Small-Scale Electric Vehicle DC-DC converter for Nano-grids Applications

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Abstract: - Have you ever wondered what it would be like to have a self-sustained charging system that does not cost you any money on your electric bill? Electric car owners know that even though their cars do not require gasoline to run, they will require electricity and like everyone else that is tied to the grid will have to pay a price per kilowatt hour that is determined by their utility company. With gasoline prices falling somewhat in the past year the hype of electric vehicles has been somewhat less but who knows what the oil market is going to be like in the future, so why not be prepared. Our paper involves implementing an electric vehicle charging station that uses harvested energy from the sun.

Key-Words: - DC-DC Converter, EV, Battery, Photovoltaic.

1 Introduction

There are some different options of how to create the DC-DC converter. Some are very simple and others have very complex structures. The Boost and Buck converters are the simplest converters. These converters are not used for high power therefore were eliminated from the options for out project. Next we evaluated the push /pull topology along with the Half Bridge Converter. Each of these methods has pros and cons. In our project, due to limited time, resources and lab safety measures, 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. Our project will work relatively the same no matter what size load system we choose; this is due to the high power converter type we are choosing. 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.

In order for the DC-DC charger to meet our requirements we want a DC voltage from a solar panel to be able to be converted to a higher voltage level to be able to charge the load battery. We want this converter to have the highest efficiency that is possible for our setup to make this project economical. 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. The main objective of this project is to be able to show that an EV battery can be charged by a simple 12 volt DC photovoltaic panel. To do this we have designed a DC-DC converter that will implement this process. Our panel will be connected to a 12 volt DC battery; this will serve as our source voltage. A full-bridge converter is used to convert this DC voltage into AC to be able to increase the voltage level so we can obtain the desired current to charge the battery. We plan to use a step-up transformer to transform 12 volts from the primary side to 48 volts on the secondary side. We will 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. Two major factors for these panels are that they are noiseless and produce zero emissions. These factors play a major role when consumers are looking for alternate power supplies [1]. Also, there are incentives for people who chose to implement these panels. Some states in the U.S. have lowered the cost for these solar systems and also given tax breaks to the consumers who choose to install this system [2]. A fixed voltage charger, exactly how it sounds, is a charger that keeps a fixed voltage to the terminals of a battery. This type of charger relies on the battery to pull whatever it needs from the source. For example, a very empty battery will pull a high amount of current, and as the battery becomes more and more full, it will pull less and less current. The battery begins charging fast and then tapers off as its capacity fills; this is a result of the impedance. Its internal impedance increases as its capacity increase.

Fig. 1 shows our solar panel and charge controller delivering over 12 volts to charge our primary battery.

A fixed current charger, again just how it sounds, supplies a fixed current to the battery and allows the voltage to vary across the terminals of the battery. If you take a 12V battery for example that is quite dead, a fixed current charger will supply a fixed current, and the voltage will be around 10.5V (10.5V for a 12V battery means it is dead). As the capacity of the battery fills, the voltage across the load terminals increases.

A charge controller is just a voltage/current regulator to keep batteries from overcharging when they are connected directly to a solar panel. One important thing to note about solar panel is their nominal rating may be 12V, but they can still put out 16V to 20V. The question out of this is why will a solar panel put out significantly more than 12V? The answer to this resides in the solar panel itself. Because most times a solar panel will not have optimal conditions to output a voltage, it is made to put out an average of 12V. Most times a solar panel will only experience average, not optimal, conditions.

Maximum power point transfer controllers are the best type of charge controller to receive maximum power from the solar panel. They are meant to make the photovoltaic panel operate at the most efficient voltage aka maximum power point. It works like this: the charge controller will check the output of the solar panel and compare it with the voltage of the battery; it then picks the best power the PV panel can produce to charge the battery.

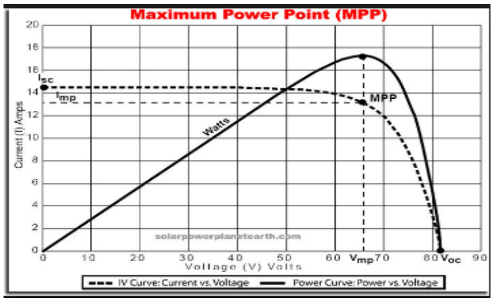


Fig. 1 Maximum Power Point tracking graph

Figure 2 is an example of MPPT in the graph above. It shows the voltage-current curve in the dashed line, and the power line as the solid line. We can see that at the point where the power is the greatest corresponds to a specific voltage and a current. As a result, this is the voltage and current the charge controller will use to get the most power it possibly can from the solar panel. No other voltage or current will give the maximum power. [9]

2 Ethical Issues

There are several factors and ethical issues to be discussed about our project. The main topics range from copyrighting issues, user health and environmental impact issues. We are going to start by covering the highlights of some of the issues we have faced as an introduction. Before beginning our project, it was discovered in some preliminary research, that this project was already being developed by other companies out there. The main existing projects covered strictly electric vehicle battery chargers with a few in the works using the same technology as we are. What separates us from the rest of the projects is the DC-DC conversion method for our project which was entirely designed by us and has its distinct features that was manipulated to meet our needs. Another part of our project that makes us stand out, is the load we have chosen. Our original design included a 48-volt battery load, but due to safety hazards in our lab and availability of components we chose to lower our load voltage level to 24 volts. In making these manipulations to our project, there came some other ethical issues that we had to address. In order to fit our DC-DC converter into our application, we had to add a second transformer for design purposes. In doing this, it lowered our efficiency and also added another electromagnetic field to our circuit. Electromagnetic fields or EMFs have been linked to causing health issues such as immune system trouble and even in high doses it can be linked to cancer and leukemia in children. From understanding this information and being engineers, we evaluated this risk and reached the decision that this would not be very high powered instruments and would most likely have minimal EMF effects. Even from this result, if indeed our project will be used on a daily basis that we will mount our final design in such a way to minimize the users' exposure to the transformers, or at least away from vital organs in the body. Another ethical issue we have faced has been using lead acid batteries over lithium ion. Lead has been determined by several states to be linked to many adverse health effects. Battery usage plays an important role in our project, being that we have to store as much energy that we extract from the sun as we can to become more efficient. When developing a project, as an engineer it is crucial to make decisions that keep the public health in best interest along with being cost effective and efficient. In this section of the report we will take a closer look on the ethical issues we faced in our project, by taking a look at both positive and negative issues. More on these issues will be discussed later in this part of the report [11].

2.1 Positive Issues

In this sub section we will discuss some positive ethical occurrences and outcomes of our project. The largest positive outcome from our project is going to be energy sustainability. There is nothing more absolutely ethical in power systems than harvesting energy, whether it be from the sun like our case, or wind. Taking advantage of natural resources provided by our planet is crucial in the longevity of our world. Let's look at some other ways that power can be produced, so that we can understand how impactful energy harvesting is. The first type of energy production we will discuss is coal fired energy plants. In recent years, the number of coal fired plants have decreased to the criticism they have received for the air quality. In coal fired energy plants, coal is burned to create heat then that heat is then used to create steam which turns a turbine and generator. Another popular energy producer is nuclear power. In a nuclear power plant, the carbon footprint is much lesser than a coal fired plant, but there are still some downfalls to the production. One of the major downfalls to nuclear power production is safety. Although nuclear power plants exercise great caution, there is still the fact that in the process of nuclear fission radiation is released. Within nuclear facilities the radiation containment is more than adequate to protect its workers and the environment which makes it more of a "what if" situation. Also along with coal there is an environmental impact due to the radioactive waste that is built up over time. The last type of major power production plant is the gas fired plant. The gas fired plant runs along the lines with the coal fired, but with the difference being the price between the two and the effects to the air. Natural gas plants are a cleaner burning plant, but gas has been the more expensive option for producing heat. After reviewing all of the different types of power production, it can easily be seen that harvesting energy from natural forces such as sunlight and wind can be used to combat some of these adverse effects from other methods such as carbon footprints and safety. Another negative factor along these lines especially for natural gas and coal is that these commodities are nonrenewable resources which cannot be used for long periods of times because the supply will deplete. [20]

2.2 Negative Issues

Some of the not so good issues have been outlined at the beginning of this section, but will be further expanded on in this sub-section. The first one we will start with will be the fact of the transformers that we are using will remit electromagnetic fields which have been linked to creating adverse health effects. As discussed previously these fields have been studied on a higher power level such as in people leaving near sub stations or high powered transmission power line areas. Knowing that this has been a widely discussed topic as stated before we plan to combat this issue by enclosing our transformers and mounting them in a user safe location if this project were to get implemented on the commercial side. Another issue talked about was the use of lead acid batteries. Lead acid batteries have been known to create negative views on both the environmental side and health side of topics. We will start by talking about the environmental side of lead acid batteries. This side of the argument is widely disputed because these effects are only seen as negative if they occur. The environmental impact from lead acid batteries would be the buildup of solid waste, in this case lead which like I said before has been linked to adverse health effects and is not something you want an excess amount of just sitting around. These effects can only be true if the batteries are not recycled. Retailers have come up with ways to combat this issue by offering core charges on the original battery when buying a new one. This offering, in turn allows the retailer to recycle or remanufacture the battery and sale it as reconditioned instead of the owner just dumping the old battery in the trash can. The lead acid battery recycle rate is fairly high and has drove down negative environmental accusations in recent times. The other side of this story is the adverse health effects from lead. These health effects have been proven to be more adverse to pregnant women or young children. One kick back of lead acid batteries from the health standpoint is lead poisoning. Although most of the racket involving lead acid batteries is not in fear for people to become ill will lead poisoning but rather the effects of the long term exposure even to what seems to be a minimal amount of lead. [21]

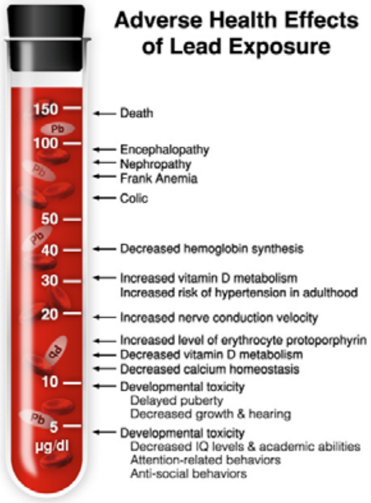


Fig. 2 Health Exposure Limits and Symptoms at different levels [23]

In our project we understand lead acid can be potentially harmful over a period of time, but the other alternative was lithium ion which has proven to be safer in that department but harmful in others. The lithium ion battery has been proven to contain a less amount of harmful material, but in turn is more expensive than lead acid batteries and can be potentially dangerous if the charging mechanism is not correct or malfunctions. There have been several instances in the recent times of products containing lithium ion batteries that have either exploded or caught on fire from charging issues. A number of reports have come out that these incidents have been caused by not the battery, but the companies cutting corners in the charging mechanism which is a huge ethical talking point. These lithium ion batteries can be very sensitive to overcharging and if the charge controller part of the charger itself is not functioning properly these batteries can become dangerous. With the safety issues being the case, we could have looked into this issue further and still may do so if this project were to be created on a mass scale, but for a one-time design and implementation it was more economically feasible for us to choose lead acid. Below you will see a figure explaining the difference from a money standpoint and also prove the ethical point about designing using a lithium ion for user payback and life of the charger.

COST SAVINGS	LEAD ACID	LITHIUM ION
Life Span (in daily cycles)	300	5000
Amp Hours	110	100
Cost	$339.71	$1,299.99
Batteries needed x 10 Years	11	1
Total cost for 10 years spend	$3,736.81	$1,299.99
Total Savings	$0.00	$2,436.82

Fig. 3 Cost savings on using Lead Acid batteries vs. Lithium Ion [24]

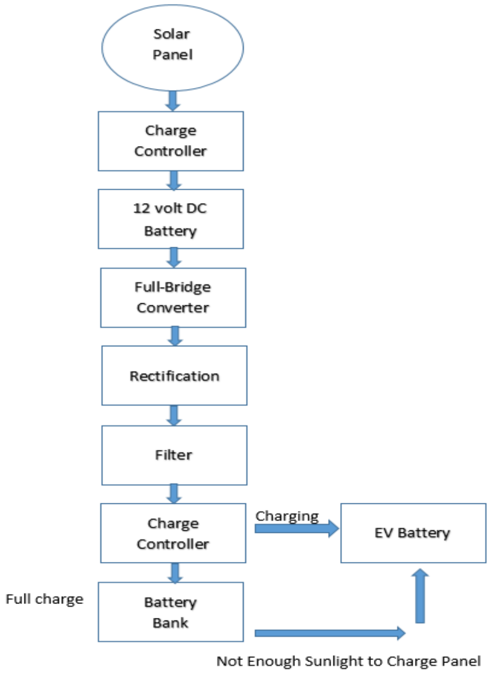
2.3 Overall Ethics

As discussed previously, our project was not the first of its kind. While we were researching this idea we came across several ideas on how we could make our system work. Some other companies had even gone on to actually build this system. Of the ones we found, we tried to make ours unique as I mentioned before by scaling the project down and also designing our DC-DC converter from the ground up. The main purpose behind what every other electric vehicle charging design is the same as ours, which supports a very positive ethical motive to work together to have a "greener" earth. Years ago when the electric vehicles made their first mark on the public, it seemed like a no brainer to consumers since gas prices were on the rise but what little did they know was there was still a somewhat high cost for the electricity that was being used to charge their vehicles. The one goal for our project is to lower the cost for electric vehicle users by producing a relatively less expensive, yet safe design. By designing a cost effective charging system, it will then most likely increase the sales of electric vehicles and in turn lower gasoline consumption. Gasoline consumption, especially in a great abundance is not a good thing as gasoline is made from the refinement of petroleum which is a fossil fuel. The usage of fossil fuels especially petroleum can be harmful to both the environment and the sustainability of the earth. Petroleum, as of recently has been a fossil fuel that has been on the verge of depletion due to the high demand for the commodity and also has been challenged recently on the method of extraction for the fossil fuel over how it affects the earth internally besides what it will do to the atmosphere which I will get to later.

The exhaust from gasoline/diesel engines has been a very touchy subject in the world and especially in the United States, due to the fact of it being harmful to our environment and also harmful to our population because of the emission of carbon monoxide which is a bi-product of the combustion of a gasoline/diesel engine. There have been many accusations and test ran on how exactly the gasoline engine has affected things from the climate to the air quality and carbon monoxide long term exposure health trials. Developing from the harmful accusations of air quality from the gasoline/diesel engine has come a board that specializes on the emission control and this board is known as the ARB or Air Resources Board which is concentrated in the state of California and is a division of the environmental protection agency. The talk in the recent news in the air resource world is that this type of governance has been discussed nation-wide and is slowly being enforced in other areas. The major reason for this is to prevent what has affected mostly densely populated countries such as China for example, where they have a very dense population and between the factories and exhaust emissions they have a serious air quality issue. From this type of experience that China is having, the Air Resources Board has been developed as a very proactive approach to prevent the air quality from becoming contaminated and our climate from being shifted in such a way that it creates a negative impact. From the Air Resources Board being developed and the high gas prices, it has somewhat raised the consumers interest in electric vehicles, so our ethical issue solution is to finish attracting interest by lowering the production cost and developing an affordable system. Our hopes are to further the research and implementation of electric vehicle technology and show the consumers that "going green" is something that can be done fairly easy and cost effectively.

Fig. 4 Carbon footprint from 2014 in metric tons [25]

3 Flow Diagram for First Scenario



3.1 Components

To begin the process of our project we start the flow of energy by harvesting solar energy through a 100 Watt DC solar panel. We will use a charge controller in between the solar panel and the DC battery. This will serve to show the voltage we are getting from the panel and also to prevent the battery from getting harmed. The solar panel is then connected to a battery which allows us to obtain the power needed to charge the battery. From this step we use MOSFET switches with a switching frequency of 30 kilohertz. This allows the DC voltage to be converted to AC voltage. This AC voltage is then passed across a step up transformer. This transformer increases the voltage to a high enough level to decrease the charging current which serves as an overcurrent protection. On the secondary side of the transformer the voltage is rectified to make the output voltage purely DC. After the rectification step of our circuit we will have a second charge controller to regulate the power delivered to the load. This will also allow us to determine when the load battery becomes fully charged. With this information we will be able to prevent overcharging the load and damaging the battery. Below are the steps of the MOSFET switching sequence which allows the voltage to be pushed across the transformer.[13]

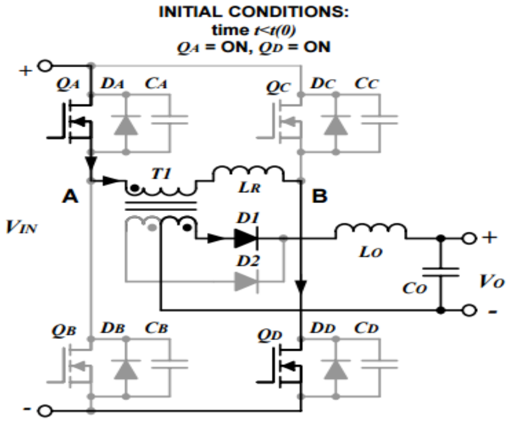


Fig. 5 Initial Condition of MOSFET Circuit

Figure 6 is the first setting of the switches, it show that Qa and Qd are conducting at the same time which allows current to flow through and pass through the high side of the rectifier. The time between the switching stages is known as transition time. This transition time allows the capacitors to charge and discharge accordingly. Diodes are used to prevent the switches from reverse current. The next switching stage is when Qc and Qb are conducting simultaneously.

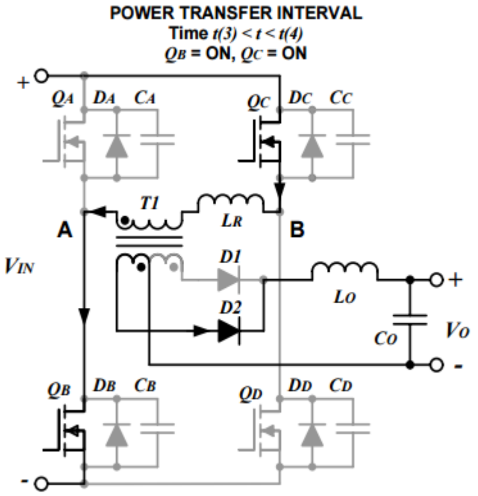


Fig. 6 The Power Transfer interval of the MOSFET Circuit

Figure 7 is known as the power transfer interval because the switches have gone through one complete rotation which gives the same output only converted from DC to AC. This is shown in the graph below.

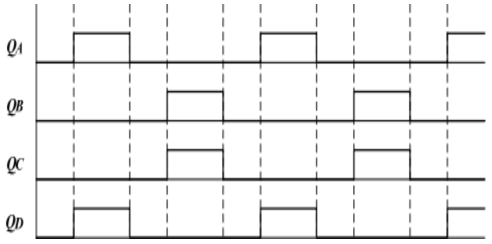


Fig. 7 AC Voltage Conduction after the MOSFET Circuit

3.2 First Simulations

DC-DC conversion has many different configuration options. We tried to use the simple DC-DC boost converter for our project to begin with. The boost converter along with many other converters were analyzed and overruled because they were not capable of dealing with the high operating power we want to obtain. After much trial and error we created a working simulation with Simulink. This simulation was done through MATLAB and the 12 volt solar panel was shown as a normal 12 volt DC battery. The results for this simulation prove to be the correct output we needed to charge our battery load. The simulation file is shown below. The transformer we used had a 1 to 4 ratio which allowed the voltage to be increased from 12 volts to 48 volts. The MOSFETS were switched using pulse-width modulation with a very high switching frequency of 30 kilohertz to obtain the correct power that we needed. We used metering tools to show the output from each MOSFET and also the output to the load. These graphs are shown below.

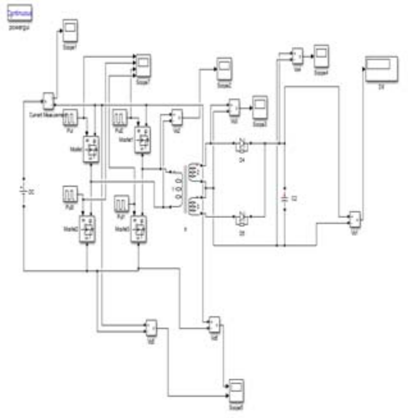


Fig. 8 First Simulink Circuit Simulation

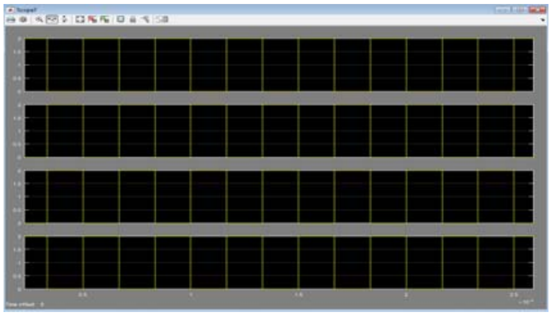


Fig. 9 Scope of MOSFET conduction sequence

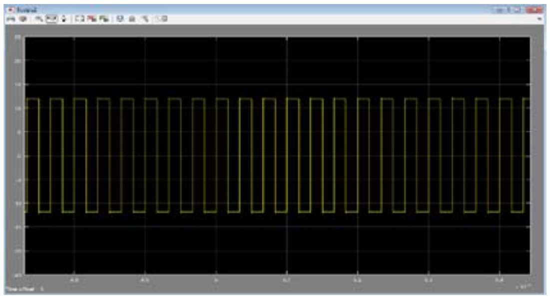


Fig. 10 Scope of input voltage to transformer

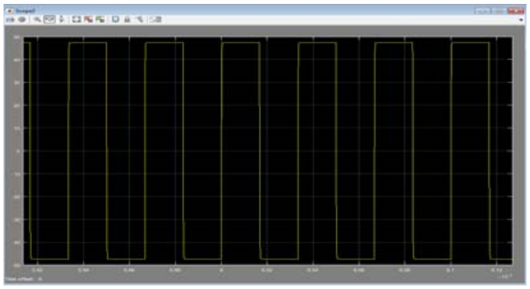


Fig. 11 Scope of output voltage from the transformer

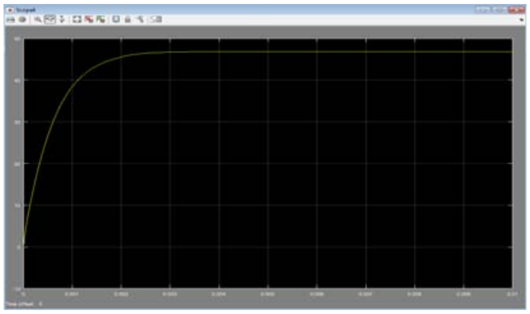


Fig. 12 Scope of the Output delivered to the load

4 Full Bridge Configuration

The full bridge topology was the configuration we used in the simulations because it could handle the high power we desired. Also this configuration can handle the high switching frequency of the MOSFETs. The full bridge converter is known for the high efficiency rate. This configuration is said to have around eighty five percent efficiency at high power rates. This configuration has two MOSFET switches conducting at the same time as you can see in the waveforms and descriptions above. This allows the voltage to be increased to desired levels. The main benefit of using this converter is that it is most efficient at high power applications. The drawback of using the full bridge is that you are risking having high switching losses when using such high switching frequency at high power levels. We controlled the output by making the turn’s ratio of the transformer equal a ratio that would give us our desired output level on the secondary side to be rectified. The MOSFETs on the primary side of the transformer were controlled by Pulse Width Modulation to transform the DC voltage to AC for the input voltage on the transformers primary side.

4.1 Changes and Challenges

As we were ordering our parts for our project we came across a few challenges in finding the specific transformer we intended on using. This transformer was a high frequency transformer that operated at relatively low voltage. We found this to be impractical and also this would require us to build the transformer ourselves. Due to time constraints and the original idea of our project we decided not to waste valuable time trying to design this transformer. We then made the change necessary for our design that would allow us to obtain the desired output by removing the transformer we originally had. This led us to replacing it with two sixty hertz transformers. This was done so that our switching frequency of the MOSFETS and the frequency of the transformers would match up. These transformers are Triad toroidal transformers that we purchased for our project. The first transformer after our full-bridge configuration is a 12 volt to 115 volt transformer. This transformer will step up the original voltage from the battery so that we can obtain the values we need to supply our load. The second transformer is the same brand as the first one but this is a 48 volt to 115 volt transformer. We will use the secondary side of this transformer as the primary side in our physical implementation because the 48 volt side is the side we will need to supply our load properly. We are supplying a 24 volt DC load therefore we will need more than 24 volts. In our calculations we have shown that we will need a minimum of 27 volts for the battery to charge. Anything less than 27 volts will not charge the battery. This is the reasoning behind our 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.

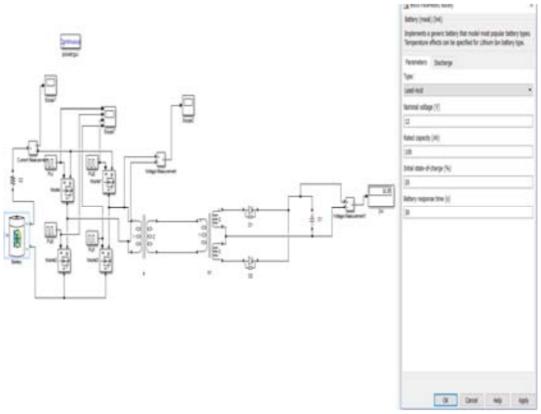


Fig. 14 New Simulations a

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.

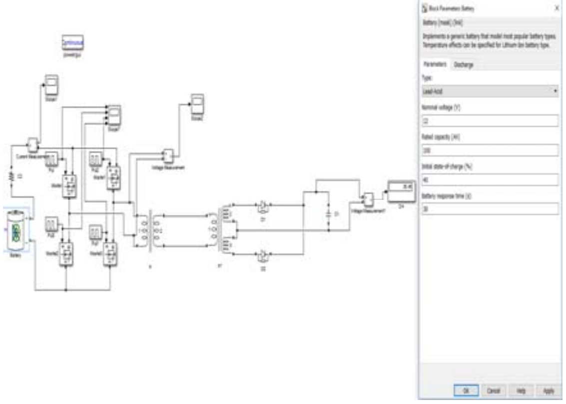


Fig. 15 New Simulations b

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.

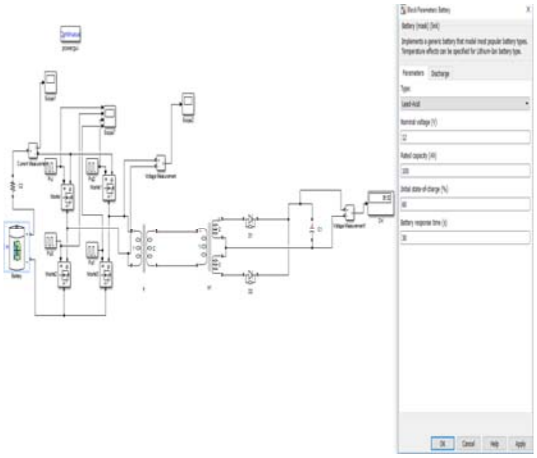


Fig. 16 New Simulations c

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.

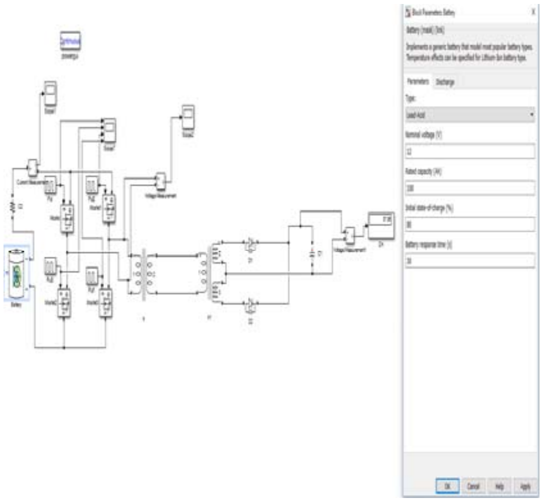


Fig. 17 New Simulations d

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

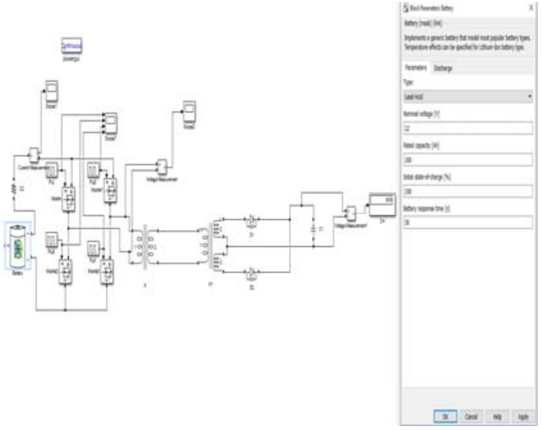


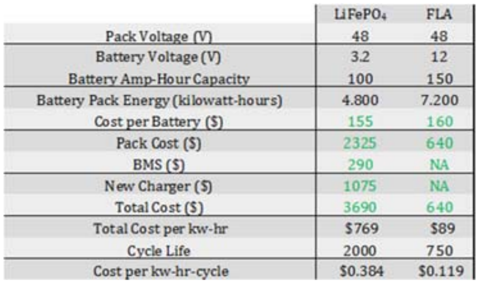
Fig. 18 New Simulations e

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.

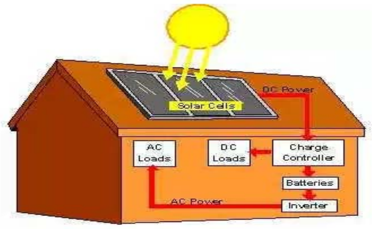


Fig. 21 Flow of solar energy throughout a household.

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.

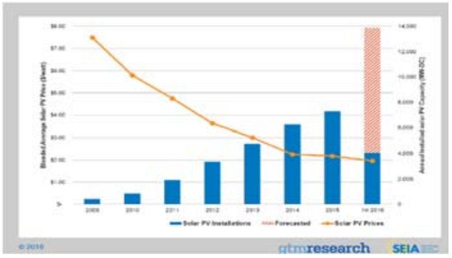


Fig. 23 Correlation between price decrease and installation increase for solar panels.

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.

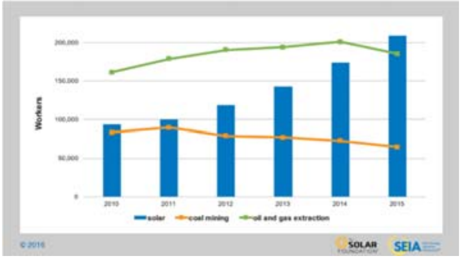


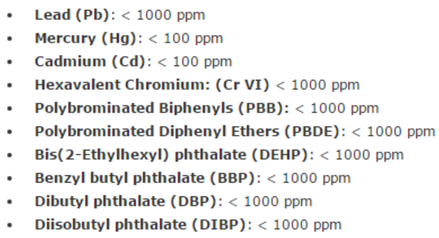
Fig. 24 Employment rates due to solar energy

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

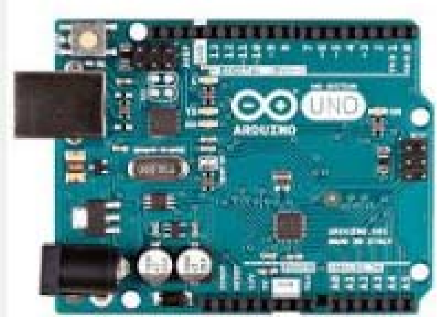


Fig. 27 Ardiuno Uno

Fig. 28 Secondary Transformer

Fig. 29 Schotkky Diode

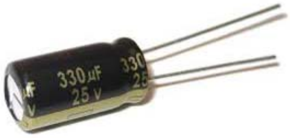


Fig. 30 Smoothing Capacitor

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].

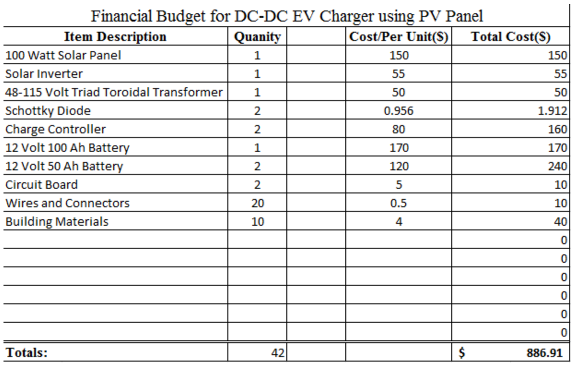
Most of our components unfortunately do not meet the RoHS compliancy which is an issue for sustainability with regards to the environment. Fortunately, there are always many other components to choose from and finding RoHS compliant parts would not be an issue.

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

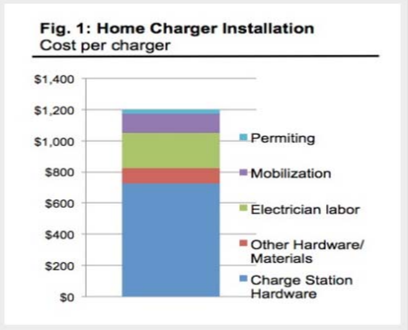


Fig. 32 Average household installation cost for charging station [27]

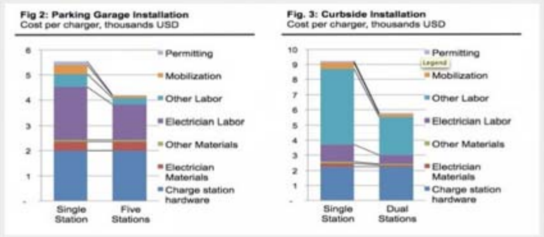
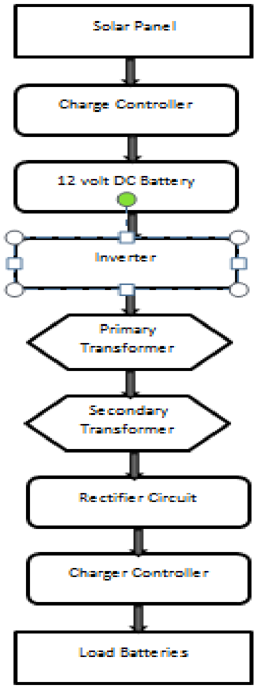


Fig. 33 Cost for garage or curbside installation [27]

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).

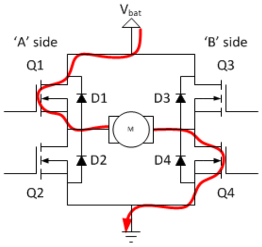


Fig. 34 Proper flow of current for MOSFET to act as switch

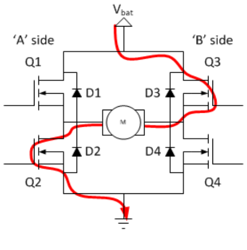


Fig. 35 Next switching sequence

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.

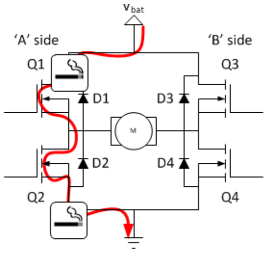


Fig. 36 Reason behind not being able to use the Ardiuno Uno for to control switching

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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