AC 2008-2705: MEDIUM VOLTAGE SWITCHGEAR, TRANSFORMER AND INTERCONNECTION SPECIFICATION IN AN ECE CLINIC

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I. Abstract

Working on real world engineering technology projects with industry is a key component of Rowan University's engineering clinics. Our College of Engineering has Industrial affiliates who regularly act as sponsors of the ECE curriculum by bringing important and diverse real world engineering design challenges to ECE students. This paper discusses how undergraduate ECE students were called upon to first learn about the proposed renewable energy system (in this case a 3MW photovoltaic system – the largest of its kind east of Arizona in the U.S.) optimize the array field and the DC wiring, and then to assist in the development of specifications for the low voltage (480V) and the medium voltage (33 kV) switchgear, transformer and e-metering system specifications for the project. This paper provides an overview of how the engineering clinic engaged the students in applying their power system knowledge as well as the mechanism the College uses to engage industrial sponsors in the ECE curriculum. The ECE professor and his graduate student aided the student engineering clinic project team and assured that students would learn by doing on this important 'power system of the future' project. The students learned how theoretical work links to real applications in the case of interfacing the largest PV system ever connected to the world's largest Regional Transmission Organization (PJM). The paper describes the approach to creating the required specifications which included the development of student understanding of the role such equipment plays in the electric power system and the importance of integrating clean energy technology into the system to reduce the climate change impacts of electricity in the U.S.

II. The Kick-Off Meeting - [Thursday 20 September 2007 – 2PM]

PECO District and interconnection engineers, customer service folks, SunTechnics solar engineers and project managers have converged on a 15-acre site in Tulleytown PA adjacent a multi-acre landfill to discuss the layout and design of the largest photovoltaic system being constructed in the United States east of Arizona. It is mid afternoon on a September weekday and six undergraduate engineers from Rowan University and their professor are there as well as the discussions of interconnection, pole locations, array filed placement and foundation types are shared among the project team. Why are the students there? They too are part of the project team to learn their assignment for designing the AC interconnection for the autumn semester in engineering clinic. This real world experience with cutting edge engineering technology projects with industry creates an excitement and sense of ownership, interdependence and responsibility for the junior and senior engineering students. Their professor has given them a chance to see how real engineering projects are designed and how communication among team players is crucial to the success of the final design. Throughout the following semester the engineering students will interact with each other, their professor and professional engineers from the utility as well as their industrial sponsor (SunTechnics) to ensure that they deliver their part of the project which includes: specifications, designs and plans for the medium voltage switchgear, 480V to 33kV transformers, 480V switchgear and cable sizing for the required project deadline. Their key resources include their engineering education, their professors, their new contacts on the utility professional team and their partners at SunTechnics. Have they done this type of work before? Not yet, but that is why they are in college. The engineering clinic was based upon the medical model for training physicians by teaching them the basics of human anatomy, physiology etc. and then make sure that before they go out in the real world to practice alone they gain clinic or residency experience where they can be supported by other physicians. The engineering clinic is a key component of the Rowan University student educational experience and spans all four of the students' years in their undergraduate training. The details of the clinic are described elsewhere[1,2,3] as are the many opportunities that students at this university have had to apply the clinic to innovative renewable energy and sustainability activities[4-11].

III. The Challenge: Switchgear, Transformer, Inverter House Specifications and Plans

The project team was created to bring into reality a concept developed by SunTechnics[12], their sister finance company Epuron and Exelon[13]. Exelon Generation Company, LLC through their Wholesale Power Marketing Division located in Kennett Square, Pennsylvania, USA is one of the most active companies within PJM and MISO in creating structured power marketing deals that can best optimize resources for the supply and demand portfolios (including renewable energy) of Exelon and other electric utilities. The growing market for renewable energy certificates (RECs) in the PJM market place (particularly Pennsylvania and New Jersey) has been spawned by the aggressive renewable portfolio standards that have been legislated in many states within the US and across PJM. In this project Exelon serves as the primary off-taker of the RECs that will be generated by this PV power and power purchaser/broker for the electricity this project delivers to the PJM[14] grid. Epuron has developed a group of investors who desire to own

TABLE I
EQUIPMENT SPECIFIED FOR THE 3-MVA PV POWER PLANT

Item	Component Descriptions		
	Device	#	Model
1	175 watt Photovoltaic Modules	17,160	Conergy S – 175 MU *UL 1703*
2	DC Combiner Boxes	130	SMA SCCB12 *NEMA 3R/4*
3	Lightning Arrestors	130	Delta LA602
4	DC Disconnects	79	Square D HU363RB *NEMA 3R UL98*
5	DC-AC 500 kW Inverters	6	Satcon Powergate *UL 1741* *IEEE 929, 1547, 519* *ANSI 62.41*
6	480V Switchgear	3	Square D
7	480V/30kV 1-MVA Transformer	3	Cooper
8	Medium Voltage Switchgear	1	G&W

this project based upon the cash flow that the annual purchase of energy and RECs by Exelon creates and the value of the tax credits in the near-term. By the summer of 2007 the financial team was able to reach agreement on pricing and the technical aspects of the project were started. It was at that time that, SunTechnics, a former Industrial Affiliate of Rowan University clinics, saw a perfect role for using the College of Engineering to assist them in the medium voltage (33kV) AC aspects of the project. Table 1 provides an overall equipment list for the project; the undergraduate and graduate engineering students were responsible for specification, details and plans for items 6, 7 and 8. After the successful kick-off meeting the professor met with the students to review the project's single-line diagram and describe what components the project team would be responsible for specifying, reviewing quotations, developing specifications and final plans and details. The switchgear portion of this single line is shown in Figure 1.

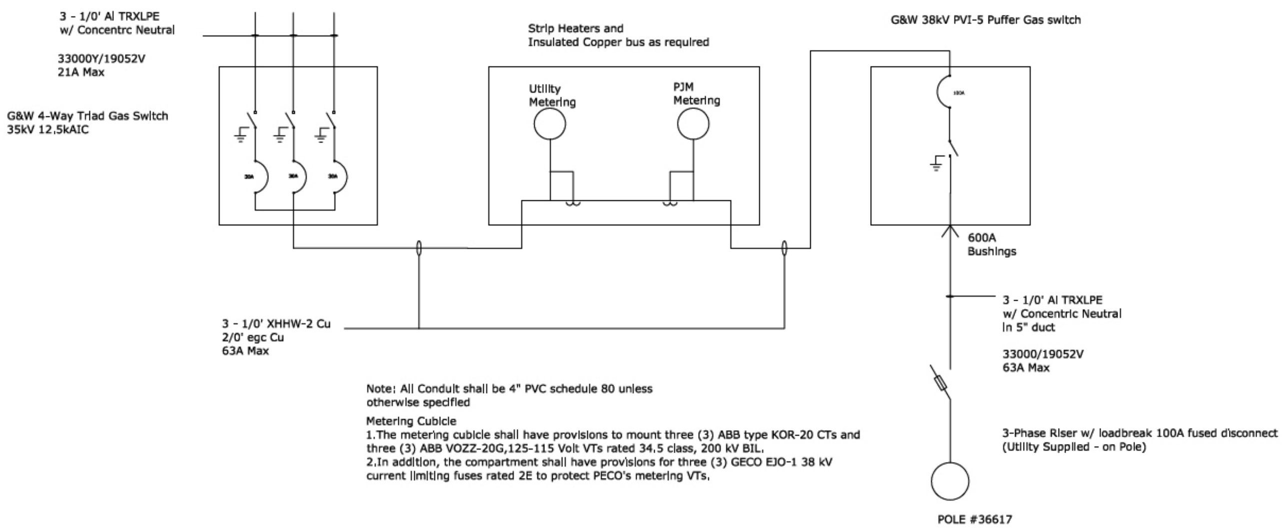

Figure 1 – Project Single Line Diagram

IV. The Results and Student Efforts

The students were responsible to read and become familiar with the interconnection requirements of the local electric utility PECO[15] as well as PJM. Their first introduction to these requirements was through discussions with SunTechnics and PECO engineers during the kick-off meeting at the project site. At this meeting they became aware of potential locations where the switchgear could conveniently be placed on the site and to learn the location of the new utility pole where it would ultimately be interconnected. During the clinic the student team also reviewed and became familiar with the requirements of medium voltage switchgear and the PECO Blue Book[15] requirements for equipment that could be placed into service on their system. The engineering students were required to participate in teleconferences so that they could become familiar with the differences between each manufacturer's equipment. Once SunTechnics selected a manufacturer (in this case G&W) the student team was charged with developing the computer aided design (CAD) drawings which were used in the final plans for the project. Figure 2 illustrates one of the views that an ECE student developed for the 33 kV switchgear –

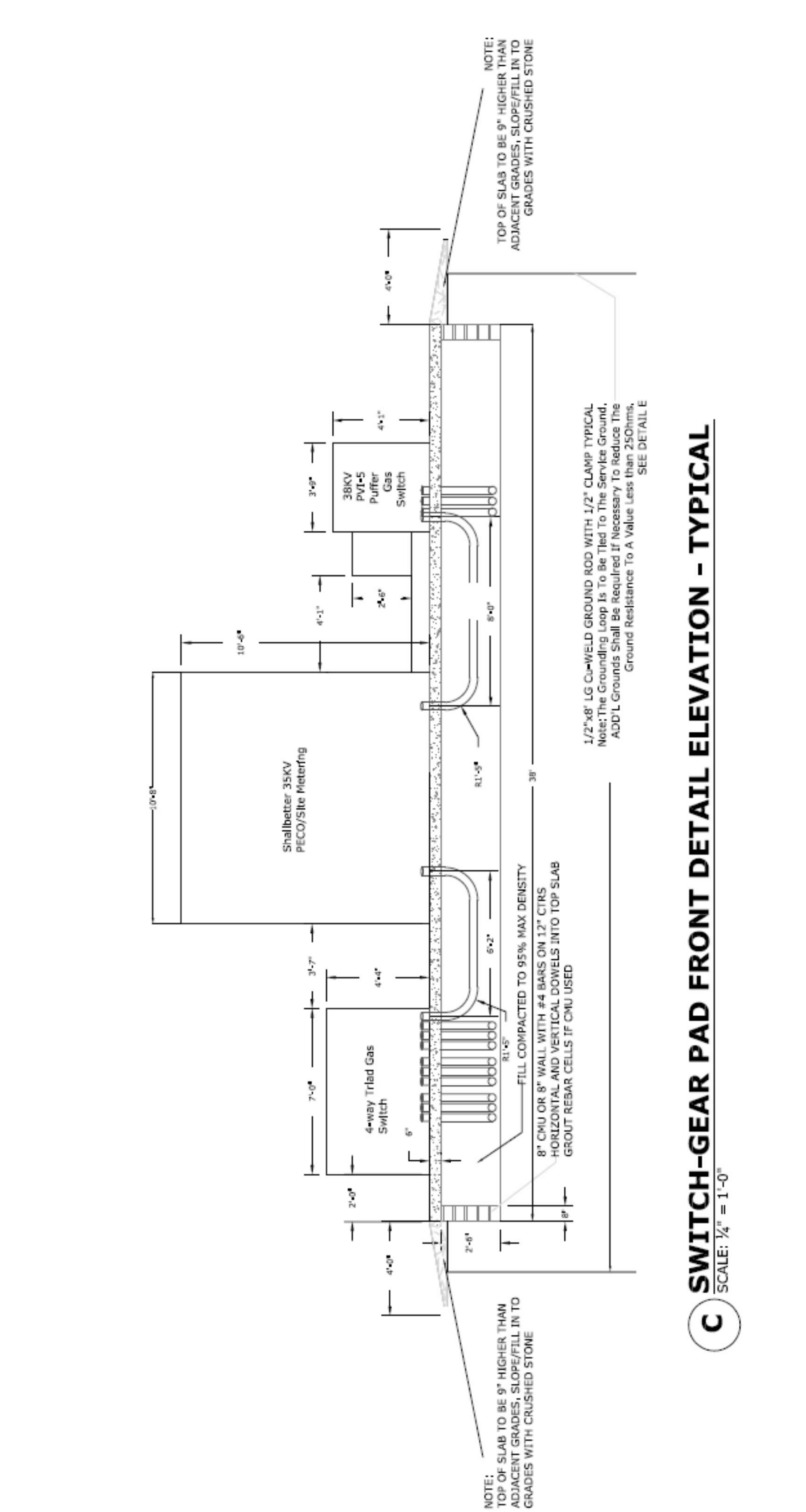

Figure 2 – Student Designed Switchgear Pad Elevation View with Details

the drawing reveals that the clinic team had to learn significant new information to complete the plans beyond their normal classroom knowledge (i.e., equipment clearances per NEC and acceptable engineering practice, cable bending radii, conduit requirements, grounding protection lightning protection, etc.). The design that SunTechnics engineers gave the clinic students included coupling each 500 kW Satcon DC to AC inverter with one other 500 kW inverter in a roofed shelter called an inverter house (an open side roofed structure). The team was responsible for developing various arrangements that met the initial layout requirements of the industrial sponsor and then build the CAD structure so that the design of the single line could be visualized in three dimensions and from all directions. These plans enabled them to determine the feasibility of the locations and clearances they had specified for all the real hardware and its actual dimensions. As they created their first drafts they quickly learned about the difficulty of making trade-offs between cost and size of structures. The single line for the inverter houses and one of the many views the students developed for the plans are shown in Figures 3 and 4.

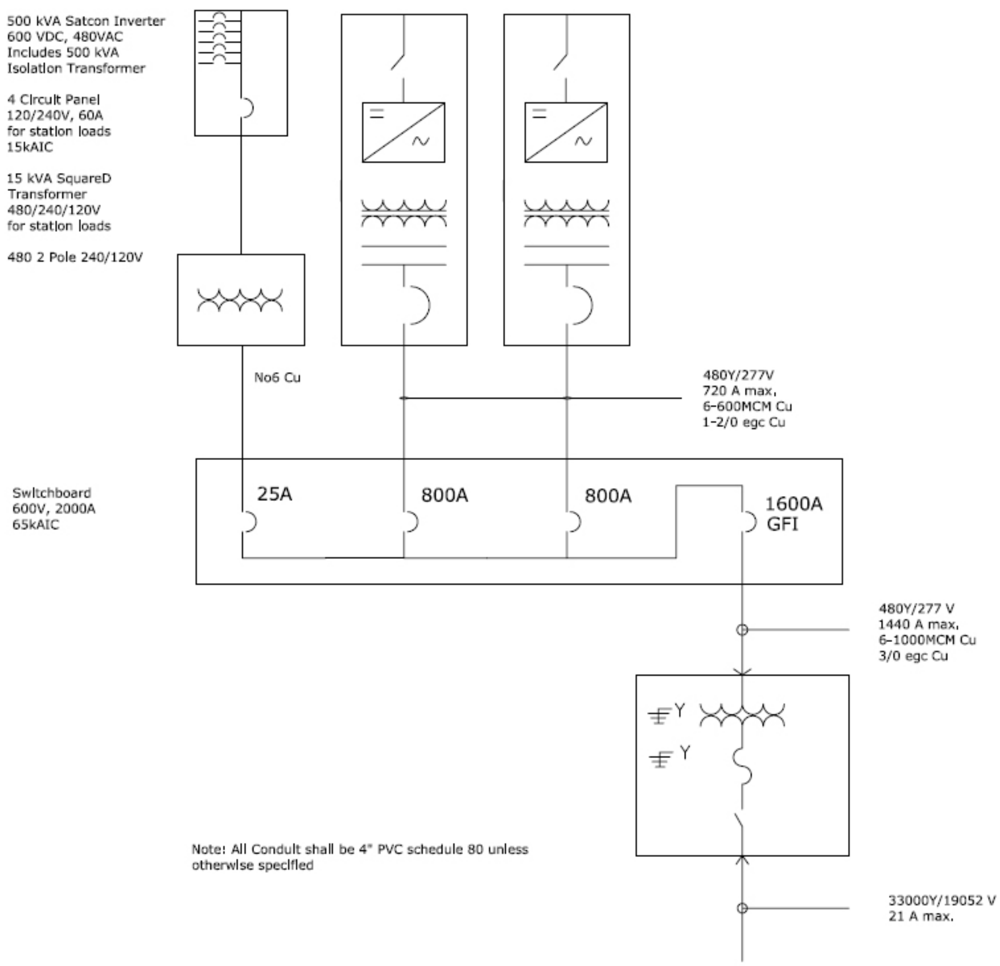

Figure 3 – Inverter Pad Typical Single Line

As shown in Figure 3 the power output of each inverter is combined through the 480V switch board before being connected to the 480V/33kV step-up transformer. The clinic team assisted SunTechnics engineers in the specification and design of that switchboard. The 480V switchgear

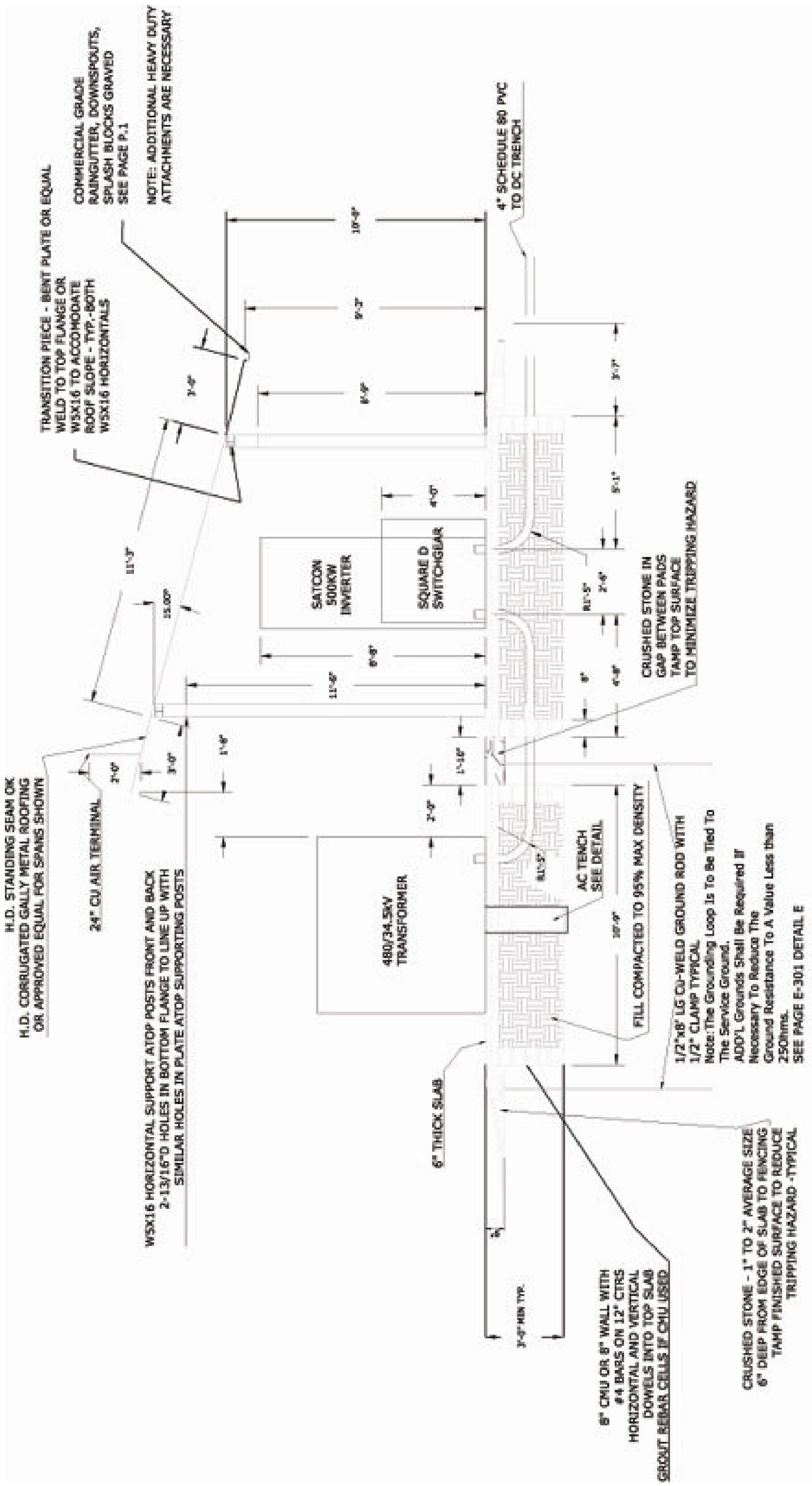

Figure 4 – Elevation View CAD Drawing Typical Inverter House

includes a main bus rated for 600V, 2,000A with four breakers. The main breaker (480V/277V) three phase is rated for 1,600A while the two, three-pole breakers feeding the Satcon inverters are each rated for 800A. In addition a 25A breaker feeds a small station service transformer converting the 480V/277V to single phase 120V/240V for loads such as lighting, telemetry, security, etc. The project includes three such inverter houses feeding three step-up transformers that are interconnected at the medium voltage switchgear. The team specified the 480V/33kV pad mounted step-up transformers for this application that met the highest efficiency standards published. Specifically, these are the NEMA TP-1 requirements[16]. The student design team found from the manufacturers' bids that the higher efficiency units required a premium of about $1,200 (USD) in upfront capital cost but would produce a reduction in standby losses of 1,840 kWh/year and production losses of 7,454 kWh/year for a total savings of 9,293 kWh/year. At typical utility costs for the project this high efficiency unit will save $270/year in electricity bills and have about a 5-year payback. However, in the renewable energy market the value of production savings at the value of the renewable energy credits to the market would be worth over $2,000. It is clear that this high efficiency unit will pay for its premium cost in less than six months. Over its 25 year life the high efficiency transformer will generate $62,825 in economic benefit to the project. The transformer selected was a Cooper Power Systems 1,000 kVA three phase, 480V/33kV grounded Wye configuration which has an efficiency of 99.2% and uses 1.2 kW at no-load conditions when the PV system will not be producing electricity.

After very positive discussions with the utility engineers at PECO and PJM and manufacturers who have regularly provided switchgear meeting the PECO Bluebook requirements[15] the team was able to create an acceptable set of specifications for interconnection switchgear. Due to the inverters that had been selected by the project team no additional relays or protective devices were required by the PECO engineers for the medium voltage equipment. This equipment specification included the 33kV – 100A service entrance gas insulated main switch, two cabinets for the PECO and PJM metering (with adequate space for the three ABB KOR-20 current transformers, and the three ABB VOZZ-20G potential transformers – specified by PECO interconnection requirements). Finally, three 33kV gas insulated 30A switches protecting the cable runs to the 3 transformers and PV inverter houses. The cables specified can be seen in the single-line diagram in Figure 1 and were three 1/0 aluminum TRXPLE cables with concentric neutral. The main service entrance cable from the switchgear to the PECO feeder was also three 1/0 aluminum TRXPLE cables in a 5" PVC duct to continue up the riser pole. The three phase riser pole included loadbreak 100A fused disconnects per PECO requirements. The selected vendor was G&W who provided switchgear to meet the design team's specification and delivery requirements. Their PECO Blue Book switch was G&W Catalog No. PV121-396-12-5: 38kV, 150kV BIL, SF_6 insulated, dead front, padmounted, front/back access, two way switch with 1 loadbreak way and 1 vacuum interrupter way. The service entrance switch was a separate device, the metering cabinets were constructed as one large device, howbeit partitioned, and the triple switch was a third device all sharing the same concrete pad. The devices were separated minimally to meet NEC requirements for bending radii for the cables entering and exiting the adjacent cabinets.

The IEEE Guide for Direct Lightning Stroke Shielding of Substations[17] and our local utility's Substation Manual – Section 12 Surge Arresters, Insulation Coordination and Lightning Protection[18] were used to develop the lightning protection strategy for the inverter houses. The

NFPA and National Electrical Codes as well as best utility practices were employed in the design of the ground grid for the electrical equipment and switchgear. Each inverter house included three (3) roof mounted 24", Class II, ½" diameter, Cu Air terminals connected together by No. 4 equivalent braided conductor and brought to ground to connect with two 8' copper ground rods (½" diameter) buried ten feet (10') beneath the ground and separated by ten horizontal distance. The location is not a very high risk zone for lightning with only 28 thunderdays per year.

This project will generate over 3,725 MWhrs during its first year of operation and is modeled to generate over 3,500 MWhrs per year (on-average) over its 25-year life. The PV electricity provides significant utility and environmental benefits. It reduces the amount of greenhouse gases entering the atmosphere by at least 3.8 million pounds annually nearly 2,000 tons of CO_2. Over its life this is over 50,000 tons of carbon will be kept from the atmosphere. The project contributes to the lessening of summer peak demand on the electric grid. In this part of the US the electric grid is extremely strained during the summer due to air conditioning loads which are very coincident with solar energy availability. This project is near the end of a PECO feeder so it actually provides grid support through its production of unity power factor electricity and voltage support near the feeder end. Finally, this project uses the capital of the free market to invest in electric power facilities that save rate payers from investing in traditional utility generation. It also provides rate payers the opportunity to select green power as part of their option of buying electricity – those who want to make a difference in the environment or protect it for future generations can buy RECs on the open access utility market to make their electricity greener. As more states across the US adopt aggressive renewable portfolio standards the market for this type of large scale PV power plants will continue to expand to meet an ever growing consumer preference for clean and green electric power. From our university's perspective it provides one of the greatest opportunities to get young engineers excited about learning and seeing the role engineers can play in making the world a better place.

V. Conclusions and Assessment

The project was a success in terms of each aspect we hoped the clinic experience would create: 1) a real world engineering design challenge, 2) students learning practical engineering techniques and content knowledge not otherwise available in the ECE curriculum, 3) students gaining an appreciation of how utility engineers and renewable energy engineers work in the practice of engineering, and finally 4) the satisfying of a client by meeting their engineering needs in terms of workable design and credible plan/drawing development. While specific assessment of individual clinics is not typically part of our ABET assessment process due to the few number of students participating in any particular clinic, each project provides its own opportunities for performing a meaningful evaluation. This is typically through reviewing student work in terms of their reports, designs, customer feedback, drawings, etc. by the professor or other qualified professionals. As to the success of the project in achieving the first three goals, we have culled some student comments which seem applicable

"This clinic project offered a great overview of power engineering and PV system design. Having no previous experience in PV design, I learned how solar modules are interconnected to produce power while keeping DC current and system losses low. This project also enhanced my knowledge of how both DC and AC power is transmitted using proper system protection and grounding. " – Senior engineering student

"The start of this project was by far the hardest. As students without any prior knowledge of utility grade designing, NEC codes, medium/high voltage lines and their design it was a frightening experience having immediate deadlines for the completion of specs, outlines and diagrams for a project of this size. It was a learning experience that challenged our resilience and capacity for new knowledge all the while forcing us to immediately make use of newly learned material and guidelines. Not only was it interesting to learn about such an intricate system, but designing it at the same time created a whole new understanding of things we see everyday and take for granted. Transformers, inverters and cables never looked to be such a result of delicate calculations as they do now. " – Graduate student

It was also possible to directly evaluate the fourth goal by assessing the customer's satisfaction with the result and by reviewing the feedback from the construction code officials of the design. The industrial affiliate, SunTechnics, was very pleased with the clinic project work and has expressed their satisfaction with the College of Engineering. The electrical details, plans and designs were approved by the building code officials without revision. The system is currently under construction and so the greatest test of success will be when the 3 MW PV power plant comes on line and goes live as the largest on PJM in the summer of 2008. Each of the student team will know they played an important role in the design of that complex engineering system,

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