Course Title: ***Advanced PV Design (PV201) (NRG 220)*** **5 credits (55 hours)**
Prepared by: Larry Owens **Date:** August 31, 2012

New course (Proposed),Clean Energy Technology/Science Department, Shoreline Community College
Skill set used: Energy Project/Program Management.

Description: This is a 5 credit (quarter system) follow-up class after successfully completion of an Introduction to PV (NRG 120) class. The focus is to expand upon what was learned in the intro class and expand it by designing complete Photovoltaic systems that are compliant with NEC codes and regulations. Emphasis on correct component selection for the system's purpose, string sizing, inverter/module matching, conductor sizing, overload protection, system & equipment grounding, mounting systems, battery backup and accurate 3-line drawings. At the end of the course, successful students will be able to design code-compliant PV systems for both grid-tie and battery back-up applications. This will be done by providing real-world PV design and installation scenarios.

Required Text: *"Photovoltaic Systems"* second edition, by James P. Dunlap
Recommended Text: "***Understanding NEC Requirements for Solar Photovoltaic Systems"***, by Mike Holt.

Prerequisite classes: NRG 101 (Intro to Renewable Energy), NRG 120 (Intro to Photovoltaic Systems), or permission by instructor. This class requires prior knowledge of PV systems through either a required class or on-the-job training.

Recommended Prerequisite classes: Electric Theory AC & DC, Math 100, SketchUp 3D modeling class

Unit 1: Basic DC electronics review. (D3, C3, E1)

Introduction: PV systems work with both DC and AC circuits. The most common mistakes in PV system design involve the DC side of the system. Understanding the basics of DC circuits is essential to proper PV system design. This unit will focus on DC circuits and their characteristics. Safety issues regarding DC circuits in PV systems such as proper DC disconnect wiring and over-current protection will be introduced.

Topics: Ohm's Law, sources of DC circuits, series and parallel circuits

Learning objectives:
1. Describe/draw a series circuit
2. Describe/draw a parallel circuit
3. Describe a series-parallel circuit
4. Use Ohm's Law to solve for E, I, and R in series circuits
5. Calculate voltage and current in provided series and parallel circuit drawings

Major Activities:

- Instructor lecture and AV presentation.
- Group work: draw series and parallel circuits on board or using DCCK.
- Students use DC Circuit Construction Kit (DCCK) (software) to design circuits.
- Hands-on activity: Using dry cell batteries and conductors create series and parallel circuits. Measure the voltage in each circuit. Calculate the current in each based on current data per battery provided by instructor.
- Readings – Chapter 5, sections on series and parallel connections.
- Homework – design series and parallel circuits meeting criteria provided by instructor.

Assessment: Primary assessment will be through written quiz and lab work using DCCK in addition to assigned homework.

Unit 2: Basic PV review: (D3, D7, D8, E6)

The photovoltaic process, types of PV systems (thin film, crystalline), PV terminology: cells/modules/arrays, simple PV parallel and series PV circuit characteristics, temperature coefficients of performance, IV power-curves, module specifications.

Introduction: Photovoltaic systems are complex with few or no "plug-and-play components", interchangeability, or standard sizes. Understanding how the photovoltaic process works coupled with PV design restraints and characteristics will lead to better system design. 'Underperforming' systems are usually a result of poor design or as a result of not fully understanding how actual system performance differs from "Rated" or Nameplate power specs.

Learning objectives:

Students will be able to describe the photovoltaic effect
Know the relationship between PV cells, modules, and arrays
Define the key current-voltage (IV) parameters and characteristics for PV devices
Demonstrate knowledge by calculating temperature corrected performance of PV modules
Describe the differences between Standard and PVUSA test conditions

Major Activities:

- Instructor Lecture & Presentations
- Reading: Chapter 5 of textbook
- Textbook's CD – The Photovoltaic effect animation
- Hands on – Examine thin film and crystalline PV modules and cells
- Using multimeter, measure and record output characteristics of PV modules
- Hands on: Determine output characteristics of PV modules by examining and comparing module labels

Terms covered:
Photovoltaic cell, semiconductor, doping, p- and n-type semiconductors, p-n junction, Voc, Isc, MPP, Vmp, Imp, I-V curve, Temperature coefficient.

Assessment: Unit Quiz and lab worksheets

Unit 3: Solar Radiation, Site surveys & planning.

Effects of tilt angle, orientation, and shading on PV systems. **(A8, C3, D3, D8, E1, E3, E6, E12)**

Introduction:
Even a perfectly designed PV system will under produce or fail to produce electricity if shading and module placement is done incorrectly. This unit teaches how solar radiation is measured, how PV modules are rated under Standard Test Conditions, and how real-world conditions can dramatically improve or decrease a PV systems' performance. Safety procedures and equipment are an essential element when planning a PV installation and while conducting an on-site survey.

Learning objectives:

Explain the effects of shading on PV modules and arrays.
Determine shading levels and the resultant effect on output.
Identify important data that must be collected during a solar site survey such as roof pitch and orientation, roof type, shading, nearby wiring or other potential hazards.
Calculate inter-row spacing required to eliminate shading of one row by another.
Explain safety measures, equipment, or procedures needed for safely conducting a rooftop survey.

Major Activities:
Instructor lecture and presentations. Group discussion. Read chapter 3. Textbook CD Pathfinder video and worksheets. Students will conduct onsite surveys to collect pertinent information that will affect PV array performance and suitability. Students will use solar survey tools such as Solar Pathfinder to determine shading. On-site visits to local installations to see, document, and evaluate potential and existing PV installations.

Terms covered:
Solar irradiation, solar irradiance, insolation, peak sun, peak sun hours, solar and magnetic declination, array angle azimuth, solar time, solstice, equinox, solar window, single- and dual-axis tracking.

Assessment:
In addition to the unit quiz, students will be evaluated on their site survey forms and in-class /online discussion.

Unit 4: Inverters & Inverter Selection Criteria: Matching inverter and array characteristics for optimal power output. **(C2, C3, C5, C6, D3, D8, E1, E4, E6)**

Introduction:

Inverters change the DC electricity produced by the photovoltaic modules into AC that is most commonly used in a residence or commercial property. It is critical to properly match the input and output characteristics of both the modules and inverter to maximize power output. A mismatched system will not only underperform, but may also be a fire and safety hazard. Students will learn to calculate output characteristics of various PV arrays and how to identify and select an appropriate inverter to match those characteristics.

Learning objectives:

Be able to specify inverters for different system types and sizes. Specify combiner box sizing for inverters. Understand inverter ratings, specifications, and limitations. Identify basic waveform types. Explain the difference between single phase and three-phase AC Power. Determine appropriate inverter size for a given PV array.

Major Activities:

Instructor lecture and presentations. Read Chapter 8

Labs: Hands on - Examine actual string and micro-Inverters using specifications and labeling to determine operating parameters.

Given the power output characteristics of a PV array, students will identify appropriate inverter(s) that match those characteristics.

Hands-on: Students will properly wire an-un-energized inverter and combiner/fuse box.

Terms covered: DC, AC, waveform, sine wave, modified square wave, single and three-phase power, maximum power point tracking, stand-by losses.

Assessment: Unit Quiz, lab worksheets, and practical wiring exercise

Unit 5: Battery Back-up for grid-tie and off-grid applications: (C2, C3, C5, C6, D3, D8, E1, E4, E6)

Introduction:

Although the large majority of all PV systems installed in the US and other industrialized countries do not include battery backup, the demand for electrical storage for PV systems is rising. In less developed countries or areas without a stable electrical grid, battery backup storage is essential. As battery storage solutions become less expensive and easier to integrate their usage will grow significantly. This unit will focus on battery technology, function, and integration, along with a focus on the balance of system components needed for a properly designed system.

Learning objectives:
Differentiate between the different classifications and types of batteries. Understand the characteristics and stages of battery charging and discharging. Explain how temperature, discharge/charge rates and electrolyte specific gravity affect battery life, capacity, and performance. Identify potential battery hazards including electrical, electrolyte, explosion and personnel protection. Demonstrate how to increase voltage and/or current through parallel and serial connections.

Major Activities:
Instructor lecture and presentation. Text-CD videos on "Battery Discharge & Charge"and "Charge Control." Use Charge Controller Profile worksheet to identify appropriate equipment.
Using load sizing worksheet from textbook students will determine proper battery bank sizing to meet load demand. Create line drawings with integrated battery backup.

Terms covered:
Battery cell, electrolyte, plate, active material, capacity, Amp-Hour, Depth of Charge, State of Charge, cutoff voltage, bulk/absorption/float charging, equalizing charging, specific gravity, sulfation, stratification, primary battery, secondary battery.

Assessment: Quiz and worksheets

Unit 6: System sizing to meet load and design criteria: Single vs multiple inverter systems, over-current/over-voltage considerations. **(B10, C1, C2, C3, C4, C5, C6, C8, C9, C13, D2, D3)**

Introduction:
In unit 5 students learned how to match PV characteristics with inverter specifications for maximum power output. This unit takes a deeper look into the strategies of inverter and system sizing. For example, when is it more appropriate to use ten 10kW inverters rather than one 100kW inverter? Significant performance and cost considerations due to inverter choices can drastically affect system design.

Learning objectives:
Understand the main factors in PV system sizing. Calculate the size and configuration of a PV array based upon load calculations and system requirements. Using a load analysis determine a PV system energy and power requirements. Calculate the size and configuration of a battery bank system based on the overall system requirements. Students will integrate the performance parameters of PV modules, inverters, and batteries learned in previous units to appropriately size complete systems.

Major Activities:
Instructor lecture & presentation. Read Chapter 9 in textbook. Complete a load analysis worksheet using nameplate values and tested values using a Kill-A-Watt meter (or equivalent). Re-calculate using energy efficient appliances/loads to determine best PV System size. LAB: includes using watt meter and data sheets to determine total electric load, average daily load, peak loads, and surge/start loads for PV systems.

Terminology:
Duty Cycle, amp-hours, kilowatt hours, critical design ratio, critical design month, autonomy, load fraction, load analysis, power demand, average daily load, peak load, surge load.

Assessment: Quiz and worksheets

Unit 7: NEC 690 & other code requirements for photovoltaic systems (H1 – H12)

Introduction:
Photovoltaic systems must meet all federal, state, and local safety and code requirements. Special rules and conditions apply to PV systems that sometimes directly contradict with other parts of the National Electric Code. This unit will focus on the key portions of Section 690 of the NEC that pertain to photovoltaic systems and discuss other code requirements. A later unit (Unit 8) will focus on the components such as conductors and disconnects more than on the codes and rules themselves.

Learning objectives: Students will be able to:
- Identify the electrical codes, and in particular Section 690 of the NEC code which is applicable to Photovoltaic systems.
- Understand the role of electrical and building codes in connection with PV systems.
- Calculate minimum sizing requirements for conductors and circuits of PV system according to NEC code.
- Find the appropriate section of NEC code that covers conductor sizing, over-current protection, temperature and fill corrections, and conduit size.

Major Activities:
Instructor lecture and presentation, Read chapter 11 and 13 in textbook.
Lab: "Find the Code" exercise where students will find the appropriate code section dealing with specific scenarios presented by the instructor. For example, finding the code sections that specific minimum wire size and type for a DC circuit that is 200' long, will be exposed to temperatures in excess of 80C, and carrying a current of 30 Amps.

Assessment: Quiz, lab worksheets

Terms used:
NFPA 70: National Electric Code, Article 690 (of NEC code), maximum system voltage and current, short circuit current rating, code compliant junction boxes and disconnects, JHA (Jurisdiction Having Authority), plans examiner, building code, NRTL (Nationally Recognized Testing Laboratory), UL 1703 for PV modules, UL 1741 for inverters, UL Recognized Component Mark, OSHA.

Unit 8: Electrical Integration (C2-C6, D3, D6, D8, E1, E3, E6, H1-H4, H6, H12)

Introduction:
In the previous units, students have learned how to appropriately size the major components of a photovoltaic system. This unit covers all the rest of the electrical integration components such as conductors (wires), fuses, disconnects, and how to use the NEC tables and charts to correctly size these components. Integration with an electrical grid or off-grid building requires attention to specific details and codes. Special emphasis is on grounding.

Learning objectives:
Be able to size grounding conductors for both AC and DC portions of PV systems.
Identify potential causes of ground-faults and explain troubleshooting procedures for them.
Perform sizing and interconnection calculations for large systems. Determine the appropriate types and locations of disconnects. Optimize the match between the PV output and inverter input for maximum performance.

Major Activities:
Instructor lecture and presentation, Read chapter 11. Students will draw complete system designs with BOS components and properly sized wiring and disconnects. Students will discuss and review multiple PV system designs provided by the instructor to determine whether they show correctly sized conductors/fuses/disconnects, and whether they are properly designed to meet the code requirements they learned in unit 7.

Terms covered:
PV power source, PV source circuit, PV output circuit, ground-fault protection, circuit breaker, combiner box, fuse / fusible link, overcurrent protection device, disconnect, equipment grounding conductor, GFCI, load-side connection, supply side connection, back-fed circuit breakers, net metering, islanding, synchronizing.

Assessment: Unit quiz, worksheets and system design drawing

Unit 9: Mechanical Integration (C2-C6, D3, D6, D8, E1, E3, E6,H1-H4, H6, H12)

Introduction:
Mechanical design and integration of a PV system requires knowledge of the key elements and characteristics of buildings and racking systems including loads (uplift, weight), attachment methods, and safety. Students will learn how to evaluate the advantages and disadvantages of mounting options in order to determine an appropriate, safe, and secure installation method. The use of on-site surveys is valuable in making these determinations.

Learning objectives:
Identify key elements in a mounting system. Differentiate between different mounting system options

for a given installation scenario. (rooftop, ground mount, pole mount, etc.) Calculate uplift calculations for PV arrays. Calculate inter-row spacing requirements to prevent shading.

Major Activities:
Read & understand chapter 10, take CD quiz for chapter, conduct a site survey for a potential rooftop installation. Students in small groups will design 3 mounting systems: ballasted rooftop, pole mounted, and standard (sloped) rooftop based on parameters provided by the instructor.
Lab: Safely mount PV modules to the training roof using rack system and best practices.

Terms Covered:
INOCT (installed nominal operating cell temperature), fixed-tilt and tracking mounting systems, galvanic corrosion, sacrificial anode, design load, dead load, live load, wind load, snow load, vibration load, exposure factor, allowable withdrawal load, spanning and blocking, J-bolt, ballast systems.

Assessment:
Unit Quiz, homework. Student configured mounting system will be evaluated both as a group activity and by the instructor. Lab will be graded based on safety, secure attachment, and appearance.

Unit 10: System drawings, system labeling requirements, and interconnection Requirements (E1-E6, G1, G2, H1-H12)

Introduction:
Every utility requires specific system drawings before approval of grid-interconnection can occur. In addition, national and local codes have system labeling requirements so that the system can be easily identified, shut off or isolated from the grid and house, and to prevent accidents. This unit coves 1-line and 3-line drawings, NEC 690 labeling requirements, and other common interconnection requirements.

Learning objectives:
Students will be able to correctly label all the parts/components/systems in a grid-tied PV system.
Students will be able to draw an accurate 1-line and 3-line drawing of that system.
Students will be able to complete a typical utility's interconnection agreement's requirements regarding specifications, drawings, and labeling.

Major Activities:
Instructor lecture and presentation. Examine and review of actual nameplate labels. Lab activity: Match labels with components and identify correct labeling on actual PV system(s). Examine and discuss at least 5 different line drawings for various systems. Students (in small groups) will design and draw line diagrams for 2 different PV systems. The drawings will include all required labels as specified by a utility.

Assessment:
Students will be evaluated on their lab assignments and take a quiz on labels and drawings. Be able to perform labeling calculations for single and three-phase AC service.

Terms covered:
1-line drawing, 3-line drawing, site drawings, electrical diagrams, Equipment specifications, array mounting design drawings, PV module labels, Array-disconnect labels, AC-Disconnect labels, Point-of-Connection Labels, Battery System Labels, Power-Source Identification, Ground-Fault-Indicator Labels, Ungrounded-System Labels, Single 120 V Supply Labels, Operating Labels, Maintenance Labels, Inspection checklist.

TERM PROJECT: (A1, A6, A15, A18, B1-4, C1-C6, C8-C9, C14, D2, D3, E1-4, E6, E9, E13, F3, G1, H1-H11)

The term project will be carried out by small groups of students working together. The students will design multiple systems including a 10kW, a 100 kW, and a 1 MW PV system that complies with NEC and other codes. In addition, due consideration to siting, shading, and other location-specific conditions must be made so that the system will operate optimally after installation. Assessment will be a based on all of the elements covered in each unit of this course. The complete designs will be presented along with a cost analysis, expected performance outcomes, and 1-line and 3-line drawings. The appropriate labels and codes must be included. There will be both a group evaluation of each design and an instructor evaluation of both the project and the feedback quality from the students. In other words, their class peers will evaluate their projects and the instructor will evaluate the projects.