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# DEVELOPMENT OF DC-DC BUCK CONVERTER FOR SOLAR PANEL ENERGY STORAGE THROUGH LOAD OPTIMIZATION AND FEEDBACK CIRCUIT

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## ABSTRACT

Solar panels are crucial components in converting sun radiation into electrical energy through the photovoltaic effect. A solar panels cannot be connected directly to the load due to its low energy conversion efficiency and low output voltage. One of the methods used to control solar cells to operate efficiently at their maximum power point is MPPT. In this paper, we design a DC-DC converter by modifications of the Butterworth filter circuit and feedback circuit in the MPPT system for storing solar panel electrical using the Hill Climbing (HC) method. The device consists of a DC-DC buck converter circuit, two pieces of INA219 sensors, a DS18B20 temperature sensor, a MAX44009 light intensity sensor, a SD card module and a DS3231 RTC. The DC-DC buck converter circuit simulation is carried out to determine the optimal load. The load optimization was conducted by analyzing the AC simulation using Ltspice software. The magnitude of the output voltage ripple in nine different loads was observed. From the simulations performed, it was found that the 50  $\Omega$  load has an output voltage ripple of 8.96 mV and is smaller than the other loads. The main DC-DC buck converter circuit is designed using a butterworth low pass filter with a cut-off frequency of 1000 Hz ( $R = 50 \Omega$ ,  $L = 33.8 \text{ mH}$  and  $C = 750 \text{ nF}$ ) and a feedback circuit with a cut-off frequency of 500 Hz is added. From the prototype measurement, it was found that the average output power was 3249,7 milliwatts and the average input power was 4779

milliwatts, thus the average efficiency was 68%. With these results, the DC-DC converter circuit configuration is suitable for use in electrical energy storage systems from solar panels that have high efficiency.

**Keywords:** MPPT, DC-DC buck converter, load optimization, cut off frequency, hill climbing

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## INTRODUCTION

Using renewable energy is a crucial step towards reducing our dependence on fossil fuels. Indonesia has significant potential for solar energy due to its geographic location near the equator, resulting in high solar irradiance throughout the year. The country's abundant sunlight makes solar power an attractive renewable energy option. Solar panels, also known as photovoltaic (PV) panels, are crucial components in converting sun radiation into electrical energy through the photovoltaic effect. This process involves the direct conversion of sunlight into electricity by exploiting the properties of semiconductor materials [2,3].

Solar panel output voltage can vary based on the specific design, configuration, and purpose of the panel. Its output is also influenced by environmental factors, such as length of sunlight, environmental temperature, shading, cleanliness of solar panels [4,5]. However, individual solar panels often produce voltages in the 12V to 75V range [6]. Meanwhile, the output power produced by solar panel systems ranges from several milliwatts (mW) to megawatts (MW) for residential or industrial applications [7].

The Maximum Power Point (MPP) is the point at which a solar panel, or an array of solar panels, produces the maximum amount of power [8]. It is determined by a specific combination of solar radiation level and temperature [9]. The relationship between the output power of a solar panel and the operating conditions can be visualized on a graph known as the power-voltage (P-V) or power-current (P-I) curve. The MPP on this curve represents the ideal operating point for maximum power output. Therefore, maximum power point tracking (MPPT) is important in PV systems [10].

DC-DC Converter is an electronic device designed to regulate solar panel output voltage fluctuations [11]. DC-DC Converters function to control and stabilize the output voltage of solar panels to match the voltage levels of other devices and minimize energy loss during the conversion process [12-14]. There are three types of DC-DC converters, that are Boost, Buck, and Buck-Boost Converter. The boost type converter aims to increase the working voltage level relative to the input voltage [15]. The Buck type converter changes the DC voltage to a lower voltage than the input voltage [16]. Meanwhile, the Buck-Boost Converter regulates the output voltage to be higher or lower relative to the input voltage depending on the duty cycle and polarity reversal at the output [17].

In MPPT operation, an algorithm is employed to enable the PV system to efficiently track and operate at the maximum power point of the solar panels [18]. Some popular types of MPPT algorithms are Perturb and Observe (P&O), Incremental Conductance (IC), and Hill Climbing (HC). Each algorithm has differences in implementation, complexity and capabilities. The

P&O method has a simple design and uses a very small number of sensors to measure voltage and current thus it can save costs [19]. Meanwhile, the Incremental Conductance method can find MPP accurately under rapidly changing radiation conditions [20]. The HC algorithm works by varying changes in output voltage or current and monitoring the resulting changes in power. The HC algorithm is widely used in research and industry because it is easy to implement [7].

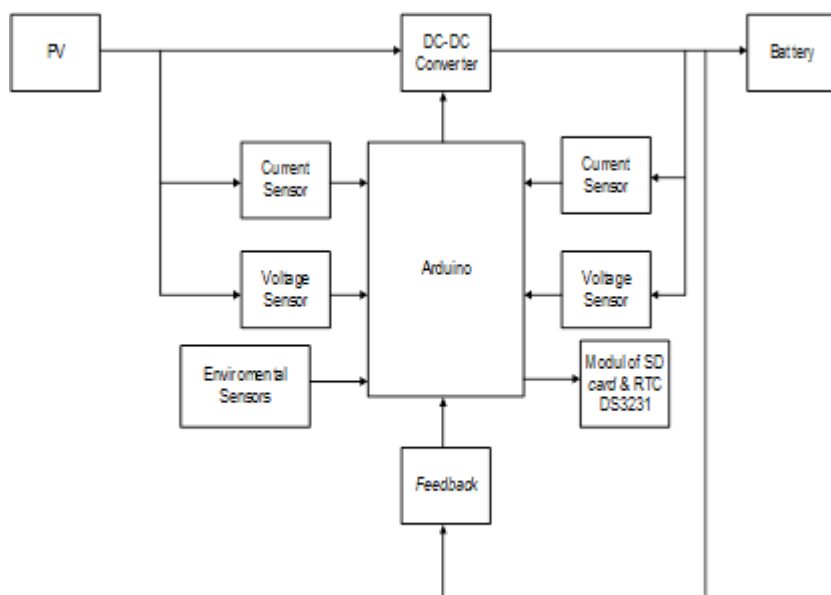
In this paper, the development of a DC-DC Buck Converter circuit with modifications to the Butterworth filter circuit and feedback circuit is presented. The used of Butterworth filter to attenuate the harmonic components of the output voltage or current and ensured that the load receives a DC voltage with minimal ripple [21,22], as well as affects other performance of converter [23]. Furthermore, the feedback circuit enhance the efficiency and stability through adjustment of switching parameters in response to the output voltage. The feedback loop ensures that the converter adapt to the load and input variations to prevent oscillations in the output voltage [24]. To increase system efficiency, MPPT is used with HC algorithm and load optimization on the filter circuit. The sensors used in this research are voltage sensors, current sensors, temperature sensors, and light intensity sensors. The SD card module is used as a data logger and the RTC DS3231 is added with the aim of capturing data in real time.

## METHOD

In this research, we used a basic topology of DC-DC buck converter [3]. The buck converter circuit consists of diodes, inductors, capacitors, load resistors and active switches. The development of the DC-DC buck converter was carried out using a Butterworth type low pass filter circuit with a cut off frequency of 1000 Hz. The magnitude of R, L, and C on the filter are based on filter cut off calculations with a source frequency of 50 kHz from the microcontroller. Thus, the obtained magnitude are  $R = 50 \Omega$ ,  $L = 33.8 \text{ mH}$ , and  $C = 750 \text{ nF}$ . In the buck converter circuit, feedback is also added using a cut off frequency of 500 Hz. The feedback circuit are widely used to generate the PWM signal, maintaining the output voltage at the set point and controlling the gate driving signal to assure the transistor do not switch simultaneously [24]. The feedback circuit is built using the TLC2272CP OP-AMP IC, a 100 nF capacitor, and 4K  $\Omega$ , 1K  $\Omega$  and 3.3K  $\Omega$  resistors. Load optimization was also carried out to increase electrical power efficiency in the prototype.

The prototype was designed using a 10 WP monocrystalline solar panel as the main power source for the circuit and was positioned at a tilt angle of  $10^\circ$  [25]. The prototype uses two current and voltage sensors (INA219), as well as two environmental sensors, there are a light intensity sensor type MAX44009 and a temperature sensor type DS18B20. The environmental sensors was used to observe the influence of the surrounding environment on the amount of power produced by the prototype. The prototype is equipped the RTC DS3231 to capture data in real time thus the data measurements can be stored automatically on the SD card. The optocoupler type of 4N25 is installed in the circuit performs as the MOSFET driver IC. The MOSFET acts as a switch in the buck converter circuit. Meanwhile, the optocoupler works as a gate driver on a MOSFET which has a high-speed switching process. The Arduino, as control system, uses as a system interface that is integrated with the MPPT control algorithm to receive

and transmit data from sensor reading results. The block diagram of this system is depicted in FIGURE 1.



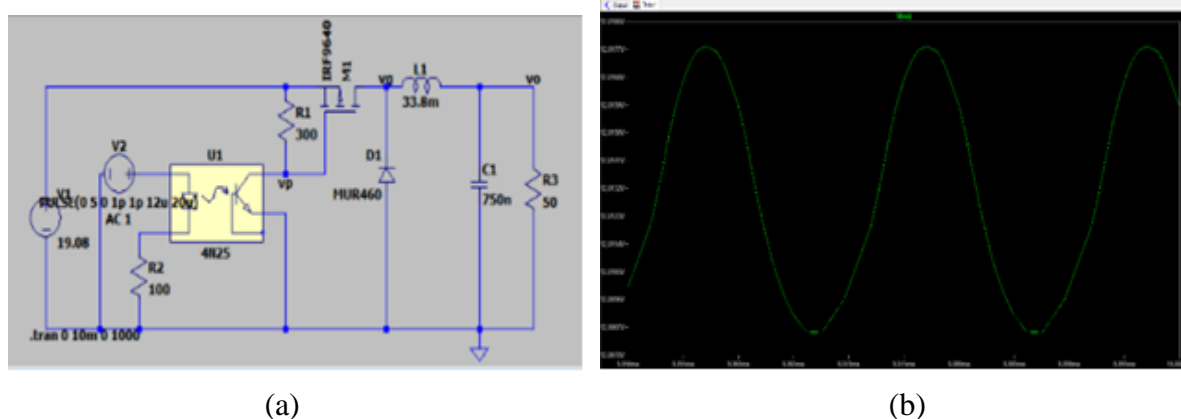
**FIGURE 1.** Block diagram

Based on FIGURE 1, the solar panel block functions as a producer of unregulated DC power produced from sunlight. The voltage sensor block functions as a voltage meter before and after entering the DC-DC Converter. The current sensor block functions as a current meter before and after entering the DC-DC converter. The DC-DC Converter Block functions to convert unregulated DC current into a more stable DC current. DC-DC converters consist of MOSFETs, inductors, diodes, capacitors and optocouplers as MOSFET drivers. Arduino block as MPPT algorithm processor, PWM duty cycle processor, and sensor data processor. The Feedback Block is a control system that keeps the output voltage from the DC-DC Converter constant. Battery Block as a load to store power supplied from DC-DC.

## RESULT AND DISCUSSION

### Load optimization on the buck converter circuit

The load optimization of the buck converter circuit is carried out to obtain an optimal load magnitude. The load optimization was conducted by analyzing the AC simulation on the circuit of FIGURE 2a using Ltspice software. The circuit simulation aims to observe the magnitude of the output voltage ripple that may appear on each filter with different loads. The experiment was conducted with nine load variations, while the input voltage used was 20 V and the input frequency from the Arduino UNO was 50 kHz.



**FIGURE 2.** (a) Schematic of the initial DC-DC Buck Converter circuit [3] (b) Output voltage ripple simulation results

The simulation results in FIGURE 2b show that there is an output voltage ripple. The output voltage ripple can be determined by calculating the difference between the peak and valley voltages. The calculation results obtained from the circuit simulation are presented in TABLE 1.

**TABLE 1.** Calculation of output ripple voltage ( $V_{\text{peak}}$ )

No.	Load ( $\Omega$ )	$V_{\text{peak}}$ (mV)
1	10	10,44
2	50	8,96
3	100	9,01
4	150	9,27
5	200	9,28
6	250	9,21
7	300	9,25
8	350	9,22
9	400	9,24

TABLE 1 shows the relationship between filter load and output voltage ripple ( $V_{\text{peak}}$ ). It can be seen that the filter with a  $50 \Omega$  load has an output voltage ripple ( $V_{\text{peak}}$ ) of 8.96 mV. This voltage value indicates a leak in the filter during the dampening process. This  $V_{\text{peak}}$  is smallest than the other  $V_{\text{peak}}$  using other loads resistor. Thus, it is concluded that a load of  $50 \Omega$  is the most optimal load for the filter circuit.

### The feedback circuit

The feedback circuit works to control the output voltage by feeding back the output voltage to be transmitted to the microcontroller. The feedback circuit shown in FIGURE 3 is designed by applying the voltage divider principle to resistors R3 and R2, and using input from the DC-DC Converter voltage. The principle of this voltage divider aims to reduce the output voltage that will be fed back that its magnitude is less than 5V.

FIGURE 3 shown that there is an RC low pass filter with a resistance of  $3.3K \Omega$  and a capacitance of 100 nF. These components are applied to obtain a cut off frequency of 500 Hz based on EQUATION 1.

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2 \cdot 3,14 \cdot 3300 \cdot (100 \cdot 10^{-9})} \approx 500 \text{ Hz} \tag{1}$$

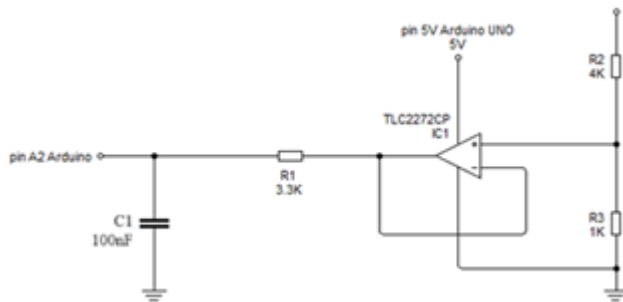


FIGURE. 3. The Feedback Circuit

Determining this frequency aims to reduce noise from the previous filter and to stabilize the feedback voltage. The output voltage of an RC low pass filter will be transmitted to the Arduino UNO through an analog pin 2. The TLC2272CP OP-AMP IC is used as a buffer circuit, so that the output of the feedback circuit will be more stable.

### DC-DC Buck Converter Circuit

The final DC-DC buck converter circuit design process is conducted by combining the basic circuit of the DC-DC buck converter with a feedback circuit. The results of the final DC-DC buck converter circuit are presented in FIGURE 4. Characterization of the output voltage needs to be carried out to determine the minimum input voltage limit when the duty cycle condition is 100%. The buck converter input voltage variation is 13 V to 22 V sourced from a DC power supply. Meanwhile, the output voltage is set at 12 V according to the battery's level voltage. This process aims to determine the duty cycle value for each given input voltage variation.

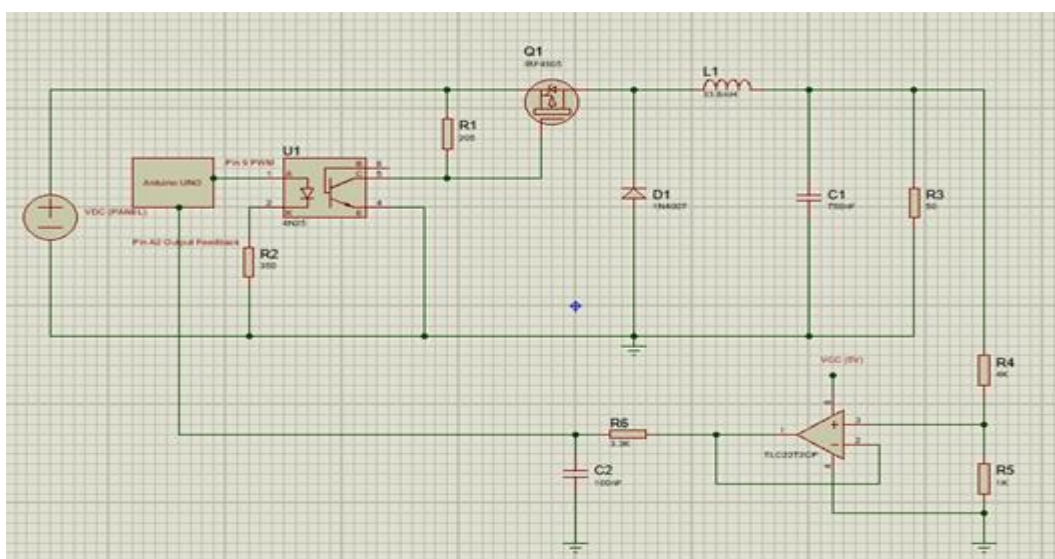


FIGURE. 4 DC-DC buck converter Circuit

The results of the buck converter output voltage characterization are shown in FIGURE 5. Based on FIGURE 5, it is found that the relationship between the duty cycle when the output voltage is 12 V and the input voltage is exponential, so we get the equation:

$$D = 197,94e^{-0,058x} \quad (2)$$

Where D is the duty cycle (%), and x is the input voltage (V). This equation is then coded into the Arduino UNO programming though the duty cycle is immediately set up when the system starts, and the output voltage value of the buck converter circuit is 12 V.

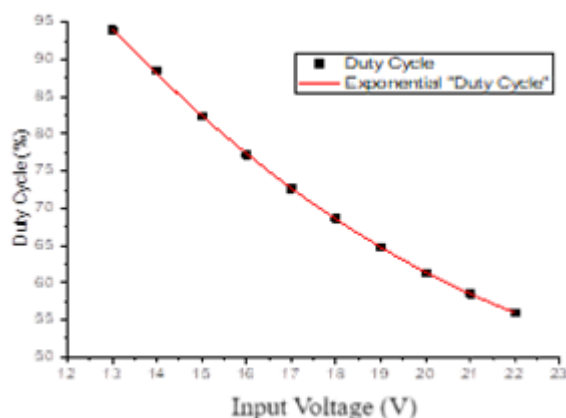
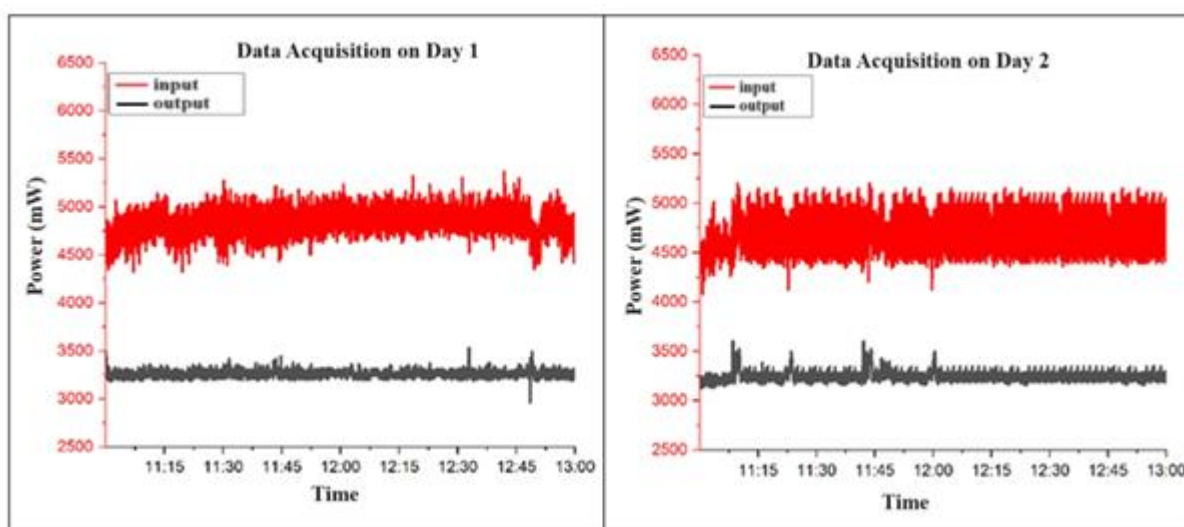


FIGURE 5. Duty Cycle at an output voltage of 12 V for input voltage variations

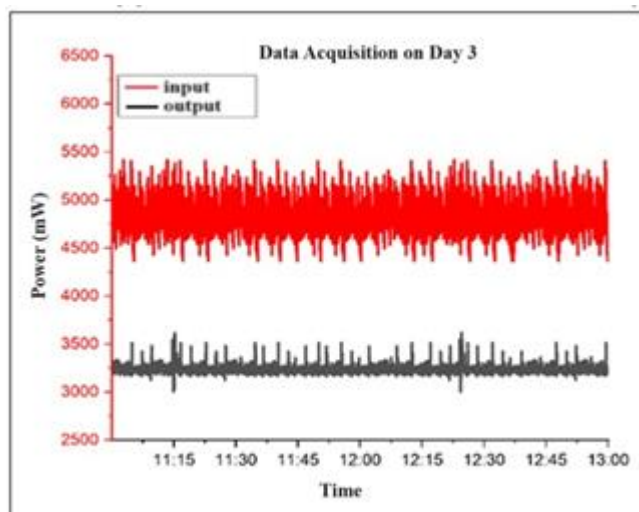
### Data Acquisition

Prototype data acquisition was carried out for 3 days on 11.00 to 13.00 using the sun as an energy source for solar panels. The selection of this time range is based on the consideration that the intensity of sunlight received by the solar panels is greater than other time ranges, as well as the power produced by the solar panels [17]. The result in three days is shown in FIGURE 6.



(a)

(b)



(c)

**FIGURE 6.** The Power of Prototype (a) First day, (b) Second day and (c) Third day

Based on FIGURE 6, the prototype output shows power stability in the range of 3,100 to 3,300 mW. There is a power spike resulting from a significant change in the prototype's voltage. On the first day, it was found that the average input power was 4,825.28 mW and the average output power was 3,261.14 mW. On the second day, the average input power was 4,675.75 mW and the average output power was 3,247.45 mW. On the third day, the average input power was 4,836.89 mW and the average output power was 3,240.63 mW. Based on this data, the amount of efficiency produced by the prototype can be calculated. This efficiency is obtained by comparing the average output power with the average input power from the source (solar panels) as measured by the sensor at any time. The average efficiency of the prototype on the first, second and third days was 67.58%, 69.45% and 67.00% respectively. The difference in efficiency values depends on the amount of power entering and leaving the prototype. Apart from that, weather conditions also greatly influence differences in prototype efficiency values. This is in accordance with environmental data obtained from environmental sensor measurements. Where the average incoming light intensity values on the first, second and third days were 70,242.16 lux, 99,117.03 lux, and 65,865.69 lux, respectively. Meanwhile, the average temperature values on the first, second and third days were 37.10°C, 37.25°C and 36.46°C respectively.

## CONCLUSION

The development of a DC-DC Converter with a modified Butterworth Low Pass Filter and a feedback circuit in cut off frequencies of 1000 Hz and 500 Hz respectively has been successfully carried out. The DC-DC buck converter circuit simulation carried out to determine the optimal load shows that a 50  $\Omega$  load has the lowest output voltage ripple ( $V_{peak}$ ) of 8.96 mV. Based on data acquisition for three days, the average input power was 4,779 mW and the average output power was 3249.7 mW, so the average power efficiency obtained was



68%. With these results, the DC-DC converter circuit configuration is suitable for use in electrical energy storage systems from solar panels that have high efficiency.

### ACKNOWLEDGEMENT

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