

Enhancing Solar Smartphone Charger Efficiency Through MPPT Technology

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Abstract

This work focuses on the comprehensive design and development of a solar-powered smartphone charger integrated with Maximum Power Point Tracking (MPPT) technology. The research encompasses the study of Photovoltaic (PV) systems to understand their principles and characteristics. Additionally, an exploration of buck converter methodologies is undertaken to efficiently regulate the output voltage from the PV system to meet smartphone charging requirements. Calculations involving power, voltage, current, load, selection of the capacitor, inductor for PV system buck converter are crucial components of the design process. The research extends to the meticulous selection of components, considering their specifications, availability, and suitability for the intended application. MATLAB is employed for simulation purposes, enabling the assessment of the proposed system's performance under varying conditions. The work progresses to the hardware configuration, where the theoretical aspects are translated into a practical setup. The combination of these research components aims to provide a holistic understanding of the solar smartphone charger design, from theoretical principles to practical implementation, contributing to the advancement of sustainable and efficient charging solutions.

1. Introduction

In today's digital era, smartphones are vital for communication and entertainment, yet ensuring a constant and sustainable power supply remains a challenge. While traditional charging methods help, the global shift towards renewable energy demands innovative solutions, especially in remote areas lacking reliable electrical grids. This work addresses these issues by combining solar power and Maximum Power Point Tracking (MPPT) technology in a smartphone charger. MPPT dynamically adjusts solar panels to maximize power output, overcoming limitations of traditional solar chargers. Aligned with sustainable development goals, this work aims to provide a reliable, renewable energy source for smartphones worldwide, contributing to global efforts for eco-friendly solutions.

1.1 Problem Statement

In an era dominated by portable electronic devices, particularly smartphones, the reliance on these gadgets has become indispensable. However, conventional charging methods encounter challenges, especially in areas with limited access to electricity. To tackle this issue, the objective of this work is to design a solar smartphone charger

integrated with Maximum Power Point Tracking (MPPT) technology. The primary challenge lies in developing a charger that not only captures solar energy but also optimizes its utilization under various solar conditions. The work aims to achieve this by simulating and developing a smartphone charger powered by a solar panel using the buck converter method, implementing the MPPT controller to enhance output efficiency, and analyzing the impact of sunlight intensity on solar output before and after the MPPT implementation.

2. Literature Review

2.1 Charge Controller

A charge controller, or a charge regulator as an alternative term, functions primarily as a voltage and/or current regulator designed to prevent batteries from experiencing overcharging. Its role involves regulating both the voltage and current transmitted from the solar panels to the battery. Given that the majority of 12V panels typically generate around 16 to 20 volts, the absence of proper regulation could result in potential damage to the batteries due to overcharging [1].

There are two main types of charge controller for charging batteries using solar energy, which is Pulse Width Modulation (PWM), and Maximum Power Point Tracking (MPPT).

2.2 Maximum Power Point Tracking (MPPT)

The device responsible for optimizing the operation of a photovoltaic (PV) system to achieve maximum power extraction is called the Maximum Power Point Tracking (MPPT) controller [2]. Operating intentionally at the Maximum Power Point (MPP), irrespective of climatic conditions, enhances the efficiency of the PV system. Efficient power production is attained by aligning the PV source with the load under any climate condition. Two methods facilitate extracting maximum power from the PV array: mechanical tracking, involving adjustments to the PV panel direction based on seasonal changes, and electrical tracking, as in Fig. 1, which utilizes the I-V curve to locate the Maximum Power Point (MPP).

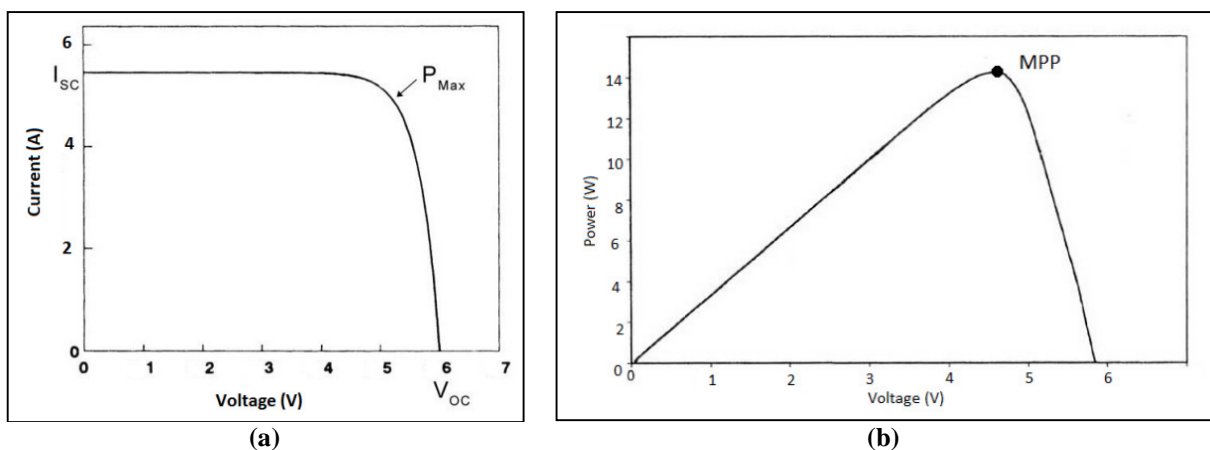


Fig. 1 Standard solar panel characteristic (a) I-V characteristics; (b) P-V characteristics curve

There are many types of MPPT algorithm. The following is some of it [3]:

- Perturb and Observe (P&O)
- Incremental Conductance (IC)
- Current Measurement Method
- The Fuzzy Logic Controller Method

2.3 Switching Voltage Regulator

Switching regulators convert one voltage to another by temporarily storing energy and then releasing that stored energy to the output at a different voltage [4]. The terms DC to DC converter, switched mode power supply (SMPS), switching regulator, and switching converter all refer to the same concept. These devices utilize a solid-state switch, such as a transistor or diode, to control the flow of current. By interrupting the current to an energy storage component like a capacitor or inductor, the voltage can be transformed from one level to another. There are various types of switching regulator topologies, with the three most common ones being:

- Buck (Step-Down) Switching Regulators
It reduces a higher input voltage to a lower output voltage, offering higher efficiency compared to linear regulators, especially when the input voltage is significantly higher than the desired output voltage.
- Boost (Step-Up) Switching Regulators

These converters can generate a higher output voltage than the input voltage, enabling applications like producing higher voltage levels from a single lower voltage source.

- Buck/Boost (Step-Down/Up) Switching Regulators

These converters provide a fixed output voltage even when the input voltage can vary above or below the desired output voltage, allowing for both step-down and step-up voltage conversion.

Table 1 shows the advantages and disadvantages of switching voltage regulators according to ROHM Semiconductor [5].

Table 1 *Advantages and Disadvantages of Switching Voltage Regulator*

Advantages	Disadvantages
<ul style="list-style-type: none"> • Demonstrates high efficiency, ensuring efficient conversion of voltage. • Generates low levels of heat during operation, minimizing thermal issues. • Capable of both boost (step-up) and buck (step-down) voltage conversion, as well as supporting negative voltage operation. 	<ul style="list-style-type: none"> • Requires a greater number of external components compared to other designs. • Involves a more complex circuit design. • Tends to exhibit increased levels of noise during operation.

3. Methodology

For the methodology, this work attempts to produce 9 to 10 volts of output to charge a smartphone. Generally, most smartphones nowadays use lithium-ion batteries. The minimum voltage required in order to charge it is around 3-4 volts. Under that, the battery will likely ignore the supply and refuse to charge. Theoretically, the latest smartphone is required around 9 volts of direct current at 2 amperes. However, a smartphone can still be charged at a lower current (1 ampere) but at a lower speed. Table 2 list all the components for this work.

Table 2 *Lists of Components*

No.	Components
1.	Solar panel (30W)
2.	ACS712 (5A) Current Sensor Module
3.	B25 0 to 25V Voltage Sensor Module
4.	Arduino Mega 2560 rev3
5.	L298N Motor Driver (as a MOSFET driver)
6.	IRF530N (MOSFET)
7.	47uF 50V Electrolytic Capacitor
8.	10uF 50V Electrolytic Capacitor
9.	Toroidal Inductor 3A (Ring) 470uH
10.	Schottky Diode
11.	Resistor (5W 22 Ohms)
12.	MTS-103 SPDT Toggle Switch 3 Pin 3 Ways
13.	3A Fuse (with fuse holder)
14.	USB Module

3.1 Designing Buck Converter

For the buck converter, there are several parameter values that need to find in order to get the desired output, such as the inductance (L), input capacitance (Ci), output capacitance (Co), load resistance (Ro).

Since PV array is used in this work, the conventional buck converter calculation cannot be used for several reason:

- Voltage input is not fixed (0V to Voc).
- Duty cycles are fluctuated.
- Power provided by the PV array can varies from zero power to maximum power (therefore output current, Io and load resistance, Ro cannot be calculated).

Note that there is no standard procedure to design the buck converter for PV system. Engineers usually design buck converter through trial-and-error method.

Therefore, after several consideration, for the calculation, systematic method explains by Ahsan Mehmood via YouTube will be used [6]. This method will consider Standard Test Condition (1000W/m² and 25°C) and Worst Condition (500W/m² and 25°C).

$$L = \frac{2 \times V_{mps} \times D_{mps} \times (1 - D_{mpw})}{\Delta I_{ow} \times fs} \tag{1}$$

$$C_i = \frac{\Delta I_{is}}{\Delta I_{iw} \times fs} \tag{2}$$

$$C_o = \frac{\Delta I_{os}}{32 \times \Delta V_{ow} \times fs} \tag{3}$$

3.2 System Block Diagram, Flowchart and Schematic Diagram

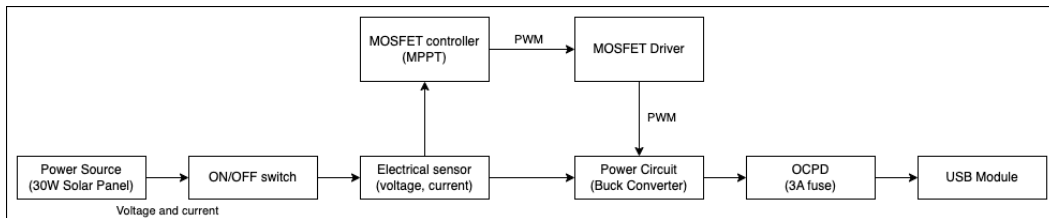


Fig. 2 System block diagram of the Solar Powered Smartphone Charger

Fig. 2 shows the system block diagram whilst Fig. 3 illustrates the configuration of the Solar-Powered Smartphone Charger system. The initial stage involves the PV panel harnessing solar energy and delivering power based on the prevailing irradiance and temperature conditions. Subsequently, the voltage and current are monitored and gauged through the implementation of sensors, specifically the B25 0 to 25V Voltage Sensor Module and ACS712 5A Current Sensor Module. These measurements serve as inputs for the MPPT algorithm embedded in the Arduino Mega 2560. The algorithm calculates power and determines the duty cycle. If the computed duty cycle maximizes power output, a PWM signal is generated for the MOSFET within the buck converter. In case the initially computed duty cycle fails to reach the maximum power output, the MPPT algorithm initiates a recalculation and issues a revised duty cycle. This iterative process persists in a continuous loop until the system successfully achieves the optimal power output. Next, converter steps down the voltage to achieve the desired output. Finally, the regulated voltage is directed to the USB Module.

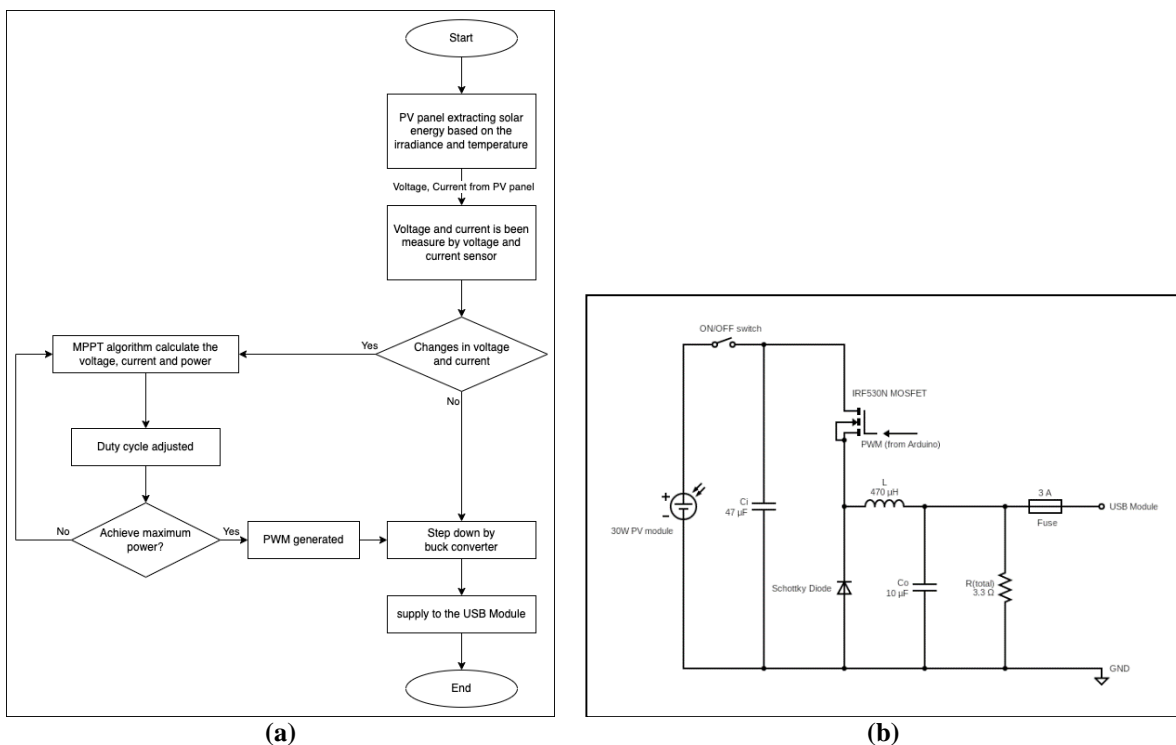
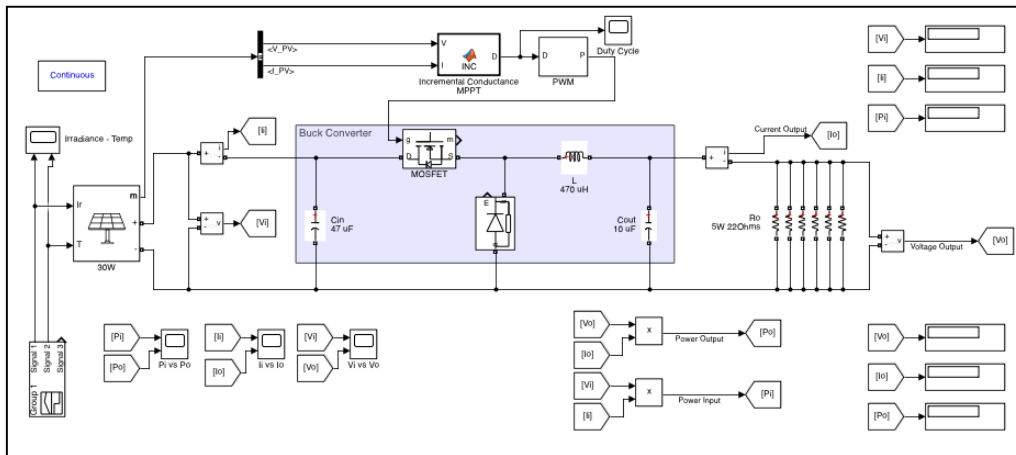


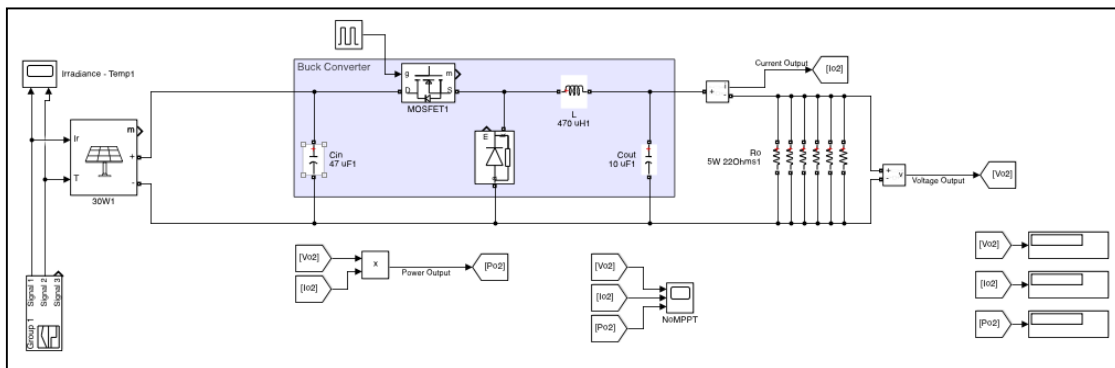
Fig. 3 (a) System flowchart; (b) System schematic diagram

3.3 MATLAB Simulation Circuit

Fig. 4(a) shows the circuit for the simulation using MATLAB Simulink. The circuit consists of a few blocks such as PV array, signal builder, series RLC branch, MOSFET, diode, MATLAB function block, PWM generator (DC-DC). For the buck converter, the parameters are set based on the calculation; $C_{in}=38.11\mu F$, $C_o=5.37\mu F$, $L=2740.72\mu H$, $R_o=3.32\text{ Ohms}$. Fig. 4(b) shows another simulation circuit without the implementation of the MPPT. This circuit aim to give comparison output result with and without MPPT.



(a)



(b)

Fig. 4 Simulation circuit using MATLAB Simulink (a) With MPPT; (b) Without MPPT

As shown in Fig. 5, Signal Builder Block was used to shows result at different irradiance condition (1000W/m², 700W/m², 500W/m²) while keeping a constant temperature at 25°C. Whilst Fig. 6 shows the algorithm for incremental conductance.



Fig. 5

Builder Block setting for the irradiance and temperature

Signal

```

function D = INC(V,I)
Dinit = 0.42;
Dmax = 0.85;
Dmin = 0.1;
deltaD = 0.00005;
persistent Vold Pold Dold M Iold;
dataType = 'double';
if isempty(Vold)
    Vold = 0;
    Pold = 0;
    Iold = 0;
    Dold = Dinit;
    M = 1;
end
P = V*I;
dV = V - Vold;
dP = P - Pold;
dI = I - Iold;
M = 1;
if M < 0.005
    D = Dold;
else
    if dV == 0
        if dI == 0
            D = Dold;
        elseif dI > 0
            D = Dold - (M*deltaD);
        else
            D = Dold + (M*deltaD);
        end
    else
        if dI/dV == -I/V
            D = Dold;
        elseif dI/dV > -I/V
            D = Dold - (M*deltaD);
        else
            D = Dold + (M*deltaD);
        end
    end
end
if D >= Dmax || D <= Dmin
    D = Dold;
end
Dold = D;
Vold = V;
Iold = I;
Pold = P;

```

Fig. 6 Incremental Conductance algorithm for MATLAB simulation

4. Result and Discussion

The simulation outcomes present a comparative analysis between input and output parameters, encompassing current, voltage, and power. Additionally, the results explain the impact of variations in irradiances on the system's output. Furthermore, the simulation demonstrates the influence of the implemented Maximum Power Point Tracking (MPPT) technique on the output. These findings collectively contribute to a comprehensive understanding of the system's behavior under different conditions, offering valuable insights for the advancement of solar power technology.

4.1 Irradiance, Temperature, MPPT Duty Cycle

The shown Fig. 7 illustrates the output from the signal generator block set specifically for the PV array in the simulation, which spanned a duration of 3 seconds. In Fig. 7(a), the irradiance profile is detailed, beginning at 1000 for 0.5 seconds, followed by a decrease to 700 for another 0.5 seconds, further dropping to 500 for an additional 0.5 seconds. Subsequently, the irradiance rises to 700 for 0.5 seconds and then returns to 1000 for the remainder of the simulation. Fig. 7(b) showcases a consistently set temperature of 25 degrees Celsius.

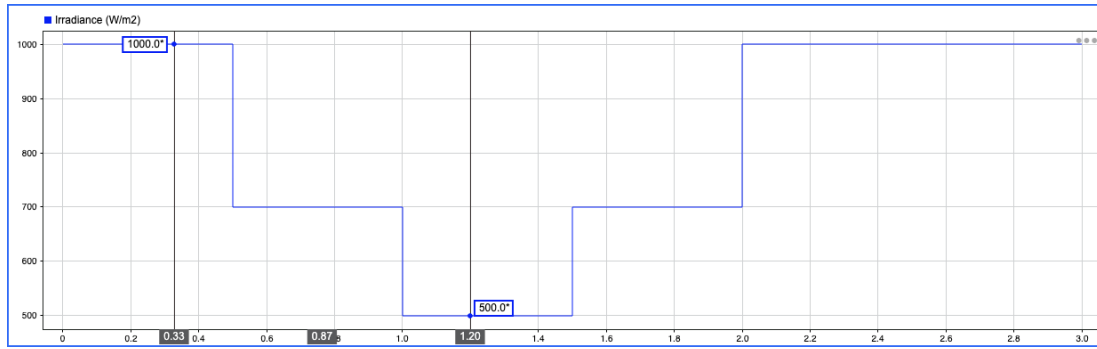
Lastly, in Fig. 7(c), the duty cycle generated by the Maximum Power Point Tracking (MPPT) for the buck converter MOSFET is presented. The graphical representation reveals that the MPPT successfully attains both the maximum and minimum duty cycles, closely aligning with the calculated values, namely $D_{mps} = 56.18\%$ and $D_{mpw} = 41.76\%$.

4.2 Input, Output (without MPPT), and Output (with MPPT) Comparison

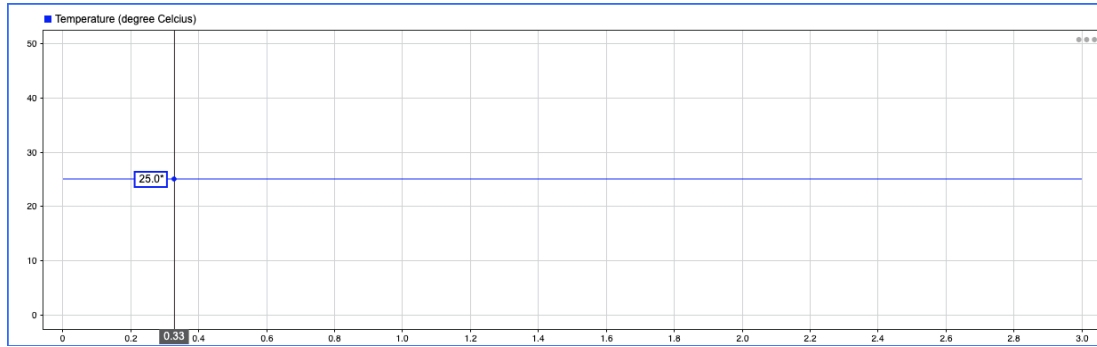
The presented Fig. 8 depict a comparative analysis between the input and output signals of voltage, current, and power subsequent to the implementation of Maximum Power Point Tracking (MPPT) in MATLAB Simulink. Fig. 8 (a) illustrates the stability of the input voltage within the range of 17.8V-18.1V under standard and worst irradiance conditions (1000W/m² and 500W/m², respectively). The output voltage, however, drop to 6.8V at standard and 3.4V at worst condition. Post-MPPT application, a notable increasing is observed, with voltage ranging between 9.7V and 6.8V.

Fig. 8 (b) demonstrates the input current, maintaining levels of approximately 1.7A-0.8A during standard and worst irradiance conditions. The output current shows a slight increase to 1.84A – 0.93A followed by another amplification to 2.9A-2A after MPPT integration.

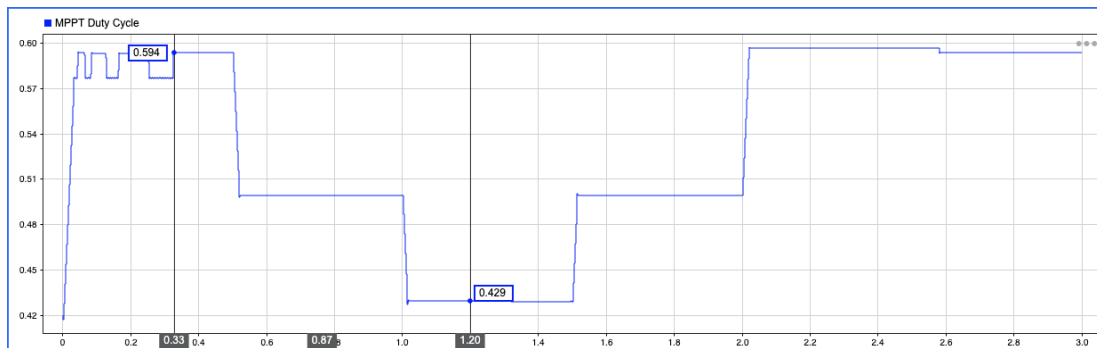
Fig. 8 (c) shows the input power ranging between 30.1W to 15.2W. However, the output power shows 41% drop in power, around 12.4W to 3.2W. After MPPT implementation, the output power has been brought up close to the input power which is around 28.6W to 13.9W. This shows the MPPT successfully draw the maximum power as possible and increase the efficiency of the product.



(a)

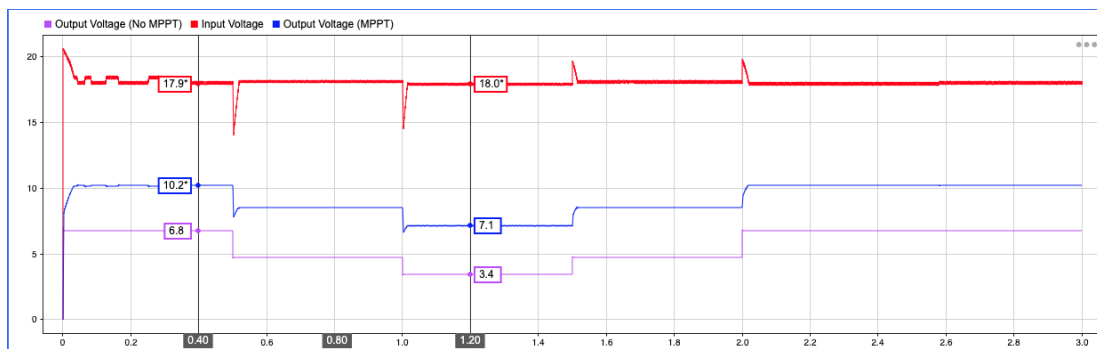


(b)



(c)

Fig. 7 (a) Irradiance (W/m²); (b) Temperature (°C); (C) MPPT Duty Cycle



(a)

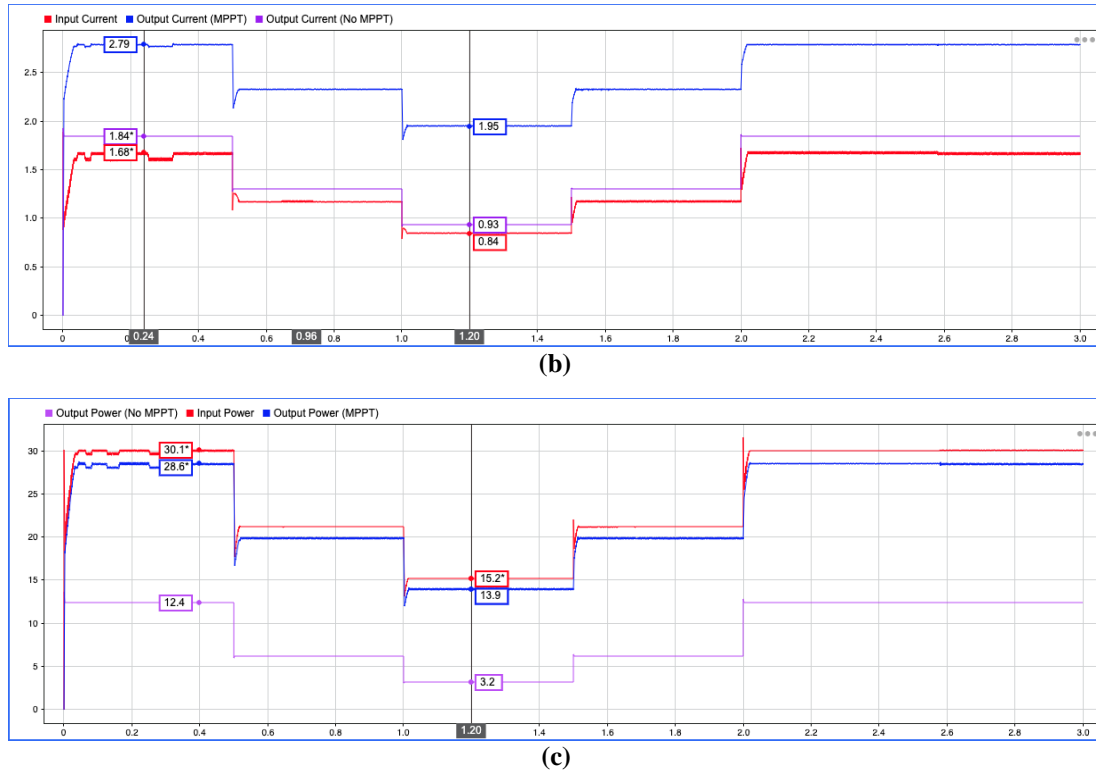


Fig. 8 (a) Input voltage, output voltage (no MPPT), output voltage (with MPPT); (b) Input current, output current (no MPPT), output voltage (with MPPT); (C) Input power, output power (no MPPT), output voltage (with MPPT)

4.3 PWM test on Arduino Mega

Fig. 9 shows the snippet of code in Arduino IDE to generate the PWM shown in the Fig. 10.

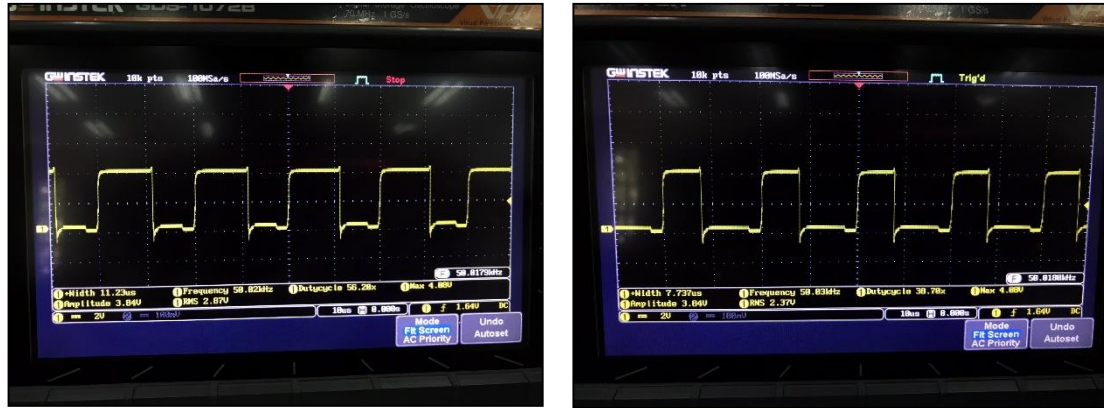
```

1  int count_icr, frequency, duty_cycle, dataf ;
2
3  int16_t Loop;
4
5  void setup()
6  {
7      Serial.begin(9600);
8      pinMode(11, OUTPUT);
9
10     TCCR1A = 0xA2;
11     TCCR1B = 0x19;
12     TCNT1H = 0x00;
13     TCNT1L = 0x00;
14
15     duty_cycle = 0; //0-100%
16     count_icr = 319; //319 for 50kHz
17     frequency = 16000 / (1 + count_icr);
18     Serial.println("Input pwm value 0 - 100% :");
19     Serial.print("F(kHz) = "); Serial.println(frequency);
20
21     ICR1H = count_icr >> 8;
22     ICR1L = count_icr & 0x00ff;
23 }
24
25
26
27 void loop()
28 {
29     if (Serial.available())
30     {
31         if (Loop == 0)
32         {
33             duty_cycle = Serial.parseInt();
34             OCR1A = count_icr * (duty_cycle / 100.0);
35             delay(50);
36             Loop = duty_cycle;
37         }
38     }
39
40     if (Loop == duty_cycle)
41     {
42         Serial.println("Input pwm value 0 - 100% :");
43         Serial.println(duty_cycle);
44         duty_cycle = Serial.parseInt();
45         Loop = duty_cycle;
46         delay(50);
47     }
48 }

```

Fig. 9 Arduino coding to generate the PWM

Fig.

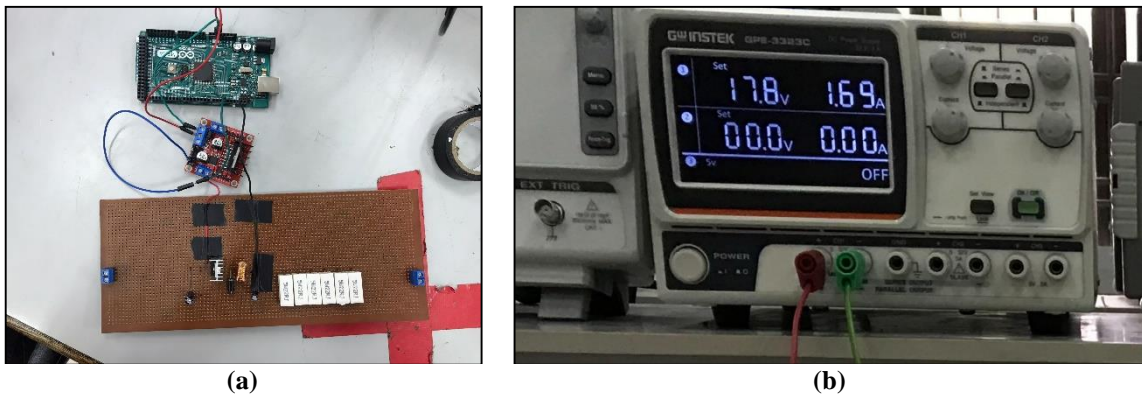


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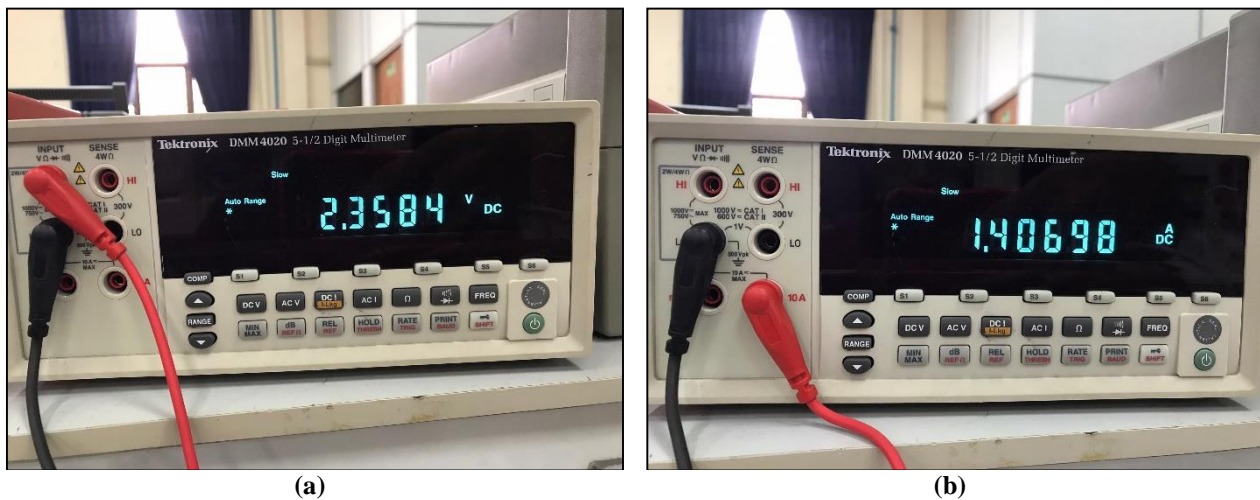
(a) (b)
Oscilloscope result (a) 56.18% duty cycle; (b) 41.76% duty cycle

4.4 Buck Converter Test

Fig. 11 shows the hardware buck converter and its power supply setting. Whilst, Fig. 12 shows the output readings for voltage and current measured by a digital multimeter. As shown, the buck converter did not perform as intended (according to the calculation and simulation), as the expected output should be around 10V at 3A. Further investigation, including a continuity test on the circuit, revealed a short in the MOSFET at the drain and source pins following the completion of the buck converter testing. Notably, both the input capacitor and inductor displayed no signs of damage, burn, or smoke. The PWM signal was scoped and appears to be working accordingly.



(a) (b)
Fig. 11 Buck Converter Test (a) Hardware buck converter; (b) Power supply setting



(a) (b)
Fig. 12 Buck converter output at 56.18% duty cycle (a) voltage; (b) current

5. Conclusion

In the pursuit of designing a solar-powered smartphone charger integrated with Maximum Power Point Tracking (MPPT) technology, a comprehensive exploration into various aspects of photovoltaic systems has been undertaken. The study delved into the elaborate principles and characteristics of solar panels, providing a nuanced understanding of energy extraction from sunlight. The in-depth examination extended to the realm of MPPT algorithms, encompassing diverse algorithms and acquiring proficiency in coding for Arduino implementations. Further, the study involved a meticulous exploration of buck converter design, including comprehensive calculations and simulations using MATLAB Simulink. The experiential journey unfolded with hands-on learning in hardware configuration, unveiling the intricacies and challenges inherent in the practical realization of the designed system.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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