DC-DC Buck Converter Circuit Simulation on Solar Panel Electricity Storage System

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Abstract. Electrical energy is one of the energies that humans widely use. One of the components used to generate electrical energy is solar cells. By using solar cells, energy can be stored in a battery or used directly. In stores electrical energy into the battery using DC-DC converter is still found to have a loss of power that affects the low efficiency of electricity generated. So it needs a system that can control the process of storing energy to the battery, one of which uses a DC-DC converter with Buck topology that will be used on solar panel electrical power storage system. To optimize the DC-DC Buck converter circuit, we plan a circuit simulation by considering the value of the quality factor Q of the Butterworth filter. The test results showed that the filter with a value of Q = 0.707 was of good quality with a gain of -3.1 dB. If the Q value increase, the gain will be increased, and the time it takes until the voltage stabilizes increases.

1. Introduction
Energy has an essential role in human life to date, one of which is electrical energy. Today's electrical power still uses fossil energy sources, where its availability has been depleted in nature and has an environmentally unfriendly effect [1]. By looking at this condition, new renewable energy that is environmentally friendly is needed. One of the efforts to use renewable energy is using solar cell technology. Solar cells are made of semiconductor materials that can convert solar radiation into electrical energy with the photovoltaic principle [2]. The electrical energy produced by solar cells can be used directly or stored in batteries.

Various kinds of developments in the use of solar cells have been carried out to increase the production of energy produced, ranging from technology by combining solar cells with other energy producers (hybrid) and the use of solar tracker technology [3]–[4]. In addition, further developments are carried out using a DC-DC converter in the energy transmission process. One of these types of converters is the buck converter. Buck converter functions to control the DC voltage by making the output voltage equal to or smaller than the input voltage. This converter works with the switching process on and off using a MOSFET based on the applied duty cycle value. In the working process of this converter, it is still found that there is a loss of power, which affects the resulting efficiency. A previous study [5] found that the power loss in the buck converter applied to the Maximum Power Point Tracker (MPPT) system was 57.69%. Also, another study [6] has a result obtained shows that the buck converter has many power losses when controlled by the four Maximum Power Point Tracker (MPPT) algorithms. To solve the
problem, it is necessary to correct and develop the filter design used in the buck converter, a low pass filter with the Butterworth type of order-2. A low pass filter or low pass filter is a filter that will pass frequencies below the cutoff frequency and hold frequencies more significant than the cutoff frequency. The quality of the filtering performance carried out by a filter is influenced by the quality factor Q [7]. In this article, an analysis of the output signal generated by the buck converter is carried out by providing a variety of the Q quality factor, which is simulated with LTSpice software. The data obtained is then used to determine the output quality factor of the filter. The results of this study will be used in the design of the buck converter design for the application of a solar panel electrical power storage system.

2. Method
The developed DC-DC converter circuit uses a buck topology which functions as a voltage reducer. The buck converter uses a Low Pass Filter (LPF), which consists of the main components, namely inductor L, capacitor C, and load resistance R. In addition; a MOSFET acts as an active switch and a diode as a passive switch. In this circuit, the IRF2805 MOSFET is used. The IRF2805 MOSFET is a n-channel MOSFET with fast switching characteristics, with a maximum voltage of 55V and a maximum current of 75A [8]. So that the application of the MOSFET in this study is considered relatively safe because, in the simulation, the buck converter will reduce the supply voltage of 20V. Although the buck converter circuit shown in FIGURE 1 is considered simple, the resulting efficiency is considered relatively high [9].

\[
D = \frac{T_{ON}}{T} = \frac{T_{ON}}{T_{ON} + T_{OFF}} = f_s T_{ON}
\]  

\( T_{ON} \) is the period of the switch in the on mode, \( T_{OFF} \) is the period of the button in the off mode, and \( f_s \) is the switching frequency (Hz).

Figure 1 is a schematic of the basic circuit of a buck converter. Inside the buck converter, a switch function to work on and off by adjusting the pulse width based on the duty cycle value applied using Pulse Width Modulation (PWM) [10]. PWM is the basis of a power electronics control system, where the PWM wave formed represents the work cycle performed by a semiconductor device on and off [11]. The equation expresses the duty cycle used by the buck converter:

\[
D = \frac{T_{ON}}{T} = \frac{T_{ON}}{T_{ON} + T_{OFF}} = f_s T_{ON}
\]  

\( T_{ON} \) is the period of the switch in the on mode, \( T_{OFF} \) is the period of the button in the off mode, and \( f_s \) is the switching frequency (Hz).

Figure 2. Buck Converter Circuit Schematic (a) When Condition is on, (b) When Condition is off
When the switch is on, as shown in Figure 2a, the diode is in a reverse-biased condition where the current will pass through the inductor, and the inductor will be charged. Then the current is passed to the capacitor for filtering and forwarded to the load, then back to the source. Then when the switch is off like Figure 2b, the diode becomes forward biased where energy discharges from the inductor to the capacitor and load, then passes through the diode back to the inductor until the switch turns on.

\[ V_o = D \times V_{in} \]  

(2)

\( V_o \) is the output voltage (V), \( V_{in} \) is the input voltage (V), and \( D \) is the duty cycle.

In a low pass filter, the quality of the filter is influenced by the quality factor \( Q \) or quality factor. The quality factor is defined as the energy dissipated per radian ratio to the point stored [12]. Then another definition states that the quality factor is the ratio between the resonant frequency and bandwidth [13]. In general, the quality factor of the filter is shown by equation [14]:

\[ Q = \frac{R}{L} \sqrt{\frac{C}{L}} \]  

(3)

Where,

\[ \omega_o = 2\pi f_o \]  

(4)

With, \( L \) is the inductor (H), \( C \) is the capacitor (F), \( R \) is the resistance (\( \Omega \)), \( d_o \) is the cutoff frequency (Hz).

The value of the component inductors, capacitors, and resistors is determined based on the value of the quality factor \( Q \), which in this study uses several variations of the value of \( Q \), which then the value of these components is applied to the circuit in Figure 1. The circuit will be tested that is simulated using LTSpice software.

3. Result and Discussion

Using the MOSFET requires a gate driver as a MOSFET controller to work on and off. MOSFET turn on when the primary side of the transformer energy is the input source. MOSFET works off when the primary coil transfers its energy to the secondary coil, and due to its polarity, the diode becomes forward biased and is now conducting [15]. This simulation circuit using IC4N25 as a gate driver. In planning, a source frequency of 50kHz will be used. However, IC4N25 has a characteristic where the cutoff frequency received is one-tenth of the source frequency, so that a cutoff frequency of 5kHz is obtained. Then the buck converter that is made has a parameter capable of reducing the voltage from an input voltage of 20 V to an output of 12 V. To achieve these parameters, and the duty cycle value is determined using equation (2) so that a duty cycle value of 60% is obtained. In designing the Butterworth low pass filter, an inductor component with a value of 10mH is selected, after which the value of the capacitor and resistor components that will be used in the filter can be determined based on the Q quality factor parameter. In this case, several variations of the Q value are given, namely 0.541, 0.707, and 1.307. The buck converter circuit that has been made is then simulated using LTSpice software to see the output signal generated by the buck converter.
Figure 3 shows the schematic of the buck converter circuit used in this study. The Optocoupler uses two resistors, namely R2 and R3, each worth 100 Ω and 410 Ω. In the variation of Q = 0.541, the value of the inductor, capacitor, and load resistor components are 10mH, 100 NF, and 180 Ω, respectively. In the variation of Q = 0.707, the component values of inductors, capacitors, and load resistors are 10mH, 100 NF, and 220 Ω, respectively. In the variation of Q = 1.307, the value of the inductor, capacitor, and load resistor components are obtained, each with a value of 10mH, 100 NF, and 430 Ω. The predetermined component values are then applied to the circuit schematic in FIGURE 3. The circuit is then simulated using a source frequency of 50kHz.

Figure 4 is a Bode diagram showing the frequency response at the output of the buck converter. Figure 4a is a graph of the frequency response in the 0-50kHz range, while Figure 4b is in the 0-10kHz range. Before reaching the cutoff frequency, the flat signal is a signal response in the fit band area, which indicates that the filter passes a signal that has a frequency value below the cutoff frequency. In the circuit with Q = 0.541, it was found that at the cutoff frequency, the filter was damped with a gain value ranging from -4.8 dB. Then the circuit with Q = 0.707 has a gain when the cutoff frequency ranges from -3.1 dB. While in the circuit with Q = 1.307, when it reaches the cutoff frequency, the gain increases with a value of around 2.7 DBs. This indicates that the quality of the filter performed by the filter with Q = 1.307 is not good.
Figure 5. Buck Converter Output Voltage Response Curve

An analysis of the output voltage response is also carried out in the circuit made, as shown in Figure 5. The figure shows that each circuit with a different Q variable still has noise in the resulting output voltage. In addition, it was also found that there was an overshoot voltage before the output voltage produced by the buck converter reached a stable condition. In a circuit with a Q value of 0.541, there is no overshoot voltage found. Then at a variation of Q 0.707, there is an overshoot voltage of 4.8%. In contrast, the most significant overshoot voltage occurs when Q is 1.307, which is 27%.

Based on the data obtained, the filter that has the best quality is a filter with a Q quality factor of 0.707 because the gain value at the cutoff frequency is closest to the gain characteristic of the low pass filter, which is -3dB when it reaches the cutoff frequency, although deviations still occur by 3.3% and still found noise at the output voltage with an overshoot voltage of 4.8%.

4. Conclusion
The design, simulation of the filter used in the Buck converter circuit based on the quality factor value of Q that has been tested shows that the filter design has a good quality with a quality factor value of 0.707. This is because the gain of the simulation circuit when it reaches the cutoff frequency is -3.1 dB, where the value obtained is close to the characteristics of the low pass filter, which has a gain of -3dB when it reaches the cutoff frequency. The greater the value of Q, so the more significant the gain and the time it takes for the Buck converter to achieve a stable output voltage increase.

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