MPPT CONTROL

Of

STANDALONE -PV SYSTEM

With

BATTERY as an ENERGY STORAGE ELEMENT

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CERTIFICATE

This is to certify that the thesis entitled "**MPPT Control of Standalone-PV System with Battery as an Energy Storage Element**", submitted by Anamika Sinha (Roll. No. 111EE0235) and Swastik Sambit Sahu (Roll. No. 111EE0231) in partial fulfillment of the requirements for the award of Bachelor of Technology in Electrical Engineering in the session 2014-2015 at National Institute of Technology, Rourkela is a bonafide record of research work carried out by them under my supervision and guidance. The candidates have fulfilled all the prescribed requirements. The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma. In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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ABSTRACT

In this thesis the main focus is on using MPPT control of standalone-PV system with battery to supply power to the loads. This implies battery is an energy storage element and it can be used as a power source when PV is insufficient for the same. The system comprises of a battery, PV panel and a boost converter circuit. The project consists of both software and hardware design. The boost converter tracks the maximum power point (MPP) of the PV panel by controlling the duty cycle and then it is given as a gate pulse to the boost converter. The function of battery is to maintain a constant dc-link voltage. Perturbation and observation method is used as MPPT (Maximum Power Point Tracking) control algorithm. MATLAB SIMULINK is used to create a simulation model of the Standalone-PV system and then the output is verified. For implementation of MPPT in hardware, a microcontroller is needed which is a part of bigger circuit, that is solar charge controller. Solar charge controller is the heart of hardware circuit. After verification of simulation, the whole set up is designed in hardware and it is tested to run according to the desired parameters.

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1. INTRODUCTION

Standalone-PV systems are generally used for isolated loads or household purposes [1]. The increase in power demand in the utility side with less harmonics and fluctuation are the major issues .The conventional sources of energy have the probability to last for limited time but renewable sources of energy like solar energy is infinite and also eco-friendly. With the increased efficiency of power electronics devices we can use this solar energy to provide the power to the consumers. The only flaw of solar energy is that the set-up required is quite expensive. The output power of PV depends on many criteria's like insolation and temperature. With variation in these two parameters the output is also varied, which will thereby lead to fluctuation in the utility side, which is totally undesirable. So it is important to have a control which will make our SOLAR-PANEL's output totally independent of weather conditions. Currently there are many algorithms like incremental inductance, perturbation and observation, fuzzy logic etc. [2]-[7]. In this project we totally concentrate on the method of PERTURBATION and OBSERVATION. This algorithm controls the duty cycle of boost converter and it is given as gate pulse to the converter then. The battery used here is like an energy storage element. It not only maintains dc link voltage across the capacitor constant but also supplies to the load during bad weather conditions when PV is unable to generate the power required by the load. A standalone PV system has many practical applications. For household purposes it can be used for any type of loads -- linear or nonlinear. The simulation results and the hardware design shows that STANDLONE-PV system can be efficiently used for isolated loads.

1.1 Requirement of Renewable Energy

Renewable energy is the energy which can be naturally replenished. It is derived from natural resources such as sunlight, wind, tides, waves, biomass and geothermal heat. Such resources are inexhaustible unlike fossil fuels which are getting exhausted at an alarming rate. REN21's 2014 report states that contribution of renewable energy sources was 19 percent in energy consumption and 22 percent in electricity generation.

Organisations all over the globe are adopting Clean Development Mechanisms (CDMs). Fossil fuels cause pollution too which has an adverse effect on the atmosphere. Renewable energy sources however do not cause any emissions, which results in clean energy; one that is not associated with effects of pollution.

Renewable energy is being rapidly adopted by countries which has resulted in significant energy security and limiting magnitude of long term climate changes mitigating deterioration of environment.

Market for renewable energy technologies has been growing at a steady rate and projects based on renewable energy being undertaken by developing countries also help in poverty reduction. Renewable energy technologies are getting cheaper because of mass production and market competition as well as mass acceptance.

1.2 Types of Renewable Energy

There are different types of renewable energy resources such as

1. Solar energy
2. Wind energy
3. Hydro energy
4. Geothermal energy
5. Biomass

1.2.1 Solar energy

Solar energy is an important source of renewable energy. It is harnessed as heat and radiant light from the sun. Solar thermal energy, used in space heating can be harnessed from solar energy. Solar energy can also be converted to electrical energy which then can be used in a wide variety of applications. Even though it has an additional cost of initial installation, the long term benefits are rewarding.

Implementation of solar energy is the huge step in mitigation of global warming. Solar energy in particular has accelerated in its adoption by countries as a source of energy generation. It is increasingly being adopted in order to balance climate changes.

1.2.2 Wind energy

Wind power is extracted from air flow by using wind turbines. Kinetic energy in the wind can be converted into mechanical power which can then be converted into electrical energy. Wind turbines are used to harness wind energy. Power output of a wind turbine is directly proportional to cube of wind velocity.

Large wind farms hold hundreds of wind turbines which are then connected to the electrical network. Wind power, somewhat reliable, is usually used in conjunction with other sources to give uninterrupted supply. Wind energy is clean, widely distributed and pollution free.

1.2.3 Hydropower

Hydropower is a form of renewable energy contained in flowing water that can be captured and turned into electricity. Hydropower is increasingly used in the field of irrigation. Water turbines convert the potential energy of water into electrical energy which is then used. Up to 10MW, hydropower installations are considered as renewable energy sources.

Hydroelectricity is generated by water; production of electrical power by using gravitational force of water. The cost of hydroelectricity is comparatively low. It is conventionally produced from dams, but can also be produced from tides and reservoirs.

1.2.4 Geothermal energy

Geothermal energy, a form of renewable energy is the thermal energy stored in the layers of the Earth. There is a conduction of heat from the core to the surface of the earth due to temperature difference. The heat is utilized to yield highly heated steam using it to run steam turbines to produce electricity.

It is cost effective, sustainable, renewable, ecologically non-damaging and reliable form of energy.

1.2.5 Biomass

Biomass is derived from plants and plant based materials and is a form of renewable energy source. Biomass acts as a natural form of battery storing sun’s energy and yielding it whenever required. Wood is the largest biomass energy source. Biomass is used for electricity generation.

1.3 Recent Trends in Renewable Energy

Currently renewable energy resources are being adopted at a steady rate. Renewable energy has provided an estimated 19 % of the total energy consumption of the world in the year of 2012 and has only grown since. Solar PV has expanded at a rapid rate with a growth capacity of 55% annually for the past 4-5 years. However it is to be noted that the use of renewable resources is still limited in comparison to the vast potential that they hold.

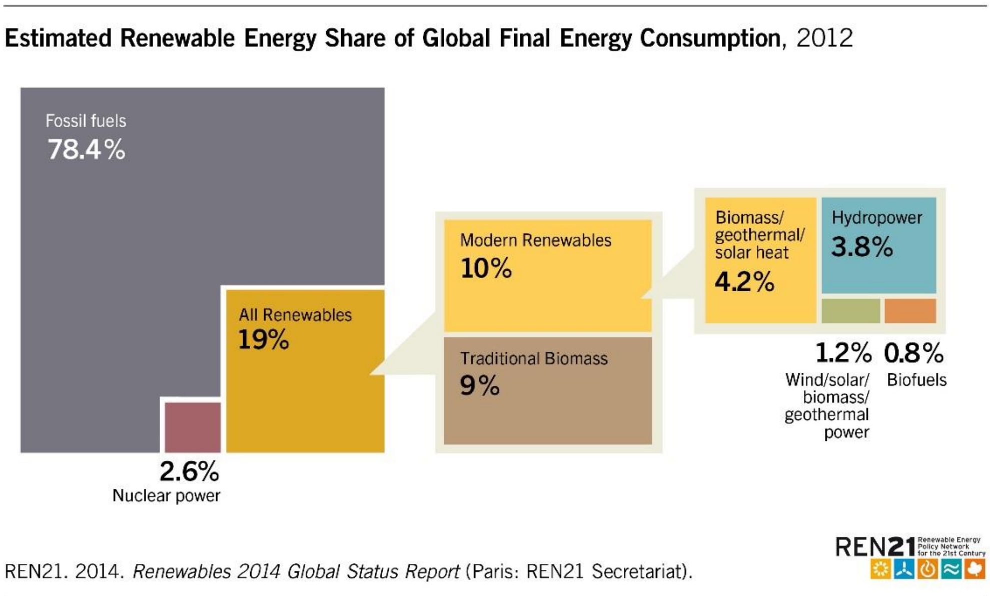


Fig.1- Estimated Renewable energy share of global final energy consumption in 2012

Fig.1 shows the percentage of energy share shared by different types of energy sources. Renewable energy sources account for 19 % of total energy share.

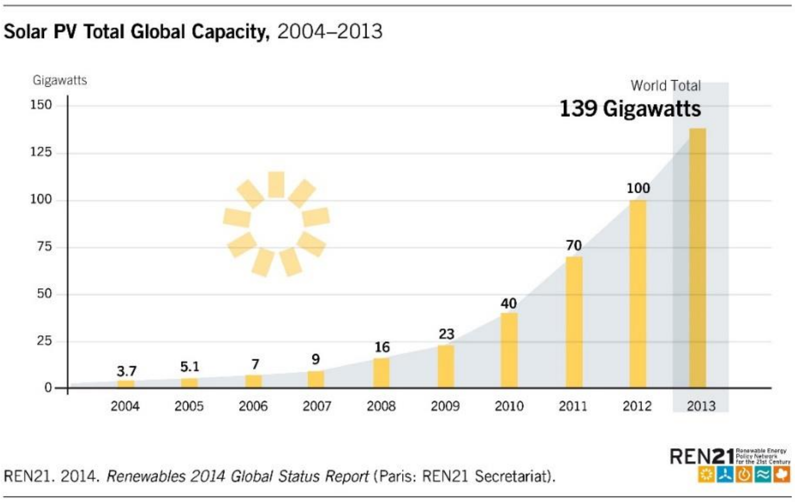


Fig.2- Solar PV total capacity, 2004-2013

Fig. 2 shows the growth of PV capacity over the period 2004-2013 from 3.7 gigawatts to 139 gigawatts

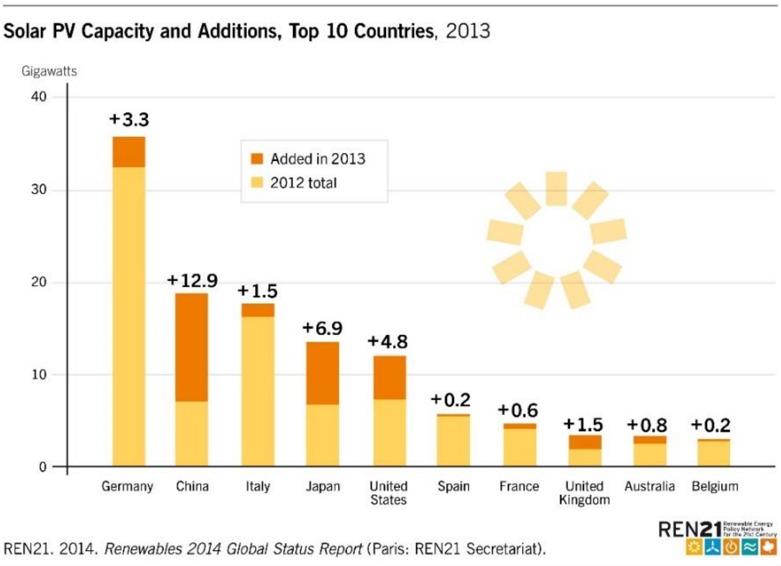


Fig.3- Solar PV capacity and additions, Top 10 countries, 2013

Fig.3 shows the growth of PV capacity in year 2013 for top ten countries w.r.t to year 2012.

1.4 Solar Cell

A solar cell is an electrical device which converts incident light rays into electricity on the basis of photovoltaic effect. Solar cells are used in building solar panels. Solar cells are considered as photovoltaic even though the incident light may be sunlight or an artificial source.

Solar modules are made of semiconductor material. Silicon crystals are the mostly used semiconductor crystal. Manufacturing of solar cells is done by the help of high purity silicon. Using melt and cast method silicon crystals are processed into cells and then the cast is sliced into wafers from the ingots.

PV cell absorbs incident sunlight and creates electron hole pairs. Then separation of charge carriers takes place and the carriers are separately extracted to external circuit.

A solar array generates solar power on the principle of photovoltaic effect. Solar cells can be connected in series or in parallel decided by the voltage and current requirements. The photovoltaic modules have a sheet of glass on the side that faces the sun so as to protect the wafers even while allowing light to pass through.

The electrical energy produced from a solar panel is DC and can be used for DC loads or stored in a battery to be used later. For homes that are connected to a utility grid, inverters can be used to convert the DC to AC thereby running AC loads.

Modules can be connected or stringed together to make an array with a specific DC voltage and current capacity, but MPPTs are preferred in order to obtain a higher value of efficiency.

1.5 Types of PV Panels

PV is not only used as standalone-systems but also in microgrids [8]. PV panels can be differentiated on the basis of their efficiency and the amount of space taken by them, i.e. installation size.

There are different types of PV panels available in the market such as

1. Monocrystalline Panels
2. Polycrystalline Panels
3. Hybrid Panels

1.5.1 Monocrystalline Panels

In this type, the cells are aligned in a particular direction, which means when the sun is incident on the cells at the correct angle; they exhibit high efficiency and work best when sun directly shining on them.

1.5.2 Polycrystalline Panels

In these panels, the individual crystals are not all perfectly aligned together which reduces their efficiency as compared to monocrystalline panel. However, this misalignment can be a benefitting factor because the cells work better even when light is incident from other angles.

1.5.3 Hybrid Panels

The extra amorphous layer behind the monocrystalline cells is able to extract more energy from the incident sunlight, especially under low light conditions. They have the highest efficiency and take up less space. These, however are more expensive than monocrystalline and polycrystalline panels.

2. LITERATURE SURVEY

PV system is one of the fuming topics in the research. Many advance level works have been done. PV has been used to supply to the grid without any energy source or even with energy source [9]. In this case bidirectional is used as we need power flow in both directions, from PV to the grid and even from the grid to the PV.

Many PV's are connected in parallel in the form of generators to supply to the load. This paper proposes a fuzzy-based frequency control method for the Photovoltaic generator in a PV–diesel hybrid system without smoothing of PV output power fluctuations [10].

In one of the papers control strategy has been proposed for the distribution network [11]. It is possible that faults (both temporary and permanent faults) or even transient disturbance can occur . At that time a control mechanism is required so that PV output does not have any effect. This paper describes the mechanism.

Another paper elaborates power control design of a battery charger for load following applications in a Hybrid Active PV generator [12].

3. SOLAR CELL MODELLING

An ideal solar cell can be modelled as a current source parallel connected across a diode.

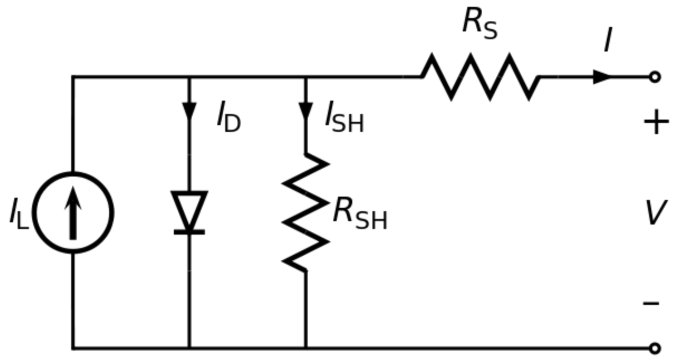


Fig.4 - Circuit diagram of PV cell

The current- voltage characteristic equation of a solar cell referred to in Fig.4 is given as-

$$I = n_p I_{ph} - n_p I_{sc}\left[e^{\left(\left(\frac{q}{AkT}\right)\left(\frac{V}{n_s + IR_S}\right)\right)} - 1 \right] \longrightarrow \quad (1)$$

The photocurrent depends on the solar insulation and cell's working temperature, is given as-

$$I_{ph} = \left[\left(I_{scc} + k_i \left(T - T_r \right) \right) \times \frac{S}{1000} \right] \longrightarrow \quad (2)$$

The cell's saturation current changes with the cell temperature and is given as

$$I_{sc} = I_{rsc} \left(\frac{T}{T_r} \right)^3 e^{\left(\frac{qE_{gap}}{kA}\right)\left(\frac{1}{T_r} - \frac{1}{T}\right)} \longrightarrow \quad (3)$$

Where I = output current

V =voltage of the PV array

Np = number of cells connected in parallel

Ns = number of cells connected in series

S =solar irradiation level

T = temperature

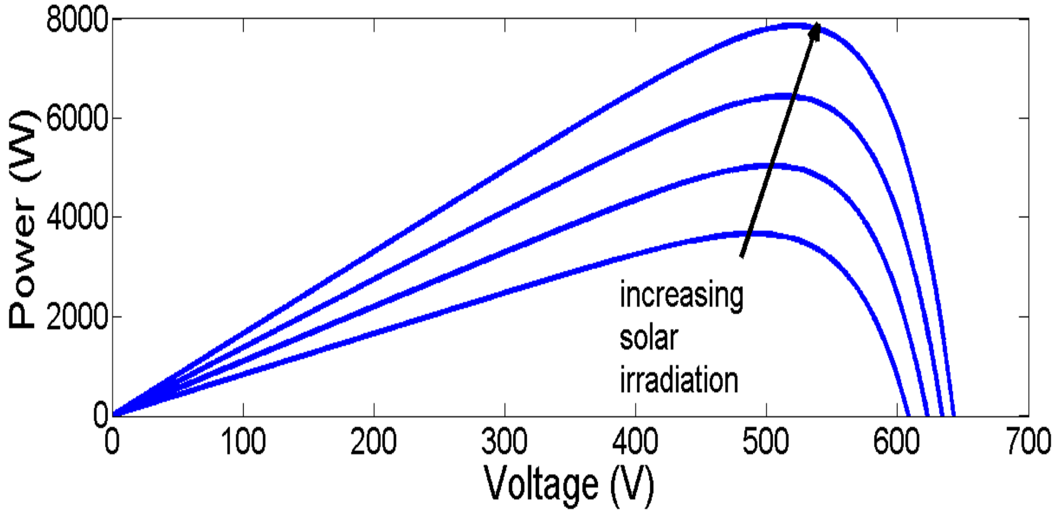


Fig.5- Power vs. Voltage graph of PV panel

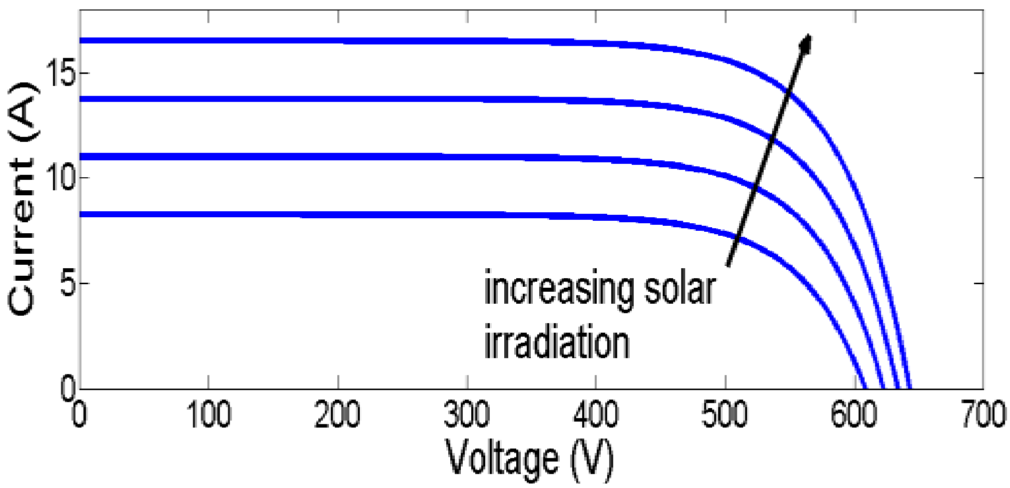


Fig.6- Current vs. Voltage graph of PV panel

The output characteristics of PV System is non-linear and it changes with INSOLATION and TEMPERATURE. When these two factors vary, MPP point varies accordingly. With increase in insolation the MPP shifts to right as shown in Fig.5. For higher magnitude of voltage we get the maximum power. In Fig.6 Current Vs Voltage graph is shown. With increase in insolation the MPP voltage increases and thereby the maximum current also increases. For the insolation level above $300W/m^2$ the MPP is almost constant.

TABLE 1:

Table 1 shows the different parameters of PV cell along with their symbols and values .

Symbol	Description	Value
Iph	Photocurrent	
Isc	Module reverse saturation current	
q	Electron charge	*1.602 × 10−19 C*
A	Ideality factor	*1.60*
k	Boltzman constant	*1.38 × 10−23 J/K*
Rs	Small series resistance	
Iscc	Short-circuit current	*3.27 A*
ki	Short-circuit current temperature coefficient	*1.7e-3*
Tr	Reference temperature of the solar cell	*301.19 K*
Irsc	*Tr* Reverse saturation current	*2.079e-6 A*
Egap	Silicon Bandgap energy	1.1*eV*
np	No. of cells connected in parallel	
ns	No. of series connected cells	
S	Solar radiation	*0~1000 W/m2*
T	PV module Surface temperature	*400 K*

4. MAXIMUM POWER POINT TRACKING (MPPT)

Normally a solar panel is able to convert only 30-40% of the total incident solar irradiation into electrical energy. Maximum Power Point Tracking (MPPT) is used to improve the efficiency of a particular solar panel.

Maximum Power Point Tracking (MPPT) is an algorithm that is used to extract maximum power from PV under specific conditions. Maximum power of a PV panel depends on factors such as solar irradiation, ambient temperature and cell temperature.

Normally a PV module produces maximum power voltage at cell temperature of 25°C. However depending on outside temperature it can fall or rise.

MPPT checks the output of a particular PV panel and after comparing it with battery voltage decides the most efficient voltage i.e. maximum power point voltage.

The purpose of a MPPT system is applying proper resistance after sampling output of PV cell in order to obtain maximum power.

MPPT is most effective in cooler conditions because PV module works better at cold temperatures. It is also very effective when the battery is deeply discharged because more current can be extracted under low charge conditions.

MPPT devices are integrated with power electronics creating an electric power converter system in form of solar inverters which convert DC power to AC power.

4.1 **MPPT Techniques**

There are different techniques used to track the maximum power point such as:

1. Perturb and observe (hill climbing method)
2. Incremental Conductance method
3. Current sweep
4. Constant voltage
5. Fuzzy Logic Control
6. Neural network

4.1.1 Perturb and observe (hill climbing method)

Perturb and observe is one of the simplest methods due to its lower value of time complexity. This method uses one voltage sensor which senses the PV voltage and measures power. If power increases, the algorithm is designed to achieve constant power. However, this method can result in oscillations of power output because the algorithm continues to perturb recursively even after reaching MPP. This can be solve by setting an error limit to end the recursion.

It is easy to implement and is known as hill climbing method because it depends on the rise and fall of power vs. voltage curve with respect to maximum power point.

4.1.2 Incremental conductance

In this particular method, the controller measures incremental changes in voltage and current in the incremental conductance method. Even though it takes more number of computations it is better at tracking changes than perturb and observe method.

Maximum power point is calculated by comparing incremental conductance (I_Δ / V_Δ) with PV array conductance (I / V). The output voltage is the voltage at which both ratios, i.e. conductance are same. The voltage is maintained till there are changes in irradiation levels upon which the process is repeated.

Here both voltage and current are sensed simultaneously, therefore change due to irradiance does not cause in error. This method however is more complicated than perturb and observe method.

4.1.3 Current sweep

This method helps in obtaining I-V characteristics by using a sweep waveform of the PV array current which is updated at fixed intervals of time. MPP is calculated from the curve at the same intervals of time.

4.1.4 Constant voltage

In this method the operating point of PV array is maintained near Maximum Power Point. The PV array voltage is matched to a fixed reference voltage which is chosen to give optimal performance.

4.1.5 Fuzzy Logic Control

Fuzzy logic is also used for implementing MPPT by the use of microcontrollers. Fuzzy logic controllers are not restricted with the need of accurate models. They have a distinct advantage of handling non linearity and imprecise inputs and have a fast rate of convergence.

A fuzzy control system operates on the principle of fuzzy logic. It studies analog input values in context of logical variables having continuous values between zero and one.

4.1.6 Neural Network

Neural networks are also used for implementing MPPT and they are also suitable for microcontrollers. They are a family of statistical learning algorithms used in estimation of approximate functions. They have three layers: input, output and hidden layers which have user dependent nodes whose number can be changed.

Input variables such as open circuit voltage and short circuit current; temperature and solar irradiation can be used to find outputs such as duty cycle signal which in turn can be used to find maximum power point and make the converter operate around the point.

TABLE 2:

Table 2 shows the different MPPT methods and compares their convergence speed and efficiency.

MPPT method	Type	Complexity	Digital or analog	Convergence speed	Sensed parameters	Prior training	Efficiency
Open circuit voltage	Offline	Low	Both	Medium	Voltage	Yes	Low (=86%)
Short circuit current	Offline	Medium	Both	Medium	current	Yes	Low (=89%)
Artificial neural networks	Offline	High	Digital	Fast	Depends	Yes	High (=98%)
Fuzzy logic	Offline	High	Digital	Fast	Depends	Yes	High
P&O (fixed perturbation size)	Online	Low	Both	Low	Voltage and current	No	Low
P&O (variable perturbation size)	Online	Medium	Digital	Fast	Voltage and current	No	High (=96%)
ESC	Online	Medium	Both	Fast	Voltage and current	No	High (=97%)
IncCond	Online	Medium	Digital	Depends	Voltage and current	No	High

4.2 Algorithm of Perturbation and Observation

NOTE: The change of duty cycle has to be done in the direction of MPP.

- STEP-1:

Initialize initial value, maximum value, minimum value of duty cycle and also the increment value to increase/decrease the duty cycle.

- STEP-2:

If rate of change in power and rate of change in voltage both are negative, then duty cycle has to be decreased else if rate of change in voltage is positive, then duty cycle has to be increased.

- STEP-3:

If rate of change in power is positive but rate of change in voltage is negative, then duty cycle has to be increased else if rate of change in voltage is positive, duty cycle has to be decreased.

- STEP-4:

If the duty cycle value exceeds the maximum initialized value or is lesser than the minimum initialized value, then the duty cycle value must not be changed and it must be same as the previous value.

- STEP-5:

The first four steps should be repeated that means should be in for or while loop until Maximum Power point is reached.

5. WORK DONE

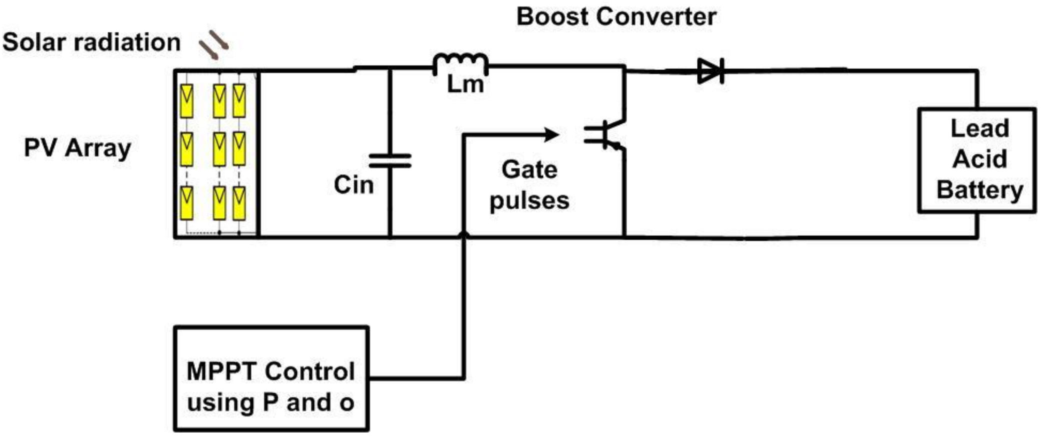


Fig.7-The Complete Setup

Fig.7 shows the whole set up of our SIMULATION/HARDWARE .It comprises PV panel, boost-converter and battery (as the energy storage element).Capacitor Cin is to reduce the ripples in MPP voltage. It should be smaller in magnitude otherwise more time will be consumed to obtain MPP.

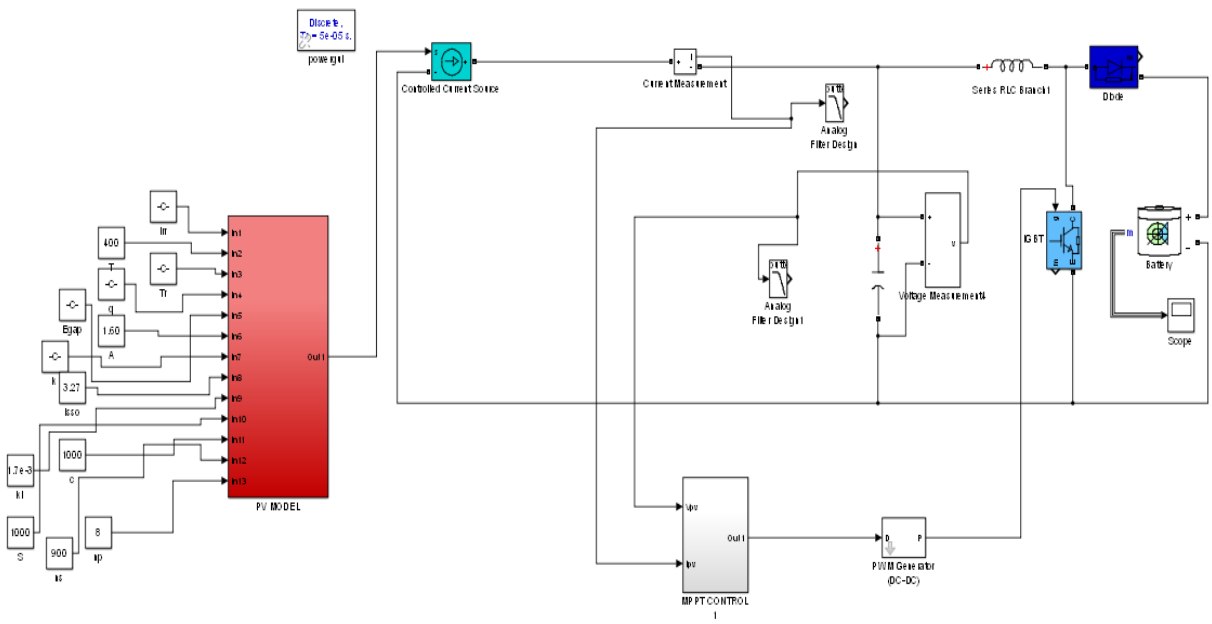


Fig.8- MATLAB Simulink file

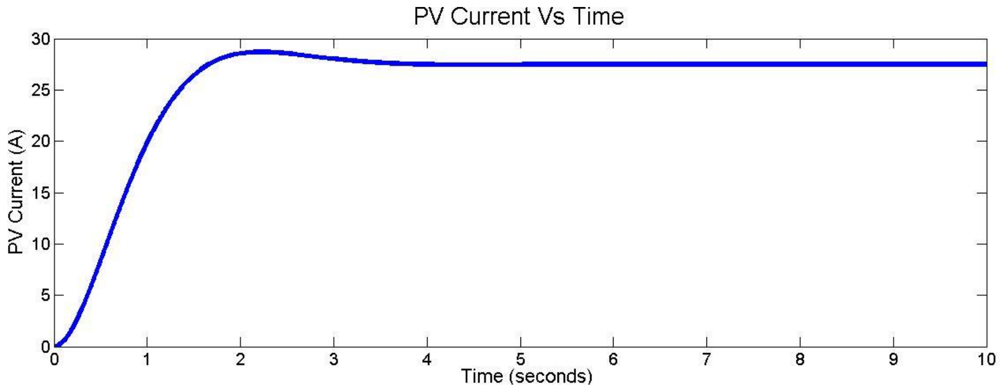


Fig.9 -PV Current vs. Time

Fig.9 represents output current of PV panel after doing a MPP control. Total number of cells taken in simulation are 900 cells in series and 8 cells in parallel. The current first increases but after reaching the MPP voltage it becomes constant.

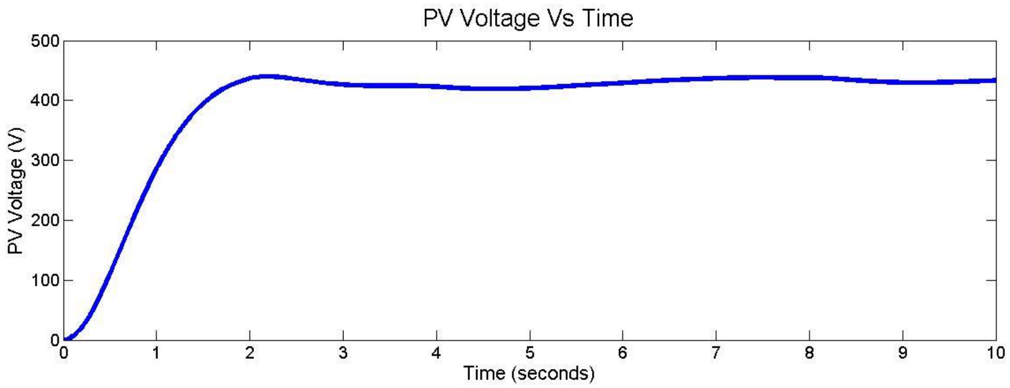


Fig.10 -PV Voltage vs. Time

Fig.10 represents the output voltage of PV panel after doing a MPP control. It is also maintained at MPP which is 450 V for the cell configuration which we have taken here.

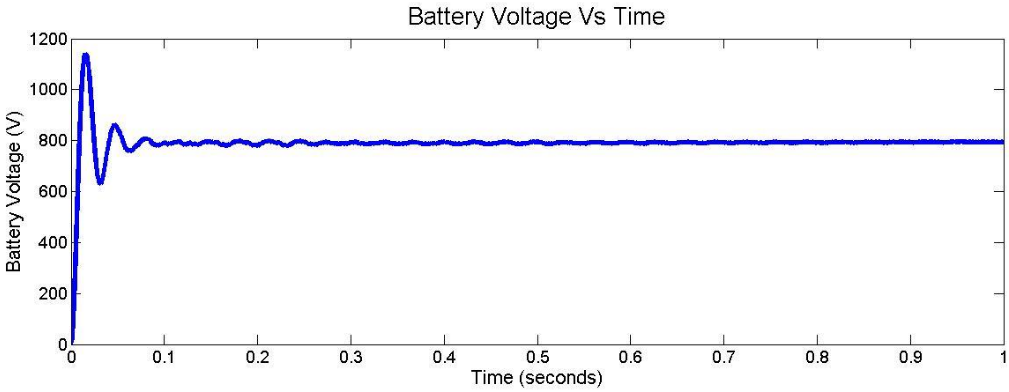


Fig.11- Battery voltage vs. Time

Fig.11 represents battery voltage Vs time . If battery is charging more current is drawn from PV and if it is discharging, less amount of current will be drawn.

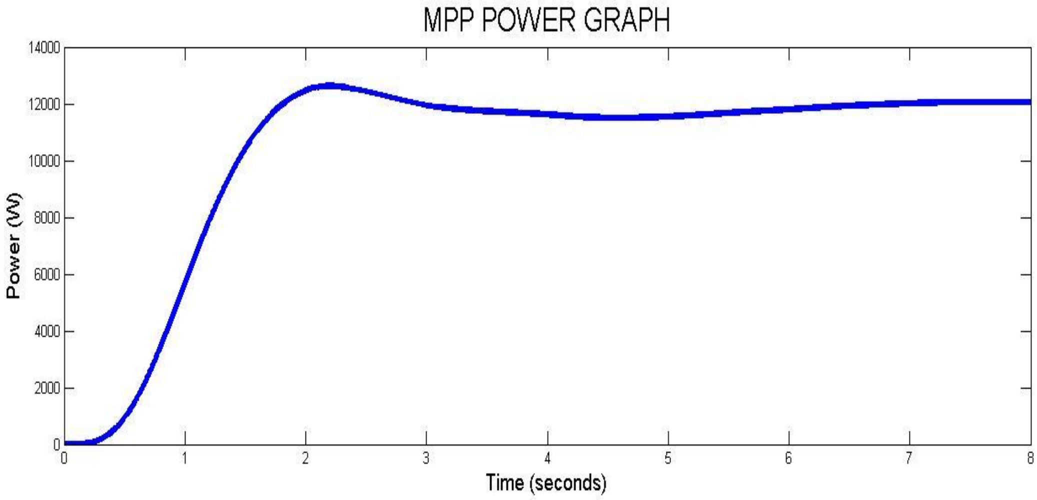


Fig.12-MPP Graph-Power vs. Time

Fig.12 is the MAXIMUM POWER graph. It shows that once MPP is reached there will be certain perturbation as actual P-V curve will tend to decrease from MPP so then the algorithm will take its action and once perturbation occurs it will not allow further decrease of power and the output power will remain constant. This totally depends on algorithm. The more effective the algorithm is the better the output will be. The algorithm must be written in such a way that if the obtained power is less than MPP, we should proceed in direction of MPP. Once MPP is reached perturbation will occur then after that no more changes have to be done in the code; the obtained power has to be maintained. Here MPP power is 12000 W.

6. HARDWARE IMPLEMENTATION

TABLE 3: Table 3 shows the hardware components used in the hardware of project.

Components used	Type
1 PV Panel	100 W, 5A(short circuit current), 21.5V (open circuit voltage), 17V (MPP voltage)
MICROCONTROLLER	ATMEGA-328
Current Sensor	ACS712-5A
LCD display	20x4 I2C
MOSFETs	3x IRFZ44N
MOSFET driver	IR2104
3.3V Linear regulator	AMS 1117
Diodes	2x IN4148 , 1 x UF4007
TVS diode	2x P6KE36CA
Resistors	3x 200R ,3 x330R,1 x 1K, 2 x 10K, 2 x 20K, 2x 100k, 1x 470K
Capacitors	4 x 0.1 uF, 3 x 10uF, 1 x100 uF, 1x 220uF
Inductor	1x 33uH -5A
LEDs	1 x Red, 1 x Yellow, 1 x Green
Screw Terminals	3 x2 pin ,1 x 6pin
Fuses	2 x 5A
Fuse Holders	2 no
Push Switch	2 no
Heat Sinks	4

6.1 Buck Converter

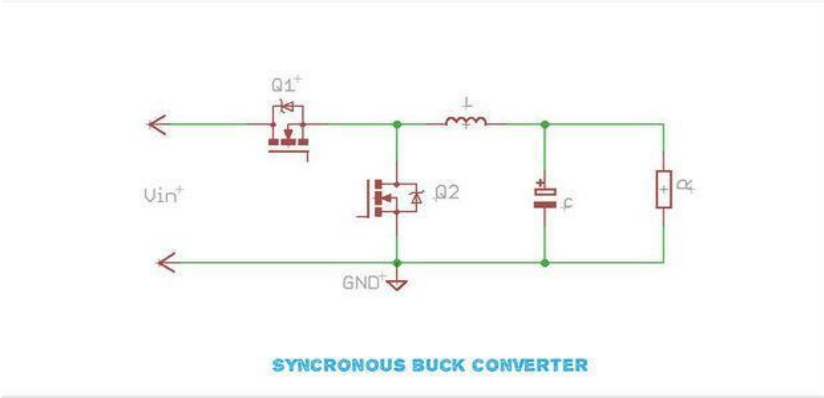


Fig.13 Synchronous Buck Converter

A buck converter is a kind of DC-DC converter. It steps down the level of high voltage to another voltage level. Here the buck converter used is a type of synchronous buck converter. The main difference here is that instead of diode, we use two MOSFETs. The advantage is that we can control the switching of MOSFETs but not the diodes and also forward voltage drop in diode is more thus losses will be more which thereby reduces the efficiency. The inductor used reduces the ripples in current. A schematic diagram of a buck converter is given in the Fig.13.

Working Principle:

MODE-1: When the mosfets is ON, current will flow in a clockwise direction through MOSFET Q1, inductor and finally into the load and simultaneously charging the capacitor. At this point the other MOSFET is not triggered so the current does not flow through it. Initially, the current rises slowly through the inductor and during ON state, energy is stored in the inductor.

MODE-2: Now the first MOSFET is switched off since the Q2 mosfet is triggered .Now the flow of current is through this MOSFET, inductor , and finally through the load. But this time the polarity of voltage across inductor is reversed as the stored energy in inductor starts decreasing. The decrease in energy is because the magnetic field across the inductor starts to collapse. For continuous conduction mode, the inductor must sustain its energy before another mosfet is triggered and the cycle repeats.

6.1.1 Buck Converter Design

The design was done for a 100W solar panel and 12V battery was taken as the output.

While designing a buck converter important factors are switching frequency and filter design. Higher the switching frequency means smaller will be filter size which thereby means smaller will be inductor and capacitor size which reduces the overall cost. But the problem is that if switching frequency is too high that will increase switching losses in the MOSFETs and thus reduces the efficiency so it is important that compromise has to be done between these factors.

Here PWM frequency taken was 50 kHz.

Buck converter comprises

1. Inductor

2. Capacitor

3. MOSFETS

6.1.2 Inductor Design

Inductor is used to reduce the ripples in current, thus smooth waveform of current can be obtained. So it is very important that the value of inductance chosen is such that it can efficiently satisfy our requirements.

Assumption: We are designing for a 100W solar panel and 12V battery

Input voltage (V_{in}) =15V

Output Voltage (V_{out}) =12V

Output current (I_{out}) =100W/12V

Switching Frequency (F_{sw}) =50 KHz

Duty Cycle (D) =V_{out}/V_{in}= 12/15 =0.8 or 80%

Calculation

L= (V_{in}-V_{out}) x D x 1/$_{Fsw}$ x 1/ dI ⟶ (4)

Where dI is Ripple current

Typical value of ripple current is in between 30 to 40 % of load current.

Let dI =35% of rated current

dI =35% of 8.33=0.35 x 8.33 =2.9A

So L= (15.0-12.0) x 0.8 x (1/50k) x (1/2.9) = 16.55uH

Inductor peak current =Iout + dI/2 = 8.33+ (2.9/2) = 10A

A toroid inductor of 16.55uH and 5A was made.

Fig.14- Toroidal Inductor

6.1.3 Capacitor Design

Capacitance is used to reduce both the overshoots in voltage and ripples in the output of buck converter. So it is mandatory that even the value of capacitance should be such that it can sufficiently meet our system's requirements.

Calculation:

The output capacitor (Cout) = dI / (8 x F_{sw} x dV) $\longrightarrow$ (5)

Where dV is ripple voltage

Let voltage ripple (dV) = 20mV

Cout= 1.47/ (8 x 50000 x 0.02) = 183.75 uF

6.1.4 MOSFET Design

The most important parameters which has to be kept in kind for selection of right MOSFET is as follows:

1. Voltage Rating: Vds of MOSFET must exceed the rated voltage by 20%.

2. Current Rating: Ids of MOSFET must exceed the rated current by 20%.

3. ON Resistance (Rds on): The MOSFET with low ON Resistance (R_{on}) must be preferred.

4. Conduction Loss: It depends on duty cycle and ON drain to source resistance. Conduction loss must be kept as low as possible.

5. Switching Loss: This occurs during the transition phase. It depends on switching frequency, voltage, current etc. It should be also as low as possible.

The open circuit voltage (V_{oc}) of our Solar Panel is 21.5V and short-circuit current is 5A.

We have chosen IRFZ44N MOSFET. It is shown in Fig.15

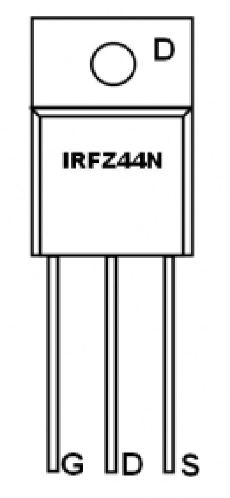


Fig.15- IRFZ44 MOSFET

6.1.5 MOSFET Driver

Fig.16- Mosfet Driver IR2014

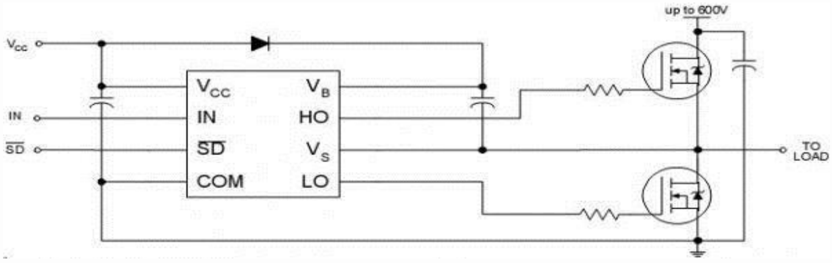


Fig.17- IR2014 Circuit diagram

The output of a microcontroller is very low only 5V which is not sufficient enough to run/drive the gate of a mosfet. A MOSFET has a gate capacitance that needs to be charged very fast to turn on the mosfet and it should even discharge very fast so that MOSFET gets switched off. This whole process needs high current so that our purpose can be achieved. Therefore we need a driver to amplify the small level of current, obtained from microcontroller, to the current level required for driving the gates of a MOSFET. The PWM signals generated from ARDUINO is given to the driver. In a driver circuit the capacitor is there along with the diode which forms a charge pump circuit. This circuit doubles the input voltage. But these switching are only for MOSFETs Q2 and Q3.

Protection Circuit:

MOSFET Q1 is for protection which prevents the reverse flow of current from solar charger circuit to solar panel. The switching of this MOSFET is done simultaneously with MOSFET Q2. This has to be done in a very fast rate so a fast switching diode is used in between MOSFETs Q1 and Q2.It makes the converter more efficient.

6.2 Schematic and Working

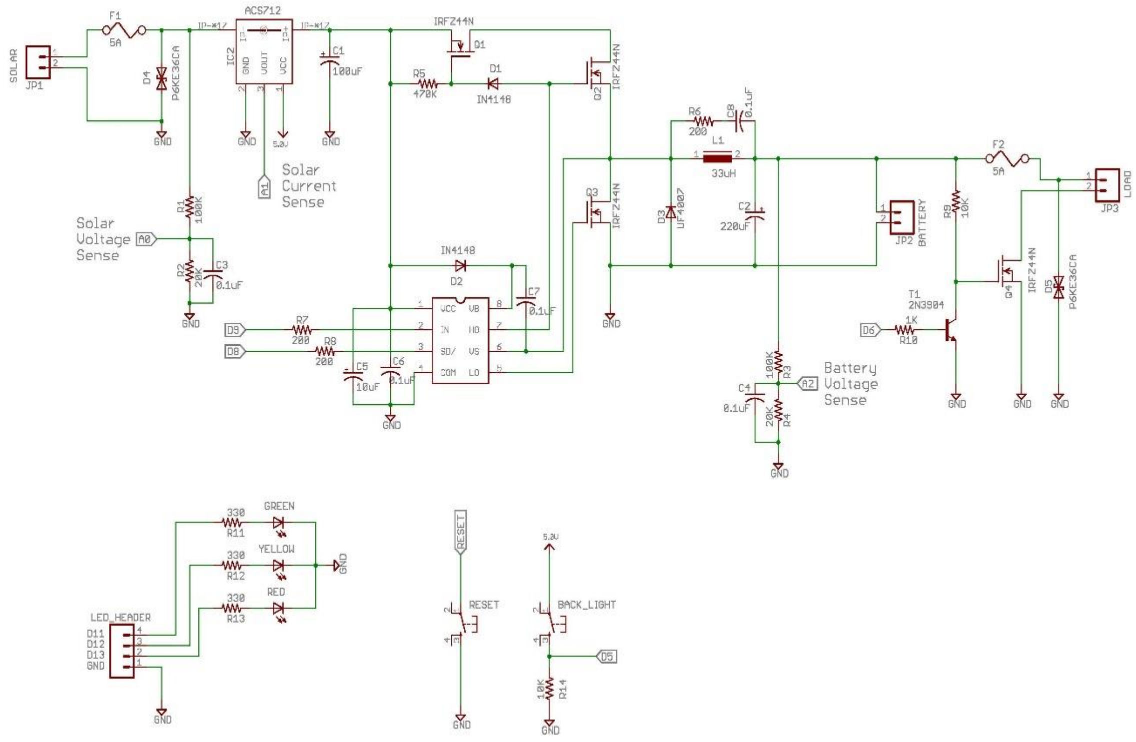


Fig.18- Circuit diagram of charger circuit

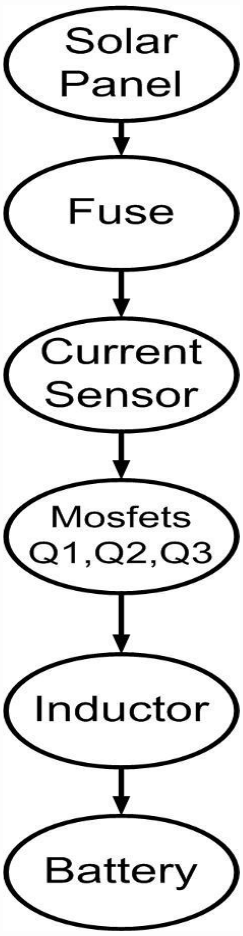
The solar panels terminals are connected to the screw terminal JP1 and JP2. The third connector JP3 is connection for the load.

F1 and F2 are the 5A safety fuses.The synchronous buck converter comprises MOSFETs Q2 and Q3 and inductor L1 and capacitors C1 and C2 as energy storage devices. The inductor smoothens the switching current and along with C2 it smoothens the output voltage. Capacitor C8 and R6 are a snubber network. Snubber circuit is always required whenever an inductor is there. This is used to reduce the ringing of voltage in inductor.

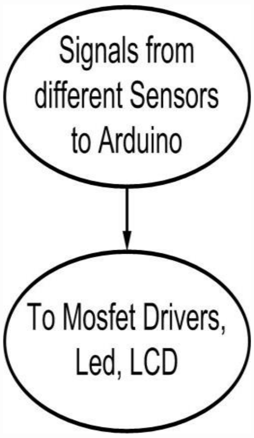
The PWM signal from the Arduino (Pin -D9) goes to the MOSFET driver. The IR2104 can also be shut down with the control signal (low on pin -D8) from the Arduino on pin 3. The coding is done in such a way that keeps record of the PWM duty cycle and never allows the MOSFETs to be 100% or always on.

There are two voltage divider circuits (R1, R2 and R3, R4) . Here the voltage of both the solar panel and battery is reduced to small value of 2-3V.Since these signals will be sent to microcontroller, it is important that it should be in the range of 0-5V. This is fed to Analog pin-0 and Analog pin-2 .The ceramic capacitors C3 and C4 are used to remove high frequency spikes. The diodes D4 and D5 are Transient Voltage Suppression (TVS) diodes used for over voltage protection from solar panel and load side.The current sensor ACS712 senses the current from the solar panel and feeds to the Arduino analog pin-1. The 3 LEDs are connected to the digital pins of the microcontroller and is used to show the state of charge of the battery. If green LED glows means battery is fully charged. If orange LED glows means it is in between the range of nominal voltage to fully charged voltage.

FLOWCHART -1: POWER SIGNALS



FLOWCHART -2: CONTROL SIGNALS



6.3 Voltage Measurement:

For a voltage divider circuit

Vout = R2/ (R1+R2) x Vin ⟶ (6)

Vin = (R1+R2)/R2 x Vout ⟶ (7)

The analog Read ( ) function reads the voltage and converts it to a number between 0 and 1023

The above code gives an ADC value in between 0 to 1023

Calibration:

Output value is read with one of the analog inputs of Arduino and its analogRead() function. That function outputs a value between 0 (0V in input) and 1023 (5V in input) that is 0,0049 V for each increment (As 5/1024 = 0.0049 V)

Vin = Vout*(R1+R2)/R2; R1=100 k and R2=20 k

Vin= ADC count*0.0049*(120/20) Volt // Highlighted part is Scale factor

6.4 Current Measurement

For current measurement a Hall Effect current sensor ACS 712 (5A) is used.

The ACS712 sensor read the current value and converts it into a relevant voltage value, the value that links the two measurements is sensitivity.

As per data sheet for an ACS 712 (5 A) models:

1. Sensitivity is 185 mV/A.

2. The sensor can measure positive and negative currents (range -5A…5A),

3. Power supply is 5V

4. Middle sensing voltage is 2.5 V when no current.

Calibration:

Value = (5/1024)*analog read value

Current in amp = (value-2.5)/0.185

7. RESULTS AND DISCUSSION

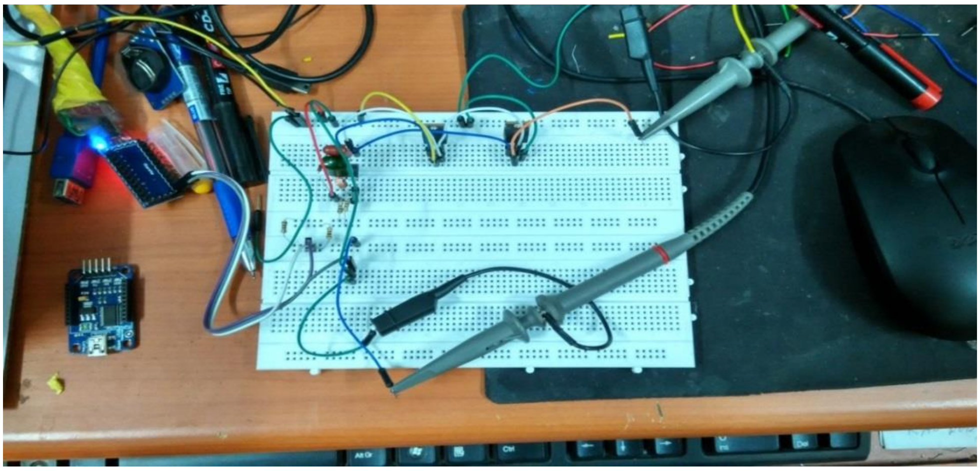


Fig.19- Testing for gate pulse of MOSFET

Fig.19 shows testing of gate pulse of MOSFET. 5V supply is given to microcontroller ATMEGA 328. The output of the microcontroller provides gate pulse to mosfets but this voltage is not sufficient to provide triggering of the mosfet so mosfet driver is required here.

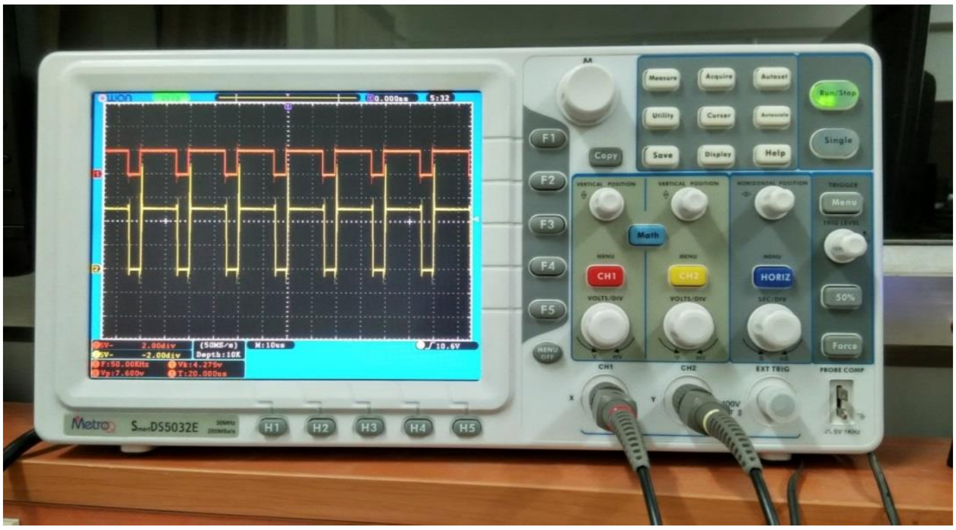


Fig.20- Gate Pulses Traced

Fig.20 shows the waveforms of gate pulse. The frequency generated is f=50 KHz. This is the gate pulse given to the MOSFETs.

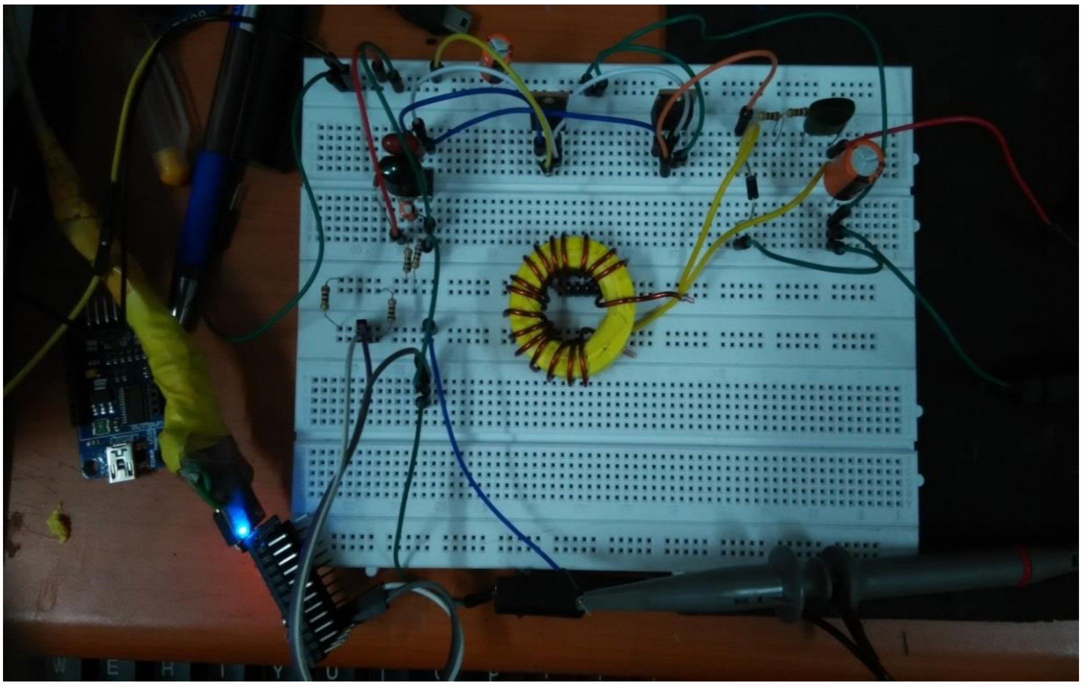


Fig.21- Testing of Buck Converter.

Fig.21 shows ATMEGA 328 and the gate pulse generated from it is given to MOSFETs through MOSFET driver. This circuit has two MOSFETs as it is a synchronous buck converter configuration. Toroidal inductor and capacitor is used so that output across this converter is smoothened.

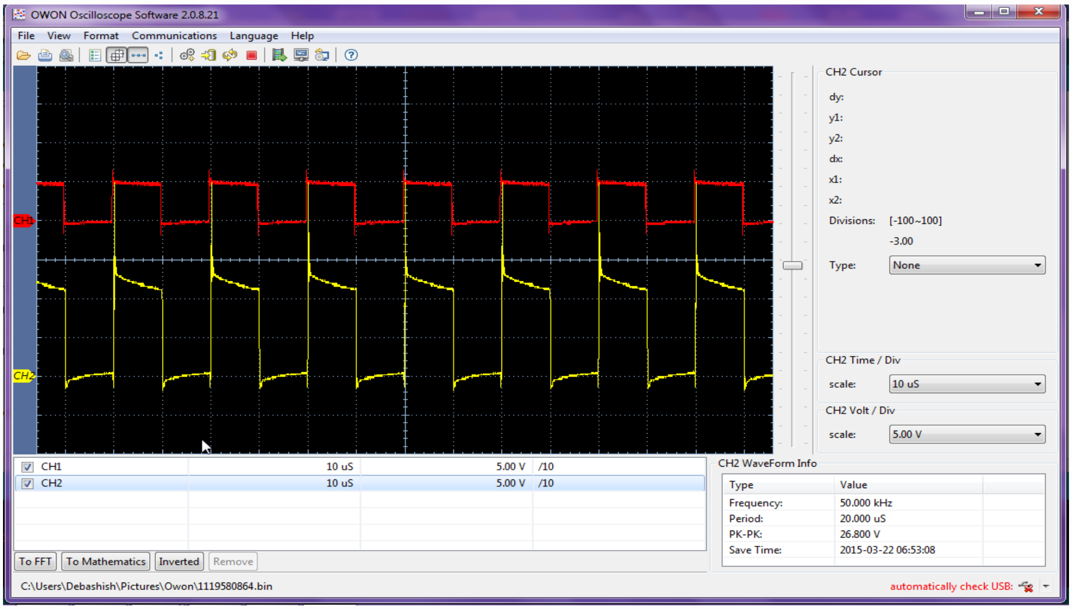


Fig.22- 50% Duty with unfiltered output

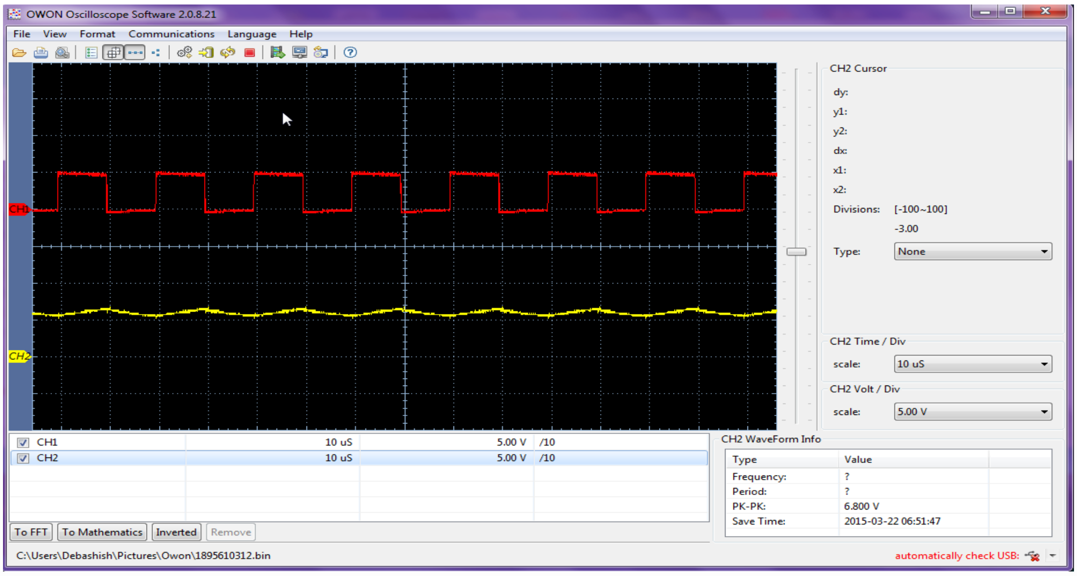


Fig.23- 50% Duty with Filtered output

Fig.22 shows the the output across the mosfet but without using any filter so it is little distorted. This is smoothened by using filter . Thus in Fig.23 waveform is smoothened.

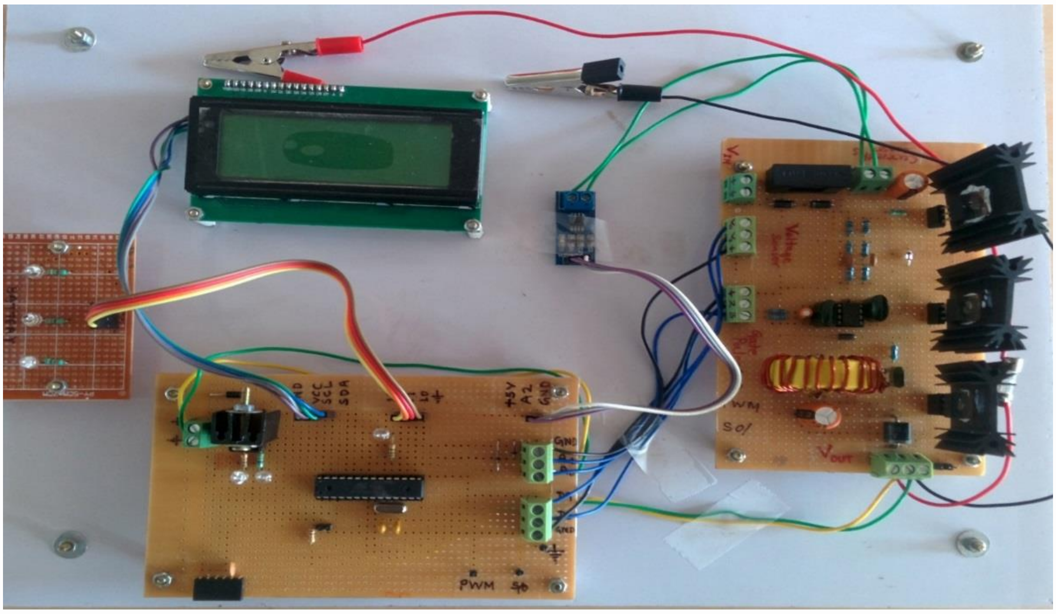


Fig.24- Complete Solar Charge Controller

Fig.24 shows the complete solar charge controller. LCD display is there to show solar panel's parameters and battery's parameters. The LED display has three LEDs. If green LED glows that means battery is highly charged upto fully charged state; if orange LED glows that means battery is having nominal voltage; and if yellow LED glows that means battery is discharged.

Fig.25- Complete Hardware Set-Up

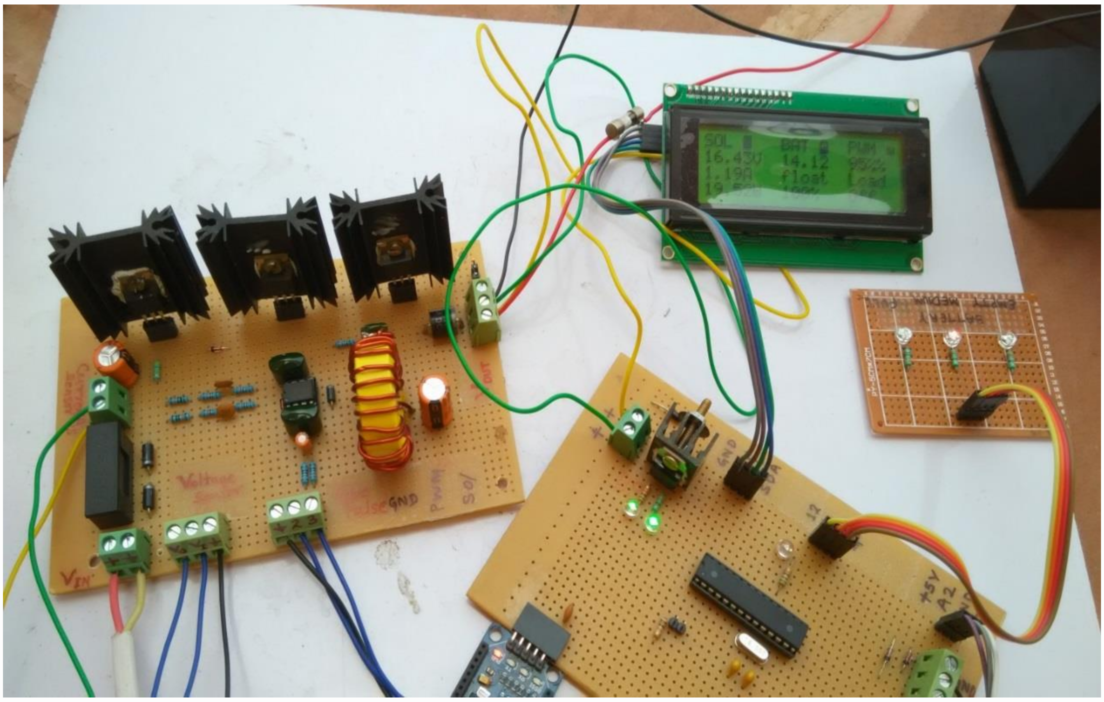


Fig.26- Circuit connected to LCD Display

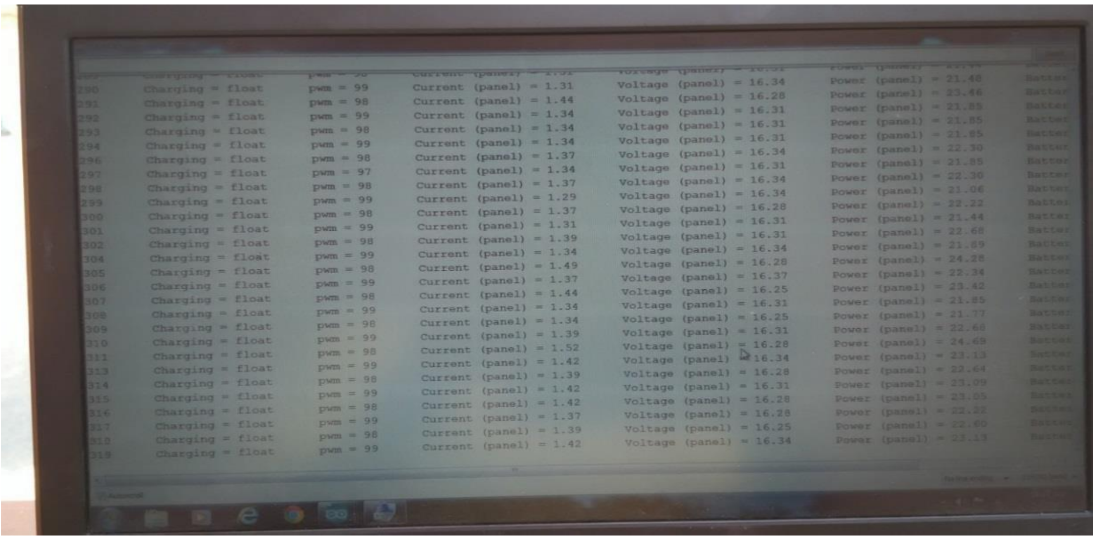


Fig.27- Results of Solar Panel and Battery captured in Laptop

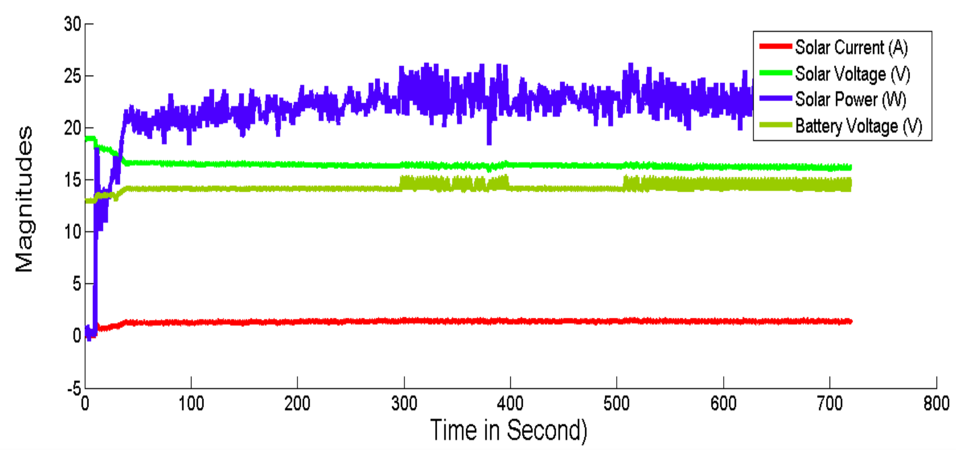


Fig.28- Plotted Graphs for Captured Datas in the Laptop

In Fig.28 the graphs for Solar Current, Solar Voltage, Solar Power and Battery Voltage is drawn for the datas captured in Fig.27. Initially the rated voltage for PV that is near about 20V comes but when MPP is tracked it settles down to 17 V. Solar current is 1-2 A. Here load used is 12V battery which requires 20-24 W power. It is observed that when battery is charging more current is drawn from PV, thus current increases till battery is in its fully charged state. Here it is 14V. When the battery voltage reaches 14 V the current drawn from PV is decreased. Thus successfully our MPP is tracked with MPP voltage (17 V). At this MPP voltage, the MPP power tracked is 22W for the load used here, which is a battery.

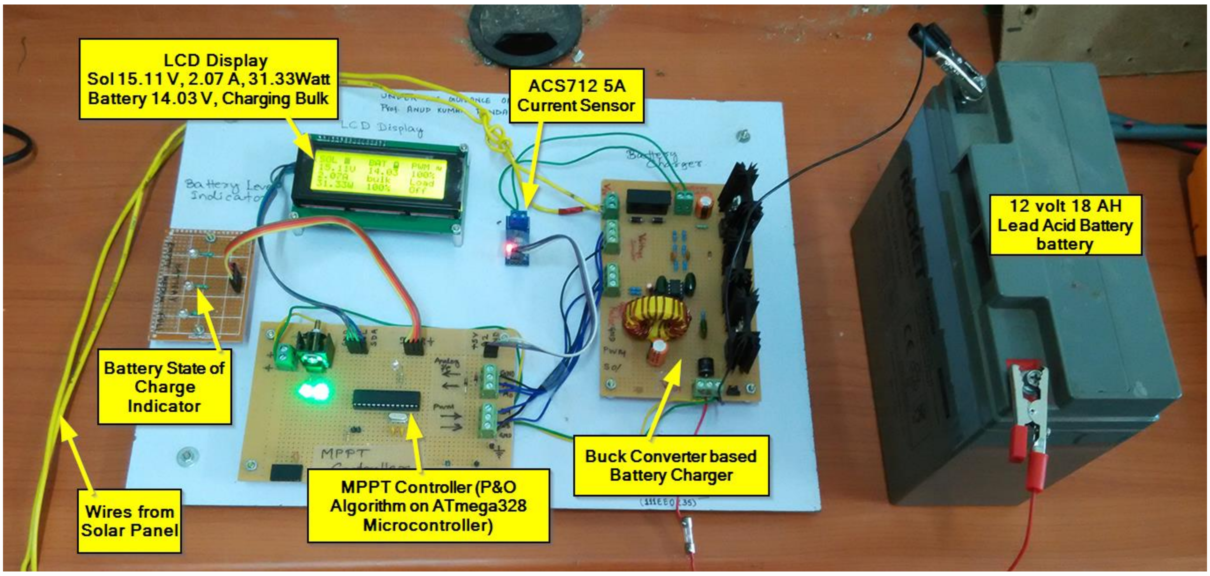


Fig.29- Complete Hardware SET-UP in Operation

Fig.29 shows complete hardware in operation. It has LCD and LED display. LCD displays solar panel's and battery's parameters. LED displays state of charge of battery at every instant. The connection is from solar panel to solar charge controller and 12V battery is used as a load.

8. CONCLUSION

A Stand-alone Photovoltaic System for residential applications is modelled with the help of MATLAB/Simulink. The hardware components of the total system is designed for the purpose of creating the real proposed system to test the results of the simulation and to ensure hardware and software work in tandem. Control schemes and mathematical models containing MPPT control (method of perturbation and observation) are provided for the boost converter . Control methods are employed and verified for the optimum working of the specified model. Simulation results prove that the boost converter successfully tracks the maximum power point (MPP) of the solar panel and battery is charged accordingly. For the hardware implementation MPPT control is achieved by using a microcontroller. The solar charge controller is no such thing in simulation. This is because the theoretical circuits do not have so simple configuration when we do it practically. We need extra components in addition to what we do in simulation. In the simulation we just used boost converter to track MPPT. This is not so simple in case of hardware. So solar charge controller helps not only in obtaining MPP but also in maintaining state of charge of battery in case of hardware. Microcontroller is needed to maintain MPP and also to generate PWM signal. Battery plays here two roles. One is it acts as a load and other is it acts as an energy storage element. In simulation we took 900 cells in series and 8 cells in parallel but was not feasible for us to use those many number of cells in hardware. So we used one PV cell of 100 W. The results ensure an optimum and efficient model for reliable and high quality stand-alone PV system.

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