SOLAR READY VETS®
U.S. DEPARTMENT OF ENERGY

Solar Curriculum Design and Activities

The SOLAR FOUNDATION™

Powered by SunShot
U.S. Department of Energy

August 2017

This material is based upon work supported by the Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), under Award Number DE-EE0007320.

Contributors to this material include Penn State University, Solar Energy International, Tidewater Community College, Interstate Renewable Energy Council, North American Board of Certified Energy Practitioners, Fayetteville Technical Community College, Pikes Peak Community College, Salt Lake Community College, The State University of New York Canton, Savannah Technical Community College.

SOLAR READY VETS CURRICULUM DESIGN

INTRODUCTION: The solar energy industry is experiencing significant growth and holds promise as a sound career direction for individuals across multiple types of fields and professional backgrounds. The U.S. Armed forces offers a steady source of talented individuals with vast array of leadership experience and disciplines that offer an excellent source of talent that could serve the solar industry.

THE PURPOSE of the Solar Ready Veteran (SRV) Program is: To: prepare veterans across all divisions of the armed services for transition into the solar industry in a way that jointly serves veterans and the solar industry so that mutually benefits veterans seeking meaningful employment and solar industry members seeking to expand and improve their professional workforce.

PROGRAM DESIGN: The 5-week SRV program includes four sets of program learning goals aligned around (1) the ***NABCEP Entry Level*** body of knowledge; (2) ***gaining hands-on experience*** with solar system site analysis, design, installation, commissioning, operation, maintenance and financial considerations; (3) ***Safety*** issues unique to solar + OSHA 30; (4) ***Transition*** planning and individual support of entry into the solar industry. These goals, and the learning objectives associate with each, are pursued in parallel during the course.

COURSE OBJECTIVES: Upon completion of this course, participants will be:

- Knowledgeable of fundamental photovoltaic systems concepts and learning objectives defined in the North American Board of Certified Energy Practitioners (NABCEP).
- Experienced in core processes of solar PV projects including basic site analysis, system design, system assembly, commissioning, inspection, maintenance, and financial analysis,
- Familiar with the solar industry organization, career paths, and job opportunities that leverage their unique skills, traits, and interests.
- Certified as completing OSHA 30 Safety training

COURSE MATERIALS: Course materials include handouts to support note taking during class presentations and activities, online materials and resources, and the course textbook: "***Photovoltaic Systems***", 3rd Edition by James Dunlap.

HANDS-ON LEARNING EXPERIENCES AND LABS: The SRV program provides hands on experience using actual PV systems. Four sets of equipment are required for select activities including site analysis, electrical measurement devices and systems for assembly (grid tied/grounded, micro inverter, battery systems. At least one permanent system with monitoring data should also be accessible to students, and one nearby utility scale system (preferably on base) is suggested for case study and site visit purposes.

SUCCESSFUL COMPLETION: Participants will be evaluated based upon:

- Participation in daily course activities and required content
- Completion of daily quizzes and a mid-term examination
- Demonstration of career planning, resume, and interview skills
- Completion of NABCEP Entry Level Exam

COURSE CONTENT: The Solar Ready Vets program is designed to be offered in an intensive 5-week format to a cohort of participants. Four curriculum blocks are included which align with overall course objectives and are summarized below:

BLOCK 1: Technical PV Fundamentals (NABCEP Entry Level Exam + Expanded SRV LO's): Provide participants with working understanding of PV technology, systems configuration, and solar resource assessment. This course block provides industry recognized credential indicating basic vocabulary and knowledge of PV fundamentals, and participation in a formal learning process.

Topic	Approx. Hours
PV Block 1: PV Market and Applications: Objectives include defining PV system types (PV direct, stand-alone and grid-tied and battery back-up systems), key features and benefits of different PV system, variability of Residential, commercial and utility scale PV systems, centralized vs decentralized power systems, relationship between energy conservation and efficiency	2.5 Hour
PV Block 2: Safety: Objectives include recognition of hazards unique to solar projects and ability to conduct site-specific hazard analysis.	4 Hour
PV Block 3: Electricity Basics: Objectives include basic knowledge of electrical theory as it applies to PV systems including Current, voltage and resistance, OHMS Law, function and purpose of common electrical devices and equipment, basic electrical testing tools, Utility systems structure	4 Hour
PV Block 4: Solar Energy Fundamentals: Objectives include basic knowledge necessary to determine the best means of maximizing the amount of solar power available at a given site	4.5 Hour
PV Block 5: PV Module Fundamentals: Objectives include ability to describe the design, manufacturing and operation of PV modules, module types, construction, IV curves, and calculation of temperature impacts, efficiency, power density, and understanding of performance ratings, standards.	3 Hour
PV Block 6: PV System Components: Objectives include describe the design and operation of the major components including PV modules, inverters, charger controllers, chargers, load centers, batteries.	9 Hour
PV Block 7: PV System Sizing Principles: Objective is to teach students how to size PV systems (grid-tied and standalone)	6 Hour
PV Block 8: PV System Electrical Design: Objectives is to enable students to do simple designs of PV systems according to the most basic requirements of the NEC	6 Hour
PV Block 9: PV System Mechanical Design: Objective is to provide students with an overview of PV mounting systems including roof types and construction and mounting systems	7 Hour
PV Block 10: Performance Analysis, Maintenance, and Troubleshooting: Objective is to understand processes required for evaluating performance and the management of inspection, commissioning, operation, and maintenance.	7 Hour
PV Block XX: Operations and Maintenance: Understand the economic drivers for the implementation of an O&M Program, identify modes of failure, discuss the set-up, documentation, calculations, and tools used in an O&M program	6 Hour
PV Block 11: Marketing, Sales, and Business Development: Objective include familiarization with solar project development processes and markets, sales methods, and structure of solar industry organizations.	4 Hour

Topic	Approx. Hours
PV Block 12: Financial Analysis Methods and Tools: Objective is to be familiar with the role of financial analysis in solar project development and to be experiences with the use of basic solar financial analysis tools.	4 Hour
PV Block 13: Basic math refreshers: Objective is ability to perform fundamental mathematical functions needed in PV system design and evaluation.	3 Hour
PV Block 14: NABCEP Exam Review and Completion: Objective is to prepare for online participation of NABCEP Entry-level examination	8 Hour

BLOCK 2: Hands-on PV Systems Design, Construction, Operations, and Maintenance Activities: Provide hands-on experience with PV system components, site assessment, and system diagnostics. This course block reinforces systems understanding and introduces processes used by solar professionals for installation, operation, and maintenance.

Block Description	Approx. Hours
Hands on Activity 1: Site survey and analysis: Objectives include Identify factors to consider when choosing array locations, including shading, accessibility, structural concerns, and existing electrical equipment.	4 Hour
Hands-on Activity 2: Module characterization: Includes Measure **of** PV module output and IV curve and experience using electrical testing equipment to evaluate PV module performance	3 Hour
Hands-on Activity 3: System components: Familiar with major PV system components, name plate characteristic, including PV modules and arrays, inverters and chargers, charge controllers, energy storage and other sources.	1 Hour
Hands-on Activity 4: PV System exploration: Examine an existing system or systems and the specific technical features of the inverter and modules. Identify the maximum and minimum string size for the paired module and inverter.	2 Hour
Hands on Activity 5: System Assembly and Building Integration: Includes assembly of multiple types of PV systems, inverters, and racking from system orientation, assembly, grid interconnection.	8 Hour
Hands-on Activity 6: Commissioning: Includes the procedures to systematically evaluate the performance of a PV system to ensure proper operation.	4 Hour
Hands-on Activity 7: System Design: String Inverter Matching: Includes determine the maximum and minimum number of modules that may be used in source circuits and the total number of source circuits that may be used with a specified inverter	2 Hour
Hands-on Activity 8: PV system operations and maintenance: includes an overview of O&M services, typical activities and measurements, the design of an O&M plan, and practice performing O&M activities on an existing system operating in proximity to the class location	2 Hour
Hands-on Activity 10: PV system financial analysis: includes experience using financial analysis tools to evaluate feasibility of solar and support sales and how incentives can encourage investment in PV	4 Hour
Hands-on Activity 11: Case Study and Field Trip: includes an examination of a utility scale installation nearby, including development process, sitework, construction, performance, and operations/ maintenance. Project details and documentation are reviewed and coordinated with a site visit.	4 Hour

BLOCK 3: PV System Safety and OSHA 30: Provide a comprehensive overview of construction safety with an emphasis on electrical construction. This course block provides industry recognized credential and perquisite to advanced safety credentials needed on solar construction projects.

Block Description	Approx. Hours
PV Safety OSHA 30 Part 1: Introduction to OSHA, Contractor's Safety and Health Program Reporting and Record Keeping	7.5 Hour
PV Safety OSHA 30 Part 2: Electrical Hazards, Fall Protection, Materials Handling	7.5 Hour
PV Safety OSHA 30 Part 3: Cranes and Rigging, Motorized Mobile Platforms, The Competent Person	7.5 Hour
PV Safety OSHA 30 Part 4: Excavations, Work Zone Traffic Control, Forklift Hazards	7.5 Hour

BLOCK 4: Transition Solar: Provide an understanding of the solar industry organization, market growth, and professional development pathways Support the identification of entry points and career trajectories that are aligned with the unique skills and interests.

Block Description	Approx. Hours
Transition Solar Block 1 - Skype Sessions with Veteran in Industry: Objectives include: Describe the perspective of veterans and their transition out of the military into the solar industry	8 Hour
Transition Solar Block 2 - Solar resume design and strategy: Objectives include Represent individual backgrounds, skills, and education in a solar industry-focused resume and professional development plan. Author career objectives customized to specific job and career opportunities	6 Hour
Transition Solar Block 3 - Solar Career Mapping: Objectives include: Gain experience using resources that are designed to help identify entry points and pathways in solar design, construction, manufacturing, and project development. Gain experience in the use of career and job placement tools and services targeting veterans. Gain experience in the self-assessment of core values and contributions. Gain experience with solar Foundation workforce research	4 Hour
Transition Solar Block 4 - Solar industry organizations and professional associations: Objectives include Gain experience in the evaluation of solar companies, industry organizations, NGO's and respective markets, strategies, and growth trajectories, and Human Resource needs	2 Hour
Transition Solar Block 5 - Using the Post 9-11 GI Bill to enter the Solar Industry: Objectives include Understand and apply for the post 9-11 GI Bill and the pathways it supports.	1 Hour
Transition Solar Block 6 - Interview Skill and Job Search: Objectives include Confidently participate in both informal and formal interview settings. Develop ability to communicate personal strengths and aspirations, understand methods to follow up with opportunities.	4 Hour

COURSE DELIVERY AND ORGANIZATION: Each week of the SRV program is designed to support the concurrent achievement of the four course objectives and learning blocks. It is expected that the day to day content of this 5-week program may vary slightly based on instructor preferences. A summary of the major milestones and objectives for each week of the SRV program is described below:

WEEK 1

BLOCK 1 - Technical Fundamentals: The goal of this week is to introduce students to the foundation concepts in which PV systems are deployed, and the electrical characteristics and cost trends of PV modules and installed $/kwH. In week 1, participants gain a fundamental understanding of solar energy and the solar industry.

BLOCK 2 - Hands-on: Activities in this week compliment classroom learning and include visiting a rooftop PV system, preview of lab equipment that will be used in the course, and experimentation with basic electrical measuring devices and module performance.

BLOCK 3 - Safety: Students are introduced to electrical hazards associated with *PV systems and sites* complete 7.5 hours of OSHA 30 training

BLOCK 4 - Transition: Students are familiarized with the solar industry and resources that support job placement. The design of a solar-specific resume is initiated.

WEEK 2

BLOCK 1 - Technical Fundamentals: The goal of week 2 is to familiarize students with the components of PV systems including inverters, modules, and balance of systems. The translation of modules into arrays, and the calculations of associated electrical output are also included. ***Week 2 builds directly off the understanding of PV module output from week 1***

BLOCK 2 - Hands-on: Week 2 activities are centered upon providing experiences with all types of PV system components through the inspection of components and preparatory activities leading to the assembly of multiple types of PV systems including grounded and ungrounded inverters, micro inverters, and off-grid systems.

BLOCK 3 - Safety: Students are introduced to electrical hazards associated with *PV systems components* and complete 7.5 hours of OSHA 30 training

BLOCK 4 - Transition: Students interact with veterans who work in the solar industry and explore their unique strengths and passions that need to be communicated through resumes and interviews.

WEEK 3

BLOCK 1 - Technical Fundamentals: The goal of week 3 is to provide participants with design concepts and codes / regulations that apply to the PV industry, as well the financial considerations, sales, and marketing that apply to the design of PV systems. ***Week 3 builds off the familiarity of system components provided in week 2.***

BLOCK 2 - Hands-on: Week 3 activities are centered upon gaining experience with design procedures including string inverter matching, conductor sizing while working with actual systems. Commissioning procedures and activities are also practiced. Instructional systems built be students and existing systems at location are used as context.

BLOCK 3 - Safety: Students are introduced to electrical hazards associated with PV system *construction* and complete 7.5 hours of OSHA 30 training

BLOCK 4 - Transition: Students are familiarized with Post 911 GI Bill and complete the development of resume and career planning.

WEEK 4

BLOCK 1 - Technical Fundamentals: The goal of week 4 is to provide students with experience evaluating the performance of PV systems, and to gain an understanding of operations, and maintenance services of PV systems. Additionally, Marketing sales, and O&M services are presented. ***Week 4 builds upon both the knowledge of PV system components in week 2, and the design experiences in week 3.***

BLOCK 2 - Hands-on: Week 4 activities focus on the diagnostic procedures needed to evaluate the installation and operation of PV systems against performance goals as well as compliance with codes. Typical operations and maintenance procedures are practiced on instructional equipment.

BLOCK 3 - Safety: Students are introduced to electrical hazards associated with PV systems *commissioning and inspection*, and complete 7.5 hours of OSHA 30 training

BLOCK 4 - Transition: Students evaluate various types of companies in the solar industry including background research in preparation for interviews.

WEEK 5

BLOCK 1 - Technical Fundamentals: The goal of week 5 is to facilitate the *synthesis of the course topics into a systems-understanding of solar energy technology and markets* reinforced with a case study and site visit to a significant PV installation as well as review and administration of the NABCEP ELE exam.

BLOCK 2 - Hands-on: Week 5 activities include the evaluation of a large-scale PV project design, construction, and performance, and a site visit to the system.

BLOCK 3 - Safety: Students review fundamental PV systems safety per block 2 of the NABCEP Entry Level body of Knowledge

BLOCK 4 - Transition: Students gain experience meeting with and discussing career and job opportunities in the solar industry.

Example Curriculum Outline

Day	AM Topic	PM Topic	Resources
1	Kick-off / Entry processing	Block 1 – PV Markets and Applications	Text, online materials
2	Block 3 – Electricity Basics / Tour of solar array	Block 4 – Solar Energy Fundamentals Part 1	Text, online materials
3	Block 4 – Solar Energy Fundamentals Part 2	**Activity:** Site survey and analysis	Text, online materials
4	Block 5 - PV Module Fundamentals	**Activity:** PV module characterization	Text, online materials
5	OSHA 30	OSHA 30	Text, online materials
6	Block 7 – PV System Components	Block 7 – PV System Components	Text, online materials
7	Block 7 – PV System Components	**Activity:** PV System components exploration	Text, online materials
8	Mid Term Review	Mid Term Exam	Text, online materials
9	Solar Career Resources research	Solar resume development	Text, online materials
10	OSHA 30	OSHA 30	Text, online materials
11	Block 9 – PV System Mechanical Design	**Activity**: PV System Assembly	Text, online materials
12	**Activity**: PV System Assembly (Cont.)	**Activity:** Commissioning, Trouble Shooting	Text, online materials
13	Block 8 – PV Electrical Design	**Activity**: String inverter matching	Text, online materials
14	Block 10 – Permitting and Inspection	**Activity:** Inspection procedures (rooftop systems)	Text, online materials
15	OSHA 30	OSHA 30	Text, online materials
16	Block 10: Trouble Shooting, Operations, and Maintenance	**Activity**: Operations, and Maintenance (rooftop systems)	Text, online materials
17	**Activity**: Field trip to PV site		
18	Block 11: PV System customer, sales, marketing, and development	Block 11: PV System customer, sales, marketing, and development (cont.)	Text, online materials
19	Block 12: PV System Financial Analysis	**Activity:** Financial Analysis tools	Text, online materials

Day	AM Topic	PM Topic	Resources
20	OSHA 30	OSHA 30	Text, online materials
21	Practice exam	Exam review	
22	Exam review	NABCEP ELE Exam (online format)	
23	Company Research	Interview Skills	Text, online materials
24	Meetings with Solar Companies	Interviews	
25	Interviews / final course evaluation discussion	Completion / Graduation	

Curriculum Content

Four set of resources are included that can be adopted fully or on an a-la-carte basis depending on the level of existing materials and expertise at a given delivery location. These resources include:

1) **Curriculum Design** including description, learning objectives, resources, and assessment methods used for the four sets of learning blocks.
2) **PowerPoint presentations** adopted from Jim Dunlap's instructor resource guide and organized into individual presentations aligned with Block 1 Technical content.
3) **Resources** including articles, websites, example documents, and reference manuals.
4) **Online quizzes** aligned with each Block 1 topic and formatted to emulate NABCEP Entry-level exam topics and questions. Questions for quizzes, mid-term, and practice exam are drawn from a central database of 120 questions.
5) **Online content and learning modules**: Alternative content and activities that can be utilized as alternative to lecture content. Includes online materials, videos, and additional resources.

Contents

Technical Block 1: PV Markets and Applications

DESCRIPTION

Provide the students with an overview of the PV market and applications. Key concepts are:

- PV system definition (PV direct, stand-alone and grid-tied and battery back-up systems)
- Key features and benefits of different PV systems
- Residential, commercial and utility scale PV systems
- Centralized vs decentralized power systems
- Energy conservation and efficiency

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Identify key contributions to the development of PV technology.
2. Identify common types of PV system applications for both stand-alone and utility interactive systems with and without energy storage.
3. Associate key features and benefits of specific types of PV systems, including residential, commercial, BIPV, concentrating PV, and utility-scale.
4. List the advantages and disadvantages of PV systems compared to alternative electricity generation sources.
5. Describe the features and benefits of PV systems that operate independently of the electric utility grid.
6. Describe the features and benefits of PV systems that are interconnected to and operate in parallel with the electric utility grid.
7. Describe the roles of various segments of the PV industry and how they interact with one other.
8. Understand market indicators, value propositions, and opportunities for both grid-tied and stand-alone PV system applications.
9. Discuss the importance of conservation and energy efficiency as they relate to PV system applications.

RESOURCES:

- Dunlop, Jim. "Photovoltaic Systems." Chapter 1 – Introduction to Photovoltaic Systems
- Solar Energy International, "Solar Electric Handbook." Unit 1 – Overview of Renewable Energy and the Solar Industry
- Penn State online course "Photovoltaic System Design and Construction." Unit 1.1 – Introduction and Application of PV Systems
- SunShot Identity Video: http://energy.gov/eere/sunshot/about
- Energy 101: Solar PV: http://energy.gov/eere/videos/energy-101-solar-pv
- Solar Professional magazine: http://solarprofessional.com/
- "Three Perspectives on the Solar Industry" https://www.youtube.com/watch?v=q2_OKGm_TOE

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 3: Electricity Basics

DESCRIPTION:

Provide students with a basic knowledge of electrical theory as it applies to PV systems. Key concepts include:

- Current, voltage and resistance
- Ohm's Law
- The function and purpose of common electrical devices and equipment
- The ability to understand and use basic electrical testing tools
- Utility systems structure (generation, transmission, distribution and delivery)

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Understand the meaning of basic electrical parameters including electrical charge, current, voltage, power and resistance, and relate these parameters to their hydraulic analogies (volume, flow, pressure, hydraulic power and friction).
2. Explain the difference between electrical power (rate of work performed) and energy (total work performed).
3. Describe the function and purpose of common electrical system components, including conductors, conduits/raceways and enclosures, overcurrent devices, diodes and rectifiers, switchgear, transformers, terminals and connectors, grounding equipment, resistors, inductors, capacitors, etc.
4. Identify basic electrical test equipment and its purpose, including voltmeters, ammeters, ohmmeters and watt-hour meters.
5. Demonstrate the ability to apply Ohm's Law in analyzing simple electrical circuits, and to calculate voltage, current, resistance or power given any other two parameters.
6. Understand the fundamentals of electric utility system operations, including generation, transmission, distribution, and typical electrical service supplies to buildings and facilities.

RESOURCES:

- Solar Energy International, "Solar Electric Handbook." Chapter 3 – Basics of Electricity
- Penn State online course "Photovoltaic System Design and Construction." Unit 1.3, Module 1 – Review of Electrical Concepts
- The Khan Academy – Electricity and Magnetism: https://www.khanacademy.org/science/physics/electricity-magnetism

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 4: Solar Energy Fundamentals

DESCRIPTION:

Provide students with the basic knowledge necessary to determine the best means of maximizing the amount of solar power available at a given site. Key concepts include:

- Basic solar energy terminology
- Solar radiation (spectrum and direct, diffuse and albedo)
- Measurement of available solar power
- Earth's movement around the sun
- Longitude, latitude, magnetic declination
- Solar vs local time
- Peak sun hours
- Impact of tilt angle, orientation and shading on solar energy production
- Site assessment practices and tools

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Define basic terminology, including solar radiation, solar irradiance, solar irradiation, solar insolation, solar constant, air mass, ecliptic plane, equatorial plane, pyranometer, solar declination, solstice, equinox, solar time, solar altitude angle, solar azimuth angle, solar window, array tilt angle, array azimuth angle, and solar incidence angle.
2. Diagram the sun's apparent movement across the sky over any given day and over an entire year at any given latitude, and define the solar window.
3. For given dates, times and locations, identify the sun's position using sun path diagrams, and determine when direct solar radiation strikes the north, east, south and west walls and horizontal surfaces of a building.
4. Differentiate between solar irradiance (power), solar irradiation (energy), and understand the meaning of the terms peak sun, peak sun hours, and insolation.
5. Identify factors that reduce or enhance the amount of solar energy collected by a PV array.
6. Demonstrate the use of a standard compass and determine true geographic south from magnetic south at any location given a magnetic declination map.
7. Quantify the effects of changing orientation (azimuth and tilt angle) on the amount of solar energy received on an array surface at any given location using solar energy databases and computer software tools.
8. Understand the consequences of array shading and best practices for minimizing shading and preserving array output.
9. Demonstrate the use of equipment and software tools to evaluate solar window obstructions and shading at given locations, and quantify the reduction in solar energy received.
10. Identify rules of thumb and spacing distances required to avoid inter-row shading from adjacent sawtooth rack mounted arrays at specified locations between 9 am and 3 pm solar time throughout the year.

11. Define the concepts of global, direct, diffuse and albedo solar radiation, and the effects on flat-plate and concentrating solar collectors.
12. Identity the instruments and procedures for measuring solar power and solar energy.

RESOURCES:

- Dunlop, Jim. “Photovoltaic Systems.” Chapter 2 – Solar Radiation; Chapter 3 – Site Surveys and Preplanning.
- Solar Energy International, “Solar Electric Handbook.” Chapter 8 – Solar Site Analysis
- Penn State online course “Photovoltaic System Design and Construction.” Unit 1.2, Solar Radiation; Unit 2.1 – Array Positioning and Site Evaluation

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 5: PV Module Fundamentals

DESCRIPTION:

Describe the design, manufacturing and operation of PV modules. Key concepts include:

- PV module types (mono/poly crystalline, amorphous, CIGS, CdTe, etc.)
- PV module construction
- IV curves
- Impact of irradiance and temperature on module performance
- Module efficiency / Power density
- Similar modules in series and parallel
- Dissimilar modules in series and parallel
- Performance ratings (STC, SOC, NOCT and PTC)
- PV module standards and testing
- Bypass diodes

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Explain how a solar cell converts sunlight into electrical power.
2. Distinguish between PV cells, modules, panels and arrays.
3. Identify the five key electrical output parameters for PV modules using manufacturers' literature (Voc, Isc, Vmp, Imp and Pmp), and label these points on a current-voltage (I-V) curve.
4. Understand the effects of varying incident solar irradiance and cell temperature on PV module electrical output, illustrate the results on an I-V curve, and indicate changes in current, voltage and power.
5. Determine the operating point on a given I-V curve given the electrical load.
6. Explain why PV modules make excellent battery chargers based on their I-V characteristics.
7. Understand the effects of connecting similar and dissimilar PV modules in series and in parallel on electrical output, and diagram the resulting I-V curves.
8. Define various performance rating and measurement conditions for PV modules and arrays, including STC, SOC, NOCT, and PTC.
9. Compare the fabrication of solar cells from various manufacturing processes.
10. Describe the components and the construction for a typical flat-plate PV module made from crystalline silicon solar cells, and compare to thin-film modules.
11. Given the surface area, incident solar irradiance and electrical power output for a PV cell, module or array, calculate the efficiency and determine the power output per unit area.
12. Discuss the significance and consequences of PV modules being limited current sources.
13. Explain the purpose and operation of bypass diodes.
14. Identify the standards and design qualification testing that help ensure the safety and reliability of PV modules.

RESOURCES:

- Dunlop, Jim. "Photovoltaic Systems." Chapter 4 – System Components and Configurations; Chapter 5 – Cells, Modules, and Arrays.
- Solar Energy International, "Solar Electric Handbook." Chapter 4 – Components; Unit 3 – Modules, Series and Parallel, and Meters
- Penn State online course "Photovoltaic System Design and Construction." Unit 1.3, PV Cells, Modules, and Arrays
- "Exploring a Solar Module": https://www.youtube.com/watch?v=xQTmUv6_uMg

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 6: System Components

DESCRIPTION:

Describe the design and operation of the major components in both grid-tied and standalone PV systems. Also, to examine how these components can be combined in different combinations to create different types of PV systems. Key concepts include:

- Major components – PV modules, inverters, charger controllers, chargers, load centers, batteries
- BOS equipment – Combiner/junction boxes, disconnects, raceways/conductors and overcurrent protection devices
- Inverters
- Battery types and charging cycles
- Battery capacity factors (ampacity, days of autonomy, temp. compensation, DOD/SOC)

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Describe the purpose and principles of operation for major PV system components, including PV modules and arrays, inverters and chargers, charge controllers, energy storage and other sources.
2. List the types of PV system balance of system components, and describe their functions and specifications, including conductors, conduit and raceway systems, overcurrent protection, switchgear, junction and combiner boxes, terminations and connectors.
3. Identify the primary types, functions, features, specifications, settings and performance indicators associated with PV system power processing equipment, including inverters, chargers, charge controllers, and maximum power point trackers.
4. Understand the basic types of PV systems, their major subsystems and components, and the electrical and mechanical BOS components required.

RESOURCES:

- Dunlop, Jim. “Photovoltaic Systems.” Chapter 4 – System Components and Configurations; Chapter 6 – Batteries; Chapter 7 – Charge Controllers; Chapter 8 – Inverters.
- Solar Energy International, “Solar Electric Handbook.” Chapter 4 – Components
- Penn State online course “Photovoltaic System Design and Construction.” Unit 3.1, Introduction to the NEC and PV System Components
- “Exploring Low and High Frequency Inverters”: https://www.youtube.com/watch?v=iMHBw93W-XM

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 7: PV System Sizing Principles

DESCRIPTION:

Students learn how to size PV systems (grid-tied and standalone). Key concepts include:

- String and inverter matching for grid tied PV systems
- Voltage temperature correction calculations
- Electrical loads (Startup and running power, energy consumption, duty cycles)
- Standalone PV systems (Manual calculations, critical design months, matching PV array size to loads, determining battery requirements)

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Understand the basic principles, rationale and strategies for sizing stand-alone PV systems versus utility-interactive PV systems.
2. Given the power usage and time of use for various electrical loads, determine the peak power demand and energy consumption over a given period of time.
3. Beginning with PV module DC nameplate output, list the de-rating factors and other system losses, and their typical values, and calculate the resulting effect on AC power and energy production, using simplified calculations, and online software tools including PVWATTS.
4. For a specified PV module and inverter in a simple utility-interactive system, determine the maximum and minimum number of modules that may be used in source circuits and the total number of source circuits that may be used with a specified inverter, depending upon the expected range of operating temperatures, the inverter voltage windows for array maximum power point tracking and operation, using both simple calculations and inverter manufacturers' online string sizing software tools.
5. Given a stand-alone application with a defined electrical load and available solar energy resource, along with PV module specifications, size and configure the PV array, battery subsystem, and other equipment as required, to meet the electrical load during the critical design period.

RESOURCES:

- Dunlop, Jim. "Photovoltaic Systems." Chapter 9 – System Sizing.
- Solar Energy International, "Solar Electric Handbook." Unit 5 – Grid-Direct System Sizing; Unit 8 – Battery Based Systems
- Penn State online course "Photovoltaic System Design and Construction." Unit 4.1- Grid-Tied Systems without Batteries; Unit 4.2 – Off-Grid Systems; Unit 4.3 – Emergency PV systems and Grid-Connected PV Systems with Batteries.

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 8: PV System Electrical Design

DESCRIPTION:

To enable students to do simple designs of PV systems according to the most basic requirements of the NEC. Key concepts include:

- Basic knowledge of Article 690, Solar Photovoltaic Systems in the National Electrical Code
- PV equipment selection and specifications (PV modules, inverters, charge controllers, combiner/junction boxes, disconnects and overcurrent protection)
- Preparation of simple one-line electrical diagrams
- Putting modules in series (Max voltage and inverter DC voltage limits)
- Putting modules series in parallel (building PV array size)
- Review of voltage temperature correction calculations
- NEC ampacity calculations (max current, conductor derating factors)
- Conductor types and applications
- Voltage drop calculations
- Project documentation, permitting, etc.

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Draw and prepare simple one-line electrical diagrams for interactive and standalone PV systems showing all major components and subsystems, and indicate the locations of the PV source and output circuits, inverter input and output circuits, charge controller and battery circuits, as applicable, and mark the directions of power flows through the system under various load conditions.
2. Understand how PV modules are configured in series and parallel to build voltage, current and power output for interfacing with inverters, charge controllers, batteries and other equipment.
3. Identify basic properties of electrical conductors including materials, size, voltage ratings and insulation coverings and understand how conditions of use, such as location, other conductors in the same conduit/raceway, terminations, temperature and other factors affect their ampacity, resistance and corresponding overcurrent protection requirements.
4. Understand the importance of nameplate specifications on PV modules, inverters and other equipment on determining allowable system voltage limits, and for the selection and sizing of conductors, overcurrent protection devices, disconnect means, wiring methods and in establishing appropriate and safe interfaces with other equipment and electrical systems.
5. Determine the requirements for charge control in battery-based PV systems, based on system voltages, current and charge rates.
6. Identify the labeling requirements for electrical equipment in PV systems, including on PV modules, inverters, disconnects, at points of interconnection to other electrical systems, on battery banks, etc.

7. Understand the basic principles of PV system grounding, the differences between grounded conductors, grounding conductors, grounding electrode conductors, the purposes of equipment grounding, PV array ground-fault protection, and the importance of single-point grounding.
8. Apply Ohm's Law and conductor properties to calculate voltage drop for simple PV source circuits.
9. Identify the requirements for plan review, permitting, inspections, construction contracts and other matters associated with approvals and code-compliance for PV systems.
10. Demonstrate knowledge of key articles of the National Electrical Code, including Article 690, Solar Photovoltaic Systems.

RESOURCES:

- Dunlop, Jim. "Photovoltaic Systems." Chapter 9 – System Sizing; Chapter 10 – Electrical Integration; Chapter 12 – Utility Interconnection.
- Solar Energy International, "Solar Electric Handbook." Unit 6 – Grounding, Wiring, and Overcurrent Protection.
- Penn State online course "Photovoltaic System Design and Construction." Unit 3.2 – Electrical Integration and Code Compliance; 4.1- Grid-Tied Systems without Batteries; Unit 4.2 – Off-Grid Systems; Unit 4.3 – Emergency PV systems and Grid-Connected PV Systems with Batteries.
- "Solar PV Inspection Walkthrough" video series: https://www.youtube.com/watch?v=APrbl0Ngp8o&index=1&list=PLa8_mvXW28yLqZjgEidnbEjBFgD1mFIl9

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 9: PV System Mechanical Design

DESCRIPTION:

Provide students with an overview of PV mounting systems. Key concepts include:

- Intro to roof types and construction
- Description of different mounting systems (fixed flush, ballasted, attached, ground mount, trackers and BIPV)
- Pros and cons of different mounting systems
- Intro to design loads (live, dead, wind, snow, seismic)
- PV array layout considerations
- Geotechnical issues
- Fire safety requirements
- Rack manufacturer installation instructions

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Identify the common ways PV arrays are mechanically secured and installed on the ground, to building rooftops or other structures, including rack mounts, ballasted systems, pole mounts, integral, direct and stand-off roof mounts, sun tracking mounts and for other building-integrated applications.
2. Compare and contrast the features and benefits of different PV array mounting systems and practices, including their design and materials, standardization and appearance, applications and installation requirements, thermal and energy performance, safety and reliability, accessibility and maintenance, costs and other factors.
3. Understand the effects on PV cell operating temperature of environmental conditions, including incident solar radiation levels, ambient temperature, wind speed and direction for various PV array mounting methods.
4. List various building-integrated PV (BIPV) applications and compare and contrast their features and benefits with conventional PV array designs.
5. Identify desirable material properties for weathersealing materials, hardware and fasteners, electrical enclosures, wiring systems and other equipment, such as UV, sunlight and corrosion resistance, wet/outdoor approvals and other service ratings appropriate for the intended application, environment and conditions of use, and having longevity consistent with the operating life expectancies of PV systems.
6. Understand the requirements for roofing systems expertise, and identify the preferred structural attachments and weathersealing methods for PV arrays affixed to different types of roof compositions and coverings.
7. Identify the types and magnitudes of mechanical loads experienced by PV modules, arrays and their support structures, including dead loads, live loads, wind loads, snow loads, seismic loads, in established combinations according to ASCE 7-05 Minimum Design Loads for Buildings and Other Structures.

8. Identify PV system mechanical design attributes that affect the installation and maintenance of PV arrays, including hardware standardization, safety and accessibility, and other factors. `
9. Identify mechanical design features that affect the electrical and thermal performance of PV arrays, including array orientation, mounting methods and other factors.
10. Review and recognize the importance of PV equipment manufacturers' instructions regarding mounting and installation procedures, the skills and competencies required of installers, and the implications on product safety, performance, code-compliance and warranties.

RESOURCES:

- Dunlop, Jim. "Photovoltaic Systems." Chapter 10 – Mechanical Integration.
- Solar Energy International, "Solar Electric Handbook." Chapter 9 – Mounting; Chapter 10 – Roofing Systems.
- Penn State online course "Photovoltaic System Design and Construction." Unit 2.2 – System Mounting and Building Integration.
- National Roofing Contractors Association Guidelines for Roof Systems with Rooftop Photovoltaics System Components

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 10: Performance Analysis, Maintenance, and Troubleshooting

DESCRIPTION:

Provide a basic understanding of how to analyze the PV system performance. Also, the learning objective provides the students an introduction to PV operation and maintenance, and trouble-shooting activities. Key concepts are:

- Intro to roof types and construction
- PV system performance indicators
- Energy production modeling vs actual performance
- Common PV system failure modes
- Safety equipment for PV system analysis work
- Typical O&M requirements and scheduling
- Use of equipment manuals for troubleshooting work.
- Discuss various potential problems related to PV system design, components, installation, operation or maintenance that may affect the performance and reliability of PV systems.
- Understand the safety requirements for operating and maintaining different types of PV systems and related equipment.
- Identify and describe the use and meaning of typical performance parameters monitored in PV systems, including DC and AC voltages, currents and power levels, solar energy collected, the electrical energy produced or consumed, operating temperatures and other data.
- Compare PV system output with expectations based on system sizing, component specifications and actual operating conditions, and understand why actual output may be different than expected.
- Understand basic troubleshooting principles and progression, including recognizing a problem, observing the symptoms, diagnosing the cause and taking corrective actions leading from the system, subsystem to the component level.
- Identify the most common types of reliability failures in PV systems and their causes due to the equipment, quality of installation and other factors.

OBJECTIVES:

(Based on NABCEP PV Entry Level)

1. Discuss various potential problems related to PV system design, components, installation, operation or maintenance that may affect the performance and reliability of PV systems.
2. Identify and describe the use and meaning of typical performance parameters monitored in PV systems, including DC and AC voltages, currents and power levels, solar energy collected, the electrical energy produced or consumed, operating temperatures and other data.

3. Compare PV system output with expectations based on system sizing, component specifications and actual operating conditions, and understand why actual output may be different than expected.
4. Describe typical maintenance requirements for PV arrays and other system components, including inverters and batteries, etc.
5. Understand the safety requirements for operating and maintaining different types of PV systems and related equipment.
6. Identify the most common types of reliability failures in PV systems and their causes due to the equipment, quality of installation and other factors.
7. Review component manufacturers' instructions for operation, maintenance and troubleshooting for PV modules and power processing equipment, and develop a simple maintenance plan for a given PV system detailing major tasks and suggested intervals.
8. Understand basic troubleshooting principles and progression, including recognizing a problem, observing the symptoms, diagnosing the cause and taking corrective actions leading from the system, subsystem to the component level.

RESOURCES:

- Dunlop, Jim. "Photovoltaic Systems." Chapter 13 – Permitting and Inspection; Chapter 14 – Commissioning, Maintenance, and Troubleshooting.
- Solar Energy International, "Solar Electric Handbook." Unit 7 – Safely Installing and Commissioning Grid-Direct Systems.
- Penn State online course "Photovoltaic System Design and Construction." Unit 5.2 – Commissioning, Maintenance, and Troubleshooting.
- "Solar Operation and Maintenance" video series: https://www.youtube.com/watch?v=gp-uuWMwCaI&list=PLa8_mvXW28yKZ86aGYBQkikfmjeJJB0cx

ASSESSMENT:

Students will be expected to respond to a random subset of the questions included in Appendix A: Online Learning Checks.

Technical Block 11: Marketing, Sales, and Business Development

DESCRIPTION:

Familiarization with solar project development processes and markets, sales methods, and structure of solar industry organizations.

OBJECTIVES:

1. Fundamental understanding of the roles of marketing, sales, and business development
2. Understand types of ownership models for PV systems
3. Familiar with types of business development methods used by solar companies

RESOURCES:

- Chapter 3 - Site Surveys and Preplanning
- NABCEP PV Technical Sales Resource Guide
- OnGrid Solar (http://www.ongrid.net/classes_schedule)
- Invite business development manager from local PV installation company to make presentation on PV marketing / sales process
- Have students obtain PV system quotes for their own homes from different PV companies.

ASSESSMENT:

Students obtain PV system quotes for their own homes from different PV companies. Quiz questions included in appendix.

Technical Block 12: Financial Analysis and Tools

DESCRIPTION:

This section of the course focuses on financial strategies that are utilized in the solar industry including direct purchase, self-financed, lease, and power-purchase agreement (PPA), and community / cooperative solar projects. The types and sources of variable incentive programs are also presented, including local, utility, state, and federal incentives as applied to private individuals, businesses, and organizations.

OBJECTIVES

1. Understand the role of financing in the solar industry and primary alternative pathways for financing e.g. self, lease, PPA
2. Experience using financial analysis tools to evaluate feasibility of solar and support sales and how incentives can encourage investment in PV

RESOURCES:

- http://www.dsireusa.org/
- PVFAST Excel tool
- Moodle Content description

ASSESSMENT:

Quiz questions included in Appendix

Technical Block 13: Math Refresher

DESCRIPTION:

Typical math topics required for calculations are included as needed throughout the class through lectures, tutoring, or through online remedial math tools.

OBJECTIVES

1. Ability to solve for variables using basic algebra (Ohms Law)
2. Ability to solve right triangles for roof slope and area analysis
3. Ability to convert SAE to metric units
4. Ability to make module temperature correction calculations
5. Ability to conduct conductor voltage drop calculations
6. Ability to complete derating calculations

RESOURCES:

Dunlop book

- Chapter 5 – Cell, Modules and Arrays (module temperature correction)
- Chapter 11 – Electrical Integration (voltage drop calculations and derating calculations)

Website(s)

- http://khanacademy.org (Basic mathematics)

ASSESSMENT

Assessments for this block are limited to individual remedial math activities recommended by instructor for specific students as needed.

Technical Block 14: NABCEP Exam Review and Completion

DESCRIPTION

This aspect of the course supports the successful completion of the targeted exam / credential used in the class. The objectives are achieved by providing repetitive practice in the administration of quizzes, a mid-term examination, and practice examination using questions that are aligned with the learning objectives and task analysis of the targeted credential. An important aspect of this element of the course is the use of practice environments (paper or online) that are aligned with the method the actual examination is administered.

OBJECTIVES

1. Experience in responding to multiple choice and fill-in-the-blank type questions aligned with the credentials and learning objectives of the course
2. Confident in the management of time and exam-taking skills

RESOURCES:

- Online Quiz Question Database
- Manual quiz questions (appendix and online)
- Mid Term examination
- PV Entry Level Practice Exams
- NABCEP PV Installation Professional Resource Guide (practice questions relevant to Entry Level learning objectives only)

ASSESSMENT:

All elements of the course assessments are designed to achieve this learning objective

Activity 1: Site Survey and Analysis

DESCRIPTION:

Teams of students are provided an opportunity to gain experience with the processes and tools used to examine a prospective location for a PV array. This group of activities reinforces solar energy fundamentals in terms of the path of the sun and sun angles, and provides students with the opportunity to examine and calculate the estimated solar exposure on a given location accounting for shading.

NOTE TO INSTRUCTORS:

The results of the student's work in this Activity can be used in several other Activities.

OBJECTIVES:

- Demonstrate the ability to locate true south, accounting for magnetic declination.
- Identify factors to consider when choosing array locations, including shading, accessibility, structural concerns, and existing electrical equipment.
- Demonstrate the use of equipment and software tools to evaluate solar window obstructions and shading at given locations, and quantify the reduction in solar energy received.
- Understand the consequences of array shading and best practices for minimizing shading and preserving array output.
- Identify customer concerns and site issues that may arise during a preliminary site assessment.
- Gain experience with Solar Pathfinder and Solmetric SunEye, as well as navigating a physical space while considering the solar window.

RESOURCES:

- Unit 1.2 – Solar Radiation, Module 1: Knowing the Sun Path from Penn State's PV Design and Construction course.
- Unit 2.1 – Array Positioning and Site Evaluation from Penn State's PV Design and Construction course.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 4, Solar Site Analysis and Mounting.
- Dunlop, James. "Photovoltaic Systems" Chapter 2 – Solar Radiation.
- Dunlop, James. "Photovoltaic Systems" Chapter 3 – Site Surveys and Preplanning.
- "Developing Site Plan Drawings." SwitchBoard – From the Forum. Solar Professional Magazine. June/July 2014, p.66.
- "How to Use a Solar Pathfinder." https://www.youtube.com/watch?v=sXKGGW8-7dM
- Galli, Mark. Hoberg, Peter. "Solar Site Evaluation." Solar Professional Magazine. Dec/Jan 2009. https://solarprofessional.com/articles/design-installation/solar-site-evaluation?v=disable_pagination
- Tobe, Jeff. "Successful PV Site Evaluation." Home Power Magazine. Dec/Jan 2014. http://www.homepower.com/articles/solar-electricity/design-installation/successful-pv-site-evaluation?v=print

WORKSHEET:

Activity 1 – Site Survey and Analysis.docx

ASSESSMENT:

Students are assessed based on their participation in the activity and demonstration of competence in the use of the Solar Pathfinder in addition to related topics covered in quizzes. Student's results can be compared between groups and standardized into a "real" solution, or compared to a professional analysis or 3D CAD model (with shading of the space.

Activity 2: Module Characterization

DESCRIPTION:

This activity enables students to experiment with a solar module in daylight or artificial light sufficient to generate voltage and current. Output of module is measured and IV curve traced using testing tools and compared to expected results based on name plate data.

OBJECTIVES:

- Demonstrate the safe measurement of voltage and current of individual PV modules.
- Predict the effect of module tilt and orientation on open circuit voltage and short circuit current.
- Summarize the effects of shading on single cells, rows, and columns of a solar module on the electrical characteristics of the modules.

RESOURCES:

- Sanchez, Justine. "The Circuit – Methods: Testing and Verifying Module Voltage & Current…Prior to Installation." Home Power Magazine. April/May 2010. http://www.homepower.com/circuit-methods-testing
- PVEducation.org "Shading" http://www.pveducation.org/pvcdrom/modules/shading
- Unit 1.3 – PV Cells, Modules, and Arrays from Penn State's PV Design and Construction course.
- Unit 2.2 – Array Positioning and Site Evaluation, Module 4: Shading from Penn State's PV Design and Construction course.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 3, Modules, Series and Parallel, and Meters.
- Dunlop, James. "Photovoltaic Systems" Chapter 5 – Cells, Modules, and Arrays.

WORKSHEET:

Activity 2 – Module Characterization.docx

ASSESSMENT:

Students are assessed based on their participation in the activity and demonstration of competence safely using electrical testing equipment in addition to related topics covered in quizzes.

Activity 3: PV System Components

DESCRIPTION:

This activity provides students to see actual PV system components in live systems and or in training system settings. The objectives are accomplished by providing a tour of equipment and systems and providing students a chance to see and touch various types of systems and components. Removal of cover plates of non-active equipment is required, along with time taken to point our electronic components in devices. This activity can also be combined with staging activities necessary to prepare for hands-on activities to follow.

NOTE TO INSTRUCTOR:

This Activity includes references to electrical and structural drawings, including single line, 3 line, or as-built drawing of the array at hand. If available, these resources can serve as an introduction to the 'language' of plan sets, and give the student practice orienting themselves electrically and physically in relation to a PV system.

OBJECTIVE:

- Become familiar with major PV system components, name plate characteristic, including PV modules and arrays, inverters and chargers, charge controllers, combiner boxes, disconnects batteries and other sources.
- See examples of how basic electronic devices are used in PV systems (transformers, diodes, etc.)

RESOURCES:

- Unit 3.1 – Introduction to the NEC and PV System Components from Penn State's PV Design and Construction course.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 2, Electricity and Components.
- Dunlop, James. "Photovoltaic Systems" Chapter 4 – System Components and Configurations.
- Dunlop, James. "Photovoltaic Systems" Chapter 8 – Inverters.

ASSESSMENT:

Students are assessed based on their participation in the activity in addition to related topics covered in quizzes.

Activity 4: PV System Exploration

DESCRIPTION:

This activity provides students in small groups with experience gathering inverter and PV modules name-place information from an existing system or systems or from inverters in a classroom setting. Students are asked to calculate an estimate of the maximum and minimum modules that could be paired with the inverter. Ideally teams are distributed across variable types of systems including 600V and 1000V inverters and micro inverters.

NOTE TO INSTRUCTOR:

Depending on how this topic has been covered up to this point, the instructor may choose to walk through each step in the worksheet with a given inverter and ask student s to replicate that step with other inverters.

OBJECTIVES:

- Locate and assess the specific attributes of photovoltaic inverters.
- Calculated the maximum and minimum string size for given modules and inverters.
- Understand rational for over-sizing strings of modules and concept of inverter clipping.

RESOURCES:

- Unit 3.2 – Electrical Integration and Code Compliance from Penn State's PV Design and Construction course.
- Unit 4.1 – Grid-Tied Systems Without Batteries from Penn State's PV Design and Construction course.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 5, Grid-Direct System Sizing.
- Dunlop, James. "Photovoltaic Systems" Chapter 4 – System Components and Configurations.
- Dunlop, James. "Photovoltaic Systems" Chapter 5 – Cells, Modules, and Arrays.
- Dunlop, James. "Photovoltaic Systems" Chapter 8 – Inverters.
- Dunlop, James. "Photovoltaic Systems" Chapter 10 – Mechanical Integration.
- Dunlop, James. "Photovoltaic Systems" Chapter 11 – Electrical Integration.

ASSESSMENT:

Students are assessed based on their participation in the activity, the correctness of their answers to the worksheet, and their demonstration of key concepts in a team presentation of findings for the system their team examined in addition to related topics covered in quizzes.

Activity 5: System Assembly and Building Integration

DESCRIPTION:

This activity enables students to gain experience in the assembly of PV systems with variable types of mounting, racking, and inverter configurations. Four-Five separate systems are assembled simultaneously by small groups, with some rotations of groups enabled to offer students the chance to work with different types of equipment. Desirable attributes to include in systems: grounded and ungrounded inverters, 600Vac and 1000Vac inverters, micro inverters, sloped roof installation, flat-roof installation, single string, and multiple string systems.

NOTE TO INSTRUCTOR:

If possible, plan sets reflecting physical layout for any training equipment should be made available to the student so that the student can gain experience placing an array and its individual components according to a defined, code compliant plan and within the constraints of a specific site.

OBJECTIVES:

- Describe the main factors to consider in the integration and mounting of arrays and other equipment.
- Identify the common ways PV arrays are mechanically secured and installed on the ground, to building rooftops or other structures, including rack mounts, ballasted systems, pole mounts, integral, direct and stand-off roof mounts, sun tracking mounts and for other building-integrated applications.
- Compare and contrast the features and benefits of different PV array mounting systems and practices, including their design and materials, standardization and appearance, applications and installation requirements, thermal and energy performance, safety and reliability, accessibility and maintenance, costs and other factors.
- Determine the available space for an array, taking module size, module and panel spacing, roof or ground support structure and attachment points, and fire and safety limitations into account
- Identify mechanical design features that affect the electrical and thermal performance of PV arrays, including array orientation, mounting methods and other factors.
- Identify PV system mechanical design attributes that affect the installation and maintenance of PV arrays, including hardware standardization, safety and accessibility, and other factors.
- Identify the types and magnitudes of mechanical loads experienced by PV modules, arrays and their support structures, including dead loads, live loads, wind loads, snow loads, seismic loads, in established combinations according to ASCE 7-05 Minimum Design Loads for Buildings and Other Structures.
- Review and recognize the importance of PV equipment manufacturers' instructions about mounting and installation procedures, the skills and competencies required of installers, and the implications on product safety, performance, code-compliance and warranties.

- Gain experience with the assembly of steep roof, ballasted, and ground mount PV systems including racking assembly, module installation, wiring, grounding, and inverter hook-up and grid interconnection

RESOURCES:

- Activity guides and specification sheets for equipment used
- Training equipment
- Appropriate hand tools
- Appropriate personal protective equipment and fall protection gear

ASSESSMENT:

Students are evaluated on their participation and engagement in these activities, and in related quiz questions described in technical blocks.

Activity 6: System Commissioning

DESCRIPTION:

This activity utilizes training systems assembled by students to present commissioning and start-up procedures based on equipment specifications and safe practices for energizing PV systems. An emphasis is placed on an understanding of expected and measured performance of systems, and as such, this activity is best conducted in sunny conditions.

NOTE TO INSTRUCTOR:

The Activity described here can be combined, included with, or switched with elements of Activity 9: PV Systems Operations and Maintenance. Except for insulation resistance testing (usually done only during commissioning, and not covered in this course) and the initial turn-on procedures for equipment, system commissioning and O&M are very similar. The Activities described here and in Activity 9 reflect that overlap.

OBJECTIVES

- Represent the I-V curve of a specific PV module through direct measurement.
- Describe a PV module's operating point.
- Become familiar with procedures to systematically evaluate the performance of a PV system to ensure proper operation.
- Identify and describe the use and meaning of typical performance parameters monitored in PV systems, including DC and AC voltages, currents and power levels, solar energy collected, the electrical energy produced or consumed, operating temperatures and other data.
- Compare PV system output with expectations based on system sizing, component specifications and actual operating conditions, and understand why actual output may be different than expected.
- Understand basic troubleshooting principles and progression, including recognizing a problem, observing the symptoms, diagnosing the cause and taking corrective actions leading from the system, subsystem to the component level.
- Gain experience using diagnostic equipment to evaluate the performance of PV systems.

RESOURCES:

- Unit 5.2 – Commissioning, Maintenance, and Troubleshooting from Penn State's PV Design and Construction course.
- Penn State Solar Operations and Maintenance video series - https://www.youtube.com/watch?v=gp-uuWMwCaI&list=PLa8_mvXW28yKZ86aGYBQkikfmjeJJB0cx
- Dunlop, James. "Photovoltaic Systems" Chapter 14 - Commissioning, Maintenance, and Troubleshooting.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 7, Safely Installing and Commissioning Grid-Direct Systems.

- FLIR Application Story, “Inspection of Roof-Mounted Solar Panels with Thermal Imaging.” http://www.flir.com/uploadedFiles/Thermography/MMC/Brochures/T820452/T820452_EN.pdf
- Auditing and module characterization spreadsheets
- Mackey, Andy and United Management and Consultants. “Commissioning & Troubleshooting PV Process Guide.” PowerPoint Presentation.
- United Management and Consultants. “Commissioning and Testing of PV Systems” PowerPoint Presentation
- Example Commissioning Documents

ASSESSMENT:

Students are evaluated on their participation and engagement in these activities, including their completion of the I-V curve worksheet, and in related quiz questions described in technical blocks.

Activity 7: System Design - String and Inverter Matching

DESCRIPTION:

For a specified PV module and inverter in a simple utility-interactive system, students determine the maximum and minimum number of modules that may be used in source circuits and the total number of source circuits that may be used with a specified inverter depending upon the expected range of operating temperatures, the inverter voltage windows for array maximum power point tracking and operation. Both manual calculations and inverter manufacturers' online string sizing software tools are used in this activity. This activity can be conducted in class and/or complimented with online string-inverter matching activities.

NOTE TO INSTRUCTORS:

This activity can be blended with Activities 1 and 2, where the space assessed by the students in Activity 1 and the modules used for Activity 2 can be used as the design basis for the Activity. The attached worksheet assumes this is the case.

OBJECTIVES:

- Become familiar with process for evaluating string and inverter matching design
- Understand the factors and variable affecting string-inverter matching
- Adjust the open circuit and maximum power voltages of PV module to reflect high and low temperature extremes at an installation site.
- Understand roles and value of manufacturer sizing tools and application engineers
- Calculate an acceptable string size based on a chosen module and inverter

RESOURCES:

- Unit 3.1 – Introduction to the NEC and PV System Components, Modules 5, 6, and 7 from Penn State's PV Design and Construction course.
- Unit 3.2 – Electrical Integration and Code Compliance from Penn State's PV Design and Construction course.
- Unit 4.1 – Grid-Tied Systems Without Batteries from Penn State's PV Design and Construction course.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 5, Grid-Direct System Sizing, and Unit 6, Grounding, Wiring, and Overcurrent Protection.
- Wire sizing, string sizing, orientation, and interrow shading spreadsheets
- Example spec sheets, Sketchup files, and images of board work included for reference.

WORKSHEET:

Activity 7 - System Design - String and Inverter Matching.docx

ASSESSMENT:

This activity reinforces topics on module characteristics, inverters, and PV systems which are assessed in quiz questions.

Activity 8: System Inspection

DESCRIPTION:

This activity enables students to experience the processes and activities required to prepare for and document inspection of PV activities. Common problems found during inspections, and the value of high quality permit drawings are emphasized.

OBJECTIVES:

- Become familiar with processes required for preparing systems for inspection including labeling.
- Understand the safety requirements for inspecting different types of PV systems and related equipment.
- Understand the procedures and tools to support permitting and inspection activities of PV systems
- Highlight the ways in which a system might change between a pre-construction plan review and an as-built system.

RESOURCES:

- Unit 3.1 – Introduction to the NEC and PV System Components from Penn State's PV Design and Construction course.
- Unit 3.2 Electrical Integration and Code Compliance from Penn State's PV Design and Construction course.
- Unit 5.1 Safety, Permitting, and Inspection from Penn State's PV Design and Construction course.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 5, Grid-Direct System Sizing, and Unit 6, Grounding, Wiring, and Overcurrent Protection.
- Dunlop, James. "Photovoltaic Systems" Chapter 13 – Permitting and Inspection.
- Mayfield, Ryan. "Common Code Violations: Residential PV Systems." Solar Professional Magazine. December/January 2010.
- Penn State Inspecting PV video series - https://www.youtube.com/watch?v=APrbl0Ngp8o&list=PLa8_mvXW28yLqZjgEidnbEjBFgD1mFIl9
- Wright, Kevin. "Inspecting PV." PowerPoint Presentation.
- Wright, Kevin. "Code Training." PowerPoint Presentation.
- United Management and Consultants. "PV System Checklist." Excel spreadsheet checklist.

ASSESSMENT:

This activity reinforces objectives in technical blocks and is assessed through quiz questions.

Activity 9: PV Systems Operations and Maintenance

DESCRIPTION:

This activity reinforces learning objectives associated with commissioning systems in the context of maintenance and operations. An emphasis is placed on common problems with PV systems over time, and on the role of operations and maintenances services in the PV industry, including how decisions about investments and procurement of these services take place.

NOTE TO INSTRUCTOR:

The Activity described here can be combined, included with, or switched with elements of Activity 6: System Commissioning. Except for insulation resistance testing (usually done only during commissioning, and not covered in this course) and the initial turn-on procedures for equipment, system commissioning and O&M are very similar. The Activities described here and in Activity 6 reflect that overlap.

OBJECTIVES:

- Discuss various potential problems related to PV system design, components, installation, operation or maintenance that may affect the performance and reliability of PV systems.
- Understand the safety requirements for operating and maintaining different types of PV systems and related equipment.
- Identify and describe the use and meaning of typical performance parameters monitored in PV systems, including DC and AC voltages, currents and power levels, solar energy collected, the electrical energy produced or consumed, operating temperatures and other data.
- Compare PV system output with expectations based on system sizing, component specifications and actual operating conditions, and understand why actual output may be different than expected.
- Understand basic troubleshooting principles and progression, including recognizing a problem, observing the symptoms, diagnosing the cause and taking corrective actions leading from the system, subsystem to the component level.
- Identify the most common types of reliability failures (Failure Modes) in PV systems and their causes due to the equipment, quality of installation and other factors.
- Understand how O&M services are procured, and parameters for making decisions about O&M investments

RESOURCES:

- Dunlop, James. “Photovoltaic Systems” Chapter 14 – Commissioning, Maintenance, and Troubleshooting.
- United Management and Consultants. “PV Systems Operation & Maintenance” PowerPoint Presentation

- Example O&M economic calculations and documents.
- Example plan sets and monitoring data.
- NREL 63235 Best Practices in PV System Operations and Maintenance
- Example array living documents, IR reports, IV reports, monitoring data, and plan sets
- Sanchez, Justine. “Potential PV Problems & New Tools for Troubleshooting.” Home Power Magazine. June and July 2011, p 78.
- Williams, Dave. “Large Scale PV Operations and Maintenance.” Solar Professional Magazine. June/July 2010.
- Unit 5.2 Commissioning, Maintenance, and Trouble-shooting from Penn State’s PV Design and Construction course.

ASSESSMENT:

This activity reinforces objectives in technical blocks and is assessed through quiz questions.

Activity 10: PV System Financial Analysis

DESCRIPTION:

This activity provides students with an opportunity to use basic financial analysis tools to evaluate the cash flow expectations for PV projects. An emphasis is placed on the role of financing strategies in the development of PV projects, and the impacts of variable forms of incentives on the return on investment and rate of return.

OBJECTIVES:

- Understand the role of financing in the solar industry and primary alternative pathways for financing e.g. self, lease, PPA
- Experience using financial analysis tools to evaluate feasibility of solar and support sales and how incentives can encourage investment in PV
- Understand how a system's mechanical and electrical design can influence the final installed cost of a PV system and the payback period.
- Understand how taxes, depreciation, SRECs, and other financial tools and techniques can influence the final installed cost of a PV system and the payback period.

RESOURCES:

- The Database of State Incentives for Renewables and Efficiency. http://www.dsireusa.org/
- PVFAST finance tool examples
- United Management and Consultants. "PV System Financing and Economics" PowerPoint Presentation
- Unit 5.3 Metering and Interconnection Agreements from Penn State's PV Design and Construction course.
- Unit 5.4 Economic Analysis and Financing from Penn State's PV Design and Construction course.
- Solar Energy International, "Solar Electric Handbook: Photovoltaic Fundamentals and Applications." Unit 9, Solar Business and Finance.
- Dunlop, James. "Photovoltaic Systems" Chapter 15 – Economic Analysis.

ASSESSMENT:

Quiz questions included in appendix

Activity 11: Case Study and Site visit: Armed Forces PV Installation

DESCRIPTION:

By learning about a project's history, from inception through operation, this activity will provide an opportunity for students to learn more about the variety of design, engineering, construction, and financing found in the modern solar industry. Students will be expected to understand the reasoning behind decisions made during the project's inception and construction, as well as the implications of those decisions on other parts of the project.

OBJECTIVES:

- Gain a comprehensive understanding of a local project (preferably military base) case including project development, site, geo-technical solutions, construction processes, O&M needs, and performance evaluation based on monitoring data
- Gain an understanding of the goals and objectives for solar energy deployment on Armed Forces facilities.

RESOURCES:

- Engineering or construction drawings and proforma documents for the selected project
- Interviews or guest lectures with project owners, engineers, or contractors
- Articles about project in periodicals
- Construction management and O&M professionals to support tour/presentation

ASSESSMENT:

Discussion questions in class

Transition Solar Block 1: Veterans in the Solar Industry

DESCRIPTION

This course component enables veterans to learn about jobs and career experience in the solar industry from their peer. Video interviews and Skype meetings distributed during class meetings are used to achieve objectives.

OBJECTIVES

- Describe the perspective of veterans and their transition out of the military into the solar industry.
- Describe what aspects of solar careers veterans have found rewarding and fulfilling

RESOURCES:

- DOE SRV video
- First Solar Video 1
- First Solar Video 2
- Skype interviews with class (see contact list)
- Solar Foundation Report
  http://www.thesolarfoundation.org/wp-content/uploads/2015/01/VeteransInSolarWEB.pdf

ASSESSMENT:

Discussion Questions

- (Class Discussion) What surprised you about the way other veterans talk about their jobs and careers in the solar industry?
- (Class Discussion) What are some attributes about the solar industry that you feel are aligned with the values and traits of veterans? In other words, in what ways do you think veterans might be uniquely suited to work and thrive in the solar industry?

Transition Solar Block 2:
Solar Resume Design and Strategy

DESCRIPTION

This course component focuses on the development of a 2-page resume that reflects skills and experiences of participants, as well as defined career objectives that are aligned with the opportunities in the solar industry. This objective is fulfilled through the incremental improvement of resumes with feedback from peers and solar industry / instructors.

OBJECTIVES

- Represent individual backgrounds, skills, and education in a solar industry-focused resume and professional development plan.
- Author career objectives customized to specific job and career opportunities

RESOURCES:

Online SRV placement systems (for example Futures, Inc)

- Sample resumes from veterans that have obtained jobs
- Sample objective statements

ASSESSMENT

Resume Design

- (online) Evaluate the online resources that are available to veterans to support resume development and job placement. How do you feel these resources can be useful to you?
- (online) Summarize the initial feedback you received on your resume and how you will respond to this feedback
- Submit a final resume for the package of resumes that will be distributed for your cohort of SRV.

Transition Solar Block 3: Solar Career Mapping

Description This course component provides an opportunity for participants to learn about the variable types of career pathways that exist in the solar industry, and to gain experience with assessment tools that can help participants make connections between their interests, skills, and passions and the job/career opportunities that exist in the solar industry. A part of this discussion is an in-class activity in which students spend 30 minutes interviewing each other to learn about each other's' interests and passions using an active listening approach.

OBJECTIVES

- Gain experience using resources that are designed to help identify entry points and pathways in solar design, construction, manufacturing, and project development.
- Gain experience in the use of career and job placement tools and services targeting veterans.
- Gain experience in the self-assessment of core values and contributions.
- Gain experience with Solar Foundation workforce research

RESOURCES:

DOE Solar Career Map http://energy.gov/eere/sunshot/solar-career-map

- Active Listening Interview PPT
- Self-Assessment (Futures, Inc or another tool)
- Sample objective statements

ASSESSMENT

Career Identification

- (Class discussion) Summarize the core qualities and traits you learned about a colleague in your class during your active listening interview.
- (Class discussion) What qualities and passions do you possess that might be valuable to a solar industry organization?
- (online) Which of the vertical pathways on the Solar Career Map are of greatest interest to you and why?
- (online) Select two high level career positions on the map that are of interest to you and outline the background, experience, and credentials for these positions.
- (online) Describe some of the driving forces in the solar job market

Transition Solar Block 4: Solar Industry Organizations and Professional Associations

DESCRIPTION:

This course component provides an opportunity for participants to learn about the way solar companies have formed and evolved in recent years, and provides exposure to the trade associations and periodicals that can help them learn about and stay current on key issues in the solar industry.

OBJECTIVES

- Describe the driving forces shaping solar companies
- Describe the roles manufacturers play in supporting solar project development
- Describe the mission of SEIA and the services offered by regional chapters of SEIA

RESOURCES:

Company websites and guest speakers

- Solar Industry Magazine
- Solar Pro Magazine / website

ASSESSMENT:

Solar industry organizations

- (Class discussion) After reviewing multiple website of large and small solar companies that operate in regions you would like to work; how would you describe some of the major differences?
- (Class discussion) What types of solar companies, or traits of companies are appealing to you, and why?
- (online) Write 2-3 sentences describing your interest in at least two different solar companies that operate in your region. These paragraphs will be used in cover letters or thank you letters during your job search.

Transition Solar Block 5: Post 9/11 GI Bill

DESCRIPTION:

This course component helps expose participants to the resources that support education and continuing education for veterans.

OBJECTIVES:

- Understand purpose and scale of post 9/11 GI Bill resources
- Understand process to apply for Post 9/11 GI Bill resources

RESOURCES:

- DOE SRV Webinar on Post 9/11 GI Bill

ASSESSMENT:

Post 9/11 GI Bill

- (online) Based on your job and career interests, what types of additional education and training might you pursue, and how would you seek Post 9/11 GI Bill resources to support them?

Transition Solar Block 6: Interview Skills and Job Search

DESCRIPTION:

This course component provides participants with experience preparing for and participating in interviews for actual jobs and careers in the solar industry.

OBJECTIVES:

- Confidently participate in both informal and formal interview settings.
- Develop ability to communicate personal strengths and aspirations, understand methods to follow up with opportunities.

RESOURCES:

Webinar with Solar Recruiting Professional

- SRV PPT with interview tips and strategies

ASSESSMENT:

Interview Skills

- (Discussion) What are the four things that an interviewer is seeking to learn about you?
  – Can you do the job?
  – Will you take the job?
  – Are you a good fit for the job?
- (online) What are the top three take-aways you hope an interviewer will learn about you?
- Complete at least one online or face to face interview for a job opening in the solar industry.

Activity Worksheets

Activity 1: Site Survey and Analysis #1

Assume the red area below is the surface of a commercial scale building, and that the relative elevations of surrounding objects remain the same. You have been asked to determine the amount of space usable for an array in this area. You must define all obstructions --trees and buildings, for instance-- that would affect performance between 9AM - 3PM all year long anywhere inside this red area.

INSTRUCTIONS:

1. Measure the dimensions of the red outline as closely as you can. The inside of the red line follows the edges of buildings – use your best judgment. Copy the outline and dimensions to a sheet of graph paper.
2. Use a Solar Pathfinder to define areas that are experience shading between 9AM-3PM all year long inside the red outline. Mark the shaded areas on your drawing.
3. Define an UNSHADED, USABLE area in your drawing. Include dimensions on your drawing.

Activity 1: Site Survey and Analysis #2

Your company was called by a customer who had a solar system installed on the roof of their building. They say they were told the array would produce a certain amount of power, but so far it has underperformed. Can you tell them why? And can you suggest improvements?

INSTRUCTIONS:

1. Sketch the existing array on a piece of graph paper. Include tilt angle (i.e., angle between the modules and the horizon), array azimuth angle (angle between the direction the array is facing and south), the array dimensions, and the building or structural dimensions. Also write down all the specs of the modules, the conductors, and the inverters.
2. Use a Solmetric SunEye to determine the shading at the existing array that would affect performance at all times, all year.
3. Determine if there is a problem.
4. If there is a problem, recommend a solution.

Activity 2: Module Characterization

In this Activity, you will be given a solar module and five pieces of equipment: a compass, an angle meter, a multimeter, an irradiance meter, and a thermometer. You will be asked to perform measurements and record your results in the provided tables.

1. SPECIFICATIONS

Record the rated specifications for your module in the table below.

Manufacturer	
Model #	
Rated Power (Watts)	
Open Circuit Voltage (Voc)	
Voltage at Maximum Power (Vmp or Vpp)	
Short Circuit Current (Isc)	
Current at Maximum Power (Imp or Ipp)	

2. CHANGES IN TILT ANGLE

1. Record the date and time and use the attached sun chart to estimate the altitude and azimuth angles of the sun at the time of your test.
2. Find an optimal azimuth angle for your module (meaning one where the module is facing towards the sun)
3. Complete the "expected" columns in the table below. Ask yourself, "How will changing the tilt angle affect my voltage and current measurements? And by how much?"
4. Use the inclinometer to measure your tilt angle while holding the module at each of the following tilt angles
5. Take and record the requested measurements, and calculate the power column. Compare that to your expected values.

Date and time:			**Approx. altitude angle:** **Approx. azimuth angle:**		
Tilt Angle (degrees)	**Expected Voltage (V)**	**Expected Current (A)**	**Recorded Voltage (V)**	**Recorded Current (A)**	**Calculated Power (W)**
0 (flat on ground)					
15					
30					
45					
60					
75					
90 (standing straight up and down)					

6. Answer the following questions:
    a. Did your expected measurements match your actual measurements? Why or why not? How did they differ?
    b. Was there a point where voltage or current peaked? If so, why did it occur when it did?
    c. Was there a point when power peaked? If so, why did it occur when it did?

3. CHANGES IN AZIMUTH ANGLE

1. Record the date and time and use the attached sun chart to estimate the altitude and azimuth angles of the sun at the time of your test.
2. Use the tilt angle from the table above that resulted in the highest calculated power.
3. Complete the "expected" columns in the table below. Ask yourself, "How will changing the azimuth angle affect my voltage and current measurements? And by how much?"
4. Assuming that NORTH IS 0 DEGREES, take measurements at the indicated array orientation angles using a compass or another method, record your measurements, and calculate power.

Date and time:			Approx. altitude angle:		
			Approx. azimuth angle:		
Array orientation angle (degrees)	Expected Voltage (V)	Expected Current (A)	Recorded Voltage (V)	Recorded Current (A)	Calculated Power (W)
90 (due east)					
120					
150					
180 (S)					
210					
240					
270 (due west)					

5. Answer the following questions:
    a. Did your expected measurements match your actual measurements? Why or why not? How did they differ?
    b. Was there a point where voltage or current peaked? If so, why did it occur when it did?
    c. Was there a point when power peaked? If so, why did it occur when it did?

4. SHADING

1. Record the date and time and use the attached sun chart to estimate the altitude and azimuth angles of the sun at the time of your test.
2. Use the tilt angle and azimuth angles from the tables above that resulted in the highest calculated power.
3. Complete the "expected" columns in the table below.
4. Hold your module at the best performing tilt and array orientation angles from the previous two steps. Make note of the angles you're using in the upper right corner of the table.
5. Record all expected values. Ask yourself, "How will shading one cell, one column, and one row change my voltage and current?"
6. Take the requested measurements and record the results.
7. Using a piece of cardboard cover one cell in the corner of the module, take the requested measurements, and record the results.
8. Using a piece of cardboard, cover one vertical column, take the requested measurements, and record the results.
9. Using a piece of cardboard, cover one horizontal row, take the requested measurements, and record the results.
10. Calculate power of the shaded module AND power loss compared to the power of an uncovered module.
    (Calculated Power of Unshaded Module) – (Calculated Power of Shaded Module) = (What you Record)

<table>
<tr><td colspan="2" rowspan="4">Date and time:</td><td rowspan="4"></td><td colspan="2">Approx. altitude angle of sun:</td><td colspan="2" rowspan="4"></td></tr>
<tr><td colspan="2">Approx. azimuth angle of sun:</td></tr>
<tr><td colspan="2">Tilt angle you’re using:</td></tr>
<tr><td colspan="2">Array azimuth angle you’re using:</td></tr>
<tr><th>Shading scenario</th><th>Expected Voltage (V)</th><th>Expected Current (A)</th><th>Recorded Voltage (V)</th><th>Recorded Current (A)</th><th colspan="2">Calculated Power (W)</th></tr>
<tr><td>NO SHADE</td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Calculated Power (W)</td><td>Power Loss (W)</td></tr>
<tr><td>One cell</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>One column</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>One row</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

11. Answer the following questions:
    a. Did your expected measurements match your actual measurements? Why or why not? How did they differ?

    b. Which shading scenario had the highest amount of power loss? Why?

    c. Describe the relationship between these elements:
        i. The azimuth angle of the sun at the time of the test.
        ii. The altitude angle of the sun at the time of the test.
        iii. The array tilt angle that had the highest power production.
        iv. The array orientation angle that had the highest power production.

Activity 3: PV System Components

DESCRIPTION

In this activity, students will move through an existing solar array, following the path of current from the point of generation to the point of integration. At each point in the array, the students will answer the following questions, either vocally in a larger group or in writing as smaller groups.

QUESTIONS

At this point in the array…

1. What are you looking at? Find this part, piece, component, or system on both the mechanical and electrical drawings and make note of its 'official' name.
2. Are there any visible markings or signage? If so, what do they say, and what do they mean? If not, should there be?
3. What elements of this part, piece, component, or system are safe to touch, if any? How would you make this safe to touch?
4. Is there AC power, DC power, or both?
5. Which way does power flow?
6. Would voltage measured here be DC voltage of just one module, a whole string of modules, the entire array, or the grid AC voltage?
7. Assuming the array is currently operational, would a current measurement here be DC current of just one module, DC current of a whole string of modules, DC current of the entire array, or the grid AC current? How would you measure current here?
8. What part, piece, component, or system protects people from electrical shock hazards, if any?
9. What part, piece, component, or system protects the building from mechanical or electrical hazards, if the array is roof mounted?
10. Does anything look out of place or unusual? Does this part, piece, component, or system show any change from being exposed to the elements?
11. Assume this part, piece, component, or system was broken. What would be involved in replacing it (i.e., labor, parts, preconditions for work, time)?

Activity 4: PV System Exploration

In this Activity, you will be given a solar module and a selection of inverters and you will be required to determine appropriate string lengths.

1. SPECIFICATIONS

Record the rated specifications for your module in the table below.

Manufacturer	
Model #	
Rated Power (Watts)	
Open Circuit Voltage (Voc)	
Voltage at Maximum Power (Vmp or Vpp)	
Short Circuit Current (Isc)	
Current at Maximum Power (Imp or Ipp)	

Record the rated specifications for **two** inverters in the tables below.

Inverter #1

Manufacturer	
Model #	
Maximum DC Input Power	
Maximum DC Input Voltage	
MPPT Voltage Range	
Continuous AC Output Power	
Number of Strings	

Inverter #2

Manufacturer	
Model #	
Maximum DC Input Power	
Maximum DC Input Voltage	
MPPT Voltage Range	
Continuous AC Output Power	
Number of Strings	

1. Using only the rated power of the module and inverter, what would be the maximum number of your given module that you could use with each inverter?

   Inverter #1: Inverter #2:

2. Which value should you use to determine the maximum number of modules that you could place in each series string?

   a. Open circuit voltage of the module
   b. Voltage at maximum power of the module
   c. Maximum DC input voltage of the inverter or from the NEC, whichever is smaller
   d. Maximum DC input voltage of the inverter or from the NEC, whichever is larger
   e. Both a and c
   F. Both a and d

3. Assuming that the temperature coefficient is -0.37%/K for this module, and that the lowest expected ambient temperature where you'll install your array is -22°C, determine the adjusted voltage for your solar module. You can use the following equation skeleton or do it on your own:

________	+ (	________	x	________	x (	________	-	________	)) =	________
Voltage to be adjusted on module		Voltage to be adjusted on module		Temp. coeff		Minimum expected temp		Temp at STC		**Temp. adjusted voltage**

4. Using this new adjusted voltage, what would be the maximum number of modules that you could use **per string** for **each inverter**? Show your calculations.

   Inverter #1:

   Inverter #2:

5. Which value should you use to determine the minimum number of modules that you should place in each series string?

   a. Open circuit voltage of the module
   b. Voltage at maximum power of the module
   c. Minimum DC input voltage of the inverter
   d. Maximum DC input voltage of the inverter
   e. Both b and c
   F. Both b and d

6. Assuming that the temperature coefficient is -0.37%/K for this module, and that the expected highest ambient temperature where you'll install your array is 32°C, not including a 30°C adder for a roof mount array, determine the adjusted voltage for your solar module. You can use the following equation skeleton or do it on your own:

______	+ (______	x ______	x (______	- ______	)) = ______
Voltage to be adjusted on module	Voltage to be adjusted on module	Temp. coeff	Max temp. at array	Temp at STC	**Temp. adjusted voltage**

7. Using this new adjusted voltage, what would be the minimum number of modules that you could use **per string** for **each inverter** to ensure that the inverter will turn on during high temperature conditions? Show your calculations.

   Inverter #1:

   Inverter #2:

8. If your client wanted an array of no less than 32kW using your module:

   a. How many inverters would be required?

   Inverter #1: Inverter #2:

   b. How many modules and strings of modules would be required?

   Inverter #1: Inverter #2:

Activity 5: System Assembly and Building Integration – Grounded Grid-Tied System without Batteries

DESCRIPTION

This activity station will consist of assembling nine (9) Sharp 220s on a sloped roof, using Unirac Mounting, and a Solectrica 1800W inverter into a functioning, safe grid-tied PV system.

KEY QUESTIONS

1. Why might you want to use standoff mounts instead of directly attaching the L-brackets to the roof? Why might you want to increase or decrease the height of the array and what are the advantages and disadvantages of either? How might your climate affect this decision?
2. What is the minimum distance from the end of the rail to the end clamp in this mounting system?
3. What does the Unirac manual recommend doing to fix the first panel in a column to vertically mounted rails?
4. What are the advantages and disadvantages of the different grounding methods in this installation? (WEEB clips vs. lugs and bare wire)
5. Should we cover the array with an opaque material or not? What steps can an installer take to prevent electrical shock during the installation process?
6. What does the Unirac manual say about when the electrical connections are made between panels? What does the instructor say?
7. Why did we wait to connect the columns of modules until last?
8. What are the features of this inverter? Is there a disconnect included?
9. What governs the size of the various wires?
10. What are the issues with pulling wire through conduit? Are there any restrictions?
11. What order should we turn things on?
12. What is the process for checking system voltages? Where’s an appropriate place to check for those voltages?
13. Using a light meter, how would we find out how much the array “should” be producing?

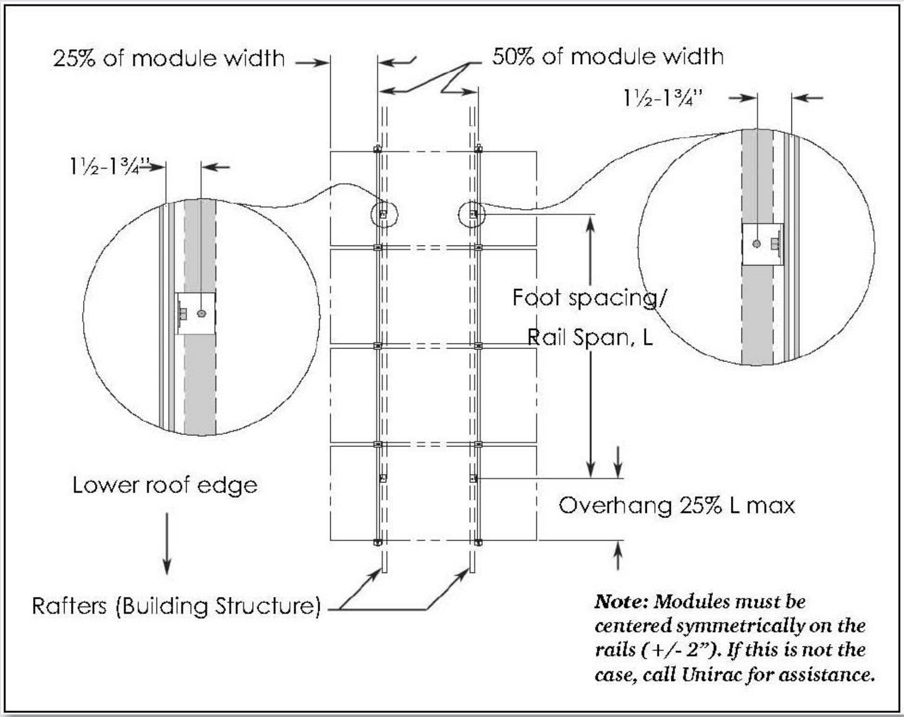
ACTIVITY OUTLINE

Materials:

- (9) Sharp 220 W PV panels.
- (6) Unirac rails, flashed white with electrical tape.
- (12) Unirac top mounting end clamps and hardware.
- (12) Unirac top mounting mid clamps and hardware.
- (6) top mounting grounding lugs.
- (6) bolt assemblies to attach grounding lugs to rail. Each assembly consists of (1) ¼" bolt, (1) nut, (1) lock washer, and (1) regular washer.
- (6) WEEB ground clips that go between grounding lugs and rail.
- (12) WEEB between-panel ground clips
- (1) longer pierce of bare copper wire that will attach to each top mounted ground lugs, and act as a home run
- (2) Home run cables with MC connectors on each end.

PROCESS:

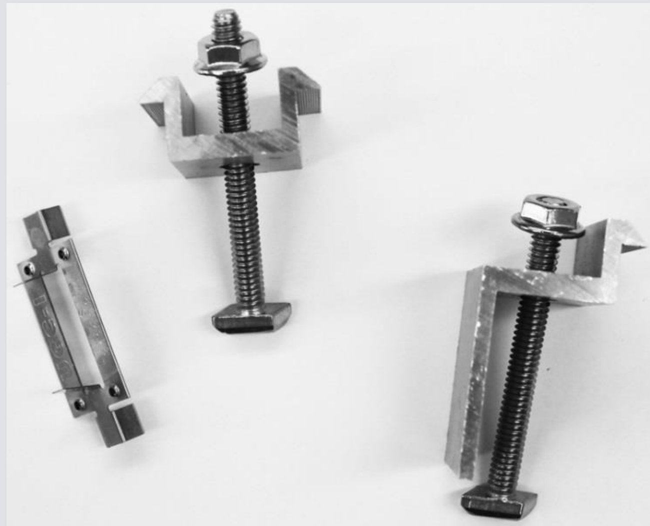
1. If the L-feet and rails have not been mounted to the stand off mounts on the mock roof, install them per the Unirac installation manual's recommendations. Allow for proper distance between the end of the rail and where the L-foot connects (see below).



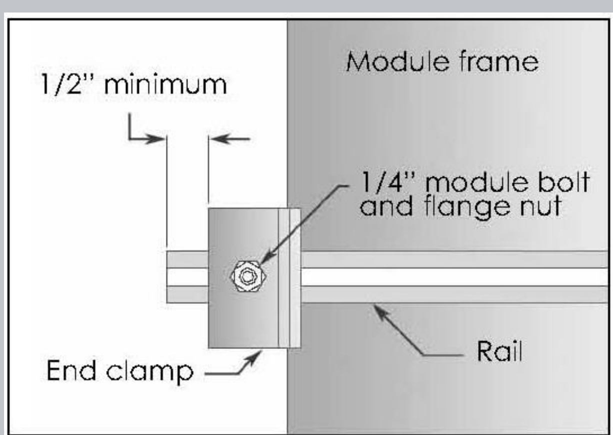
2. Inspect and test the equipment grounding conductor to make sure ground is available through the inverter all the way to the junction box at the array.

3. Begin the panel mounting process.

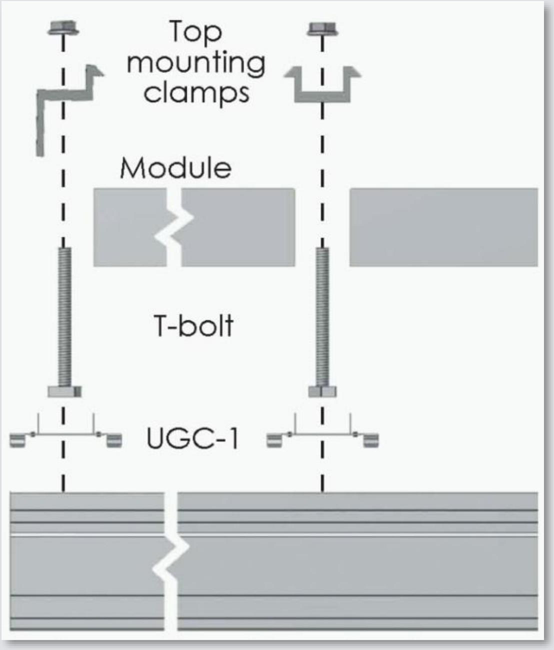
   Prepare (2) top mounting end clamps and (2) top mounting mid clamps, as well as (2) WEEB grounding clips and associated hardware.



4. Mount the first panel to the bottom of the rails. Have a teammate hold the panel to ensure it doesn't slide off. Place the end clamps on the module, ensuring at least ½" minimum distance between the bottom of the end clamp and the end of the rail.

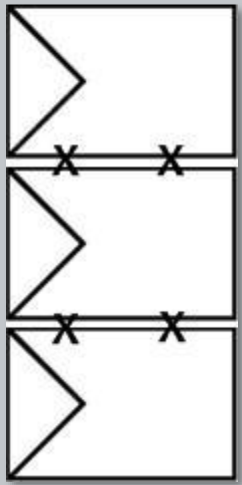


5. Prep the mid-clamps, and place WEEB clips in the rails.



6. The Unirac manual recommends placing the second panel face down on the first while you make the connections between the two modules, in effect blacking them both out while the connection is made. Make sure you understand what size of series string you are making, and which panels are to be connected to which.

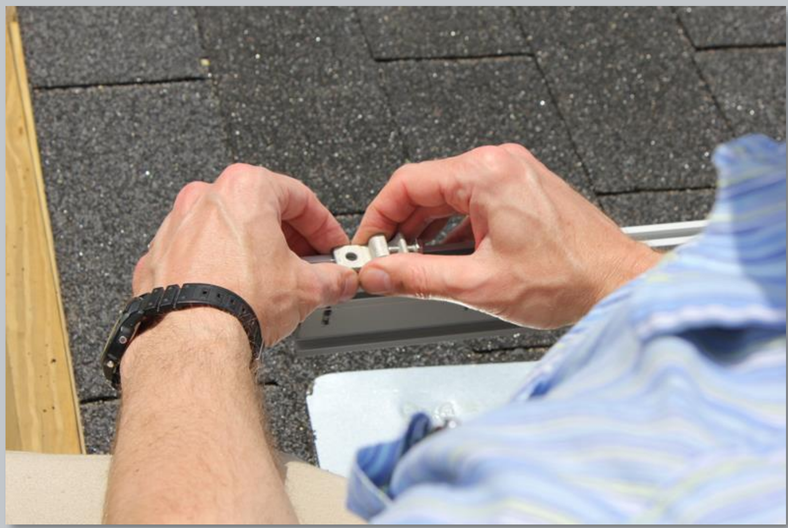
Note: The installation instructions for the WEEB clips suggests that you only need to install two WEEB clips per panel, not four, and despite what the drawing step 5 indicates, does not suggest placing a WEEB clip underneath the end rail. Because there are only 3 panels in a column in this installation, still place 4 WEEB clips total per column (Xs indicate WEEBs in the drawing to the right).

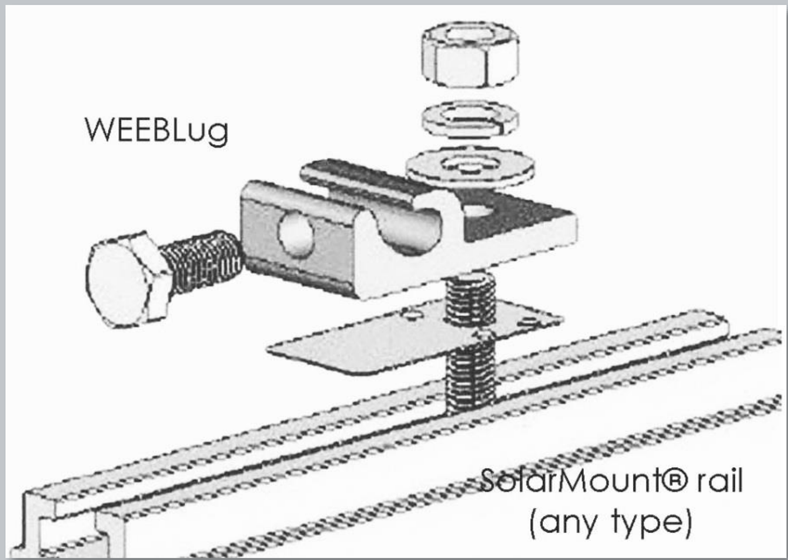


7. Repeat the procedure for the next panel in a column, using an end clamp when the other ends of the rails are reached.

   Keep you work neat but gathering the PV cables in bundles or loops and attaching them to the rails with zip ties as you place the panels.

8. Attach the top mounted grounding lugs using the associated hardware. Place one lug at the top of each rail. Remember to place a flat WEEB grounding clip between the rail and the lug.





9. Run a grounding wire through the system that will catch all of the rails (using the top mounted clips).

10. Connect the grounding wire to the ground in the junction box.

11. Connect the Grounding Electrode Conductor from the inverter to the grounding rod.

12.	Inspect the AC wires from the inverter to the meter to the AC switch.
13.	Connect the DC disconnect to the junction box at the array using the premade cord.
14.	Connect power wires at the ends of the strings to the junction box using the home run cables.
15.	Check voltages.
16.	Follow the recommended commissioning procedure.

Activity 5: System Assembly and Building Integration – Microinverters

DESCRIPTION

This activity station will consist of assembling six (6) Sharp 175 PV panels, using a Unirac tilt mount and Enphase micro inverters into a safe, functioning PV system.

KEY QUESTIONS

1. What are the limitations of the low-profile tilt leg?
2. What would the grounding system look like if WEEB clips were not used in this system?
3. What type of disconnect is required with this system?
4. Will the installation of one inverter per panel increase or decrease installation time? Why?
5. What is the process for checking system voltages? Where's an appropriate place to check for those voltages?

ACTIVITY OUTLINE

Materials:

- (6) Sharp 175 W PV panels.
- (6) Enphase Micro-inverters, either 208V or 240V
- (2) 76" sections of Uni-Strut
- (1) 82" section of Uni-Strut
- (2) 120" sections of Uni-Strut
- (4) Unirac low-profile tilt legs.
- OR
  (4) Unirac high-profile tilt legs
- (4) Unirac rails
- (8) Unirac top mounting end clamps and hardware.
- (8) Unirac top mounting mid clamps and hardware.
- (4) top mounting grounding lugs.
- (4) bolt assemblies to attach grounding lugs to rail. Each assembly consists of (1) ¼" bolt, (1) nut, (1) lock washer, and (1) regular washer.
- (4) WEEB ground clips that go between grounding lugs and rail.
- (8) WEEB between-panel ground clips
- (12) bolt assemblies to attach micro-inverter to rail. Each assembly consists of (1) ¼" bolt, (1) nut, (1) lock washer, and (1) regular washer.

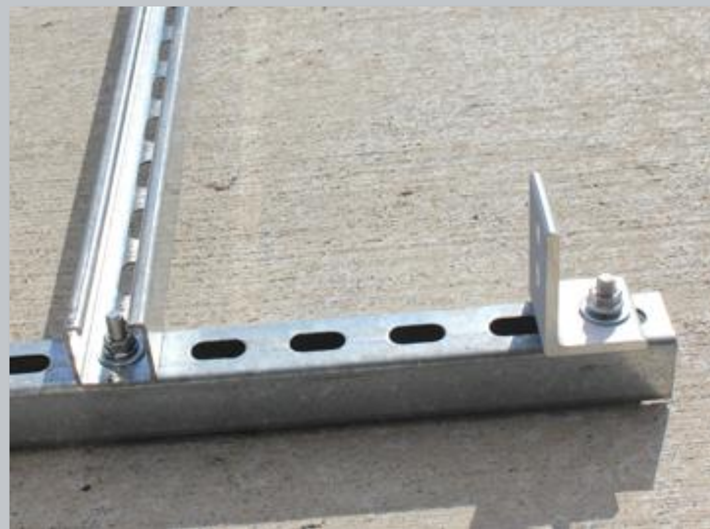
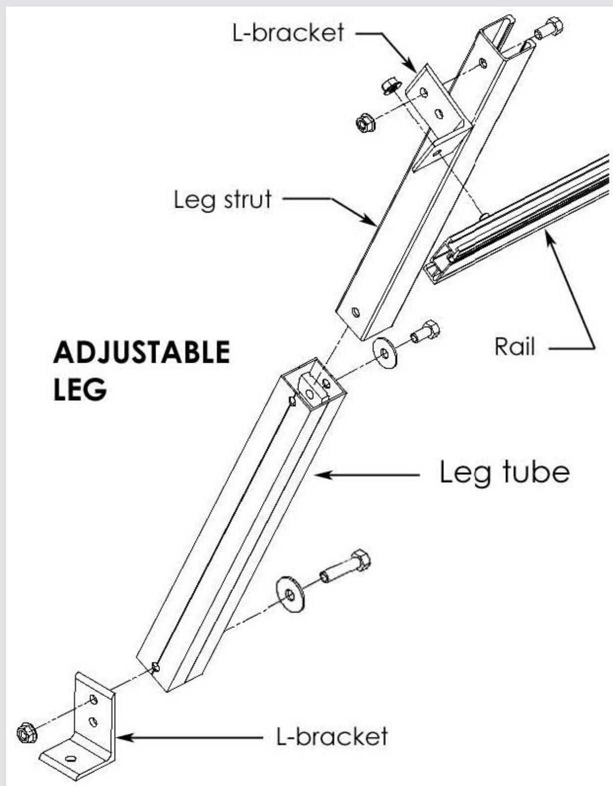
- (1) Enphase micro-inverter installation kit, including a 6’ branch cable, (1) end cap, and (1) bracket to hold a junction box.
- (1) longer pierce of bare copper wire that will attach to each micro-inverter’s grounding point, ground the racking system itself at the top mounted ground lugs, and act as a home run

PROCESS:

1. Assemble the Uni-strut base that will support the Unirac mounting system.

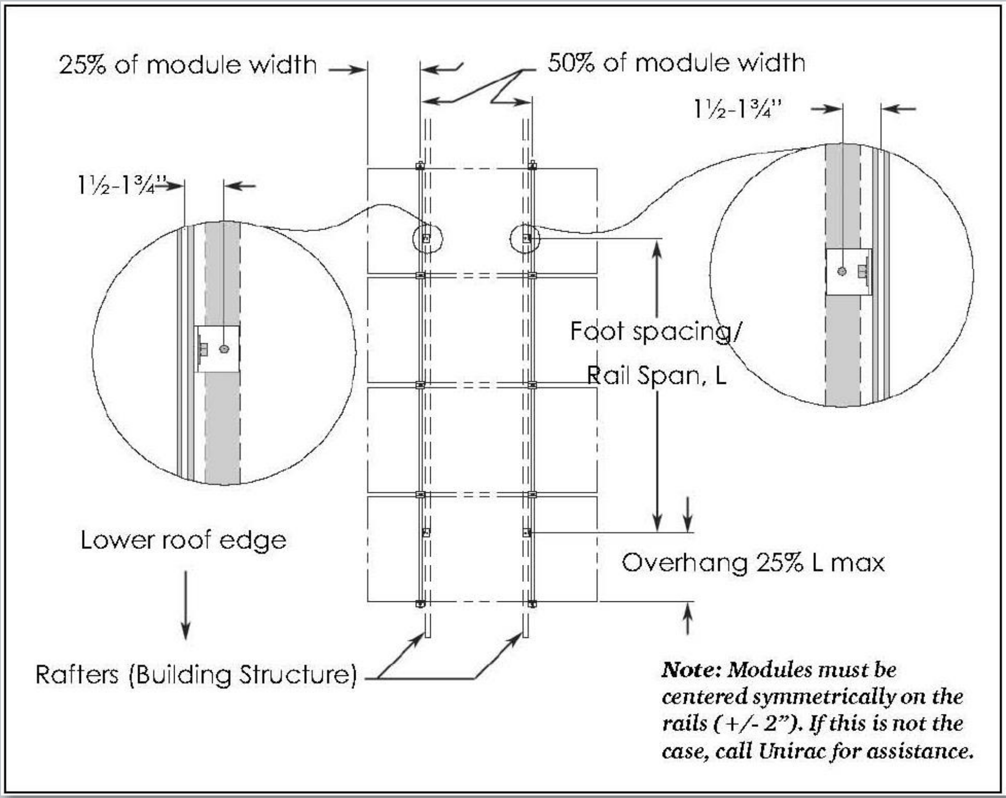
   This system is a substitute for attachment points that might exist in the real world – driven or poured piles, for instance.

   a. Lay out the 120” Uni-strut pieces on an east-west line such that the piece marked “rear” is North of the other.
   b. Lay out the 76” Uni-strut pieces on a north-south line so that you’ve formed a square.
   c. Attach the 76” pieces to the 120” pieces using the second bolts in from the ends of the 120” pieces. These bolts will not have lock washers.
   d. Lay the 82” Uni-strut, marked “Diagonal,” across the square, and use the bolts that do not have lock washers to attach the diagonal to the front and rear Uni-strut.
   e. Check that the assembly is square and tighten all bolts.

2. Attach the L-feet to the North and South rails. The bolts included on the Uni-strut might not be in the appropriate location for the type and style of installation you are trying to do. Bolts may be moved to new locations.	
3. Choose the appropriate tilt leg for the exercise. Attach either the the low-profile tilt legs or the high-profile tilt legs to the L-feet on the northern side as the diagram on the right shows.	

4. Attach a rail between each tilt leg and the corresponding L-foot on the South Uni-strut.

   Follow the Unirac installation manual recommendations for the distance between the end of the rail and where the L-foot connects, as well as the distance between where the top of the tilt leg is in relation to the top end of the rail. Repeat with the other rails.



5. Install the Enphase micro-inverters using the appropriate mounting hardware (the head of the bolt slides in the top of the rail). Locate each micro-inverter in the middle of the eventual location of its corresponding PV panel, and place them on the 2 inside rails.

   The micro-inverter should be mounted so that the grounding point is up.

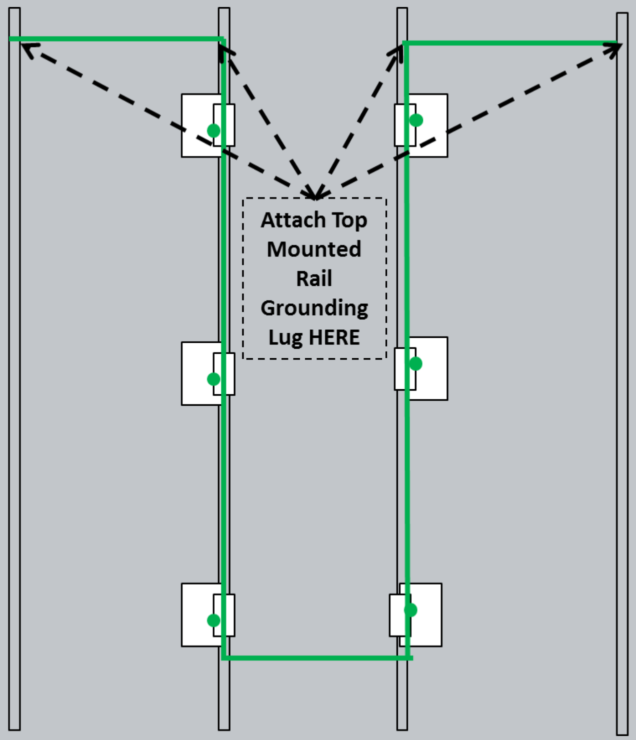
6. Connect each Enphase micro-inverter to the one beside it. Place the end cap on the last unused connector, and on the other end, attach the branch cable to the final inverter. This branch cable will go into a junction box that will attach to the utility connection cart.

   The micro-inverter cables can be zip tied to the rails now, or later, after the modules have been mounted.

7. Attach the top mounted grounding lugs using the associated hardware. Place each lug at the tops of the rail. Remember to place a flat WEEB grounding clip between the rail and the lug.

8. Run a grounding wire through the system that will catch all the rails (using the top mounted clips) and all the micro-inverters, connecting the wire at the grounding point.

   Note: The image to the right shows one version of this, but the actual route is up to the installer's preference. For instance, the micro-inverters could each have their own line that connects to a single grounding wire (using split bolts) that goes straight across the top (or bottom) of the rails.



9. Connect the grounding wire to the ground in the junction box.

10. Begin installing panels. Ready two top mounting end clamps, two top mounting mid-clamps, and two WEEB clips. Place a panel across the rails, attach the panel's connectors to the connectors on the micro-inverter, position the clamps and WEEB clip, and bolt the end clamps down.

Use caution when connecting the cables to the micro-inverter. Either cover the panel with cardboard or carpet, or turn it upside down during the moment of connection.

11. Attach the loose PV wires in neat loops or bundles to the rails using cable ties. Make sure to gather the micro-inverter cables as well, if you had not done so earlier.

12. Mount the rest of the panels in a similar fashion, connecting each to its corresponding micro-inverter.

13. Connect the junction box to the cart using the umbilical.

14. Follow the recommended commissioning procedure:
    a. Turn ON the AC disconnect on the cart.
    b. Turn ON the main utility-grid AC circuit breaker. The system will wait 5 minutes before it begins producing power.

Activity 5: System Assembly and Building Integration – Ungrounded Grid-Tied System without Batteries

DESCRIPTION

This activity station will consist of assembling Sanyo 210N watt PV panels, an Eaton inverter and several Sunwize ground mounts into a safe, functioning PV system.

KEY QUESTIONS

1. What are the requirements for a built-in DC disconnect?
2. How do the requirements for fuses and disconnects for an ungrounded system differ from those for a grounded system?
3. How do the requirements for wire for an ungrounded system differ from those of a grounded system?
4. Why do we not need to attach a grounding lug to the other half of the leg assembly?
5. How do we make sure it is safe to open a fuse holder?
6. What factors influence the placement of junction boxes in this lab activity? How would those factors result in a different configuration in a real-world installation?

ACTIVITY OUTLINE

Materials:

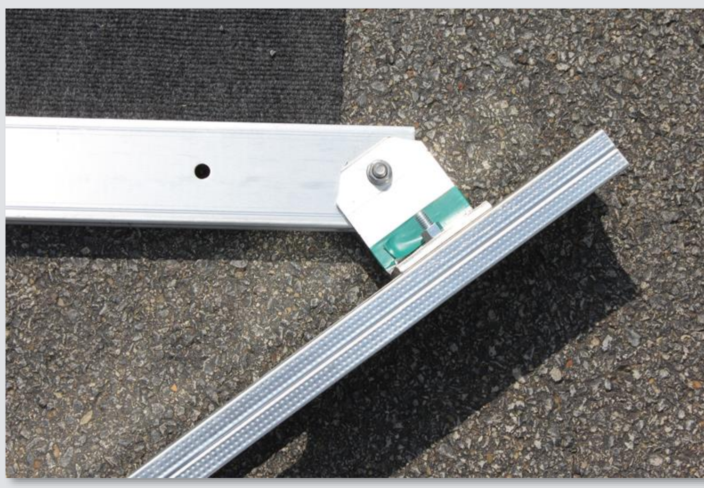
- (21) Sanyo 210N solar panels.
- (7) Sunwize racking systems, each consisting of (2) preassembled legs, in pairs. The legs are flashed green with electrical tape.
- (14) Unistrut bases, one for each leg assembly. This will simulate a real attachment point on the ground or a roof.
- (28) bolt assemblies to connect preassembled legs to Unistrut bases. Each assembly consists of (1) bolt, (2) washers, and (1) nut.
- (84) bolt and wingnut assemblies to attach panels to preassembled legs. Each assembly consists of (1) bolt, (2) washers, and (1) wingnut.
- (21) grounding lug assemblies, one per panel. Each assembly consists of (1) grounding lug, (1) machine screw, (1) nut, (1) flat washer, (1) lock washer, and (1) star washer.
- (14) grounding lug assemblies, one per preassembled leg
- (14) pieces of bare copper wire to ground each rack's panels
- (1) longer pierce of bare copper wire that will attach to each panel's grounding, ground the racking system itself, and act as a home run

- (7) split bolts to attach the panel grounding to the home run grounding cable
- Home run cables, assembled out of PV wire with the appropriate MC connectors crimped onto the ends

PROCESS:

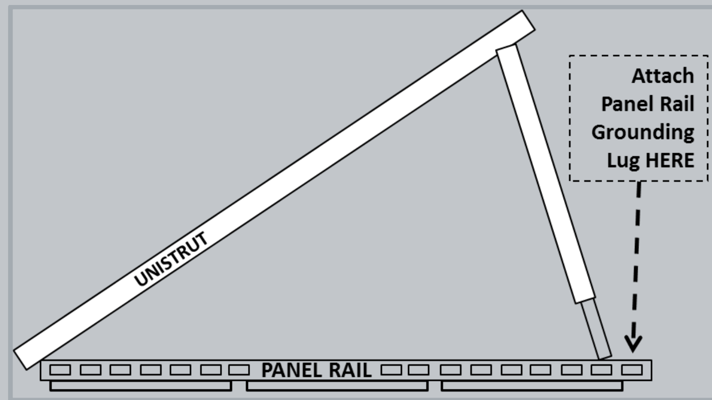
1. Build the SunWize racking system by attaching each end of a preassembled racking system to the Unistrut, using the preattached L-feet and the correct bolt assemblies.

NOTE: Use the Sunwize drawings on the following pages to ensure correct assembly. Notice that the panel rails face opposite directions – each preassembled leg is half of a pair.



2.	Lay 3 panels in landscape, face down, onto a rug. Ensure that the junction boxes on each panel are facing the same way. Lay the assembled rack on top of the panel, and bolt modules to the panel rail using the bolt and wingnut assemblies. Ensure that the module is square with the rack and spaced evenly!	
3.	Attach grounding lugs to each panel using the grounding lug assemblies. The machine screw should go through the lug, through the star washer, through the hole in the module marked “G.” On the other side, place the star washer, then the flat washer, then the lock washer, and finally the nut. Orient the lug in the same direction of the panel (**Rotated 90° from what’s shown in the picture to the right**). Tighten.	

4. Attach grounding lugs to each panel rail. Using an appropriately sized drill bit, drill a hole in the panel rail near the eventual top of the rail. Attach a grounding lug in the same way they were attached to the panels.



5. Attach the bare copper grounding wire to each PANEL lug (NOT the lugs on the rack installed in step 4!). Leave extra wire on the same side of the assembly as the panel rack grounding lug.

6. Inspect all mechanical connections, and, using 4 people, flip the entire assembled rack.

7. Repeat steps 1 – 6 for the other 6 racks.

8. Run the long grounding wire across all the racks, attaching at each lug, starting from the farthest point from the inverter cart. Go back through and attach each rack's panel grounding wire to the home run grounding using the split bolts.

9. Connect the grounds to the grounding rod near the array.

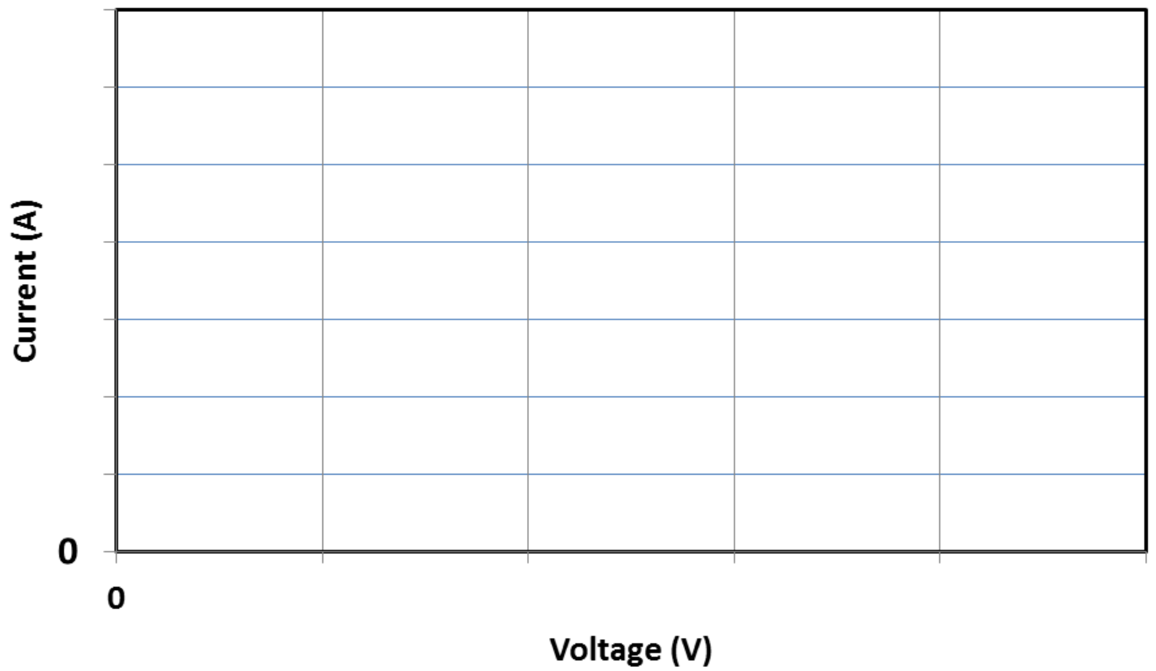
10. Connect the Grounding Electrode Conductor from the inverter to the grounding rod.

11. Connect the grounding wire from the modules and racks to ground in the junction boxes.
12. Connect your series strings together (+ to -). Attach the home run cables at the appropriate ends, and bring the (+) and (-) at each end of the series string to the junction box.
13. Connect each (+) and (-) to the appropriate connectors at the junction box.
14. Inspect fuses in the inverter.
15. Connect the power cables from the inverter to the central panel.
16. Check voltages at the array junction boxes.
17. Connect the power cables from the modules to the inverter.
18. Compare the system output with the expected output based on a light meter.

Activity 6: PV System Commissioning – I-V Curve Worksheet

In this Activity, students will be asked to determine the I-V curve for a string of modules connected to an inverter by drawing the "ideal" curve, either by best guess using the given specifications of the module, or by finding it in the spec sheet, and comparing it to a curve created by individual measurements.

Using the blank sheet below, draw the ideal curve as a solid line. Remember to fill in the scale values on the x and y axes.



1. It would be much too dangerous to determine the short circuit current for an entire string of modules at once. Record the short circuit current of a single module below.

Current (Amps)	Voltage (Volts)
	0V

2. Following best practices and proper safety, measure the open circuit voltage of the string when the inverter is either off or disconnected from the string (as appropriate). Simultaneously record the temperature of the back of one of the modules and the irradiance in the same plane as the modules (same tilt and azimuth angle).

Current (Amps)	Voltage (Volts)	Temperature (°C)	Irradiance (Watts/m^2)
0A			

3. Connect the string or module back to the inverter and ensure the inverter is operational. If there are multiple strings, all strings except the one being tested should be disconnected (touch safe fuse holders opened, for instance). Record the current and voltage of the string, along with the temperature of a representative module and the irradiance.

Current (Amps)	Voltage (Volts)	Temperature (°C)	Irradiance (Watts/m^2)

4. Record these three values on the graph above. Draw a best fit line.

KEY QUESTIONS:

1. If your line differs from the ideal line, how does it differ and why?
2. What information can you derive from this curve? Could you identify a problem with the module?
3. Is this procedure easy to do? How much time did it take?
4. Is this procedure safe to do?
5. Calculate the production in step 3. How does this value differ from the rated power of the module?

Activity 7: System Design - String and Inverter Matching

An engineer has given you a basis of design for an array that should make the maximum use of the space to the right.

The engineer has specified you must use

- Solarworld Sunmodule Pro 315 XL mono, 315-watt PV modules
- An AET Rayport B racking system
- Advanced Energy AE 3TL 1000 series inverters

Your task is to:

1. Determine the maximum number of modules that can physically fit in this space, such that no module is shaded from surrounding obstructions or from other parts of the array between 9AM-3PM all year long.
2. Determine array orientation and tilt angle taking into account optimum orientation versus maximum density with consideration towards energy yield with respect to system costs.
3. Determine the inverter or combination of inverters that have a power range equivalent to the wattage of your maximum array.
4. Calculate the maximum number of modules per series string that will work with your chosen inverter(s).
5. Calculate the minimum number of modules per series string that will work with your chosen inverter(s).
6. Identify a likely point of array electrical integration and determine if a load side or supply side tie-in point is needed.
7. Calculate available bus capacity for the installation of back-feed breakers if necessary.
8. Determine if you will need combiner boxes in this array, and where they might go.
9. Size all source circuit and output circuit conductors and over current protection devices (OCPD).
10. Size the overcurrent protection devices and the grounding system, including equipment grounding conductors and grounding and bonding points and equipment.

Activity 8: System Inspection

DESCRIPTION

In this Activity, students will experience what the plan review and electrical inspection process is like from the perspective of an electrical inspector. Students will review a plan set of a “not yet built” PV system for compliance with the applicable building codes, and then accompany an inspector on an inspection of the “as built” PV system.

Note to Instructor: Questions included below can be emphasized or deemphasized as appropriate to the class and student. For instance, a plan reviewer would verify the size of every conductor. While good practice for the student, this might be more than is necessary for that class.

KEY QUESTIONS – PLAN REVIEW

1. What electrical and building codes apply to this project?
2. What information is required for the plan reviewer to do their job effectively?
3. What calculations would a reviewer have to perform during a plan review?
4. How do the answers to questions 2 and 3 affect how materials are organized in a plan set? Does it seem as if the plan set used here has addressed this in any way?
5. Are the source circuit and output circuit conductors sized to the appropriate code?
6. Are the strings sized according to the appropriate code?
7. Are the overcurrent protection devices sized according to the appropriate code?
8. Are the lanes between array sections or the edge of the array and roof edges sized to the appropriate code?

KEY QUESTIONS – INSPECTION

1. Who makes the decision about how the code is interpreted in a particular situation?
2. Why does the inspector work from the array to the utility meter, and not the other way?
3. When in the installation or planning process should you contact an electrical inspector?
4. What practices can an installer do to ensure a smooth inspection?
5. What parts of a PV installation will an electrical inspector not examine (depending on location)?
6. What are the differences between an inspection with a separate plan review and an inspection without a plan review?
7. What is the process for introducing new equipment to an electrical inspector?

Activity 9: PV Systems O&M – I-V Curve Worksheet

In this Activity, a lab assistant will create various problems in a string of modules outside of the view of the student. The students will assist the instructor in wearing correct PPE, properly isolating strings in a combiner box, attaching equipment and clamps, and testing individual strings. Each curve will be sketched by the students. The students will then propose a reason for any difference from ideal curve shape. If time allows, the I-V curve tracer should be disassembled between each reading, giving several students a chance to begin from a live, untouched combiner box.

Describe the situation and if there is anything strange about the I-V curve:

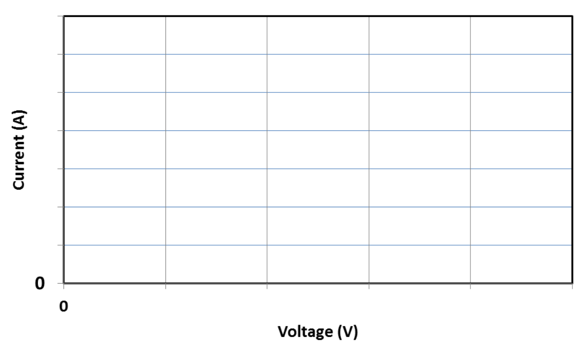
Example: “10 cells shaded on one module of one string” or “Two different array azimuths” or “Weird bump at knee of curve,” or “Low current.”

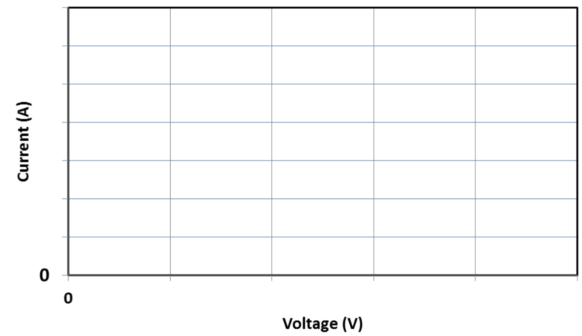
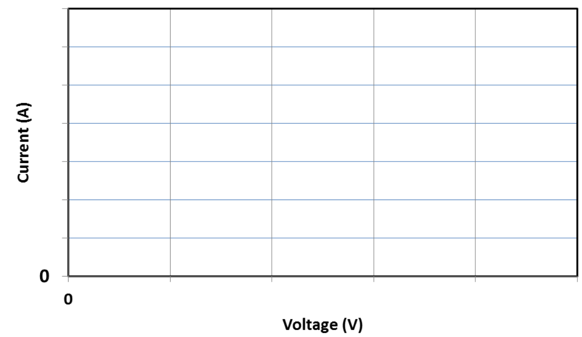
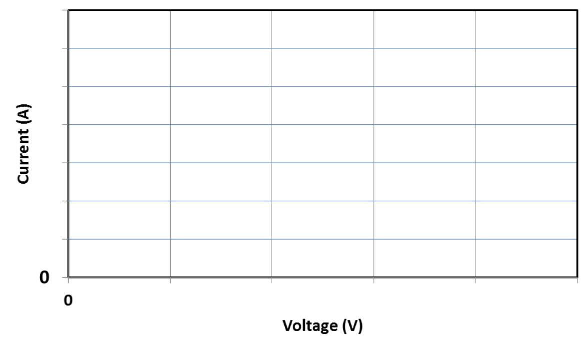
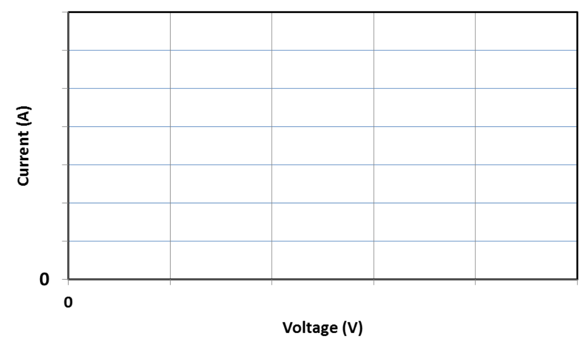
Draw the I-V Curve:

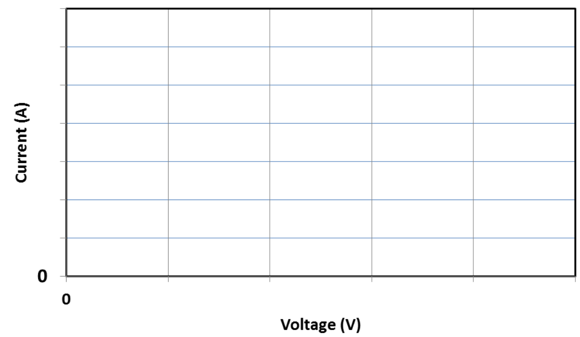
Remember to include numbers on the voltage and current scales.

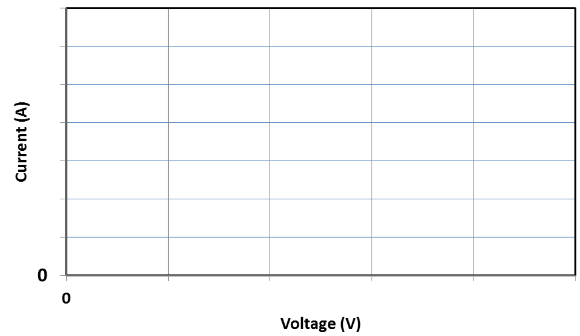
Options:

- Optimal azimuth and spacing
- Sub-optimal orientation
- Inter-row shading
- Selective shading
- Differing irradiance
- Poor module performance
  - Shading
  - Soiling
  - Mix in odd module
  - Remove module from string
- Differing temperature



	Current (A) 0 0 Voltage (V)
	Current (A) 0 0 Voltage (V)
	Current (A) 0 0 Voltage (V)
	Current (A) 0 0 Voltage (V)


Current (A)
0
0
Voltage (V)


Current (A)
0
0
Voltage (V)

Activity 10: Financial Analysis

DESCRIPTION

In this Activity, students will begin by performing a simple financial calculation on the array designed in Activity 7. Various additional factors will be added in to show both the effect those factors will have on relevant factors, but also so that the student can understand the scope of financial techniques used in the modern PV industry.

Some of the topics covered here might have been covered in Activity 7.

KEY QUESTIONS

1. Using the array as designed, what is the simple payback period? What is the cost per watt?
    a. Simple payback factors
        i. Cost of system
        ii. Value of avoided cost of electricity
        iii. ITC (investment tax credit)
        iv. Local rebates or incentives

2. Add other payback elements. What differences exist between simple payback and a full financial analysis?
    a. SRECs
        i. SREC terms and contracts changing over time
    b. Depreciation
    c. Financing options
        i. Loan interest
        ii. Tax implications of loans

3. What is the payback period on the array with a different tilt angle (meaning more modules at a lower, less ideal angle, or fewer modules at a higher, more ideal tilt angle)?
    a. How does orientation effect the amount of electricity offset?

4. What is the payback period on the array with a non-ideal azimuth angle (meaning more modules at a less ideal azimuth angle, or fewer modules at a more ideal azimuth angle, whichever is more appropriate to the situation)? Can the calculation be done with a decreased cost per watt due to economies of scale?
    a. How much of the electricity usage would this system offset?
    b. How would cost per Watt and payback period change if this went from a ground mount to a roof mount, or vise-versa?

5. Using the array design, how do the elements from Question 2. effect the payback of the system?
    a. If the current state has an SREC market, how does including this affect the payback period and cost per watt?
    b. How do taxes affect the payback period?
    c. How does the financing model affect the payback period?
    d. How do the state incentives affect the payback period?
    e. What changes if this system were owned by a commercial entity or by a residential owner?

6. What would a PPA agreement look like for this system? What would the company issuing the PPA charge for the electricity from the system?

Activity 11: Case Studies

DESCRIPTION

In this Activity, students will learn about a complete project from beginning to end. Students will be expected to demonstrate an ability to acquire and interpret information about the project from relevant project documents.

KEY QUESTIONS

1. Who is the owner of the project? What is the ownership model?
2. What other parties were involved (i.e. contractors, commissioning agents, financiers, engineering firms)?
3. How was the array financed?
4. What was the total cost of the array?
5. Does the array face south? What are the azimuth and tilt angles? Are they what you expected, and can you account for why they might differ?
6. How much production is lost due to non-optimal orientation? What are the financial impacts? Why was this choice made?
7. What is the mounting system like, and what work (if any) was required to prepare the site (i.e. earth moving, or new roof installation)? Are there inter-row shading issues? What was the design consideration?
8. Does the array use a central inverter, string inverters, or microinverters? Is this the choice you would have made?
9. What type of system is used to protect conductors (i.e. are they free floating, in conduit, in a cable tray, buried, etc.)?
10. How are the modules and racking system grounded and bonded?
11. Were there any delays or problems in construction?
12. Did the job use union or non-union labor?
13. Was an experienced solar contractor hired or consulted, or was it the first PV project for the contractor?
14. Who designed the array?
15. Were there any problems with the plan review or inspection process?
16. Is the array performing as expected?
17. Is there a commissioning report?
18. Is there a monitoring system?
19. Have there been any problems at the array since it was commissioned?
20. If you were charged with performing a retro-commissioning of the site, what tests would you do and where would you start?
21. Are there any visible signs of wear or damage at the array?