Roadmap to a Grid-Tied PV Array

This material developed through the 2012 SEET Technology Workshop

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  Delaware Technical & Community College
- **Peter Parrish**
  College of the Canyons, California

Organization of Webinar

- System Design
  - Determine customer needs.
  - Perform site survey.
  - Document size and condition of service panel, and location of utility disconnect.
  - Develop detailed engineering plans: mechanical and electrical.
- The Permit Package
  - Assemble documentation package and submit permit application to Building and Safety / Fire Departments for review and approval.
  - Utility company performs “PV service spot” & issues their interconnection requirements.
- System Installation
- Post Installation
  - Approvals
    - Building and Safety
    - Utility company
- Instruction Ideas
- Next Steps...

Design Sequence

- Start with customer usage and tariffs (salesperson).
  - 12 months of history to average out seasonal variations
  - Determine the applicable rate: flat rate, seasonal rates (summer/winter), time-of-use rates, or tiers (the more you use, the more it costs!)
- Customer strategy and budget (salesperson)
  - Eliminate bill
  - If time-of-use, shift loads to base period and add solar to eliminate peak and shoulder usage.
  - If tiers, employ peak shaving.

Design Sequence (cont)

- Back-of-envelope estimates (salesperson)
  - 4.25 kWh/d/kWh
  - South-facing roof produces 10 W/sq. ft.
  - $6.00/W-dc
  - ~ 10 year payback, 6-8% Return on Investment (ROI)
- Prediction of system performance (with software)
- Google Earth & Bing/Zillow (salesperson)
  - Identify premium roof space
  - Preliminary layout
- Site survey (surveyor)
- Detailed design (engineer)

System Design

Case Study

- Customer wants to eliminate their electricity bill.
  - Energy usage: 6,600 kWh/yr (550 kWh/mo; 18.1 kWh/d)
  - Small home (2,000 sq. ft.)
- Design constraints
  - BP Solar BP175B modules
  - Inverter SMA SB4000US
- System simulation tools
  - PV WATTS2 or other software
  - Inverter string sizing: basically checking voltages
  - www.weather.com for record low & average high temperatures (needed for string sizing)

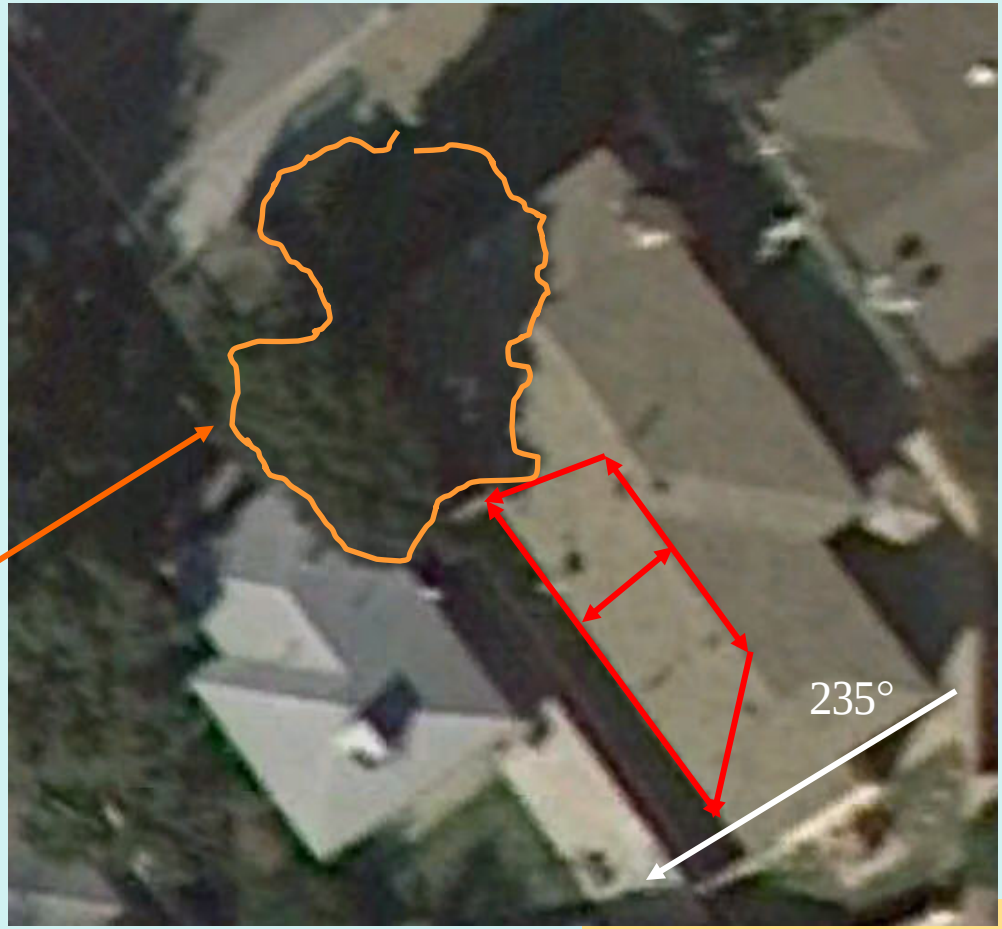
System Design

Site Survey Results

- Customer roof section
  - Roof pitch is 5:12
  - Azimuth 225 degrees (SW)
  - Some shading
  - Some minor roof damage (documented)
- Candidate system 4.3 kWdc
  - 24 ea BP-175B
  - 1 ea SMA SB4000US

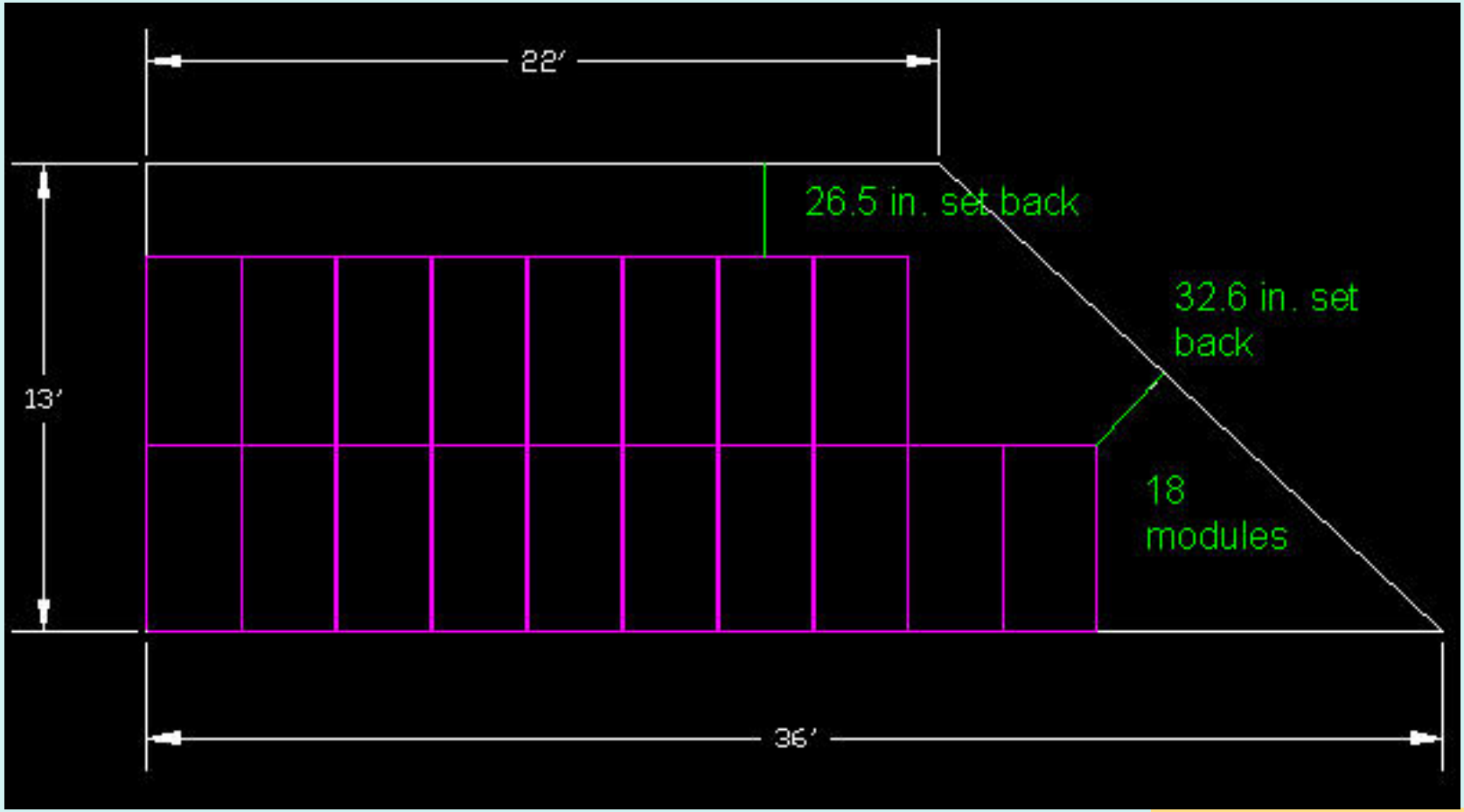
Physical Layout—Preliminary

- Google Earth
  - 13 ft. ridge to eaves
  - 22 ft. along ridge
  - 36 ft. along eaves
  - Orientation 235° true
- Bing / Zillow
  - Roof pitch 3:12 (14°)
- Preliminary layout
  - Look at obstructions.
  - Observe shading.
  - Calculate setbacks for fire dept.



System Design

Preliminary Layout



System Design

PVWatts2 Simulator

Site Location:

Cell ID:	0175361
State*:	California
Latitude*:	34.075
Longitude*:	-117.951

Roof space limitations reduce system to 18 modules or 3.15 kWdc

PV System Specifications:

DC Rating (kW):	3.15
DC to AC Derate Factor:	0.803 (Derate Factor Help)
Array Type:	Fixed Tilt

Fixed Tilt or 1-Axis Tracking System:

Array Tilt (degrees):	14 (Default = Latitude)
Array Azimuth (degrees):	235 (Default = True South) What's this?

Energy Data:

Cost of Electricity (cents/kWh):	13

http://mapserve3.nrel.gov/PVWatts_Viewer/index.html

System Design

PVWatts2 Simulator (cont)

Calculator for Overall DC to AC Derate Factor

Component Derate Factors	Component Derate Values	Range of Acceptable Values
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.96	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.97	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	0.98	0.00 - 1.00
Sun-tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC to AC derate factor	**0.803**	

http://mapserve3.nrel.gov/PVWatts_Viewer/index.html

System Design

PVWATTS2 Simulator

Station Identification	
Cell ID:	0175361
State:	California
Latitude:	34.1 ° N
Longitude:	118.0 ° W
PV System Specifications	
DC Rating:	
DC to AC Derate Facto	
AC Rating:	
Array Type:	Fixed Tilt
Array Tilt:	14.0 °
Array Azimuth:	235.0 °
Energy Specifications	
Cost of Electricity:	13.5 ¢/kWh

12.6 kWh/d / 3.15 kWdc = 4.0
Shading 98%, Soiling 97%, SW

Results			
Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	3.40	248	33.48
2	4.17	278	37.53
3	5.17	382	51.57
		430	58.05
		505	68.17
		526	71.01
7	7.43	518	69.93
8	6.97	487	65.75
9	5.94	403	54.41
10	4.70	336	45.36
11	3.82	266	35.91
12	3.13	226	30.51
Year	5.46	4604	621.54

8.0
9.9
12.3
14.3
16.8
17.5
16.7
15.7
13.4
10.8
8.9
7.3
12.6

http://mapserve3.nrel.gov/PVWatts_Viewer/index.html

System Design

SEC# 6018

CITY OF GLENDALE WATER & POWER
PHOTOVOLTAIC SERVICE SPOT

PV METER

JOB ADDRESS ______
PROJECT NUMBER 11874

–IF A REVISION OF THIS SPOT IS REQUESTED, A MIN. $65.00 FEE WILL APPLY
–SPOT IS VALID FOR TWO YEARS FROM DATE OF SPOT

SERVICE SPOT DATE 2-2-10
SERVICE SPOT BY GILBERT
OFFICE (818) 548-____ FAX (818) 240-4734

OWNER / ELEC / ARCH
PHONE # (818) ______
FAX # ______
OTHER # (323) 258-8883
SPOTTER'S NOTES CA SOLAR ENG'G

REQUIREMENTS:

1. SIGNED PHOTOVOLTAIC INTERCONNECTION AGREEMENT ON FILE WITH CUSTOMER SERVICE ELECTRIC ENGINEERING SECTION BEFORE BUILDING AND/OR ELECTRIC PERMITS ARE SIGNED AND SERVICE SPOT IS RELEASED TO CONTRACTOR OR HOMEOWNER.
2. METER SOCKET CLEARANCE TO SIDEWALLS / OBSTRUCTIONS: *10" MIN.*
3. SERVICE CONNECTION WILL NOT BE MADE UNTIL:
   a) APPLICATION FOR BUILDING AND/OR ELECTRICAL PERMIT(S) ARE SIGNED AT 141 NO. GLENDALE AVENUE, 4TH LEVEL, GLENDALE, CA 91206-4496. WATER & ELECTRICAL SERVICES COUNTER (818) 548-3921.
   b) OBTAIN ELECTRICAL PERMIT AT 633 E. BROADWAY, PERMIT SERVICES CENTER, ROOM 101, (818) 548-3200.
   c) LABEL SERVICE METER, SERVICE METER DISCONNECT, PV METER, & PV METER DISCONNECT PER BUILDING & SAFETY REQUIREMENTS.
   d) REQUEST A FINAL BUILDING & SAFETY INSPECTION BY CALLING (818) 548-4830.
   e) REQUEST A FINAL GWP CONSTRUCTION INSPECTION BY CALLING (818) 548-3920.
   f) AFTER GWP RECEIVES THE INSPECTION RELEASES FROM BUILDING & SAFETY INSPECTOR AND GWP CONSTRUCTION INSPECTOR, ALLOW 7 TO 10 WORKING DAYS FOR GWP TO INSTALL THE PHOTOVOLTAIC METER AND SEAL THE METER.

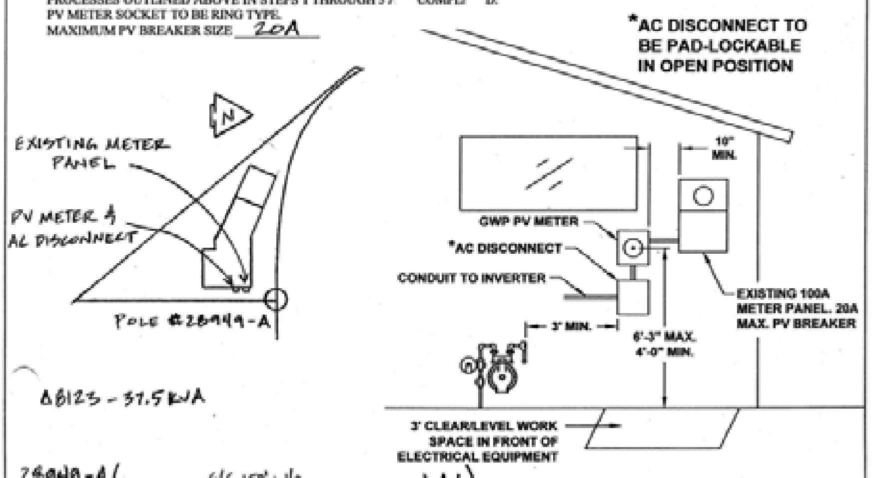
☒ CONTACT GWP CONSTRUCTION INSPECTOR (818) 548-3920, 48 HOURS IN ADVANCE FOR A PRECONSTRUCTION MEETING REGARDING: AC DISCONNECT AND GWP PV METER.

THE DISCONNECT OPERATING HANDLE IS TO BE NO HIGHER THAN 6'-7" FROM GRADE WHEN THE HANDLE IS IN THE HIGHEST POSITION.

THE PV SYSTEM SHOULD NOT BE ENERGIZED / ACTIVATED UNTIL PROCESSES OUTLINED ABOVE IN STEPS 1 THROUGH 3 ARE COMPLETED.

PV METER SOCKET TO BE RING TYPE.

MAXIMUM PV BREAKER SIZE 20A



☐ CUSTOMER ☐ METER SHOP ☐ BUILDING AND SAFETY ☐ CONST. INSPECTOR ☐ LOG IN ☐ APP'D 2-3-10 SHEET ___ OF ___

Detailed Financials—Flat Rate

- Price: $6/Wdc * 3,150 Wdc = $18,900
- Rebate (state or local): $4,725
- Contract for $14,175
- Federal tax credit: $4,253
- 1st year energy bill savings: $622
- Out-of-pocket at Year 1 = $9,300
- Break even at 11 years
- IRR = 6%

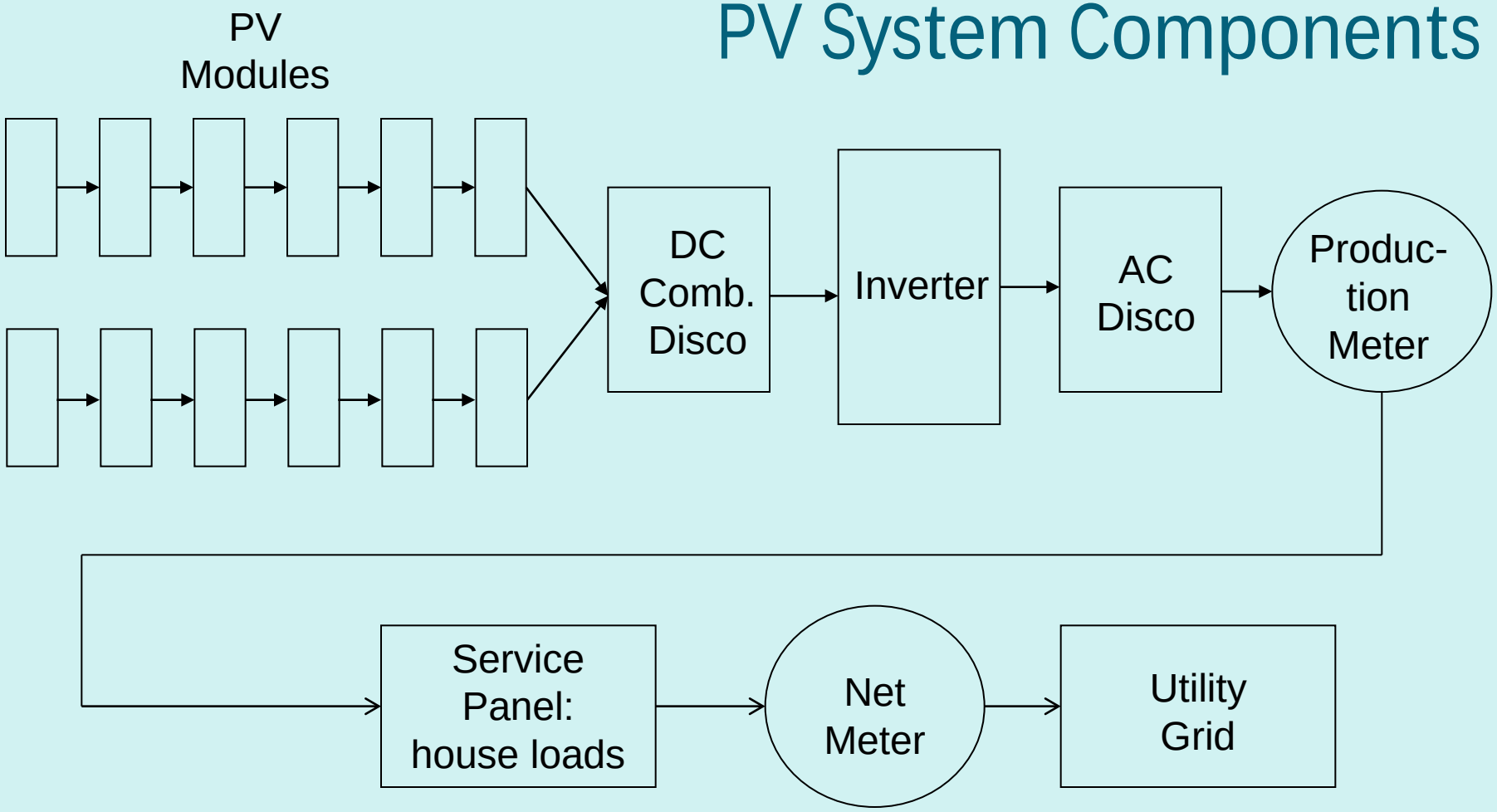
System Design

Physical Layout

- Starting from preliminary layout
  - Precise layout specifying exact location of anchors, rails and modules
  - Anchors must be located on rafters (16” spacing in most cases)
  - End module cannot cantilever more than 50% beyond last anchor
  - Minimize shading and avoid obstructions
- Bill of materials (racking hardware)
  - Anchors
  - Flashing
  - Rail (piece lengths) and possibly splices
  - Module brackets (center and end)

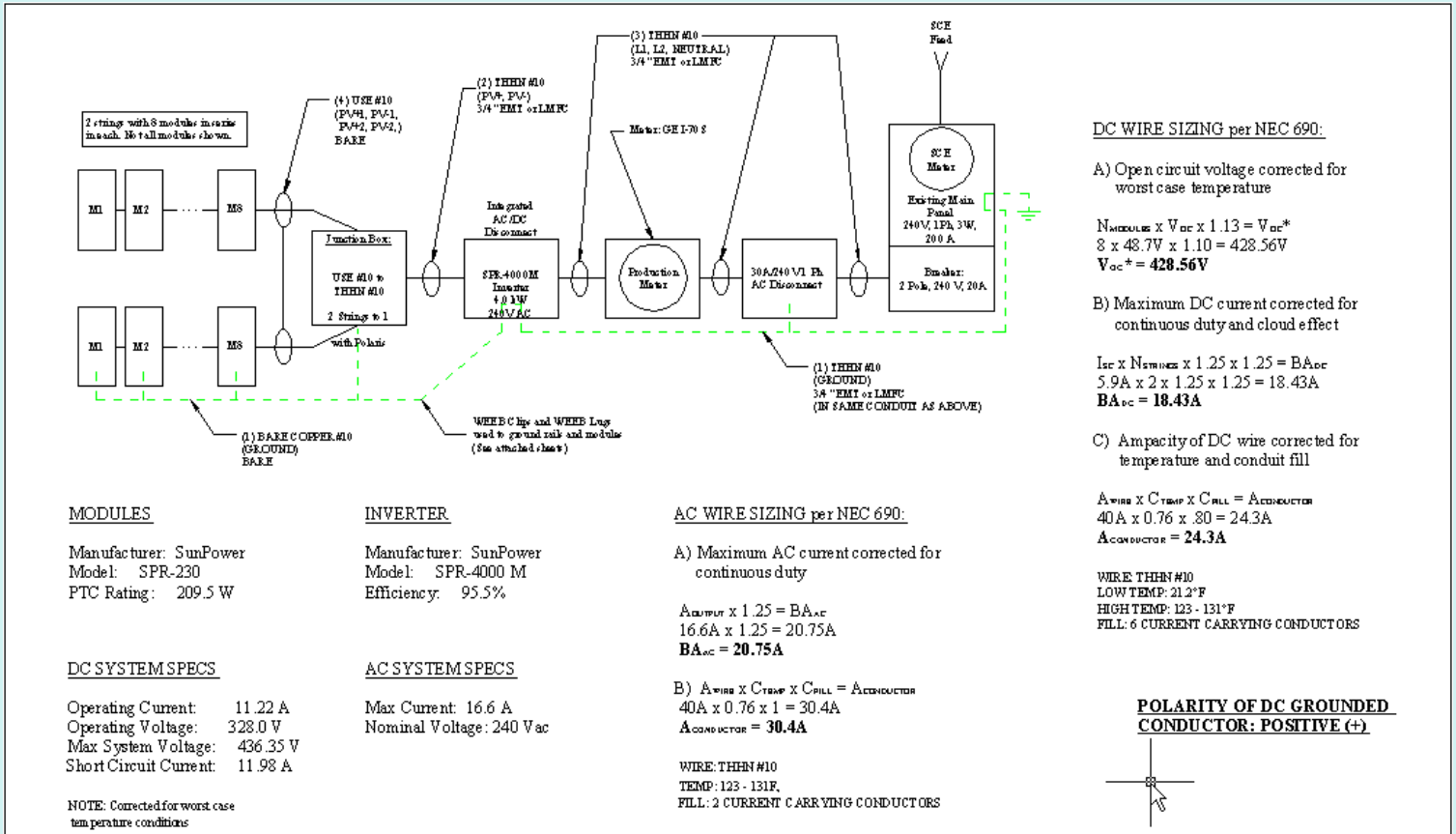
System Design

PV System Components



The Permit Package

Single Line Diagram



DC WIRE SIZING per NEC 690:

A) Open circuit voltage corrected for worst case temperature

$N_{MODULES} \times V_{OC} \times 1.13 = V_{OC}$*
8 x 48.7V x 1.10 = 428.56V
V_{OC}* = 428.56V

B) Maximum DC current corrected for continuous duty and cloud effect

$I_{SC} \times N_{STRINGS} \times 1.25 \times 1.25 = BA_{DC}$
5.9A x 2 x 1.25 x 1.25 = 18.43A
BA_{DC} = 18.43A

C) Ampacity of DC wire corrected for temperature and conduit fill

$A_{WIRE} \times C_{TEMP} \times C_{FILL} = A_{CONDUCTOR}$
40A x 0.76 x .80 = 24.3A
$A_{CONDUCTOR}$ = 24.3A

WIRE: THHN #10
LOW TEMP: 21.2°F
HIGH TEMP: 123 - 131°F
FILL: 6 CURRENT CARRYING CONDUCTORS

POLARITY OF DC GROUNDED CONDUCTOR: POSITIVE (+)

MODULES

Manufacturer: SunPower
Model: SPR-230
PTC Rating: 209.5 W

INVERTER

Manufacturer: SunPower
Model: SPR-4000 M
Efficiency: 95.5%

DC SYSTEM SPECS

Operating Current: 11.22 A
Operating Voltage: 328.0 V
Max System Voltage: 436.35 V
Short Circuit Current: 11.98 A

NOTE: Corrected for worst case temperature conditions

AC SYSTEM SPECS

Max Current: 16.6 A
Nominal Voltage: 240 Vac

AC WIRE SIZING per NEC 690:

A) Maximum AC current corrected for continuous duty

$A_{OUTPUT} \times 1.25 = BA_{AC}$
16.6A x 1.25 = 20.75A
BA_{AC} = 20.75A

B) $A_{WIRE} \times C_{TEMP} \times C_{FILL} = A_{CONDUCTOR}$
40A x 0.76 x 1 = 30.4A
$A_{CONDUCTOR}$ = 30.4A

WIRE: THHN #10
TEMP: 123 - 131F.
FILL: 2 CURRENT CARRYING CONDUCTORS

CUSTOMER: Elvez Presley 1123 Main St. Memphis, MS Phone:	APN: 5478-024-008 THIS DRAWING IS THE PROPERTY OF CALIFORNIA SOLAR ENGINEERING INC. AND CAN NOT BE USED, COPIED OR DISCLOSED WITHOUT PERMISSION	California Solar Engineering, Inc. 820 CYNTHIA AVE. LOS ANGELES, CA 90065 Phone: (323) 258-8883 Fax: (323) 258-8885 854779 C-46 2/28/11	PHOTOVOLTAIC SYSTEM Peter Parrish	ELECTRICAL SINGLE LINE PV-E1

The Permit Package

Electrical Calculations

- DC string sizing
  - Vmax = N * Voc (Trec-low) < 600 V-dc
  - Imax = Isc * 1.25 * 1.25
  - Select wire gauge and temperature rating.
    - Ampacity of wire corrected for temperature and conduit fill
    - Temperature of conduit exposed to sunlight on rooftops can be 14°C to 33 °C above ambient.
- AC wiring
  - Imax = Pmax/240 V
  - Ioutput = Imax * 1.25
  - Select wire gauge and temperature rating.
    - Ampacity of wire corrected for temperature and conduit fill
  - OCP device < Ioutput (Always round up.)

The Permit Package

BC 100166

Document ID: 145376

DR

Permit Number: BC 2010

Plan Check Number:

Printed On: 13-MAY-10

Expiration Date: 09-NOV-10

CITY OF GLENDALE - BUILDING AND SAFETY
633 E.Broadway, Rm.101
Glendale, CA 91206 - (818)548-3200 (818)548-4830(INSP)

91020
SFD-ALTERATION/REPAIR

Permit Status: OPEN
Status Date: 13-MAY-2010

Combination Bldg./Trade Permit

Scope of Work
PV SYSTEM INSTALLATION W/ELECTRIC

Individual's / Company Name	Address / City, State Zip	City, State Lic. / Worker's Comp.	Phone Number
(APP) California Soar Engineering	820 CYNTHIA AVE Los Angeles Ca 90065		
(OWN)	Glendale, Ca 91208		323-
(CNT)			
(SOL) California Soar Engineering In	820 Cynthia Ave Los Angeles, Ca 90065		323-258-8883

Tract Name / Number	Block(s)	Lot(s)	Assessor's ID
11306		06	5 00

Estimated Value: **Calculated Value:** $15,000

Permit Quantities	Qty Comments or Y / N	Permit Quantities	Qty Comments or Y / N

Comments

Fees	Amount	Fee Description	Amount
COMBINATION BUILDING/ALL	$265.18	GREEN BUILDING	$0.90
GREEN BUILDING ADMINISTRA	$0.10	MICROFILM	$43.26
PLANNING SURCHARGE	$17.77	TECHNOLOGY SURCHARGE	$18.03
		Total Fees:	$345.24
Total Fees Due:	$0.00	Total Fees Paid:	$345.24

Clearances Agencies

Activity Code	Status	By	Date		
BUILDING	DONE	TCHRISS	13-MAY-10	Signature:	Date:
BUILDING	OPEN			Signature:	Date:
FIRE	DONE	FMCLEAN	13-MAY-10	Signature:	Date:

Condition Code	Status	By	Date
WATER	DONE	GARTEAGA	13-MAY-2010

The person signing for this permit acknowledges that there are NO Oak, Bay or Sycamore Trees with trunks larger than an eight inch (8") diameter within a twenty foot (20 ft.) influence of the proposed construction.

At the time of final inspection, the inspector shall verify the installation of smoke detectors in all sleeping rooms and hallways leading thereto. Battery operated smoke detectors are acceptable in existing construction.

*** No rooftop equipment will be allowed unless the applicant obtains a separate variance or administrative exception from the Planning Division. Issuance of this permit shall not be construed as an approval to install equipment on the roof without a variance or administrative exception.

*** Issuance of trade permits, without complete architectural plans, shall not constitute a waiver of any provisions of the building or zoning codes of the City of Glendale. It is solely the responsibility of the applicant to verify that proposed installations are in compliance with the regulations of all applicable codes or else obtain written approval for any deviation from the regulations.

*** Upon completion of the work authorized by this permit, the permittee shall notify the Building Inspection office of such completion by requesting the Final inspection. Such request can be made by calling (818)548-4836. The permittee is hereby advised that they may be entitled to reimbursement of the permit fees if the city fails to conduct an inspection of the permitted work within 60 days of the request for final inspection.

***No construction is permitted before 7 a.m., nor after 7 p.m., Monday through Saturday. No construction is permitted on Sundays or on holidays. (Mun. Code Sec. 8.36.080)

The City of Glendale restricts issuance of the building permit to the property owner or licensed general contractor only. Signatures of this individual must be verified by personal identification. Any person signing the permit application as agent for the owner or contractor shall have an original letter of authorization at the time of permit issuance.

Applications shall expire 180 days after the date of submittal unless accepted by sec. 107.4 of the Glendale Building Code, and thereafter, any documents submitted to the department shall be returned to the applicant or destroyed by the building official. Upon written request from the applicant, the building official may extend the period of permit application.

System Installation

- Anchor and rail installation
- Module mounting
- Junction box installation
- Inverter installation
- Final completion of the array circuit

System Installation

Know how to use and put on your safety gear.

System Installation

Correctly install safety anchor points.

System Installation

Lay out chalk lines and measure for mounting bracket holes.

System Installation

Position modules in landscape mode with vertical rails.

System Installation

Install rails to anchors.

http://www.youtube.com/v/ir9c0zCbEF0

System Installation

Check for squareness by equating the diagonals.

System Installation

Position module junction box to facilitate wiring, attach ground wire, position module, and install end clamps.

http://www.youtube.com/v/0-FxFjtLE1E

System Installation

http://www.youtube.com/v/1poG-A-zQSI

System Installation

Install ground wire and second module.

http://www.youtube.com/v/rl-8_MF31A8

System Installation

Connect wires in the string.

http://www.youtube.com/v/E_C_-SBP4QU

System Installation

Install remaining modules.

System Installation

Connect PV wires to the Soladeck combiner/junction box that feeds through roof to attic space.

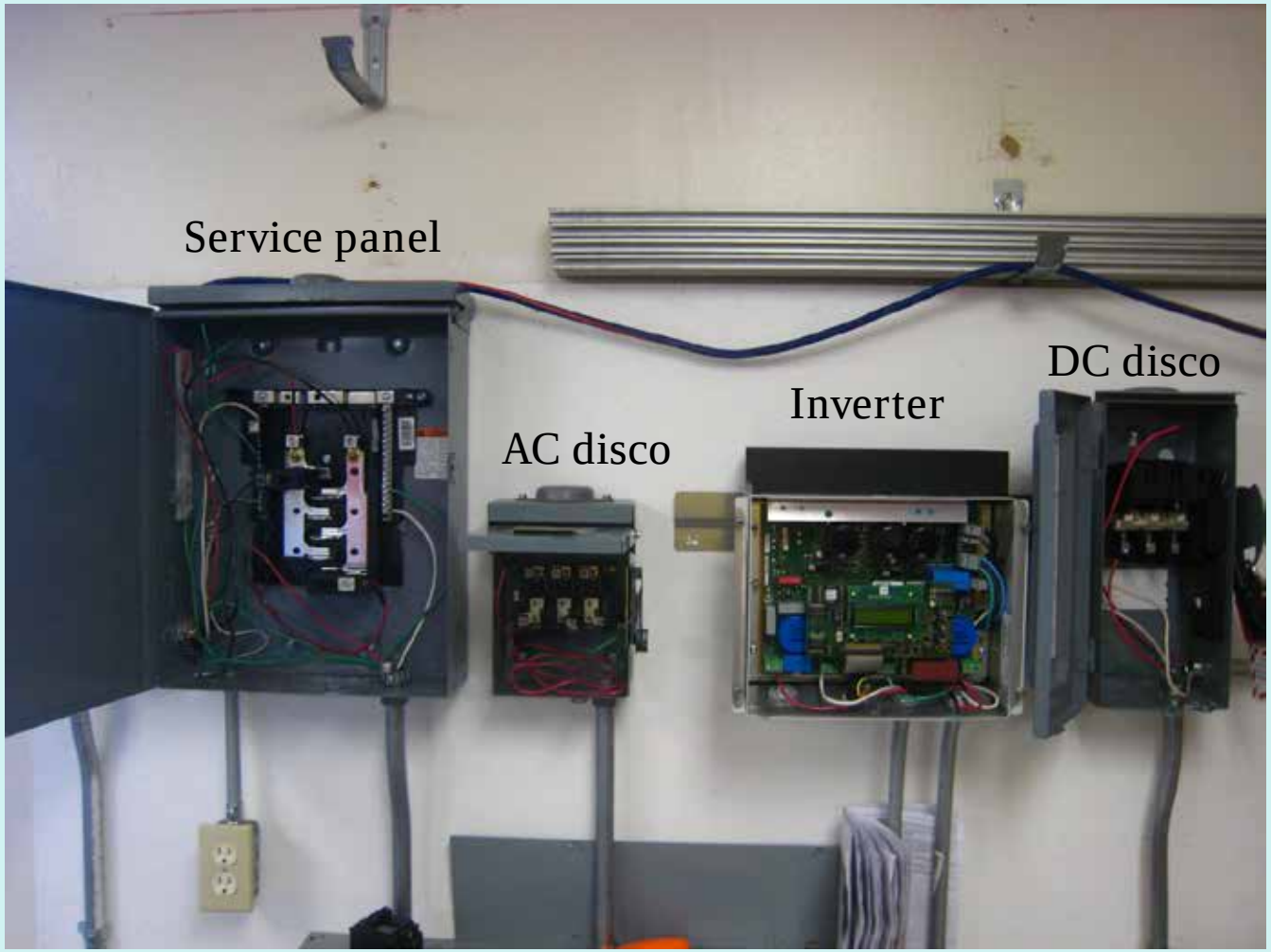
System Installation

The Soladeck enclosure

System Installation

Attach conduit from Soladeck on roof to junction box in attic.

System Installation

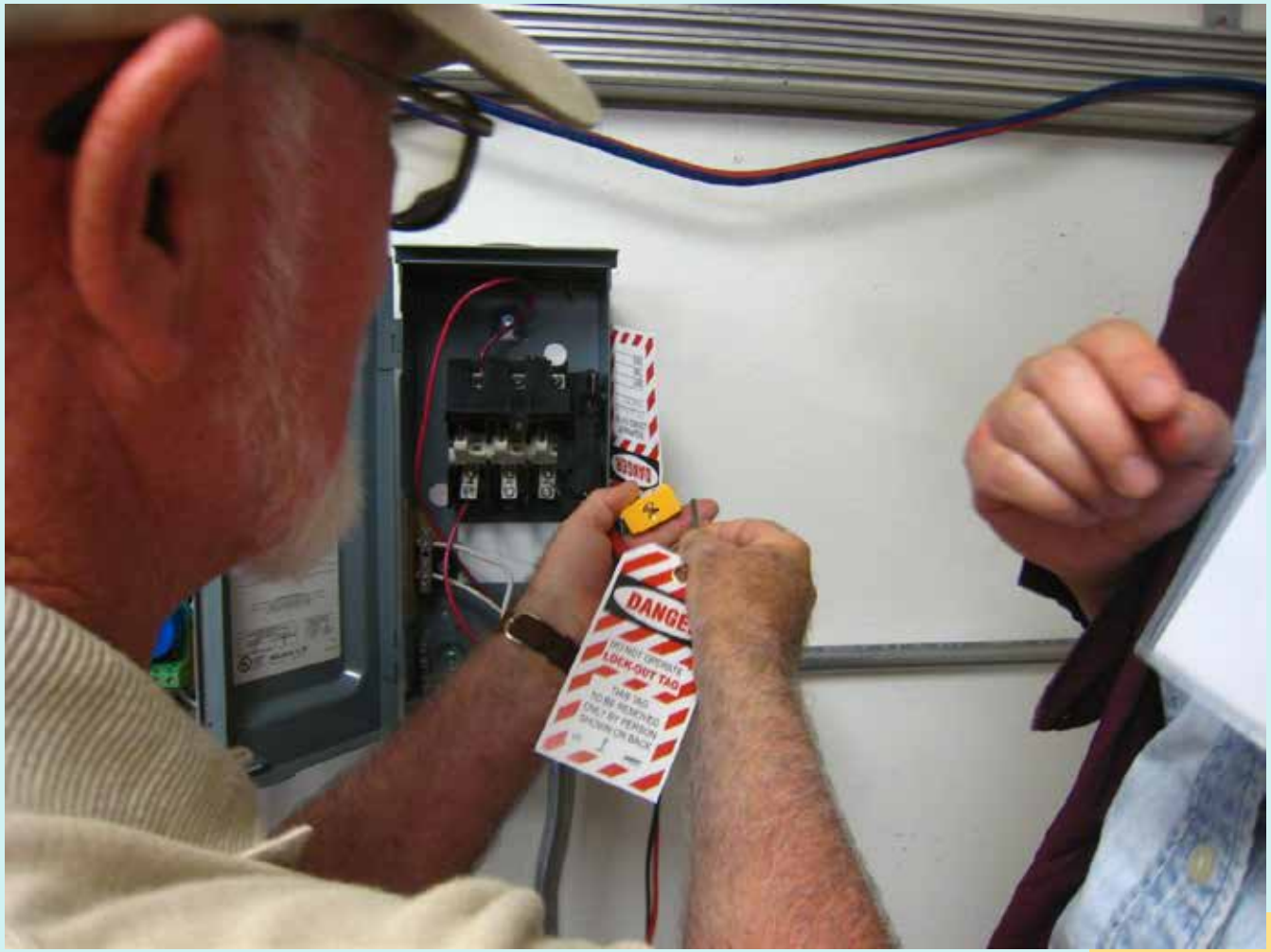


System Installation

Net meter

System Installation

DC disconnect with lockout/tagout



System Installation

Checking for array voltages and polarities

System Installation

Inverter is powered up and begins a 5-minute “countdown” before producing AC power.

Post Installation

- Commissioning & certification
- Inspections
  - Building and safety
  - Utility
- Owner's manual

System Certification

- Document system:
  - Date, time, ambient temp, irradiance
  - Lead installer
  - Person doing certification
- Specify manufacturer and model no.:
  - PV Module
  - Inverter
  - DC & AC disconnects
- Document:
  - DC measurements
  - Number of modules/string and number of strings
  - Open circuit string voltages (V+ to V-, V+ to gnd, V- to gnd)
  - String voltages under load
  - AC measurements
    - L1 – L2, L1 – neutral, L2 – neutral voltages
    - AC power and cumulative energy produced

Example of Certification Sheet

CALIFORNIA SOLAR ENGINEERING

California Solar Engineering, Inc. PV System Certification Sheet

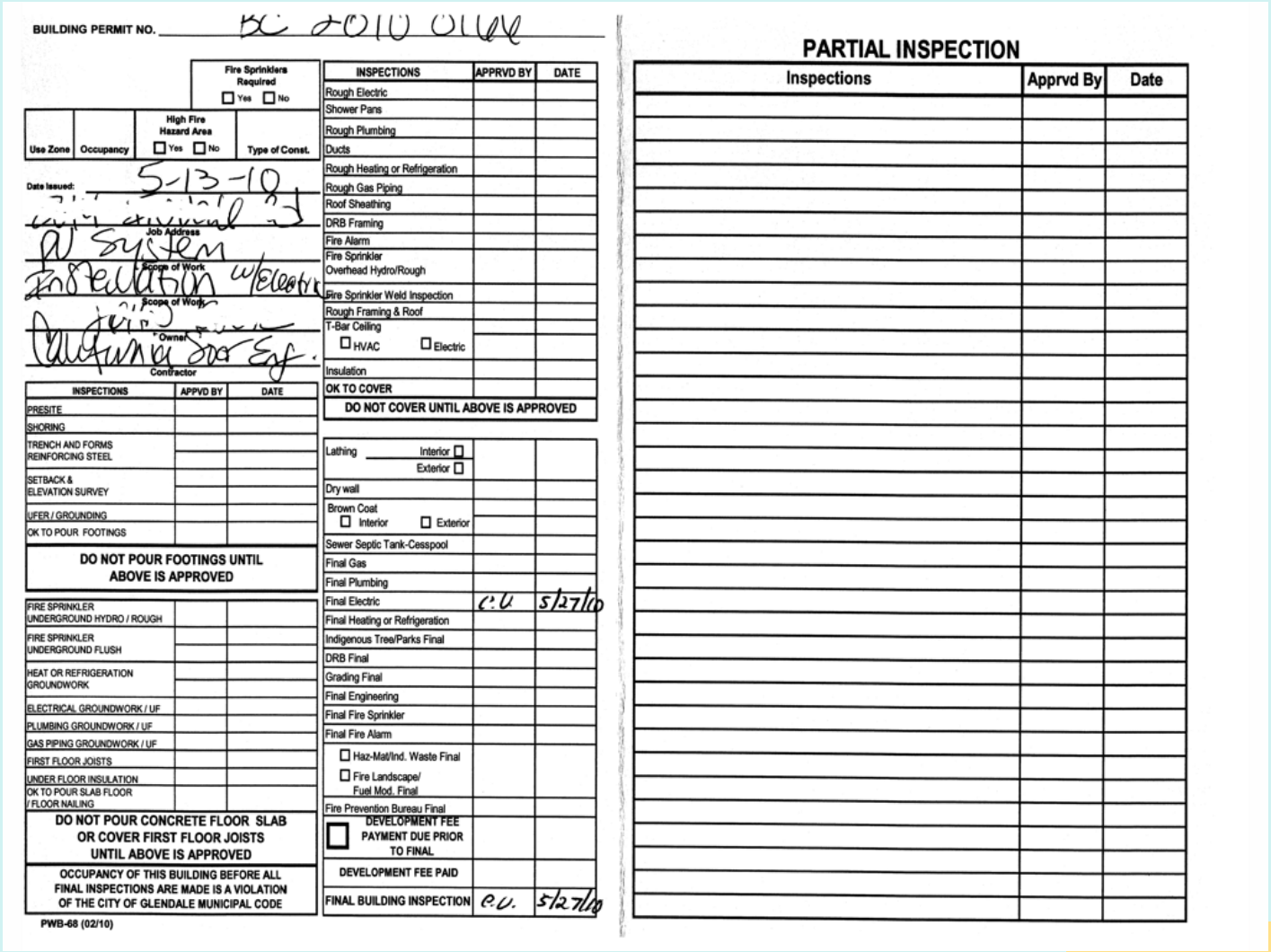
System Information					
Customer Name:			Date Certified:		
Address:			Certified By:		Lead Installer:
City/State/Zip:			DC Disconnect(s)		AC Disconnect
System Size in kW:			Size		Size
Modules Total #:	Make/Model:		Make		Make
Main Panel *PV Breaker* size:			Model#		Model#
Time:	Weather:		Temperature (estimate) °F:		

Inverter #	1	2	3	4	5
Inv. Make					
Inv. Model					
Inv. Ser #					
A/C Watts (Now)					

A/C Test Data					
Inverter #	1	2	3	4	5
VAC @ Inv (measured L1-L2)					
L1 V - Ground (measured)					
L2 V - Ground (measured)					

D/C Test Data (Voltmeter)										
String Number	1	2	3	4	5	6	7	8	9	10
Source Ct ID (if used)										
Inverter #										
Total# Modules										
Open Ct V (+/-)										
Volts (+) to Ground (actual reading)										
Volts (-) to Ground (actual reading)										

Inspection Card



BUILDING PERMIT NO. BC 2010 01666

Fire Sprinklers Required ☐ Yes ☐ No

Use Zone	Occupancy	High Fire Hazard Area ☐ Yes ☐ No	Type of Const.

Date Issued: 5-13-10

Job Address

Scope of Work: Fire Sprinkler System Installation w/Electric

Scope of Work

Owner

Contractor

INSPECTIONS	APPVD BY	DATE
PRESITE		
SHORING		
TRENCH AND FORMS REINFORCING STEEL		
SETBACK & ELEVATION SURVEY		
UFER / GROUNDING		
OK TO POUR FOOTINGS		

DO NOT POUR FOOTINGS UNTIL ABOVE IS APPROVED

FIRE SPRINKLER UNDERGROUND HYDRO / ROUGH		
FIRE SPRINKLER UNDERGROUND FLUSH		
HEAT OR REFRIGERATION GROUNDWORK		
ELECTRICAL GROUNDWORK / UF		
PLUMBING GROUNDWORK / UF		
GAS PIPING GROUNDWORK / UF		
FIRST FLOOR JOISTS		
UNDER FLOOR INSULATION		
OK TO POUR SLAB FLOOR / FLOOR NAILING		

DO NOT POUR CONCRETE FLOOR SLAB OR COVER FIRST FLOOR JOISTS UNTIL ABOVE IS APPROVED

OCCUPANCY OF THIS BUILDING BEFORE ALL FINAL INSPECTIONS ARE MADE IS A VIOLATION OF THE CITY OF GLENDALE MUNICIPAL CODE

PWB-68 (02/10)

INSPECTIONS	APPRVD BY	DATE
Rough Electric		
Shower Pans		
Rough Plumbing		
Ducts		
Rough Heating or Refrigeration		
Rough Gas Piping		
Roof Sheathing		
DRB Framing		
Fire Alarm		
Fire Sprinkler Overhead Hydro/Rough		
Fire Sprinkler Weld Inspection		
Rough Framing & Roof		
T-Bar Ceiling ☐ HVAC ☐ Electric		
Insulation		
OK TO COVER		

DO NOT COVER UNTIL ABOVE IS APPROVED

Lathing Interior ☐ Exterior ☐		
Dry wall		
Brown Coat ☐ Interior ☐ Exterior		
Sewer Septic Tank-Cesspool		
Final Gas		
Final Plumbing		
Final Electric	C.U.	5/27/10
Final Heating or Refrigeration		
Indigenous Tree/Parks Final		
DRB Final		
Grading Final		
Final Engineering		
Final Fire Sprinkler		
Final Fire Alarm		
☐ Haz-Mat/Ind. Waste Final ☐ Fire Landscape/ Fuel Mod. Final		
Fire Prevention Bureau Final		
☐ DEVELOPMENT FEE PAYMENT DUE PRIOR TO FINAL		
DEVELOPMENT FEE PAID		
FINAL BUILDING INSPECTION	C.U.	5/27/10

PARTIAL INSPECTION

Inspections	Apprvd By	Date

Applicable Codes

- NEC 2011
- NFPA 70
- IRC or IBC
- California State Fire Marshal: Solar Photovoltaic Installation Guideline; “Final Draft”; April 22, 2008
- Contact your state, and county/city authorities for additional rules and procedures.

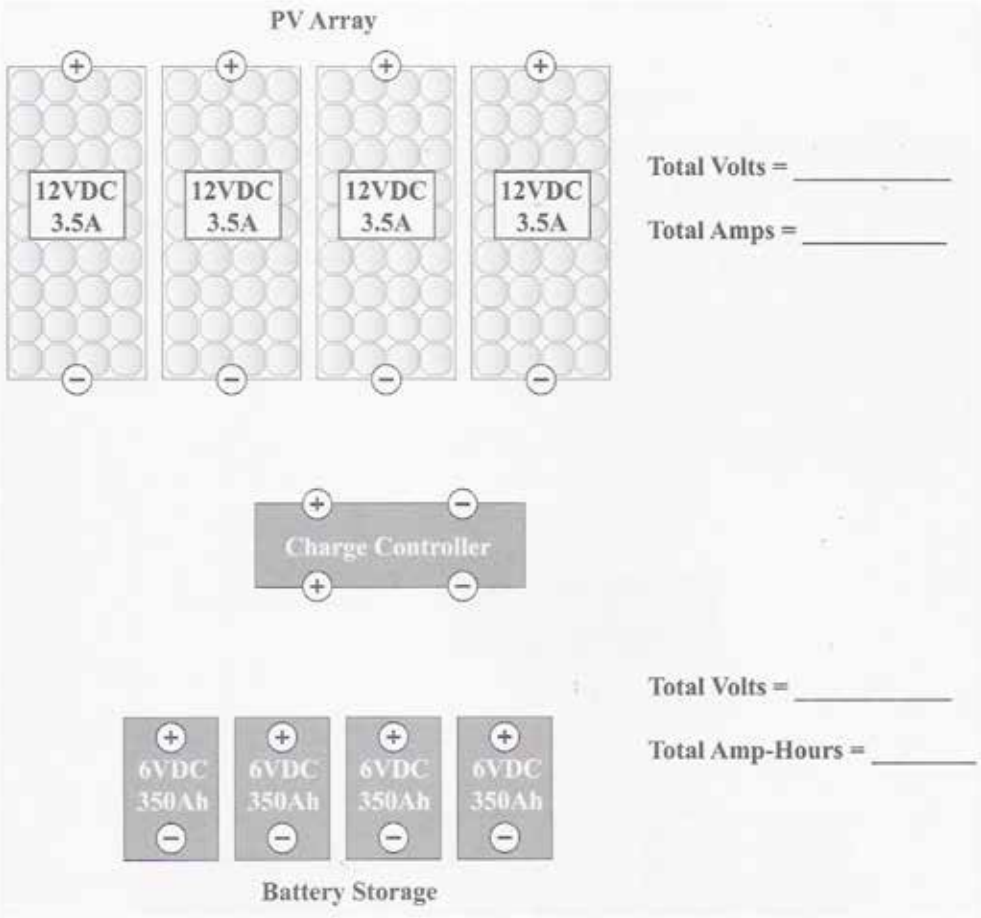
Instruction Ideas

Photo Credit: In Shik Lee

Instruction Ideas

SEET 2012 Workshop
Basic Solar Photovoltaic System Design

EXERCISE A:
Using the resources provided below, show appropriate connections to design a 12V system with battery back up. Provide totals as specified.



Instruction Ideas

Photo Credit: In Shik Lee

Next Steps...

References

- Dunlop, J.P., Photovoltaic Systems, 2nd ed., ATP Press
- Holt, M., Understanding NEC Requirements for Solar Photovoltaic Systems, 1st ed., Mike Holt Enterprises Inc.
- Solar Energy International, Solar Electric Handbook: Photovoltaic Fundamentals and Applications, 2nd ed., New Society Publishers
- www.SolarDepot.com
- www.WholesaleSolar.com

For more information on the SEET Energy Webinar Series, please contact Melonee at ATEEC

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