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Design Buck Converter for DC Motor of Transporter Model with IoT System

Mohamad Harith Haiqal Md Salih[1], Wahyu Mulyo Utomo[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn, 84600 Parit Raja, Batu Pahat, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: In this modern era with various types of technologies some of them need lower voltage to operate so the idea of a buck converter is very important with the efficiency being very high, at about 90%. This is why the buck converter is very important in industrial especially since this component is very related to DC motors. With the objective of designing the simulation, designing the buck converter and controlling it for DC motor applications using an IoT system. The design of the buck converter will focus on simulation in MATLAB Simulink with PCB design using Proteus. The system microcontroller uses ESP32 and has built-in Wi-Fi that very important for IoT systems. The DC motor power will use around 10W and estimated can carry around 2kg. Within the project process, there is a method to accomplish this project start with searching for any related research in the past few years to make it as a reference followed by the design of the circuit in a simulation then the design for hardware can start with designing the PCB, create the coding in microcontroller to create and lastly combined it with an installment of IoT system. There are a few key findings that can be observed from the data is as the different results when high duty cycle and low duty cycle, and the output voltage of the buck converter. In theory, the high-duty cycle of the buck converter will lower the voltage but it is more than 50% of the input voltage and with the low-duty cycle voltage will low less than 50% of the input voltage. Some suggestion for this project is to make sure to find an easy-to-use IC component for the PWM signal sent into the gate of MOSFET and add the feedback loop so it can control the PWM very clearly.

Keywords: IoT, PWM, PCB, Duty Cycle

1. Introduction

The equipment has a component known as a buck converter that is necessary to convert high voltage to low voltage. The efficiency of this kind of equipment is very high, at about 90% [1]. This component is very useful for operating other low-voltage components like USB, or CPU. To understand the basic principle of it is very simple. The buck converter has an inductor, switch (MOSFET or IGBT), a diode and a capacitor. Switch for controlling the current flow while diode and capacitor are used to smooth

**Corresponding author: wahyu@uthm.edu.my*

out the output voltage. Buck converters are frequently used to supply low-voltage on-board power in a range of applications, including microprocessors, communication equipment, control systems, and more, in place of conventional, inefficient linear regulators. In paper [2], the network of physical items, or "things," that are implanted with sensors, software, and other technologies for the purpose of communicating and exchanging data with other devices and systems through the internet is referred to as the Internet of Things (IoT). These gadgets include anything from common domestic items to high-tech industrial gear. Today, there are more than 7 billion connected IoT devices, and according to analysts, there will be 10 billion by 2020 and 22 billion by 2025 [3]. These are a few literature reviews, in 2020, Albira, Alzahrani, and Zohdy proposed a DC motor-buck converter setup with model predictive control. This innovative approach used input signals to accurately adjust output voltage/current, ensuring consistent speed despite changing load torque conditions. In a paper [4] and in 2020, Gheisarnejad and Khooban proposed an IoT-integrated dc-dc converter for a programmable grid with a single voltage bus. This technology enables low-cost hardware for IoT-based grid control. They employed an Active Disturbance Rejection Controller for voltage regulation in an IoT-driven DC-DC buck converter, assessing its performance using CoAP and Wi-Fi under network disruptions. This combination offers insights into system behavior and issue resolution in similar research [5]. The project aims to achieve remote monitoring of a DC motor on a transporter model. The objectives of the project are simulating the buck converter, designing a PCB circuit for the buck converter in the DC motor drive, and employing an IoT system to control a prototype transporter model.

2. Materials and Methods

A. Materials

This section will elaborate few components that are very related to designing buck converter and designing the IoT system.

Buck converter components:

- Power Semiconductor Switch – The best option is to select MOSFET and IGBT because it can be turned off by keeping the potential at zero between the gate to source terminal (MOSFET) or gate to collector terminal (IGBT) [6].
- Diode – It acts as the second switch. To lower ripples, a switch and a diode are connected to an LC low-pass filter. For DC-DC converters, PWM uses time-based modulation to operate the switch [7].
- Inductor - In the buck converter, the inductor plays a major role in lowering the input voltage [8].
- Capacitor - An electrical component known as a capacitor stores energy by dispersing charged particles between plates and generating potential difference. releases energy quickly and recharges and discharges quicker than batteries [9].
- Optocoupler - provides complete electrical isolation between circuits at the input and output terminals of the optocoupler [10].

Motor and IoT system components

- ESP32 board – For microcontroller and IoT systems due to it built-in Wi-Fi.
- Voltage sensor – To calculate output voltage via microcontroller.
- L298N – To control more than one motor at the same time.
- 12V battery – input voltage of the buck converter
- DC motor with high torque – To carry heavy weight.

B. Methods

There are four different methods used during the process of this project. Figure 1 is for overall flowchart, Figure 2 is the simulation flowchart, Figure 3 is the hardware design flowchart and Figures 4 and 5 are the IoT system flowchart.

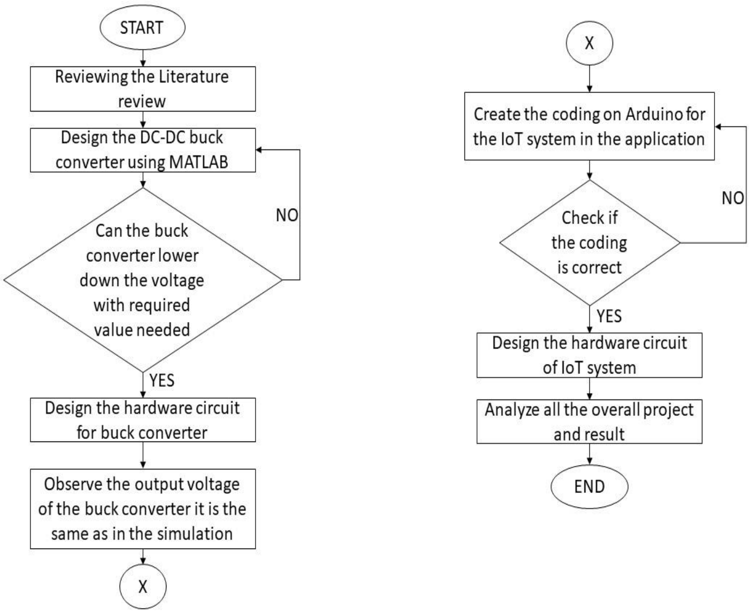

Figure 1: Research flowchart

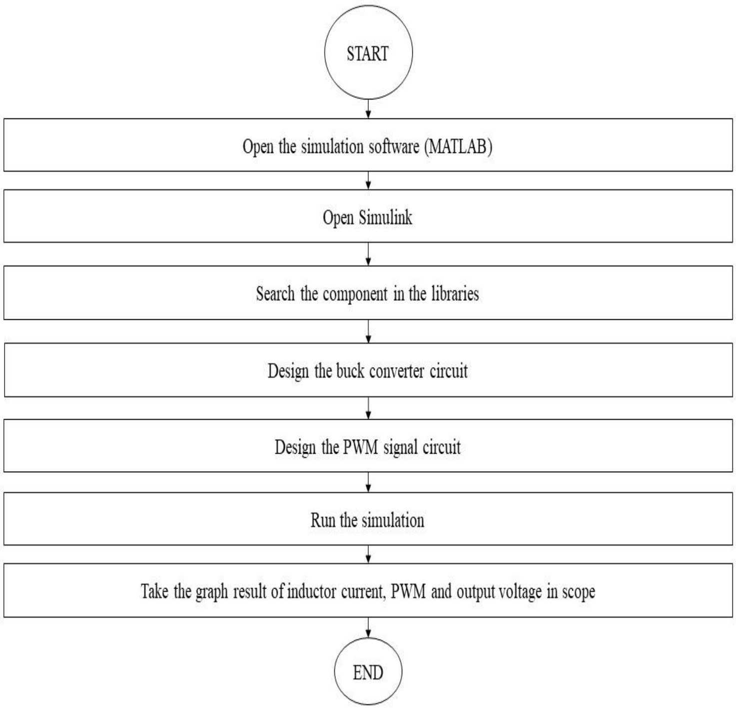

Figure 2: Simulation flowchart

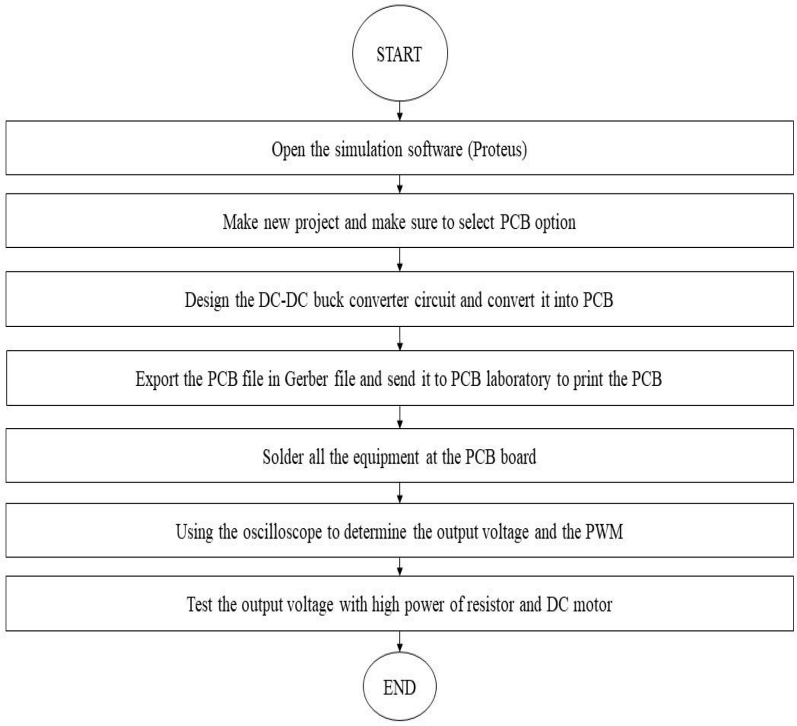

Figure 3: Hardware flowchart

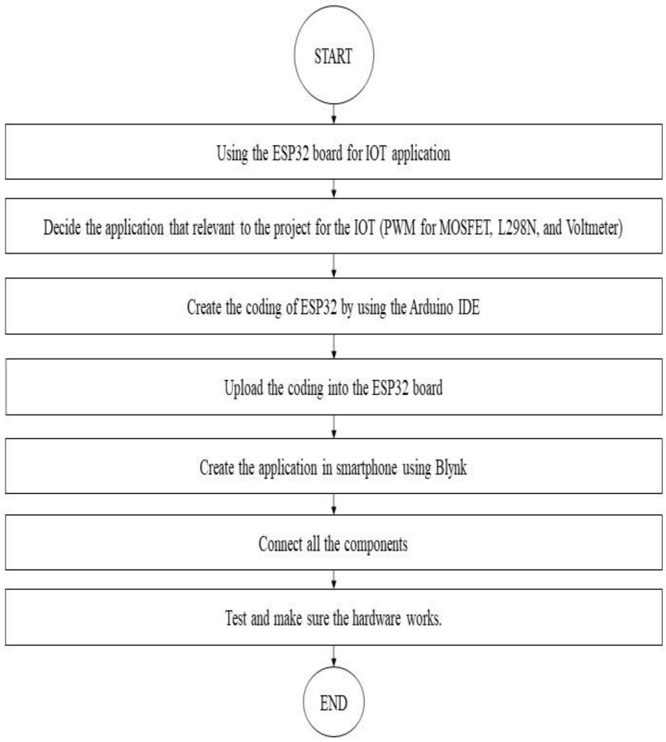

Figure 4: IoT flowchart

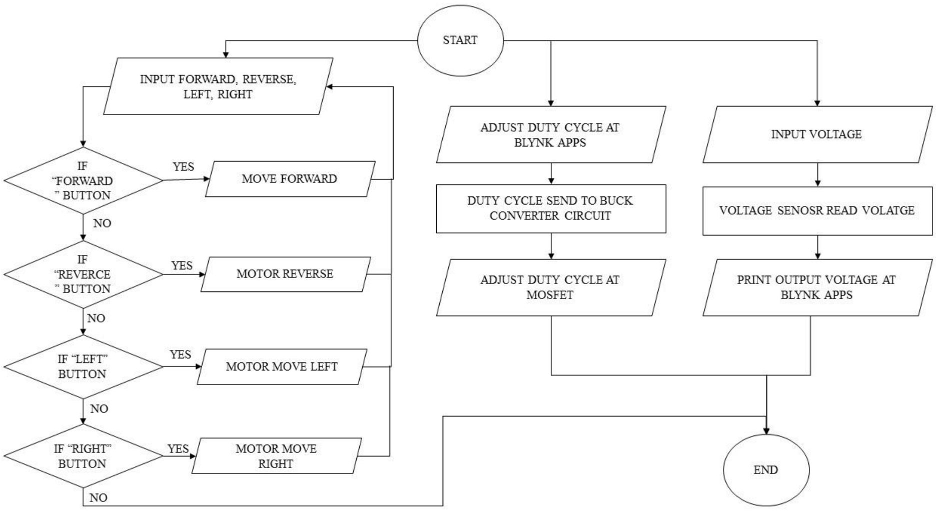

Figure 5: Flowchart Blynk algorithm

C. Equations.

The duty ratio:

$$D = \frac{V_o}{V_s} \quad \text{Eq.1}$$

Minimum inductor size:

$$L_{min} = \frac{(1-D)(R)}{2f} \quad \text{Eq.2}$$

Adding 25% to the minimum inductor to ensure the inductor current continues.

$$L = 1.25\, L_{min} \quad \text{Eq.3}$$

The capacitor value:

$$C = \frac{1-D}{8L\left(\frac{\Delta V_o}{V_o}\right)f^2} \quad \text{Eq.4}$$

Voltage drops %:

$$Voltage\ drop\% = \frac{actual\ output\ voltage - output\ voltage\ by\ voltmeter}{actual\ output\ voltage}(100) = \frac{7-5}{7}$$

3. Results and Discussion

Calculating the parameters of inductor and capacitor. All the calculations will be put in simulation of the buck converter in MATLAB.

The duty ratio for continuous-current operation:

$$D = \frac{V_o}{V_s} = \frac{5}{12} = 0.4167$$

The resistance of output voltage is 10 Ω and the frequency of 30000kHz. Minimum inductor size:

$$L_{min} = \frac{(1-D)(R)}{2f} = \frac{(1-0.375)(10)}{2(30000)} = 104\mu H$$

Let the inductor be 25 percent larger than the minimum to ensure that inductor current is continuous:

$$L = 1.25L_{min} = (1.25)(104\mu H) = 130\mu H$$

The capacitor value:

$$C = \frac{1-D}{8L(\frac{\Delta V_o}{V_o})f^2} = \frac{1-0.4167}{8(130\mu H)(0.01)(30000)^2} = 62\mu F$$

The result with divided into four different outcomes. The first one is the simulation result that has been done in MATLAB Simulink. This result will have three different waveforms and start with PWM signal, inductor current and output voltage. This simulation will be conducted by inserting the 12V input voltage with 0.4 duty cycle and resulting 5V output voltage as shown in Figure 6.

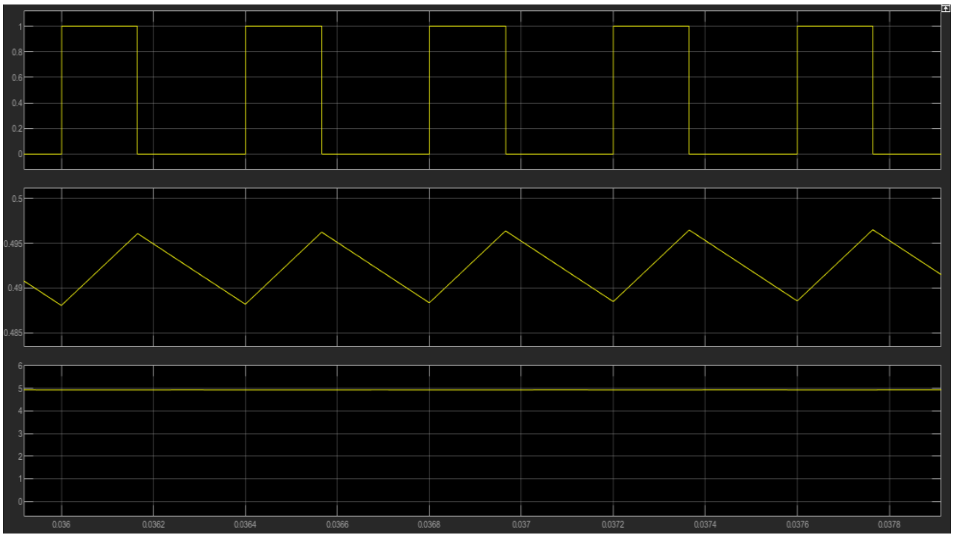

Figure 6: Output Voltage, Inductor Current and PWM waveform

Figure 7 shows the final product of hardware of buck converter that have been solder into the PCB board. This hardware will use MOSFET IRF540N and diode 1n4007. For the inductor and capacitor will choose 220uH and 100uF. This number does not match the calculation due to it being the closer and bigger number to the calculation and only that value is available at a nearby supplier.

Figure 7: Final design of buck converter

The third result is when the board is tested with the oscilloscope to find the PWM signal, gate-source voltage signal, and output voltage. The PWM waveform and gate-source voltage are shown in Figure 8 without any additional components. Around 5 kHz frequency, the PWM develops nicely. Strange behavior can be seen in Figures 9 and 10, where the output voltage is lower for the 0.67 duty cycle than for the 0.33 duty cycle. This can be caused by the gate MOSFET being positioned at the collector of the optocoupler. A reversed signal is produced when the signal transmitted to the optocoupler is received at the collector and delivered by the emitter. The emitter pin of the optocoupler, which is linked to the ground and cannot function as a gate MOSFET switching signal, is used to establish the reference voltage for the phototransistor side of the optocoupler. Although the 6N137 is a superior option, it is not offered locally and can only be obtained from internet stores outside the country.

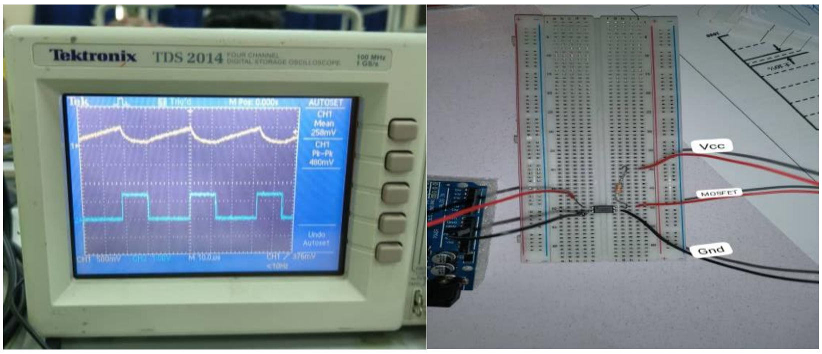

Figure 8: PWM and gate-source voltage before connecting all the component

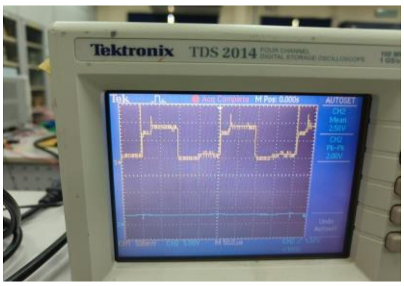

Figure 9: PWM with a duty cycle of 0.67 (yellow) and output voltage(blue)

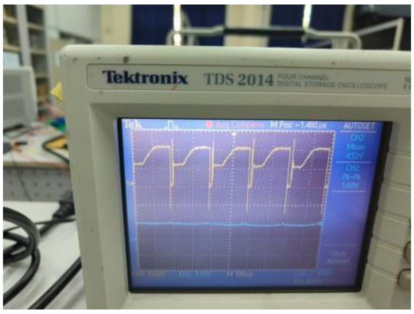

Figure 10: PWM with a duty cycle of 0.33 (yellow) and output voltage(blue)

The result of this project is on the IoT system and the connection of all the components. The Blynk mobile app UI is shown in Figure 11 and has three primary sections. The duty cycle control is shown above the voltage output of the DC-DC buck converter. The interface also has a panel for controlling motor direction.

Figure 11: Blynk mobile apps interface

The output voltage is shown as 5V with the setting of the duty cycle of 0.7 it is supposed to go around 7V to 8V. This situation occurs when the motor has a certain value of resistance that eventually will drop the voltage value.

Voltage drops of buck converter:

$$Voltage\ drop\% = \frac{actual\ output\ voltage - output\ voltage\ by\ voltmeter}{actual\ output\ voltage}(100) = \frac{7-5}{7}(100)$$
$$= 28.57\%$$

The components are connected as shown in Figure 12.

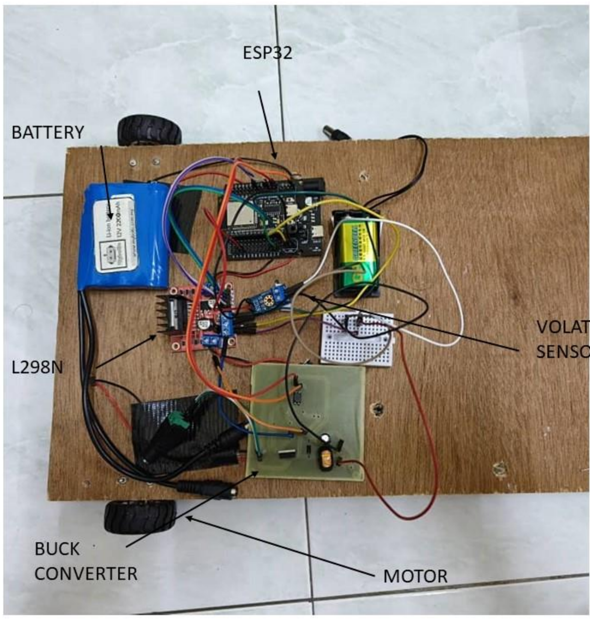

Figure 12: Connection of all the equipment.

4. Conclusion

Industries are significantly impacted by the power electronics application known as the DC-DC buck converter. By lowering power losses during conversion, this project increases energy efficiency while reducing long-term costs and minimizing the damaging impact of motor running. IoT technology was used to monitor and manage the motor remotely. Users may receive real-time motor data and remotely change direction and speed using an IoT platform. This study effectively illustrates how IoT technologies may be integrated into motor control systems, combining effective power conversion with remote monitoring, automation, and energy saving to give consumers better device control. It offers new directions for the study and development of IoT-based motor control systems, with potential applications in the home automation, robotics, and automotive industries. The suggestion that is very recommended is to add the PID controller or feedback to make sure the PWM in the buck converter can be adjusted more frequently.

Acknowledgement

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