

SOLAR: The Future of Energy

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Use contexts

island (microgrid)

This system is defined as being completely disconnected from the energy grid, creating a micro-grid with energy production, storage and load. Energy storage is used to provide power when not enough power is currently being produced. Micro-grid stability is still an ongoing area of research and power fluctuations in even these simple systems can be complicated.

grid w/o storage

The advantage of connecting a renewable energy system to the grid is that it outsources responsibility for providing power all of the time; by being connected to the electricity grid you are guaranteed to have all of your power demands met regardless of if the sun is out. Most power companies will provide their users with credits to their electricity bill when they add additional power to the grid. This makes storing energy less appealing since you can get credit for producing it on your power bill and don't have to deal with the expense of storage or the energy losses associated with it. However, if renewable energy production were to grow dramatically without coupling it with energy storage it would be extremely problematic because peak power production would not match up with peak demand, which typically occurs a few hours after peak solar production hours. This scenario could lead to significant instability in the electricity grid including brown outs and other problems.

grid w/ storage

A grid connected solar system makes sense when there is a large disparity between peak and off peak prices. In this case the user can take advantage of arbitrage between the high and low electricity prices, selling their excess power when prices are high and buying additional power when prices are low. Storage also allows for a number of other used scenarios such as load shifting, where demand for power is shifted in time via energy storage in order to lower energy costs. Power companies typically charge their users not only for the amount of total power used (number of kilowatt hours), but also for their peak demand (maximum number of kilowatts demanded at any point). Because of this, peak shaving, or reducing peak demand using stored energy, can be another way to save money on an energy bill. The down side to energy storage is that it can be costly up front and is not perfectly efficient so power is lost transferring it into and out of the battery.

Determining how to best bring storage into the grid infrastructure will also become more critical as the percentage of grid power provided by renewables increases. While outside the scope of our project, this is an exciting and somewhat controversial new frontier in the field.

Which are appropriate for Olin?

CBA of 45kWh battery

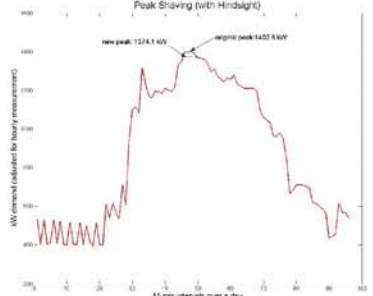


As part of the SCOPE contract between Premium Power and Olin College, Premium Power would contribute a Zinc Flow 45 battery. This battery is the smallest of the batteries that Premium Power produces, rated for 45 kWh. We critically evaluates potential roles for the ZF45 unit on Olin's campus. The system considered consists of only the battery connected to the grid, without a solar array.

Peak Shaving

Electric bills include a demand charge, which is a fee based on the greatest amount of power used every month. For example, Olin's peak demand in September 2008 was 1402.6 kW, and NSTAR charged over \$20 per kW, resulting in a demand charge of \$28,150.19. The amount charged for the total number of kWh used in September 2008 was \$4,419.31. Peak shaving may be useful to reduce the peak demand level reached every month, lowering our demand charge. In reality, it is unlikely that the peak demand for a given month is 30 kW higher than the next highest demand level, so the 37.6kWh available for peak shaving would be discharged over some period of time. Ideally we can allocate the 37.6kWh available in the most beneficial way. Assume that the battery will be charged and discharged every day to achieve a universal lowering of peak demand.

Given the data for actual energy usage every 15 minutes on the day that the peak demand level oc-



curred, Figure 2 compares the original demand curve to the one achieved using a peak shaving algorithm. The area between the two curves is equal to the 37.6 kWh available from the battery.

Conclusion: Given these two "best-case" scenarios, it seems that the battery is too small to create enough value, used to do peak shaving, to justify installment of the battery system. A maximum savings of \$600/month off a delivery services bill of \$32,806.57, not to mention the additional \$39,683.70 supplier bill, is relatively insignificant.

Arbitrage

Energy distributors sometimes charge different rates for peak and off-peak power. The battery could be charged from the grid during off-peak hours when rates are low and discharged during peak hours. When discharged, the power can be sold back to the grid, taking advantage of the disparity between the rates.

Conclusion: Olin is charged the same rates for peak and off-peak hours. Even if we were charged different rates, the rates are on the order of cents per kWh, and the size of our battery would be unlikely to result in significant savings.

Load Shifting

This concept is similar to arbitrage in that it capitalizes on the different rates charged for peak and off-peak power. For load shifting, the battery would be charged from a PV system discharged during peak hours to avoid paying the higher peak-hour rates.

Conclusion: Olin is charged the same rates for peak and off-peak hours. Even if we were charged different rates, the rates are on the order of cents per kWh, and the size of our battery would be unlikely to result in significant savings.

Uninterruptible Power Supply (UPS)

In the event of a power outage, there is a short interval (~90 seconds) before Olin's on-site generators are able to kick in. The battery is able to begin discharging immediately, and could provide an uninterrupted power supply until the generators turn on.

Conclusion: This solution is only really valuable if there are things on campus that need to be on all the time. Possible examples are IT equipment and some lab equipment, such as refrigerators in the biology labs. To the best of our knowledge, these items already have their own UPS solutions.

conclusions

We conclude that without solar panels, the cost of a ZF45 system does not justify the benefits it may provide. Overall, a much larger storage system (at least 100 kWh) coupled with a matching PV system would be needed to provide value using techniques such as peak shaving and load shifting.

Grid-connected solar

Given agreement that PV should play a key role in Olin's energy future, we investigated possibilities for adding a substantial amount of PV-generated power to the campus. Since PV technology itself is still quite expensive, we considered two options in this initial inquiry: power purchase agreement and direct-own turnkey.

Both of the PV options considered are grid-connected-only, for a few reasons. Energy storage is quite expensive; the amount of storage that would be required to support a PV array large enough to completely address the campus' energy needs is prohibitively expensive. Additionally, local solar contractors pointed out that a significant amount of energy is lost when energy storage is used (e.g. the ZF45 has a 70% roundtrip charge/discharge efficiency). For this reason, systems planned to be grid-tied are not typically designed to include energy storage.

Power Purchase Agreement

The advantage of a power purchase agreement, or PPA, lies in eliminating the substantial initial capital investment required for installing a PV power system. Under a PPA, a solar contractor installs and maintains a PV array on-site for a customer at zero initial cost, then sells the power generated by the array to that customer at a premium over the grid price of electricity. The primary benefit of such a system is the ability to visibly supply a building or campus with energy from a renewable source (unlike less-visible power company "green" energy purchasing options6), without incurring the significant up-front cost of the PV array and associated power electronics.

Investigation and conclusions

Olin Facilities and Aramark looked into this option, contracting with Borrego Solar to complete a feasibility study for a PPA system of approximately 150 kW. While the feasibility study has been completed and was favorable, the college administration is not ready at this time to increase the monthly cost of electricity. If they could be presented with compelling evidence in favor of the investment, the project could be revisited.

Aside from the additional monthly cost, a PPA would require the college to lock into an energy price for approximately 30 years. At such a transitional time for PV technology and the energy market, this is not an attractive option. Additionally, it is unclear whether Borrego Solar would upgrade the PV arrays and power electronics as technology advances; retaining the ability of the College to do this would be an important consideration against entering a PPA.

Direct-Own Turnkey

Another option for bringing renewables on campus is to contract with Borrego or another firm to install an array and conditioning system on campus, which would become property of the college. This arrangement requires a substantial initial investment in the hardware, but power generated by the array is free and any excess can be sold back to the grid through a net metering program. Payback time (dividing the capital investment by the current monthly charge for power) is the primary metric used in decision-making by the college about this option.

Investigation and conclusions

We estimated the cost of PV panels to be \$1/W; a turnkey installation of the same size as that considered in Borrego's PPA feasibility study would cost ~\$150,000 for panels alone, not including power electronics (~\$5,000/\$kW), installation hardware or labor. We inquired with Borrego for a smaller system, ~20kW, to serve as a publicly-visible demonstration system that would reduce Olin's monthly grid demand. Borrego would be willing to work with us to reduce the non-hardware cost of the project by allowing members of the SCOPE team to do the brunt of the design work (and perhaps remaining feasibility analysis). There are also programs available to reduce the total project cost. The Commonwealth of Massachusetts has a tax rebate program for approximately a third of the project cost; the Massachusetts Technology Collaborative (MTC) runs an application-based grant program that pays for a portion of the project costs if hardware (PV panels and inverters) are made by companies based in Massachusetts.

This is as far as the team pursued the turnkey option; Borrego seemed very willing to work with Olin students to pursue this, so there is opportunity for a future group to pick up where we left off and explore the financial feasibility of such a system and attempt to convince the administration that it would provide value to the college tantamount to its capital cost.

Overall Recommendations

The primacy of financial concerns of the college administration is the greatest impediment to any option for bringing a substantial amount of PV to Olin. In other words, from a financial perspective, none of the options considered are particularly attractive. A PPA would be financially attractive in the short term—requiring no initial capital investment—but would lock the college into hardware and an energy price for the next 30 years, which is a scary proposition technologically and financially. As PV technology advances, revisiting the PPA option may make sense. A turnkey system, while requiring a substantial capital investment has the advantage of providing free electricity after the initial payback period. The school would have the option of upgrading equipment to keep pace with evolving PV technology. Thus, long term, a turnkey system is probably the better option.

conclusions

While an interesting option, grid-connected solar is not currently financially feasible for the college.

Design and construction: OLIN SOLAR TEST STAND

Needs and benefits

We believe that future understanding of, use of and development of solar energy at Olin is necessary. Large scale solar installations and energy storage systems to complement such an installation are currently not economically feasible. In addition, very few students and faculty on campus have experience working with solar installations. Therefore, to facilitate future work with solar energy at Olin, we decided to build a small scale solar installation. Our goals for the system are to:

- Make solar more accessible to Olin administration, faculty and students.
- Do something useful with the power produced.

To meet these two goals, we have designed an outdoor living space targeting the student body and powered by a small scale solar installation. The outdoor living space will be defined by a pergola and flagstone flooring. The pergola

will serve to provide shade as well as reduce glare on a laptop screen, and the flooring will ensure that the area under the pergola can be easily maintained. Within the pergola, there will be lights, outdoor speakers and a standard receptacle in order to increase the functionality of the space and reduce the activation energy needed to use the space.

In order to choose a location for the solar photovoltaic energy system, we first looked for sunny areas of the campus that weren't strictly controlled by the administration where members of the community would enjoy congregating and could use power. These criteria limited us to the area in front of the dorms, the eastern end of East Hall, and the grills. We felt that installing solar panels and improving the area near the grills would have the greatest benefit to the school, as there is neither lighting nor electricity there and it is an

underutilized space. Our rationale for the outdoor living space design is that to build awareness, the solar system should have an impact on student life at Olin even if individuals are not interested in working directly with the system.

The outdoor living space will be powered completely by a 440W solar installation that will be positioned close to the pergola. All electronics will be contained in a weatherproof box at the foot of 4 solar panels. The wiring diagrams and explanation of all the components will be made available to students, faculty and administration to make the electronic system as transparent as possible. The small scale system will serve as an example power electronics system that can be scaled up in the future, and data from the system can be used for research projects. By working on a scale that is accessible to students, we hope to build confidence in and familiarity with solar systems.

System specifications

The solar array system will be capable of producing up to 440 Watts at peak production. This power will be either stored in a battery for future use or sent through an inverter for use through the 120V AC power jack that will be included in the system. The system will also provide power to a real-time data display module as well as lights and speakers for the pergola. Finally, the system will also be able to provide power for a data acquisition system, should one be implemented.

AC System

We will be providing 120V AC power. The AC system, represented by the "load" box in the high-level system diagram below, will consist of 6 LED lights, 2 outdoor speakers with amplifier and 1 standard 15A receptacle. We do not have any DC loads.

DC System

The DC system consists of 4 solar panels, a solar tracking system, a combiner box where connections are made, a charge controller, and a battery. An inverter bridges the DC and AC systems. Rationale for our DC system component choices and the connections between them are presented in this section.

Panels

We will be using 4 Evergreen Solar EC-110-GL solar panels. They will be wired in parallel in order to run a 12 volt system. Our solar generator will have a rated voltage of 17 volts and a current up to 29.92 amps. If the panels operate under cold conditions, which are a regular occurrence in Massachusetts, the current may be up to 1.25 times higher, or 37.4 amps. All components which follow

the combined output of the solar panels must be sized to handle 1.25 times the maximum current, or 46.75 amps.

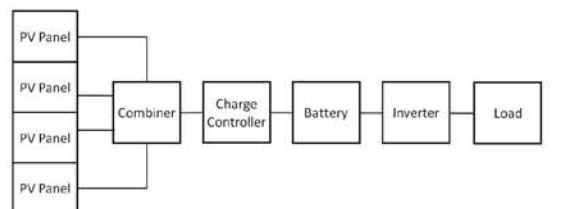
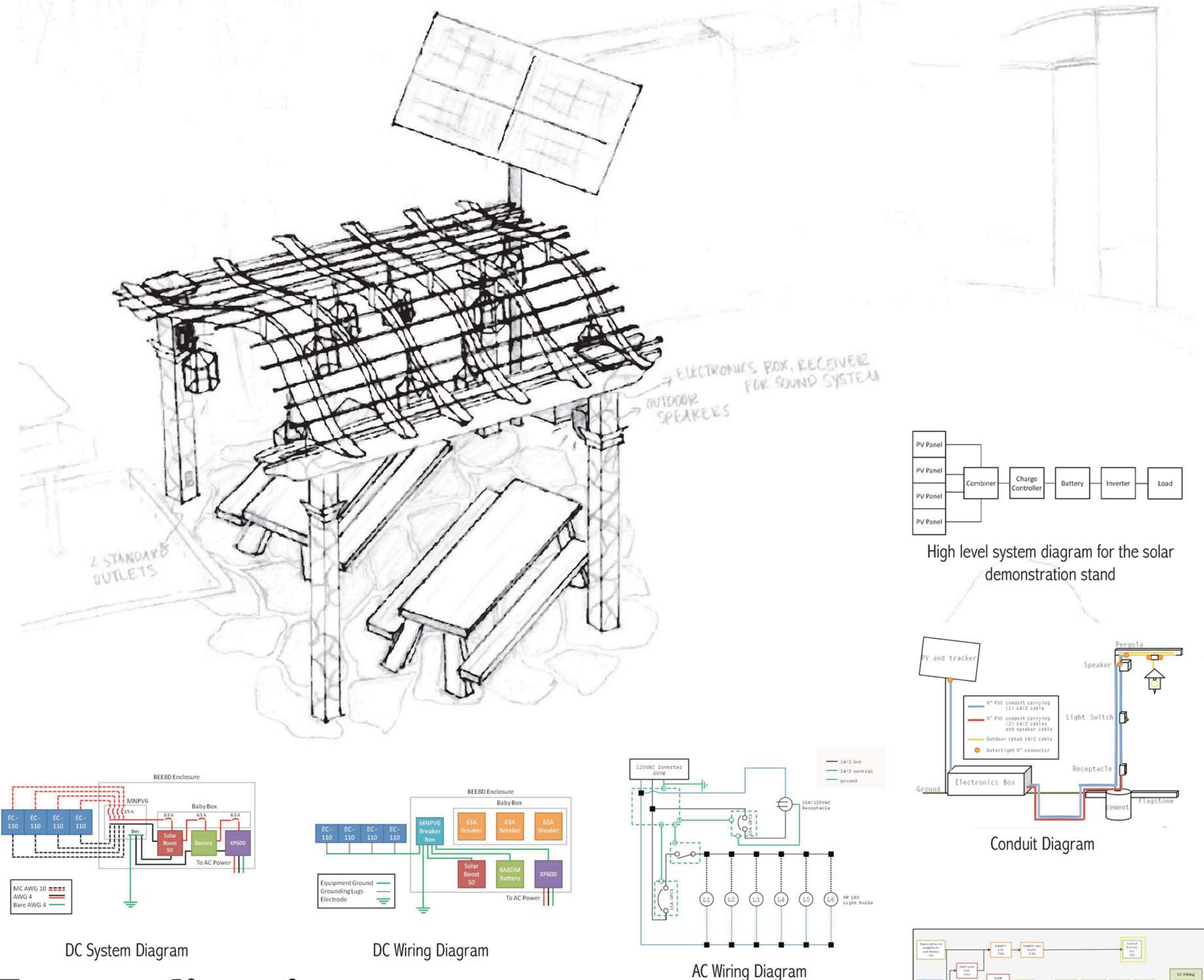
Tracking system

Two axis tracking systems can increase the yield of a PV system by 30% - 40% in the northern United States. The gains in power are greater during the winter than in the summer, though the gain in energy is usually not deemed cost effective for most systems. We will be using a Zomeworks 2 axis passive tracker for our system, as it will educate the community about solar tracking and is lower maintenance than comparable powered tracking systems.

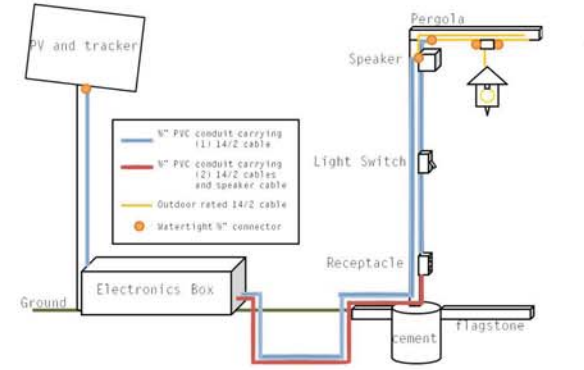
Charge controller

A charge controller is responsible not only for controlling the charging of the battery, but also improving the efficiency of our system by acting as a maximum power point tracker (MPPT). It must be capable of handling 46 amps. We will use the Blue Sky Solar Boost charge controller. This model is capable of remote sensing and output of data related to the status of our system, including battery voltage. The data will be displayed on a remote screen, though we do not yet have a way of downloading any of the data.

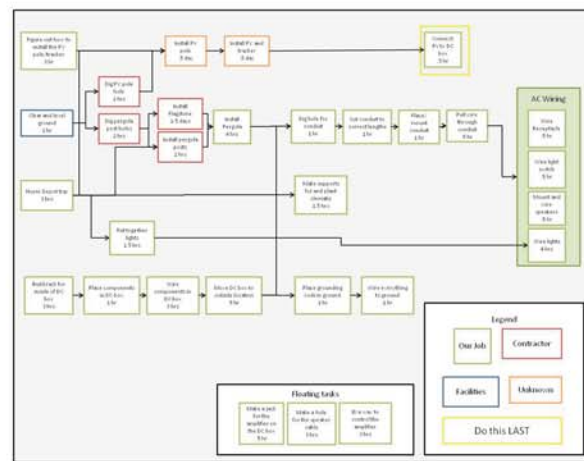
The negative output of the charge controller will be connected to ground through the equipment grounding bus in the combiner box. Grounding one of the current carrying conductors in a PV system improves the safety and operation of the system and allows us to avoid installing further ground fault protection.



High level system diagram for the solar demonstration stand



Conduit Diagram



Installation Plan

Future directions

Due to the time constraints of the SCOPE project, the Premium Power SCOPE team was unable to complete all of the work that we would have liked to in this semester. Future work for the system will include assembly of the components, testing of the system, and commissioning. This will include wiring, assembly, calibration of the maximum power point tracker, and integration of the light and speaker systems on the pergola. In addition to the completion of the initial solar power system, an excellent extension of the project would be to include real-

time data collection capabilities in the system, transmitting the current power production over wireless to the Olin network. Another option for future work would include integration with a microturbine and sensoring the system for microgrid stability research. The project will be rolled into Prof. Ben Linder's Sustainable Design research lab, and two students who have identified themselves as interested in carrying on with the project will be trained before the end of the year to ensure a smooth transition.