A Solar-Based Versatile Charging Station for Consumer AC-DC Portable Devices

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Abstract - This paper presents the design and prototype of a charging station powered by solar PV. It provides power to charge AC and DC consumer portable devices such as laptops, cell phones etc. It can be used at schools, hospitals, parks, bus stops, emergency locations etc. The station has 2 AC and 4 DC outlets which can charge 6 devices simultaneously. The system overall efficiency obtained from testing is 76.8%, which is satisfactory for solar-inverter systems. In a very cloudy day, when all 6 outlets are used to charge two laptops, three cells phones and a tablet with the total demand of 247Wh, the system could be sustainable for 2.6 hours. The system could power the average worst-case load of 155W for 4.1 hours. For better sun days, the system is likely able to supply power for a longer time. The system is portable, weather-resistant, versatile unit that can easily be expanded.

Keywords - Charging station, consumer AC-DC devices, solar PV, battery, inverter, portable.

1. Introduction

The growth of solar PV market is impressive for the past few years. The world solar electricity capacity has reached 227,000 MW by the end of 2015. The U.S. alone has 55,900 MW of installed capacity by the first quarter of 2018, enough to power 10.7 million American homes. Over 600,000 U.S. homes and businesses have on-site PV systems and the number keeps rising [1-4].

Apart from being power sources for homes and businesses, solar PV systems are being considered for use in other distributed applications, such as outdoor lighting, charging electric vehicles, and powering parking pay stations [5-13].

The latest highlight in solar PV use is to provide power to portable electronics devices such as cell phones, laptops, and music players.

A solar tree for charging mobile devices has been considered in one recent study [14]. In the United States, AT&T has built some solar-powered DC charging stations for mobile phones in New York city parks [15], North Carolina State University has provided some solar DC-USB chargers at bus stops [16], and the University of California at Riverside has installed a number of solar-powered tables where AC and DC outlets are available [17].

Analysis of the aforementioned solar PV charging systems for the portable devices reveals certain shortcomings. The systems offered by AT&T and the North Carolina State University provide only DC-USB outlets with limited space for placing devices. The AT&T systems are of limited 45-W power capacity from three small solar panels. Moreover, the solar charging systems of the University of California at Riverside and the North Carolina State University are not portable. To fill in the gaps, this project attempted to design a compact, portable, versatile, stand-alone, weather-resistant charging station for the consumer devices. It can easily be transported and used in many locations, such as schools, hospitals, offices, parks, bus stops, camping grounds, emergency and special event venues, and so on, to serve people with zero-emission solar energy. The station provides considerable power (200-W solar capacity) and both AC and DC outlets to accommodate a wide range of devices. The number of outlets is expandable.

A prototype of the charging station has been built, tested and proved to meet the performance expectation. It has been donated to Ganesha High School in Pomona city of California as an effort to serve the community on 1 June 2018. It could stand the unusually hot summer months of June and July 2018 in California while operating properly.

The paper is structured as follows: Section 2 presents the design of the charging station, Section 3 describes the construction of the station prototype and its testing results, Section 4 presents related community service and donation of charging station prototype, Section 5 contains the conclusion. The Appendix provides specifications of the system main components and related calculation.

2. Charging station design

The design involves determining an optimal power capacity for the whole station, as well as appropriate voltage and current ratings of individual components. The National Electric Code (NEC) [18], the standard for safe installation of electrical wiring and equipment in the United States, is used to ensure that the station is fully safe and compliant to the code. The key requirement is that the station is a compact, portable, stand-alone, self-sustaining, and weather-resistant system that is easily used in diverse locations.

Bus stops are used as ideal locations to analyze the charging system design and determine its parameters. The transportation data for the city of Los Angeles where 90,000 people use the bus daily are used as reference [19]. A goal is to mitigate a common problem that many people may face during their commute, namely, running out of battery on their portable electronic devices. The design also aims to accommodate various electronics devices that a person may carry at any given time, including phones, tablets and laptops. It should be emphasized that the transportation characteristics of Los Angeles can be similar to those of many big cities around the world. Therefore, using the Los Angeles transportation data does not impact the generalization of the charging station design.

Based on the Los Angeles Metro public transportation data [19, 20], the number of people that use the bus is averaged to 925,000 per day. The number of buses that are deployed in the serviced area is found to be 2,438. The number of stops per bus per day can be calculated by multiplying the interval between stops and the hours of operation. This number is averaged to be around 76 stops. Using the data, the average number of people waiting at a bus stop is calculated as 925,000 / (2438 x 76) = 5. It follows that 4 DC and 2 AC outlets would be an optimal number of outlets for the station to accommodate the 5 waiting people on average. Six devices may be charged at a time where the charging may take 15-30 minutes. The detailed calculation is provided in "Equations" section of Appendix. The block diagram of the charging station is shown in Figure 1.

The charging station is powered by fixed solar panels and uses a deep-cycle Absorbent Glass Matt AGM battery to store the energy that is produced during the day. The Charge Controller ensures a safe current for charging the battery. Meanwhile, the station operation is controlled by the Signal Controller (i.e. a microcontroller). The battery power is channeled directly to the four DC-USB outlets while the inverter converts the battery power to 60-Hz AC power for the two AC outlets. The AC outlets are equipped with GFCI for safety in accordance with Article 690.41 of the NEC [18]. For the user comfort and convenience, the station is adequately illuminated by a separate solar light fixture that turns on automatically after dark. LED indicators are used to show its availability and working conditions.

The motivation to select the topology Solar panel – Battery – Outlets is that it offers two advantages. The first is that the battery is continuously replenished by the solar panel power during daytime while it is discharging its energy to the outlets. The second advantage is that the power supplied by that battery is stabilized. The battery acts like a buffer to rectify the variations in voltage and current outputs of the solar panel due to shading.

2.1 Solar panel sizing and estimated energy production

The same Los Angeles Metro public transportation data [19, 20] are used to determine an appropriate sizing for the solar panels. It is previously calculated that 5 people wait at a bus stop on average. Their power demand would be met by having five devices connected at a time (e.g. cell phones, tablets, laptops, portable gaming devices etc.). Using the data obtained from various data sheets and specifications, the average worst-case loading for 4 DC outlets and 2 AC outlets is estimated to be 155W (see "Equations" section in Appendix for detailed calculation). Hence, the solar system size is selected to be 200W to accommodate the worst-case power demand and the system power loss. Two individual 100-W PV panels are used to make the desired 200-W capacity. The specification of the solar panels is provided in Appendix.

In accordance to NEC [18] Article 690.7, a maximum voltage of 43.8V is selected for the system, which is based on the listing labels of the open circuit voltage of each PV panel. Following NEC Article 690.8, the maximum source and output current of the panels is 6.13A. Overcurrent protection is placed after the panels in accordance to NEC Article 690.9. A switch that is readily accessible is placed in series with the panels as a mean to disconnect the PV system from all wiring systems in accordance to NEC Article 690.1.

Estimated energy production: The daily energy produced by the solar panel is estimated to be 1,100Wh (200W x 5.5 average sun hours = 1,100Wh). The average sun hours are based on the sun hour data for various cities in California, which are provided in Appendix.

2.2 Battery sizing

We use a 12-volt AGM deep-cycle battery which has the capacity of 818.4 watt-hours. The battery size is calculated as 12V x 68.2 Ah = 818.4 Wh. This means that it can store 200W (i.e. the maximum output of solar panel) for 4.09 hours (818.4 / 200 = 4.09 hours). Also, it can store 74.4% of the average energy produced by the solar panel per day (818.4 Wh / 1100 Wh = 74.4%). The battery is not designed to store 100% of the average daily energy output of the solar panel because it discharges energy during the day and the discharged energy is replenished by the solar panel energy. In addition, there is about 5-percent power loss during battery charging so the average daily energy to be stored by the battery would be 1,045Wh (1,100 x 0.95 = 1,045Wh). Hence, the battery size may be smaller to reduce its cost. The deep-cycle battery is chosen because it is the most common in the vented liquid electrolyte battery chemistry and is the ideal selection for PV systems.

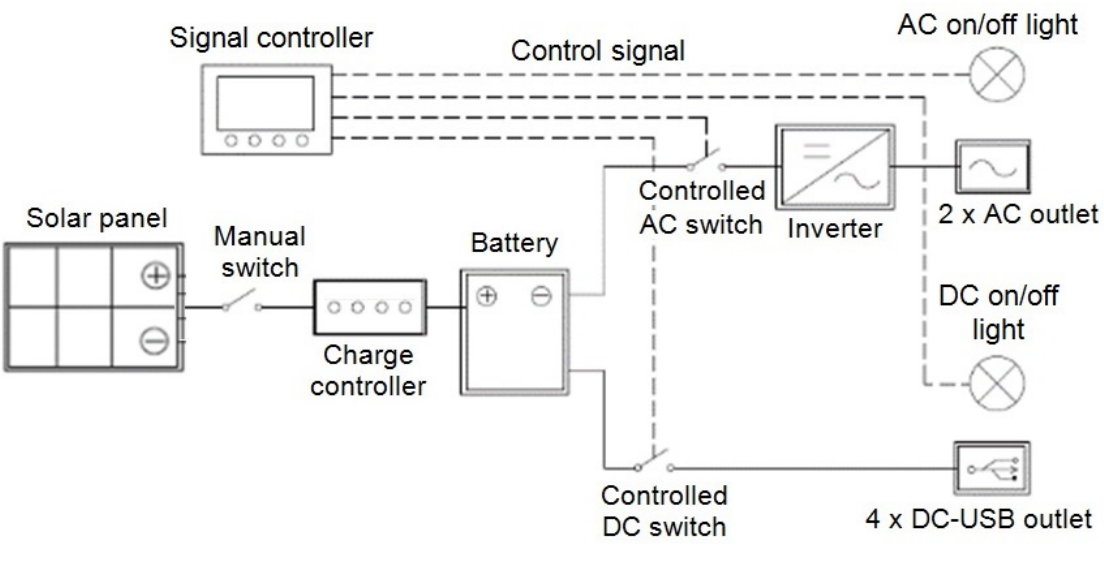

Fig. 1 Block diagram of the charging station

This type of battery is designed to be more deeply discharged before being recharged and requires very little maintenance. The selection is also based on the fact that the typical efficiency of a lead acid battery is around 85% - 95% while other batteries such as alkaline or nickel cadmium batteries are only 65-percent efficient [21]. The selected AGM battery has efficiency near 98% under optimal conditions, but its cost is twice that of a regular lead acid battery [22]. The depth of discharge is selected to be 30% and the depth of charge is selected to be 90% from the maximum capacity. These properties help extend the battery life. The battery specification is provided in Appendix.

2.3 Inverter sizing

The inverter size is selected based on the battery size of 818.4Wh. In order to minimize heat and cost, we choose a modified sine wave inverter of 360-W at 120-V continuous AC output. At full output of 360W, the inverter can completely drain the battery in around 2.3 hours (818.4 Wh / 360 W = 2.3 hours). As mentioned in Section 2.1, the average worst-case loading for 4 DC outlets and 2 AC outlets would be 155W. However, the peak load can be much higher than 155W (see Section 3.3 for testing loads). The inverter size of 360W will allow larger AC loads to be connected to the AC outlets. This would make operation of the AC outlets safer as users may plug any AC devices into the outlets. It also accounts for the inverter actual efficiency when being operated under high outdoor temperatures, which could be well below the manufacturer maximum efficiency of 90%.

Following the NEC Article 690.7, the maximum current output of the inverter is considered the inverter continuous output rating. The inverter is equipped with overcurrent protection prior to its input to follow NEC Article 690.9. The inverter specification is provided in Appendix.

2.4 Lighting for the charging station

The solar panel measurements are 5.4 feet by 3.25 feet, which results in a surface area of 17.55 square feet. It is desirable for the light fixture to light up the area and a few feet beyond it. Therefore, it is decided to provide sufficient lighting for an area of 6 x 6 feet (i.e. 36 square feet, or 3.3 m2) to make the station eye-catching for the users. The selected illumination level is based on [23] for *"Working areas where visual tasks are only occasionally performed"* where the recommended illumination is 100-150 lumens/m2. It follows that 330 – 495 lumens are needed for the area (3.3 m2 multiplied by 100-150 lumens).

A LED light fixture is chosen because it outputs "cool" light (low heat emission) and consumes little energy. To converse energy of the station battery, we use a stand-alone solar-powered LED light fixture with 3000-mAh internal battery that can provide 8-hour illumination. This unit has two lamps, which can be individually mounted at 360 degrees and provide a total of 400 lumens. By using a separate light source, the station is independently illuminated through most night time. This feature provides some protection for the station against possible vandalism.

2.5. System operation and control

Figure 2 shows the circuit wiring diagram of the charging station. Figure 3 shows the control diagram and Fig. 4 shows the flow chart of the microcontroller logic.

The station is controlled to ensure safe operation and prolong the life of the equipment using a microcontroller and relays. Two LED-based indicators are used to display the system operation conditions to the users. For preserving the lifespan of the battery, its depth of discharge is maintained between 30% and 90% of its maximum capacity. For this purpose, one (1) Arduino Uno Microcontroller, two (2) low voltage latching relays, two (2) RGB LEDs, six (6) 330-Ω resistors for the LEDs, and two (2) resistors rated at 3000Ω and 330Ω are used. We implement voltage identification logic to continuously obtain the battery voltage and use this information to dictate switching logic within the microcontroller. We disconnect the AC and DC outlets from the battery at different times to limit the amount of drain on the battery and maintain the depth of discharge.

To create the voltage identification and switching scheme, we attach the 3000-Ω and 330-Ω resistors from the battery source voltage to the Arduino Uno as a voltage divider circuit. This reduces the 12-volt battery voltage to a voltage level which is safe to input into the Arduino. This voltage is sampled and averaged to continually identify the present voltage output from the battery. The 12-volt latching relay is powered directly from the battery, with two additional 5-volt outputs from the Arduino feeding to the relay. We monitor the source voltage and implement logic to remove the 5-volt outputs at specific voltage ranges, which cut off the power to the respective DC and AC outlets. The battery at full charge has a voltage output of 12.73V. We disconnect power to the AC outlet at 50% battery capacity with 12.1-V voltage output and disconnect power to the DC outlet at 30-percent battery capacity with 11.81-V voltage output.

To visually indicate the switching, we use 2 RGB LEDs as indicators and six (6) 330-Ω resistors to limit the current into the LEDs. Both LED indicators start as green. When the battery voltage drops below the 50% threshold the AC outlet indicator will turn red. The DC outlet indicator will turn red when the battery voltage drops below the 30-percent threshold. The flow chart of the microcontroller logic is presented in Fig. 4.

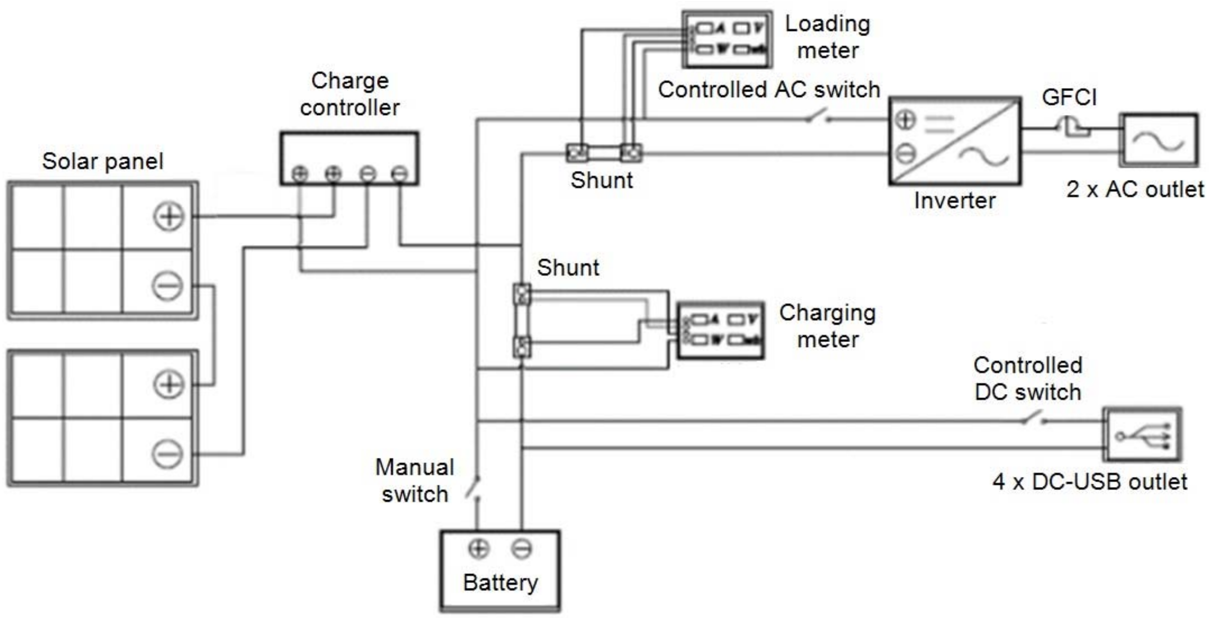

Fig. 2 Circuit wiring diagram of the charging station

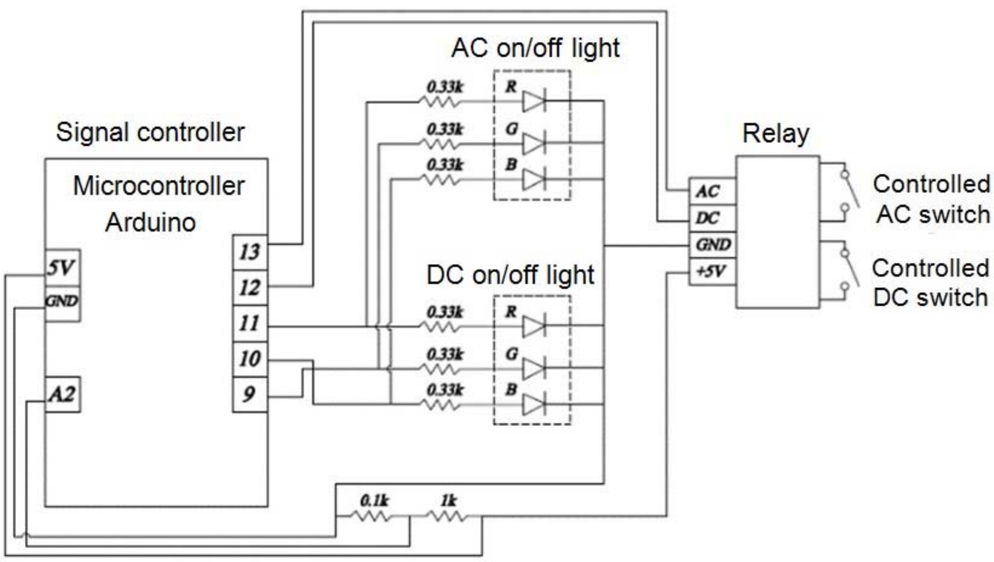

Fig. 3 Control diagram of the charging station

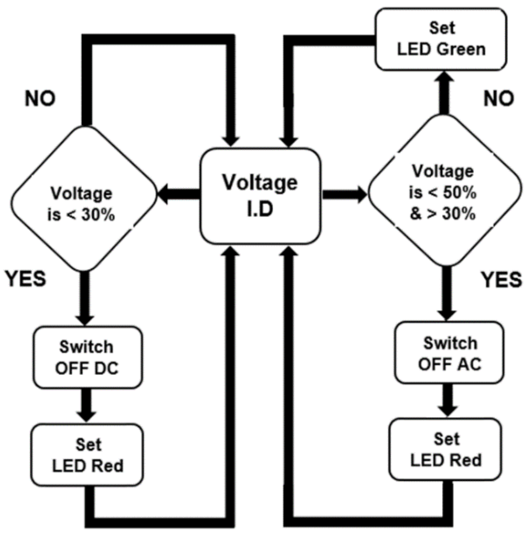

Fig. 4 Flow chart of the microcontroller logic

Microcontroller logic explanation: Referring to Fig. 4, one of the main purposes of using the microcontroller is to control the latching relays that switch AC and DC outlets. The microcontroller constantly checks for the voltage of the battery. If the battery energy level is anywhere between 100% and 50%, both AC and DC outlets are on and both LEDs that indicate the status of the outlets are green. This means that the battery has sufficient stored energy to continue discharging. When the battery energy drops below 50%, the AC outlets automatically shut down and the LED indicator for the AC outlet turns red. However, the DC outlets are still usable and the LED indicator for it is green. When the battery level drops below 30%, the DC outlets shut off and the LED indicator turns red. Under this condition, both AC and DC outlets turn off for the safety of the battery.

2.6 System protection

The charging station is compliant with NEC to ensure safety measures for public use. In lieu of a 25-A fuse, we utilize the charge controller (Fig. 1) because it provides overcurrent protection. Although it is very unlikely that a solar panel would be shorted, safety is very important so extra protection would be helpful. A manual disconnect switch is placed right after the fuse (Fig. 1) in case an emergency disconnect of the solar panel is required and for the sake of testing the station. We also install a second manual switch that is located between the battery and the inverter (Fig. 2). This switch is used to test the station load. The inverter has sufficient built-in protection against overloaded conditions.

3. Prototype and testing of charging station

A prototype of the charging station is built according to the design specification and tested to verify that all the desired features of the system have been satisfied.

3.1 System design capabilities

Based on the charging station design presented in Section 2, its capabilities are summarized as follows:

Estimated average daily energy production by 200-W solar panel: 1,100Wh

Battery size: 818.4Wh

Inverter size: 360W at 120-V AC continuous output

Estimated average worst-case load: 155W

Operation duration for average worst-case load: 5.7 hours (1,100 Wh x 0.8 efficiency / 155 W)

3.2 Physical design and specification

The key design requirement is that the station is a compact, portable, stand-alone, self-sustaining, and weather-resistant system that is easily used in diverse locations. Hence, the station frame and enclosure are designed as a self-support, free-standing, weather-resistant, portable storage case with a small table (shown in Fig. 5).

The storage case safely and securely stores all the necessary equipment and serves as a small table which two or more people can use to place their devices, including big items such as laptops. The enclosure case is designed to enable easy installation and maintain of the system equipment. For this purpose, we use tamper-proof screws on the entire rear side of the unit, where the case opens up. This gives technical personnel full unobstructed visibility and access of all the equipment stored inside the case. Same tamper-proof screws are used to secure the solar panels. To avoid flooding, all equipment is installed at an elevation of around 40cm above the base. The specification of the frame and enclosure is provided in Appendix.

To maximize the solar panel annual energy production, a fixed solar-panel tilt angle of 35 degrees is used assuming that the installation location is Southern California. For the same goal, the solar panel should face true south if it is installed in the northern hemisphere, or true north if it is used in the southern hemisphere [24, 25]. In accordance to the NEC Article 710.15, the station is labeled with a warning indicating that a 120-V supply is located in the system.

3.3 Testing results

Several tests were conducted to evaluate the charging station capabilities and verify whether the design requirements are met. Voltage, current, power, and energy outputs by the solar panel are recorded by Charging Meter and the outputs to the AC outlets is recorded by Loading Meter (Fig. 2). Another meter (not shown in Fig. 2) records the outputs to the DC outlets.

Test 1: In the first test, the system is used to charge two laptops which require 200Wh. The test lasts one hour, from 10:51am to 11:51am. The results are recorded in Table 1 and Table 2. They show that the solar panel produces power as expected and the battery can store the solar energy properly. After 1 hour, the loads receive 43W from the battery (Table 2). It follows that the two laptops would be fully charged in about 4.7 hours. In terms of energy, the system overall efficiency is measured to be 76.8% (43/56 = 0.768). The overall efficiency includes the charge controller, the battery, and the inverter efficiencies. Note that typical efficiency of a lead acid battery is around 85%-95% and typical efficiency of small-size inverters is 80% - 90%. The results show that the system meets the design expectations.

Test 2: In the second test, all the six outlets are used. The system charges two laptops, three cells phones and a tablet where the total load is 247Wh. The test lasts 3 hours, from 12:40 pm to 3:40 pm. The battery is fully charged initially. The results are shown in Table 3 and Table 4.

Table 3 and 4 show that the solar panel produces 35Wh during the test, which is less than the total energy supplied to the loads (92Wh). It follows that about 57Wh is taken from the battery while the solar panel channels 35Wh to the battery (efficiency is neglected). Under this operational condition, the system would have 642.9Wh available for 6 hours, where 572.9Wh is 70% of the battery capacity and 70Wh is provided by the solar panel. The available energy would be sufficient to supply the average worst-case load of 155W for 4.1 hours. For the heavy load of 247Wh, the system would be sustainable for 2.6 hours. Note that this test took place on a very cloudy day where the solar radiation was low so the solar panel did not produce much power. For sunny days which are common in California, the system is likely able to supply the outlets for a longer duration.

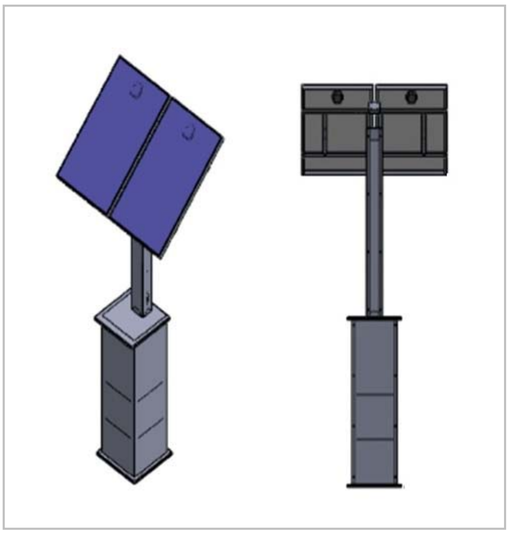

Fig. 5 Frame and enclosure of charging station

Table 1 Energy produced by solar panel for Test 1

Time, Minutes	Voltage, V	Current, A	Power, W	Energy, Wh
0	14.02	4.65	65.2	0
10	12.85	4.86	62.5	10
20	12.74	4.93	62.8	20
30	12.67	4.86	61.6	31
60	12.52	3.81	47.7	56

Table 2 Energy output to AC load from battery for Test 1

Time, Minutes	Voltage, V	Current, A	Power, W	Energy, Wh
0	13.93 (100%)	0	0	0
10	12.71	3.45	43.8	8
20	12.59	4.24	53.3	15
30	12.56	4.00	50.2	23
60	12.41	3.13	36.8	43

Table 3 Energy produced by solar panel for Test 2

Time, Minutes	Voltage, V	Current, A	Power, W	Energy, Wh
0	13.51	3.91	52.8	0
10	12.76	3.65	46.5	9
20	12.72	3.61	45.9	15
30	12.50	2.94	370.	21
60	12.41	2.20	27.3	29
120	12.28	0.15	1.8	34
180	12.12	0.08	0.9	35

Table 4 Energy output to AC and DC loads for Test 2

Time, Minutes	Voltage, V	Current, A	Power, W	Energy, Wh
0	13.43	0	0	0
10	12.64	2.08	26.2	7
20	12.62	1.91	24.1	11
30	12.52	2.17	21.1	16
60	12.34	2.58	31.8	30
120	12.25	1.64	20.0	55
180	12.11	2.47	29.9	92

Note: In Table 4, the current shown is the one going to the AC outlets. The total current going to the DC outlets is 8.4A.

4. Community service and donation of charging station prototype

As an effort to serve the community and encourage study of science and engineering, the research team has made a presentation on the project to a group of students at Ganesha High School (Pomona School District, Pomona city). The team explained basic concepts of the solar-related project, from design to implementation. It also provided easy-to-understand information of the usefulness of solar power for the environment and energy security. The presentation was a huge success where the students showed great interest in the engineering project and excitedly accepted various electrical components (LED, resistors etc.) that the team brought as gifts.

The prototype of the charging station has been donated to Ganesha High School on 1 June 2018. It could stand the unusually hot summer months of June and July 2018 in California while operating properly. Figure 6 shows the prototype of the charging station installed near the school office.

Fig. 6 Prototype of the charging station donated to Ganesha High School

5. Conclusion

In this project, a solar-based charging station for consumer portable devices has been designed, built and tested for verifying its performance. The main goal is to make it a compact, portable, versatile, stand-alone, weather-resistant charging station that can easily be transported and used in many locations. The results have led to the following conclusions:

1) All the design requirements have been met. The station can charge two laptops which require 200Wh in total. After 1 hour, the laptops receive 43Wh, or 21.5% of their total energy demand. The system overall efficiency is measured to be 76.8%, which is good for solar-inverter systems.

2) On a very cloudy day, when all 6 outlets are used to charge two laptops, three cells phones and a tablet with the total demand of 247Wh, the system could be sustainable for 2.6 hours. The system could provide sufficient energy to power the average worst-case load of 155W for 4.1 hours. For better sun days, the system is likely able to supply power for a longer time.

3) The system is expandable. The number of outlets can be easily increased. The energy storage capability can also be extended by simple addition of batteries. This will increase the energy storage capability to supply power during higher demand, help decrease the charging time for the connected devices, and lower power losses.

4) The system is proven to be compact, portable and versatile, thanks to the design of the weather-resistant frame and enclosure case. It could stand the unusually hot summer months of June and July 2018 in California while operating properly.

The charging station provides as an option to use the emission-free solar energy as a versatile and convenience power source for consumers. It can easily be transported and used in diverse locations, to bring benefits to the public while keeping the clean environment.

Appendix

Cost of components of prototype

Table 5 Cost of components

Product Number	Description	Quantity	Cost, US$
# GS-200-KIT	2 pieces of 100-W polycrystalline solar panels, a 35 Amp Xantrex charge controller, and 360-Watt Xantrex modified sine inverter with two outlets, cables and manual.	1	430.99
31DTMAGM	12V Duracell Deep Cycle Marine and RV Battery	1	169.45
#8,#10,#18,#20,#22	Wires Gauge	5	N/A
B01N0Y2BWZ	Guteauto 12V 3-way Leisure Battery Terminals Connectors Clamps	1	9.99
EL-CB-001	Arduino Uno	1	6.5
SYNCE016803	Arduino Uno Junction Box	1	10.49
EXPSFD005833	12V 2 Channel High / Low Level Trigger	1	8.59
B01N0Y2BWZ	3-way Leisure Battery Terminals Connectors	1	9.99
BAYITE-PZEM-101	LCD Display Digital Current Voltage Power Energy Meter Multimeter Ammeter Voltmeter with 100A Current Shunt	2	18.75
5007B-4.2GR	USB Charger Socket Power Outlet 2.1A	2	12.99
5031N-GR	USB Charger Socket Power Arduino	1	14.99
ED_YW05_R2R	LED RGB Diodes	2	2
OP-SL005	Solar Light	1	28.89
A0053	Solder Bread Board	1	3
7.23467E+11	Resistors		N/A
R52-01451-02W	Battery and Solar Switches	2	0.78
B118A	Non-Metallic Switch box	2	0.26
F20AL	25 A Fuse	1	1
SKFH104	Fuse Holder	1	5
Y2DCFAAZ	Electrical Connector Assortment	1	7
US2:Q120DF	20-Amp Afci/Gfci circuit breaker	1	42
MM420C	Horizontal or Vertical Weatherproof	2	8
55082103	Metallic Aluminum Flexible Conduit	20ft	N/A
IMD fabrications	Metal Frame	1	400
Miscellaneous	Paint, Wires, screws, other miscellaneous items	n/a	323
McMaster	Tamperproof Hex screws	1	18.65
	TOTAL		$1,532.3

Note: The actual total cost is approximately $1,700. There were some items whose costs were overlooked.

Specification of components

Table 6 Specification of solar panel

Characteristic	Details
Cell size	156mm x 104mm (6.14'' x 4.40'')
Module Dimension (L x W x T)	1020mm x 670mm x 35mm (40.16'' x 26.37'' x 1.38'')
No. of Cells	36
Weight	8.9 kg (19.66 lbs)
Cable Length	900mm for positive (+) and negative (-)
Type of Connector	MC-IV comparable
Junction Box	IP65 Rated
No. of Holes in Frame	4 installation holes
Electrical Specifications (STC = 25^{0}C, 1000W/m^2, Irradiance and AM=1.5)	
Max system voltage (IEC/UL)	1000V/600V
Maximum Power P_{max}	100 A (0%, +6%)
Cell type	Poly silicon
Voltage at Maximum Power Point V_{mpp}	18.0 V
Current at Maximum Power Point I_{mpp}	5.56 A
Open Circuit Voltage V_{oc}	21.9 V
Short Circuit Current I_{sc}	6.13 A
Module Efficiency (%)	14.63 %
Temperature Coefficient of V_{oc}	-0.32%/^{0}C
Temperature Coefficient of I_{sc}	+0.04%/^{0}C
Temperature Coefficient of P_{max}	-0.45%/^{0}C

Table 7 Specification of inverter

Characteristic	Details
AC output voltage (nominal)	120 V AC
DC input voltage range	10.5 – 15.5 V DC
Continuous AC output power	360 W
5 min. AC output power	450 W
Maximum AC output surge power	700 W
AC output frequency	60 $\pm$ 4 Hz
AC output waveform	Modified sine wave
Battery drain with no AC current load (at 12 V input)	0.25 A
Efficiency (maximum)	90%
Ambient operating temperature range	32 – 104^{0}F (0 – 40^{0}C)
Low battery alarm trigger point (nominal)	11.0 V
Low battery alarm shutdown point (nominal)	10.5 V
Overheat shutdown	Yes, automatic
High battery shutdown point (nominal)	15.5 V

Table 8 Specification of battery

<table>
<tr><th colspan="2">Battery type</th><th colspan="3">Bulk Volts</th><th colspan="3">Float Volts</th><th colspan="3">Equalizing charge</th></tr>
<tr><td colspan="2">AGM Lead Acid Battery</td><td colspan="3">14.4 V DC</td><td colspan="3">13.4 V DC</td><td colspan="3">Charge to 15.5 V DC or per manufacturer</td></tr>
<tr><td colspan="2">1 amp hour rate: 68.2</td><td colspan="6">Voltage: 12 V
Ampere-hours: 68.2 Ah
Watt-hours: ~ 818.4 watt-hours</td><td colspan="3"></td></tr>
<tr><td colspan="11">100 amp hour rate: 110; 20 amp hour rate: 105; 3 amp hour rate: 85; 5 amp hour rate: 86;
6 amp hour rate: 87.4; 8 amp hour rate: 90</td></tr>
<tr><td colspan="11">Battery Electrolyte Composition: Glass Mat</td></tr>
<tr><td colspan="11">Battery End Type: Top Post</td></tr>
<tr><td colspan="11">Battery Purpose: Starting Lighting Instrumentation</td></tr>
<tr><td colspan="11">BCI Group Size: 31</td></tr>
<tr><td colspan="11">CCA at 0 degrees F: 1000</td></tr>
<tr><td colspan="11">Minutes at 15 amps: 348; Minutes at 25 amps: 210; Minutes at 5 amps: 1265;
Minutes at 50 amps: 87.4; Minutes at 75 amps: 53; Minutes at 8 amps: 706;</td></tr>
<tr><th>Percent of charge</th><td>100</td><td>90</td><td>80</td><td>70</td><td>60</td><td>50</td><td>40</td><td>30</td><td>20</td><td>10</td></tr>
<tr><th>Open-Circuit 12 V</th><td>12.73</td><td>12.62</td><td>12.50</td><td>12.37</td><td>12.27</td><td>12.10</td><td>11.89</td><td>11.81</td><td>11.66</td><td>11.51</td></tr>
</table>

Table 9 Sun hours for selected cities in California [26]

State, City	Summer Avg.	Winter Avg.	Year Avg.
CA, Davis	6.09	3.31	5.10
CA, Fresno	6.19	3.42	5.38
CA, Inyokern	8.70	6.97	7.66
CA, La Jolla	5.24	4.29	4.77
CA, Los Angeles	6.14	5.03	5.62
CA, Riverside	6.35	5.35	5.87
CA, Santa Maria	6.52	5.42	5.94
CA, Soda Springs	6.47	4.40	5.60

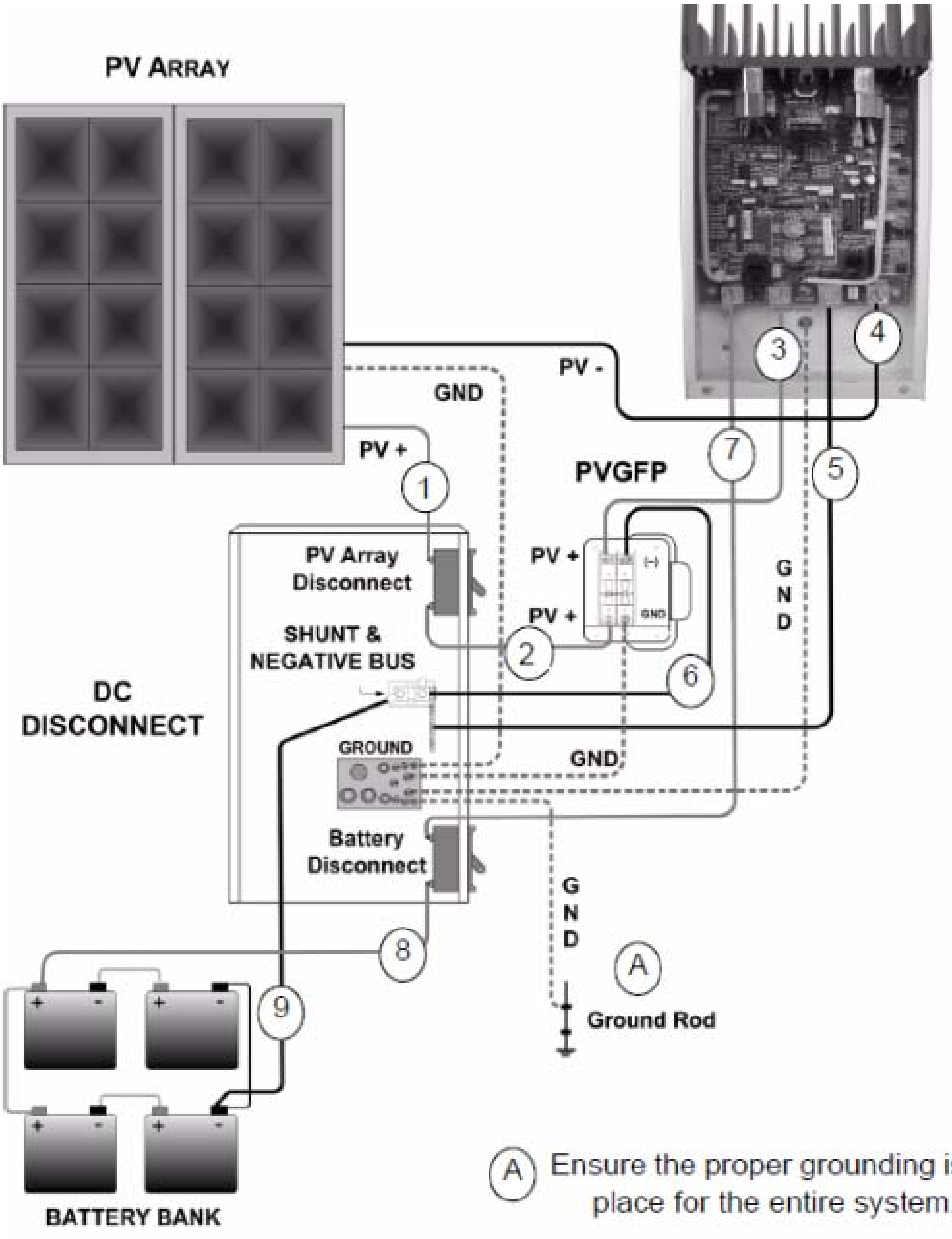

Fig. 7 Wiring diagram for solar PV system charge control mode
(Reprinted from Xantrex C-series Multifunction DC Controller Owner Manual)

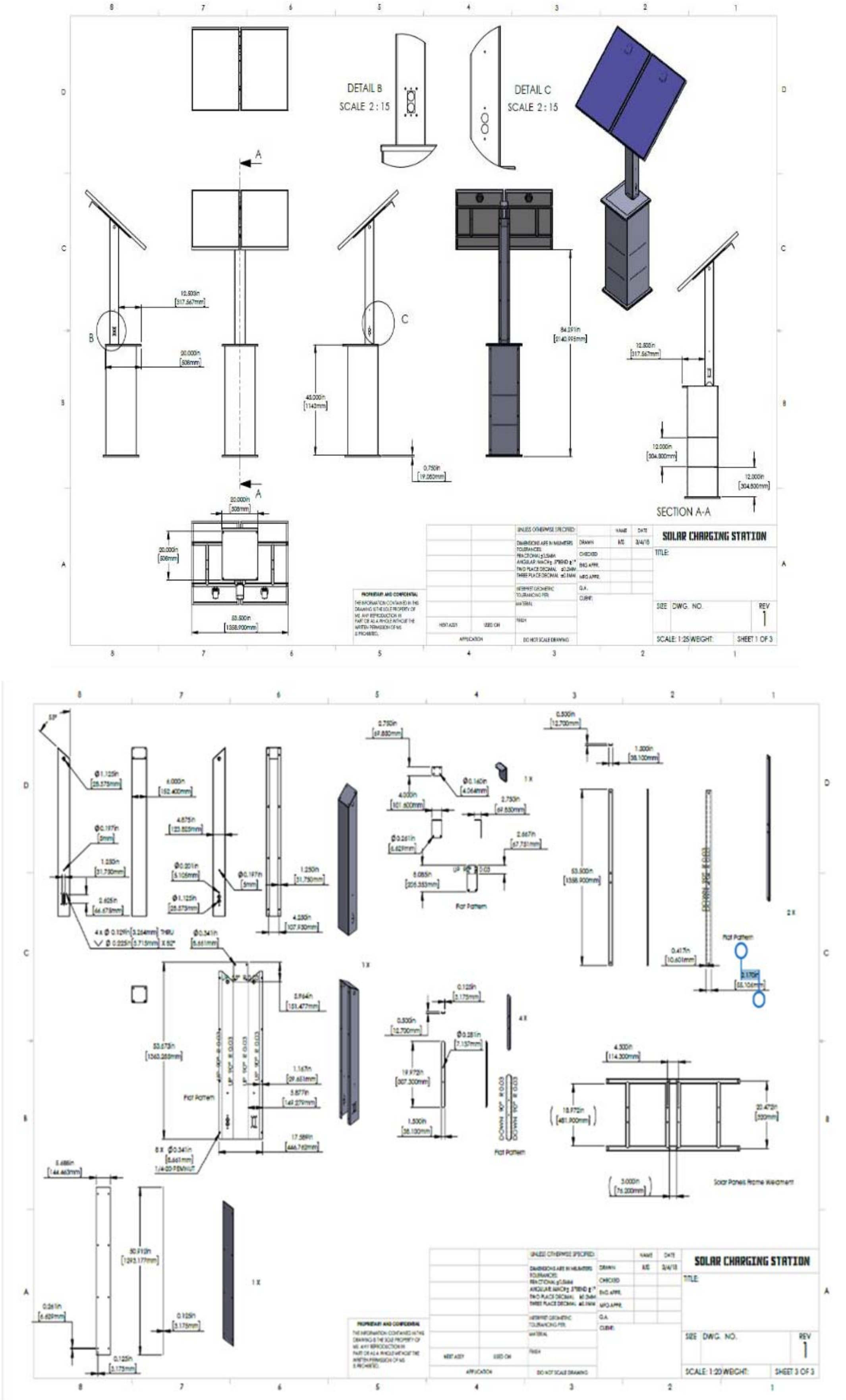

Fig. 8 Specification of frame and enclosure

Equations

$$P = 200W \times 5.5h = 1100Wh \quad (1)$$

The number of 5 people per stop on average is determined using data from the Los Angeles Metro.

p = total number of people who use LA Metro buses daily = 925 000 (average of 900k – 950k people daily)

n = number of busses that are in the field daily = 2438 buses

s = number of stops per bus per day = interval between each stop x bus hours of operation

$$Total\ stops = \frac{60\ minutes\ per\ hour}{15\ minutes\ per\ stop} \times 90\ hours\ of\ operation = 76\ stops \quad (2)$$

$$w = \frac{p}{n \times s} = \frac{925\ 000\ people}{2438\ buses \times 76\ stops} = 4.9922\ people \sim 5\ people \quad (3)$$

w = average number of people waiting at a bus stop

Average Worst Case Watt Hour load is calculated by using the range of Watt Hour (Wh) loading that could exist in the system if all charging outlets are used at the same time.

Minimum = (60Wh laptop charger × 1 AC port) + (10Wh USB charger × 4 DC ports) = 100Wh (4)

Maximum = (150Wh laptop charger × 1 AC port) + (15Wh USB charger × 4 DC ports) = 210Wh (5)

$$Average\ Worst\ Case = \frac{100\ Whr + 210\ Whr}{2} = 155\ Whr \quad (6)$$

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