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MPPT solar charge controller for automotive industry

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1. Introduction

- A solar charge controller is a device that manages the power going into a battery pack from a photovoltaic (PV) panel

- It ensures that the batteries are not overcharged during the daylight and that the power does not run backwards during the night and drains the batteries

- There are two types of solar controllers:
  - Pulse Width Modulation (PWM) controllers
  - Maximum Power Point Tracking (MPPT) controllers

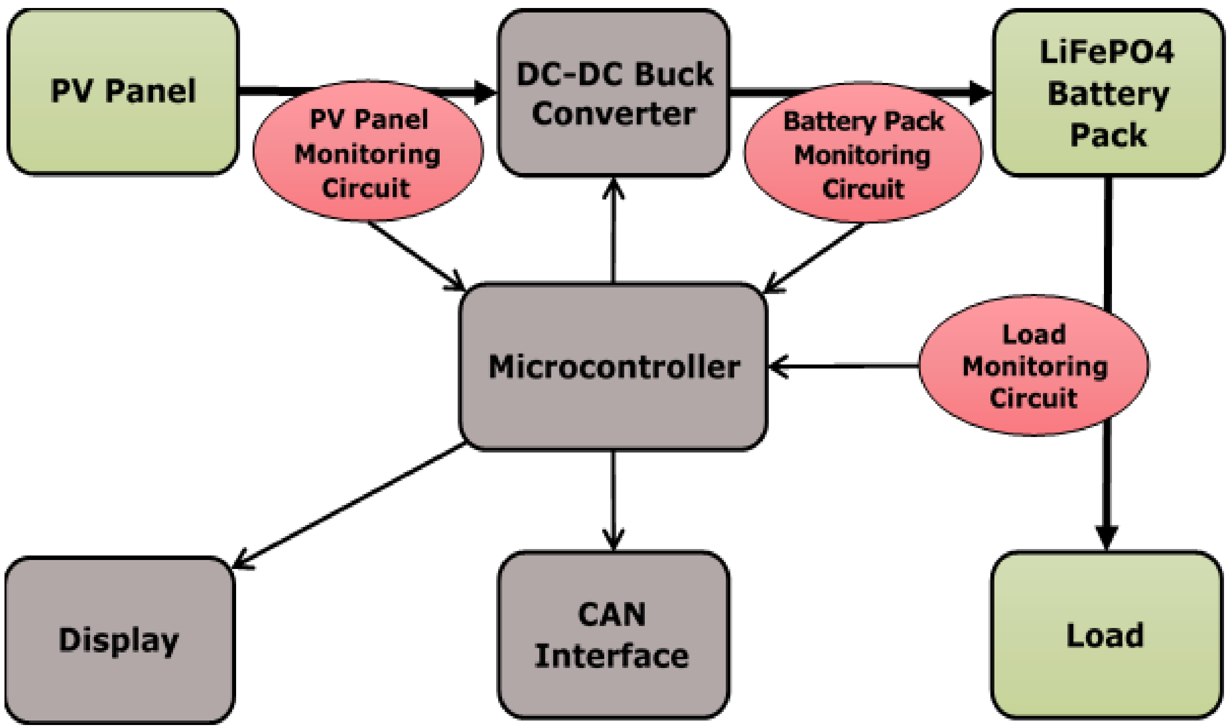
- The PWM controllers are the most common ones due to the simplicity of implementation and reduced cost, but the MPPT controllers are more efficient in power conversion

2. Objectives

- Design and implementation of a Maximum Power Point Tracking (MPPT) solar charge controller which achieves the maximum power extraction from a photovoltaic (PV) panel during the charging of four Lithium Iron Phosphate ($LiFePO_4$) cells connected in series (4S1P configuration)
- The power transfer is done using a digitally-controlled synchronous DC-DC Buck converter which has the duty cycle set using the Perturb-and-Observe (PO) algorithm
- The main parameters of PV system (voltages, currents, powers for panel and battery) are measured and displayed on the built-in Liquid Crystal Display (LCD) and are also transmitted over the Controller Area Network (CAN) interface to other Electronic Control Units (ECU) of the vehicle
- Practical measurements are performed on a 100 W flexible PV panel installed on the roof of a vehicle and on Lead-Acid battery and a $LiFePO_4$ battery pack installed in the luggage compartment

3. PV system architecture

- The block architecture for the proposed PV system



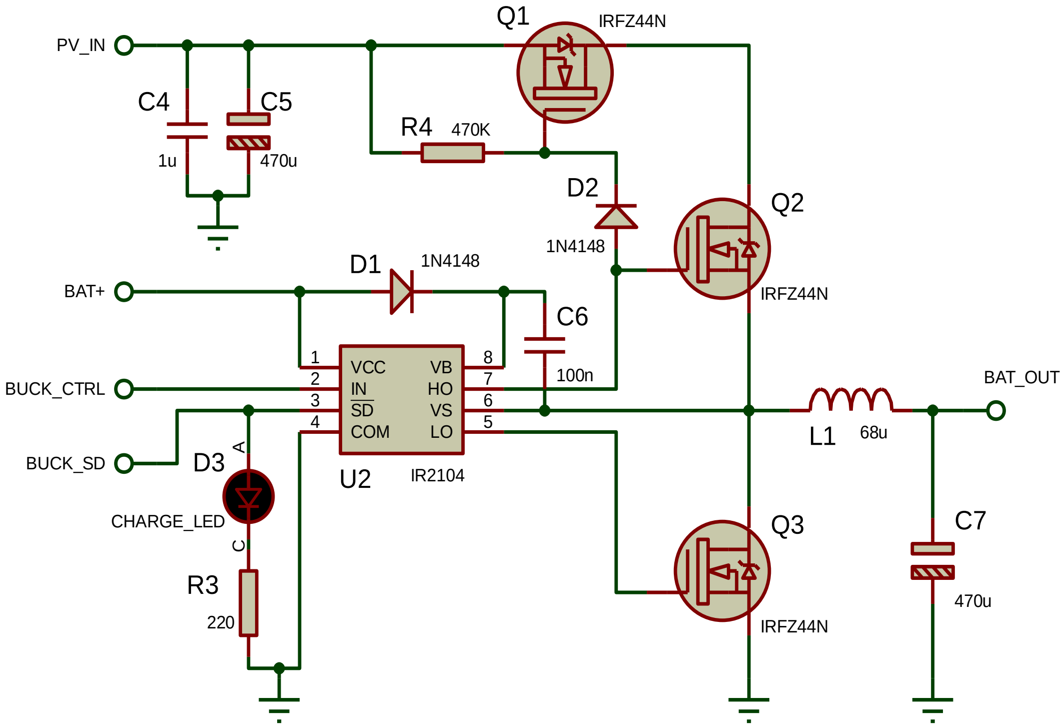
4. Photovoltaic panel

- Semi-flexible PV panel SZ-100-33MF from SolarFam
- 33 monocrystalline cells, in 3P11S configuration
- Optimized for low light conditions, the integrated bypass diode allowing the panel to work in partially shaded conditions

Nominal power	100 W
Efficiency	19.27 %
Maximum Power Point Voltage, V_{MPP}	16.70 V
Maximum Power Point Current, I_{MPP}	5.99 A
Open-Circuit Voltage, V_{OC}	19.70 V
Short-Circuit Current, I_{SC}	6.51 A
Cables	650 mm / 2.5 mm^2
Connectors	MC4
Junction box rating	≥ IP67
Working temperature	-40°C ~ +80°C
Dimensions	1225x515x3 mm
Weight	4.57 kg

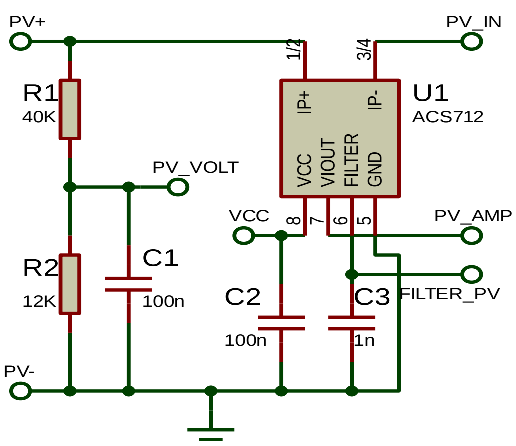
5. Proposed DC-DC Buck converter

- Synchronous DC-DC Buck converter uses Q2 and Q3 as main switching transistors
- U2 is the half-bridge gate driver used to control the transistors
- The switching frequency of the converter is 31250 Hz
- When the battery is charged, the U2 output are shut down
- The gate driver provides an internally set dead-time which prevents the outputs from being active simultaneously
- Q1 is used for reverse protection when PV voltage becomes lower than battery voltage

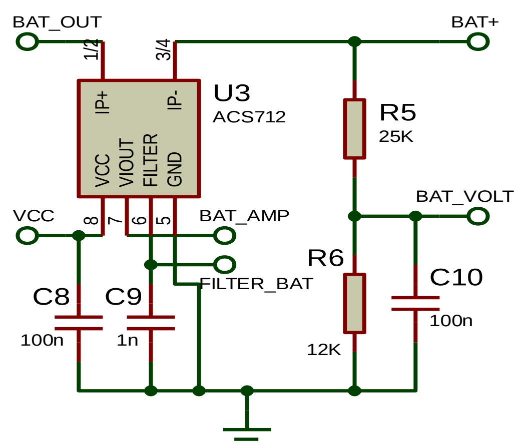


6. Monitoring circuits

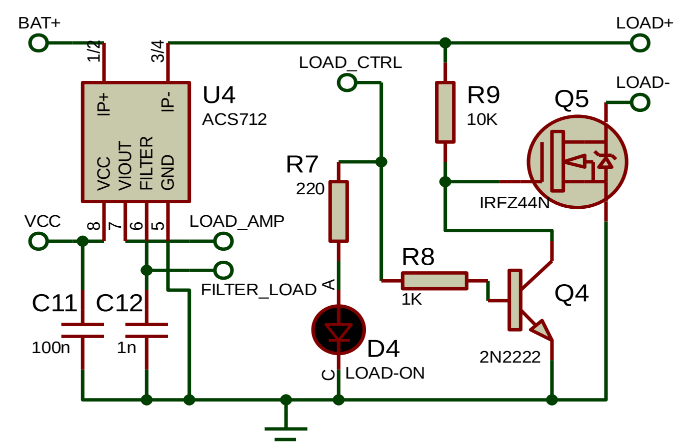
- The PV panel and battery monitoring circuits are used for the voltage and current measurement of the PV panel, and the battery respectively
- The current is measured using the ACS712 Hall-effect current sensor
- The voltage is measured by the microcontroller by scaling it down to maximum 5V through resistive dividers
- The load protection circuit provides undervoltage and overcurrent protection through transistor Q5 which disconnects the load



PV panel monitoring



Battery monitoring

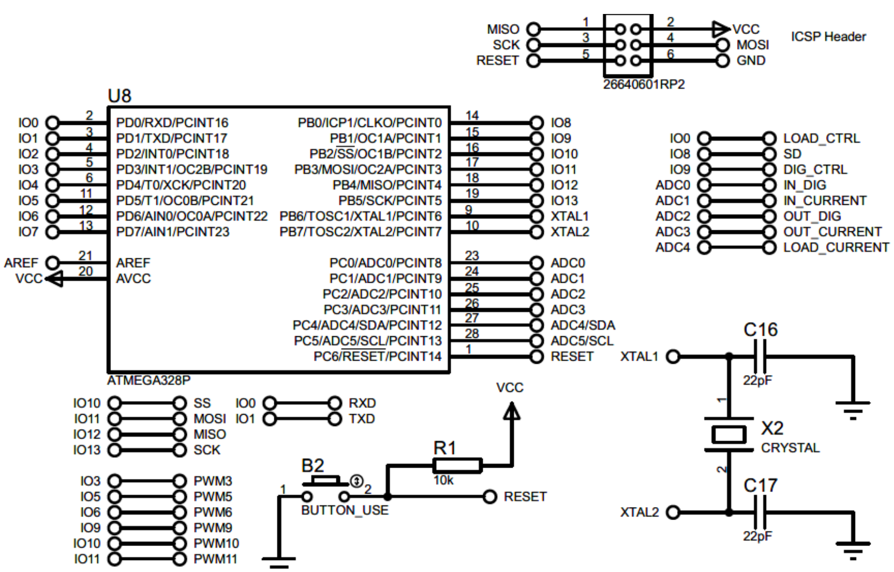


Load protection

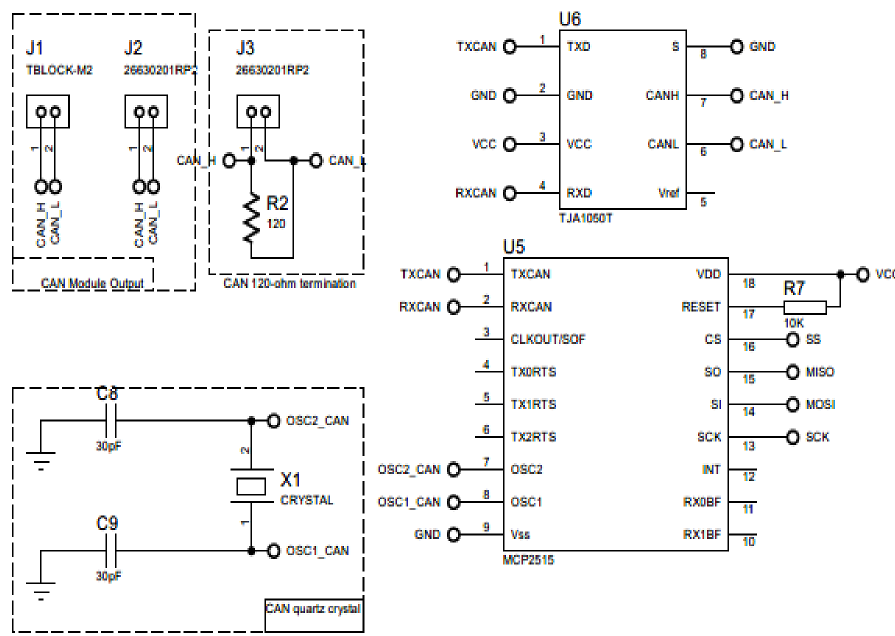
7. Control circuit

- The microcontroller circuit:
  - ATMega328P microcontroller
  - Supplied by a 5V regulator powered from the battery
- The CAN transmission circuit:
  - MCP2515 CAN controller
  - TJA1050T CAN transceiver

Microcontroller circuit

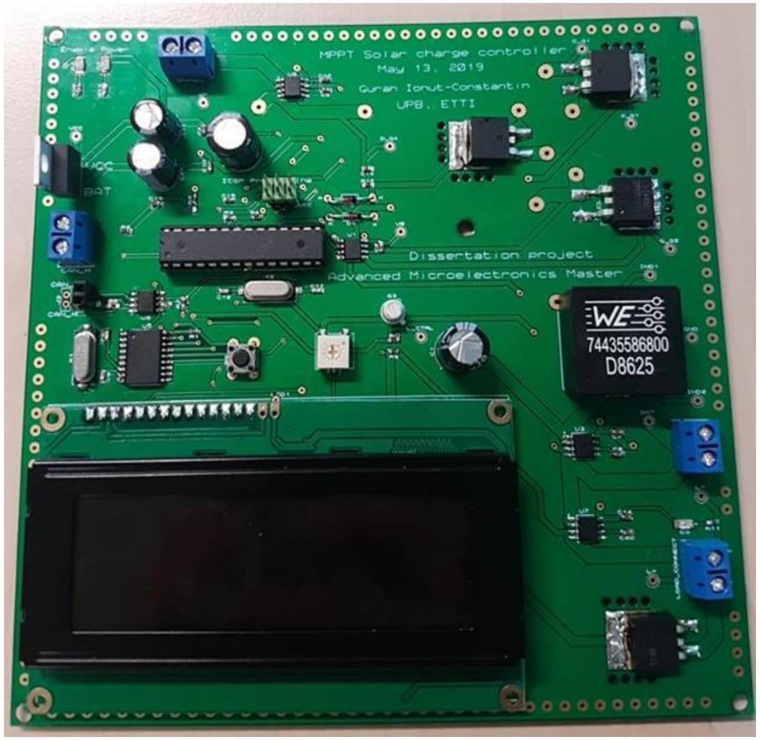


CAN transmission circuit



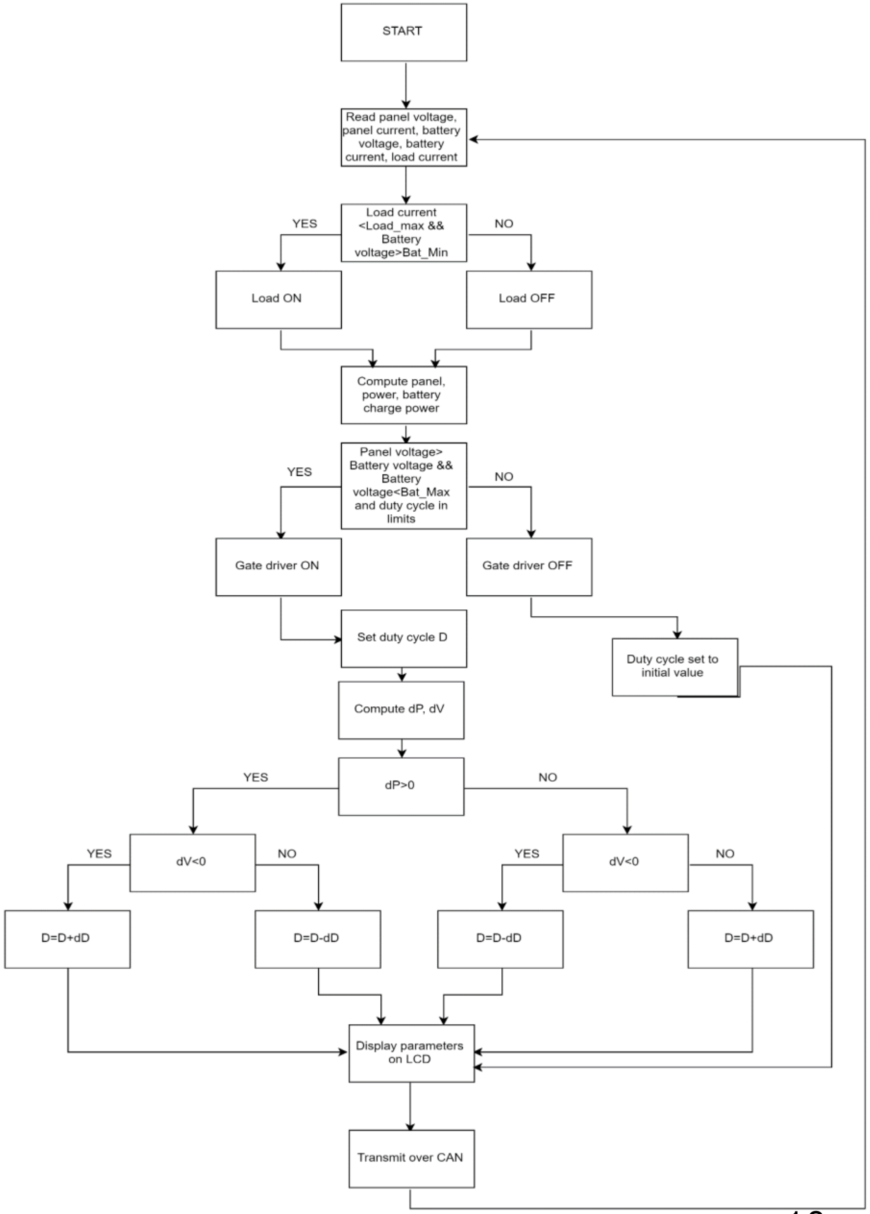
8. Final assembled PCB

- Dimensions: 150 x 150 mm
- 2 layers
- Copper thickness: 2 oz (70 µm)
- Board thickness: 1.6 mm
- Board material: FR4
- Traces width:
  - 20 mils (0.5 mm) for low current traces
  - 120 mils (3 mm) for high current traces



9. Software for microcontroller

- After microcontroller is powered up, the duty cycle is set to a high value.
- The PV voltage and current, the battery voltage and charge current, and the load current are acquired.
- The load protection activates if overcurrent or undervoltage are detected
- The panel and battery powers are computed.
- If the PV voltage is higher than the battery voltage and the battery is not fully charged, the MPPT Perturb and Observe algorithm is activated.
- Based on the current and previous duty cycle, the PV delta power and delta voltage is computed and the duty cycle is incremented or decremented.
- All the parameters are displayed on the LCD display and are transmitted over CAN for remote monitoring.



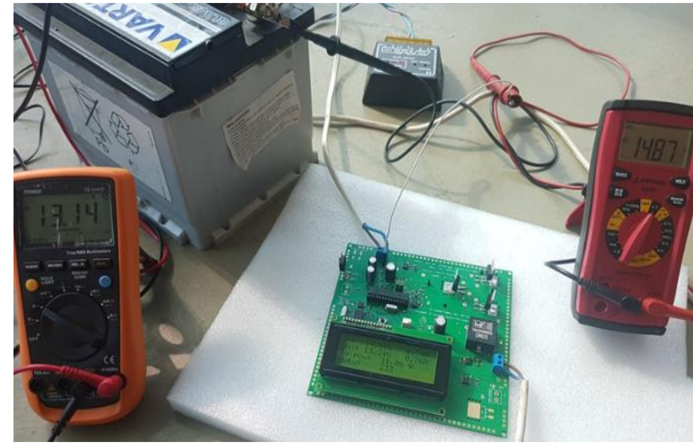
10. Measurements on a Lead-Acid battery

- Comparison between the implemented MPPT controller and a commercial PWM controller

- 12 V / 45 Ah Lead-Acid battery

- PV placed directly in sunlight with light clouds, in vertical position at 70° from the ground

- The measurements were made between 6 and 8 o’clock PM, after 15 minutes of charging



	PV panel			Battery			Efficiency
	Voltage	Current	Delivered Power	Voltage	Current	Charged Power	
MPPT controller	16.24 V	3.65 A	59.27 W	14.59 V	3.80 A	55.44 W	93.54 %
PWM controller	15.33 V	3.20 A	49.06 W	14.57 V	3.30 A	48.08 W	98.00 %

11. Measurements on a LiFePO4 battery

- The PV panel was mounted on the roof of a Renault Logan 2 passenger car, available for testing in laboratory.

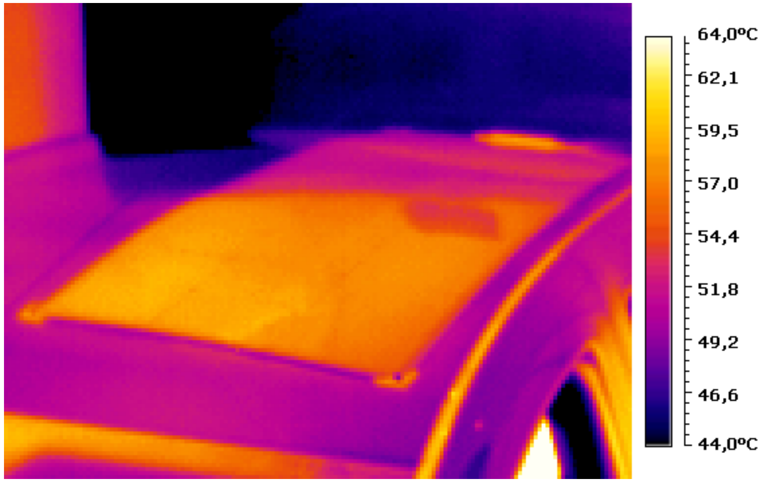
- 12 V LiFePO4 battery pack, having 4 cells connected in series (4S1P configuration).

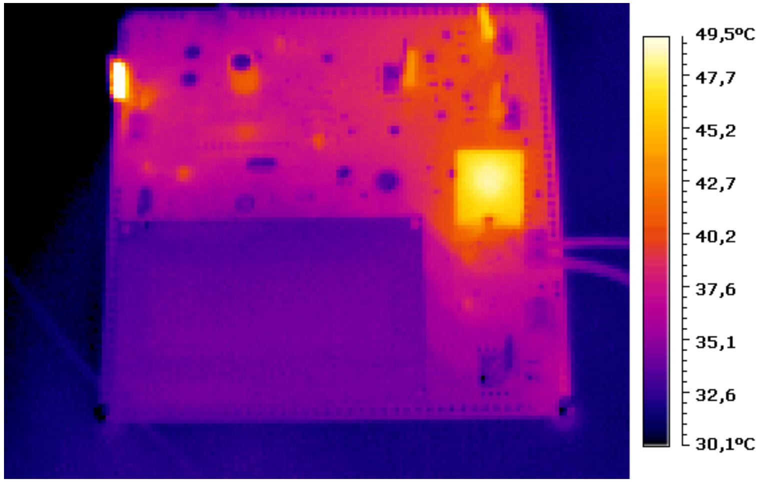
- The measurements were performed between 2 and 5 PM, partially clouded sky, air temperature of 30°C.

	PV panel			Battery			Efficiency
	Voltage	Current	Delivered Power	Voltage	Current	Charged Power	
MPPT controller	15.55 V	5.27 A	81.95 W	13.45 V	5.56 A	74.78 W	91.25 %
PWM controller	13.70 V	4.86 A	66.58 W	13.43 V	4.90 A	65.80 W	98.82 %

12. Temperature measurements

- The temperatures of the PV panel and the MPPT controller were monitored with an infrared thermal camera.
- Initially, the temperature of PV panel was 22°C. After the vehicle was left in the sunlight for 1 hour, the roof temperature was 48°C and the PV panel temperature 59°C. After 2 hours, the temperatures were 52°C and 71°C. Due to temperature increase, the efficiency of PV panel decreased.
- Initially, the average extracted power was 85 W, after 1 hour as 80 W, and after 2 hours as 70 W.
- For the MPPT controller, the highest temperatures were obtained on the voltage regulator (56°C), the output power inductor (49°C) and the high side transistor (46°C) of the DC-DC Buck converter.





13. Conclusions

- We have designed, implemented and tested a MPPT solar charge controller for a PV system mounted on a vehicle, to ensure the charging of batteries if the engine is not running and the vehicle is let in the sunlight.
- The flexible 100 W PV panel is mounted on the roof of the vehicle, and an auxiliary 12 V LiFePO4 battery pack is installed in the luggage compartment.
- The proposed MPPT controller monitors voltages and currents of the PV panel and the battery.
- Based on Perturb-and-Observe algorithm, the system achieves maximization of the panel's total power.
- All acquired parameters are displayed on LCD display and sent over the CAN interface for remote monitoring.
- The controller features different protections: reverse current protection, battery overcharge protection by deactivating the DC-DC converter and overcurrent and deep discharge protection by disconnecting the load.
- We have measured and compared the performances of the proposed MPPT controller with those of a commercial PWM controller, for two batteries: Lead-Acid and LiFePO4. In the same lighting conditions, replacing the PWM controller with the proposed MPPT controller, the power extracted from the PV panel has increased up to 23%.

14. References

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