SuPER System Safety

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Abstract

For my senior project, I will be making sure that Cal Poly's Sustainable Power for Electrical Resources (SuPER) system is in compliance with the National Electric Code (NEC). To make sure SuPER meets the NEC, I will be checking conductor sizing, short circuit protection ratings, and every other system component. Note that some aspects of the system are not covered by the code and these decisions are left with the designer.

The purpose of this project is to ensure a safe design, which is why the primary source of recommendations will come from the NEC. Where applicable, other standards and practices will be used.

Some changes will not be feasible for the current system, as it may require a complete rewiring or overhaul. These changes will be recommended to be implemented in a second generation system. Other changes will be appropriate to be implemented into the current system. A summary at the end of the report will make this distinction.

Acknowledgements

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CHAPTER 1- INTRODUCTION

1.1 SuPER project

The goal of SuPER is to provide low cost sustainable electricity to disadvantaged people in developing nations, who do not have access to a utility grid. The system will power lights, a cooler, a motor to pump water, and a television. Since the system will not be grid tied, it will be a DC system with DC appliances.

The SuPER system is to have a 20 year life cycle and cost $2-3 per month. This is achieved with a system cost projection of $500. This will be met through the hope that the amazing drop in prices for electronics will apply to the components of this system, so that future parts will be very cheap. Note that SunWize makes a system similar to SuPER that is on the market, but is sold at high cost. Through the use of student design work, the cost for development, and hence end user cost, should be much lower than a private sector system.

1.2 Report method

The goal of this report is not for everybody to understand the report as that would eliminate any possibility of brevity. Rather this report was written so that any educated engineer with basic electrical knowledge could understand what is being communicated. This is done so that future students may reference the report and foster value from its recommendations. For example it would be good if a future engineering student working on making the system weatherproof could follow what was discussed here. That is why some concepts may be explained in detail, such as the calculation of ampacity or the operation of a circuit breaker. Additionally, some of these ideas are not taught in school and were new to me and many of my senor level electrical engineering peers.

The organization of the report will describe the major components of the system in detail. The components and practices currently used in the SuPER system will be examined. Recommendations based upon the NEC will be proposed. Where there is ambiguity or unclear wording in the NEC, additional sources will be used including articles and relevant professionals. The report contains appendices that have terminology, references, a power flow diagram, a control diagram, a recommendations summary, and a qualitative project summary. For referencing, where there is a number in brackets, this refers to a source listed in Appendix B. So if this sentence were derived from information found in source #X in Appendix B, it would be cited as follows.[X] The National Electric Code is a large book and is heavily used in this report, so for easy referencing, numbers in parenthesis refer to the relevant NEC article to be discussed. So (999A) would mean that NEC article 999A was being referred to in that sentence.

1.3 National Electric Code Explanation

The purpose of the NEC is the "practical safeguarding of persons and property from the hazards arising from the use of electricity."

The NEC is conveniently divided into about 8 major sections, including wiring and protection, wiring methods, equipment, and other areas. Within each section, there are various articles that cover specific equipment. For example, NEC chapter 4, equipment, has article 445 on generators, article 460 on capacitors, and 480 on storage batteries. There are many articles in the NEC. While this makes finding relevant information easy, it does not solve all problems. Many articles cross reference each other in special asterisks or notes, so care must be taken to find the correct rule. Some articles may have been written with a specific application in mind that covers most common scenarios, but your use of the equipment may be significantly different. In this case following the rule may be too risky, conservative, expensive, or at worst unsafe. Therefore the article recommendations must be considered carefully.

The NEC article that primarily concerns the SuPER system is article 690, which covers all aspects of photovoltaic systems. There are additional articles that also apply to the SuPER system. If there is another article that conflicts with article 690, article 690 takes precedence. (690.3)

1.4 Official Permitting

For a building to be deemed officially compliant with the National Electric Code, a local inspector must come to the building and approve the installation. These inspectors come out whenever a building permit has been issued. Since SuPER is a standalone system, this process will not be applicable. According to Mark Ellery, San Luis Obispo inspector, SuPER "is a separately derived system and will need to be approved by a third party testing organization such as the Underwriter's Laboratory."

Nevertheless, meeting all NEC requirements will be a major step towards official certification by a third party organization such as the Underwriter's Laboratory. Additionally, following the NEC will insure a safe system.

1.5 Additional Codes and Standards

While system safety is being examined, there are other considerations that may be used in addition to the National Electric Code. In particular, there are IEEE standards. IEEE 1374 concerns photovoltaic systems, but it was published in 1998 and is out of date. IEEE 519 deals with harmonic control in electrical systems, but it was published in 1992. IEEE 937 describes safe practices for lead acid batteries, and it was published in 2007 and so may be relevant.

The NEC must be followed for all electrical installations in the United States while the IEEE standards simply represent suggested safe practices. Where the NEC conflicts with the IEEE standards, the NEC code will take precedence. But if there is an area that the IEEE standard differs from the NEC and appears to be a safer, more intelligent practice, the recommendation will be noted.

CHAPTER 2- CURRENT SYSTEM SUMMARY

There is a working first generation prototype at Cal Poly. The major design work for the current system is done, except for the transition from a laptop based control system to an FPGA. Furthermore, the purchased DC to DC converter will be replaced by one built by Joe Witt's for his masters thesis.

It appears that the system was built to get a working prototype. Thus thoughts of safety and the National Electric Code were not given a high priority. Also test conditions for Cal Poly will significantly differ from those of the end user. At Cal Poly, the system will be dry and run by a qualified engineer. When in use by a consumer, this will not be the case.

The project has evolved over time and many changes have been implemented. The power flow diagram made in Vizio is outdated and is difficult to understand. New diagrams will be made that show updated connections.

CHAPTER 3- SYSTEM COMPONENT DETAILS AND RECOMMENDATIONS

Each component of the system will now be covered. The existing equipment, applicable NEC standards, other considerations, and recommendations will be discussed.

3.1 PV module

The PV module must be marked with open circuit voltage, operating voltage, maximum permissible system voltage, operating current, short circuit current, and maximum power. (690.51) All of these quantities are marked on the back of the panel by the manufacturer. The BP SX150S solar cell has 43.5V open circuit voltage, 34.5V operating voltage, 4.35A operating current, 4.75A short circuit current, 150W maximum power, and 600V maximum system voltage.

The maximum operating voltage of the system is based on the rated open circuit voltage of the photovoltaic panel, which is 43.5V. The rated open circuit voltage test is conducted at 25ºC. If the operating ambient temperature is colder than that, due to the nature of photovoltaic panels, the open circuit voltage will increase. Table 690.7 found in NEC article 690.7 contains the adjustment factors for this affect. The expected location of SuPER is Central America, South America, Southeast Asia, Indonesia, and Sub Saharan Africa. Based on these locations, the coldest temperature is estimated to be 0ºF. From Table 690.7 and this expected temperature, the adjustment factor is 1.17 so the maximum voltage of the system is 1.17*43.5V=50.9V. This value should be used in selecting equipment such as cables and disconnects. (690.7) It would not make sense for all equipment in power systems to be rated for the maximum possible voltage in the system. If this were the case, all equipment connected to the utility grid would need to be rated in excess of 69kV in most cases. Rather I believe this requirement is met by rating equipment at the new calculated voltage that would normally need to be rated for the operating voltage of the solar panel. So for SuPER, equipment that might be rated for 34.5V needs to be rated for 50.9V. While this may seem a small change, in higher voltage systems the temperature adjustment factor may have a large effect.

3.2 Receptacles

Receptacles allow an electrical appliance to get power by connecting to a power source. Article 406 covers receptacle. Receptacles must be marked with the manufacturer's name or identification and voltage and ampere ratings. (406.2A) Receptacles must also be rated for at least 15 amperes and 125 volts. (406.2B) According to 210.21(B), a single receptacle on a single branch circuit must have an ampere rating not less than that of the branch circuit. Receptacles installed on 15 and 20 ampere branch circuits should be of the grounding type. (406.3A)

These requirements are all difficult to meet because there is no standard DC distribution receptacle. Receptacles may be rated with a voltage and ampere rating for AC use, but not for DC. Jennifer Cao found that "120V AC receptacles were used because 240V AC receptacles were hard to find and it was determined that DC receptacles are expensive, unpractical, and unsafe." [1] For receptacles, it is recommended that NEMA style 6 be used in 15, 20, or 30 amp versions.[2] There are two receptacle systems in SuPER though. One is the DC wall mounted type that was just discussed.

DC appliances do no directly plug into those sockets though, as they have cigarette lighter plug ends. So currently in SuPER there is an adapter between the appliance and the DC wall receptacle. This is adapter is the equivalent of allowing a square peg to properly fit into a round hole. It does not change electrical parameters, voltage, or change AC to DC. Note that "cigarette lighter sockets and plugs do not meet the requirements of the NEC."[2] That idea is an interpretation found in an article about the NEC. There is no article in the NEC that specifically forbids the use of cigarette lighter receptacles. DC appliances are sold with that connection, so at this time there is no alternative to cigarette lighter plug receptacles for the SuPER system. The adapter previously mentioned is a bit messy and may not be the safest method, though at this time there may not be a great alternative. Hopefully in the future there may be a way around the use of the adapter.

Receptacles installed in wet locations shall be in a weatherproof enclosure that functions independent of plug insertion. (406.8 B1) This means that the enclosure must be weatherproof whether or not there is a device plugged into the receptacle. On SuPER both types of receptacles are not weatherproof at any time.

3.3 Cables

As current flows through a conductor, that conductor dissipates some power due to its internal resistance, this is known as "I^2R" loss. That dissipated energy must go somewhere and it becomes heat. Conductors can carry a differing amount of current safely; this current carrying capacity is called ampacity. The ampacity is based on the AWG (thickness), conductor's insulation, and corresponding temperature rating.

Generally speaking as the AWG, temperature rating, and insulation quality increase the ampacity increases. It should make sense that as the AWG goes up the conductor ampacity goes up, as a bigger wire can carry more current. If a conductor is rated for operation at a higher temperature, it can carry a greater current. For example, size 12 AWG copper conductor rated for 60ºC can carry 30 amps, 75ºC can carry 35 amps, and 90ºC can carry 40 amps. If a large amount of time is spent above the rated temperature of the conductor, the insulation properties change. This change reduces the safety of the wire and the insulation may even catch on fire. This is why insulation quality determines temperature rating, which in turn affects the ampacity. Also note that if a conductor is rated for 90ºC, but connects to a device with terminals rated for 60ºC, then the 60ºC ampacity must be used. SuPER's circuit breakers are rated to operate at up to 60ºC, so the 60ºC ampacity must be used.

Another aspect in ampacity calculations is the ambient temperature. If the outside temperature is hot, then because of thermodynamic effects it is harder for a conductor to release its heat to the outside environment. This causes a derating factor to be applied to conductors when calculating ampacity. The hotter the surrounding environment, the less current a conductor can safely carry. Table 310.16 within article 310.15 of the NEC contains the derating factor. The expected location of SuPER is Central America, South America, Southeast Asia, Indonesia, and Sub Saharan Africa. Based on these locations, operating conditions are estimated to be as high as 130ºF. From NEC Table 310.16, the ampacity must be multiplied by 0.76 to adjust for this high temperature.

From Jennifer Cao's senior project, she states that conductors of insulation type THHN/THWN were used, but then also states that size 10 AWG is rated for up to 40 amps. This conflicts with table 310.17 of the NEC, which states that the ampacity of a THHN/THWN conductor is 55 amps, and not 40. Yet it is a standard practice in industry to use the lower rated ampacity for your conductor even if the temperature rating allows the conductor to carry more current. This is conservative engineering. In addition, the cable terminates at a 60ºC rated circuit breaker, so recall that the lower 60ºC ampacity must now be used. Note that the previously discussed temperature correction factor was used from the 90ºC column. To use the 60ºC temperature adjustment factor and 60ºC ampacity for a 90ºC rate cable would result in an oversized cable. If the conservative number was used in both the ampacity and temperature correction, for example, a 10AWG 90ºC cable that could carry 41.8A in 51-55ºC ambient temperature would be calculated to only carry 16A. Using conservative adjustment factors for both effects is clearly too conservative.

To size the cables, the full load current must be known. Power values were taken from Tyler Sheffield's master's thesis.[4] The power values used are maximum values and hence represent times such as charging and using the laptop battery at the same time and the Coleman mini fridge having to cool a large load. This ensures that the cables are sized to carry worst case current and will not be strained under maximum operating conditions.

LOAD	FLA	FLA*1.25	CABLE	AMPACITY
Television	0.7	0.88	12 AWG	22.8
Cooler	5.8	7.25	12 AWG	22.8
Lights	0.4	0.5	12 AWG	22.8
Laptop	5.0	6.25	12 AWG	22.8

Table 1: SuPER loads and corresponding amperes

Table 1 compares the temperature adjusted ampacity of the conductor with 125% of the full load amperes. For circuits operating at less than 50 volts, as is the case with

SuPER, conductors should not be smaller than 12 AWG copper. (720.4) This is why table 1 shows some cable ampacities much greater than that required by the load. Note that this conductor size requirement is referenced with respect to current carrying conductors. Not shown in Table 1 is the switches and sensors cable, which are 18 AWG. These cables are smaller than 12 AWG, but since they are not current carrying this is okay.

Article 215.2 requires that feeder circuits must have an ampacity greater than 125 percent of continuous loads plus 100 percent of non-continuous loads. The 125% is done to ensure that conductors are never operated at more than 80% of their ampacity. (1/0.8=1.25) Continuous is defined as the expectation that maximum current will persist for 3 or more hours. Note that some SuPER loads may not technically qualify as continuous, such as the cooler, which only draws full load amps when cooling a large load. To be conservative, we shall define all the loads as continuous. As Table 1 shows, even when assuming that the loads are continuous, the cable ampacity is still more then adequate. Due to the presence of one 3 cigarette lighter to a single receptacle adapter, there is a rare chance that 3 loads may be plugged into the same receptacle. Even if this were to happen, the cable ampacity would still be adequate.

The photovoltaic source circuits, which in this case run from the PV array to the PV to DC switch board, and then to the DC to DC converter, have special ampacity calculations. The ampacity shall be greater than 156% of the short circuit current of the PV array. The short circuit current is used in this calculation to allow conductors to operate safely if the PV array is at or near a short circuit current operating point. (690.8) The 156% comes from two factors. First, the current must be 125% greater than the manufacturer supplied short circuit current rating. Near solar noon the PV module can deliver greater current that the short circuit current rating for more then three hours, so this must be accounted for. (690.8A) There is a second factor of 125% coming from the fact that circuit conductors must be sized to carry current greater than 125% of the current calculated in article 690.8A. (690.8B) This is done to ensure that conductors are never operated at more than 80% of their ampacity (1/0.8=1.25) So two factors of 125% multiply together to get 156% (1.25*1.25=1.56).

The short circuit rating of the PV module is 4.75A. With the rule in mind, 156% of 4.75A is 7.41A. So the PV source circuit conductor must have an ampacity of at least 7.41A. The PV panel 10 AWG cable ampacity is 30.4 amps, which is more than sufficient.

The motor branch circuit also has special rules governing its cable ampacity. For the DC motor, the NEC specifies that table 430.247 shall be used to determine full load current. The table only lists values starting at 90 volts though. It could be argued that the motor power could be determined from the table, which then could be used to determine full load amps at 12 volts. But from this method an inaccurate current was obtained. Instead it will be more accurate to use motor nameplate data which says full load amps is 21A, which is supported by experimental data. Article 430.22A requires that motor branch circuits be sized at 125% of full load current, which in this case would be 26.3 amps. The 10 AWG cable ampacity is 30.4 amps, which is greater than 26.3 Amps, so there is no problem.

For the capacitor branch circuit, the ampacity of the conductor must not be less than 135 percent of the rated current of the capacitor. (460.6B) The Maxwell capacitor datasheet does not specify a rated current and Maxwell technical support did not have a recommendation. Yet the NEC requirement is in reference to power capacitor switching, which is the standard power system application of capacitors. In this situation, where a capacitor will be used to start a DC motor, there are different guidelines that the NEC does not specify. The capacitor cable will carry a large amount of current for less than 1 second, and is 10 AWG, so there should be no problem.

For the source circuit, the conductor must be of type SE, sunlight resistant UF, USE, or USE-2 type conductor. (690.31B) These cables are all sunlight resistant. Currently, the system has RHW-2 cable for the source circuit, and this will need to be changed to one of the aforementioned types.

In SuPER'S design, there are many cables exposed to sunlight when in use outdoors. Article 300.6C1 requires that wires exposed to sunlight be listed as sunlight resistant. Article 310.8D also requires that cables exposed to direct rays of sun be marked as being sunlight resistant. In order to avoid these requirements, the cables can be put in conduit to avoid direct sunlight. This will satisfy NEC requirements according to Robert Armet, City of San Luis Obispo building inspector.

Article 310.8C lists the acceptable conductor types for use in wet locations. Conductors listed for use in wet locations as shown in article 310 tables are acceptable as well. The conductors are currently THHN/THHW which is not one of the listed types. Table 310.13 indicates that THHN cable may be used in damp locations and THHW cable may be used in wet locations. According to Robert Armet, City of San Luis Obispo building inspector, since the cable is marked with both designations, it can be used in wet locations. The loads are Romex NM-6 cable, which is not moisture resistant. Article 334.12B4 specifically forbids the use of type NM cable where exposed to excessive moisture. The motor cord Carol 5J00W is marked water resistant, so that will need to be changed as well.

3.4 Overcurrent protection

Article 240.4A specifies that an overcurrent device shall be required on each ungrounded conductor. Overcurrent devices protect system components and conductors from fault currents. Fault currents are unwanted and result from a variety of conditions, but their magnitude exceeds the normal operating current of the circuit. Because of this fault currents can damage conductors and equipment. Article 240.4A specifies that only ungrounded conductors be protected since an opened circuit breaker on a grounded conductor would disconnect the system from ground.

There are two main types of overcurrent protection, fuses and circuit breakers. They basically perform the same function except circuit breakers can clear a fault more then once. Each time a fuse interrupts an overcurrent, it must be replaced to restore normal operations to the circuit. Circuit breakers also have another advantage since they can be used as disconnect switches.

Circuit breakers are given ratings in amperes. This is the amount of current that the device will safely carry without opening or overheating. The circuit breaker will open based on the magnitude and time duration of a fault current. For example, a 200A current will open a circuit breaker faster than a 150A current.   Additionally a 150A current lasting 30 minutes may open the breaker while a 150A current lasting 1 minute may not. This balance of magnitude and time varies by breaker size and type. These are displayed graphically, called time delay curves, and figure 1 shows the curve for one of

SuPER's circuit breakers, the CBI QY series. Note that circuit conditions below (or to the left) of the curve will not cause the breaker to trip.

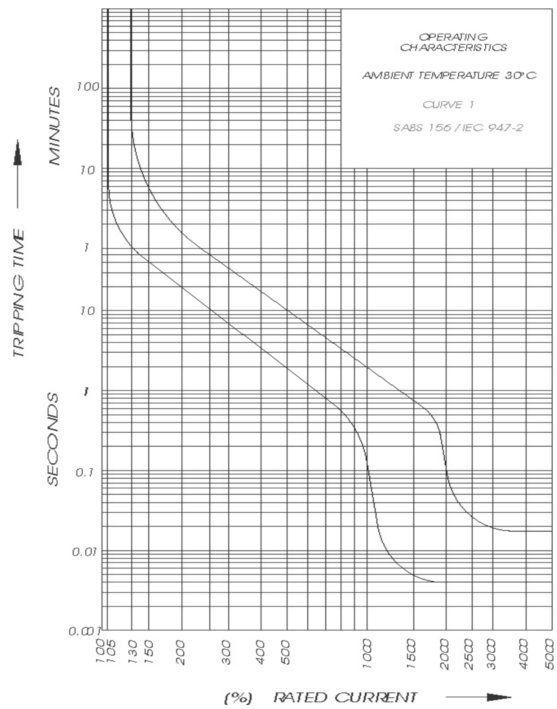

Figure 1: CBI QY Series time delay trip curve

A fuse doesn't open contacts like a circuit breaker does. Instead, when there is a fault, a metal part of the fuse melts and creates an open circuit. Due to this characteristic, each time a fuse interrupts a short circuit it must be replaced. If the fuse may be accessed to "unqualified" personnel and is energized from both directions, there are additional requirements for its installation. Article 690.16 states that disconnecting means must be supplied to remove all sources of power from the fuse. In SuPER, there is currently a fuse on the motor branch circuit that doesn't have any associated disconnect means such as switches. Instead of disconnect means, pullouts or other comparable devices may be used. Currently, there is a pullout device, so if somebody did not turn off system power and was also not qualified, the system would still be NEC compliant because of the pullout device.

DC and AC overcurrent devices have different mechanisms of operation and cannot be interchangeably used.[2] A DC fault is significantly different from an AC fault and the overcurrent device mechanisms of operation are designed for that. In SuPER, a DC system, it would be unsafe to use AC overcurrent devices. Currently on the motor branch circuit, there is a KTK 30 Limitron fuse, which is rate for 600V AC and 30 amps. This will need to be changed to a DC fuse.

Another rating of an overcurrent device is Amperes Interrupt Rating, AIR. This is how much current the device can withstand before mechanically failing. If it is possible to have a short circuit current of 2000 amps in your circuit and the overcurrent device only has an AIR of 1000, then the circuit is not fully protected. In that case many system components could be damaged and the circuit breaker may require replacement. Recall that unlike a fuse, a circuit breaker is designed to interrupt a fault more then once. For SuPER, the breakers are rated 10,000 AIR. The only components that could produce a short circuit current anywhere close to that value are the 98Ah Deka Dominator battery or the capacitor. The battery terminal to terminal short circuit current is 2350A and the capacitor is 1500A. Both values are less than the 10,000 AIR of their circuit breakers, which indicates a safe design.

For the battery circuit, if the current limiting device doesn't have a high enough AIR, then an additional device with the appropriate rating must be installed. (690.71C) As previously mentioned the breaker AIR is 10,000A and the terminal to terminal fault current of the battery is 2350A. Since the breaker's rating is good enough, no additional overcurrent protection is needed. Note that if future systems use different CB's, then this

NEC provision may apply. But it would be highly unusual for a breaker to not meet the minimum 2350AIR requirement.

PV source circuit overcurrent devices shall have a rating of 156% of the module short circuit current. The 156% comes from the same factors as the ampacity of the PV source circuit cable. Since the overcurrent device is sized above the short circuit rating of the PV module, it doesn't protect against overcurrents from the module. The NEC has recognized this situation in an exception to article 690.8. This article permits no overcurrent protection on a PV source circuit in a power system that doesn't have other external sources. The key part to that statement is the lack of other external sources. In SuPER, there is a battery, and a capacitor which can act as a source. I think this article is meant to protect a backfeed short circuit current from these other sources in which case the conductors on the PV source circuit would be at risk. Therefore a circuit breaker on the PV source circuit is required and there is currently one installed in SuPER. Yet the circuit breakers in SuPER are unidirectional, so in this case the circuit breaker on the source circuit will never operate.

There are special rules for protecting a motor branch circuit. There are maximum ratings for the overcurrent protective device. For DC motors, overcurrent devices may have a rating up to a certain percentage of full load current. The maximum for fuses is 150%, for instantaneous trip breakers it is 250%, and for inverse time breakers it is 150%. (430.52) Note that instantaneous trip breakers may only be used if they are part of a listed combination motor controller with coordinate motor overload, short circuit, and ground fault protection. (430.52C3) For SuPER, the motor FLA is 21A so the fuse rating may be no more then 31.5A. It is 30A, so this magnitude is acceptable by NEC standards. Yet the fuse is AC, not DC, so as previously discussed a new DC fuse will need to be purchased. In order to account for the large transient current of motor starting, the fuse will need to be a “slow blow” type, which means it should have a time delay before opening the circuit. The AC fuse was just replaced with a DC fuse, which needs to be tested. Bussmann manufactures 25A and 30A DC fuses. If the 25A or 30A fuses do not open during motor starting, then they are acceptable. If a 25A fuse works during starting, it should be used as its rating is closer to the FLA of the motor and may provide overload protection. If neither the 25A nor 30A fuse can withstand motor starting, then a different class should be used. The different class will require a different pullout device.

An overcurrent device is required for the capacitor. (460.8B) The rating should be as low as possible. As mentioned before, there is not a rated current for this capacitor because it is not used in power switching. Rather it is used just to supply transient current during motor starting. To protect the capacitor, Joe Witts selected a 6A circuit breaker that would not trip upon motor startup by looking at the time delay curves of the breaker.

From 240.30A, overcurrent devices must be installed in an enclosure, cabinet, cutout box, or equipment assemblies or on a switchboard, panel board, or control board. Additionally the enclosure shall be mounted vertically. (240.32) Right now the devices are in a vertically mounted enclosure, so the two previous requirements are met. Since the system will be outdoors though, it is considered to be in a wet location which adds additional requirements. There must be at least 6mm space between the enclosure and the wall, the enclosure must be weatherproof, and must prevent moisture from entering the box. (312.2a) The custom made box meets none of these requirements.

The load circuit breakers may be too large. There are three 10A breakers and one 15A breaker. The loads have much smaller FLA then those ratings as show in table 2.

LOAD	FLA*1.25
Television	0.88
Cooler	7.25
Lights	0.5
Laptop	6.25

Table 2: Load currents

The 12 AWG cable, which has an ampacity of 22.8 amps, is protected by the lower rated breakers. This would not be true if the load breaker ratings were higher then the cable ampacity. According to Juan Menendez of Southern California Edison, loads with ratings much smaller than the receptacles can be plugged in as long as they have some sort of self protection. John Wiles, author of an article applying the 2005 NEC to PV systems, states that if your equipment needs overcurrent protection for some reason, that protection should be built into the equipment. In SuPER, only an internal fault would damage the equipment, and if that happens the equipment will need replacing anyways.

3.5 Disconnect

A disconnect removes a circuit from a power source. Circuit breakers and switches provide the usual methods of disconnects.

From 690.13, all non grounded current carrying conductors from a photovoltaic power source must be able to be disconnected from all other conductors. In SuPER, there is a 10A circuit breaker that accomplishes this. When opened, the PV source would be disconnected from the rest of the system. To ensure full functionality of the grounding system, grounded conductors must not have disconnecting means. Equipment must have disconnecting means from all power sources. (690.15) The disconnecting means have installation requirements and “must be installed in a readily accessible location and be marked to indicate that it is a photovoltaic system disconnect.” (690.14) The motor has no disconnecting means, as the overcurrent protective device is a fuse and not a circuit breaker. This violates article 690.15. But article 430.109F permits an attachment plug and receptacle to serve as the disconnecting means for a cord and plug connected motor. The capacitor is also required to have a disconnecting means. (460.8C) The 6A circuit breaker on that branch currently meets that requirement.

When the terminals of a circuit breaker may be energized in the open position, a warning sign must be placed adjacent to the disconnecting means. (690.17) The warning should say something equivalent to: “Warning electric shock hazard. Do not touch terminals. Terminals on both the line and load sides may be energized in the open position.”

Each disconnecting means has to be marked to indicate its purpose. (110.22) So if a circuit breaker disconnects a motor, it must be marked “motor.” In SuPER, the breakers are marked with the receptacles they feed, with designations #2, #3, and #5. The fuse which feeds the motor is marked #6. There is no breaker labeled #1, but the USB cable connecting the hub to the laptop is labeled #1 for reasons unknown to current SuPER members. There is also a blank breaker that is probably #4 but is not labeled. The system disconnects are not clearly labeled. One recommendation might be to change the labeling for the motor. The motor can only be fed by receptacle #6 due to amperage limitations on the other receptacles. There is a breaker labeled #6 that feeds receptacle #6. For clarity, the receptacle and breaker could be relabeled from #6 to “motor.” Another recommendation is to label the blank breaker and corresponding receptacle to

#4. Since label #1 doesn’t correspond to a receptacle, and #2 through #6 does, this system may be confusing.

3.6 Grounding

There are two types of grounding systems present in most electrical systems. There is an equipment grounding system and a current carrying conductor grounding system. Grounding is done to limit the voltage due to lightning strikes, line surges, and stabilize system voltages during normal operation. (250.4A1)

Section 690.43 requires that exposed, non current carrying metal parts of appliances, modules, and conductor enclosures that could acquire a potential be grounded, regardless of system voltage. For photovoltaic source and output circuits, equipment grounding conductors shall be 125 percent of photovoltaic originated short circuit current.(690.45) For other parts of the system, the size of the conductor is based on the size of the upstream overcurrent device, as shown in table 250.122 found in NEC article 250.122A. If the cable is oversized for voltage drop or other reasons, the equipment grounding conductor must be proportionally adjusted by the method specified in 250.122B. In SuPER, some of the green equipment grounding conductors were marked 10AWG. The rest had no label and appeared to be the same size. There is no schematic with the wire size labeled for each different conductor, so it is assumed that the all of them are 10 AWG. 10 AWG is the minimum size for a 30 amp breaker from Table 250.122. For larger breakers, larger equipment grounding conductors are necessary. Since all breakers in SuPER are smaller than 30 amps the 10 AWG equipment grounding conductor size is acceptable.

Grounded conductors that normally carry current, in DC systems that is the negative wire must have a specific insulation color. They can have insulation that is colored white, gray, have three white stripes, or for conductors larger than 6AWG be any other insulation color except green with terminals marked white. (200.7B) For SuPER, the equipment grounding conductors are colored green, which is correct. The grounded conductors are black and smaller than 6AWG. Thus the insulation color needs to change to white, gray or have insulation with three continuous white stripes.

For the equipment grounding system, if the removal of a piece of equipment interrupts the path to ground of the equipment grounding conductors, then bonding jumpers shall be installed. (690.48) In SuPER, nothing special needs to be done for this rule. The same rule applies to the grounding system, except only the photovoltaic source and output circuit must remain continuous. (690.49) For SuPER, the system meets this requirement.

There are various code accepted ways of connecting the grounding system to earth potential. A metal underground water pipe, metal frame of a building, a concrete encased electrode, a ground ring, rod and pipe electrode, plate electrode, or other local metal underground systems or structures are all acceptable.(250.52) For testing the SuPER system at Cal Poly, the best choice is a plate electrode. Most likely this will be the grounding system used in the final SuPER product, as it is anticipated that most of the other grounding methods will not be available. The rod or pipe electrode is also an option, but these electrodes must be driven 8 feet into the ground at no greater than a 45º angle or buried in a 30 inch deep trench. (250.52) A plate electrode will be easier to install. It should have at least 2 square feet of material and must be 6.4mm thick of iron or steel and 1.5mm thick for nonferrous metal. Ferrous means that the metal contains iron. Nonferrous metals include Aluminum, Tin, Copper, Zinc, and Brass. A plate electrode must be buried at least 30 inches deep. The trench for the plate electrode will still be smaller than that of a rod electrode, which makes the plate electrode option more attractive. For any grounding electrode, the resistance to ground has to be less than 25 Ω or an additional electrode is required. (250.56) Resistance measurements can be conducted using a ground tester. Cal Poly does not own any ground testers and they are quite expensive, but one can be rented for about $150/month from a company such as Telogy.

There isn't yet a DC grounding electrode for SuPER. When this electrode is installed, a "grounding electrode conductor" will connect system grounded conductors to the grounding electrode which is at earth potential. The size of the DC grounding electrode conductor is covered by article 250.166. The DC grounding electrode conductor doesn't normally carry current. This conductor must be bigger than the largest conductor of the system, which is 6 AWG. (250.166B) Yet another portion of the same article states that if the DC grounding electrode is connected to a plate electrode, as will be the case in SuPER, the conductor doesn't have to be larger than 6AWG. (250.166C) Thus the correct choice for the grounding electrode conductor size would be 6 AWG. The conductor must be installed in one continuous length without a splice; otherwise it must be spliced by irreversible compression type connectors or exothermic welding. (250.64C) The DC grounding electrode conductor should connect to the electrode system by exothermic welding, lugs, pressure connectors, or clamps, and not depend on solder. (250.70)

The point of connection of the ground to system is covered by article 690.42, and it says it shall be done at any single point on the photovoltaic output circuit. The photovoltaic output circuit is defined as circuit conductors between the photovoltaic source circuit and the dc utilization equipment. For SuPER this is met.

For systems mounted on the roofs of dwellings, 690.5 requires that there be ground fault protection to prevent fires in DC circuits that results from ground faults. The system is to be placed on a cart, not a roof, so it doesn't have to meet this requirement.

3.7 Motor

Exposed current carrying parts and insulated leads must be protected against excessive moisture. (430.11)

Every motor must be protected against an overload that results from a failure to start or extended use above full load current. Overload can cause excessive heating that will damage the motor windings. Section 430.32B requires motors of one horsepower or less to be protected. Several different methods are available. A separate overload device that responds to larger than normal motor currents, a thermal protector to prevent overheating, a device integral with the motor, or protection by branch short circuit device if the impedance of the motor windings is sufficient to prevent overheating due to failure to start. SuPER's motor overload protection can be accomplished with the use of a 25A fuse.

Most motors require a controller, but since SuPER's motor is less than 1/3 HP, the controller is permitted to be an attachment plug and receptacle. (430.81B)

3.8 Capacitor

For Capacitors, a discharge circuit is required. It shall either be permanently connected to the terminals of the capacitor or be automatically connected upon removal of power from the line. (460.6B) There is a control circuit on the "capacitor switch board" that will discharge the capacitor when needed.

Capacitor cases shall be grounded. (460.10) There is an equipment grounding conductor connected to the capacitor, so that requirement is met.

3.9 Battery

Section 690.72A requires that the charging process of the battery be controlled. There is an exception to this rule, and that is if the maximum charging current multiplied by 1 hour is less than 3 percent of the rated battery capacity. The battery is 98Ah, and 3 percent of that is 2.9 Ah. Thus the maximum charging current would have to be less than 2.9 amps, which it is not. The charging current available on the 12 volt battery circuit is much greater than 2.9A. This is not a problem because there is an outback MX 60 DC to DC converter that controls the charging process of the battery. It is anticipated that eventually a Nexsys 2 FPGA will control the charging process by running Joe Witt's DC to DC converter.

Batteries produce a small amount of hydrogen, which can be explosive. Sufficient ventilation must be used to reduce fire hazards. (480.9A) In the SuPER prototype there is adequate ventilation. For sealed cells, no additional insulation support is required if there is no voltage between the battery container and ground. (480.6D) Live parts, such as the terminals of the battery, must be guarded if over 50 volts. (110.27A) The battery is only 12 volts, so no extra measures are necessary.

The battery should be in an enclosure that is clean, dry, and adequately ventilated. (IEEE 937-4.1) Currently there is no enclosure, so when exposed to the elements this would pose a significant safety hazard. The NEC does not mention this, but the IEEE standard seems would add to safety and seems reasonable to implement.

3.10 Equipment

Article 110.2 requires that all equipment and conductors be approved. This means that they must be acceptable to the inspection authority having jurisdiction. The authority will usually require compliance with 110.3A listing many equipment criteria such as mechanical strength and durability. Commonly used evidence to show that 110.3A criteria are met is to have the product certified by agencies such as the Underwriter's Laboratory, Canadian Standards Association, and ETL testing laboratories. Additionally, some inspectors simply require that all devices be listed.[2] UL recognized components are not tested to UL standards but rather to manufacturer's specifications. [2] Normally these standards are lower, but most times the product will be used in a whole system that will be UL certified. Table 3 lists all of the purchased components and their certification status. The items that have a ~~strikethrough~~ indicate components that will not be used in future systems for a variety of reasons. These reasons include safety, desire for UL certified components, or replacement with student designed components.

MAJOR PURCHASED COMPONENTS	NOTE	DESCRIPTION	UL CERTIFICATION
power			
Solar Panel		BP 5x150s 150W max	Yes
Battery		Deka dominator 8G31	UL recognized
protection			
Circuit Breakers		CBI QY series	Yes
Fuse	1	30A LP-CC DC fuse	Yes
loads			
Fridge	2	Coleman 5640	Yes
Motor	3	Dayton (Grainger) ¼ HP, 6MK98	UL recognized
Capacitor		Maxwell 58F 15V	UL recognized
LED's	4		No
TV	5		
control			
keyboard		Microsoft Wired500	Yes
monitor		Generic VGA	
control	6	Digilent Nexys 2 design platform	n/a
USB 6009		National Instruments	Yes
to be replaced			
~~TV~~	6	~~GPX portable~~	~~?~~
~~Laptop~~		~~Dell PP 21L~~	~~?~~
~~Fuse~~	1	~~KTK 30 Limitron~~	~~Yes~~
~~DC to DC converter~~	7	~~Outback Inverter MX-60~~	Yes

Table 3: Important SuPER purchased components

NOTES:
1- As described in this report, the current fuse is unsafe. A suitable UL certified fuse is Bussman 30A LP-CC DC fuse that was recently put into the system. This may be changed to a lower rating in the future to provide better overload protection, as long as the lower rating can withstand the transient motor starting current.
2- A phone call to Coleman verified that the cooler is indeed UL certified.
3- Only motors with loads can be UL certified.
4- There is no marking to indicate that the LED's are certified.
5- The current television is not UL certified. A suitable replacement television that appears to be UL certified is Audiovox 507BWR 5in, but this needs a solid verification.
6- According to Digilent technical support, UL does not apply to their product, but the boards are ROHS compliant.

7- The MX 60 MPPT charge controller is UL certified. The eventual plan is to replace this with a student built DC to DC converter charge controller.

Furthermore, custom made parts are also not UL certified. [2] This means that all student built boards and project are not NEC compliant because they are not UL certified. Even though it is not explicitly written in the NEC, Robert Armet, City of San Luis Obispo Building inspector, confirmed that all equipment must be UL certified. This means that much of SuPER is not NEC compliant, including electronics and other components. Table 4 lists major student designed contributions. The description for the control components was given to me by Joe Witts.

UNIVERSITY DESIGNED COMPONENT	DESCRIPTION
power	
DC to DC converter	Changes the PV voltage of 40V to load voltage of 12V
control	
PV to DC switch board	Allows power to flow from the PV to the converter. Measures current and voltage
Main switch board	Switches for all the loads, current measurements. (maybe voltage)
Cap switch board	Used to initially charge the capacitor, discharge the capacitor, or run the system normally
PIC	generates the PWM
Sensors	
Battery temperature	
PV sensor	Measures voltage, current, and temperature
DC to DC temperature sensor	
Insolation meter	

Table 4: SuPER student built components

If it were desired to have the system be officially NEC compliant, the non UL certified equipment would not be acceptable. But as described in the beginning of the report, the system cannot be officially deemed NEC compliant by a local building official. The advantages and difficulties of acquiring official certification will be discussed in the conclusion.

3.11 General

SuPER is a stand alone system, which means it is isolated and is not connected to the grid through an inverter. For stand alone systems, there must be a plaque installed that indicates the location of system disconnecting means and that the structure contains a stand alone electrical power system. (690.61)

Connections of conductors to terminal parts can't damage the conductor and can be made through pressure connectors, solders lugs, or splices to flexible leads. (110.14A) SuPER has many wires smaller than 10 AWG, in which case wire binding screws or studs/nuts that have upturned lugs may be used.

For the terminals of receptacles, the conductor entrance hole shall be colored white or marked with the word white or the letter W. (200.10B) For SuPER, this requirement is met.

A splice, or the joining of two electrical wires, must meet code requirements. Article 110.14B specifies acceptable methods, including use of a splicing device, brazing, welding, or soldering after a secure connection has been made without solder. Insulation as good as that found on the conductor must also be used to cover the joint. For some splices, the requirement of having a secure connection without solder may be difficult to meet. For example, the connection of the grounding plate to the grounding electrode conductor may be a challenge.

Article 300.6 deals with protecting equipment against corrosion. All support hardware must be suitable for the environment in which it is to be installed. For ferrous metal equipment, that requirement means a coating of corrosion resistant material. If the corrosion protection is enamel, the equipment can't be used outdoors. Non ferrous metal must have supplementary corrosion protection.

Electrical equipment is required to be installed in a "neat and workmanlike manner." (110.12) While that requirement is open to interpretation, some of the SuPER junction boxes are a jumble of wires. This is certainly not a neat installation and was perhaps done for the purposes of having a working prototype. On future systems, work should be done as neatly as possible, considering the work is done by students and not professionals.

CHAPTER 4- POWER AND CONTROL DIAGRAMS

There are many components in SuPER and is the case with most electrical projects, schematics become important. Originally in Jennifer Cao's project, power flow and control diagrams were shown on the same drawing. Since that diagram was made, changes have been made to the project. While updating the diagram, the SuPER team decided that it would be better to have two different diagrams. One diagram would show power flow, which is figure 2. The other shows control connections, which is figure 3.

In Figure 2, I did not understand many of the circuit boards, even after tracing the wires. Joe Witts knew this information and gave the electrical descriptions shown in Table 5. Table 5 also includes a physical description of the board so that future students may easily trace wires.

BOARD	ELECTRICAL	PHYSICAL
PV to DC switch	Allows power to flow from the PV to the converter. Measures current and voltage too.	Yellow 3” x 3”
Main switch	Switches for all the loads, current measurements and maybe voltage too.	Yellow 4” x 9”
Cap switch	Used to initially charge the cap, discharge the cap, or run the system normally.	Green 5” x 7”
PIC	Generates the PWM for the DC to DC converter.	Green 2” x 2”

Table 5: SuPER circuit board functions

Figure 3 describes the control diagram. Most of the boards get their power from a bus that is fed by a 2A circuit breaker. The power diagram shows this 2A breaker feeding a bus which powers a load called sensors/control. The only board that is powered differently is the Cap Switch board, which gets it power from the battery. Dotted lines or dotted component borders represent items that are not being used, are not connected, or are still in development.

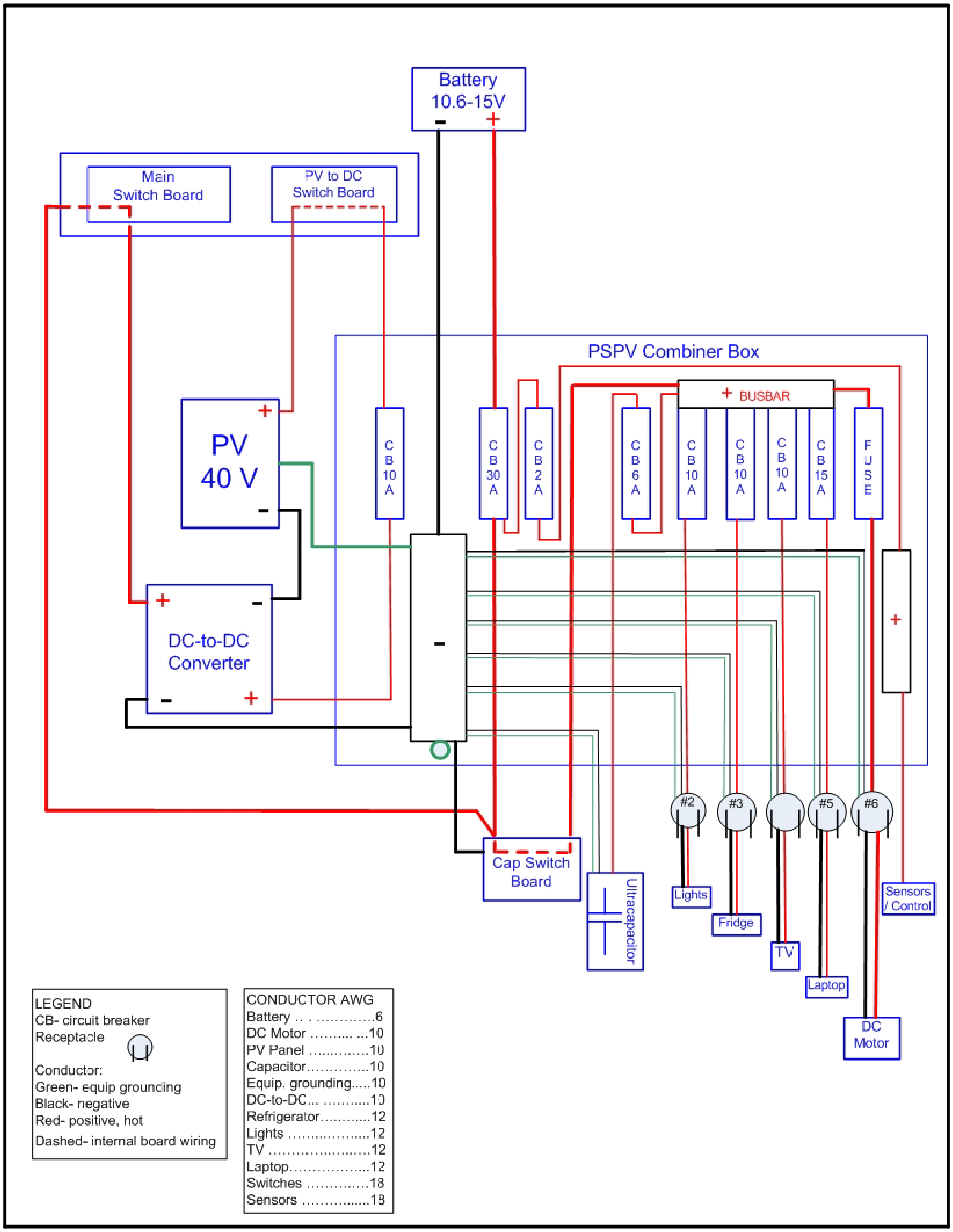

Figure 2: March 14 SuPER power diagram

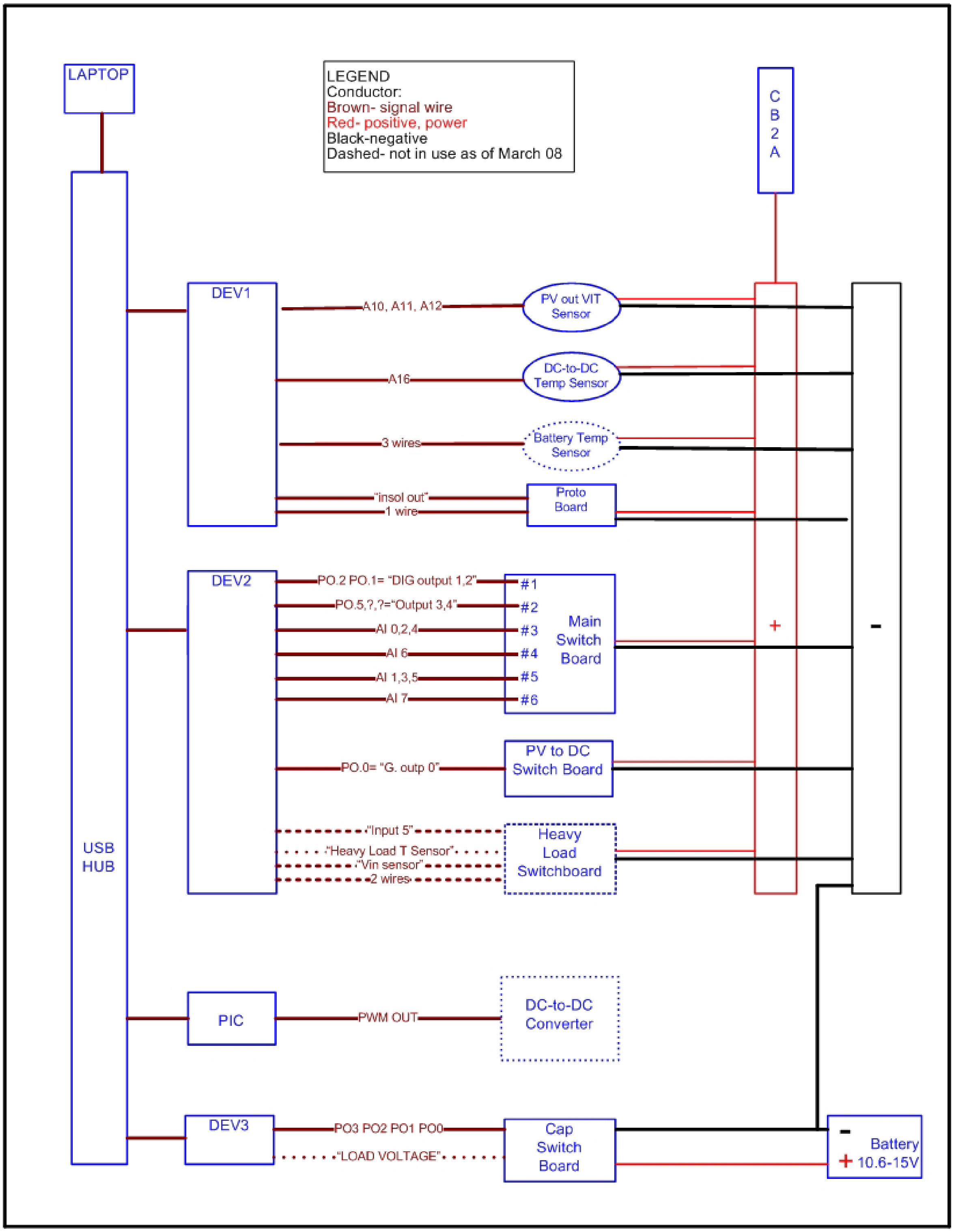

Figure 3: March 14 SuPER control diagram

CHAPTER 5- CONCLUSION AND SuPER FUTURE

The original scope of this project was to ensure NEC compliance. As the project progressed, I discovered that there were other applicable standards and that an official NEC certification could not be done for this project. The purpose of the NEC is safety, so that goal became primary.

Appendix A contains the list of recommendations and changes for the current system. These changes would be good for safety and should not be unreasonable to implement. Table B shows changes that should be implemented on the second generation system. Table B changes would simply not be feasible on the current system. For instance, one change requires changing all the grounded wires that have black insulation to wires with white insulation, and another change is to make the entire system "neat and workmanlike."

It may be difficult to follow some of this report's recommendations. For example, finding certain UL certified components like LEDs or a TV, or the Nema style 6 receptacles will be a challenge. Also this report cannot cover the second generation system to double check if the corrections are implemented or to suggest other options if some are not feasible. So this report does not guarantee a safe system.

To ensure robust safety, an official NEC inspection would be good. The problem is that an official NEC inspection cannot be done according to Mark Ellery. This leaves certification by a third party nationally recognized laboratory, such as UL or ETL. John Wiles says a UL or other nationally recognized laboratory certification cost may exceed $50,000. A large goal of the SuPER project was to create a low cost power system. There is the potential that a grant or other funding may be able to take care of the costs of certification. But it would be a large problem if the cost of certification were wrapped up into the consumer price of the system. This decision is one that must be made by the Cal Poly SuPER team and professors.

Since the original purpose of this project was to examine the NEC, I found out at the end of this project's timeline that UL certification may be the most desirable route. I submitted some documents to the UL photovoltaic expert, Robert Pence. Of course the laboratory is busy, and as of March 6, 2008 I am still waiting to hear back from them. To get a precise quote from UL is a lengthy process and is not necessary at this point. Rather the goal was to get a ballpark estimate.

While waiting for their answer, John Wiles gave a number of $50,000. A rough number from UL would be better as they have more information to work with. I suspect a high quote because there is a lot of custom made equipment in the system. I also know that the certification process will be expensive based on information given to me by UL employee Robert Pence. He said that before certification, you can request a UL representative to come out to your project and give you recommendations during design and construction. This process is an expensive $2750/day. Based on that you can get an idea for what full certification might cost.

From the things I found in my project, I see a potential for several more projects. If it is decided that UL certification is desirable, guiding that process may be a project.

While the maximum power output of the solar panel is only 150W, which isn't enough to run a hair dryer, that does not automatically ensure system safety. The capacitor and battery have large short circuit currents and have the potential to do much harm.

The project is to be marketed to persons who do not have more then very basic technical knowledge. Even if the system is certified, it may still not be safe if used incorrectly. Thus a user workshop and layman's user manual would be absolutely essential for safety. While manufacturer obligation usually ends at the shelf, I think more then that is needed for safety in this project. Thus creating a workshop and manual may be another project.

Another project could change the way the user interfaces to the system. Currently the interface is functional, but does require a working knowledge of code. A good project would be to create a user friendly interface, perhaps even graphical, as this would add to safety. Or more simply a button or switch based system.

The major challenge for this project will be the weatherproofing. The project should be tested in the rain or even left in the rain for an extended period of time. Ultimately this is how the product is going to be used. One project could be to figure out ways to weatherproof the system.

It should be recognized that everything is student built and is first generation. I am sure that there are few products that can be sold after being manufactured one time. Also this project is truly one of a kind. It is a great idea, but since it is so unique there are many areas that do not have standards. One example that comes to mind is direct current receptacles.

Note that there are many electronics products sold in the United States that are not UL certified. Usually this is done to have a lower priced product. For products that are not UL certified, I am sure that thorough internal testing is performed, especially given the strong consumer rights and successful class action litigation presence in the United States.

For PV systems in the U.S., the NEC must be followed by law for most electrical installations. There are some exceptions as outlined in this report. In some cases, IEEE standards and nationally recognized laboratory certifications may apply. Other countries also have codes for PV systems installed in their countries. According to Solarbuzz, an international solar photovoltaic consulting firm, applicable standards are PVRS and IEC for Switzerland, CSA for Canada, and CEC for Italy. Notice that none of those countries are the expected location of SuPER, which is to operate in Central America, South America, Southeast Asia, Indonesia, and Sub Saharan Africa. For most underdeveloped countries, the primary energy source is still fossil fuels. Also, for most of the places where SuPER will be marketed, there is no engineering organization to make codes and there is no law to follow any code.

I did find some exceptions, particularly references to Botswana and Zimbabwe having PV codes. The actual codes were difficult to find. Additionally, for most of these countries it would be a challenge to get English versions and industry advice. The U.S. has built up great technical expertise, and hence has codes and standards that are more thorough then codes that might be found in those countries. When it does come time to market the product to a particular country, adherence to UL or NEC standards should be more then adequate, and only minor adjustments should be necessary.

Nevertheless, it is still safe engineering to adhere to U.S. standards as closely as possible. While other standards may be effective, the NEC is written in English and practiced in the United States, making it the most sensible choice to guide decisions in SuPER.

If it is decided that official certification would fundamentally change the nature of the project due to the high cost barrier, at the very least thorough testing should be done on the final second generation system under expected user conditions.

While the challenges faced in making the system safe are large, I believe the benefits of a successful project will outweigh this workload. I see the potential for many challenging, rewarding projects. I hope this paper will be a large step towards creating a safe system, which will ultimately allow this project to succeed.

Appendix A- Recommendations Summary

The following tables A and B show a summary of this reports finding. The areas in question for table A should be changed on the current SuPER system if possible. Table B shows what should be done, if feasible, on the next generation system for safety, code compliance, and a step towards official certification.

DESIRED	EXISTING	SOURCE	REPORT PAGE #
Change fuse on motor branch to 25A DC to provide overcurrent and overload protection	30A AC changed to 30A DC. A 25A DC will need testing.	430.32B, 430.52	16/17
Mark each circuit breaker with its purpose	a circuit breaker that is not labeled which appears to power an unlabeled receptacle.	110.22	20
Place warning on circuit breaker: "Warning Electric Shock Hazard. Do not touch terminals. Terminals on both the line and load sides may be energized in the open position"	Nothing.	690.17	20
Grounding electrode conductor sized at 6AWG	No grounding electrode	250.166B	22
Install grounding electrode system. Grounding plate: 2 square feet of material and must be 6.4mm thick of iron or steel and 1.5mm thick for nonferrous metal, buried at least 30 inches deep	No system	250.52	23

Table A: current system

DESIRED	EXISTING	SOURCE	REPORT PAGE #
All circuit equipment must be rated greater than 50.9V	Yes.	690.7	6
Use NEMA type 6 receptacles	AC receptacles.	[2]	7
Safer transition from DC appliance to wall receptacle. Possibly done with a different wiring method or DC appliances with different plus. (latter not made at this time)	Cigarette lighter to wall socket adapter.		8
Receptacles shall be installed in a weatherproof enclosure	No enclosure	406.8B1	8
Current carrying conductors must be greater than 12AWG	Met.	720.4	11
Change source circuit to SE, sunlight resistant UF, USE, or USE-2	RHW-2	690.31B	13
Put all cables directly exposed to sunlight in conduit or use cables marked as sunlight resistant	Many exposed to sunlight.	300.6C1/310.8D	13
Change cables to types that may be used in wet locations.	Romex NM-6 for the loads, carol 5J00W for the motor	334.12B4	13
Vertically mounted enclosure, 6mm space between the enclosure and the wall, weatherproof enclosure, and must prevent moisture from entering the box.	Only requirement met is vertical mounting	240.32, 312.2A	18
Change the grounded conductor to white, gray or have three white stripes. Currently the conductor is	Negative conductor is black, (all the negative conductors are grounded)	200.7B	22
Grounding electrode resistance to ground of 25Ω or less.	No measurement due to no grounding system	250.56	23
The battery should be in an enclosure that is clean, dry, and adequately ventilated.	No enclosure.	IEEE 937 – 4.1	26
Use UL certified equipment whenever possible	Television, LEDs,	[2], Robert Armet	26
Plaque indicating the location of system disconnecting means and that the structure contains a stand alone electrical power system	Nothing.	690.61	29
Coating of corrosion resistant material for ferrous metal equipment	TBD	300.6	29
Electrical equipment installed in a “neat and workmanlike manner”	Some areas much worse than others	110.12	30

Table B: second generation system

Appendix B- References

[1] Cao, Jennifer “SuPER Project Wiring and System Protection, Cal Poly, December 2006

[2] Wiles, John “Photovoltaic Power Systems and the 2005 National Electric Code: Suggested Practices,” Southwest Technology Development Institute February 2005

[3] Early, Mark and Sargent, Jeffery, et. al. “NEC 2005 Handbook” National Fire Protection Association, Inc. 2005

[4] Sheffield, Tyler “Cal Poly SuPER System Simulink Model and Status of Control System, Cal Poly, April 2007.”

[5] Circuit Breaker Industries, CBI product curves “tripping characteristics,”

<http://www.cbibreakers.com/curves_products.asp?PFType=6>

[6] IEEE standards coordinate committee 21, IEEE standard 937 “Recommended practice for Installation and Maintenance of Lead-Acid batteries for Photovoltaic (PV) systems,” New York 2007

Appendix C- Terms and Abbreviations

TERM	DEFINITION
AC	alternating current
ambient temperature	the temperature of the environment, usually refers to the temperature outdoors
ampacity	the amount of current, in amperes, that a cable or other piece of equipment can safely carry without overheating or melting
amps	amperes, the unit that describes current magnitude. A mechanical analogy would be the amount of flow.
capacitor	energy storage element.
CB	circuit breaker
DC	direct current
dc to dc converter	changes the higher voltage of the PV circuit to the lower voltage that is used by the loads.
derating factor	this factor accounts for environmental or other conditions that cause a particular characteristic of electrical equipment to be smaller than it should
discharge	to use or dissipate stored energy. Batteries, capacitors, and inductors may discharge their energy into loads.
FLA	full load amperes
ferrous	ferrous means that a metal contains iron, which would include iron and steel. Nonferrous metals include aluminum, tin, copper, zinc, and brass.
fuse	a fuse is a protective device that creates an open circuit when there is a short circuit. It must be replaced every time that it is used
insulation	usually plastic or some other high resistance material, insulation covers exposed metal parts to insure that contact by a human or other source does not create a short circuit.
NEC	National Electric Code
photovoltaic	an element that converts energy from the sun into electricity
sensor	provides system information to a control center.
short circuit current	undesirable, and usually occurs due to faulty insulation or old equipment. Short circuit current is much higher than normal operating current
Switch	controls power flow. The simplest example is a light switch. In SuPER, the switches will be controlled by the laptop and USB 6009 devices.
SuPER	Sustainable Power for Electrical Resources
V	volts, the unit that describes voltage magnitude. A mechanical analogy would be water pressure, or thinking from what height the water fell from.

Appendix D- Analysis of Senior Project Design

Functional Requirements

SuPER is to convert energy from the sun to electricity in order to power various loads. My role in the project is to ensure it is safe, to adhere as strictly as possible to relevant safety standards including the NEC and IEEE. Furthermore, the process to get the system certified will be examined.

Primary Constraints

The National Electric Code is not taught at Cal Poly. In addition, it is not taught in masters or doctoral programs, so faculty advisors do not know the smaller technical details which may significantly impact system decisions. Due to this, industry sources were heavily used. Since these sources are not fully invested in the outcome of the project, in the way that Cal Poly students and faculty might be, these busy individuals are less inclined to spend time on the project answering questions.

Additionally much of the system is one of a kind, so safety standards may not exist or may be intended for a different application, usually AC power systems.

Economic

The cost for my portion of the project was $0. The only resources I required were the National Electric Handbook and a computer with Vizio, both of which were already purchased by Cal Poly. I replaced the AC motor fuse with a 30A DC motor fuse, which was donated by Bussman. Eventually this may be changed to a 25A fuse.

Implementing the changes recommended in this report will not be free. New components for the current system include a plate electrode. For the second generation system, there should be no additional cost if newly purchased components follow this report's guidelines. But as discussed earlier, certification will be very expensive.

Estimated development time was 84 hours. Actual development time was 78 hours, plus 12 hours of SuPER meetings and 5 hours of office hours for a total of 94 hours.

It does not make sense to compare the breakdown of estimated and actual time spent on the project. The original project outline had time for tasks that could not be done for a variety of reasons, such as modeling the system in Etap, software that models power systems.

The work log for the actual project is not entirely useful either, as the log might show one hour of work in applying the NEC, yet at the same time the report was being written from that session's findings. So it would be hard to tell the time spent actually reading the NEC and time spent writing the report, for example.

Manufacturability

The largest challenge for the project, is that "work must be installed in a neat and workmanlike" according to the NEC. In the first prototype, there are jumbles of wires in combiner boxes. Since this is probably the first time for student's doing this sort of work, it is understandable that the work may not look professional. Furthermore, since the product will be used outdoors, it will be a major challenge to insure that the system is weatherproof.

Sustainability

For maintenance, the battery will have to be replaced every 5 years. Every time the motor is overloaded, the fuse will have to be replaced. The lifespan of the solar panel is approximately 20 years, but that time-span is also the desired lifespan for the entire system.

Ethical

If the project were unsafe, it would not be a good idea to allow it to be used.

Certification by a third party testing organization will be costly and may raise expenses enough to defeat the original purpose of the project.

While safety is a matter of interpretation, there are certain basics that must be followed. Beyond this, the extent of time and money invested in project safety will ultimately be up to the SuPER professors and students.

Health and Safety

In developing nations, often times kerosene is used as the fuel source for lighting. There is numerous health risks associated with this fossil fuel. LED's on the other hand, emit no toxic chemicals and do not pose the same health hazards.

The cooler will stop food from spoiling, thereby increasing diet quality and reducing commons stomach problems.

Now if the project is misused, there is great potential for injury or even death. A short circuit across the battery terminals, or capacitor terminals, produces currents in the thousands of amps. If the protective system operates incorrectly the results would be awful.

Social and Political

This system will foster social change. In developing nations, students will be able to do their homework at night without the health risks of kerosene lighting. System users will save time using the motor to pump water. The cooler will add options to their dietary selection and the food will be fresher leading to less stomach ailments that may be very common in these countries.

Development

There were many things I learned during this project not taught at Cal Poly or found in the NEC due to contact with industry professionals and various articles.

The biggest thing I learned was working knowledge of the National Electric Code. I saw that the book was written with certain applications in mind and that you can not blindly apply the articles without thinking of their meaning. While most of the time this might work, in atypical applications such as SuPER this would be unsafe.

While I knew the general purpose of fuses and circuit breakers, I did not understand the technical details of their operation.

I knew that different sized conductors carry differing amounts of current safely. But I learned that conductors made of the same metal and same size may safely carry differing amounts of current depending on their insulation quality.

I did not know that the temperature rating of the terminals of a device may limit the ampacity of a branch circuit. I had previously thought of conductors overheating as being the limiting factor in ampacity, but it is interesting to consider that a circuit breaker or other device operating temperature may limit the branch ampacity.

I also found out that the circuit breaker on the PV source circuit does not protect against a short circuit of the PV panel. As described in the report, this circuit breaker protects against short circuit from multiple sources.