. D is the digital reading and V is the voltage from the panels. Note that strings 19 and 22 are not calibrated as string 19 (3 phase inverter) is not set up to record data and string 22 does not have an inverter.

1. $V = .1203 * D - 5.1689$
2. $V = .1183 * D - 5.2284$
3. $V = .1148 * D - 4.8011$
4. $V = .121 * D - 5.0848$
5. $V = .1197 * D - 2.7493$
6. $V = .0946 * D - 5.1505$
7. $V = .1223 * D - 4.7372$
8. $V = .1182 * D - 4.219$
9. $V = .0949 * D - 6.7839$
10. $V = .0941 * D - 4.3815$
11. $V = .0916 * D - 1.5695$
12. $V = .0901 * D - 1.5297$
13. $V = .1008 * D - 1.4301$
14. $V = .0894 * D - 1.9024$
15. $V = .0976 * D - 2.0324$
16. $V = .1027 * D - 1.7876$
17. $V = .1224 * D - .4413$
18. $V = .1205 * D - 4.1754$
20. $V = .0955 * D - 5.1712$
21. $V = .1188 * D - 4.4589$

DC Current Calibration

The same external supply is used to calibrate the hall probes for each string. As with the voltage calibrations be certain that the PV panels are disconnected and that it is safe to operate inside the DC sensors box. For the present calibrations, the high voltage wires were removed from each hall probe and a separate wire was looped through the hall probe 20 times. In the future, it may be beneficial to permanently wrap a small gage wire capable of carrying up to approximately 5 amps through each hall probe in order to eliminate the need to remove the high voltage wires. Attach the current supply to the calibration wire so that the current passes through the hall probe in the direction toward the sticker with the serial number. This is essential as if the current is passed through in the opposite direction, the hall probe will produce a negative voltage. Diodes have been installed on each string that prevent large negative voltages to pass to the data loggers in order to avoid damaging them. As with the voltage calibrations, vary the current supply from zero to its maximum value and record in a spreadsheet the total current (current from supply multiplied by the number of wraps in calibration wire), the voltage from the hall probe (as measured with a DMM between the white (negative) and green (positive) wires), and the average digital reading (channel 2) from the data logger. To obtain the calibration equation, make a linear fit of the data points using the average digital measurement from the loggers as your x value and the total current through the probe as your y value. This equation must then be multiplied by the fraction formed by dividing the number of parallel strings by the total number of wraps through the hall probe. For example, if a string has three parallel wires coming from the panels and each of those wires passes through the hall probe three times (for 9 total wraps), the calibration equation will be multiplied by one third. This is to ensure the calibration equation finds the total current in the system and not simply the current through an individual wire. The current calibration equations for each string are listed below where C is the total current in the system and D is the digital reading from the data logger. Just as before strings 19 and 22 are not included.

1. $C = (.02 * D + 1.1024) * \frac{1}{10}$
2. $C = (.02 * D + .496) * \frac{1}{3}$
3. $C = (.0199 * D + .5644) * \frac{1}{3}$
4. $C = (.0201 * D - .078) * \frac{1}{5}$

5. $C = (.02 * D + 1.1153) * \frac{1}{5}$
6. $C = (.0201 * D + .1004) * \frac{1}{3}$
7. $C = (.0199 * D + .2144) * \frac{1}{3}$
8. $C = (.0199 * D - 5.3497) * \frac{1}{2}$
9. $C = (.02 * D - .0402) * \frac{1}{6}$
10. $C = (.0201 * D + 1.0398) * \frac{1}{5}$
11. $C = (.0199 * D - .0344) * \frac{1}{3}$
12. $C = (.0199 * D - .075) * \frac{1}{8}$
13. $C = (.0199 * D - .078) * \frac{1}{4}$
14. $C = (.02 * D + .2516) * 1$
15. $C = (.0201 * D + .7135) * \frac{1}{10}$
16. $C = (.0198 * D + .8625) * \frac{1}{3}$
17. $C = (.0201 * D + .2385) * \frac{1}{4}$
18. $C = (.0199 * D + .0466) * \frac{1}{10}$
20. $C = (.0199 * D + .1764) * \frac{1}{5}$
21. $C = (.02 * D + .2403) * \frac{1}{2}$

Temperature Calibration

The Omega devices that convert the temperature measured by the thermocouple on each string to a voltage that can be read by the data loggers are all calibrated the same for each string. They are set to operate between zero and 95 degrees Celsius. The calibration equation is listed below where T is the temperature and V is the voltage (digital reading divided by 1000).

$$T = 33.485 * V - 38.462$$

Safety Considerations

Safety is extremely important at the test yard. It is highly recommended that you do not work on the high voltage lines while alone at the yard. Many of the high voltage lines from the PV panels run through fuse boxes with switches to turn off the power from the panels; however, many of these fuse boxes are not correctly wired. Always be sure to use a DMM to check the voltages inside all equipment before touching anything. In some cases it is necessary to disconnect the high voltage lines at the panels. When doing this be sure to use safety precautions and remember that common sense goes a long way.

Public Relations Responsibilities

In addition to your responsibilities working with the equipment at the test yard, there will be times that Dr. Cronin will ask you to interact with members of the public. These responsibilities could include but are not limited to giving tours of the yard, being interviewed by members of the media, or presenting the research at a formal talk or poster presentation. It is important to be able to discuss the research being conducted at various levels of complexity as at times your audience may be professionals in the solar industry and other times they may be a group of middle school students.

Future Research

With the exception of a few strings that are not working properly due to malfunctioning inverters, the majority of the test yard is set up to continuously monitor the DC and AC power produced by each string. Now that the facility is set up to monitor this information, it is time to expand the scope of the research. Future projects include learning how the weather stations operate and setting them up to record data. Also, there are plans to install accurate irradiance detectors at the yard in order to more accurately determine the efficiency of the panels. Another experiment could be performed to determine if cleaning the dirt from the surface of the panels increases their power production. In the future, it is Dr. Cronin's goal to begin to develop the yard as a testing facility for new solar technologies such as power storage systems and smart inverters that are capable of compensating for intermittent power production due to clouds. The research possibilities at the test yard are far from being exhausted.