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Design and Development of Maximum Power Point Tracking Solar Charge Controller for 12V Lead Acid Battery

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ABSTRACT

Maximum power point tracking charge controller simulation is done in in proteus 8 professional software and validate using development of hardware model of MPPT solar charge controller for battery. Development of MPPT Solar Charge Controller is done using ardunio nano controller board, ACS 712 current sensor, mosfet driver IR2102, dc-dc buck converter using mosfet, inductor, capacitor and wifi module for data collection, LCD display, LED indication for battery status of charging. Battery charge using three state charging say buck, absorption and float mode. Performance analysis done using simulation model using LCD display status, where first column of display shows PV voltage, PV current and PV power. Second column of display reads battery voltage, battery status of battery. Third column reads pwm duty cycle in percentage and load status. Three LEDs reads battery voltage level. Red Led for low voltage, green LED for normal voltage, yellow LED for fully charge battery. Model has been verified using hardware model and performance analysis has been carried out. Hardware display show the real-time status of all parameters and functions for measured Solar Panel Voltage, Current, Power, Battery Voltage, Charger state, SOC, PWM duty cycle, and load status. Three-state battery charging algorithms viz., buck stage, absorption stage, float stage are adopted.

Keywords : BUCK, DC-DC, PWM, SOC, MPPT

INTRODUCTION

Battery life and performance are mainly dependent on charging methods of battery. Various methods used for protecting battery from undercharge or overcharge. There are two types of charge controller are used : PWM charge controller and MPPT charge controller. PWM charge controllers have same voltage at battery and PV panel. MPPT charge controller can operate at higher voltage than battery. Synchronous buck converter is used in design, which decreases the voltage of PV panel for charging of battery at 12V. Ardunio controller is used to maximize the panel power by operating at peak voltage and use maximum available power from solar panel. The maximum power point tracking mechanism uses algorithm and electronic circuitry based on principle of impedance matching between load and PV panel, maximum power transfer takes place between source and load which ensures that maximum power is extracted form PV panel.

MATERIALS AND METHODS

Maximum Power Point Tracking charge controller is an electronic device that regulates the charging of batteries from panel by maximizing the amount of power from the solar panel that is stored in the battery. It does this by continuously adjusting the voltage and current of the panel to match the charging voltage of the battery. This allows the battery to charge more quickly and efficiently, and can also increase the overall power output of a solar system.

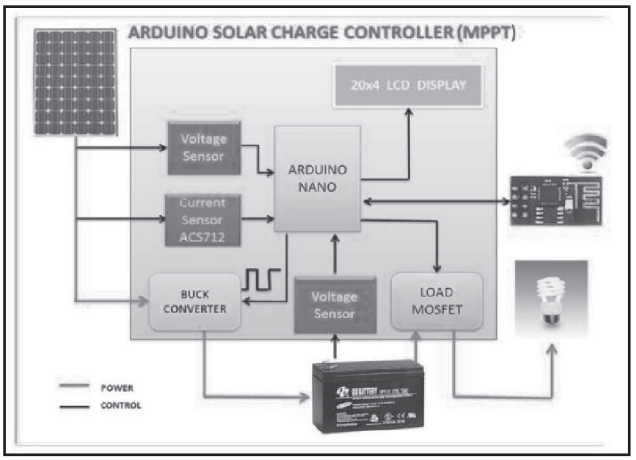


Fig.1 : Block schematic

Specification:

- Based on maximum power point tracking algorithm
- SOC indication by LED
- 20×4 character display. Solar Panel Voltage, Current, Power, Battery Voltage, Charger state, SOC, PWM duty cycle, load status.
- Overvoltage protection
- Short Circuit, Overload and Reverse Polarity protection
- Rated Voltage= 12V
- Maximum current = 5A
- Maximum load current =10A
- Input Voltage from 12 to 25V
- Solar panel power = 30W, 12V
- Maximum power (Pmax)-30Wp
- Maximum voltage (Vmp)-18.57V
- Maximum current (Imp)-1.61A
- Open circuit voltage- 22.50V
- Short circuit current-1.77A
- battery specification: 12V,7Ah

Schematic and circuit diagram

Generated voltage of panel depends on different parameters like the quantity of sunlight, connected load & temperature of the panel. Complete schematic of the MPPT solar charge controller is shown in Fig.2 As the solar radiation changes throughout the day. Hence, the voltage produced by the solar panel will constantly vary. Due to the varying voltage, the varying current is produced.

For a 30W Solar panel, load of 12V lead-acid battery, we need to design a Buck Converter. A buck converter is a DC-DC converter in which the output voltage is always lower or the same as the input voltage.

The Solar Panel voltage is fed as an input voltage. The buck converter designed using synchronous MOSFET Q4 and Q5 & the energy storage devices inductor L1 & capacitors C4 and C9. The inductor helps in smoothing the switching current and output voltage. Capacitors C3 & Resistor R4 are snubber networks, used to reduce the ripple of the inductor. The MOSFET Q3 is used to block reverse power flowing from battery to panel.

Inductor Calculation

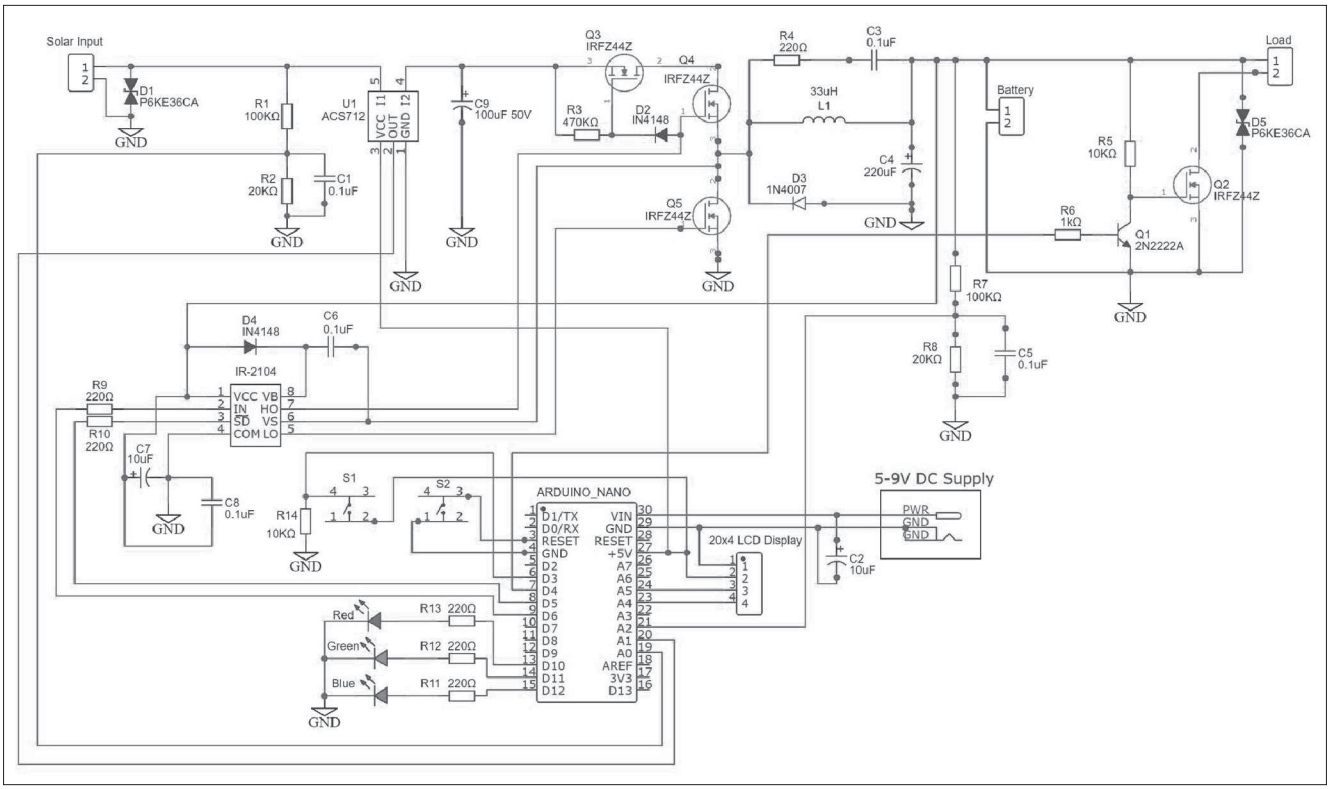
We are designing board for panel ranges from 30W to 80W and 12V battery.

Considering maximum wattage panel, voltage is 21V and board can handle maximum current upto 5A. Maximum battery output voltage (Vout)=13V maximum. Output current (Iout)(consider max wattage) 105W/13V=8.07A. Switching Frequency (Fsw)=50 kHz

Duty Cycle (D) =Vout/Vin= 13/21 =0.6190 or 61.90%

$$L = \frac{(V_{in} - V_o) \times D}{f_{sw} \times d_I}$$

Where d_I is ripple current. Ripple current is 30 to 40% load current. Let d_I =35% of rated



The Buck converter consist the Inductor, Capacitor, and MOSFETS. The switching frequency is inversely proportional to the size of the inductor and capacitor and directly proportional to the switching losses in MOSFETs. Keeping these constraints into consideration the selected frequency is 50KHz

current =0.35 X 8.07A = 2.82A

So, inductor of 33uH, 5A

Capacitor Calculation:

To reduce the voltage overshoot and output ripple, output capacitance is required in buck converter.

For ripple specification of buck converter circuit output capacitor should be high capacitance and low ESR.

$$C_{out} = \frac{d_I}{(8X f_{sw} X d_V)}$$

where d_V is ripple voltage let

it 50mV

So available capacitor is 220uf electrolytic capacitor

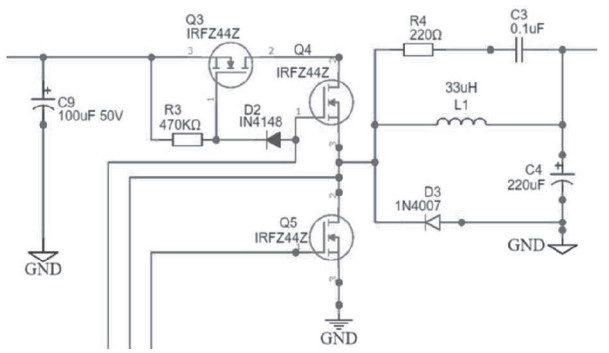


Fig. 3 Buck converter with MOSFET

MOSFET selection:

1. Voltage Rating : Vds greater than 20% of rated voltage.
2. Current Rating : Ids greater than 20% of rated current
3. ON Resistance (Rds on) : low ON Resistance (Ron)
4. Conduction Loss : minimum
5. Switching Loss : For the MOSFET part, we used IRFZ44N MOSFET as it is easily available. The IRFZ44N MOSFET Vds and Ids value have enough margin & low Rds(On) value. So low switching loss.

MOSFET Driver :

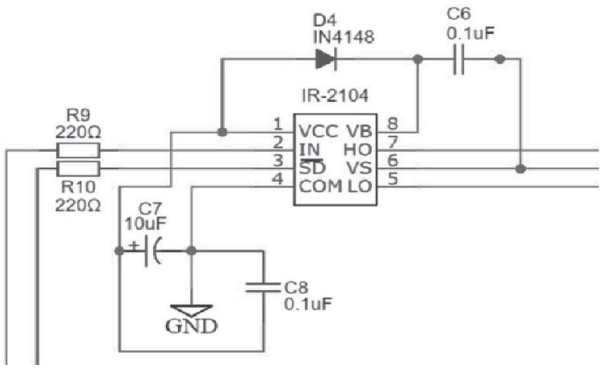


Fig.4 MOSFET driver circuit

The IC IR2104 half-bridge MOSFET gate driver. MOSFETs are driven by PWM signal from the Arduino Pin D6. The IR2104 driver have control signal from ardunio pin D5

Bootstrap circuit formed by D4 & C6. PWM duty cycle is never reach at 100% or fully on.

There are two voltage divider circuits (R1, R2, and R7, R8) to measure the panel and battery voltages respectively. Voltage divider output given to ardunio pin Ao and A2.

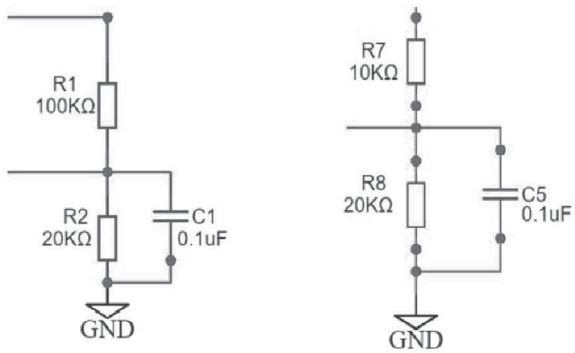


Fig.5 Voltage divider network (for solar input and battery)

Diode is used to make converter more efficient. D1 and D5 are for overvoltage protection from the PV panel and load side. The MOSFET Q2 control the load. The driver for this MOSFET consists of a 2N2222 transistor Q1 and resistors R5, and R6.

ACS 712 senses the current and given to pin A1of ardunio. Output LED gives the charging status.

Simulation Model of MPPT solar charge controller :

MPPT SOLAR CONTROLLER

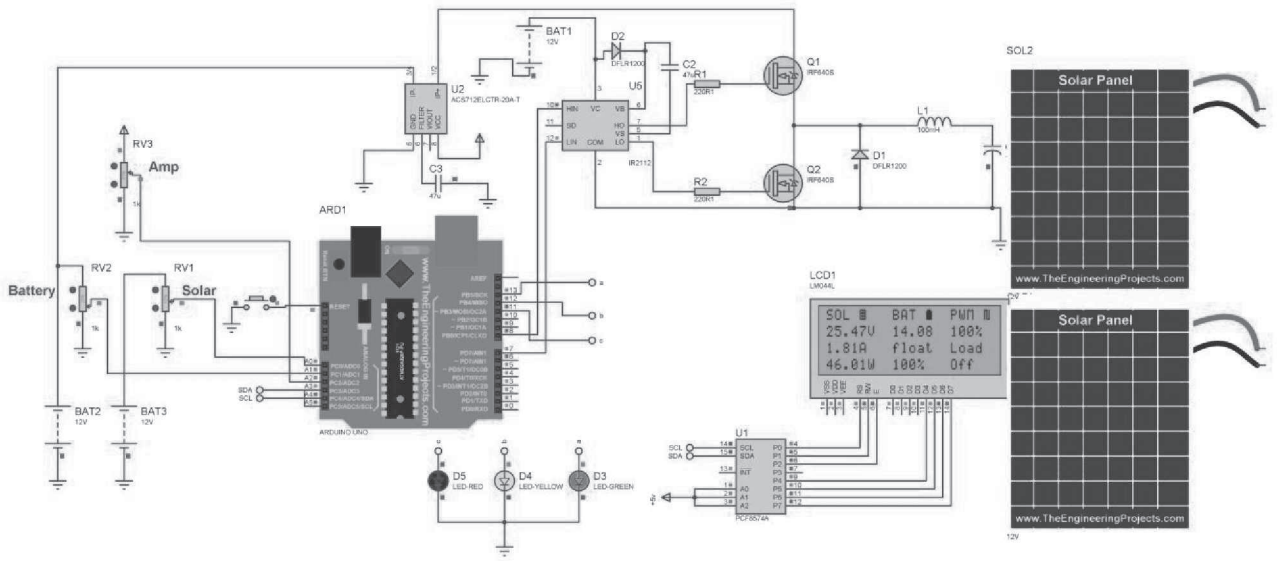
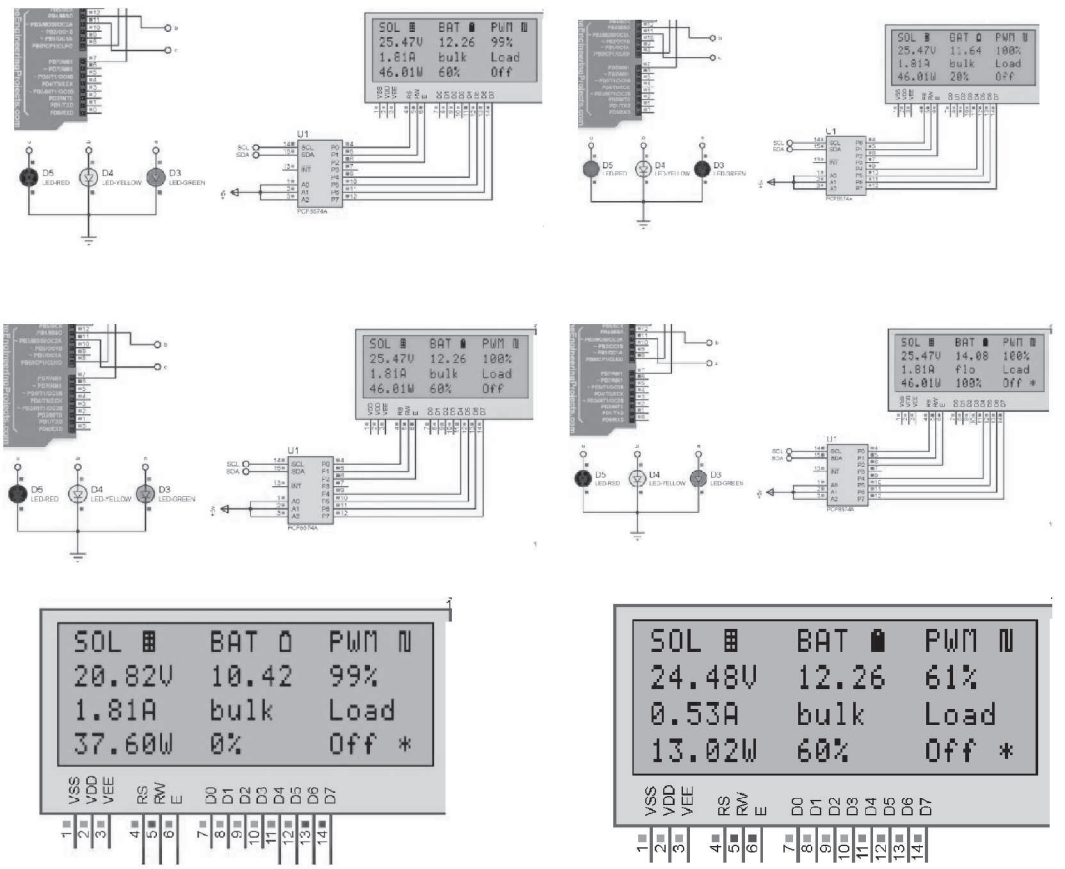
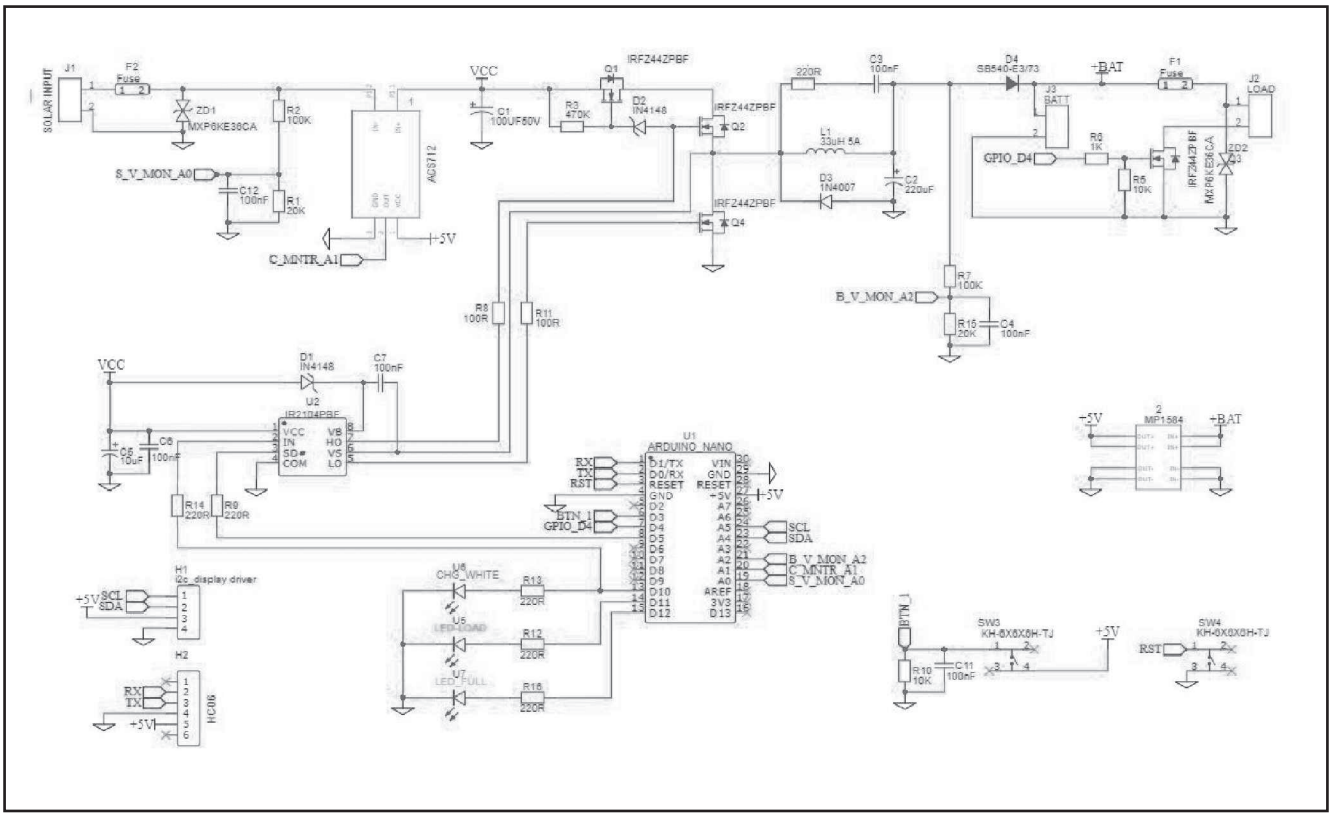


Fig.6 : Simulation model

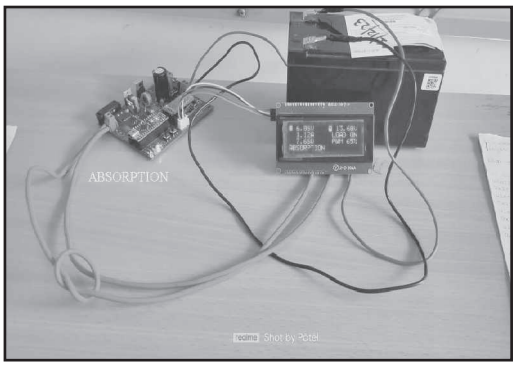
Simulation Results :

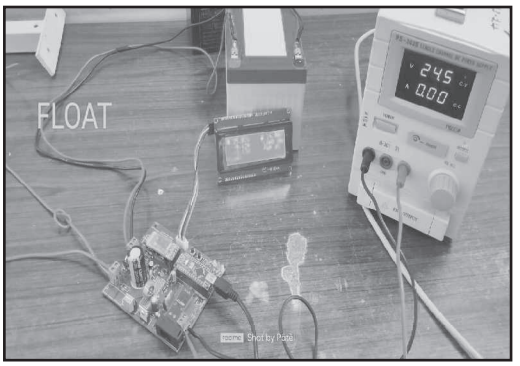


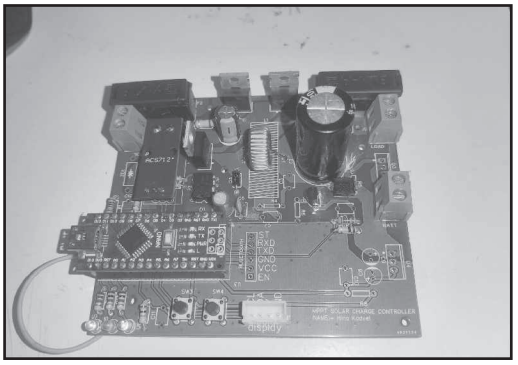
Hardware assembly of MPPT solar charge controller for actual model:

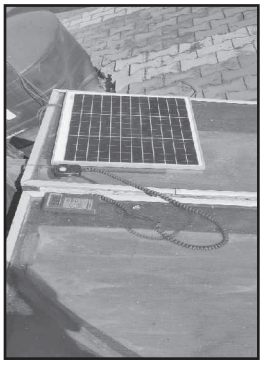


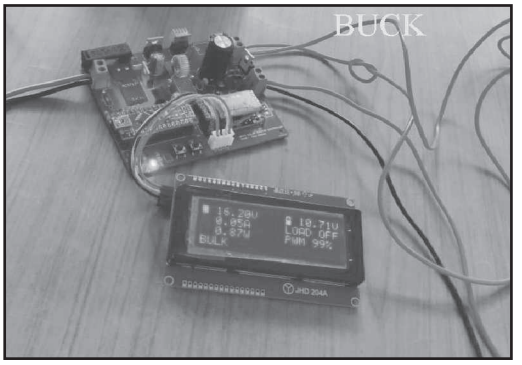
RESULTS :







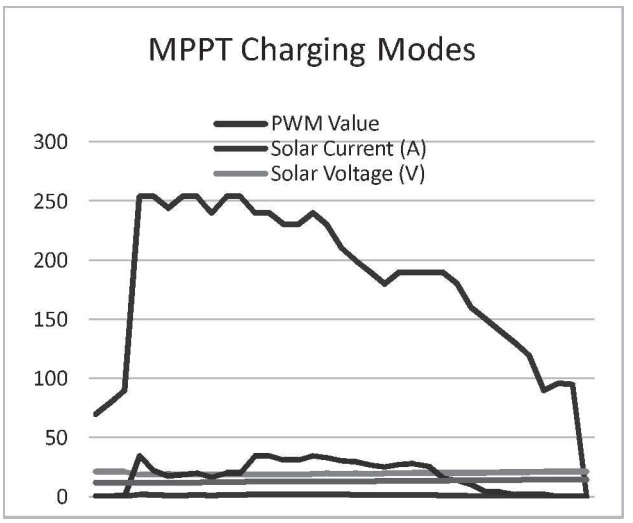




Time 23rd Jan, 2024	Solar Radiation (W/m^2)	Charging Mode	PWM Value	Solar Current (A)	Solar Voltage (V)	Power (Panel)	Battery Voltage (V)
12:13 PM	1089	BULK	70	0.02	21.2	0.424	11.5
12:18 PM	1090	BULK	80	0.02	21.2	0.424	11.6
12:23 PM	1096	BULK	90	0.04	21.2	0.848	11.6
12:28 PM	1098	BULK	254	1.9	18.2	34.58	11.7
12:33 PM	1105	BULK	254	1.2	18.2	21.84	11.7
12:38 PM	1107	BULK	244	0.9	19.2	17.28	11.8
12:43 PM	1102	BULK	254	1	18.2	18.2	11.8
12:48 PM	1103	BULK	254	1.1	18.2	20.02	11.9
12:53 PM	1105	BULK	240	0.9	18.2	16.38	12
12:58 PM	1100	BULK	254	1.1	18.3	20.13	12.1
1:03 PM	1113	BULK	254	1.1	18.3	20.13	12.2
1:08 PM	1107	ABSORPTION	240	1.9	18.3	34.77	12.6
1:13 PM	1102	ABSORPTION	240	1.9	18.3	34.77	12.7
1:18 PM	1105	ABSORPTION	230	1.7	18.3	31.11	12.7
1:23 PM	1102	ABSORPTION	230	1.7	18.3	31.11	12.8
1:28 PM	1098	ABSORPTION	240	1.8	19.2	34.56	12.8
1:33 PM	1078	ABSORPTION	230	1.7	19.3	32.81	12.9
1:38 PM	1073	ABSORPTION	210	1.6	19.1	30.56	12.9
1:43 PM	1071	ABSORPTION	200	1.5	19.5	29.25	12.8
1:48 PM	1070	ABSORPTION	190	1.4	19	26.6	12.9
1:53 PM	1065	ABSORPTION	180	1.3	19.5	25.35	13
1:58 PM	1057	ABSORPTION	190	1.4	19.5	27.3	13
2:03 PM	998	ABSORPTION	190	1.4	19.8	27.72	13.1
2:08 PM	988	ABSORPTION	190	1.3	19.9	25.87	13.2
2:13 PM	978	ABSORPTION	190	0.8	19.9	15.92	13.4
2:18 PM	970	ABSORPTION	180	0.7	20	14	13.8
2:23 PM	968	ABSORPTION	160	0.5	20	10	13.7
2:28 PM	937	ABSORPTION	150	0.2	20.2	4.04	13.8
2:33 PM	910	ABSORPTION	140	0.2	20.3	4.06	13.9
2:38 PM	858	ABSORPTION	130	0.1	20.3	2.03	13.9
2:43 PM	808	FLOAT	120	0.1	20.5	2.05	14.2
2:48 PM	768	FLOAT	90	0.08	21	1.68	14.4
2:53 PM	802	FLOAT	96	0.01	20.9	0.209	14.4
2:58 PM	770	FLOAT	95	0.01	21.2	0.212	14.4
2:58 PM	633	FLOAT	0	0.01	21.2	0.212	14.5

RESULT AND DISCUSSION

Maximum power point tracking charge controller working and functioning are observed in clear sunny days. The charge controller board working with 30W PV panel with current handling capacity is upto 2A. Here 30W panel is used for testing purpose and 12V,7Ah battery has taken for charging application. Observation are recorded as per Table.1 LCD display shows the first column as solar panel voltage, solar panel current, solar panel power and battery charging mode. Second column shows battery voltage load status on/off and pwm duty cycle.



The study was carried out to gain maximum power from PV under varying weather conditions. Solar panel had an internal resistance, which vary with variable irradiance condition. PV panel deliver maximum power at specific voltage and current, which will vary with solar radiation. This power point can be tracked using algorithm of power and voltage with respect to time. Three-state battery charging algorithms viz., buck stage, absorption stage, float stage are adopted. In buck stage, the battery peak charges to 90% SOC and battery current nearly constant. Thus battery voltage increases till peak 14.4V in buck stage. In second phase absorption will take place during battery voltage will constant and current will reduces. In last phase battery current will be very small as trickle current 0.02 or less with increases state of charge.

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Data Sheet No. PD60046-S Half Bridge Driver IR2104(S) & (PbF) International Rectifier