Solar Charger using Boost Converter

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***Abstract*—This report presents the design, analysis, and implementation of a solar charger using a boost converter taking an input voltage of 0.6V. The key components involved are a solar panel, MPPT charge controller, boost converter, Charging module (TP4056), Battery Management System board, and batteries.**

***Index Terms*—Solar Panel, MPPT, Boost converter, MOSFET, Diode, Gain**

I. Introduction

With increased consumption of nonrenewable energy, the demand for solar powered systems increased. Solar systems are environmentally friendly, quiet, and reliable. The aim of this project is to raise an input voltage from 0.6V to 5.15V using a boost converter circuit. This voltage is then used to charge a battery using a BMS board.

1) Solar Panel : Provides input power for the system by converting sunlight into electrical energy.
2) MPPT Charge controller : Variations in lighting intensity cause the maximum power point to deviate. An MPPT charge controller dynamically adjusts the operating point to minimise energy loss.
3) Boost Converter : This circuit steps up input voltage (DC) to a higher DC voltage.
4) Charging Module : Regulates the voltage and current provided and charges a battery.
5) Battery Management System : Monitors state and protects circuit from unsafe conditions.

II. Solar Panel and MPPT

This project uses a solar panel as the primary energy source, with a MPPT charge controller to minimise energy loss. Together, they ensure efficient power delivery to the circuit.

A. Solar Panel Specifications

The solar panel generates a DC voltage based on sunlight intensity. The output of the solar panel varies with light intensity, temperature and load conditions. To match the power requirements of the circuit, we use a solar panel with the following specifications :

- Open circuit voltage = 10V
- Short circuit current = 0.42A
- max Power = 3W

This panel is useful in portable charging systems.

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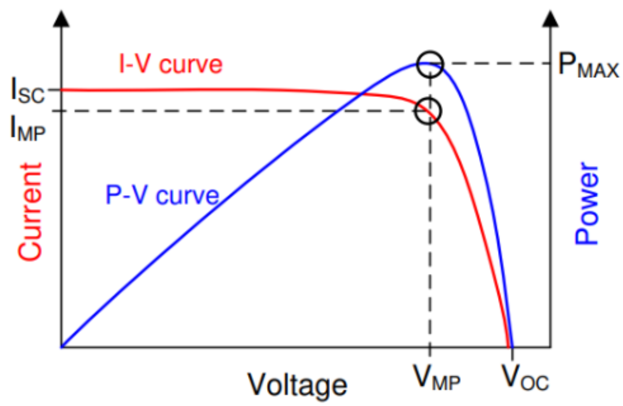

Fig. 1. VI/VQ Curve of a solar cell

Fig. 2. Hardware Setup

B. MPPT Charge Controller

*a) **The Problem**:* Solar Panels operate with maximum efficiency at a particular voltage and current condition. The optimal load characteristic which allows maximum power transfer is called the Maximum Power Point. Figure 1 shows the operating current and voltage corresponding to different loads. Due to variations in lighting, the maximum power point deviates. This leads to energy loss, leaving the battery uncharged or poor performance.

*b) **The Solution**:* A Maximum Power Point Tracking charge controller maximises power extraction from the solar panel by operating it at its MPP. It dynamically adjusts the load characteristic, improving efficiency. There are many ways to realise MPPT including current sweep, incremental conductance and the perturb and observe algorithm.

III. Boost Converter

A. Introduction

Figure 3 shows the schematic of a boost converter implemented in a simulation environment. The circuit utilizes an

IRFZ44N N-channel MOSFET as the main switching element and an 1N5822 Schottky diode for fast switching and low forward voltage drop. The input voltage V_1 is recieved as 0.6 V (variable and can be changed), and the goal is to achieve a higher output voltage across the load resistor R_1 through the boost operation.

The key components and their values are:

- Input voltage source: $V_1 = 0.6\,\text{V}$
- Inductor: $L_1 = 4.7\,\mu\text{H}$
- Switching MOSFET: IRFZ44N
- Flyback diode: 1N5822
- Output capacitor: $C_1 = 4.7\,\mu\text{F}$
- Load resistor: $R_1 = 1\,\text{k}\Omega$

The gate of the MOSFET is driven by a pulse voltage source V_2 with the following PULSE parameters:

- $V_{\text{low}} = 0\,\text{V}$, $V_{\text{high}} = 8\,\text{V}$
- Delay time = 0 s, Rise time = 0 s, Fall time = 0 s
- On-time = $8\,\mu\text{s}$, $Period = 10\,\mu\text{s}$

This corresponds to a duty cycle of 80%, which is a common setting for boosting low input voltages. The circuit is simulated over a time span of 15 ms using the SPICE directive:

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.tran 15m
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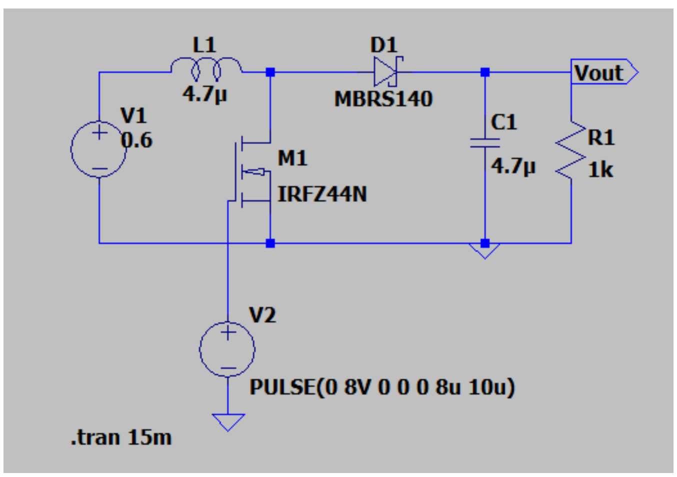

Fig. 3. Boost converter ckt

B. Working Of ckt

During the ON period of the pulse, the MOSFET conducts, storing energy in the inductor. In the OFF period, the inductor releases its stored energy to the output capacitor and load through the diode, thus boosting the voltage.

A boost converter is a DC-DC power converter that steps up (increases) the input voltage to a higher output voltage. The fundamental operation of the boost converter relies on the energy storage capability of the inductor and the controlled switching action of a MOSFET. The operation occurs in two main modes during each switching cycle: the **ON state (charging mode)** and the **OFF state (discharging mode)**.

a) 1. ON State (MOSFET Conducting): When the gate of the MOSFET (IRFZ44N in this case) is driven high by the pulse voltage source V_2, the MOSFET turns ON and provides a low-resistance path between its drain and source. This creates a closed loop between the input voltage V_1, inductor L_1, and the MOSFET. During this interval:

- The inductor L_1 is connected directly across the input supply.
- It starts storing energy in the form of a magnetic field.
- The diode D_1 is reverse biased due to the polarity across it, preventing current from flowing to the output.
- The output capacitor C_1 supplies energy to the load R_1, maintaining V_{out}.

b) 2. OFF State (MOSFET OFF): When the MOSFET turns OFF (i.e., the gate voltage from V_2 goes to 0 V), the inductor's stored energy is released. Due to the collapsing magnetic field, the inductor generates a voltage in the opposite polarity (Lenz's Law) and tries to maintain current flow. At this moment:

- The inductor's voltage adds to the input voltage, effectively boosting the total voltage applied to the output.
- The diode D_1 becomes forward-biased, allowing current to flow from the inductor to the output.
- Energy is transferred from the inductor to the capacitor C_1 and load R_1, raising the output voltage V_{out}.

c) Steady-State Operation: In steady-state, the switching between ON and OFF states happens rapidly (e.g., at a frequency of 100 kHz in this circuit with a $10\,\mu\text{s}$ period), and the output voltage stabilizes to a level higher than the input. The output voltage V_{out} of an ideal boost converter is given by:

$$V_{\text{out}} = \frac{V_{\text{in}}}{1 - D}$$

where D is the duty cycle (ratio of ON time to the total switching period). For a duty cycle of 0.8 (as in this case), the theoretical output is:

$$V_{\text{out}} = \frac{0.6}{1 - 0.8} = 3\,\text{V}$$

d) Key Design Considerations:

- The switching device (MOSFET) should have low on-resistance and fast switching speed to minimize losses.
- The diode should be a fast-recovery type (like the 1N5822) with low forward voltage drop.
- The inductor value determines the current ripple and affects efficiency.
- The output capacitor smooths the voltage and provides energy during switching transients.

By selecting appropriate component values and controlling the duty cycle of the gate signal, the desired boosted output voltage can be achieved efficiently.

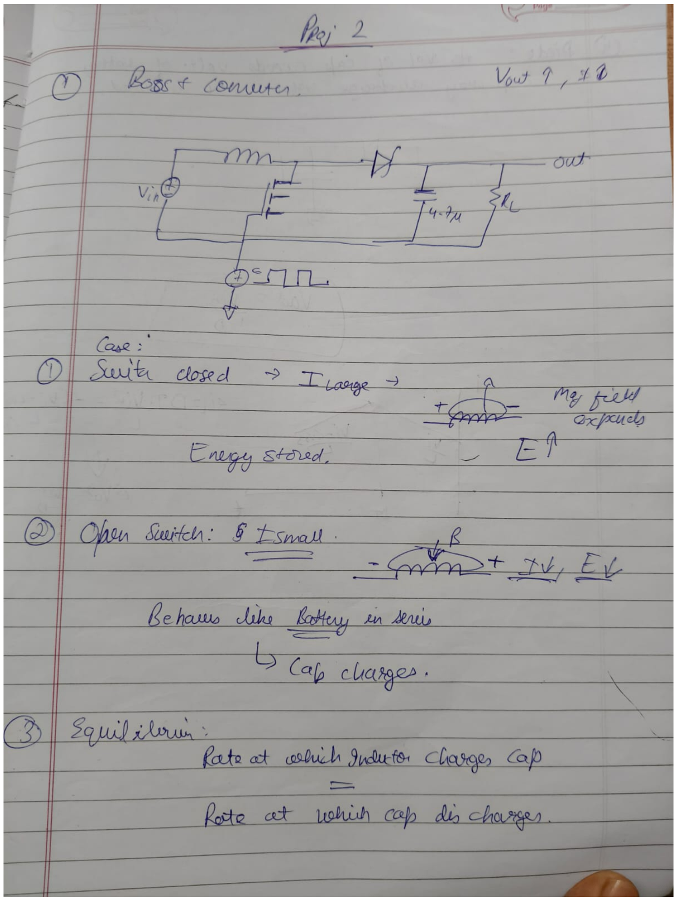

Fig. 4. Theory for Components

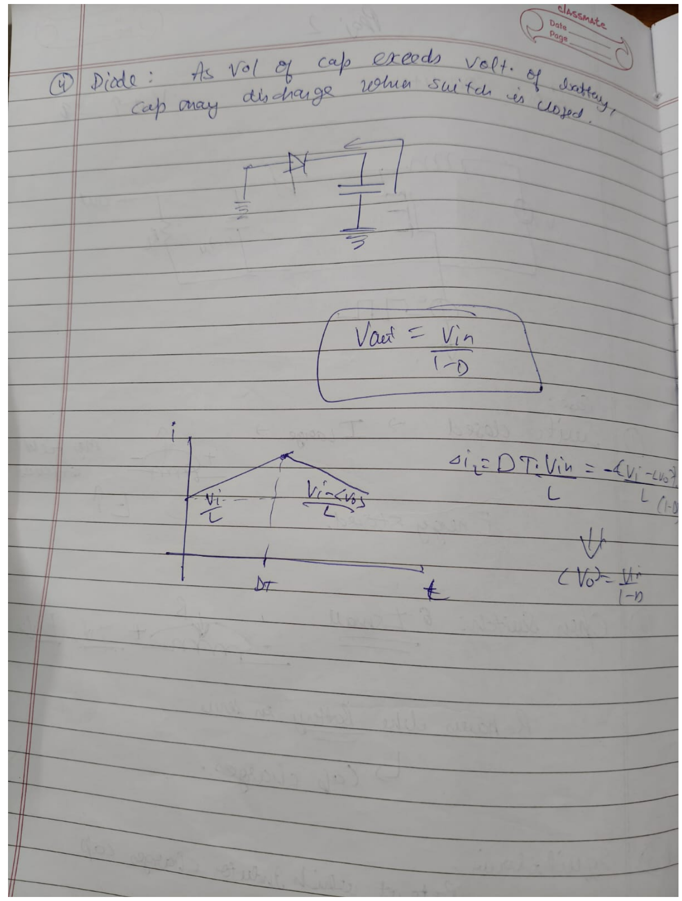

Fig. 6. Derivation of Vout

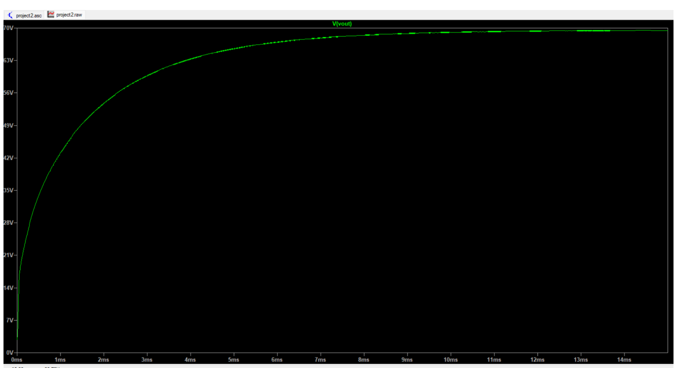

Fig. 5. LTspice simulation output

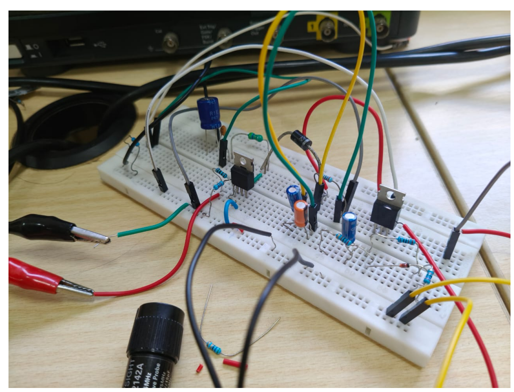

Fig. 7. Hardware Ckt for boost converter

IV. Voltage Regulation and Battery Charging using LM7805 and TP4056

After boosting the low input voltage to a higher level using the boost converter, it is necessary to ensure a regulated and safe voltage is supplied to the battery charging module. To achieve this, the output of the boost converter is passed through a linear voltage regulator—**LM7805**—which provides a stable 5 output.

LM7805 Voltage Regulator Stage: The LM7805 is a widely used linear voltage regulator that outputs a fixed 5 from a higher input voltage (typically 7 or more). In this circuit, it acts as an intermediary between the unregulated boost converter output and the battery charger, ensuring that voltage fluctuations do not affect the sensitive charging process.

- **Input Voltage:** Output of the boost converter (typically 7 to 12)
- **Output Voltage:** Regulated 5
- **Purpose:** Prevent overvoltage at the input of the TP4056 charging module

TP4056 Charging Module: The **TP4056** is a linear Li-ion battery charging controller IC designed to safely charge single-cell 3.7V lithium-ion batteries. It features constant current/constant voltage (CC/CV) charging, internal thermal regulation, and automatic charge termination. The module is suitable for applications where simple, space-efficient charging is required.

- **Input Voltage:** 4.5–5.5 (from LM7805)
- **Charging Method:** Constant current / constant voltage (CC/CV)
- **Charging Voltage:** 4.2 (for standard Li-ion cells)
- **Output:** Connected to a lithium-ion battery (typically 3.7 nominal)

The TP4056 ensures that the battery is charged safely by:

- Regulating charging current (typically 1, set by an on-board resistor)
- Monitoring battery voltage to switch between bulk and float charge phases
- Terminating charging when the battery reaches 4.2

Combined Operation: The combined use of LM7805 and TP4056 ensures a two-stage regulation:

1) The LM7805 provides a clean and stable 5 output regardless of boost converter ripple or fluctuations.
2) The TP4056 receives this stable voltage and manages the precise charging of the lithium-ion cell.

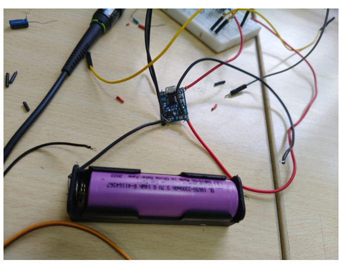

Fig. 8. Charging Module powering a 3.7 Lithium-ion Battery

This setup is compact, efficient for low-power applications, and helps in safely charging lithium-ion batteries from low-voltage sources such as harvested energy or portable power supplies.

V. Battery Management System

We use a 3-cell BMS board designed for a 3.7 V Li-ion batteries. The BMS board ensures a safe and reliable operation of the battery. It monitors state and protects the circuit from unsafe conditions. It also balances the voltage across cells. It optimises charging and extends battery life.

A. State Monitoring and Protection

- Prevents overcharging : The BMS monitors the battery voltage and cuts off charging if it exceeds 4.2 V.
- Prevents over-discharging : The battery powers the load through the BMS. The BMS cuts off the load if the battery voltage drops below 3.0 V or if the current exceeds 3 A.

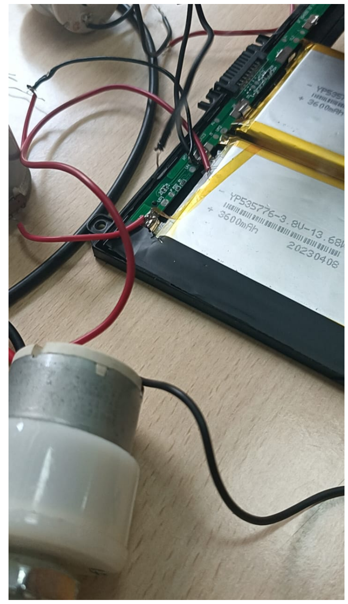

Fig. 9. BMS Board

- Overcurrent and short-circuit protection : The BMS limits the current to 3 A, disconnecting the circuit if this threshold is exceeded.

B. Cell balancing

BMS balances the voltage of each cell during charging to prevent overcharging of individual cells.

- Active balancing : The BMS transfers energy between cells using capacitors, inductors, or DC-DC converters, moving charge from higher-voltage cells to lower-voltage ones.
- Passive balancing : If a cell's voltage exceeds the threshold, the BMS dissipates excess energy as heat(across a resistor).

VI. Output Parameters

- **Output Voltage :** 5.15V
- **Response time :** approx. 15ms
- **Fluctuations :** The output was stable.

VII. DEMO

Video Link