ENERGY HARVESTING SYSTEM

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LIST OF SYMBOLS AND ABBREVIATIONS

CO_2	Carbon Dioxide
PPM	Part Per Million
KW	Kilo Watt
KWh/m^2	Kilo Watt Hour Per Meter Square
MoEE	Ministry Of Electricity And Energy
NREA	New & Renewable Energy Authority
PV	Photovoltaic
DC	Direct Current
AC	Alternating Current
PCU	Power Conditioning Unit
V_{OC}	Open Circuit Voltage
$\mathbf{I_{sc}}$	Short Circuit Current
V_{MP}	Voltage Of Maximum Power
FLA	Flooded Lead Acid
MPP	Max Power Point
MPPT	Max Power Point Tracking
SMPS	Switch Mode Power Supply
SNR	Signal To Noise Ratio
Wh	Watt Hour
Wp	Power Needed By Panel
Vin	Input Voltage
Vout	Output Voltage
Iout	Output Current
F_{sc}	Switching Frequency
kHz	Kilo Hertz
PWM	Pulse Width Modulation
CCM	Continuous Current Mode
ESR	Equivalent Series Resistance
V_{ds}	Voltage Rating
I_{ds}	Current Rating

F	Total Force
A	Total Area
V	Speed Of Wind
IOT	Internet Of Things
SOC	System On Chip
TCP/IP	Transmission Control Protocol/Internet Protocol
GPIO	General Purpose Input/output
VoIP	Voice Over IP
APSD	Apple Push Notification Service
RF	Radio Frequency
I-V	Current-voltage
UPV	Voltage of photovoltaic
PPV	Power of photovoltaic
SPH	Sun Peak Hours

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ABSTRACT

There is no doubt that the increasing demand on power sources is a global issue. Egypt is not the only country suffering this problem. Through this thesis, we address solar energy from a social, engineering and financial point of view.

The purpose of this project is to design and implement a Solar Tree (green energy harvesting system) to provide a sustainable source of electricity in open working areas. Due to the rapidly growing technologies with limited capacity of used batteries, the demand for electricity in open areas has been increasing which motivated us to divest to renewable and reliable sources of energy.

Alternative power source seems at first glance to be a great solution. Our project is providing AC and DC power outlets to charge various electronic components such as mobiles and laptops in open areas. That is beside the inspirational advantage of the solar tree. The Solar Tree consists of Solar panels, charge controller (to charge batteries) and a DC/AC inverter for the AC loads. The panels used at our prototype provide DC power of 100 watts which will be accumulated to provide 500 watt hour daily for loads. Moreover, the tree is extendable to increase number of panels and provide more energy.

This project presents a developed charge controller which includes an MPPT (Maximum Power Point Tracker). MPPT is a circuit used to track the maximum DC power provided by the solar panels. It senses the output voltage and current generated by the panels and using a pre-specified algorithm, it tracks the maximum produced power that loads need. That is done in order to make a total use of the panel efficiency overcoming the variable factors affecting the panels such as heat and solar radiation.

1 INTRODUCTION

We live in a planet that has been here for more than 4 billion years. Humans exist on this planet only for 200,000 years yet they had huge impact on planet. At first, humans mainly depended on animals for transportation as an effective solution to overcome the limited resources to travel for long distances. After the industrial revolution, humans figured out how to make the best use of the various sources of energy that earth is rich with. Those energy sources are two types, renewable and non-renewable sources of energy. Renewable energy sources such as solar energy, wind energy, hydropower and biogas. Through this thesis we focus on one of the most reliable sources of renewable energies, solar energy. As long sun exists, human are capable to live on a suitable temperature. [1]

Solar energy technology harvests the energy of light emitted by the sun and converts it through various technologies into electrical energy. Those systems, such as photovoltaic systems, are made of solar cells that are used to utilize the energy of photons to excite electrons producing continuous direct current. Another track of using solar energy is thermal system where heat is used to generate steam to rotate a turbine producing continuous alternating current.

Charles Fritts constructed the first solar cell in 1880's then a photo cell is developed by Dr. Bruno Lange using silver selenide instead of the used copper oxide yet with low efficiency of only 10%. By 2012, researchers have acquired an efficiency for the photovoltaic system of 40%.

As will be discussed in Chapter 2, the reasons why we chose solar energy and its usage as a solution to climate change are mentioned. Egypt has a huge potential that motivates us to use solar energy locally. In addition, different types of PV systems are discussed in Chapter 3, illustrating the different designs of solar cell technology and focusing on the most appropriate system that fits our project the most.

Our project is implemented in what so called "solar tree". Solar tree is a combination of engineering and artistic effort to harvest the energy of sun efficiently and utilize the solar cell technology. Our project focuses on an energy harvesting system which includes a tracking device to get the maximum peak power out of the PV solar panels. In Chapter 4, we will elaborate more about a device called MPPT (Maximum power point tracker) which help the system utilizes itself to adapt to the various changes in I-V curve characteristics of the solar panels. The challenge that we face is that the solar cell I-V curve rapidly fluctuates as a response to the rapidly changing solar radiation and temperatures. [2]

We used Arduino based circuit to implement the MPPT device using algorithm which calculates the maximum power that loads will operate on. That is elaborated in details in Chapter 6. Besides, we implemented in Chapter 5 the PV system without the MPPT device to get clear information about the real-time impact of our power tracking device.

To implement the project practically, we manufactured a prototype of a solar tree with more details in chapter 6. Solar tree merges solar technology and art in a sculptural structure. The term solar tree has been used to describe various structures that harvest solar energy with artistic point of view. Solar trees are both artistic and green machines. We deigned our solar tree to support inhabitants with pre-specified amount of energy as will be also mentioned in Chapter 6. This amount of energy is based on updated power calculations to make the best use of solar energy in the form of electrical energy.

When it comes to financial analysis, solar energy faces some challenges considering its price and cost compared to energy generated by the fossil fuel. Usually, fossil fuel seems to be cheaper than solar energy as its cost is not including a social impact. Fossil fuel has a massive carbon footprint that is harming the environment and the health of citizens. In Chapter 7, we discuss the financial analysis of our project compared to the tariff of local electricity provided by national grid. This tariff is set by the Egyptian government.

The existence of that sculptures needed several analysis like choosing the appropriate orientation of solar tree to best harvest solar energy. As long this sculpture is designed to best fit in public areas, it is supposed to have several social impacts on consumers and communities. This social aspect and the implementation of the solar tree are both discussed in Chapter 7.

To guarantee the sustainability of our product from a market based point of view, we designed it on software that takes into consideration several aspects such as: the variable wind speed and the stress analysis of used materials. That design is discussed Chapter 9.

The step by step results and issues that we faced during implementation will be discussed in details in chapter 10

Through Chapter 11, we mention various ambitious future plans to modify our prototype to meet the customized consumer demands and the global rapidly increasing energy needs.

2 WHY SOLAR ENERGY?

2.1 Problem Addressed

2.1.1 Climate Change

The reasons behind climate change are very complicated to be mentioned in one report. However this thesis will provide a general description of what climate change is, impacts of climate change, and solution to the problem that majority of humans are facing nowadays.

The temperature of the planet is mainly caused by the most powerful source of energy, the Sun. The huge amount of radiation produced by the sun reaches our planet in the form of light. That radiation is represented in various wavelengths. Sun generates that light thanks to huge chemical reactions. That light is emitted to travel through space and to penetrate our atmosphere. After passing the atmosphere, it hits our surface where it is converted into another form of energy which is heat. That heat is responsible for keeping our planet warm enough to enable humans to live in a suitable environment. The heat then is reflected by the surface of the earth to be radiated back to the space. Due to the existence of what so called greenhouse gases, the heat cannot easily pass through atmosphere to space. Methane and CO_2 are famous examples of greenhouse gases. That results in keeping our planet warm and saves it from becoming very cold. [3]

The amount of that greenhouse gases has been steadily increasing during the last decades due to the rapid increase in industrialization. As a result, an increase in the amount of heat kept inside our atmosphere is caused. Moreover, the sun keeps sending its radiation to the earth that is always kept inside the atmosphere and yet it is not able to escape to space. This results into what is called Global Warming. It means that the temperature of planet keeps rising. [3]

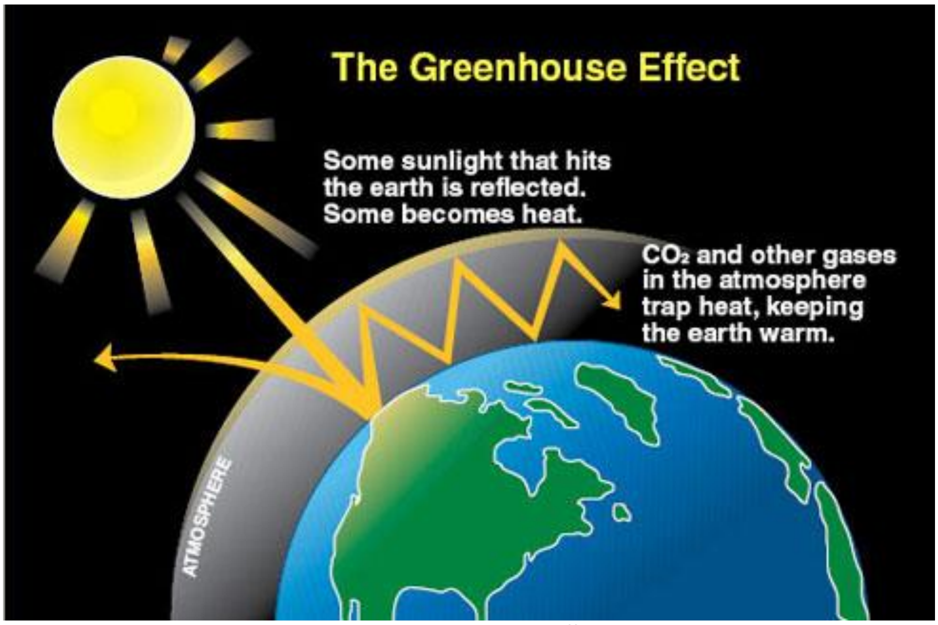


Figure 1 the Greenhouse Effect [4]

Still, that does not mean that temperature is increasing everywhere in the planet. The weather of planet is complex that its patterns are changing continuously. Now, scientists know well that our planet has been warming up during the last century. They know it is us –humans- who caused that increase in planet temperature by the continuous burning of fossil fuels like coal, oil and gas. This caused an increase in the greenhouse gases trapped inside our atmosphere which traps heat as well. As a result, the planet is predicted to keep warming for the upcoming years. Global warming has significant impacts on ocean levels, humans' health, ecosystem, global economy and climate patterns. Unless we stop producing CO_2 emissions with huge amounts, disasters will occur. [3]

2.1.2 Climate Change Impacts

The planet is getting warmer. The average planet temperature has increased by more than 1 degree Fahrenheit over the last century with average increase of 4 degrees Fahrenheit in some regions, as mentioned in figure 2. [5]

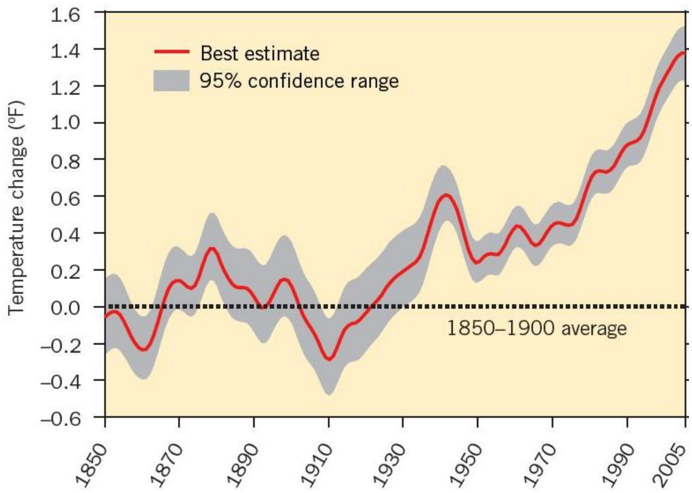


Figure 2 Average planet temperature during last century [5]

According to the researchers, this warming pattern has quickened lately. The ten hottest years -since thermometer records got to be accessible in 1860- all happened between 1995 and 2005. The World Meteorological Organization has reported that 2005 was the second hottest year on record surpassed just by 1998 when El Niño conditions in the Pacific Ocean were added to above-normal temperatures around the world. For the United States, the initial six months of 2006 were the hottest of such period on record. No U.S. state was cooler than normal for the six-month period; five states—Texas, Oklahoma, Kansas, Nebraska and Missouri- experienced warm records. [5]

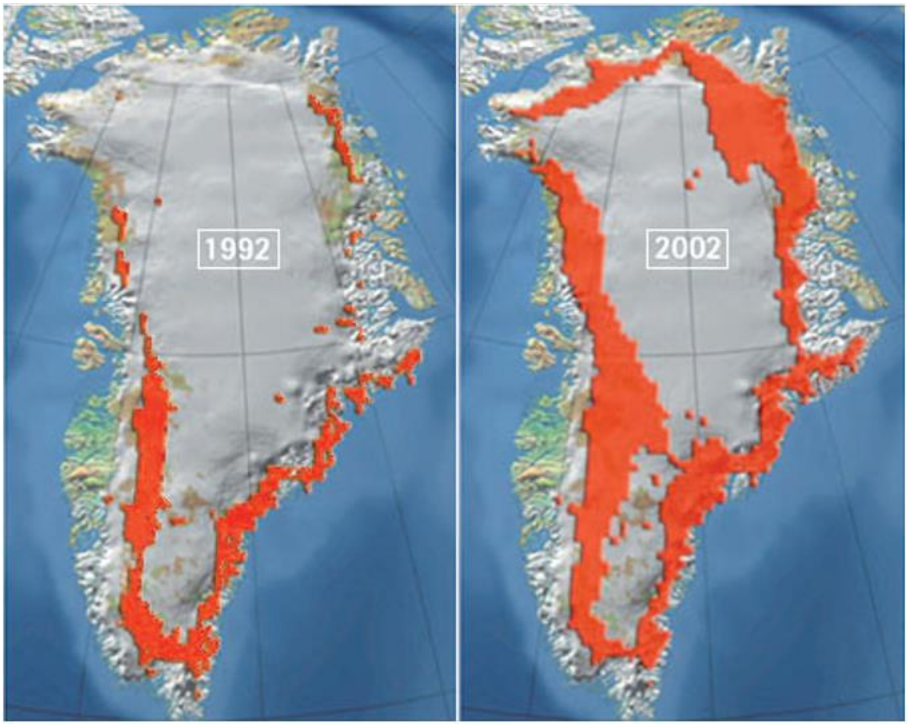


Figure 3 GREENLAND ice sheet melt extent [6]

Climate change has enormous huge impacts such as causing some areas to be wetter in winter and drier in summer. Storms are happening more often in particular places. Also, droughts and floods have become more frequent. Ice melting can be noticed in the arctic. Figure 3 shows the amount of melting of ice sheet in Greenland during just 10 years. To avoid the wrong perception that Global warming is affecting the whole planet to become warmer everywhere. We preferably use the term Climate Change.

One of the main problems of climate change properties is that its effect on nature is continuously rising up. That impact on life on earth increases a lot due to the effect of nonlinear elements like solidified methane being discharged as permafrost soil is gradually warming up – in the sea. Discussing seas, not just will they develop bigger and swallow waterfront territories, they are as of now turning out to be more acidic because of rising levels of CO_2 breaking down in the water. That destroys the whole ecosystem and uproots a critical source.

The science of climate change says that we're coming up short on time—that we have only few years to start a quick move to a worldwide clean energy sources. Climate change researchers now say that we should be expected to settle CO_2 levels in the environment at a level beneath 350 part per million (ppm). With melting of ice glaciers, often happening storms, droughts and the increased numbers of wildfires, it ought to shock no one that we're above 350 ppm. While you are reading this thesis, we are at 403.7 ppm and rising so we have to cut down our carbon emissions immediately. It is too late to be pessimists. Figure 4 shows the carbon emissions per person in different countries. [7]

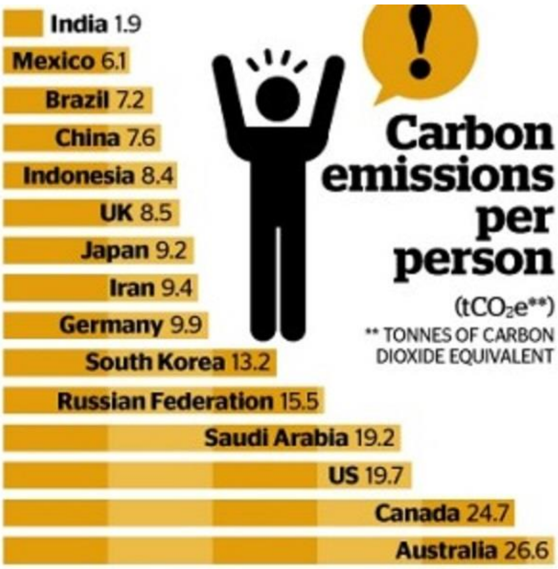


Figure 4 Carbon emissions per person [8]

Climate change impact is not uniformly distributed and it is not related to the financial or social capabilities of various nations. As a result, it is important to clarify the term Climate Justice. Climate Justice tries to make a superior harmony between the countries who created environmental change and benefitted from it (the industrialized countries) and countries that are currently suffering the consequences (generally poorer nations with less alternatives to adjust to environmental change and relieve its harm). [3]

2.1.3 Climate Justice

Climate justice studies the impact of climate change from a moral point of view. It is mainly about the countries of the north which are the most responsible for the greenhouse gases emissions (as a result of the industrial revolution developed in the Global North), but when we are talking about the countries that suffer the most from the impact of climate change then they are the Global South countries (specially the extreme weather attitudes) however, they never had the chance to produce or cause CO_2 emissions of any comparable quantity.

In figure 5, we notice the injustice of climate change effects around the globe. Nations checked in red are the most defenseless against climate change effects (rising ocean levels, floods and natural disasters). They all exist in the countries of the Global South that have just joined the industrial revolution lately, if at all. In the meantime the wealthiest nations are all checked in blue or light blue, which shows less effect of climate change (but they still have impacts of climate change affecting their environment) Simply think about the warmth wave in France in 2003, tropical storm Katrina in the US in 2005 or the dependable serious dry spell in Australia). [3]

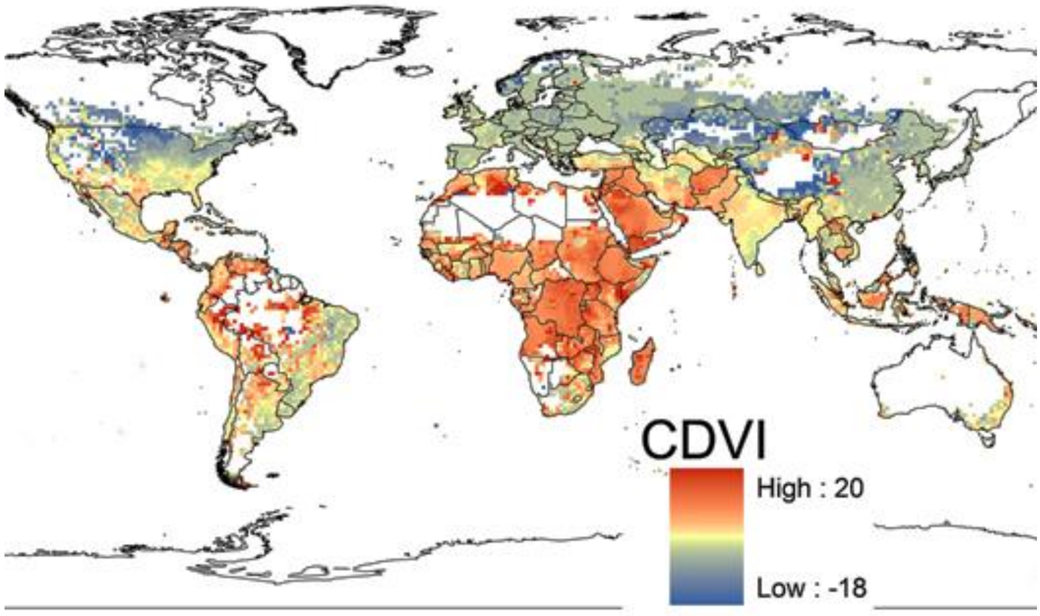


Figure 5 Vulnerability to climate change [9]

"We must also understand that to be neutral in the face of injustice is to side with the powerful. And that means that we can't talk about consumerism without differentiating between those who are driving it and those who are suffering from it; we can't talk about growth without distinguishing between those who gain from it and those who are losing out. We can't talk about climate change without being absolutely clear who it is that is driving the changes in our climate and who is suffering from them."

'My environmentalism will be intersectional or it will be bullshit', Adam Ramsay, Open Democracy

Climate change is not only an ecological issue: it postures more difficulties to our financial framework, health awareness and national security. So what does a sustainable way of life really means? Is it the demonstration of isolating waste and recycling all over? More group bonds? More opportunities for one another? A healthier way of life? Neighborhood living and more contact with nature?

These acts demonstrate that lower-carbon ways of life are related -at least for a few individuals- with a much more extensive vision of 'the good life', wellbeing, satisfaction, and community. Whether we name it transforming cultures or transition towns, it is mainly about having a better life. You don't even need to believe in climate change to need to live in a low-carbon world on account of all the advantages it brings to you, to your society and to every single living creature. [3]

2.1.4 Solutions to Climate Change

Nowadays we have various solutions to climate change promoted as sustainable methods to start healing the impacts we have already caused. Unfortunately those solutions are not stopping the climate change impacts but only slowing us down on the way to catastrophic climate change.

As an example, we can use less packaging materials for daily produced goods which sounds great as we will then leave behind less trash but if we do not stop using the over packaging all together, sooner or later the row materials will be trashed. So what effective way to stop the climate change impact would look like? For example depending on local products is better as they do not have to be transported to hundreds of kilometers. As a result to those shorter distances, we will use less packaging or we can even use no packaging at all. New policies should be taken into consideration that make it easy for inhabitants to access clean tap water instead of the plastic bottled water. Also punishing policies to stop companies that dump their waste without any treatment which contaminates the soil can be applied. In addition, forcing companies to produce products with parts that can be easily modified instead of products that need to be replaced too often to meet the fast daily growing technologies. [3]

To achieve the change we need, individuals' attitudes are crucial elements in the divestment process. That happens when those changed behaviors are integrated into collective actions. We need an ecological system that motivates individuals to divest into more sustainable and green alternatives easily. We need a system where those green alternatives have to be cheap and the unsustainable choices are expensive and unacceptable widely. Figure 6 shows an implementation of how sustainable and unsustainable systems could look like.

Figure 6: Sustainable system V.S. unsustainable system [10]

To get to CO_2 levels of 350 ppm we require a renewable energy revolution everywhere and it needs to begin now. It will require phenomenal cooperation over all parts of society, with everybody moving at record-speed. This sort of cooperation might be achievable if nations of the entire world hold a worldwide arrangement that will return the planet on track. [7]

Committing no mistakes and recovering the planet to the security zone beneath 350 ppm will not be a simple task. If we decide to face that challenge, a way to 350 ppm offers an exceptional chance to reevaluate and rethink the world's energy system. We have several solutions to get back to 350 ppm such as using solar energy instead of the coal plants, using less packaging to decrease our trash and planting trees instead of deforestation. You can help shape what 350 methods are in your own group, in your nation, and in the world. [11]

However great climate occasions around the world such as: rising sea levels, floods, droughts and wildfire are damaging our planet, we know the solutions to face those impacts but our politicians have not taken a positive step towards it yet. It is clear that climate change is no longer a future danger.

Consistently, the fossil fuel industry spends a huge number of dollars to degenerate our majority rule government. In case we're going to restrict warming to 2°C -an objective that even the most preservationist governments on the planet have consented to meet- then we can just discharge 565 Giga tons more of carbon dioxide. However, the fossil fuel industry has 2,765 Giga tons of carbon in their stores -about five times the protected sum- , consistently they're always searching for more. A global divestment is up to challenge the fossil fuel industry for the sake of the planet and our future on it. While it’s actual that fossil fuel organizations are greatly gainful (the main five oil organizations, a year ago, made $137 billion in benefit -that is $375 million for every day), they're likewise exceptionally unsafe investments. Coal, oil and gas organizations emit five times more carbon into the environment than they can deal with, which makes their offer price five times higher than it is ought to be in reality. Furthermore, catastrophes like the BP oil slick and Exxon Valdez make energy markets unstable.

Report after report has demonstrated that divesting to clean energy and sustainable innovations can be even more gainful than fossil fuels. It's a developing business, with over $260bn contributed universally last year. [11]

2.1.5 Renewable Energy as a Solution

As mentioned before, the heart of the problem is that our energy system mainly depends on fossil fuel which is responsible for the emission of greenhouse gases. On the other side, renewable energy is one of the most effective solutions to climate change issue. It provides energy for our various daily demands such as: heating, cooling and transportation with zero-carbon emissions. Renewable energy options such as solar energy, wind energy, biomass, hydropower and geothermal energy offer a green sustainable economy. [12]

80% of the worldwide energy production comes from fossil fuel energy sources as clear in figure 7. Every week 2 new electricity generating plants based on coal are built in China alone. However in Denmark, there is a prototype of an electricity generating plants powered by coal that releases its carbon emissions into the soil instead the air. It might be a solution for the next generations? Nobody knows. In Iceland, there are a power plant fueled by the Earth's geothermal heat force. An ocean snake lying on the swell to ingest the vitality of the waves and produce electricity is an innovative solution as well. In Denmark, wind turbines off the coast deliver 20% of the nation's power demand. Where on Earth doesn't the wind blow? The U.S.A., China, India, Germany and Spain are the greatest investors in renewable energies. Renewable energy has effectively created more than over two million employments. [1]

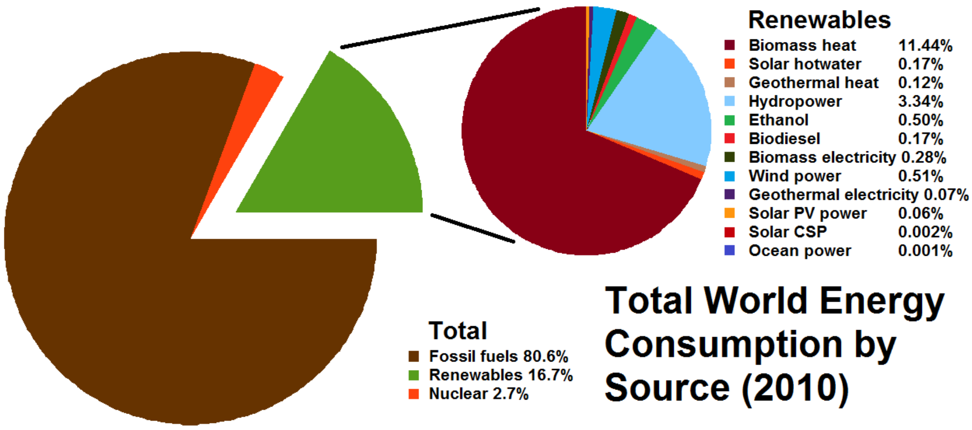


Figure 7 Total world energy consumption by source (2010) [47]

2.2. Solar Energy

Everything on Earth is connected, and the Earth is connected to the sun -its unique energy source. Could not people simulate plants and catch its huge amount of energy?

In 60 minutes, the sun gives the Earth the same amount of energy as that consumed by all humankind in one year. As long as the earth exists, the sun's energy is infinite. We should simply quit drilling the Earth and begin looking up to the sky. We should simply figure out how to cultivate the sun. [1]

The sun is a gorgeous source of energy that is necessary for life on earth. Without it, humans do not exist. The sun delivers an amount of power of $3.8*10^{23}$ kW. While not the majority of this energy achieves the earth, we still get an incredible amount of power of $1.73*10^{16}$ kW, which is a huge number of times more than enough to satisfy humankind's yearly energy needs. Thomas Edison always quoted

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that." [13]

Then it is about creating new innovative methods to use the sun's energy effectively. Plants do this consistently, converting the energy of sunlight into chemical energy through Photosynthesis. PV systems convert the energy of solar light into electric energy through what so called Photovoltaic effect. Besides, the sun's heat is not only used to heat water through the solar water heaters or to dry people's clothes but also is developed to make use of the sun's heat where it is used to create steam that is then used to move turbines generating electricity in a large scale as shown in figure 8.

Figure 8 Solar thermal plant [48]

Solar energy is clean, green, carbon free and best of all, it is not going anywhere in the upcoming five billion years. When you begin to consider it, it is astonishing what number of the diverse sorts of energy sources around us really originated from the sun and are solar driven forms. Investigate figure 9 which proves that all energy sources come from the sun. Even fossil fuel comes from the sun. Fossil fuels are the remaining parts of dead creatures and plants that have been exposed to high temperatures for millions of years. Those animals used to feed on the plants that existed during that time. Those plants have already been there as a result of the solar energy as well. Therefore, **the Sun is the source of all energies.** [12]

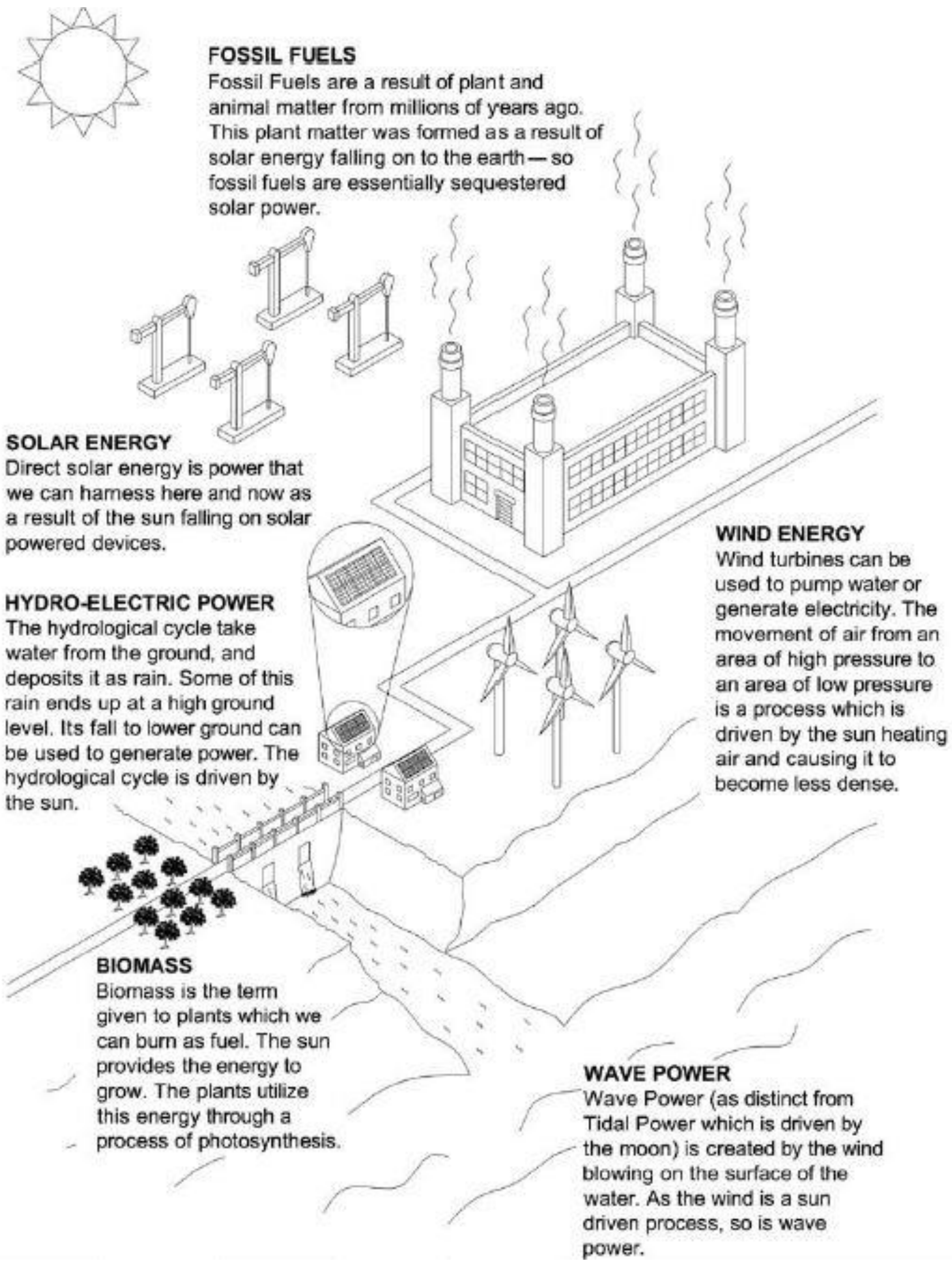


Figure 9 Sun is the source of all energies [12]

2.3 Solar Energy Potential in Egypt

Egypt is situated in the global sun-belt. This geographical position has made a great chance for Egypt to depend on solar energy. A solar energy atlas was created for Egypt on 1991 indicating that Egypt has a huge potential for solar energy with 2900-3200 Peak Sun Hours annually with incident energy intensity of 1970-3200 kWh/m^2. Also, it showed that the country has a thermal electricity generating potential of 73.6 Peta watt hour (PWh). Figure 10 shows a solar map for Egypt. [14]

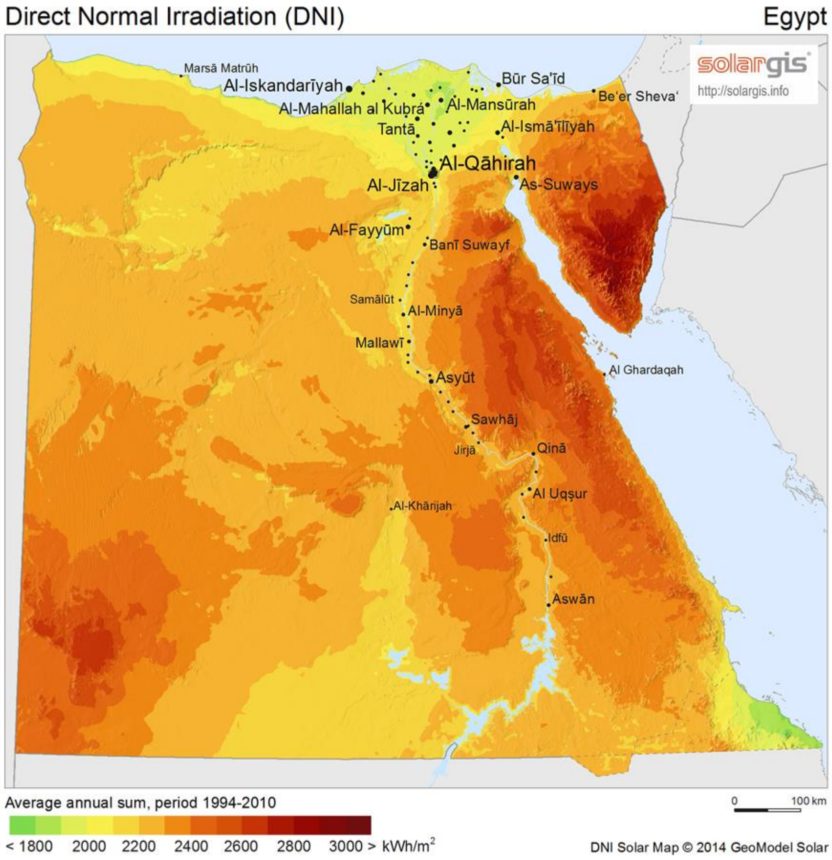


Figure 10 Solar GIS map for Egypt [49]

Astonishing yet true, in August 1913, Maadi was the site of history-production advancement when American innovator architect Frank Shuman (1862-1918) picked this still-nascent Nile side suburb to dispatch his astonishing contraption, a solar thermal power plant. Shuman constructed the world's first solar thermal power station in Maadi, Egypt (1912-1913). Shuman's plant shown in figure 11 utilized parabolic troughs to power a 60-70 torque motor that pumped 6,000 gallons of water for each moment from the Nile River to adjacent cotton fields. [15]

Figure 11: Solar power plant in Maadi, Egypt [16]

These days the use of solar energy incorporates utilization of photovoltaic cells, solar water heating and solar thermal power. Utilization of solar thermal power may incorporate both power generation and water desalination, which is beneficial for Egypt taking in thought its lack in water supply.

In Egypt, just like the rest of the world, energy is very important for the country's development. Also, Egypt suffers from the rapid increase in the number of population which has a current rate of 1.68%. The country's population is expected to be 110 million by 2031 and 128 million by 2051. As a result of that fast growth in addition to the limited energy sources and environmental challenges, it is necessary to depend on a renewable source of energy to meet the country's energy demand.

The Egyptian power sector is drafting another power act to support renewable energy use and private sector association. The current Power mix in Egypt is 86.07% for gas and oil, 12.58% for hydropower and 1.35% for wind power. The plan of the Ministry of Electricity and Energy (MoEE) focuses to fulfill 11.26% of the electric energy from renewable energy sources by the year of 2027.

PV systems in Egypt are viewed as a standout amongst the most fitting applications for remote areas far from national grid. as (NREA) reported, the photovoltaic systems are being used for lighting, business ads, remote interchanges, phone systems, water pumping for irrigation systems, refrigeration, and so on. As for the national strategy wind and solar power are to be utilized to cover ~20% of introduced power by 2027. [17]

Through next chapter, you will be exposed to a basic introduction to the different PV system types and which one we have decided to go for to get the best use of solar energy.

3 PV SYSTEM TYPES

3.1 Definition

The “photovoltaic” expression is a combination of two terms, the term “photo” which means light and the term “voltaic” which means voltage. PV system is a system that uses photovoltaic cells to turn the sunlight into electrical energy that can be used in different applications. [18]

3.1.1 The Photovoltaic Module

The PV module is usually made of approximately 36 or 72 PV cells connected in series. Basically the PV cell is a large PN junction that produces electrical DC power when exposed to sunlight

3.1.2 Operation of PV Cell

Basically a PV cell is a big silicon PN junction (diode), when a photon falls on the junction it causes current to flow, the PN junction is turned to a PV cell. As shown in the figure below.

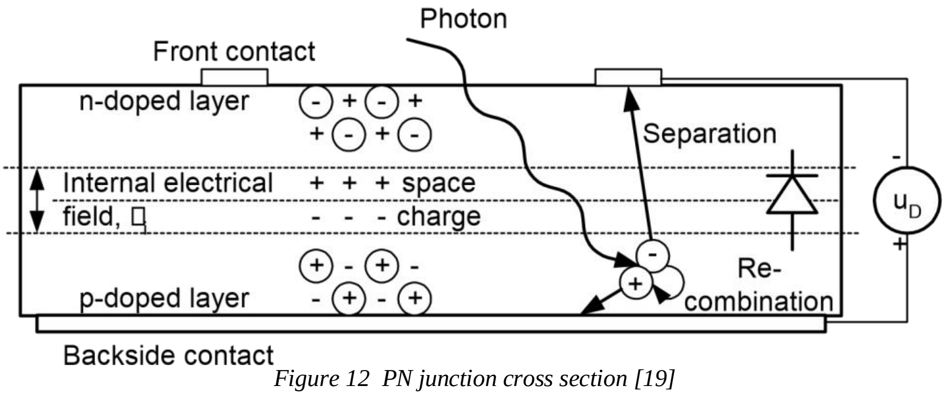


Figure 12 PN junction cross section [19]

The outer most shell of a silicon atom has four electrons. The electrons contribute in the electron sets binding with other four silicon atoms. In case of doping the silicon with boron (p-type), which has just three electrons in the external shell, the silicon turns to have shortage in electrons. Along these lines, a "hole" is available in the silicon structure, and positive charges can move around in the structure. In case of doping with phosphorus (n-type), which have in the outer shell five electrons, the silicon turns to be saturated with electrons. These additional electrons are likewise allowed to move around in the structure.

The PN junction permits free electrons in the n-type part to flow into the holes of the p-type part. A field is formed between the p-type and the n-type until the electrons can no more compel the junction to have current, subsequently the layers have come to equilibrium.

A photon may ‘knock’ off an electron from the p-type, which results in a free hole, then the electron moves around in the p-type. If the electron reaches the PN junction without recombination, the internal field will make it move in the n-type. On the other hand, the electron may suffer from recombination before reaching the junction, thus it won't help in the current generation. Impurities in the lattice causes the recombination, once the electron has been forced into the PN junction, it has two possible return paths: it can either pass through the junction (to work as a diode) or it can pass through a circuit as generated electrical current. [19]

3.2 Types of PV Systems

Photovoltaic power systems are usually classified according to their function, the operations performed by this system, their component configurations, and the way we connect the equipment to power sources and loads. The two main categories in the PV system types are grid-connected systems and stand-alone (off grid) systems. The design of photovoltaic systems can be implemented to give DC and/or AC power, it can operate connected to the utility grid or independent from it.

3.2.1 Grid Connected Systems (On-Grid)

Grid-connected PV systems are the systems which operate in parallel with the utility grid and connected to it. One of the most important components of the on-grid systems is the inverter, sometimes called the power conditioning unit (PCU). The inverter turns the output DC power of the PV panels into AC power which is compatible with the requirements of voltage and power quality of the grid. Between the PV system AC output and the grid network a bi-directional interface is made. Most probably the interface is placed at the distribution panel. This provides the AC power -which is produced by the system- the ability to either provide electricity to the loads within the on-site, or to feed back the grid whenever the output of the PV system is greater than the load demand. During night or when the on-site loads demand is greater than the system output power, the extra power required by the loads is supplied by the grid. This feature is the main requirement in all grid-connected PV systems which ensures that the PV system won't operate and feed back into the grid if the grid is down for any reason.

The main components required for a grid-connected system are:

- PV panels
- DC/AC Inverter
- DC dis-connector
- AC breaker panel
- KW-hr meter
- Utility disconnect
- Wirings

All these components work together inside the design to provide and to distribute a clean renewable source of energy as shown in figure 12. The design starts with the PV modules that collect solar energy from the sun, then they give DC power that can be converted using the inverter for home use.

An on-grid system needs an array DC disconnect which gives the chance for the user to stop the flow of electricity from the solar panels in case of emergency or maintenance. Also there is a utility disconnect which can be used by the local utility to prevent the energy from flowing when they need to perform maintenance. The electricity travels from the on-site to the utility grid through the AC breaker panel. The KW-hr meter gives the read-out of the power supplied by the panels to be able to calculate the utility bills. Therefore, when the on-grid system is connected to an existing power grid producing energy, the solar panel pump all excess energy into the grid through net metering program which exists in most of communities now. [20]

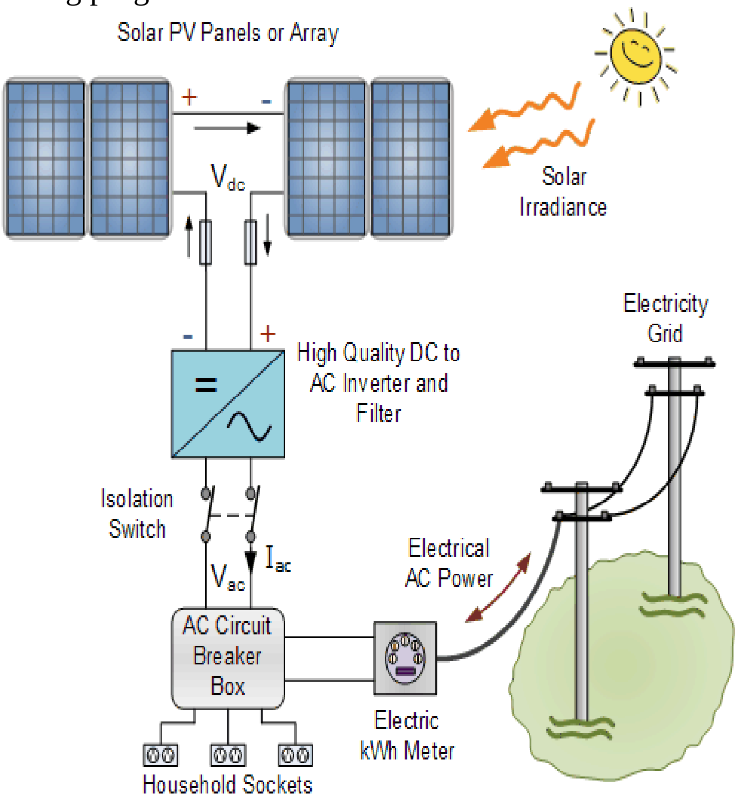


Figure 13 on Grid System [21]

3.2.2 Standalone Systems (Off Grid)

These systems are designed to work totally independent from the utility grid, they have batteries for energy storage. These systems can be used as a backup solution for electricity blackouts or to supply electricity for areas where the grid is far and can't be extended to supply energy.

PV Standalone Systems can produce energy in case the sun isn't available such as: night times or during cloudy and stormy days. An important part of the Standalone systems is the charge controller, which prevents overcharging or over discharging the batteries. An Inverter is used in this system to convert DC output power produced by the PV modules and stored in the batteries to AC power such that it can be used to supply the AC loads. PV standalone system is shown below in figure 13. [22]

Standalone systems are perfectly used for remote areas where they can be most cost effective, however they suffer from some problems such as:

- Battery losses
- The PV panel usually operates well off its most efficient operating point
- Batteries are expensive (almost half price of the whole system)
- During summer, if extra energy is produced from the system while the batteries are full, this energy will be lost and will be neither used by the loads nor stored in the batteries.

The off-grid system differ from the grid-connected one as it never sends electricity into the local utility grid, but it collects the solar energy the same way as on-grid system and converts DC power into AC power to operate required loads or charge batteries directly from the DC power.

The same as grid connected systems, the standalone systems also have a DC disconnect to give the chance to stop operating the system in case of emergency or maintenance, and will have a rectifier which acts as a reverse inverter converting AC power to DC power in order to charge the batteries. Batteries are usually a part of the system which require a lot of care and attention, therefore they require some additional components to make sure that they run and last for long time such as charge controller.

Another important part for the PV standalone system is the charge controller which has a very hard mission to monitor and control charging and discharging. ??? In case of using standalone system for homes that are totally separated from the utility grid, another different source of power can be used such as a backup generator which uses diesel or gas to provide electricity in case of night or cloudy days where the sun is not shining and batteries are not charged. In this case the system is called a hybrid system. [23]

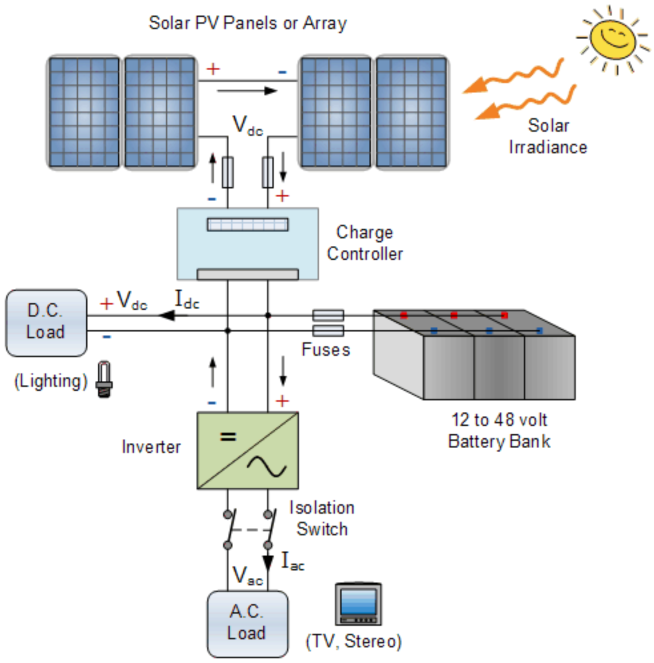


Figure 14 Standalone System [24]

Since our project aims to provide a reliable energy constantly, we chose to go for the PV standalone system design. Standalone system has an advantage of containing batteries that makes it reasonable to depend on especially at night and during power cuts.

3.3 PV Standalone System Design

Standalone systems mainly consist of: PV solar panels, charge controller, and batteries.

3.3.1 PV Solar Panels

From the sizing point of view, the panels are of a secondary importance however, they are the heart of any PV system. Important parameters of PV modules are:

- **V_{oc} (open circuit voltage) and I_{sc} (short circuit current)**: They cannot exceed the input voltage and input current of the charge controller or the inverter used in the system. The damages caused by increasing the V_{oc} or I_{sc} cannot be covered by the warranty of the inverter or the warranty of charge controller provided by the system supplier. If modules are connected in series, the PV total voltage will sum up to give the accumulate voltage that can be obtained from these modules. If modules are connected in parallel, so the voltage V will stay the same as for one module but the electrical current will sum up.
- I_{sc}: is the maximum current that can be generated form the PV panel when exposed to the sunlight. According to the I_{sc} , we specify the size of wirings and overcurrent protection (fuses and circuit breakers) calculations which should be rated as minimum 125% of the charge controller rated power. For example, a 30A charge controller should operate with PV current I_{sc} with maximum 24 A (24A x 1.25 = 30A).
- V_{mp}: is the output voltage of the panel when it gives maximum power.

3.3.2 Charge Controller

It is the most important component in the off-grid systems. The main responsibilities of the charge controller are performance and durability functions. Charge controller is also named a solar regulator as it coordinates and regulates the main components of the system which are the PV generator, batteries and loads. Usually the voltage of the charge controller is 12/24V and 48V which matches the batteries' voltage. The most common charge controller failures are burnouts.

There are two main types of charge controllers: PWM and MPPT. The charging mode is the main difference between the two types. PWM charge controllers use the Pulse-Width-Modulation technique while the MPPT controller uses the Maximum Power Point Tracking technique which gives 30% more energy than the PWM controller. [25]

3.3.3 Batteries

There are two main kinds of batteries available for standard PV systems: sealed batteries (AGM or Gel cell) and flooded lead acid (FLA) batteries. Sealed batteries have the advantages of little maintenance and longer lifespan. We define below the factors that are related to the batteries.

- **Depth of discharge:** it is the percentage of discharging the solar battery.

- **A cycle of the battery:** It is discharging and recharging a battery back to its full level. Deep cycle batteries are designed to discharge up to 80% of its capacity (depth of discharge is 80%), usually used for systems above 200 Ah capacity. On the other hand, the shallow cycle battery is when the discharge level is 20% or less of the battery capacity, they are designed to give much power over short period of time mostly used in cars and vehicles but not sufficient for PV systems.

- **DC/AC Inverter:** It is used to convert the DC power produced by the PV panels to AC power where AC loads are required to be operated. The input power rating of the inverter should never be lower than the AC loads total power. The inverter must have nominal voltage the same as the batteries voltage (12/23/48V). The output signal maybe a pure sine wave or modified sine wave. The Inverter size must be large enough to handle the power used at one time, therefore inverter size should be 25-30% higher than the total power needed by the AC loads.

3.4 First Phase System Implementation

First, we implemented our system using Solar Charge Controller (12V/24V - 10A) without MPPT. That controller is illustrated in figure 15. We used that design illustrated in figure 14 at the first phase of our project to get an eye on how the system really works and to get power readings that can be compared to these out from the charge controller with MPPT. That can help us to calculate clearly the gained power thanks to using the MPPT.

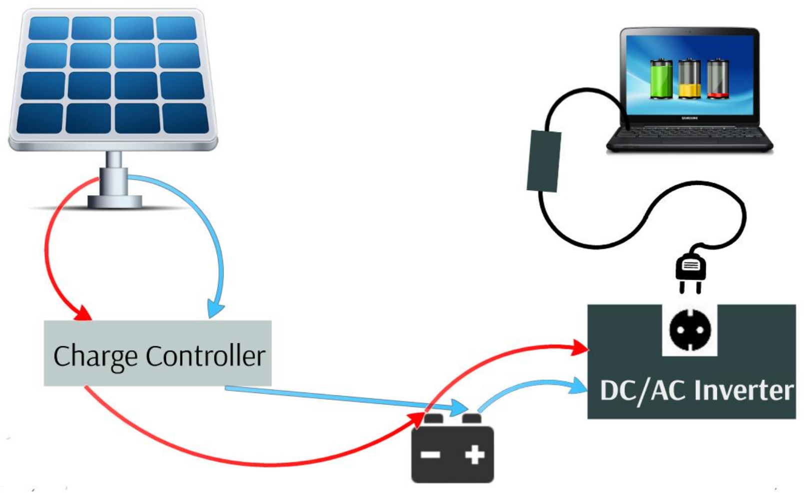


Figure 15 system with charge controller

As mentioned before, the basic function of the solar charge controller is to regulate voltage and/or current to prevent over-charging of the batteries. It works as regulator of the DC voltage and current provided from the solar panels to the battery. For example Panels with 12V provide voltage range among 16 to 20 V, if we didn’t use a regulator (charge controller), the batteries will be damaged because of the over-charging of the batteries. [26]

Figure 16 charge controller [26]

This Charge controller has 18 Modes form 0 to 17 as the following table 1:

Table 1 charge controller modes

Mode 0	Pure charge Mode (turning off all loads)
Modes range (1 to 15)	Light control and delayed Mode
Mode 16	Manual Mode
Mode 17	Debug Mode

Next, we implemented a charge controller which includes an MPPT (Maximum Power Point Tracker). In the next chapter MPPT is discussed in depth illustrating its benefits and challenges.

4 MAXIMUM POWER POINT TRACKING

MPPT is a circuit used to track the maximum DC power provided by the solar panels. It senses the output voltage and current generated by the panels and using a pre-specified algorithm, it tracks the maximum produced power that loads need. That is done in order to make a total use of the panel efficiency overcoming the variable factors affecting the panels such as heat and solar radiation. Those factors are discussed below in depth.

4.1 Factors Affecting the Solar Output Power

The power from the PV module is an element of: [19]

- Solar irradiance (power per unit area on the Earth's surface delivered by the Sun as electromagnetic radiation).
- Module temperature.
- Amount of incomplete shadow and climate conditions. As found in Figures 17 and figure 18, we need to study the impact of every component by settling one element and studying the impact of the other one.

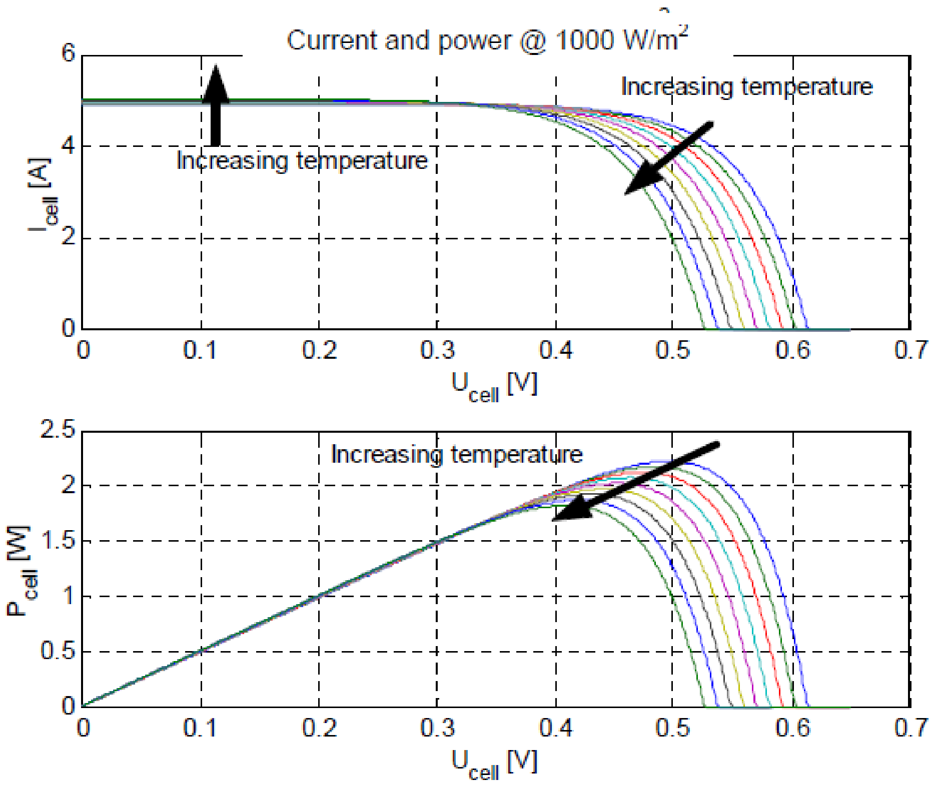


Figure 17 computed current and power characteristic for the BP4160 module, at fixed Irradiation and different cell temperatures (from 25 °C to 65 °C in steps of 5 °C). [17]

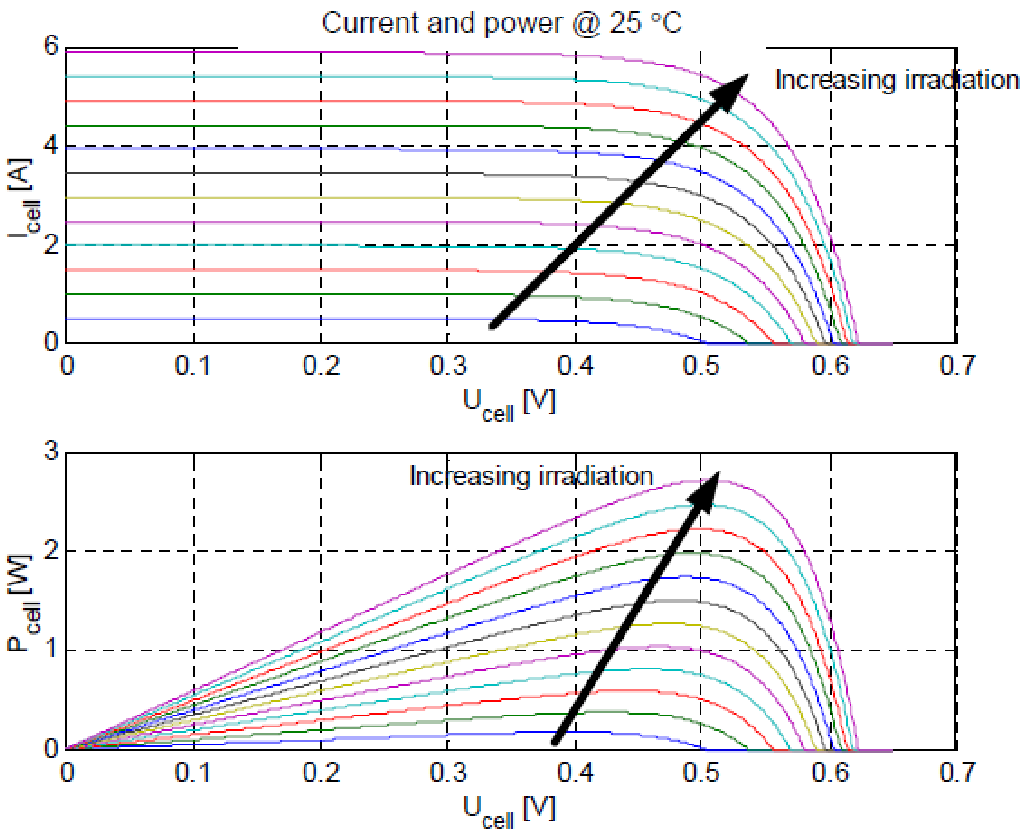


Figure 18 Computed current and power characteristic for the BP4160 module, at fixed cell Temperature and different irradiations (from 100 W/m2 to 1200 W/m2 in steps of 100 W/m2).[17]

From the previous factors we find that a higher irradiance gives a more efficient I-V curve but a higher temperature gives a less efficient I-V curve. Also we find that the solar panel's Maximum Power Point (MPP) is never consistent but fluctuates constantly. Sometimes it changes quickly because of quick changes in the climate such as the irradiance can change as much as 500 W / ($m^2 \cdot s$) or can change from zero to bright sunlight in 2 seconds. Sometimes it is genuinely steady when no mists are available. So, we need a controller that monitors the system & decides if it operates at MPP or not. In other words, to track this point. Then it forces the panels to operate at it. This circuit (controller) is called Maximum Power Point Tracking (MPPT). [19]

4.2 How Does MPPT Controller Extract Maximum Power From the Panels?

In order to understand this concept in details we first need to look at the power curve characteristics of a solar panel shown in figure 19.

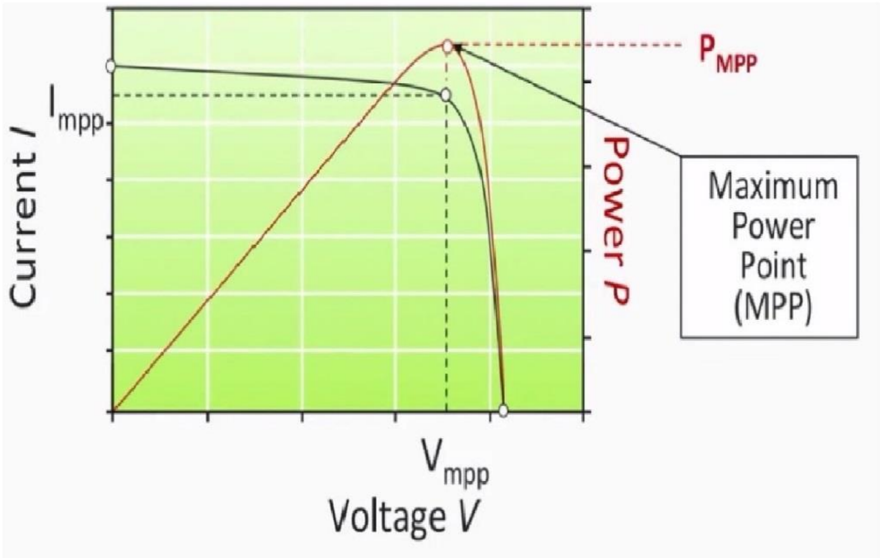


Figure 19 Power curve of Solar panel [17]

Let's assume that we have a 12V sun powered panel, it is not by any means a 12V panel. It's truly at some place in the middle of 12V and 21V panel depends on what load is associated with and how splendid the daylight is. The panel has an inner resistance which changes progressively with contrasting irradiance levels.

Say we have a solar panel, its specifications (50 watts, 12V at 4.1666 amps). The 12 V at 4.1666 amps means that the Solar panel should see a load of 12/4.1666 = 2.88 ohms. With whatever load the panel will convey under 50 watts. If we connect a static load to a panel knowing that its resistance is bigger or smaller compared with the interior resistance at MPP, then the power extracted from the panel will not be exactly the most extreme (Max) power that can be extracted. Taking a basic illustration, say we associated the 50 watt panel connected to a lead acid battery with voltage 6V , the panel voltage would be dropped down near to the stack voltage of the battery because the batteries resistance is below the panel's resistance, but the current will remain at 4.166 amps. This happens due to the fact that sunlight based panels act as current source, so the current is controlled by the available daylight. So the power (P) = V x I = 6x4.1666=25 W. Then, as we see the Solar panel acts as a 25 watt panel. This leads to a loss of 50W-25W = 25W (50%). This is where MPPT plays its role. MPPT controllers are based on topologies called (SMPS) which stands for Switch Mode Power supply. Generally they have a constant frequency but a varying width duty cycle. This varying duty cycle is input to a buck converter as we will discuss in the next chapters .The width of the duty cycle is controlled by a code to track the varied MPPT. [27]

4.3 Tracking Algorithm of Maximum Power Point Tracker

The MPPT uses a different method of finding this rapidly changing Maximum Power Point. This approach is called Perturb and Observe or hill climbing algorithm. To track the MPP, the system changes the voltage from the solar panel by tiny changes and calculates power, if the calculated power is higher than the previous one, the controller moves in the same direction. These calculations are constantly repeated until power is not increasing any more. So, voltage from the solar panel is increased constantly so the output power is increasing until it is no longer increasing due to deviating from the MPP. When power starts decreasing the corresponding voltage is decreased as well until we reach MPP again and the process goes on and on repeatedly as a result voltage is constantly oscillating around the MPP. [28]

4.3.1 Modes of Operation

The first step to understand the algorithm is to assume that the PV module is operating at a given point. The voltage reference of the PV module is initialized to UPV[n]. After the reference has been reached, the generated power PPV[n] is calculated and stored. The reference is then changed to UPV[n+1] and the generated power PPV [n+1] is computed and stored. If PPV[n] > PPV[n+1], the MPP is located in the opposite direction of which the reference was changed. Thus, the new reference should be equal to: UPV[n+2] = UPV[n+1] - ΔU. In the opposite case where PPV[n] < PPV [n+1], the MPP is following the same direction and the new reference must be in the same direction such as UPV[n+2] = UPV[n+1] + ΔU.

This way of searching in the MPP is fast when the irradiance is constant. On the other hand, it includes some limitations. First, the generated power is fluctuating around the MPP and the PV voltage is alternating around the MPP. Making ΔU sufficiently small can mitigate this however this affects the cost of increasing the searching time when large variation in the irradiance is present. It is preferred to make ΔU large to catch the MPP during rapid changes since the power loss due to the oscillations around the MPP is small. A large ΔU also enhances the signal-to noise ratio (SNR) in the sensed current. Second, rapidly changing in the irradiation can lead to a wrong decision about the direction of the MPPT [29]. Another solution is to ensure that the change in power as function of the change in the voltage-reference is always larger than the change in power due to change in radiation. Figure 20 below shows a flow chart of Perturb and Observer algorithm. [30]

Since implementing the MPPT circuit is the main objective of our project, we used an Arduino based circuit to implement it using a pre-specified algorithm as mentioned before to get the maximum efficiency of the solar module. Through next chapter, you will be guided through our implementation technique.

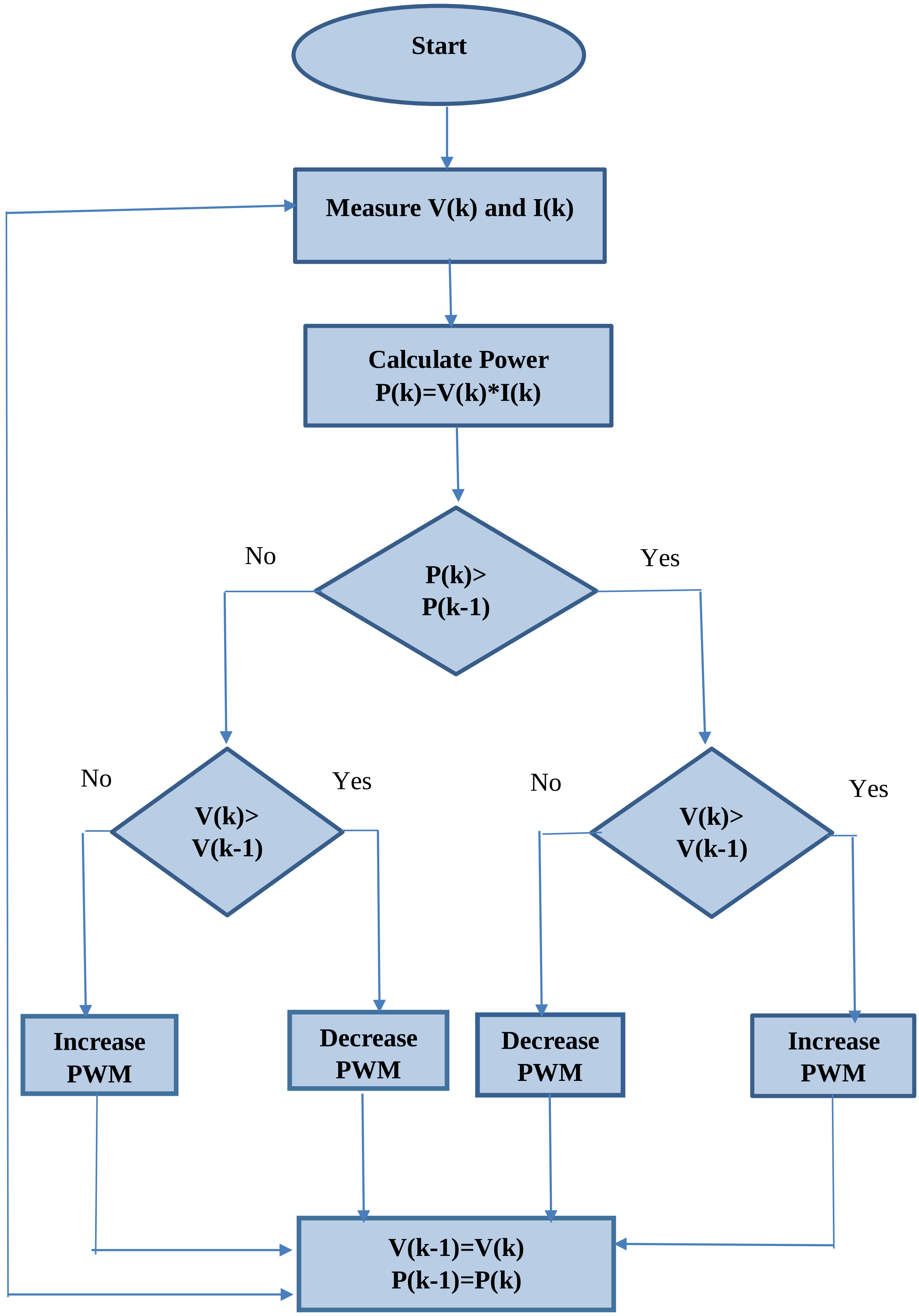


Figure 20 Flow Chart of Perturb and Observer Algorithm

5 ARDUINO MPPT SOLAR CHARGE CONTROLLER

As mentioned before, The MPPT is used to get the maximum power from the solar PV module and transfers that power to the load. The MPPT circuit is based on a DC-DC converter that acts as an interface between the load and the PV module. It transfers maximum power from the solar PV module to the load. The project is built around Arduino Nano based Solar MPPT charge controller. Our circuit is as shown in figure 21. [31]

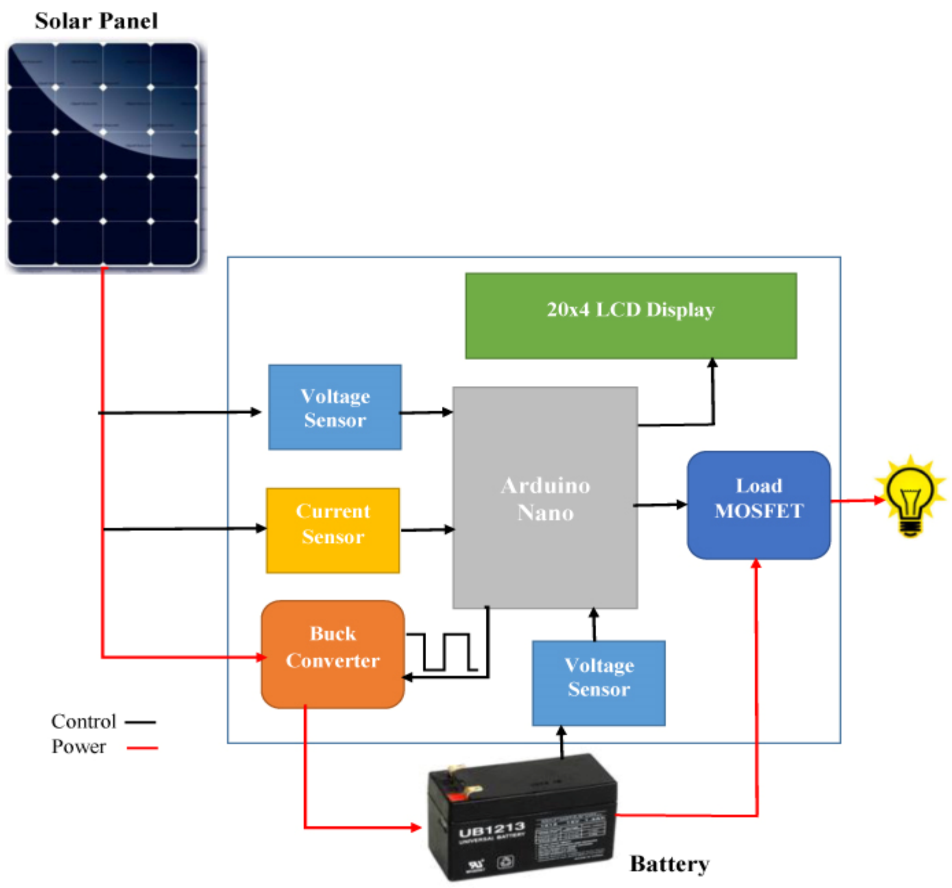


Figure 21 MPPT Arduino circuit

The main element in our design is an Arduino Nano circuit programmed with an Algorithm that calculates the maximum power that could be gained from the solar panels. To execute these calculations voltage and current sensor circuits are used to measure the panel's produced voltage and current. The Algorism provides a variable PWM. This signal is used inside what so called a buck converter. Due to the high cost of the DC cables, system voltage is chosen to optimize that cost. System voltage is presented by the batteries' voltage. Since that voltage is different from the voltage provided by the solar panel, the buck converter plays its rule to step down the solar voltage maintain the same amount of generated energy.in addition, voltage sensor is used to measure the charging status of the battery, LCD display is used to indicate the system's different properties, WI-FI module is used to accomplish the monitoring task of the system. Below the system's blocks will be demonstrated.

5.1 Voltage Sensor

One of the most important blocks is the voltage sensor since it keeps track of the voltage supplied from the panel or battery. The circuit used to track the voltage is a voltage divider circuit that decreases the voltage measured to within the range of the Arduino analogue pins. The code used for testing this part is mentioned in appendix E.1

Circuit:

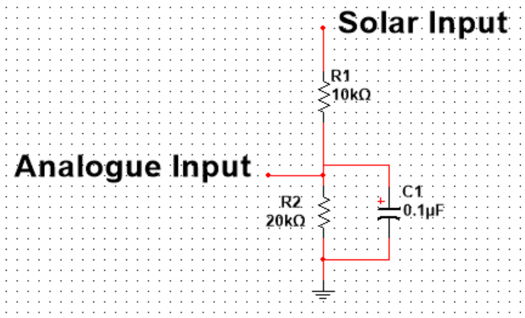


Figure 22 Voltage divider circuit

Arduino's analog inputs measure DC voltage between 0 and 5V (when using the standard 5V analog reference voltage of the Arduino Nano) and this range can be increased by using a voltage divider. The analog inputs convert the voltage read to number range from 0 to 1023. A way to obtain a more accurate reading is to calibrate the circuit. Calibration can be done by measuring the actual value of the reference voltage from the Arduino pin named 5V. The value can then be used in the calculations in the Arduino sketch code.

5.2 Current Sensor

After measuring the voltage of either the panel or battery, the current supplied by the panel is also measured. In this way the power of the panel could be calculated to maintain maximum power point (MPP). A current sensor ACS 712 is used to sense the current output of the panel. The ACS712 sensor read the current value and convert it into a relevant voltage value. The value that links the two measurements is the sensitivity of the current sensor. From the data sheet of the ACS 712 found in appendix B the sensitivity equals to 185 mV. That means that only current above this value could be measured, else it will give zero reading. In case of zero reading the offset value which is 2.5 V from data sheet of the current sensor will appear. The code used for testing this circuit is demonstrated in appendix E.2.

Circuit:

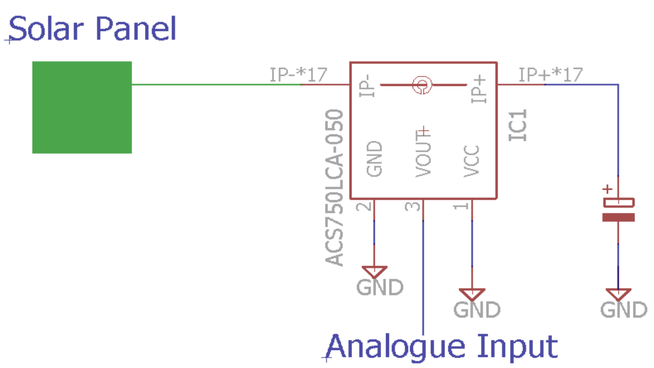


Figure 23 Current sensor circuit

5.3 Buck Converter

A buck converter is basically a DC to DC converter that steps down the higher solar panel voltage to the charging voltage of the battery, with very little loss of power. The main principle at work in a buck converter is the susceptibility for an inductor to oppose changes in current. The buck converter output voltage will always be lower or the same as the input voltage.

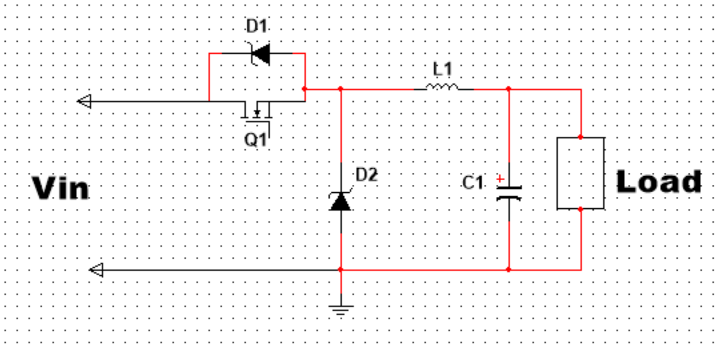


Figure 24 Buck Converter

5.3.1 Working Principle

There are two working principles: MOSFET is ON and MOSFET is OFF. When the MOSFET is ON, the current flows clockwise passing through the inductor and the capacitor. At the inductor, the magnetic field increases as energy is stored. While at the capacitor, charge is stored. The diode here acts as a reverse biased since the voltage at the cathode of the diode is positive, therefore blocking any current to pass maintaining a current flow only clockwise.

When the MOSFET is OFF, the voltage across the inductor is reversed. The magnetic field of the inductor starts to decrease therefore releasing energy that allows current to flow from the inductor to the load. In this case the diode acts as forward biased since there is a negative voltage at the cathode. Therefore the current flows clockwise through the load and back again to the diode. Once the inductor's energy has fallen below a certain value, the charged capacitor becomes the main source of current, to ensure that the load is still supplied until the next switching cycle begins. To guarantee continuous conduction mode the inductor must not be fully discharged before the MOSFET is switched on again, and the cycle repeats.

To make the circuit more efficient, a synchronous buck converter must be used in which the diode is replaced with a MOSFET as shown in figure 25. In this way the losses of the voltage drop on the diode is eliminated. The circuit became more complex, as the second MOSFET switching needs to be carefully timed with the switching of the first MOSFET. The MOSFET switching must be 180 degrees out of phase with a short delay period between each transition referred to as a Dead-Band to maintain a current flow to the load and to avoid short circuit. [32]

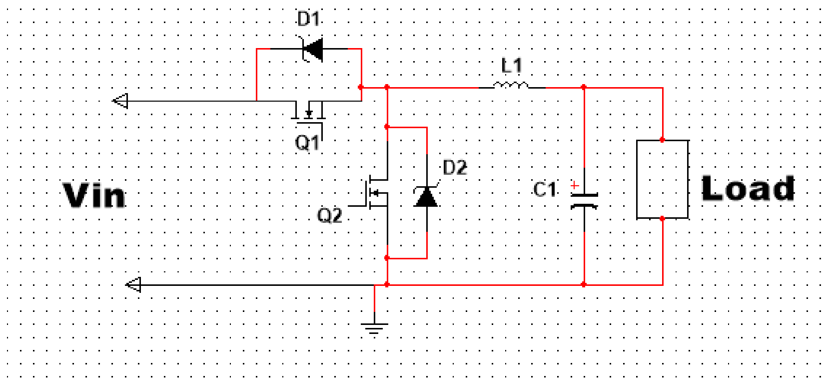


Figure 25 Synchronous Buck Converter

5.3.2 Design of Buck Converter

A general rule must be taken into consideration when designing the buck converter. The rule says that the higher the frequency the smaller the size of the inductor and capacitor, resulting in low cost. However at higher pulse width modulation frequency the system efficiency decreases due to losses of switching MOSFETs, so a tradeoff has to be reached to meet the design constraints. For this design a PWM frequency of 50 kHz is chosen.

The first step to design the buck converter circuit is to determine the output parameters of the system and its load which is for one panel:

- 50W solar panel and a 12 V output (battery voltage).
- Input voltage (Vin) = 18V
- Output Voltage (Vout) = 12V
- Output current (Iout) = 50W/12V = 4.16A = 4.2A (approx.)
- Switching Frequency (F_{sw}) = 50 KHz

The main parameters of the buck circuit are the inductor, capacitor, and MOSFETs. When calculating a buck circuit, the frequency of operation, inductor size and output capacitor size must be taken in consideration because they determine the current and voltage ripple size. It is desired to have a small current and voltage ripple. A large current ripple can cause additional losses in a system, as there are times when the peak current is greater than the load requirements. A large voltage ripple is obviously not desirable, good quality regulated power supplies have very low voltage ripples.

First the system duty cycle must be determined at maximum power point, note the duty cycle will change to track the maximum power point with differing irradiance as mentioned in Chapter 4. [32]

$$Duty\ Cycle(D) = \frac{Vout}{Vin} = \frac{18}{12} = 0.667\ or\ 66.7\% \qquad (1)$$

Calculating the inductor value is most critical in designing a buck converter assuming the converter is in continuous current mode (CCM). CCM means that the inductor doesn't fully discharge during the switch-off time. There are other factors for the inductor and capacitor that are important to consider: the **inductor peak current** and the **capacitors Equivalent Series Resistance (ESR).** The inductor peak current is the inductor ripple current. For a good design typical value of ripple current is in between 20% to 40 % of load current.

Let inductor current peak be

$$\Delta Il \ = 35\% \ of \ Iout = 0.35 \bullet 4.2 = 1.47 \ A$$

Then the inductor size will be

$$L = \frac{D\bullet(Vin-Vout)}{dl\bullet Fsw} = \frac{0.667(18-12)}{1.47\bullet 50} = 54.4 \ \mu H = 54 \ \mu H \qquad (2)$$

A toroidal coil must be used as an inductor because it will bear the high voltage of the solar panel. To know how to wind a toroidal coil check appendix A.

The capacitors ESR can affect the reliability of the capacitor. A capacitor will dissipate power as heat depending on its ESR, so a low ESR is desirable as excessive heating will shorten the life of a capacitor and will be less efficient. Output capacitance is required to minimize the voltage overshoot and ripple presented at the output of a buck converter. Thus, to meet the ripple specification for a buck converter circuit, an output capacitor with large capacitance and low equivalent series resistance (ESR) must be included.

Let voltage ripple be $\Delta V = 20mV$

Then the capacitor size will be

$$C = \frac{\Delta Il}{8\bullet Fsw\bullet \Delta V} = \frac{1.47}{8\bullet 50000\bullet 20} = 183.75 \ \mu F \qquad (3)$$

To choose a practical capacitor a 220 μF is used in this circuit.

Another important component for the buck converter is the MOSFET. Due to wide variety of MOSFETS, there are some basic parameters must be taken in consideration. [33]

- Voltage Rating: V_{DS} of MOSFET should be greater than 20% or more than the rated voltage.
- Current Rating: I_{DS} of MOSFET should be greater than 20% or more than the rated current.
- ON Resistance (R_{DS} on): Select a MOSFET with low ON Resistance (Ron)
- Conduction Loss: It depends on R_{DS} (ON) and duty cycle. Keep the conduction loss minimum.
- Switching Loss: Switching loss occurs during the transition phase. It depends on switching frequency, voltage, current etc. Must be minimum.

Now to drive the gate of a MOSFET by a microcontroller, a MOSFET driver is used. The switching of the MOSFET depends on the charging and discharging of the gate capacitor so the more current to be provided in the MOSFET the faster is the switching. For this design an IR2111 Half Bridge driver is used. The IC takes the incoming PWM signal from the microcontroller, and then drives two outputs for a high and a low side MOSFET.

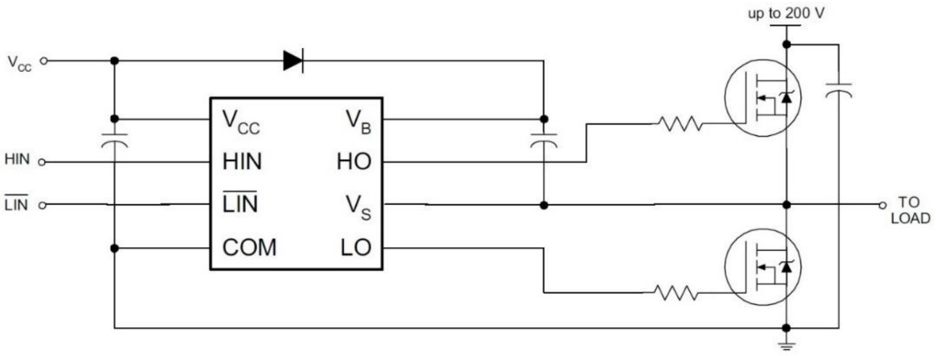


Figure 26 MOSFET driver connected to MOSFETS [17]

The capacitor connected between V_B and V_S along with the diode form the charge pump. This circuit doubles the input voltage so the high switch can be driven on.

5.4 LCD Display

After measuring the parameters of the solar panel and battery, a 20x4 character LCD is used for monitoring these parameters. The LCD displays also the percentage of the charge battery which helps in keeping track of the battery. Like any charge controller, the PWM duty cycle is also displayed. The connections and library code of the LCD depends on the manufacturer for more details check appendix D and E.3.

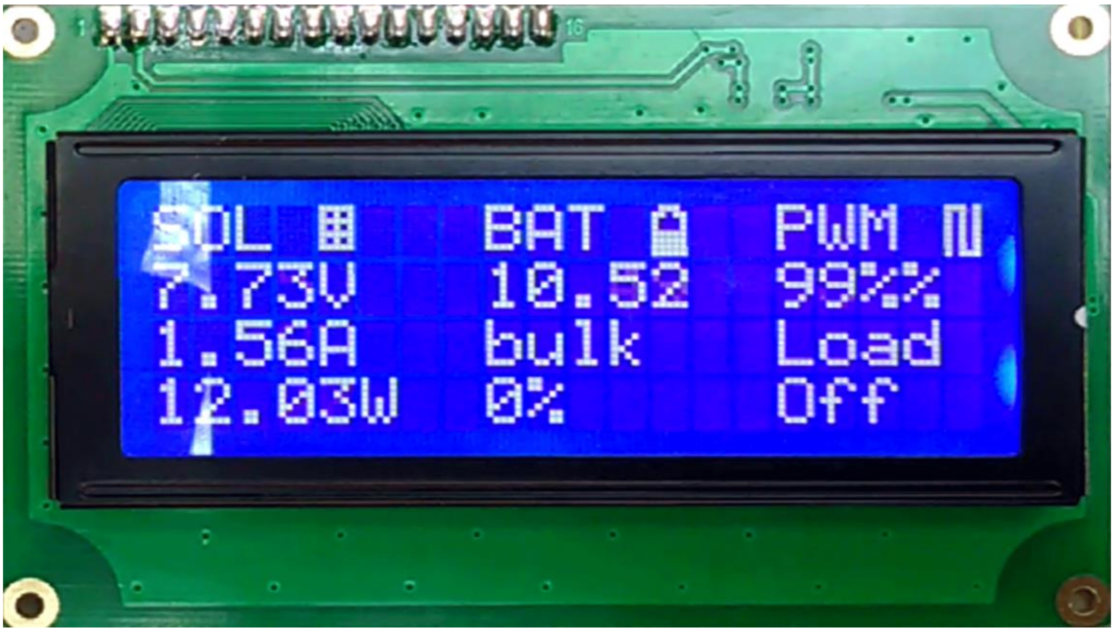


Figure 27 LCD display

5.5 Connecting the Controller to a Web

We can use a Wi-Fi module (ESP8266) to accomplish the monitoring task for our product. It is a self-contained SOC which stands for (System on Chip) support integrated TCP/IP protocol stack which provides any microcontroller with an access to any Wi-Fi network. The ESP8266 is able to host or offload an application from another application processor doing all Wi-Fi networking functions. Every ESP8266 module comes pre-programmed with a firmware, at command set, so we can simply connect it to our Arduino device and get about as much Wi-Fi-ability as a Wi-Fi Shield offers.

The ESP8266 module is cost effective chip. This module has a storage capability and powerful processing that allows it to work with the sensors through its GPIOs and other application specific devices with minimal loading during runtime, minimal development up-front and minimal external circuitry. It is also designed to possess minimal PCB area. Bluetooth interfaces and VoIP applications are available as the module supports APSD. It operates at all conditions because it has a self-calibrated RF, no RF parts are needed. It is a practical and cheap way for putting your sensors on the internet. In our project we are concerned about voltage and current sensors. [34]

5.5.1 Specification of Wi-Fi Module [35]

- Module operates at 3.3V (needed to power it), 240mA is the peak current regular current consumption at 70ma,
- 100M for max transmitting distance on ideal case.
- When module is powered up it is ok and common that a random error data might happen
- +20Dbm power

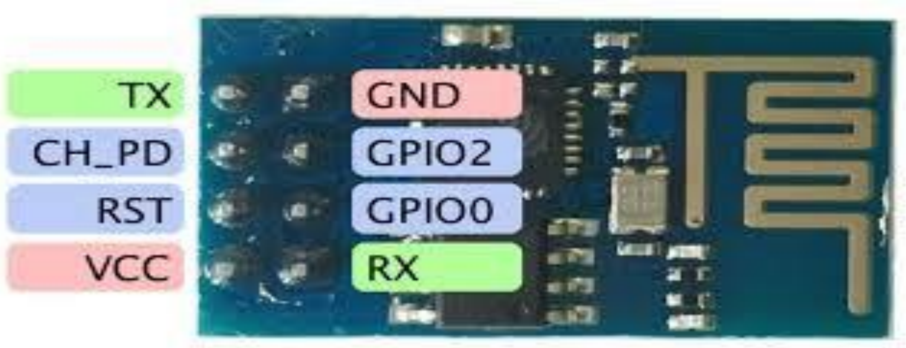


Figure 28 Wi-Fi Module (ESP8266) [35]

5.5.2 IC Features

- 802.11 b / g / n
- WIFI @ 2.4 GHz, supports WPA / WPA2 security mode
- Ultra-small size module 11.5mm * 11.5mm
- Built-in 10 bit precision ADC
- Built-in TCP / IP protocol stack
- Built-in TR switch, balun, LNA, power amplifier and matching network
- Built-in PLL, voltage regulator and power management components
- 802.11b mode + 19.5dBm output power
- Supports antenna diversity
- Off leakage current is less than 10uA
- Built-in low-power 32-bit CPU: can double as an application processor
- SDIO 2.0, SPI, UART
- STBC, 1x1 MIMO, 2x1 MIMO
- The guard interval A-MPDU, the polymerization of the A-MSDU and 0.4 s of
- Within 2ms of the wake, connect and transfer data packets
- Standby power consumption is less than 1.0mW (DTIM3)
- Operating temperature range -40 ~ 125 ℃

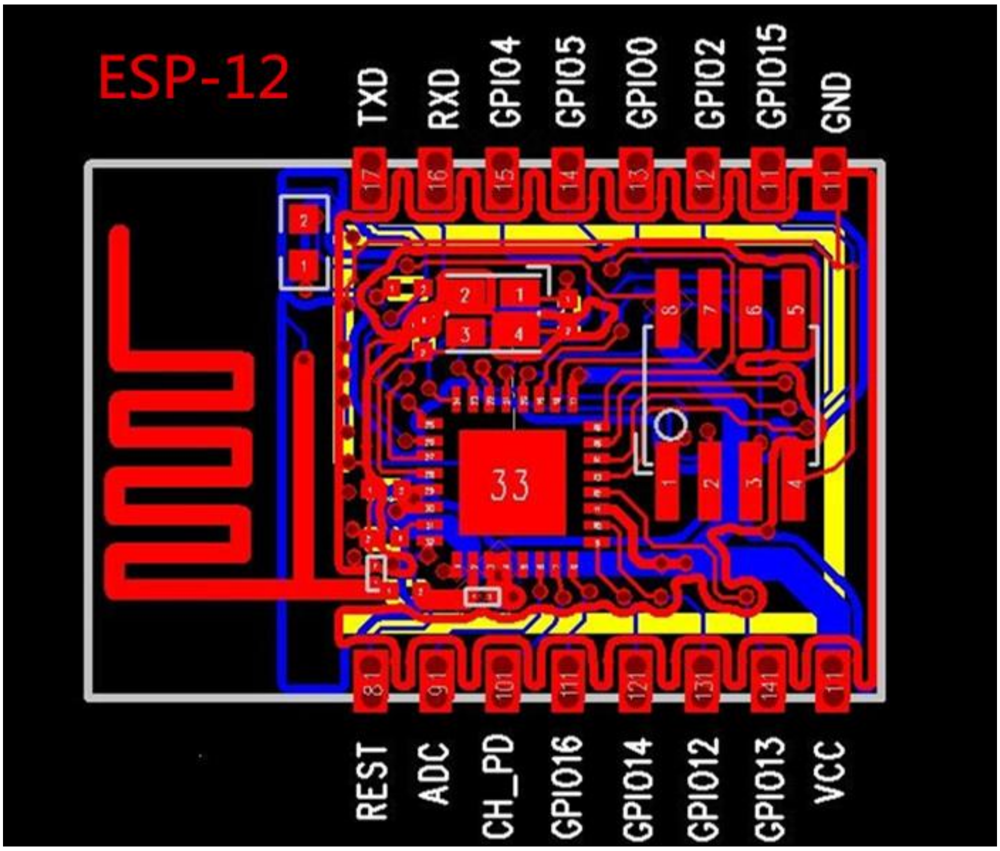


Figure 29 ESP8266 Pin definition [35]

5.5.3 Interface between the Controller and Wi-Fi Module

As we said above in the specification. ES8266 module operates at 3.3 V so voltage more than 3.7 V damages it. So we must use a regulator (3.3 V) to startup (power) the module on. A voltage divider can be used to drop the Arduino Transmitter TX (5V) to ESP8266 receiver RX (3.3 v). Figure (30) shows the interface circuit between the module and controller. [34]

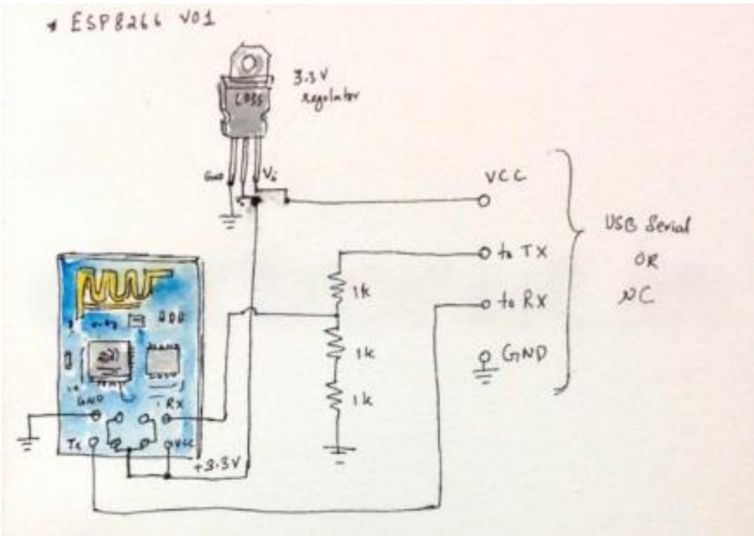


Figure 30 interface circuit between the ES8266 and controller. [44]

The first step to do is to create (establish) a communication channel between the Arduino and the ESP8266. To do this step we must connect adapter (USB to TTL) to the module, and write commands using a serial port terminal application (e.g. cool term). Then connect the module to a Wi-Fi router.

There are three ways of using this module:

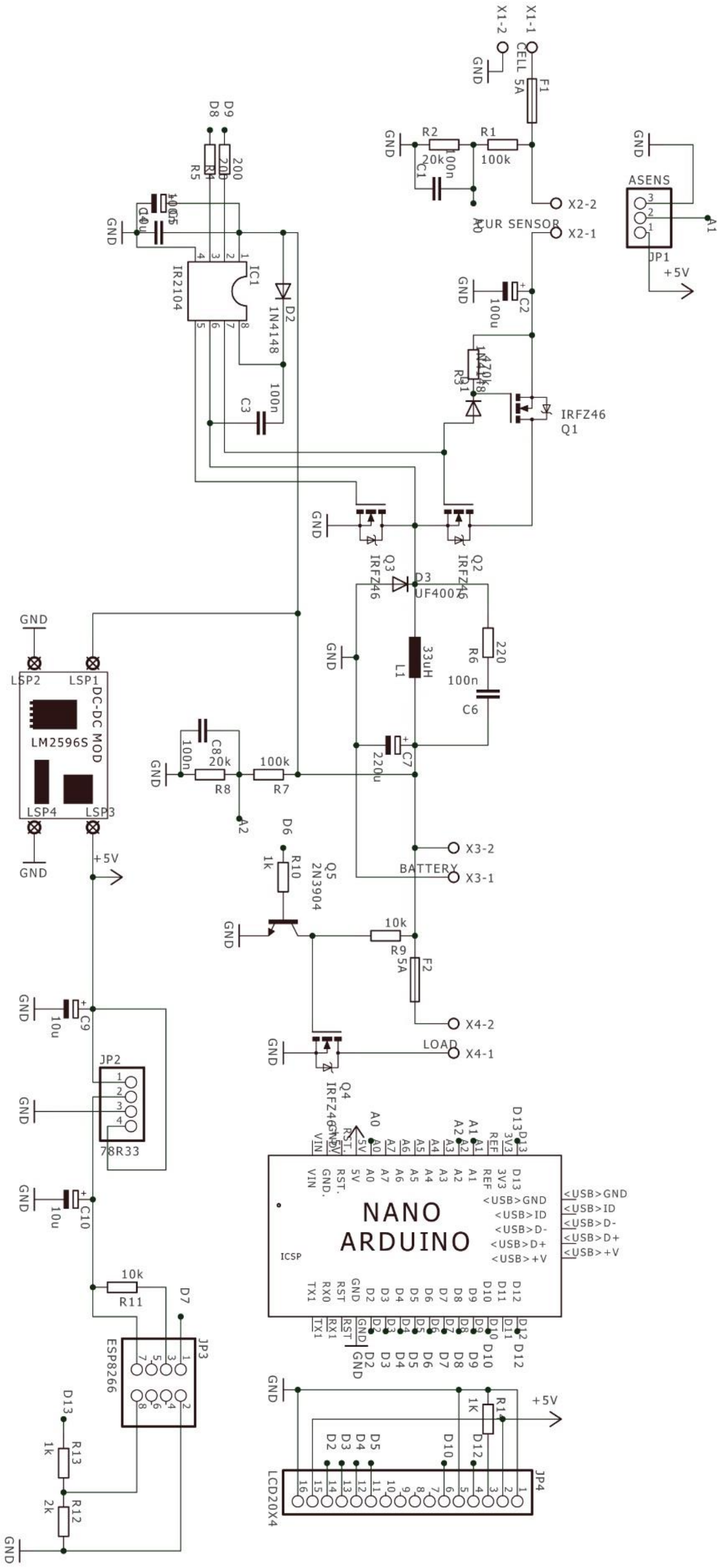
- Sending it AT commands from a computer to serial adapter by an USB. It is useful for testing and setup.
- Interfacing with any other microcontroller (e.g. Arduino) or and using this circuit as a peripheral.
- Programming it directly using its GPIO pins to connect to your sensors, so no need for another controller.

The Wi-Fi module (ESP8266) automatically uploads power generated at every certain time slot. (Voltage, Current). It uploads data to a website that we design or we can use any free servers of IOT that is available on the Internet.

5.5.4 Benefits of Data Monitoring System

By data logging, we can gather data about the solar PV system that could be invisible. Maybe we would like to measure solar system parameters or atmospheric conditions like (solar irradiance and temperature) during months, weeks or days, and then search similar solar systems in a geographical area to compare data between different systems or to compare the different results for the same system at different time in a day or between different countries (different states). We can also send the locations of the nearest solar tree system for the users' smart phones. [36]

5.6 Schematic of the Entire Circuit



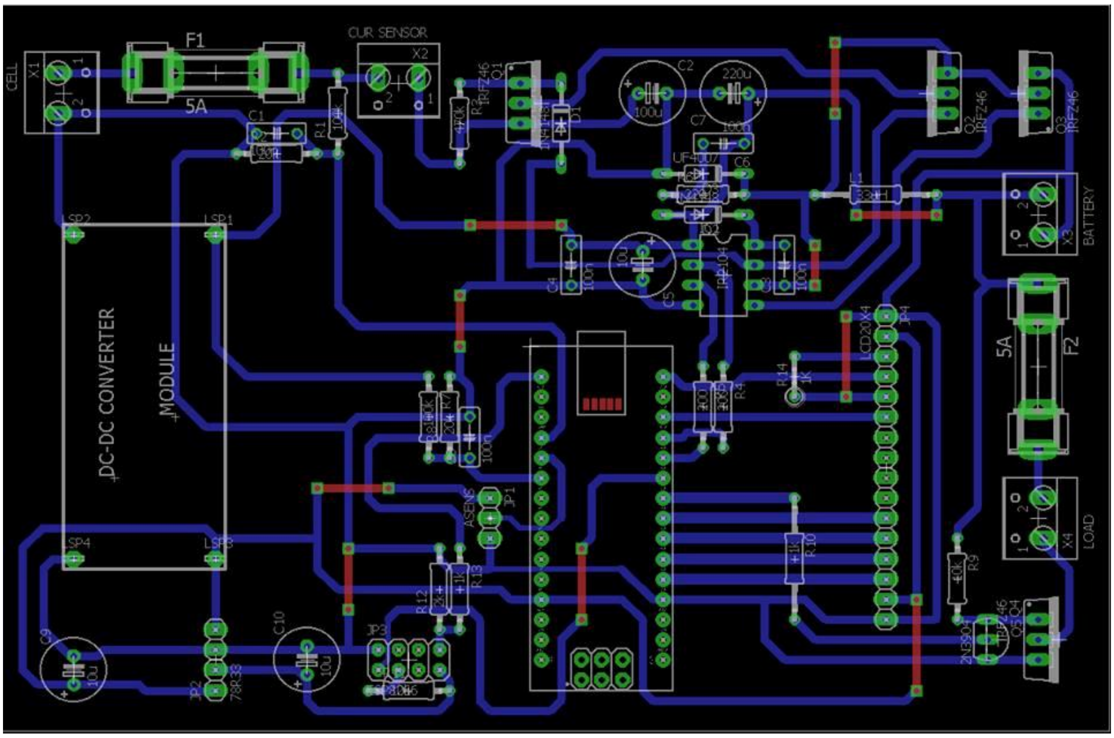


Figure 31 PCB implementation

In this schematic there are three main terminals: solar panel, battery, and load. Fuses, F1 and F2 -connected at the terminals- are used for safety in case of high input current. As mentioned before, the buck converter is made of two MOSFETS Q2 and Q3 and the energy is stored in inductor L1 and current stored in capacitors C1 and C2. Capacitor C8 and resistor R6 are added to cut down on the ranging of the inductor voltage generated by the switching current in the inductor. The third MOSFET Q1 is used to prevent the battery current from flowing back to the solar panel at night. For more efficiency, a fast diode D3 is added to conduct current before Q3 turns ON.

The MOSFET driver is used in this circuit at high and low sides of the MOSFET using PWM signal from Arduino pin D9. To shut down the MOSFET driver a control signal sent from Arduino pin D8 to pin 3 of driver. Diode D2 and capacitor C7 are parts of the bootstrap circuit that generates the high side gate drive voltage for Q1 and Q2. The software keeps track of the PWM duty cycle and never allows 100% or always on. It caps the PWM duty cycle at 99.9% to keep the charge pump working.

At the load terminal, a MOSFET Q4 is used to control load and prevent current from moving back to the battery. This MOSFET is driven by a transistor that is connected to Arduino pin D6.

5.7 Functions of MPPT

One of the most important functions in the MPPT charge controller is the PWM cycle. First, set the limit of the PWM duty cycle by comparing the PWM read from the circuit and the PWM minimum and maximum value defined at the beginning of the code. Then use Timer1 routine to set PWM duty cycle at 20 μsec period.

Other important functions of battery charge controllers and system controls are:

- Prevent battery overcharge: to limit the energy supplied to the battery by the PV array when the battery becomes fully charged

Figure 32 Schematic of the Entire Circuit

- Prevent battery over-discharge: to disconnect the battery from electrical loads when the battery reaches a low state of charge
- Provide load control functions: to automatically connect and disconnect an electrical load at a specified time, for example, operating a lighting load from sunset to sunrise.

In the charger state machine, there are four states: on, off, bulk and float. But first we must define a few constants.

- Minimum solar power: the minimum power that can be produced from the panel
- Low solar power: the least acceptable power from the panel
- Minimum battery volt: the minimum voltage charged in battery
- Maximum battery volt: the maximum voltage charged in battery
- Battery Float: the acceptable charged battery

The battery charger can be in one of the following four states:

- On State: is charger state for solar power value in between minimum solar power value and low solar power value (minimum solar power < solar power < low solar power). In this state the solar watts input is too low for the bulk charging state but not low enough to go into the off state. In this state the PWM is set to 99.9% to get the most of low amount of power available.
- Bulk State: is charger state for solar power is greater than the minimum solar power. In this state, the bulk of the battery charges and the circuit runs the Peak Power Tracking algorithm by running the maximum amount of current that the solar panels are generating into the battery.
- Float State: As the battery charges, its voltage rises until it gets to the maximum battery voltage. Therefore the state is shifted from the bulk battery charging and enter the battery float state.
- Battery float state: In this state, we keep the battery voltage maintained at maximum battery voltage by adjusting the PWM value. If PWM reach 100%, the battery voltage can’t be kept at maximum battery voltage which probably means the battery is being drawn down by some load so need to back into the bulk charging mode.
- Off State: The charger goes into this state when there is no more power being generated by the solar panels (solar power < minimum solar power). The MOSFETs are turned off in this state so that power from the battery doesn't leak back into the solar panel.

If the solar panel isn’t producing power then it’s probably night. Therefore the load state will be on which means that the load connected will take from the battery and there is no return from the solar panel. The final code of the Arduino circuit used in the MPPT is mentioned in appendix F.

To implement the project practically, we manufactured a prototype of a solar tree. The implemented charge controller with MPPT is used in that prototype.

6 POWER CALCULATIONS OF SOLAR TREE PROTOTYPE

As a primary phase, we implemented our solar tree on moderate scale prototype. Solar tree merges solar technology and art in one structure as shown in figure 33. It both artistic and green machine consists of Solar panels, charge controller (to charge batteries) and a DC/AC inverter for the AC loads. In chapter 11, we mention various ambitious future plans to modify our prototype to meet the customized consumer demands and the global rapidly increasing energy needs.

Figure 33 Solar Tree Prototype

The panels used at our prototype provide DC power of 100 watts which will be accumulated to provide 500 watt hour daily for loads. Moreover, the tree is extendable to increase number of panels and provide more energy. The delivered power is calculated through different steps illustrated below.

6.1 Power Calculation Main Steps

- Calculating the energy consumption of the required loads (Wh per day)
- Calculating the power needed from the panels (Wp)
- Sizing of the DC charge controller
- Sizing of the Inverter
- Calculating the batteries capacity (Ah)

6.2 Power Calculation Steps for the Solar Tree prototype

6.2.1 Calculating the Energy Consumption of the Required Loads

- Loads to be operated are supposed to be 2 laptops and 4 mobile phones charging for 2 hours each or equivalent in energy demand.
- Power consumed by 1 laptop for one hour = 50 W

- Power consumed by 1 mobile for one hours = 5 W
- Total power consumed = (2 laptops x 50 W) + (4 mobiles x 5 W) = 120 W
- Total energy consumption for 2 hours per day = 120 W x 2 = 240 Wh

6.2.2 Calculating the Power Needed From the Panels

- Total energy needed from panels can be calculated by dividing the energy consumption per day by the number of SPH (sun peak hours). Sun peak hours are the hours when the subjected module area receives the maximum radiation during the day. By observation, they equals an average of 5 SPH daily in Cairo. Then dividing the result by 0.6 which is the total loss in the PV system, therefore the equation will be:
- Total power needed from PV panels = $\frac{(\text{watt hours})}{sun\ peak\ hours * efficiency\ of\ the\ system}$ *(4)*

  = 240 Wh / (5 *0.6) = 80 Wp
- According to our design we need 2 panels each of them is 50 Wp

6.2.3 Sizing the DC Charge Controller

- According to the standard practice calculations, the sizing of the charge controller should take the short circuit current (I_{sc}) of the PV panel and multiply it by 1.3 as inverter size should be minimum 3 times the capacity of appliances and must be added to the inverter capacity to handle surge current during starting.
- Therefore according to our panels (50 Wp), the I_{sc} = 2.99 A
- So, the nominal charge controller current = 1.3 x 2.99 = 3.887 A
- We Chose a Charge controller with rated current = 10 A
- And maximum panel voltage that can operate with the charge controller is 40 V which is lower than our panel size.

6.2.4 Calculating the Batteries Capacity

- Calculate the total energy used per day of appliances in watt-hours
- Divide the total energy in watt-hours by 0.85 for battery losses
- Divide the number obtained by 0.7 which is batteries' depth of discharge as discussed in 3.3.3.
- Divide the number obtained by the nominal voltage of the battery
- To get the required capacity of the batteries, multiply the number obtained by the number of days that the system can operate with no power delivered form the PV panels due to autonomy as example.

Battery Capacity =

$$\frac{(watt\ hours)*(Days\ of\ autonomy)}{battery\ losses*depth\ of\ discharge*nominal\ battery\ voltage} \quad (5)$$

$$\frac{240 * 1}{0.85 * 0.7 * 12} = 33.6\ Ah$$

We designed the system to have 3 batteries of 12V and 12 Ah capacity connected in parallel.

6.2.5 Sizing the Inverter

- Since the input rating should never be lower than the total power of AC loads, therefore we chose the inverter to have total output power of 500W and the input power rating will be 100W coming from the 2 x 50W panels in our design.

- Also the inverter should have the same nominal voltage as the batteries. We bought a batteries of 12 voltage operation range. So, according to our design the inverter minimum input voltage is 12 V. [25] [37] [38] [39]

To maintain the sustainability of our project, those power calculations should be translated into money through financial analysis. This analysis will help us clearly analyze more the economic challenges that our generated energy shall face in the existence of fossil fuel. Tis financial analysis will be discussed in the next chapter in depth.

7 FINANCIAL ANALYSIS AND SOCIAL IMPACT OF SOLAR TREE

7.1 Financial Analysis

For our future designed solar tree it is intended to get maximum power 2 KW. An assessment of the viability, stability and profitability of our project is mandatory to study the sustainability of our project from an economical point of view. Costs of the different components attached to our design are as follows:

- 8 panels with cost of 2000 LE each;
- Steel Structure (body of solar tree) with cost of 6000 LE;
- Batteries with cost of 7500 LE/KW;
- Charge controller and inverter with combined cost of 7000 LE.

Normal yearly generation of energy of our solar tree equals:

250 Wx5 h x 8 panels x 365 days = 3650kWh/year

For the entire system operating at maximum power. To calculate the entire energy produced by the solar tree during full life time of 20 years:

3650KWh/year X 10 years + 3650KWh/year X 0.9 (degradation effect) X 10 years = 69350 KWh for 20 years

Cost of the entire system is:

Cost of panels + cost of structure + cost of batteries + charge controller and inverter=

8X 2000LE + 6000LE + 10 years X 15000LE +4 years X (3000+4000) LE =200000 LE

Cost of Generated kWh equals 200000/69350 =2.857 LE Compared to 0.29 LE for each KWh from grid + 6 LE (taxes). [40] [41] [36]

Our financial analysis is not taking into consideration the consequences of side effects on inhabitant's health. Apparently, energy produced from fossil fuel seems to be cheaper yet it has major effects on several aspects like environment and health. If we add the value of medications and social effect of fossil fuel then renewable energy would be not only convenient but also cheaper compared to non-renewable energy prices. Talking about environment and health, they are so precious that they are priceless to be valued.

As motivational progress, the Egyptian government has created a new law that allows citizens to sell energy produced from renewable energy sources like solar and wind energy. The new law includes a fed-in tariff that represents a milestone for a green future. [42]

7.2 Social Impact of the Project

Solar tree demonstrates urban idea that will represent new social point of view with its design and will provide eco-innovative attributes with its environmental-friendly concept, cultural, social and aesthetic viewpoints. The Goal of the project is to accomplish efficient and productive outcome, including multifunctional part (Wi-Fi, mobile, laptop charging etc.), social, stylishly, natural and practical adequate.

Social element is essential in the shadow of engineering viewpoint and innovative qualities of any actualized project. That is the reason why social acknowledgement of any project brought into society speaks to dynamical process more than static one. This stride fundamentally incorporates bringing advancement into society and in addition, current control of area where project is implemented. Implementation of this sort of projects which advance renewable energy at the nearby level is essentially vital for the further improvement of alternative technologies. It is crucial to comprehend social and recorded perspectives, or attributes of society, so as to comprehend certain impacts that could get to be apparent in solid utilization of renewable energy. [2]

Solar tree aims to advance the pattern of implementing renewable energy source. Drift that is simply starting to grow in Egypt. Uniqueness of the project lies in the advantage which is given to the general public and additionally producers of solar panels. With consistent information, training and functional practices, it is conceivable to accomplish these objectives that could have gigantic and basic part in bringing issues to light and acknowledgement of these new innovations.

Nearby colleges together with media can bolster outline and usage of new activities through exercises as local tests, displays and different instructive occasions. Issues that we day by day experience can be explained if community works and goes about as a gainful society, in light of the fact that just with dynamic investment and empowering diverse developments, little upgrades can be accomplished which will in the nearby future speak to vital and essential viewpoint in the advancement of the society. [2]

Figure 34 Example of solar tree in Austria (Gleisdorf) [2]

7.3 Goals of the project

This project will be used to provide access to green energy used for charging portable devices such as mobiles and computers in different locations, also with free access to WIFI. It is also a good way to raise public awareness about green renewable energy. Also it will motivate engineering collages and schools in Egypt presenting new ideas of Energy harvesting systems implemented by green concepts.

Considering future arrangement for the project: it could be developed in nationwide levels .It could be executed in appealing territories, close to green zones, grounds, squares and in residential compounds. In that way, it consolidates urban with traditional idea. Campuses for instance are day by day meeting ranges for distinctive society individuals.

Actualizing of a venture , for example, Solar tree inside Campuses will make it conceivable to accomplish the objective of designer/investor and additionally the general public, considering conditions that project needs to fulfill and to accomplish quality by social, financial, innovative and what is most essential environmental viewpoints.

Since our project is designed to be situated in public areas, implementing a full scale solar tree is a great way to raise awareness of the community about solar energy and the advantages of green technologies. That is discussed through the next chapter.

8 Implementation OF THE SOLAR TREE

Projects like solar tree are not new or recent, they already have been implemented in many European countries to raise society environmental awareness. Benefits and social impact are also demonstrated, with emphasis on the geographical position of Egypt and relating number of peak sun hours/days per year and its effect on the utilization of the project. This chapter covers the designing process of the solar tree and its technical aspects.

As mentioned in our introduction, the “Solar Tree” is a mixture between artistic and technological aspects which depends on solar artwork. For the past few years, many inventors tried to improve new methods to gain maximum impact from solar cell technologies. This new concept is an attempt to mix new technologies regarding the use of solar power and environmental aspect. The inspirational design of the Solar Tree has visual pleasing side as well as efficient purposes. Although the objective of the Solar Tree project may differ depending on its implementation, the general idea is an environmental friendly tree-shaped structure utilizing solar green power. [2]

8.1 Designing the “Solar Tree”

Solar tree is represented by steel structure that has a tree-like shape. On its top, solar panels are placed which are used for harvesting solar energy to power various portable devices such as laptops and smart phones. These devices will be charged using output plugs in the tree body.

8.1.1 Selection of Potential Locations in Cairo

Amid the determination of potential areas in Cairo for effective implementation of the project, we must consider the accompanying:

- Orientation
- Choice of area
- Annual temperatures of area
- Distribution of the area

Orientation, distribution and choice of area impact amount of solar energy that will be harvested by the solar panels. Geological components as atmosphere normally impact the nature of our project implementation. Satisfying location aspect represents an important factor for local improvement and Institutional support. [2]

Considering the location of Egypt, it fits into the global sun-belt as shown in Figure 35. The topographical position of the country is beneficial with solar energy. As mentioned before in chapter 2, solar atlas for Egypt was issued in 1991 showing that Egypt enjoys 2900-3200 hours of daylight annually with yearly direct typical energy density of 1970-3200 kWh/m2 and technical solar-thermal electricity creating potential of 73.6 Peta watt hour (PWh).

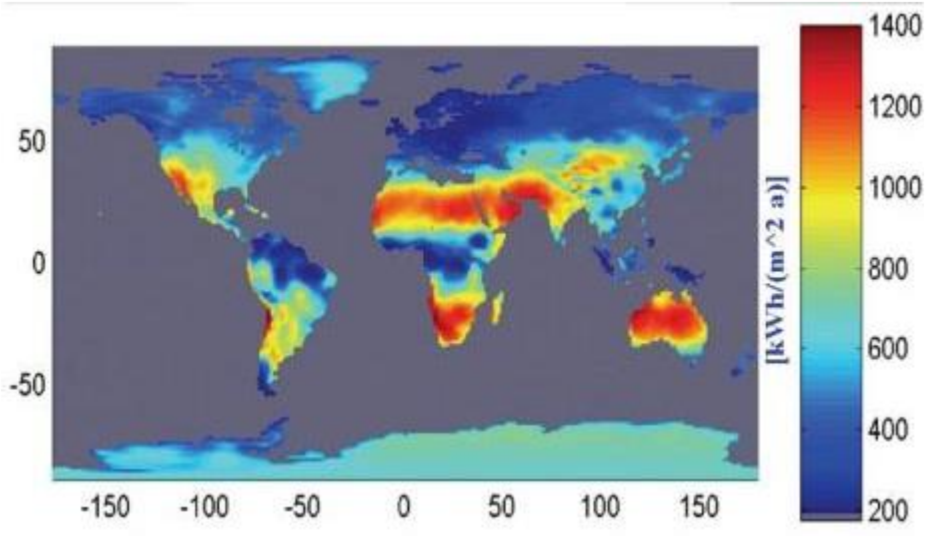


Figure 35 global Sunbelt [17]

For Egypt, the biggest solar radiation of solar harvest panel is accomplished if it is directed to the south. Ideal angle of panel's orientation relies on the purpose of solar system and the period in which it is basically utilized. For the orientation of location acceptable deviation is ±30°. Regardless of the fact that it is conceivable to situate up solar panels toward the southeast and southwest, it is clear that the angle of solar panels orientation would be productive to give greatest output power. [14]

The Optimal angle is around 33° when it is utilized for summer or winter seasons. In the event that it is important to gather more Solar energy amid winter time, the panel angle ought to be 50-60°.during summer more energy is given utilizing the angle of 25-35°. [14]

Suggestions of perfect location for establishing the "Solar tree" are urban parts of the city where there is extensive concentration of society. The reason for choosing these areas is that the essential part of this project is to advance renewable energy technologies through practical examples, in a manner to increase the awareness of the public and to acknowledge and promote eco-innovations. Society will be keen on how comparable models could be executed in more extensive scale. [2]

8.1.2 Intensity of Solar radiation during the year at Cairo

Information about intensity of solar radiation are essential to compute power generation of photovoltaic system.

Table 2 Annual Day Time in Cairo

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Sunlight Hours/ Day	06:52	08:16	08:40	09:42	10:27	11:54	11:42	11:19	10:22	09:25	08:16	06:23	09:26
Average Daylight Hours & Minutes/ Day	10:26	11:04	11:56	12:52	13:39	14:02	13:52	13:12	12:18	11:22	10:36	10:14	12:00
Sunny & (Cloudy) Daylight Hours (%)	67 (33)	76 (24)	74 (26)	76 (24)	77 (23)	86 (14)	85 (15)	87 (13)	85 (15)	84 (16)	79 (21)	63 (37)	79 (21)
Sun altitude at solar noon on the 21st day (°).	40	49.3	60.1	71.8	80.1	83.3	80.2	71.9	60.5	49	39.9	36.5	60.2

The information shows daylight hours in Cairo in extent from 6:23 for consistently in December to 11:54 every day in July. The longest day of it is 13:56 long and the briefest day is 10:03 long. The longest day is 3:53 more extended than the briefest day. The normal of daylight every year (of a conceivable 4383hours) is 3451 hours with a normal of 9:26 of daylight for each day.

It is sunny 78.7% of sunlight in hours. The staying 21.3% of sunshine in hours are likely overcast or shady, or low sun power. The normal at early afternoon of the sun is 60.2° over the skyline at Cairo. [43]

8.1.3 Effectiveness of the Solar Tree

Effectiveness of investing into construction of PV systems relies upon numerous factors such as:

- Size, Orientation of the tree, effectiveness, orientation of panels to the sun;
- Solar radiation;
- Tariff rates and cost of electricity;
- Incentive for delivered power;
- Interest rate and taxes

For efficient implementation for the structure of the solar tree .simulations using mechanical analysis programs were made .in the next chapter we will demonstrate these tests and the data computed from them.

9 STRUCTURE ANALYSIS: SIMULATION AND TESTING OF MECHANICAL ELEMENTS OF SOLAR TREE

To determine the most efficient kind of material used to build this structure, some simulations and analysis were made using mechanical design programs.
According to the following assumptions:
Maximum wind speed is 20 m/sec and this design is according to the data given with units mentioned in table 3.
Wind force is calculated according to the following relation: $F=0.5*A*V2$ where:
F: is the total force (Newton).
A: is the total area which will be hit by the wind.
V: the speed of wind.

Table 3 Units

Unit System	SI (MKS)
Length/Displacement	Mm
Temperature	Kelvin
Angular Velocity	Rad/sec
Pressure/Stress	N/m^2

To manufacture our project in a reliable way, we have mentioned below some tables of the various specifications and analysis for desired materials.

9.1 Model Information

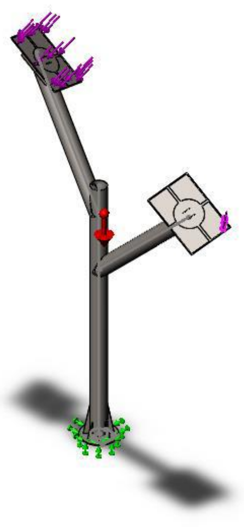
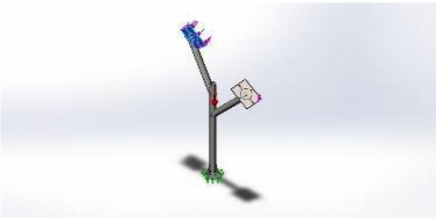
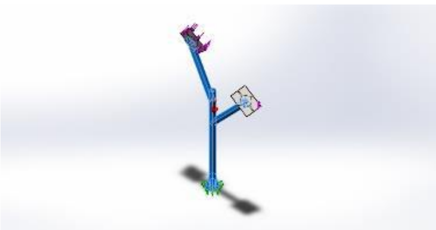


Figure 36 Model name: Assem1, Current Configuration: Default

Table 4 Model Information, Properties and Documentation

Solid Bodies		
Document Name and Reference	**Treated As**	**Volumetric Properties**
Boss-Extrude2 	Solid Body	Mass:1.2817 kg Volume: 0.000163274 m^3 Density:7850 kg/m^3 Weight:12.5607 N
Boss-Extrude2 	Solid Body	Mass:1.2817 kg Volume:0.000163274 m^3 Density:7850 kg/m^3 Weight:12.5607 N
Boss-Extrude3 	Solid Body	Mass:8.191 kg Volume:0.00104344 m^3 Density:7850 kg/m^3 Weight:80.2718 N
Boss-Extrude3 	Solid Body	Mass:8.191 kg Volume:0.00104344 m^3 Density:7850 kg/m^3 Weight:80.2718 N
Cut-Revolve2 	Solid Body	Mass:195.129 kg Volume:0.0248572 m^3 Density:7850 kg/m^3 Weight:1912.27 N

9.2 Study Properties

Table 5 Components and Properties

Model Reference	Properties	Components
	Name: ASTM A36 Steel Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength:2.5e+008 N/m² Tensile strength:4e+008 N/m² Elastic modulus:2e+011 N/m² Poisson's ratio:0.26 Mass density: 7850 kg/m³ Shear modulus: 7.93e+010 N/m²	SolidBody1(Boss-Extrude2)(pin-1), SolidBody1(Boss-Extrude2)(pin-2), SolidBody1(Boss-Extrude3)(solar base-1), SolidBody1(Boss-Extrude3)(solar base-2), SolidBody1(Cut-Revolve2)(trail 2 main part-1)
Curve Data: N/A		

Table 6 Loads and Fixtures

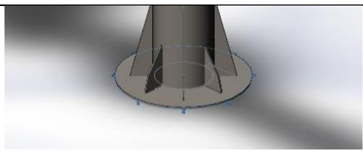
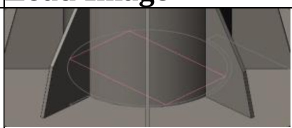
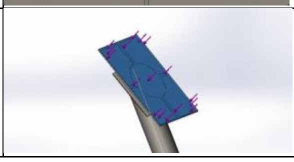
Fixture Name	**Fixture Image**	**Fixture Details**
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Table 7 Resultant Forces

Components	X	Y	Z	Resultant
Reaction Force(N)	141.238	2738.09	0.198911	2741.73
Reaction Moment(N.M)	0	0	0	0

Table 8 Load Details

Load Name	**Load Image**	**Load Details**
Gravity-1		Reference: Top Values: 0 0 -9.81 Units: SI
Distributed Mass-1		Entities: 1 face(s) Coordinate System: Global Cartesian coordinates Remote Mass: 20 kg

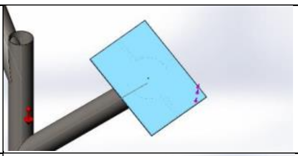
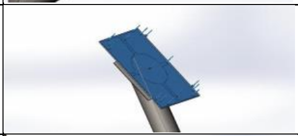
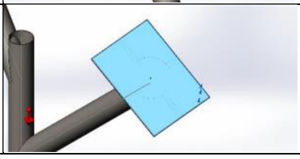
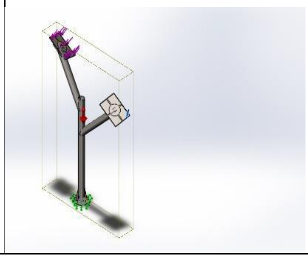
Distributed Mass-2		Entities: 1 face(s) Coordinate System: Global Cartesian coordinates Remote Mass: 20 kg
Force-1		Entities: 1 face(s) Type: Apply normal force Value: 150 N
Force-2		Entities: 1 face(s) Type: Apply normal force Value: 150 N

Table 9 Contact Information

Contact	Contact Image	Contact Properties
Global Contact		Type: Bonded Components: 1 component(s) Options: Compatible mesh

9.3 Resultant Forces

Table 10 Reaction Forces

Selection Sets	units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	141.238	2738.09	0.198911	2741.73

Table 11 Reaction Moments

Selection Sets	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

9.4 Study Results

Table 12 Stress 1 Analysis

Name	Type	Min	Max
Stress1	VON: von Mises Stress	21.5176 N/m^2 Node: 78930	3.06904e+007 N/m^2 Node: 11349

Figure 37 Assem1-Static 1-Stress-Stress1

Table 13 Displacement Analysis

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 20697	3.01319 mm Node: 1182

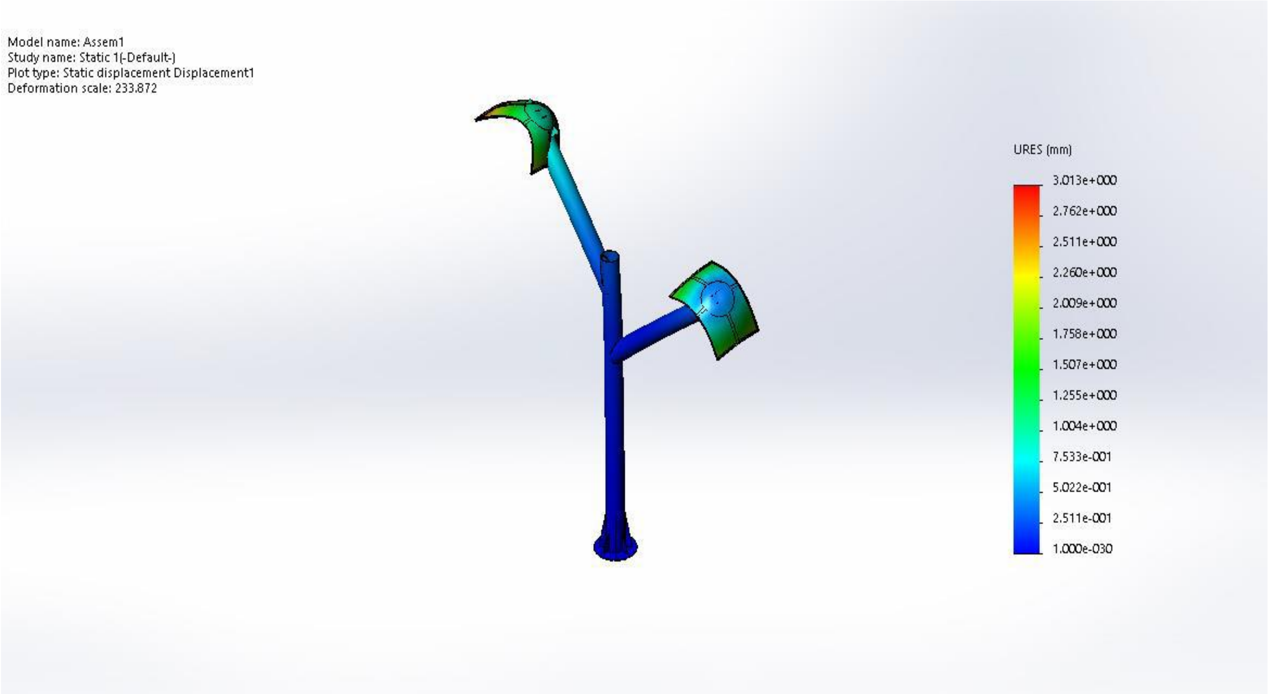


Figure 38 Assem1-Static 1-Displacement-Displacement1

Figure 39 Assem1-Static 1-Strain-Strain1

Table 14 Strain 1 Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	4.17489e-010 Element: 39143	0.000120974 Element: 5035

10 RESULTS AND OPPOSITIONS

10.1 First Phase Implementation

Testing the system consists of: Panels, Charge Controller with No MPPT and Battery .We started by testing the system with an ordinary charge controller with no MPPT

Figure 40 first phase implementation

10.2 Second Phase Implementation (Testing the MPPT Arduino Circuit)

10.2.1 Testing the voltage sensor circuit on the Arduino kit

The voltage sensor circuit is connected to a battery of voltage 12v for testing the circuit. We got a result of almost 14v constant voltage output of the sensor.

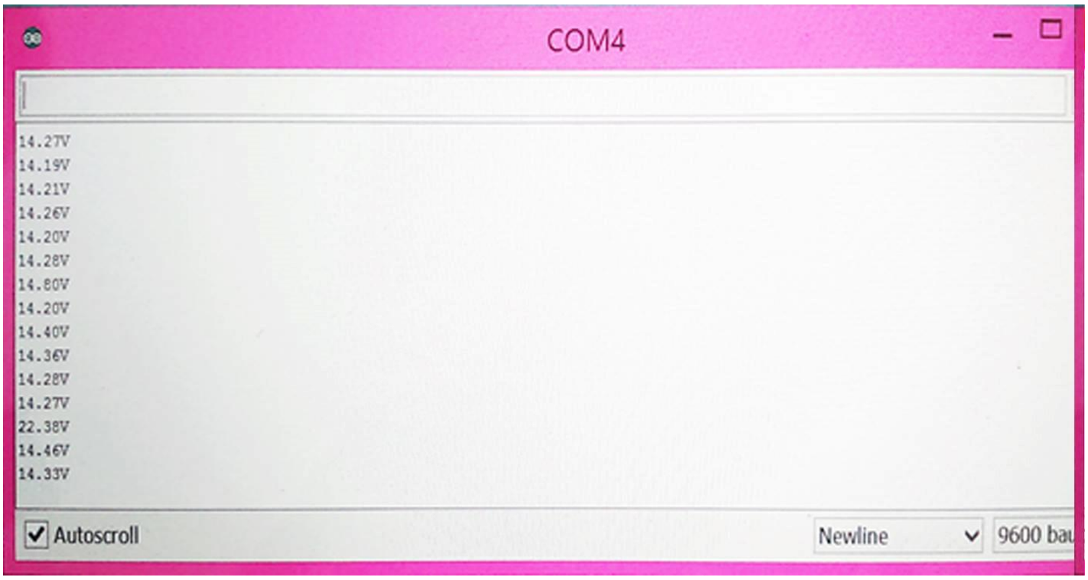


Figure 41 voltage sensor test results

10.2.2 Current sensor circuit using the Arduino current sensor

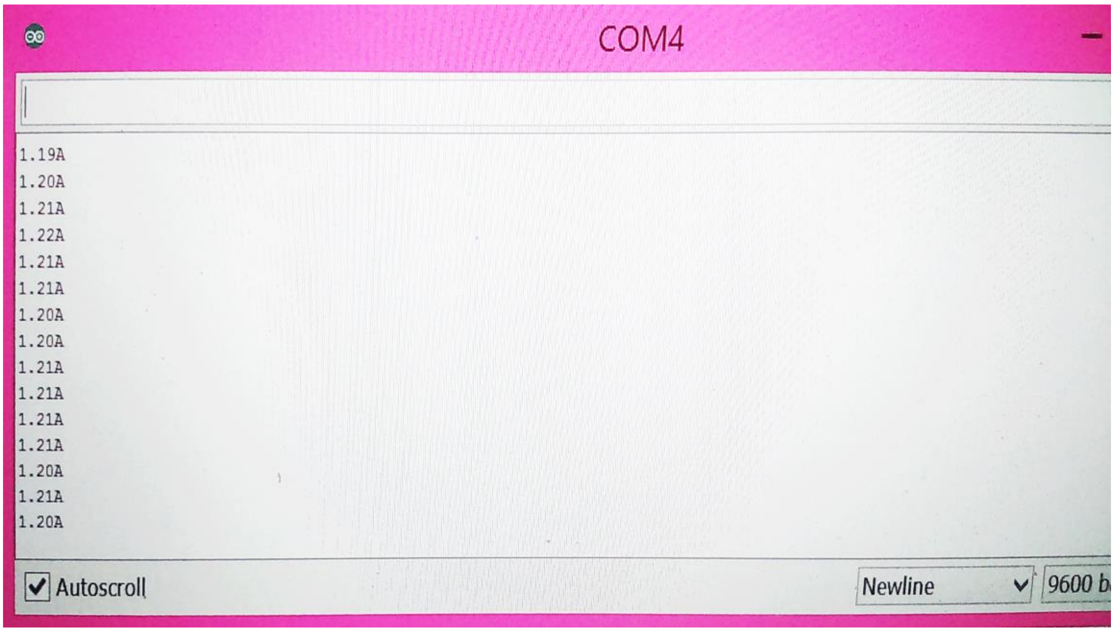


Figure 42 current sensor test results

The current sensor circuit is connected to the 12v battery to perform testing. We got the result almost 1.2A

10.2.3 The whole MPPT circuit testing

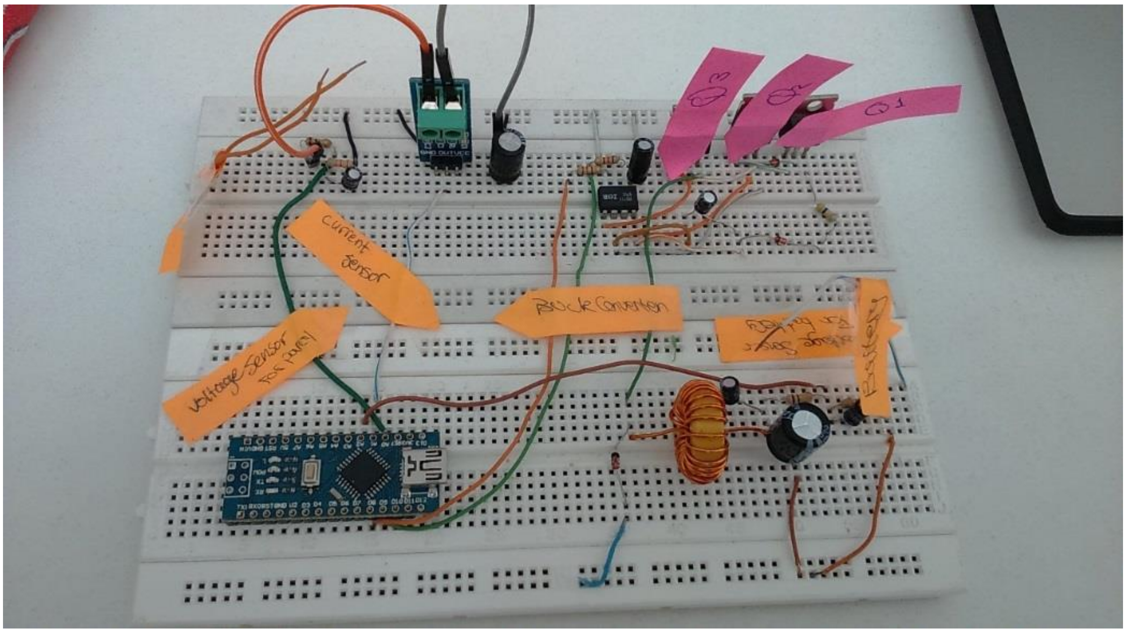


Figure 43 full circuit on breadboard

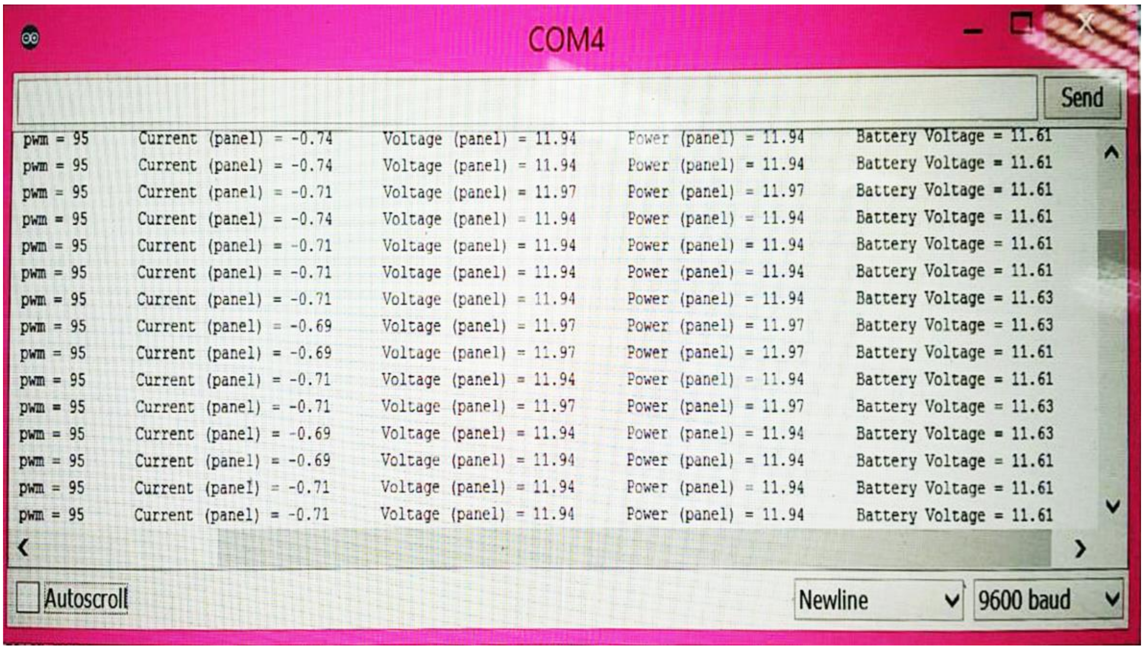


Figure 44 full system results

10.2.4 Testing the LCD

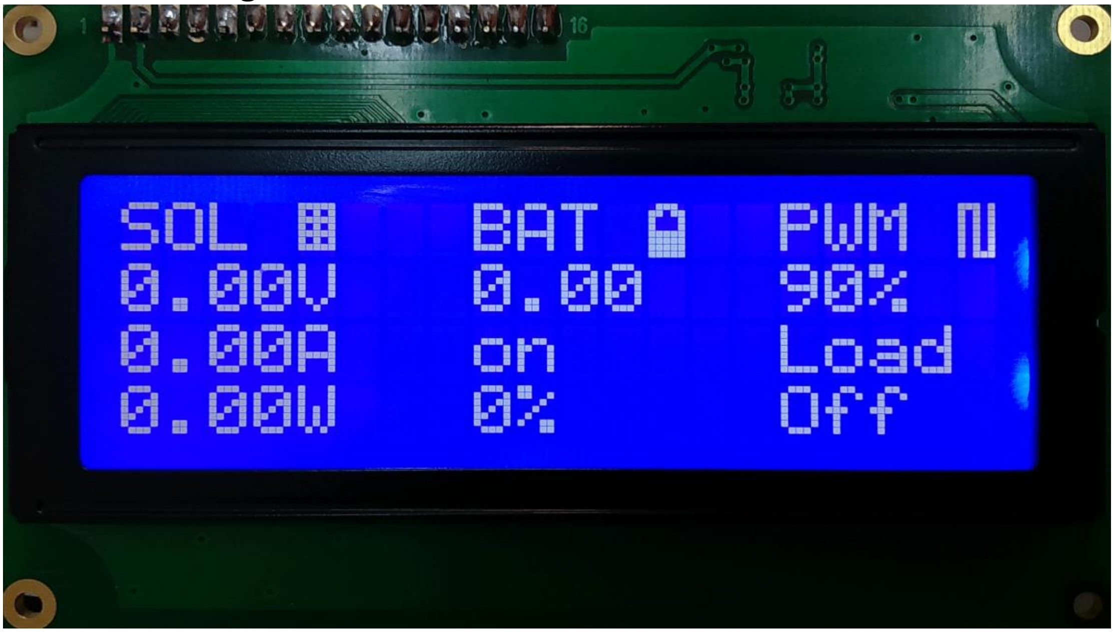


Figure 45 LCD testing

10.2.5 Testing the whole circuit with the LCD after welding

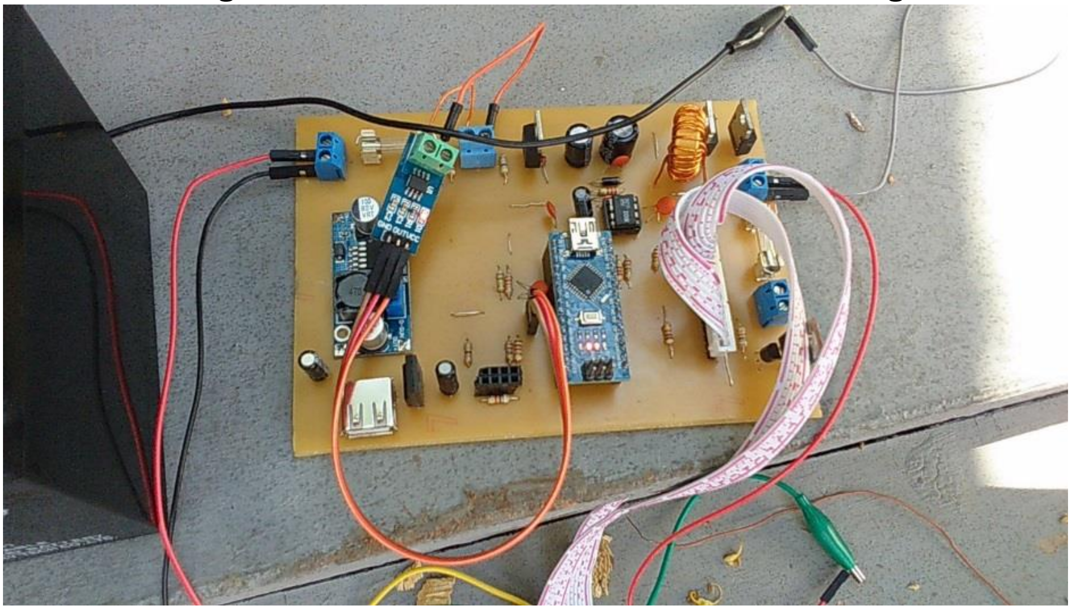


Figure 46 full circuit after welding

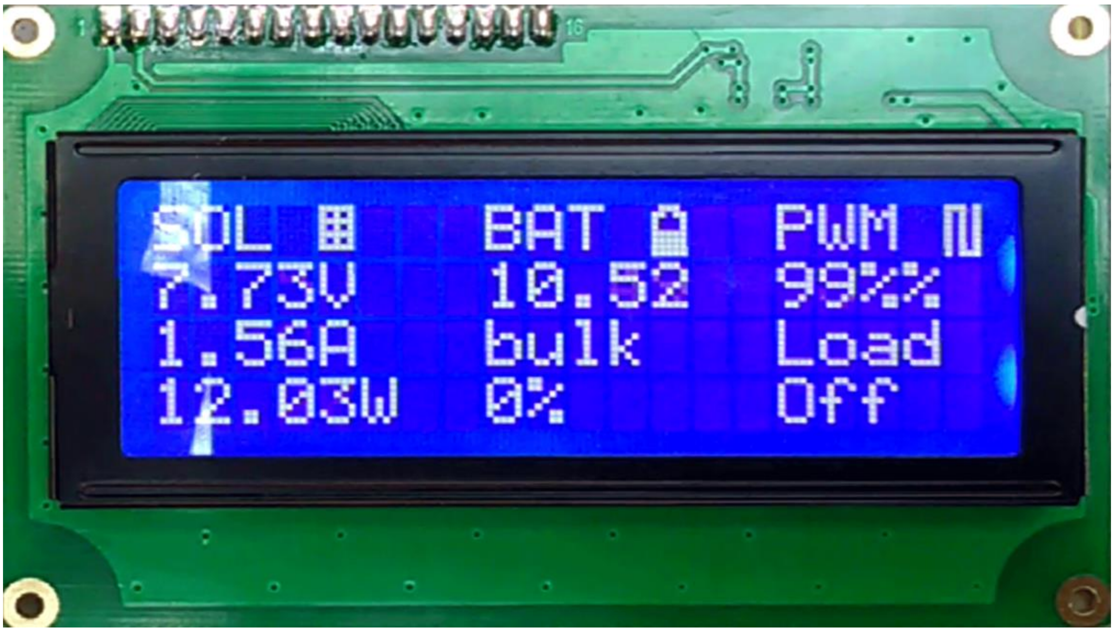


Figure 47 full system results on LCD

10.3 Prototype Implementation

Figure 48 prototype implementing step 1

Figure 49 prototype implementing step 2

Figure 50 prototype implementing final step

10.4 Challenges

- Calibration of the system was an issue because it depends on the Arduino used so we had to do series of tries and error to decide the constant used in the calibration.
- The inductor with core was a problem due to the fact that this core was hard to find in Egypt and we searched a lot to find it and we took it from an old power supply.
- We faced a problem in our circuit that the MOSFET works for 2 minutes and then it burns due to the high current of the battery, as a solution to this problem we added as a trial resistance and Zener diode to decrease the current entering the gate of the MOSFET.
- Designing the full system was an issue for us. Due to the different aspects effecting the structure such as wind force and deciding the proper height, we used mechanical design programs to simulate the full structure. The issue was deciding the proper material for the structure and after choosing steel cylinders we faced a problem that the diameter of the proper cylinder to be used was very large.

To meet the rapidly increasing consumer demands globally, we are planning ambitious future plans to modify our solar tree that by then can even meet customized consumer needs. Those future plans are mentioned in the next chapter.

11 FUTURE WORK

11.1 Introduction of Monitoring System & Internet of Things

Because solar panels can be implemented at remote areas, checking system parameter is essential for us. This gives us the thought to add the information logging component to our controller. 2016 may be the beginning age of the Internet of Things (IOT). IOT is the system of physical items or “things" inserted with hardware, programming, sensors, and integration. That is done to empower devices to trade information with the producer (company), administrator and/or other joined devices taking into account the foundation of International Telecommunication Union's Global Standards Initiative. The Internet of Things permits devices to be detected and controlled remotely crosswise over existing system network. That is making open doors for more straightforward reconciliation between the physical world and PC based systems and bringing enhanced productivity, precision and monetary advantage. Everything is particularly identifiable through its installed figuring network system however has the capacity interoperate inside of the current Internet infrastructure. Specialists appraise that the IOT will comprise of nearly 50 billion devices by 2020. [36]

11.2 Smart Lighting Control System

We can add a smart lighting control System feature to our solar tree. Digital light controllers composed of transceivers which control individual streetlight. Its basic idea is about saving energy by detecting if there are objects in the streets by sensors connected to the tree, depending on that we can control the brightness of lights in the streets.

Figure 51 smart lightening control system [44]

11.3 Cameras and Traffic Sensors System

Another feature could be supported by the tree. Cameras and traffic Sensors System will add a great value for government especially in crimes and for meteorological administration. We can conclude the advantages in the following points:

- Video surveillance.
- Weather stations.
- Traffic monitoring.

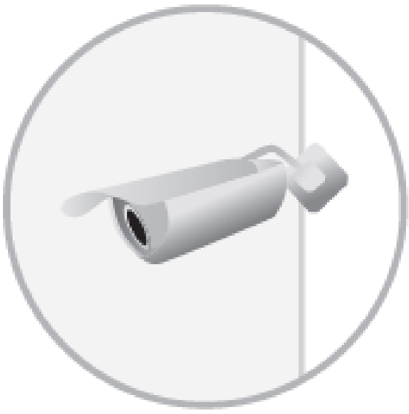


Figure 52 traffic sensors [47]

11.4 Connecting the solar system to the grid

Sometimes the output of solar systems can satisfy more than your needs at home. There are 2 forms to store the extra output: Using Batteries or feeding to the grid. So for further work, we can try to connect the solar tree into the grid to make the consumer able to use the provided green source of electricity to earn money by selling green electricity into the grid powered by the government.

On the other hand if the provided power is less than the consumer's need, he could draw the rest of needed power from the grid so he could save more money. For example, this technique is used in Canada and USA called Net Metering Program.

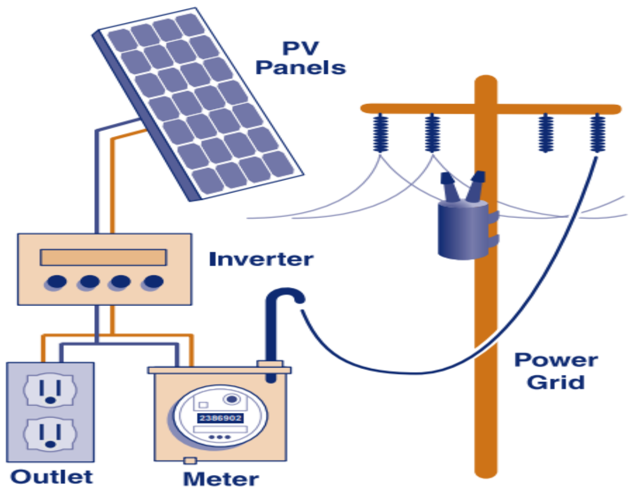


Figure 53 system connected to the grid [45]

12 CONCLUSION

Humans have been harming the planet for years yet we have fair examples that we all shall follow. Dependence on fossil fuel globally as a main source of energy is the main reason behind climate change. Climate change has huge impacts on planet that we should act right now to change our attitudes. It is too late to be pessimistic. We need to live inside eco-system where both investors and consumers are both winners. That eco-system is supposed to motivate inhabitants to change their attitudes towards the change that we all wish to see in the world. As an effective solution to climate change, solar energy showed a very strong potential that we all should depend on. With the rapidly increasing numbers of solar modules mounted everyday globally, solar energy has provided millions of jobs and helped the economic system to grow more efficiently where both health and environment are the main beneficial.

Being responsible humans that are honored to help healing the planet, solar energy showed us a good chance that we should never miss. Coming up with the rapidly changing global mindset, solar trees are good and reliable application of solar energy where both high technology and artistic aspects are satisfied side by side.

Since solar modules are originally made of silicon and in order to make best use of the already limited natural resources on earth, high technologies are highly recommended to apply for getting the maximum efficiency of various electronic components. Here, our project sparks. Since MPPT increase the PV system efficiency by 20-30%, it proved that it has become a mandatory component for the solar PV system. With the rapidly growing technologies, the continuous drop in prices globally and the rapid increasing of research laboratories worldwide, MPPT is expected to increase the PV system efficiency more and more.

Through our solar tree, we can create communities with public technology hubs everywhere. Those hubs are the places where knowledge can be shared reliably and information can be enriched among community members where electricity is a sustainable source of energy.

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APPENDIX A: HOW TO WIND A TOROIDAL INDUCTOR

A.1 How to Wind the Wire

Winding by hand is very painful for skin as well as it can't make the winding so tight. So we made a simple tool from Popsicle stick for winding the toroidal core. This simple tool is very handy and can make perfect and tight winding. Before making the inductor we have to know the core specification and number of turns.

The important parameters of toroidal core are

1. Outer diameter (OD)

2. Inner diameter (ID)

3. Height (H)

4. Al value

To know the part number, we used an indirect method to identify it. First we measured the OD and ID of the unknown core by using Vernier caliper, it was around

OD= 23.9mm (.94'"), ID= 14.2mm (.56"), H= 7.9 mm (.31") and yellow white in color.

We used a toroid core in the following chart

IRON POWDER TOROIDAL CORES

Physical Dimension

Core	OD (in)	ID (in)	HGT (in)	Mean lgth. (cm)	Cross sect. (cm^2)	Core	OD (in)	ID (in)	HGT (in)	Mean lgth. (cm)	Cross sect. (cm^2)
T- 12	.125	.062	.050	.75	.010	T-130	1.30	.78	.437	8.29	.73
T- 16	.160	.078	.060	.95	.016	T-157	1.57	.95	.570	10.05	1.14
T- 20	.200	.088	.070	1.15	.025	T-184	1.84	.95	.710	11.12	2.04
T- 25	.250	.120	.096	1.50	.042	T-200	2.00	1.25	.550	12.97	1.33
T- 30	.307	.151	.128	1.83	.065	T-200A	2.00	1.25	1.000	12.97	2.42
T- 37	.375	.205	.128	2.32	.070	T-225	2.25	1.40	.550	14.56	1.50
T- 44	.440	.229	.159	2.67	.107	T-225A	2.25	1.40	1.000	14.56	2.73
T- 50	.500	.300	.190	3.20	.121	T-300	3.00	1.92	.500	19.83	1.81
T- 68	.690	.370	.190	4.24	.196	T-300A	3.00	1.92	1.000	19.83	3.58
T- 80	.795	.495	.250	5.15	.242	T-400	4.00	2.25	.650	24.93	3.66
T- 94	.942	.560	.312	6.00	.385	T-400A	4.00	2.25	1.000	24.93	7.43
T-106	1.060	.570	.437	6.50	.690	T-500	5.20	3.08	.800	33.16	5.46

A_L Values (μh/100 turns)

For complete part number, add Mix number to Core Size number.

Core Size	26 Mix Yel-Wh $\mu=75$ Pwr Frq	3 Mix Gray $\mu=35$ .05 -0.5	15 Mix Rd-Wh $\mu=25$ 0.1 - 2.	1 Mix Blue $\mu=20$ 0.5 - 5.	2 Mix Red $\mu=10$ 2 - 30	7 Mix White $\mu=9$ 1 - 25	6 Mix Yellow $\mu=8$ 10 - 50	10 Mix Black $\mu=6$ 30-100	12 Mix Grn-Wh $\mu=4$ 50-200	17 Mix Bl/Ylw $\mu=4$ 40-180	0 Mix Tan $\mu=1$ 100-300
Mhz											
T- 12-	na	60	50	48	20	18	17	12	7.5	7.5	3.0
T- 16-	145	61	55	44	22	na	19	13	8.0	8.0	3.0
T- 20-	180	76	65	52	27	24	22	16	10.0	10.0	3.5
T- 25-	235	100	85	70	34	29	27	19	12.0	12.0	4.5
T- 30-	325	140	93	85	43	37	36	25	16.0	16.0	6.0
T- 37-	275	120	90	80	40	32	30	25	15.0	15.0	4.9
T- 44-	360	180	160	105	52	46	42	33	18.5	18.5	6.5
T- 50-	320	175	135	100	49	43	40	31	18.0	18.0	6.4
T- 68-	420	195	180	115	57	52	47	32	21.0	21.0	7.5
T- 80-	450	180	170	115	55	50	45	32	22.0	22.0	8.5
T- 94-	590	248	200	160	84	na	70	58	32.0	na	10.6
T-106-	900	450	345	325	135	133	116	na	na	na	19.0
T-130-	785	350	250	200	110	103	96	na	na	na	15.0
T-157-	970	420	360	320	140	na	115	na	na	na	na
T-184-	1640	720	na	500	240	na	195	na	na	na	na
T-200-	895	425	na	250	120	105	100	na	na	na	na
T-200A-	1550	760	na	na	218	na	180	na	na	na	na
T-225-	950	424	na	na	120	na	100	na	na	na	na
T-225A-	1600	na	na	na	215	na	na	na	na	na	na
T-300-	800	na	na	na	114	na	na	na	na	na	na
T-300A-	1600	na	na	na	228	na	na	na	na	na	na
T-400-	1300	na	na	na	185	na	na	na	na	na	na
T-400A-	2600	na	na	na	360	na	na	na	na	na	na
T-520-	1460	na	na	na	207	na	na	na	na	na	na

A.2 Finding the Part Number

We searched the **Physical dimension** table from the chart. From the table it was found that the core is **T94**

A.3 Finding the Mix Number

The color of the core is indication for mix number. As our core is yellow/white in color, it is confirmed that the mix number is 26

So the unknown core is T94-26

A.4 Finding Al Value

From the Al value table for a T94-26 core it is 590 in μH/100 turns.

After selecting the core now time to find out the number of turns required to obtain the desired inductance.

$$Number\ of\ turns\ (N) = 100\sqrt{\frac{desired\ inductance\ in\ \mu H}{Al\ in\ \mu H\ per\ 100\ turns}}$$

$$N = 100\sqrt{\frac{54}{590}} = 30.2 \sim 30\ turns$$

We also used an online calculator for finding the number of turns through this link:

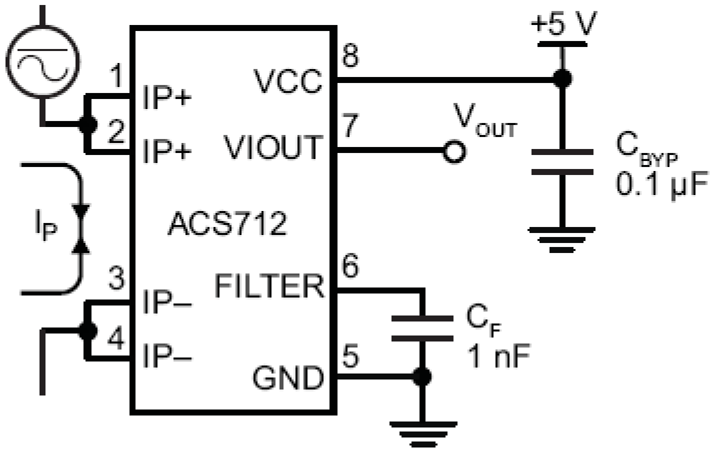
http://www.66pacific.com/calculators/toroid_calc.aspx

Then we wind a 20 AWG copper wire (30 turns) around the toroid core. At the both end of the winding leave some extra wire for connection lead. After this we remove the enamel insulation from the lead.

APPENDIX B: CURRENT SENSOR DATA SHEET

ACS712 fully integrated, hall effect-based linear current sensor IC with 2.1 Kv RMS isolation and a low-resistance current conductor

Typical Application



Application 1. The ACS712 outputs an analog signal, V_{OUT}. that varies linearly with the uni- or bi-directional AC or DC primary sampled current, I_P, within the range specified. C_F is recommended for noise management, with values that depend on the application.

Selection Guide

Part Number	Packing*	T_A (°C)	Optimized Range, I_P (A)	Sensitivity, Sens (Typ) (mV/A)
ACS712ELCTR-05B-T	Tape and reel, 3000 pieces/reel	–40 to 85	±5	185
ACS712ELCTR-20A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±20	100
ACS712ELCTR-30A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±30	66

*Contact Allegro for additional packing options.

Absolute Maximum Ratings

Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		8	V
Reverse Supply Voltage	V_{RCC}		–0.1	V
Output Voltage	V_{IOUT}		8	V
Reverse Output Voltage	V_{RIOUT}		–0.1	V
Output Current Source	$I_{IOUT(Source)}$		3	mA
Output Current Sink	$I_{IOUT(Sink)}$		10	mA
Overcurrent Transient Tolerance	I_P	1 pulse, 100 ms	100	A
Nominal Operating Ambient Temperature	T_A	Range E	–40 to 85	ºC
Maximum Junction Temperature	T_J(max)		165	ºC
Storage Temperature	T_{stg}		–65 to 170	ºC

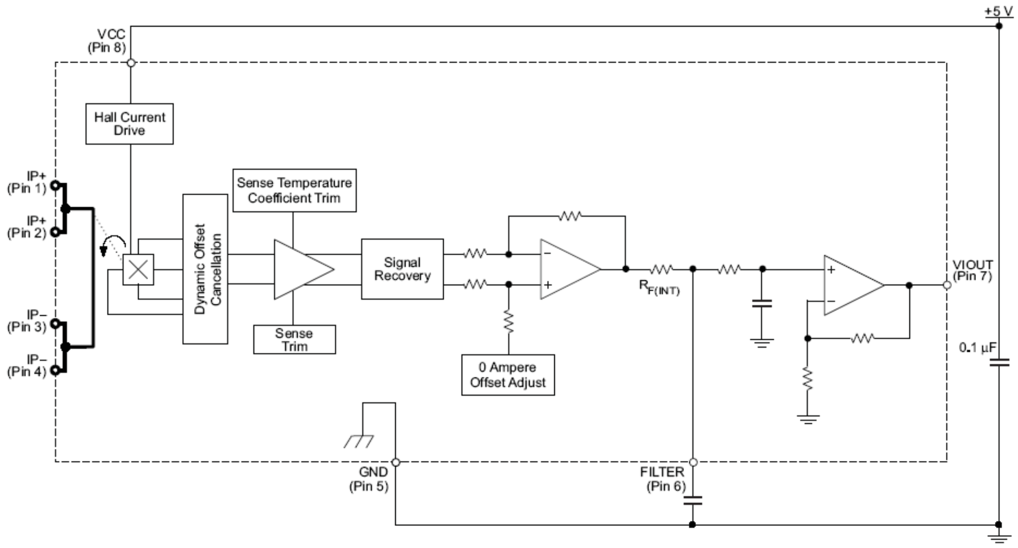
Isolation Characteristics

Characteristic	Symbol	Notes	Rating	Unit
Dielectric Strength Test Voltage*	V_{ISO}	Agency type-tested for 60 seconds per UL standard 60950-1, 1st Edition	2100	VAC
Working Voltage for Basic Isolation	V_{WFSI}	For basic (single) isolation per UL standard 60950-1, 1st Edition	354	VDC or V_{pk}
Working Voltage for Reinforced Isolation	V_{WFRI}	For reinforced (double) isolation per UL standard 60950-1, 1st Edition	184	VDC or V_{pk}

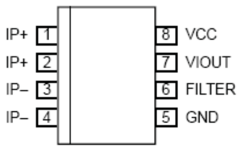
* Allegro does not conduct 60-second testing. It is done only during the UL certification process.

Parameter	Specification
Fire and Electric Shock	CAN/CSA-C22.2 No. 60950-1-03 UL 60950-1:2003 EN 60950-1:2001

Functional Block Diagram



Pin-out Diagram



Terminal List Table

Number	Name	Description
1 and 2	IP+	Terminals for current being sampled; fused internally
3 and 4	IP–	Terminals for current being sampled; fused internally
5	GND	Signal ground terminal
6	FILTER	Terminal for external capacitor that sets bandwidth
7	VIOUT	Analog output signal
8	VCC	Device power supply terminal

COMMON OPERATING CHARACTERISTICS[1] over full range of T_A, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
ELECTRICAL CHARACTERISTICS						
Supply Voltage	V_{CC}		4.5	5.0	5.5	V
Supply Current	I_{CC}	V_{CC} = 5.0 V, output open	–	10	13	mA
Output Capacitance Load	C_{LOAD}	VIOUT to GND	–	–	10	nF
Output Resistive Load	R_{LOAD}	VIOUT to GND	4.7	–	–	kΩ
Primary Conductor Resistance	$R_{PRIMARY}$	T_A = 25°C	–	1.2	–	mΩ
Rise Time	t_r	$I_P = I_P(max)$, T_A = 25°C, C_{OUT} = open	–	3.5	–	μs
Frequency Bandwidth	f	–3 dB, T_A = 25°C; I_P is 10 A peak-to-peak	–	80	–	kHz
Nonlinearity	E_{LIN}	Over full range of I_P	–	1.5	–	%
Symmetry	E_{SYM}	Over full range of I_P	98	100	102	%
Zero Current Output Voltage	$V_{IOUT(Q)}$	Bidirectional; I_P = 0 A, T_A = 25°C	–	V_{CC} × 0.5	–	V
Power-On Time	t_{PO}	Output reaches 90% of steady-state level, T_J = 25°C, 20 A present on leadframe	–	35	–	μs
Magnetic Coupling[2]			–	12	–	G/A
Internal Filter Resistance[3]	$R_{F(INT)}$			1.7		kΩ

[1]Device may be operated at higher primary current levels, I_P, and ambient, T_A, and internal leadframe temperatures, T_A, provided that the Maximum Junction Temperature, $T_J(max)$, is not exceeded.

[2]1G = 0.1 mT.

[3]$R_{F(INT)}$ forms an RC circuit via the FILTER pin.

COMMON THERMAL CHARACTERISTICS[1]

			Min.	Typ.	Max.	Units
Operating Internal Leadframe Temperature	T_A	E range	–40	–	85	°C
					Value	Units
Junction-to-Lead Thermal Resistance[2]	$R_{\theta JL}$	Mounted on the Allegro ASEK 712 evaluation board			5	°C/W
Junction-to-Ambient Thermal Resistance	$R_{\theta JA}$	Mounted on the Allegro 85-0322 evaluation board, includes the power consumed by the board			23	°C/W

[1]Additional thermal information is available on the Allegro website.

[2]The Allegro evaluation board has 1500 mm^2 of 2 oz. copper on each side, connected to pins 1 and 2, and to pins 3 and 4, with thermal vias connecting the layers. Performance values include the power consumed by the PCB. Further details on the board are available from the Frequently Asked Questions document on our website. Further information about board design and thermal performance also can be found in the Applications Information section of this datasheet.

x05B PERFORMANCE CHARACTERISTICS[1] T_A = –40°C to 85°C, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–5	–	5	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	180	185	190	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 185 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	21	–	mV
Zero Current Output Slope	$\Delta V_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.26	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.054	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.008	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±5 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, $T_{J(max)}$, is not exceeded.

[2]Percentage of I_P, with I_P = 5 A. Output filtered.

x20A PERFORMANCE CHARACTERISTICS[1] T_A = –40°C to 85°C, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–20	–	20	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	96	100	104	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 100 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	11	–	mV
Zero Current Output Slope	$\Delta V_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.34	–	mV/°C
		T_A = 25°C to 150°C	–	–0.07	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.017	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.004	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±20 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, $T_J(max)$, is not exceeded.

[2]Percentage of I_P, with I_P = 20 A. Output filtered.

x30A PERFORMANCE CHARACTERISTICS[1] T_A = –40°C to 85°C, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

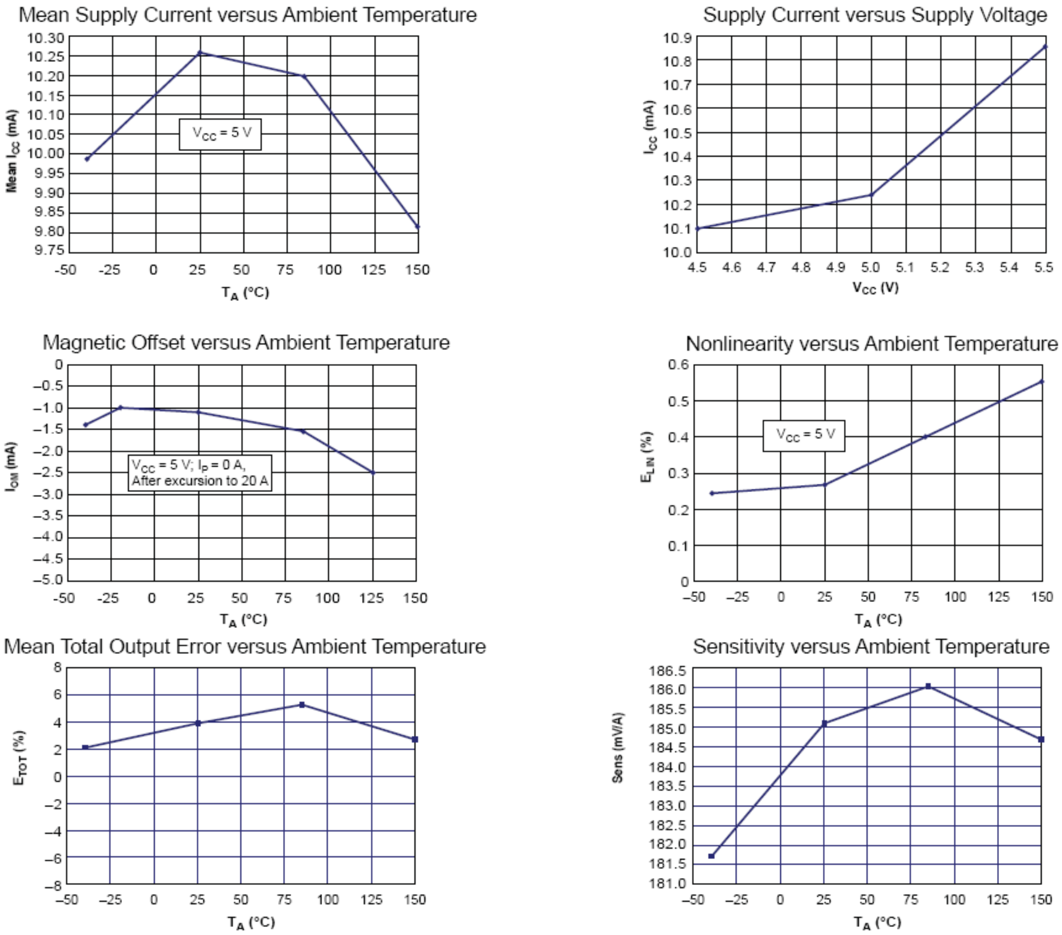
Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–30	–	30	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	63	66	69	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 66 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	7	–	mV
Zero Current Output Slope	$\Delta V_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.35	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.007	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.002	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±30 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, T_J(max), is not exceeded.

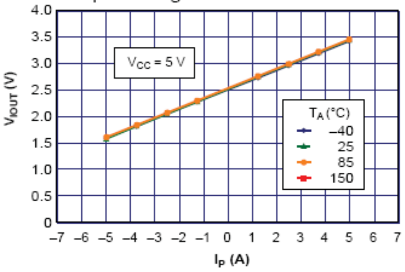
[2]Percentage of I_P, with I_P = 30 A. Output filtered.

Characteristic Performance

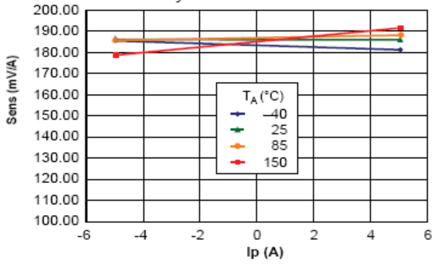
I_P = 5 A, unless otherwise specified



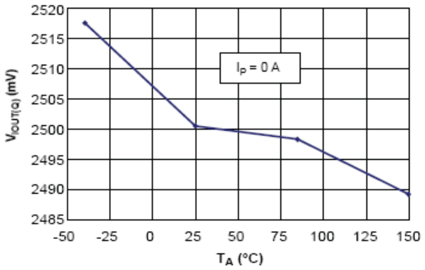
Output Voltage versus Sensed Current



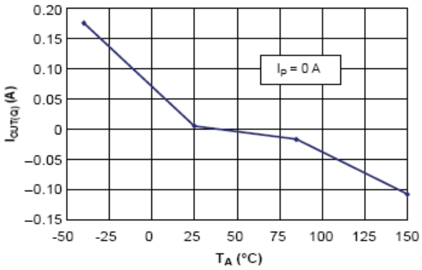
Sensitivity versus Sensed Current



0 A Output Voltage versus Ambient Temperature



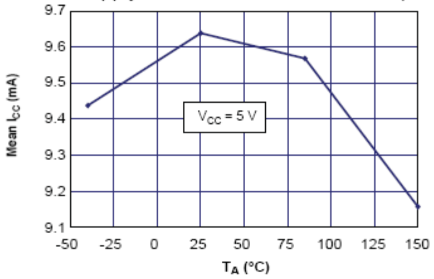
0 A Output Voltage Current versus Ambient Temperature



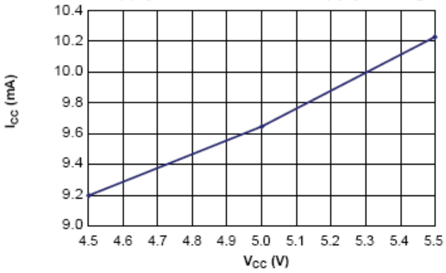
Characteristic Performance

I_P = 20 A, unless otherwise specified

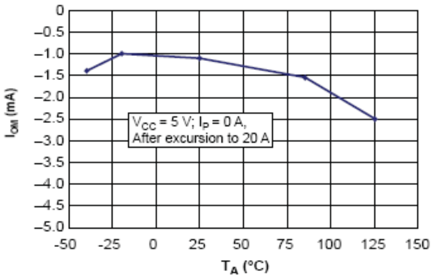
Mean Supply Current versus Ambient Temperature



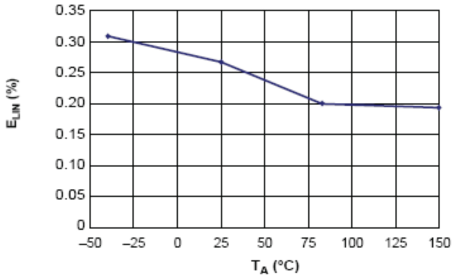
Supply Current versus Supply Voltage



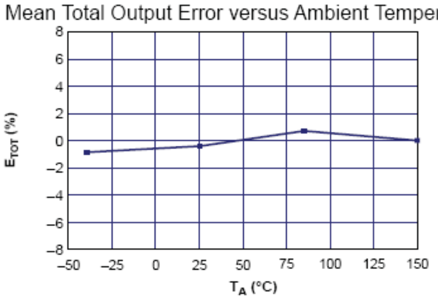
Magnetic Offset versus Ambient Temperature



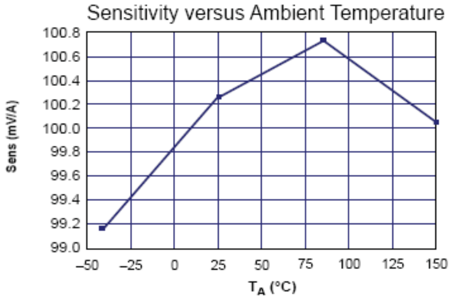
Nonlinearity versus Ambient Temperature



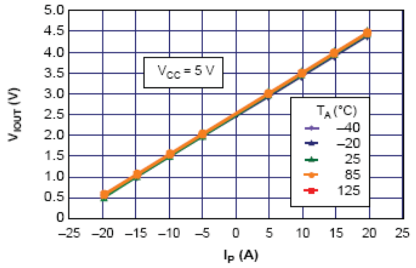
Mean Total Output Error versus Ambient Temperature



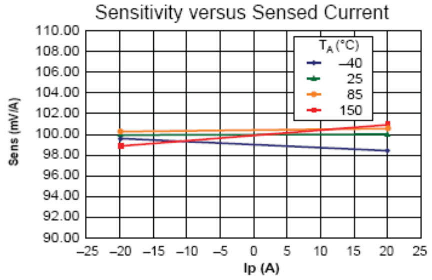
Sensitivity versus Ambient Temperature



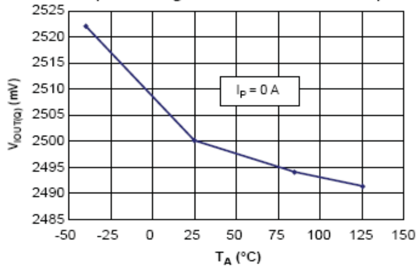
Output Voltage versus Sensed Current



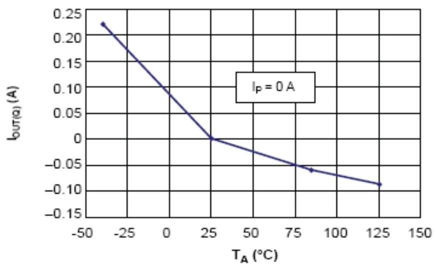
Sensitivity versus Sensed Current



0 A Output Voltage versus Ambient Temperature



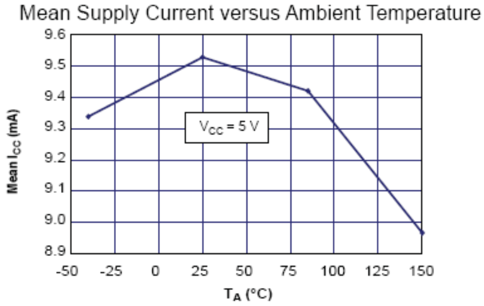
0 A Output Voltage Current versus Ambient Temperature



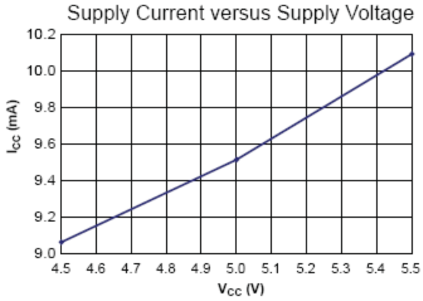
Characteristic Performance

I_P = 30 A, unless otherwise specified

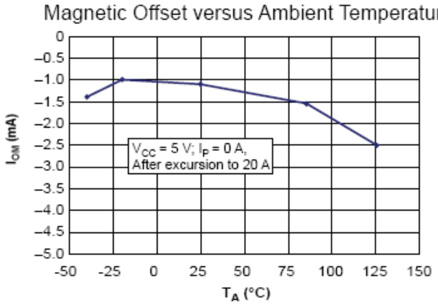
Mean Supply Current versus Ambient Temperature



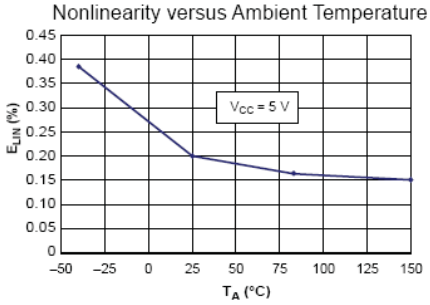
Supply Current versus Supply Voltage



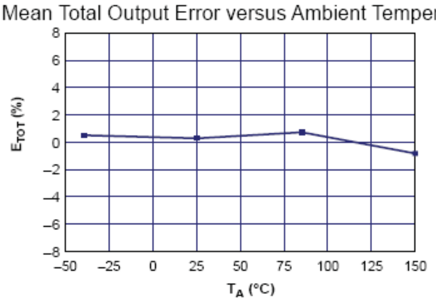
Magnetic Offset versus Ambient Temperature



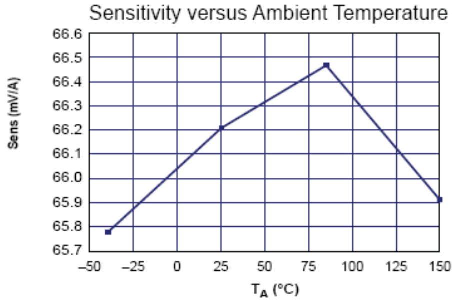
Nonlinearity versus Ambient Temperature

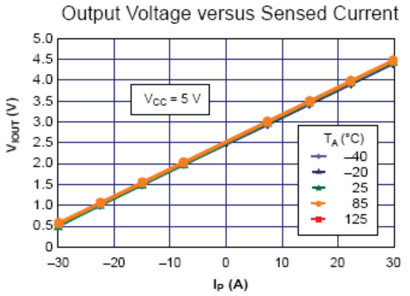


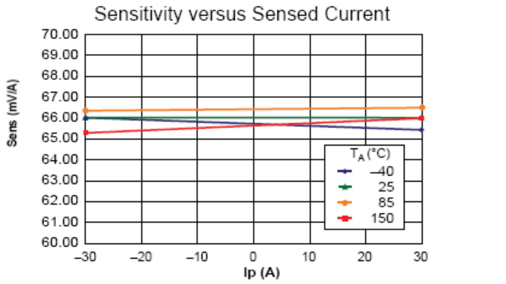
Mean Total Output Error versus Ambient Temperature

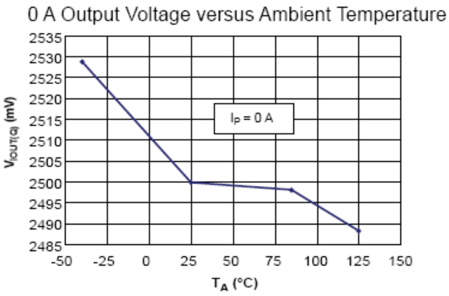


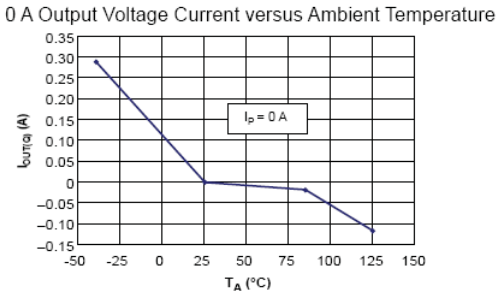
Sensitivity versus Ambient Temperature




Output Voltage versus Sensed Current
V_CC = 5 V
T_A (°C)
–40
–20
25
85
125
V_IOUT (V)
I_P (A)


Sensitivity versus Sensed Current
T_A (°C)
–40
25
85
150
Sens (mV/A)
Ip (A)


0 A Output Voltage versus Ambient Temperature
I_P = 0 A
V_IOUT(Q) (mV)
T_A (°C)


0 A Output Voltage Current versus Ambient Temperature
I_P = 0 A
I_OUT(Q) (A)
T_A (°C)

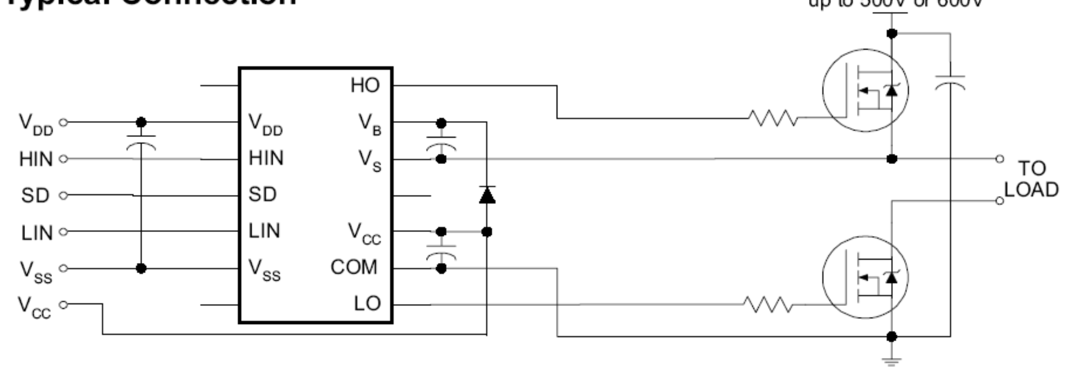
APPENDIX C: MOSFET DRIVER DATASHEET

IR2110 (-1-2) (S)PbF/IR2113(-1-2)(S)PbF High and Low side driver

C.1 Product Summary

V_{offset} (IR2110)	500v max
V_{offset} (IR2113)	600v max
I_o+/-	2A / 2A
V_{out}	10 – 20V
$t_{on/off}$ (typ.)	120 & 94 ns
Delay matching (IR2110)	10 ns max
Delay matching (IR2113)	20 ns max

Typical Connection



(Refer to Lead Assignments for correct pin configuration). This/These diagram(s) show electrical connections only. Please refer to our Application Notes and DesignTips for proper circuit board layout.

C.2 Absolute Maximum Ratings

Symbol	Definition		Min.	Max.	Units
V_B	High side floating supply voltage	(IR2110)	-0.3	525	V
		(IR2113)	-0.3	625	
V_S	High side floating supply offset voltage		V_B - 25	V_B + 0.3	
V_{HO}	High side floating output voltage		V_S - 0.3	V_B + 0.3	
V_{CC}	Low side fixed supply voltage		-0.3	25	
V_{LO}	Low side output voltage		-0.3	V_{CC} + 0.3	
V_{DD}	Logic supply voltage		-0.3	V_{SS} + 25	
V_{SS}	Logic supply offset voltage		V_{CC} - 25	V_{CC} + 0.3	
V_{IN}	Logic input voltage (HIN, LIN & SD)		V_{SS} - 0.3	V_{DD} + 0.3	
dV_S/dt	Allowable offset supply voltage transient (figure 2)		—	50	V/ns
P_D	Package power dissipation @ $T_A \leq$ +25°C	(14 lead DIP)	—	1.6	W
		(16 lead SOIC)	—	1.25	
R_{THJA}	Thermal resistance, junction to ambient	(14 lead DIP)	—	75	°C/W
		(16 lead SOIC)	—	100	
T_J	Junction temperature		—	150	°C
T_S	Storage temperature		-55	150	
T_L	Lead temperature (soldering, 10 seconds)		—	300	

C.3 Recommended Operating Conditions

Symbol	Definition		Min.	Max.	Units
V_B	High side floating supply absolute voltage		V_S + 10	V_S + 20	V
V_S	High side floating supply offset voltage	(IR2110)	Note 1	500	
		(IR2113)	Note 1	600	
V_{HO}	High side floating output voltage		V_S	V_B	
V_{CC}	Low side fixed supply voltage		10	20	
V_{LO}	Low side output voltage		0	VCC	
V_{DD}	Logic supply voltage		V_{SS} + 3	V_{SS} + 20	
V_{SS}	Logic supply offset voltage		-5 (Note 2)	5	
V_{IN}	Logic input voltage (HIN, LIN & SD)		V_{SS}	V_{DD}	
T_A	Ambient temperature		-40	125	°C

Note 1: Logic operational for V_S of -4 to +500V. Logic state held for V_S of -4V to $-V_{BS}$. (Please refer to the Design Tip DT97-3 for more details).
Note 2: When V_{DD} < 5V, the minimum V_{SS} offset is limited to $-V_{DD}$.

C.4 Dynamic Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}, V_{DD}) = 15V, C_L = 1000 pF, T_A = 25°C and V_{SS} = COM unless otherwise specified. The dynamic electrical characteristics are measured using the test circuit shown in Figure 3.

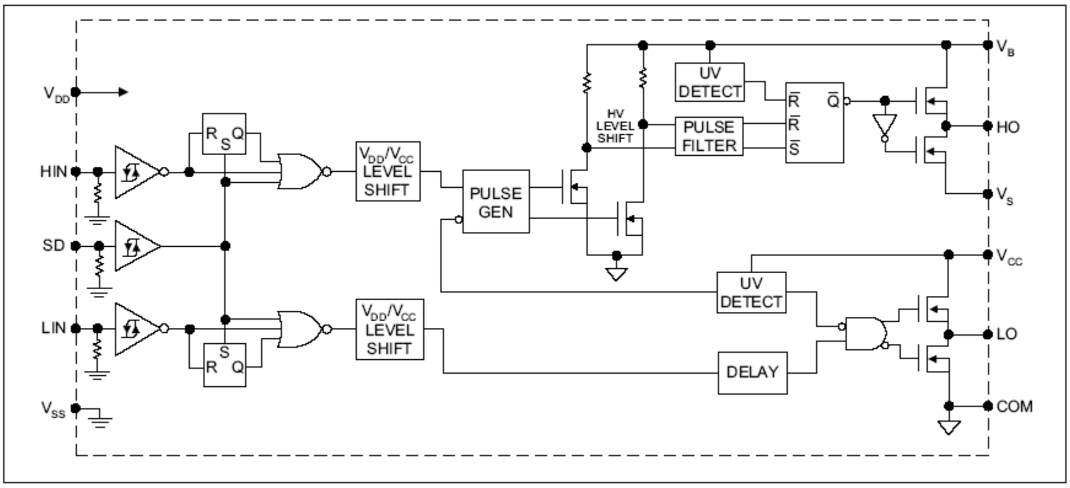
Symbol	Definition		Figure	Min.	Typ.	Max.	Units	Test Conditions
t_{on}	Turn-on propagation delay		7	—	120	150	ns	V_S = 0V
t_{off}	Turn-off propagation delay		8	—	94	125		V_S = 500V/600V
t_{sd}	Shutdown propagation delay		9	—	110	140		V_S = 500V/600V
t_r	Turn-on rise time		10	—	25	35		
t_f	Turn-off fall time		11	—	17	25		
MT	Delay matching, HS & LS	(IR2110)	—	—	—	10		
	turn-on/off	(IR2113)	—	—	—	20		

C.5 Static Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}, V_{DD}) = 15V, T_A = 25°C and V_{SS} = COM unless otherwise specified. The V_{IN}, V_{TH} and I_{IN} parameters are referenced to V_{SS} and are applicable to all three logic input leads: HIN, LIN and SD. The V_O and I_O parameters are referenced to COM and are applicable to the respective output leads: HO or LO.

Symbol	Definition	Figure	Min.	Typ.	Max.	Units	Test Conditions
V_{IH}	Logic "1" input voltage	12	9.5	—	—	V	
V_{IL}	Logic "0" input voltage	13	—	—	6.0	V	
V_{OH}	High level output voltage, V_{BIAS} - V_O	14	—	—	1.2	V	I_O = 0A
V_{OL}	Low level output voltage, V_O	15	—	—	0.1	V	I_O = 0A
I_{LK}	Offset supply leakage current	16	—	—	50	µA	V_B=V_S = 500V/600V
I_{QBS}	Quiescent V_{BS} supply current	17	—	125	230	µA	V_{IN} = 0V or V_{DD}
I_{QCC}	Quiescent V_{CC} supply current	18	—	180	340	µA	V_{IN} = 0V or V_{DD}
I_{QDD}	Quiescent V_{DD} supply current	19	—	15	30	µA	V_{IN} = 0V or V_{DD}
I_{IN+}	Logic "1" input bias current	20	—	20	40	µA	V_{IN} = V_{DD}
I_{IN-}	Logic "0" input bias current	21	—	—	1.0	µA	V_{IN} = 0V
V_{BSUV+}	V_{BS} supply undervoltage positive going threshold	22	7.5	8.6	9.7	V	
V_{BSUV-}	V_{BS} supply undervoltage negative going threshold	23	7.0	8.2	9.4	V	
V_{CCUV+}	V_{CC} supply undervoltage positive going threshold	24	7.4	8.5	9.6	V	
V_{CCUV-}	V_{CC} supply undervoltage negative going threshold	25	7.0	8.2	9.4	V	
I_{O+}	Output high short circuit pulsed current	26	2.0	2.5	—	A	V_O = 0V, V_{IN} = V_{DD} PW ≤ 10 µs
I_{O-}	Output low short circuit pulsed current	27	2.0	2.5	—	A	V_O = 15V, V_{IN} = 0V PW ≤ 10 µs

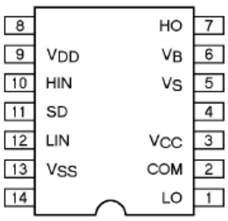
C.6 Functional Diagram



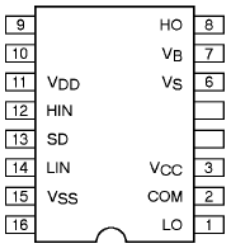
C.7 Lead Definitions

Symbol	Description
V_{DD}	Logic supply
HIN	Logic input for high side gate driver output (HO), in phase
SD	Logic input for shutdown
LIN	Logic input for low side gate driver output (LO), in phase
V_{SS}	Logic ground
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side supply
LO	Low side gate drive output
COM	Low side return

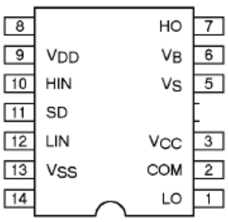
C.8 Lead Assignments



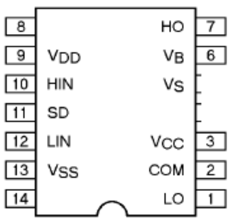
14 Lead PDIP
IR2110/IR2113



16 Lead SOIC (Wide Body)
IR2110S/IR2113S



14 Lead PDIP w/o lead 4
IR2110-1/IR2113-1



14 Lead PDIP w/o leads 4 & 5
IR2110-2/IR2113-2

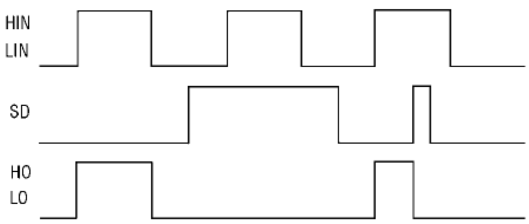


Figure 1. Input/Output Timing Diagram

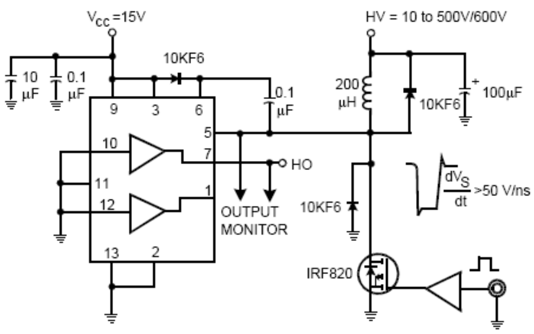


Figure 2. Floating Supply Voltage Transient Test Circuit

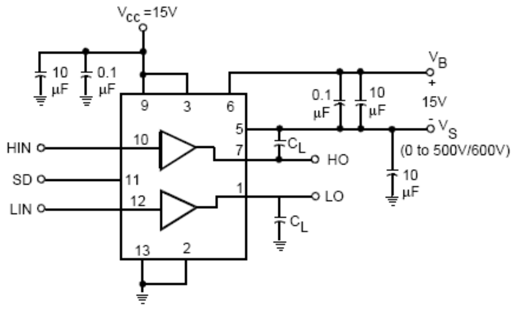


Figure 3. Switching Time Test Circuit

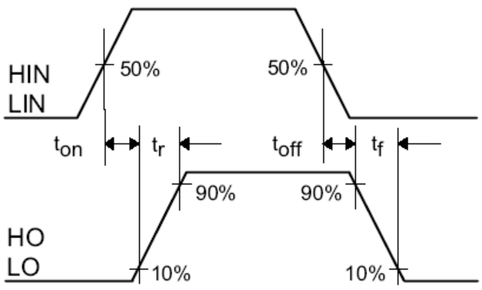


Figure 4. Switching Time Waveform Definition

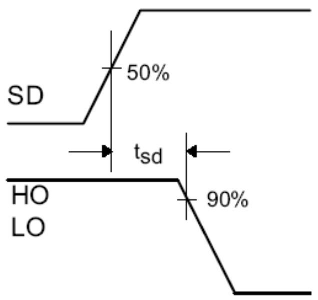


Figure 5. Shutdown Waveform Definitions

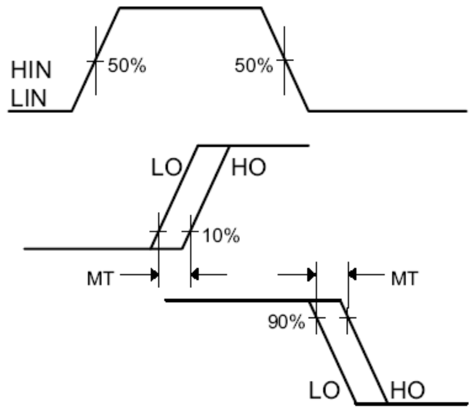


Figure 6. Delay Matching Waveform Definitions

APPENDIX D: LCD DATASHEET

D.1 Connections with Arduino

(LCD pin 1)	Potentiometer to Arduino +5V
(LCD pin 2)	Potentiometer to Arduino GND
(LCD pin 3)	Middle Pin of Potentiometer
(LCD pin 4)	Arduino pin 12
(LCD pin 5)	Arduino pin 11
(LCD pin 6)	Arduino pin 10
(LCD pin 7)	NC
(LCD pin 8)	NC
(LCD pin 9)	NC
(LCD pin 10)	NC
(LCD pin 11)	Arduino pin 5
(LCD pin 12)	Arduino pin 4
(LCD pin 13)	Arduino pin 3
(LCD pin 14)	Arduino pin 2
(LCD pin 15)	Arduino pin 13
(LCD pin 16)	Arduino GND

Note: In our circuit LCD pin 1 is connected to ground and LCD pin 2 is connected to 5v. A 1 Kilo-ohm resistance is added between pin 2 and pin 3. Pin 3 is connected to ground.

D.2 Example Arduino Code

```
#include <LiquidCrystal.h>
#include <Wire.h>
LiquidCrystal lcd(12, 11, 10, 5, 4, 3, 2);
int backLight = 13;    // pin 13 will control the backlight
void setup()
{
  pinMode(backLight, OUTPUT);   digitalWrite(backLight, HIGH); // turn backlight on.
Replace 'HIGH' with 'LOW' to turn it off.   lcd.begin(20,4);            // columns, rows.  use
16,2 for a 16x2 LCD, etc.   lcd.clear();                // start with a blank screen
  lcd.setCursor(0,0);          // set cursor to column 0, row 0 (the first row)
lcd.print("Hello, World");    // change this text to whatever you like. keep it clean.
  lcd.setCursor(0,1);          // set cursor to column 0, row 1   lcd.print("************************");
  lcd.setCursor(0,2);          // set cursor to column 0, row 2   lcd.print("Future
Electronics");
  lcd.setCursor(0,3);          // set cursor to column 0, row 3   lcd.print("*************************");
}
void loop()
{
}
```

APPENDIX E: TEST CODES

E.1 Voltage Sensor Code

```
 // Code for dc voltage measurement by using a voltage divider circuit
int sensor_pin=A0;  // variable for sensor
float sample=0;
float volt =0;
float v;
  void setup()
  {

  Serial.begin(9600);
  }
void loop()
{
    sample=0;
  for(int i=0;i<150;i++)
  {
    sample+=analogRead(sensor_pin);  //read the value from the sensor
    delay(2);
  }
  sample=sample/150;
  v = sample*(4.35/1023); // to convert the sample read to real volt using
calibration // reference voltage of Arduino equal 4.35
  volt = v*(120/20); // R1+R2/R2 // R1=100k and R2=20k // multiplying with the
factor of the voltage divider to calculate the real voltage

  Serial.print(volt);
  Serial.println("V");
  delay(500);
  }
```

E.2 Current Sensor Code

```
// Code for current measurement by using a ACS712 (5A) hall effect current
sensor
  int temp=0;
  float sum =0;
  float AMPS_SCALE =0;
  float amps=0;
  void setup()
```

```
{

Serial.begin(9600);
}

void loop()
{
  for(int i = 0; i < 100; i++)
{
  temp=analogRead(A0);     // read the input pin
  sum += temp;
  delayMicroseconds(50);
}
 sum=sum/100;              // divide sum by 100 to get average

// Calibration  for current

 AMPS_SCALE= (5/1024)/ 0.185;   // Sensitivity = 185mV
 amps = (AMPS_SCALE* sum -  (2.5/0.185));  // Offset = 2.5/0.185 = 13.51

 Serial.print(amps);
Serial.println("A");
delay(500);
}
```

E.3 LCD Code

```
#include <LiquidCrystal.h>
#include <Wire.h>

byte solar[8] = //icon for termometer
{
  0b11111,
  0b10101,
  0b11111,
  0b10101,
  0b11111,
  0b10101,
  0b11111,
```

```
  0b00000
};

byte battery[8]=
{
  0b01110,
  0b11011,
  0b10001,
  0b10001,
  0b11111,
  0b11111,
  0b11111,
  0b11111,
};

byte pwm [8]=
{
 0b11101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10111,
};

LiquidCrystal lcd(12, 11, 10, 5, 4, 3, 2);
int backLight = 13; // pin 13 will control the backlight
int backlight_State = 0;
float sol_volts=0;
float sol_amps=0;
float sol_watts=0;
float bat_volts=0;

void setup()
{
lcd.noBacklight();
```

```
  lcd.createChar(1,solar);
  lcd.createChar(2, battery);
  lcd.createChar(3, pwm);
lcd.clear(); // start with a blank screen
lcd.setCursor(0, 0);
 lcd.print("SOL");
 lcd.setCursor(4, 0);
 lcd.write(1);
 lcd.setCursor(0, 1);
  lcd.print(sol_volts);
 lcd.print("V");
 lcd.setCursor(0, 2);
 lcd.print("1.03A");
 lcd.setCursor(0, 3);
 lcd.print(sol_watts);
 lcd.print("W ");
 lcd.setCursor(8, 0);
 lcd.print("BAT");
 lcd.setCursor(12, 0);
 lcd.write(2);
 lcd.setCursor(8, 1);
 lcd.print(bat_volts);
 lcd.setCursor(8,2);
 lcd.print("V");
}

void loop()
{
}
```

APPENDIX F: MPPT CODE

```
//---------------------------------------------------------------------------
--------------------------

// ARDUINO MPPT SOLAR CHARGE CONTROLLER (Version-3)

//  Author: Debasish Dutta/deba168

//          www.opengreenenergy.in

//

//  This code is for an arduino Nano based Solar MPPT charge controller.

//  This code is a modified version of sample code from www.timnolan.com

//  updated 21/06/2015

//

//  Mods by Aplavins 06/19/2015


////  Specifications :
/////////////////////////////////////////////////////////////////////////////
//////////////////////////


//

//    1.Solar panel power = 50W


//

//    2.Rated Battery Voltage= 12V ( lead acid type )


//    3.Maximum current = 5A
//


//    4.Maximum load current =10A
//


//    5. In put Voltage = Solar panel with Open circuit voltage from 17 to
25V                                              //


/////////////////////////////////////////////////////////////////////////////
///////////////////////////////////////////////////


#include "TimerOne.h"

#include <LiquidCrystal.h>

#include <Wire.h>
```

```
//////// Arduino pins
Connections/////////////////////////////////////////////////////////////////
/////////////////


// A0 - Voltage divider (solar)

// A1 - ACS 712 Out (current sensor)

// A2 - Voltage divider (battery)

// D7 - ESP8266 Tx

// D13 - ESP8266 Rx through the voltage divider

// D6 - Load Control

// D8 - 2104 MOSFET driver SD

// D9 - 2104 MOSFET driver IN




///////// Definitions
////////////////////////////////////////////////////////////////////////////
/////////////////////



#define SOL_VOLTS_CHAN 0               // defining the adc channel to read
solar volts

#define SOL_AMPS_CHAN 1                // Defining the adc channel to read
solar amps

#define BAT_VOLTS_CHAN 2               // defining the adc channel to read
battery volts

#define AVG_NUM 8                      // number of iterations of the adc
routine to average the adc readings


// ACS 712 Current Sensor is used. Current Measured = (5/(1024 *0.185))*ADC
- (2.5/0.185)


#define SOL_AMPS_SCALE  0.026393581        // the scaling value for raw adc
reading to get solar amps   // 5/(1024*0.185)

#define SOL_VOLTS_SCALE (4.25/1023)*(120/20)        // the scaling value for
raw adc reading to get solar volts  // (5/1024)*(R1+R2)/R2 // R1=100k and
R2=20k

#define BAT_VOLTS_SCALE (4.25/1023)*(120/20)        // the scaling value for
raw adc reading to get battery volts


#define PWM_PIN 9                     // the output pin for the pwm (only pin
9 avaliable for timer 1 at 50kHz)

#define PWM_ENABLE_PIN 8             // pin used to control shutoff function
of the IR2104 MOSFET driver (hight the mosfet driver is on)
```

```
#define PWM_FULL 1023                // the actual value used by the Timer1
routines for 100% pwm duty cycle

#define PWM_MAX 100                  // the value for pwm duty cyle 0-100%

#define PWM_MIN 60                  // the value for pwm duty cyle 0-100%
(below this value the current running in the system is = 0)

#define PWM_START 90                // the value for pwm duty cyle 0-100%

#define PWM_INC 1                    //the value the increment to the pwm
value for the ppt algorithm


#define TRUE 1

#define FALSE 0

#define ON TRUE

#define OFF FALSE


#define TURN_ON_MOSFETS digitalWrite(PWM_ENABLE_PIN, HIGH)      // enable
MOSFET driver

#define TURN_OFF_MOSFETS digitalWrite(PWM_ENABLE_PIN, LOW)      // disable
MOSFET driver


#define ONE_SECOND 50000            //count for number of interrupt in 1
second on interrupt period of 20us


#define LOW_SOL_WATTS 5.00          //value of solar watts // this is 5.00
watts

#define MIN_SOL_WATTS 1.00          //value of solar watts // this is 1.00
watts

#define MIN_BAT_VOLTS 11.00         //value of battery voltage // this is
11.00 volts

#define MAX_BAT_VOLTS 14.10         //value of battery voltage// this is
14.10 volts

#define BATT_FLOAT 13.60            // battery voltage we want to stop
charging at

#define HIGH_BAT_VOLTS 13.00        //value of battery voltage // this is
13.00 volts

#define LVD 11.5                    //Low voltage disconnect setting for a
12V system

#define OFF_NUM 9                   // number of iterations of off charger
state


//----------------------------------------------------------------------------
----------------------------

// Defining load control pin

#define LOAD_PIN 6       // pin-6 is used to control the load
```

```
//----------------------------------------------------------------------------
--------------------------

// Defining lcd back light pin

#define BACK_LIGHT_PIN 13      // pin-13 is used to control the lcd back
light

//----------------------------------------------------------------------------
---------------------------

/////////////////////////////////////////BIT MAP
ARRAY//////////////////////////////////////////////////

//----------------------------------------------------------------------------
----------------------------

byte solar[8] = //icon for termometer

{

  0b11111,

  0b10101,

  0b11111,

  0b10101,

  0b11111,

  0b10101,

  0b11111,

  0b00000

};


byte battery[8]=

{

  0b01110,

  0b11011,

  0b10001,

  0b10001,

  0b11111,

  0b11111,

  0b11111,

  0b11111,

};


byte _PWM [8]=

{

  0b11101,
```

```
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10111,
};
//----------------------------------------------------------------------------
-----------------------------

// global variables

float sol_amps;                       // solar amps
float sol_volts;                      // solar volts
float bat_volts;                      // battery volts
float sol_watts;                      // solar watts
float old_sol_watts = 0;              // solar watts from previous time
through ppt routine
unsigned int seconds = 0;             // seconds from timer routine
unsigned int prev_seconds = 0;        // seconds value from previous pass
unsigned int interrupt_counter = 0;   // counter for 20us interrrupt
unsigned long time = 0;               // variable to store time the back
light control button was pressed in millis
int delta = PWM_INC;                  // variable used to modify pwm duty
cycle for the ppt algorithm
int pwm = 0;                          // pwm duty cycle 0-100%
int back_light_pin_State = 0;         // variable for storing the state of
the backlight button
int load_status = 0;                  // variable for storing the load
output state (for writing to LCD)

enum charger_mode {off, on, bulk, bat_float} charger_state;    // enumerated
variable that holds state for charger state machine

LiquidCrystal lcd(12, 11, 10, 5, 4, 3, 2);

//----------------------------------------------------------------------------
----------------------------
```

```
// This routine is automatically called at powerup/reset
//---------------------------------------------------------------------------
----------------------------


void setup()                            // run once, when the sketch starts

{

  pinMode(PWM_ENABLE_PIN, OUTPUT);      // sets the digital pin as output

  Timer1.initialize(20);                // initialize timer1, and set a 20uS
period

  Timer1.pwm(PWM_PIN, 0);               // setup pwm on pin 9, 0% duty cycle

  TURN_ON_MOSFETS;                     // turn off MOSFET driver chip

  Timer1.attachInterrupt(callback);     // attaches callback() as a timer
overflow interrupt

  Serial.begin(9600);                   // open the serial port at 38400 bps:

  pwm = PWM_START;                      // starting value for pwm

  charger_state = on;                  // start with charger state as off

  pinMode(BACK_LIGHT_PIN, INPUT);       // backlight on button

  pinMode(LOAD_PIN,OUTPUT);             // output for the LOAD MOSFET (LOW =
on, HIGH = off)

  digitalWrite(LOAD_PIN,HIGH);          // default load state is OFF

  lcd.begin(20,4);                      // initialize the lcd for 16 chars 2
lines, turn on backlight

  //lcd.noBacklight();                    // turn off the backlight

  lcd.createChar(1,solar);              // turn the bitmap into a character

  lcd.createChar(2,battery);            // turn the bitmap into a character

  lcd.createChar(3,_PWM);               // turn the bitmap into a character


}


//---------------------------------------------------------------------------
----------------------------

// Main loop

//---------------------------------------------------------------------------
----------------------------

void loop()

{

  read_data();                          // read data from inputs

  run_charger();                        // run the charger state machine

  print_data();                         // print data

  load_control();                       // control the connected load
```

```
  lcd_display();                       // lcd display


}




//----------------------------------------------------------------------------
----------------------------
// This routine reads and averages the analog inputs for this system, solar
volts, solar amps and
// battery volts.
//----------------------------------------------------------------------------
----------------------------
int read_adc(int channel){


  int sum = 0;
  int temp;
  int i;


  for (i=0; i<AVG_NUM; i++) {          // loop through reading raw adc
values AVG_NUM number of times
    temp = analogRead(channel);        // read the input pin
    sum += temp;                       // store sum for averaging
    delayMicroseconds(50);             // pauses for 50 microseconds
  }
  return(sum / AVG_NUM);               // divide sum by AVG_NUM to get
average and return it
}


//----------------------------------------------------------------------------
----------------------------
// This routine reads all the analog input values for the system. Then it
multiplies them by the scale
// factor to get actual value in volts or amps.
//----------------------------------------------------------------------------
----------------------------
void read_data(void) {


  sol_amps = (read_adc(SOL_AMPS_CHAN) * SOL_AMPS_SCALE -12.01);    //input
of solar amps
  sol_volts = read_adc(SOL_VOLTS_CHAN) * SOL_VOLTS_SCALE;          //input
of solar volts
```

```
  bat_volts = read_adc(BAT_VOLTS_CHAN) * BAT_VOLTS_SCALE;          //input
of battery volts

  sol_watts = sol_amps * sol_volts ;
//calculations of solar watts

}


//----------------------------------------------------------------------------
----------------------------

// This is interrupt service routine for Timer1 that occurs every 20uS.

//

//----------------------------------------------------------------------------
----------------------------

void callback()

{

  if (interrupt_counter++ > ONE_SECOND) {        // increment
interrupt_counter until one second has passed

    interrupt_counter = 0;                       // reset the counter

    seconds++;                                   // then increment seconds
counter

  }

}


//----------------------------------------------------------------------------
----------------------------

// This routine uses the Timer1.pwm function to set the pwm duty cycle.

//----------------------------------------------------------------------------
----------------------------

void set_pwm_duty(void) {


  if (pwm > PWM_MAX) {                                         // check limits of
PWM duty cyle and set to PWM_MAX

    pwm = PWM_MAX;

  }

  else if (pwm < PWM_MIN) {                                    // if pwm is less
than PWM_MIN then set it to PWM_MIN

    pwm = PWM_MIN;

  }

  if (pwm < PWM_MAX) {

    Timer1.pwm(PWM_PIN,(PWM_FULL * (long)pwm / 100), 20);  // use Timer1
routine to set pwm duty cycle at 20uS period

    //Timer1.pwm(PWM_PIN,(PWM_FULL * (long)pwm / 100));
```

```
  }

  else if (pwm == PWM_MAX) {                            // if pwm set to
100% it will be on full but we have
    Timer1.pwm(PWM_PIN,(PWM_FULL - 1), 20);               // keep switching
so set duty cycle at 99.9%
    //Timer1.pwm(PWM_PIN,(PWM_FULL - 1));
  }

}

//----------------------------------------------------------------------------
----------------------------
//  The charger state machine
//----------------------------------------------------------------------------
----------------------------
void run_charger(void) {

  static int off_count = OFF_NUM;

  switch (charger_state) {
    case on:
      if (sol_watts < MIN_SOL_WATTS) {                      // if watts
input from the solar panel is less than
        charger_state = off;                                // the minimum
solar watts then
        off_count = OFF_NUM;                                // go to the
charger off state
        TURN_OFF_MOSFETS;
      }
      else if (bat_volts > (BATT_FLOAT - 0.1)) {            // else if the
battery voltage has gotten above the float
        charger_state = bat_float;                          // battery float
voltage go to the charger battery float state
      }
      else if (sol_watts < LOW_SOL_WATTS) {                 // else if the
solar input watts is less than low solar watts
        pwm = PWM_MAX;                                      // it means
there is not much power being generated by the solar panel
        set_pwm_duty();                                     // so we just
set the pwm = 100% so we can get as much of this power as possible
      }                                                     // and stay in
the charger on state
```

```
      else {
        pwm = ((bat_volts * 10) / (sol_volts / 10)) + 5;    // else if we
are making more power than low solar watts figure out what the pwm
        charger_state = bulk;                               // value should
be and change the charger to bulk state
      }
      break;
    case bulk:
      if (sol_watts < MIN_SOL_WATTS) {                      // if watts
input from the solar panel is less than
        charger_state = off;                                // the minimum
solar watts then it is getting dark so
        off_count = OFF_NUM;                                // go to the
charger off state
        TURN_OFF_MOSFETS;
      }
      else if (bat_volts > BATT_FLOAT) {                 // else if the
battery voltage has gotten above the float
        charger_state = bat_float;                          // battery float
voltage go to the charger battery float state
      }
      else if (sol_watts < LOW_SOL_WATTS) {                 // else if the
solar input watts is less than low solar watts
        charger_state = on;                                 // it means
there is not much power being generated by the solar panel
        TURN_ON_MOSFETS;                                    // so go to
charger on state
      }
      else {                                                // this is where
we do the Peak Power Tracking ro Maximum Power Point algorithm
        if (old_sol_watts >= sol_watts) {                   // if previous
watts are greater change the value of
          delta = -delta;                           // delta to make pwm
increase or decrease to maximize watts
        }
        pwm += delta;                                       // add delta to
change PWM duty cycle for PPT algorythm (compound addition)
        old_sol_watts = sol_watts;                          // load
old_watts with current watts value for next time
        set_pwm_duty();                                   // set pwm duty
cycle to pwm value
      }
      break;
```

```
    case bat_float:

      if (sol_watts < MIN_SOL_WATTS) {                          // if watts
input from the solar panel is less than
        charger_state = off;                                    // the minimum
solar watts then it is getting dark so
        off_count = OFF_NUM;                                    // go to the
charger off state
        TURN_OFF_MOSFETS;
        set_pwm_duty();
      }
      else if (bat_volts > BATT_FLOAT) {                        // If we've
charged the battery abovethe float voltage
        TURN_OFF_MOSFETS;                                       // turn off
MOSFETs instead of modiflying duty cycle
        pwm = PWM_MAX;                                          // the charger
is less efficient at 99% duty cycle
        set_pwm_duty();                                         // write the PWM
      }
      else if (bat_volts < BATT_FLOAT) {                        // else if the
battery voltage is less than the float voltage - 0.1
        pwm = PWM_MAX;
        set_pwm_duty();                                           // start
charging again
        TURN_ON_MOSFETS;
        if (bat_volts < (BATT_FLOAT - 0.1)) {                   // if the
voltage drops because of added load,
        charger_state = bulk;                                   // switch back
into bulk state to keep the voltage up
        }
      }
      break;
    case off:                                                   // when we jump
into the charger off state, off_count is set with OFF_NUM
      TURN_OFF_MOSFETS;
      if (off_count > 0) {                                      // this means
that we run through the off state OFF_NUM of times with out doing
        off_count--;                                            // anything,
this is to allow the battery voltage to settle down to see if the
      }                                                         // battery has
been disconnected
      else if ((bat_volts > BATT_FLOAT) && (sol_volts > bat_volts)) {
```

```
        charger_state = bat_float;                          // if battery
voltage is still high and solar volts are high
      }
      else if ((bat_volts > MIN_BAT_VOLTS) && (bat_volts < BATT_FLOAT) &&
(sol_volts > bat_volts)) {
        charger_state = bulk;
      }
      break;
    default:
      TURN_OFF_MOSFETS;
      break;
  }
}

//----------------------------------------------------------------------------
--------------------------------------------
/////////////////////////////////////////////LOAD
CONTROL/////////////////////////////////////////////////////
//----------------------------------------------------------------------------
--------------------------------------------

void load_control(){
  if ((sol_watts < MIN_SOL_WATTS) && (bat_volts > LVD)){   // If the panel
isn't producing, it's probably night
    digitalWrite(LOAD_PIN, LOW);                           // turn the load
on
    load_status = 1;                                       // record that
the load is on
  }
  else{                                                    // If the panel
is producing, it's day time
    digitalWrite(LOAD_PIN, HIGH);                          // turn the load
off
    load_status = 0;                                       // record that
the load is off
  }
}

//----------------------------------------------------------------------------
----------------------------
// This routine prints all the data out to the serial port.
```

```
//------------------------------------------------------------------------
----------------------------
void print_data(void) {

  Serial.print(seconds,DEC);
  Serial.print("      ");

  Serial.print("Charging = ");
  if (charger_state == on) Serial.print("on   ");
  else if (charger_state == off) Serial.print("off  ");
  else if (charger_state == bulk) Serial.print("bulk ");
  else if (charger_state == bat_float) Serial.print("float");
  Serial.print("      ");

  Serial.print("pwm = ");
  Serial.print(pwm,DEC);
  Serial.print("      ");

  Serial.print("Current (panel) = ");
  Serial.print(sol_amps);
  Serial.print("      ");

  Serial.print("Voltage (panel) = ");
  Serial.print(sol_volts);
  Serial.print("      ");

  Serial.print("Power (panel) = ");
  Serial.print(sol_volts);
  Serial.print("      ");

  Serial.print("Battery Voltage = ");
  Serial.print(bat_volts);
  Serial.print("      ");

  Serial.print("\n\r");
  //delay(1000);
}
```

```
//----------------------------------------------------------------------------
-----------------------

//---------------------------------Led Indication---------------------------
-----------------------

//----------------------------------------------------------------------------
-----------------------


/*void led_output(void)

{

  if(bat_volts > 14.1 )

  {

      leds_off_all();

      digitalWrite(LED_YELLOW, HIGH);

  }

  else if(bat_volts > 11.9 && bat_volts < 14.1)

  {

      leds_off_all();

      digitalWrite(LED_GREEN, HIGH);

  }

  else if(bat_volts < 11.8)

  {

      leds_off_all;

      digitalWrite(LED_RED, HIGH);

  }


}*/


//----------------------------------------------------------------------------
----------------------------

//

// This function is used to turn all the leds off

//

//----------------------------------------------------------------------------
----------------------------

/*void leds_off_all(void)

{

  digitalWrite(LED_GREEN, LOW);

  digitalWrite(LED_RED, LOW);
```

```
  digitalWrite(LED_YELLOW, LOW);
}*/


//---------------------------------------------------------------------------
---------------------------
//-------------------------- LCD DISPLAY -----------------------------------
--------------------------
//---------------------------------------------------------------------------
----------------------------
void lcd_display()
{
 /* back_light_pin_State = digitalRead(BACK_LIGHT_PIN);
  if (back_light_pin_State == HIGH)
  {
    time = millis();                        // If any of the buttons are
pressed, save the time in millis to "time"
  }*/


 lcd.setCursor(0, 0);
 lcd.print("SOL");
 lcd.setCursor(4, 0);
 lcd.write(1);
 lcd.setCursor(0, 1);
 lcd.print(sol_volts);
 lcd.print("V");
 lcd.setCursor(0, 2);
 lcd.print(sol_amps);
 lcd.print("A");
 lcd.setCursor(0, 3);
 lcd.print(sol_watts);
 lcd.print("W ");
 lcd.setCursor(8, 0);
 lcd.print("BAT");
 lcd.setCursor(12, 0);
 lcd.write(2);
 lcd.setCursor(8, 1);
 lcd.print(bat_volts);
 lcd.setCursor(8,2);
```

```
if (charger_state == on)
{
lcd.print("     ");
lcd.setCursor(8,2);
lcd.print("on");
}
else if (charger_state == off)
{
lcd.print("     ");
lcd.setCursor(8,2);
lcd.print("off");
}
else if (charger_state == bulk)
{
lcd.print("     ");
lcd.setCursor(8,2);
lcd.print("bulk");
}
else if (charger_state == bat_float)
{
lcd.print("     ");
lcd.setCursor(8,2);
lcd.print("float");
}

//------------------------------------------------------------
//--------------------Battery State Of Charge ---------------
//------------------------------------------------------------
lcd.setCursor(8,3);
if ( bat_volts >= 12.7)
lcd.print( "100%");
else if (bat_volts >= 12.5 && bat_volts < 12.7)
lcd.print( "90%");
else if (bat_volts >= 12.42 && bat_volts < 12.5)
lcd.print( "80%");
else if (bat_volts >= 12.32 && bat_volts < 12.42)
```

```
 lcd.print( "70%");
 else if (bat_volts >= 12.2 && bat_volts < 12.32)
 lcd.print( "60%");
 else if (bat_volts >= 12.06 && bat_volts < 12.2)
 lcd.print( "50%");
 else if (bat_volts >= 11.90 && bat_volts < 12.06)
 lcd.print( "40%");
 else if (bat_volts >= 11.75 && bat_volts < 11.90)
 lcd.print( "30%");
 else if (bat_volts >= 11.58 && bat_volts < 11.75)
 lcd.print( "20%");
 else if (bat_volts >= 11.31 && bat_volts < 11.58)
 lcd.print( "10%");
 else if (bat_volts < 11.3)
 lcd.print( "0%");

//----------------------------------------------------------------------
//------------------Duty Cycle-----------------------------------------
//----------------------------------------------------------------------
 lcd.setCursor(15,0);
 lcd.print("PWM");
 lcd.setCursor(19,0);
 lcd.write(3);
 lcd.setCursor(15,1);
 lcd.print("   ");
 lcd.setCursor(15,1);
 lcd.print(pwm);
 lcd.print("%");
 //----------------------------------------------------------------------
 //------------------------Load Status-----------------------------------
 //----------------------------------------------------------------------
 lcd.setCursor(15,2);
 lcd.print("Load");
 lcd.setCursor(15,3);
 if (load_status == 1)
 {
   lcd.print("   ");
```

```
    lcd.setCursor(15,3);
    lcd.print("On");
 }
 else
 {
   lcd.print("   ");
   lcd.setCursor(15,3);
   lcd.print("Off");
 }
 //backLight_timer();                      // call the backlight timer
function in every loop
}


/*void backLight_timer(){
  if((millis() - time) <= 15000)         // if it's been less than the 15
secs, turn the backlight on
      lcd.backlight();                   // finish with backlight on
  else
      lcd.noBacklight();                 // if it's been more than 15 secs,
turn the backlight off
}*/
```