secondary voltage being higher than our load value. These toroidal transformers have settings to connect them in either parallel or series connections. These connections are determined by the output the user desires. Both of our transformers are connected in series because we need the maximum transformation from each one in this configuration. The load side of the secondary transformer has a higher voltage to account for the losses and voltage drop from the battery to the load. Below is a picture of the toroidal transformer we are using in this project.

Fig. 13 Toroidal Transformer used

As we built the physical circuit there is many different improvements and characteristics that can be changed for this design. Some of the main topics we are trying to obtain are:

- Minimal losses from the transformers
- Obtaining most efficient switching frequency
- Optimizing switches and transformer in the circuit

The next change we made in our project was how we are controlling the MOSFET switching. To begin with we were using pulse-width modulation to control the switching but we have found for our project to be more efficient we will use the Arduino Uno to control the MOSFETS. This will allow us to control the frequency, period, and duty cycle of our switches. This will allow us to optimize the way our MOSFETS work to minimize the losses from our battery to our first transformer in series. Another change we made to our project is that we eliminated the battery bank at the load. We are still using charge controllers to control the voltage and current for the load, but for our needs we took the storage bank out of our project. With more time we could implement the storage bank fairly easy but for the efficiency of our project we chose to take it out of our system.

4.2 New Configuration Simulation

This new configuration simulation proves that our method will work. Below are some screenshots of proof that our circuit will continuously work as our battery is being charged by the solar panel. The first configuration shows the scenario of the battery's initial state of charge being 20 percent of its full potential.

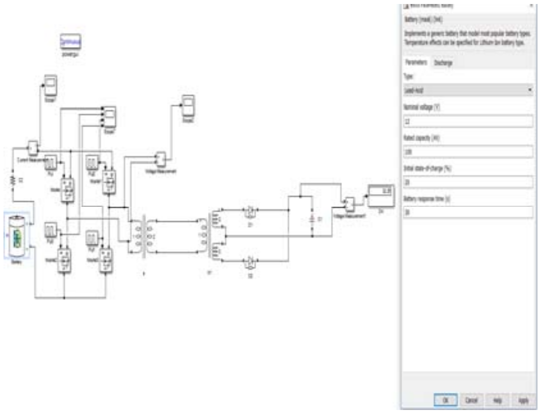


Fig. 14 New Simulations a

This figure shows that at 20 percent of full potential charge we will still obtain sufficient voltage to charge our 24 volt load. As the percentage of initial state of charge increases the voltage will increase as shown in the screenshots below.

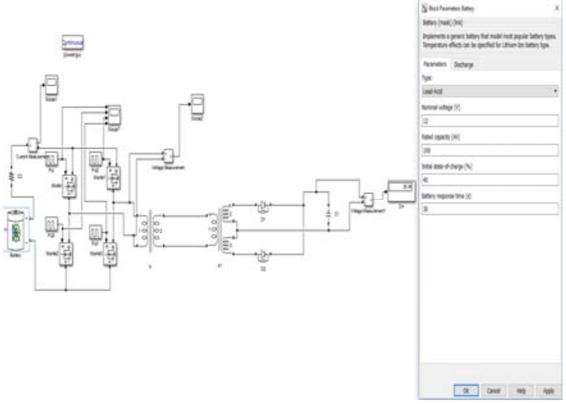


Fig. 15 New Simulations b

This figure shows the value of the initial state of charge to be 40 percent of full capacity. As you can see in this screenshot the output voltage is 35.4 volts. This is a higher value than the 32.26 volts that we got on the simulation of 20 percent initial state of charge.

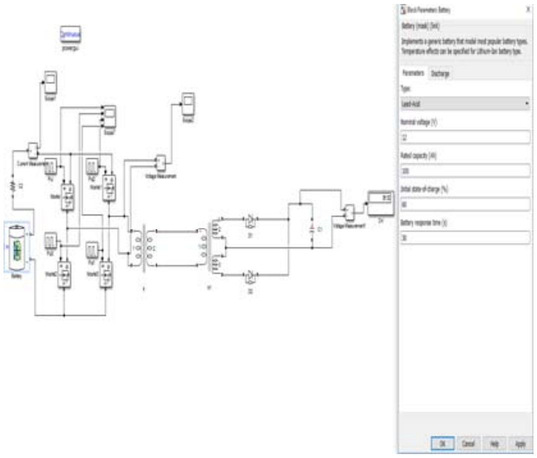


Fig. 16 New Simulations c

This figure shows the value of the initial state of charge to be 60 percent of full capacity. The output voltage for this setting is 36.52 volts. This corresponds to the trend we saw previously with the increase of output voltage with the higher initial state of charge.

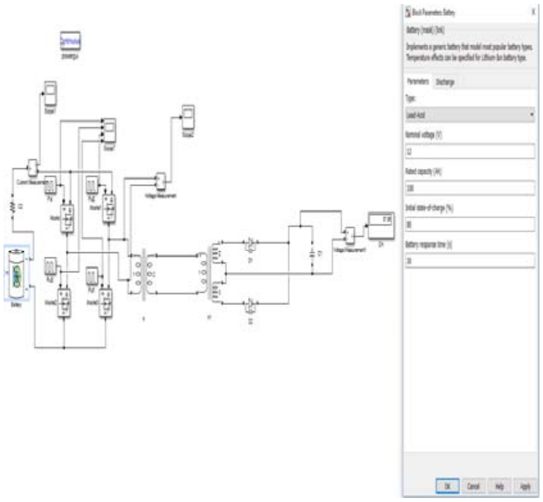


Fig. 17 New Simulations d

This figure shows that at 80 percent of full capacity we will have 37.06 volts delivered to the load.

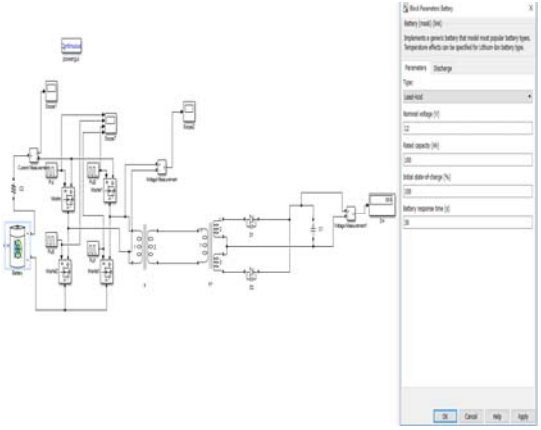


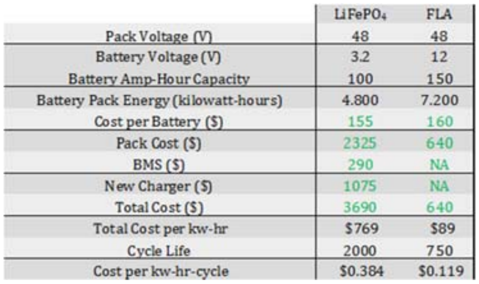
Fig. 18 New Simulations e

This figure shows the delivered output at its maximum for this circuit. This setting is at 100 percent of initial stat of charge. This means the battery was completely charged when the load was connected. This proves exactly what we are trying to deliver. We will use the panel to keep the battery charged as needed but as the battery weakens it still will be able to supply our load sufficiently. This will allow for charging to occur even when our primary battery is not being charged because of little sunlight or cloud cover, but will also allow the panel to back up the battery as needed. In order for the system to work most efficiently the battery should be at 100 percent of initial state of charged, or charged to full capacity, when the load is connected [5].

4.3 Sustainability

Fig. 19 Primary Battery

Batteries are a large part of this project. They will be required to contain the power that the solar panels will harvest from the sun. A standard 12V lead acid battery was picked for this application. This was chosen for a variety of reasons such as reliability, long term power storage capability, and a large variety of brands. Two reasons stood out to us above that rest that lead us to use lead acid batteries: cost and ease of use.



	$LiFePO_4$	FLA
Pack Voltage (V)	48	48
Battery Voltage (V)	3.2	12
Battery Amp-Hour Capacity	100	150
Battery Pack Energy (kilowatt-hours)	4.800	7.200
Cost per Battery ($)	155	160
Pack Cost ($)	2325	640
BMS ($)	290	NA
New Charger ($)	1075	NA
Total Cost ($)	3690	640
Total Cost per kw-hr	$769	$89
Cycle Life	2000	750
Cost per kw-hr-cycle	$0.384	$0.119

Fig. 20 Price comparison between lithium ion and lead acid batteries.

The above graph gives us a plethora of information about the comparison between Lithium Ion batteries and the traditional lead acid batteries. We are comparing these two types of batteries because Lithium Ion batteries are currently considered as a "green" alternative to lead acid batteries. They are described as green because they do not contain the harmful elements contained within lead acid batteries. However, one thing that is always important to consider in any project is cost. The graph gives important financial figures that helped influence our decision about which battery to buy. Look at all the figures related to cost: cost per battery, pack cost, battery management system (BMS), new charger, total cost, total cost per kilowatt-hour, and cost per kilowatt-hour-cycle. The Lithium Ion battery is considerably more expensive in every single category. A costly feature of LI batteries is the system that is required to charge them. They have to have sophisticated charging systems (called battery management systems or BMS in the chart). Having a correctly functioning BMS is essential because these batteries can be dangerous if they are not charged in the correct manner. An example of this can be seen with the recently popular hover boards. They used LI batteries to power them, but due to the poor battery management system that is used to charge the battery, it caused them to overheat and catch fire in some instances [4].

Another important topic of this chart is cycle life. Cycle life is simply the number of times that a battery can charge/discharge before the battery begins to lose capacity and needs to be replaced. The cycle life of the lithium ion battery is over 2.5 times greater than that of the traditional lead acid battery. This adds up to having to replace lithium ion batteries than the lead acid battery that is going to be used in our project. There are definitely tradeoffs with buying either of these batteries.

A large topic of debate with lead acid batteries today is their environmental effect. These types of batteries are used in on a massive scale today in all forms of transportation. Some examples where lead acid batteries are used: cars, trucks, buses, and trains. If we look at the name of the battery, it is clear that these batteries have a large amount of lead and acid within them. The acid in these batteries is extremely corrosive and can be dangerous to the environment if the battery is not disposed of in the proper manner. In addition, lead is also quite harmful to the environment. Lead can actually wipe out micro-organisms if there is a concentration of 1,000PPM or more. It is still harmful to these same micro-organisms along with plants and invertebrates at a concentration of 500 to 1,000 parts per million. As long as there is any significant amount of lead within the environment, it will negatively impact the organisms within the feed chain with an increasing PPM as it moves toward the apex predator. The EPA has placed the deadly amount of lead ingestion for a human per day is 2-8 milligram per kilogram of body weight. After ingesting lead on a daily basis, it can lead to poisoned blood in bloodstream which causes major organ failure such as heart, liver, and kidneys. However, this way seems worse than it actually is [12]. Recycling lead acid batteries is a hugely successful operation around the world. Steps have been taken to ensure that the lead and corrosive acid is not introduced into the environment because it can cause significant issues. For example, in the United States one can go to any auto shop if they are in need of a new battery, and there the auto shop will take your old lead acid battery for recycling. Taking these sorts of measures have led to the successful recycling of around 95%. Proper recycling is extremely important with respect to protecting the environment. Oftentimes lead acid batteries are placed in an area with other used goods that are meant for recycling. If lead acid batteries are recycled improperly, not only can the lead not be used from these batteries, the acid causes the other goods meant for recycling to be unusable as well. Not only does recycling batteries help protect the environment, it also says the industry energy, time, and money to produce new lead [7]. The most important equipment of our project are the solar panels that will be used. To give a brief summary of what solar panels are, they simply connect the solar energy that is emitted by the sun. As a result, this is a free form of renewable energy that will be around for at least a couple billions of years (or however long the sun emits energy). Solar panels have considerable advantages over the traditional nonrenewable energy resources that are used on a large scale today. First, and perhaps the largest advantage, solar panels create absolutely no pollution in the creation of electricity from solar energy. This electricity can be used to power any sort of electric load that one can think of whether it be an AC or DC load. There are a wide array of solar panels that can be purchased on the public market to power these different types of electric loads. Most electricity is produced using some sort of fuel source such as coil, oil, or natural gas (probably the most prevalent). Solar panels, on the other hand, require absolutely no fuel source to create its electric energy. If you refer to the figure below, you can see the process the solar energy goes through to supply these loads.

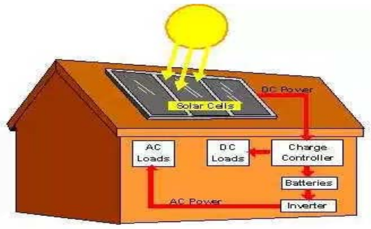


Fig. 21 Flow of solar energy throughout a household.

Not only can a person supply the DC and AC loads within their home from solar panels, the electricity is also 100% free after the initial investment of the panel itself. 100W solar panels typically cost around $100. However, the prices of them vary widely based on the price and additional technology that comes with them. If you take a 100W solar panel based on the 12 cents per kilowatt-hour, that is the average price of electricity in the US, and the average US household uses around 908kWh in a month then that solar panel will be paid off in about a months' time. One solar panel certainly will not power an entire home whenever power is required, and therefore it would still require power from the power company, but these savings would certainly add up over a long period of time. If one was to power their house completely on solar panels alone, a typical US home would require about 12-18 solar panels. This number of solar panels is somewhat unrealistic to just put in one's yard and/or roof. A large number of solar panels concentrated within one area can become a problem environmentally. These solar panels are typically quite large and close to one another. When you have a large number of solar panels within an area, it is typically referred to as a solar panel farm. A picture of one is depicted below.

Fig. 22 Solar Farm

One issue with these so called solar panel farms are the potential environmental footprint that can be left as a result of the large area close to the ground that they take up. For example, if all of these solar panels are installed where an animal or group of animals reside, they will be forced to move to another habitat. This may not be a problem on a small scale, but on a large scale, across the globe this would become an enormous issue. Estimates for utility-scale PV systems range from 3.5 to 10 acres megawatt (utility-scale means that all of your power would be produced by solar panels). This is a massive amount of land required to produce a relative small amount of energy. Fossil fuels and other nonrenewable energy currently does a much better job of taking up less space than solar panels. If we have, for example, 1,000,000 people (This may seem like an unrealistic number but 1,000,000 people is less than .014% of our population!) that want to be completely reliant on solar energy that means if you estimate energy needs on the high side to be safe (we can use the average kilo-watt hour consumption of power per person in the U.S. at this point to have the worst case scenario) the 908 kWh can be divided by four to get a rough per person average. Based on these numbers, you would need 90,800,000 acres of land just to make this tiny fraction of the population self-sufficient entirely on solar energy. Once again, these numbers are based off of the absolute worst case scenario numbers. Most people in the worst do not use the amount of energy in the world, and also, 10 acres of land was used instead of anywhere in the range of 3.5 to 10. So most likely, the number of acres would be somewhat less, but it would still be a huge amount of land [7]. The huge amount of land that is required to produce a relatively small amount of energy is due to the efficiency of the solar panels. This type of technology is not essential to the world satisfying its energy needs, and as a result the product has suffered with efficiency. Typical solar panels only have an efficiency of roughly 20%. This means that only 20% of the total energy captured by the sun is being actually being received by the user. However, scientists have achieved 34.5% efficiency which is astounding compared to the 20%. Advances are constantly being made in this blooming field as a result of our understanding that we need to harvest free energy as best we can. Not only are huge strides being made in efficiency, prices for solar panels and their installation costs are rapidly dropping.

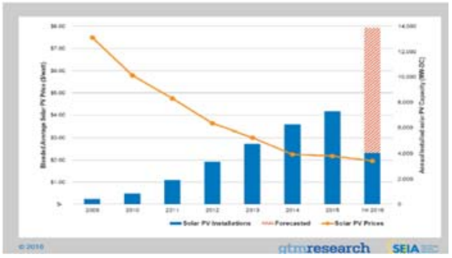


Fig. 23 Correlation between price decrease and installation increase for solar panels.

The graph above shows the number of solar panel (photovoltaic panel) prices versus the number of annual installed solar panel capacity (MW-DC). It is clear from this graph that the field is absolutely exploding with growth. From 2009, in the United States, it look like around enough solar panels were installed for about a capacity of 500 megawatts at a huge price of $7.50 per megawatt. If we look four years later at 2013, the total capacity of the solar panels is about 6,700 megawatts. That value is thirteen times greater than 500. To put that into perspective, that is a percentage growth of 1240%; that is an almost unpresented growth in just four short years. Not only that, the price per watt for these solar panels had fallen to about $2.10. That is a 72% price drop from 2009. Clearly the curve of this graph looks like an exponential growth for the capacity of the PV panels installed each year, and inversely, the price per watt looks like an exponential decay (but it looks like it is leveling off towards 2016). Surely these rates will not keep pace for years to come, but it shows the explosiveness of the solar panel market. People are realizing this is a great way to harvest free energy in an ever increasingly cost effective way.

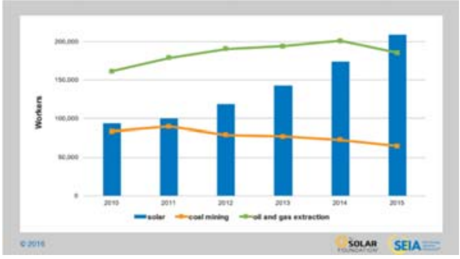


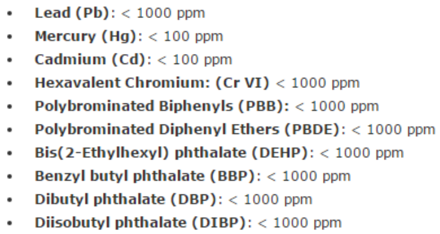
Fig. 24 Employment rates due to solar energy

Similar to the figure 20, figure 21 is showing the number of working in the solar, coal mining, oil and gas extraction industries from 2010 to 2015. It is clear from this information that the solar power industry is exploding in growth with regards to workers; one of the main reasons some people cite as not wanting to invest considerable more money into the solar industry is because the other energy industries will suffer. However, with the incredible damage to the environment that fossil fuels do, clean renewable energy is an absolute must in the not too distant future. This shift in energy sources does not mean the working man needs to be worried; there is always retraining available. The number of working from 2010 to 2015 has almost quadrupled in size. That type of growth paired with the decreasing installation price of solar panels sets up the industry for even more growth. Of course, as mentioned before, this type of growth will not continue for forever, but it is set to see massive growth in the coming year.

Fig. 25 MOSFET transistor

The figure above is a main component in our project, a MOSFET transistor. MOSFET stands for metal-oxide semiconductor field-effect transistor. An important topic to speak about when talking about the sustainability of a project is to look at the individual that goes into the project. Electrical components may seem like they are not harmful to the environment because they are not giving off emissions or anything of the sort. However, electrical and electronic components are often created with different types of toxic materials which are definitely harmful to the environment when they are discarded. These components often used multiple toxic materials when manufactured such as heavy metals, plastics, toxic gases, and solvents. Just to name a few chemicals that go into manufacturing: acetone, arsenic, lead, and hydrochloric acid (this list is certainly longer but this is a small taste). Acetone causes health problems in the nose, throat, lung, and skin. Hydrochloric acid is a highly corrosive acid that can cause eye and skin burns among other serious issues. As one can plainly see, electrical and electric components are certainly harmful in their own way.

However, there has been a huge undertaking called RoHS which stands for the Restriction of Hazardous Substances. This directive originated in the European Union and restricts the use of multiple materials that are known to be hazardous that are used in the production of electrical and electronic objects. This directive came into effect July 1, 2006. So, any business that sells electrical or electronic components that are affected by this must comply with this directive.



- **Lead (Pb):** < 1000 ppm
- **Mercury (Hg):** < 100 ppm
- **Cadmium (Cd):** < 100 ppm
- **Hexavalent Chromium: (Cr VI)** < 1000 ppm
- **Polybrominated Biphenyls (PBB):** < 1000 ppm
- **Polybrominated Diphenyl Ethers (PBDE):** < 1000 ppm
- **Bis(2-Ethylhexyl) phthalate (DEHP):** < 1000 ppm
- **Benzyl butyl phthalate (BBP):** < 1000 ppm
- **Dibutyl phthalate (DBP):** < 1000 ppm
- **Diisobutyl phthalate (DIBP):** < 1000 ppm

The materials above are the before mentioned hazardous materials that are restricted by RoHS. Take not that the allowed amounts are in parts per million. This means, for example lead, has to have less than 1000 ppm per unit mass of whatever that component may be.

Fig. 26 Solar charge controller

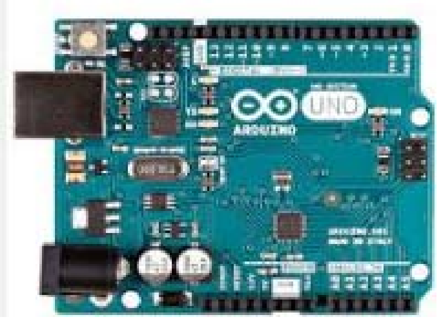


Fig. 27 Ardiuno Uno

Fig. 28 Secondary Transformer

Fig. 29 Schotkky Diode

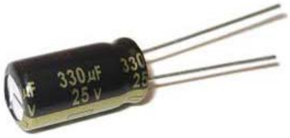


Fig. 30 Smoothing Capacitor

The above components are also essential to our project and are subject to the rules of RoHS (the parameters of such were discussed on the previous page). You can find information regarding RoHS compliancy on the datasheet of the component. For example, the picture below is from the datasheet of the toroidal transformer showing that is indeed RoHS compliant [14].

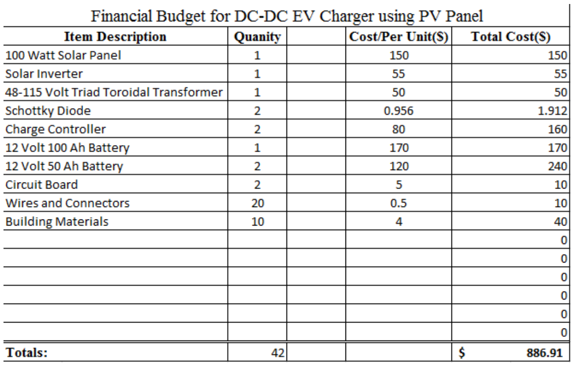
Most of our components unfortunately do not meet the RoHS compliancy which is an issue for sustainability with regards to the environment. Fortunately, there are always many other components to choose from and finding RoHS compliant parts would not be an issue.

4.4 Financial Budget

By looking at our budget spreadsheet your initial thought may be that this is an expensive project. This price on our project is a very reasonable cost. We used the middle of the market components therefore you can raise or lower this price. This project can be made as expensive as the consumer wants. The research we conducted showed that our financial budget is under average cost for installation of a residential charging station, and public charging stations. This proves that our design can help consumers reduce the initial cost of instillation for the charging station as well as not having to pay for the power bill because the system we designed is completely separated from the grid. One website we obtained numerical dollar values from for this research was insideevs.com. This website had accurate data and research that had been conducted by Josh Agenbroad and Ben Holland. The figures below show that the numbers from our project are lower than the economy prices today. Our system would be very simple for the consumer to install themselves instead of having to pay someone to install it for you.

The bullet points shown below are recorded values from insideevs.com

- home charging station – **$1,200**
- parking garage EVSE – **$5,500**, multiples in one location –**$4,000**
- curbside EVSE – **$9,000**, multiples in one location **– $5,800**
- curbside DC fast charging EVSE – **$60,000**



Financial Budget for DC-DC EV Charger using PV Panel

Item Description	Quanity		Cost/Per Unit($)	Total Cost($)
100 Watt Solar Panel	1		150	150
Solar Inverter	1		55	55
48-115 Volt Triad Toroidal Transformer	1		50	50
Schottky Diode	2		0.956	1.912
Charge Controller	2		80	160
12 Volt 100 Ah Battery	1		170	170
12 Volt 50 Ah Battery	2		120	240
Circuit Board	2		5	10
Wires and Connectors	20		0.5	10
Building Materials	10		4	40
				0
				0
				0
				0
				0
				0
Totals:	42			$ 886.91

Fig. 31 Component List and Budget

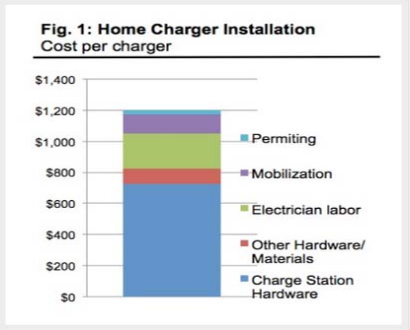


Fig. 32 Average household installation cost for charging station [27]

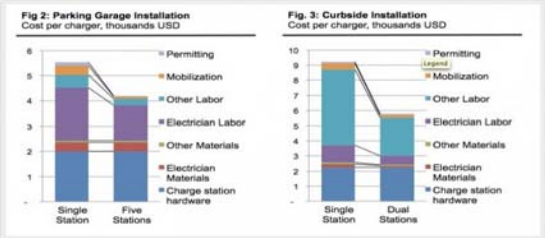
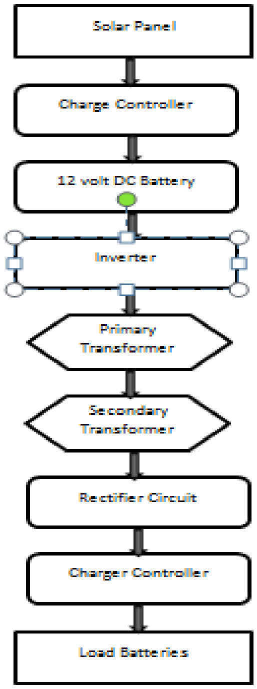


Fig. 33 Cost for garage or curbside installation [27]

These graphs show that these charging stations can get very expensive when installing. If a business or a private party wants to install a group of chargers to support multiply electric vehicles it would be very expensive to install and also the power bill would be affected dramatically. Our project proves that you can install as many chargers as you want at your own expense and the power consumed would be completely grid free. This is where our project pulls away from the competition; to have a power source completely grid free to charge your electric vehicle will make a breakthrough in the electric vehicle market [10].

4.5 Implementation Flow Diagram



5 Final Scenario

To overcome the problems we faced during the implementation of our project we have decided to make the changes necessary for the whole system to operate properly. We changed the load battery because we could not find the original battery we wanted to use because of the lack of demand for 36 volt batteries. We changed our load to a system of two twelve volt DC lead-acid batteries. Our secondary transformer is a 115 to 36 volt step down toroidal transformer. This will give us around 27 volts delivered to our load. This is enough voltage and current to satisfy our scenario for the load. This will allow the load to charge at maximum efficiency.

Another major change we had to implement was that we had to purchase an inverter for the first half of the transformation process. We used this inverter to compare the results to our inverting circuit we constructed. We initially tried to use a MOSFET switching sequence controlled by pulse-width modulation, and also the Arduino UNO. We could not get this to work properly because of the voltage we were applying to the gate was not high enough to allow the drain voltage to pass through. We now know that we cannot use just the Arduino's 5V to power full bridge inverter (also called the h bridge inverter). To use a MOSFET as a switch, you have to have the gate voltage (Vgs) higher than the source voltage (Vs).

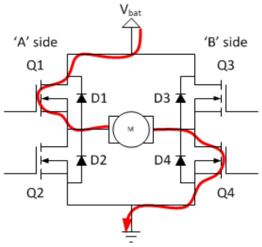


Fig. 34 Proper flow of current for MOSFET to act as switch

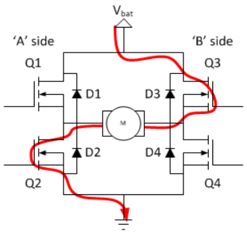


Fig. 35 Next switching sequence

So according to the modes of operation to the H bridge inverter, switches 1 and 4 will be on at the same time and switches 2 and 3 will be off. 1 and 4 will have the same clock, and 2 and 3 will have the same clock. There will be a voltage drop across transistor 1 of this circuit. Therefore, the clock voltage has to be such that it is higher than the source voltage of transistor 1 so that it will turn on. Usually you have one transistor connected directly to ground or in series with a resistor to ground. However, these two transistors are essentially in series, the source potential of transistor 1. As a result, 5V will not be enough to turn on the first MOSFET. 5V is less than rough 11.5V (given a 12V source and a 1/2V drop from drain to source of the transistor). To combat this we have come up with two different solutions.

Option A: use a relay with the Arduino as the control and the 12V battery on the power side. This will allows us to create an AC signal using just one relay versus four different transistors which simplifies our design greatly. The drawback is the frequency of the switching time is very limited.

Option B: create a common ground between the Arduino and the 12V battery. This should allow us to put the 12V battery in series with the Arduino created a DC offset for the 5V. As a result, we will have the same frequency signal (60 Hz), but with a maximum of 17V and a minimum of 12V. The question now is will this 12V keep transistor 1 and 4 on when only 2 and 3 should be on creating this.

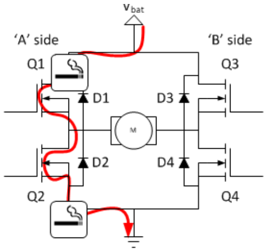


Fig. 36 Reason behind not being able to use the Ardiuno Uno for to control switching

The answer to this it seems is no. When transistors 3 and 2 are conducting, the voltage at the source of transistor 3 (roughly 11.5V) will be smaller than the 12V DC source still being applied to transistor 1 and 4. As a result, all the switches could be open at once creating incorrect operation of the h-bridge. Option A will be the path that we will have to go.

Voltage flows from drain to source in the MOSFETS we used for our charger. For this process to work the gate voltage has to be higher than the drain voltage. Our system would be losing efficiency if we added another source to make this voltage higher. We would be using more voltage to turn on the switches than we would be using for our entire system. This method is very impractical and unsustainable. The inverter being added into the system takes the place of the MOSFET switches and also the first transformer. This inverter takes a 12 volt DC input and converts it into 115 volts AC for the input to the second transformer.

After the second transformer we have a rectification circuit that converts the output of the secondary transformer back to DC voltage. This rectifier circuit consists of two schottky diodes connected to the center tapped transformer. After the diodes we used a 100 microfarad capacitor to smooth the output to get a more accurate level for our DC output delivered to the load batteries. We used charge controllers to regulate and protect the load batteries.

6 CONCLUSION

This paper proposes Charging EV battery using Photovoltaic Panel and DC-DC converter to be suitable for small-scale power grids with the name of nanogrids. It aims to design and implement self-sustained charging system without more money appeared in electric bill. This is to help Electric car owners to reduce or eliminate the cost of gasoline to run their cars without paying any money to the utility company. The proposed small electric vehicle charging station will harvest energy from the sun. This paper proposed design, simulate and implement a charger that is only powered by a 12v source (photovoltaic panel). The idea around this work involves using a DC to DC converter which will step up the voltage from the 12v input to a much higher output voltage. The push /pull topology Converter is used. We have chosen to scale our project down to achieve 100 watts of charging power. In scaling down we have chosen to scale our battery size down from the average 320-volt system to a 24-volt system. We have chosen to use a full bridge DC to DC converter, which is designed to be implemented in high power situations and works well when choosing our MOSFETS for the switching that is involved in the process. More on the design of the converter can be found further in the paper. We want this product to be as efficient and price effective as possible. This design is directed towards companies and industrial places that would require a car to be parked for a substantial amount of time. Being able to charge these cars completely separated from the grid could be very eye opening for consumers of the electric car market. We used a step-up transformer to transform 12 volts from the primary side to 48 volts on the secondary side. We have 240 watts of power since the current of the source battery is 20 amperes. The battery we are charging only requires 3 amperes of charging current. Our project is done on a relatively small scale, but still shows the convenience and reliability of solar power. The goal of this research is done with taking into consideration Ethical Issues however Positive or Negative, implementing scenarios, components, Simulations, Full Bridge Configuration, Challenges, Sustainability, Financial Budget and implementation Flow Diagram.

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