

Development of DC Converter for Battery Charger of Light Electric Motorcycles

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Abstract: The world has seen the rise of electric vehicles in recent decades and electrified two-wheeled transportation has slowly made it into the market as well. In this study, a DC/DC converter will be designed and developed with the assistance of MATLAB Simulink and produce a desired output according to set parameters that will be inputted into the system. One of the issues is that basic DC/DC converters can be rudimentary, and the outcome of that converter could be electric energy that is more unstable. Hence, a feedback control loop system such as a PID controller with fuzzy logic rules can be implemented to assist in stepping up or down electricity. Finally, the objectives to be reached are that the output of this converter shall be acquired through the simulation and to confirm that a feedback control loop system can assist in providing stable electricity for electric charging.

Keywords: Battery Charger, DC Buck Converter, Light Electric Motorcycles, PID Controller, Fuzzy Logic Rules

1. Introduction

In recent years, specifically the past two decades of the new century, many companies that involved themselves with Electric Vehicles have risen and fallen throughout these years. Most of these companies had only been prioritizing research and development with four-wheeled passenger cars and very few have worked on the development of electrified two-wheeled motorcycles.

1.1 Background of Study

Electricity is used by electric vehicles (EVs) as their primary fuel source or to improve the efficiency of conventional cars. Both battery electric vehicles (BEVs), often known as all-electric vehicles, and plug-in hybrid electric vehicles are classified as EVs (PHEVs). Even though some of these vehicles still use liquid fuels in addition to electricity, they are commonly referred to as "electric automobiles" or "EVs." EVs are renowned for their instantaneous torque and silent operation. The battery supplies the motor with the controlled power it requires via the power converter. Electric vehicles (EVs) use more effective power converters. Electric cars have fewer moving parts than ICEVs

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do when transferring energy from the source to the wheels. This is intended to reduce significant mechanical losses [1].

Less carbon-intensive drive technologies, such as full battery and hybrid-electric vehicles, are gradually replacing the manufacture of traditional vehicles with internal combustion engines (ICEs). The latter combines electric engines with smaller combustion engines. This transition implies that the automotive industry has experienced significant advancements. There is a need for new technologies and capabilities, and some of the more established ones will become less significant. For instance, battery-electric vehicles no longer need some of the fundamental components of conventional ICE vehicles, such as internal combustion engines and gearboxes, but instead require strong batteries, electric motors, and inverters engineered with the latest technologies to provide motion to vehicles. Since there are no more combustion processes being produced by fossil fuel within an engine and producing heat, in order to offer a sufficient cooling system for the batteries instead of an engine, new methods of thermo-management must be developed. A significant section of a conventional vehicle's architecture must be altered to accommodate EVs [2].

Therefore, the purpose of this study is to research the electrical charging of electric vehicles, more precisely, the charging of electric motorcycles. Aside from that, to develop an electrical charger for electric motorcycles that includes a PID controller with fuzzy logic rules to regulate the output of the DC converter of the charger in a low voltage residential domestic scenario, which is usually provided with a Single-Phase, 230V electric supply here in Malaysia [3].

2. Materials and Methods

In this part, the methodology of the project shows what methods and materials have been applied.

2.1 Materials and Methods

The materials used in this project are computer software applications such as MATLAB Simulink to run simulations and OriginLab to plot data acquired into graphs.

The method that had been employed for this project, which is developing a DC-DC buck converter for the charging of electric vehicles is the utilization of the MATLAB Simulink software as to simulate a DC-DC buck converter and acquired the data for the different sets of fuzzy logic rules from the MATLAB Simulink and analyzed the results for any similarities or differences between the five sets of fuzzy logic rules as shown in Figure 1, 2 and 3.

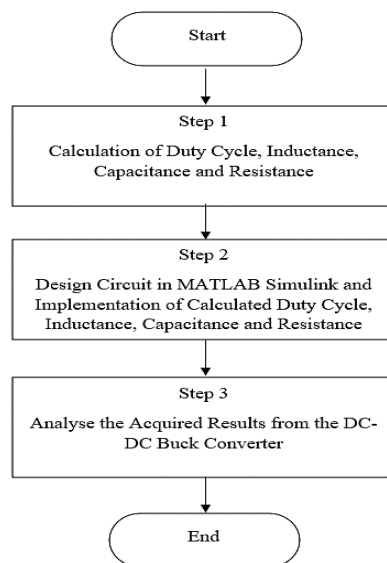


Figure 1: Flowchart of Designing of DC-DC Buck Converter

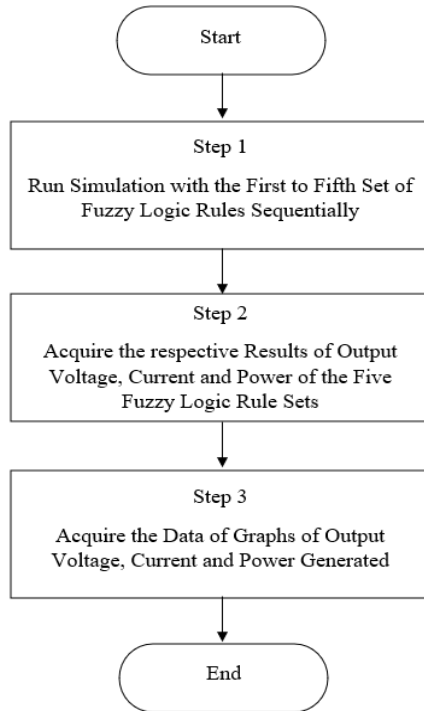


Figure 2: Flowchart of DC-DC Buck Converter Analysis

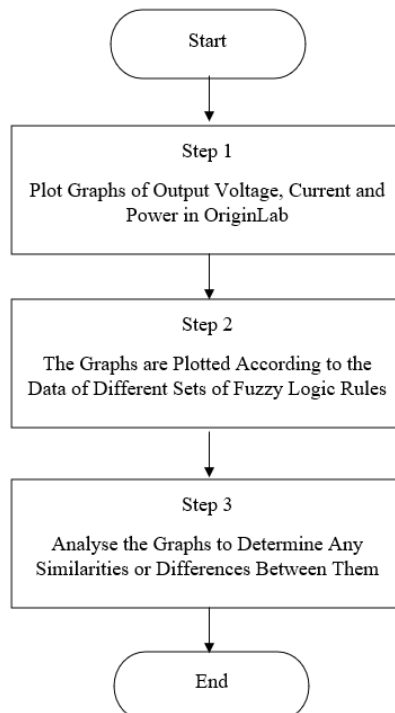


Figure 3: Flowchart of DC-DC Buck Converter Performance

2.2 Components of DC-DC Buck Converter

The DC-DC Buck Converter circuit that will be designed in the MATLAB Simulink software will consist of a few main parts such as a resistor, inductor, capacitor, MOSFET switch, diode, and fuzzy PID Controller. These components will contribute to the step-down process of the buck converter.

2.3 DC-DC Buck Converter Development

The DC-DC Buck Converter has been designed and conducted via the software, MATLAB Simulink to analyze the output of the converter as shown in Figure 3. In this project, the intention is to develop a DC-DC Buck Converter that can produce an output that is high quality to be stored by a battery. The specifications of the DC-DC Buck Converter are listed in Table 1. These are the specifications transferred into the MATLAB Simulink simulation and the simulation should run to produce the desired results that wished to be achieved. These parameters include source voltage, desired output voltage, desired output power, ripple factor, and switching frequency of the PWM generator in Table 1 as well as the fuzzy logic rule in Table 2.

Table 1: Parameters Set for DC-DC Buck Converter

Parameters	Values
Supply Voltage, V_{supply}	48 V
Output Voltage, V_{output}	36 V
Output Power, P_{output}	1 kW
Ripple Factor	1%
Switching Frequency of PWM Generator	40 kHz

Table 2: Set 1 Fuzzy Logic Rules for the Fuzzy PID Controller

Error Correction	PB	PM	PS	Z	NS	NM	NB
NB	0	-5	-50	-100	-100	-100	-100
NM	5	0	-5	-50	-100	-100	-100
NS	50	5	0	-5	-50	-100	-100
Z	100	50	5	0	-5	-50	-100
PS	100	100	50	5	0	-5	-50
PM	100	100	100	50	5	0	-5
PB	100	100	100	100	50	5	0

2.4 Tuning of Fuzzy PID Controller with Different Sets of Fuzzy Logic Rules

The Fuzzy PID Controller will tune the inputs it receives and check for errors and attempt to perform correction to those errors to produce a desirable output according to the fuzzy logic rules that had been implemented beforehand. The fuzzy logic rules that have been established can be implemented into the Fuzzy PID Controller and tuned into a controller that can provide error correction on its own. The tables show the methods of setting up and tuning the Fuzzy PID Controller. Aside from that, there are a total of five sets of fuzzy logic rules that would be implemented into the MATLAB Simulink software to observe if there are any similarities or differences if the fuzzy logic rules are varied. The tables numbered Table 3 to 6 shall show the values being used for the different sets of fuzzy logic rules from Set 1 to Set 5. The meaning behind the error variables, namely PB, PM, PS, Z, NS, NM and NB are “Positive Big”, “Positive Medium”, “Positive Small”, “Zero”, “Negative Small”, “Negative

Medium” and “Negative Big” respectively as to represent the big, medium and small values in both positive and negative integer whilst zero represents the value of zero.

Table 3: Set 2 Fuzzy Logic Rules for the Fuzzy PID Controller

Error Error Correction	PB	PM	PS	Z	NS	NM	NB
NB	0	-10	-100	-200	-200	-200	-200
NM	10	0	-10	-100	-200	-200	-200
NS	100	10	0	-10	-100	-200	-200
Z	200	100	10	0	-10	-100	-200
PS	200	200	100	10	0	-10	-100
PM	200	200	200	100	10	0	-10
PB	200	200	200	200	100	10	0

Table 4: Set 3 Fuzzy Logic Rules for the Fuzzy PID Controller

Error Error Correction	PB	PM	PS	Z	NS	NM	NB
NB	0	-15	-150	-300	-300	-300	-300
NM	15	0	-15	-150	-300	-300	-300
NS	150	15	0	-15	-150	-300	-300
Z	300	150	15	0	-15	-150	-300
PS	300	300	150	15	0	-15	-150
PM	300	300	300	150	15	0	-15
PB	300	300	300	300	150	15	0

Table 5: Set 4 Fuzzy Logic Rules for the Fuzzy PID Controller

Error Error Correction	PB	PM	PS	Z	NS	NM	NB
NB	0	-50	-100	-150	-150	-150	-150
NM	50	0	-50	-100	-150	-150	-150
NS	100	50	0	-50	-100	-150	-150
Z	150	100	50	0	-50	-100	-150
PS	150	150	100	50	0	-50	-100
PM	150	150	150	100	50	0	-50
PB	150	150	150	150	100	50	0

Table 6: Set 5 Fuzzy Logic Rules for the Fuzzy PID Controller

Error	Error Correction							
	PB	PM	PS	Z	NS	NM	NB	
NB	0	-2	-4	-8	-8	-8	-8	
NM	2	0	-2	-4	-8	-8	-8	
NS	4	2	0	-2	-4	-8	-8	
Z	8	4	2	0	-2	-4	-8	
PS	8	8	4	2	0	-2	-4	
PM	8	8	8	4	2	0	-2	
PB	8	8	8	8	4	2	0	

3. Results and Discussion

Figure 4 shows the circuit that has been successfully created in the MATLAB Simulink software whereby the main components that comprise it are the diode, inductor, capacitor, resistor, Fuzzy PID Controller and the MOSFET transistor switch.

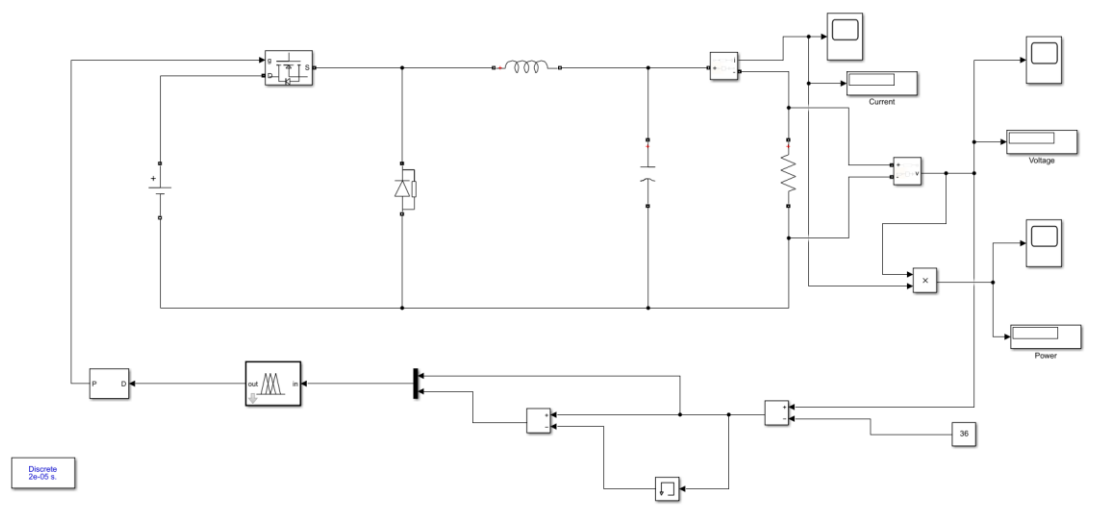


Figure 4: DC-DC Buck Converter with Fuzzy PID Controller

According to the parameters in Table 7 that had been set to the buck converter’s circuit, the graphs in the figures below show the results that had been acquired, which are the output voltage, output current and output power respectively.

Table 7: Parameters Set for DC-DC Buck Converter

Parameters	Values
Supply Voltage, V_{supply}	48 V
Output Voltage, V_{output}	36 V
Output Power, P_{output}	1 kW

Ripple Factor, r	1%
Switching Frequency of PWM Generator, f	40 kHz
Duty Cycle, D	0.75
Resistance, R	1.296 Ω
Inductance, L_{min}	4.05 μH
Capacitance, C	482.25 μF

Figure 5 shows the graph of the output voltage acquired from the simulation and the average output voltage acquired from the graphs of all five sets of fuzzy logic rules was 34.6 V, and the voltage ripple that was observed was 3.3 V. That means the ripple factor between them was 9.5%, which is quite high and far more than the targeted 1% voltage ripple. Hence, to reduce the ripple created by the circuit, the capacitance of the capacitor can be increased. Besides that, the peak output voltage acquired from the graphs was 36.2 V as well.

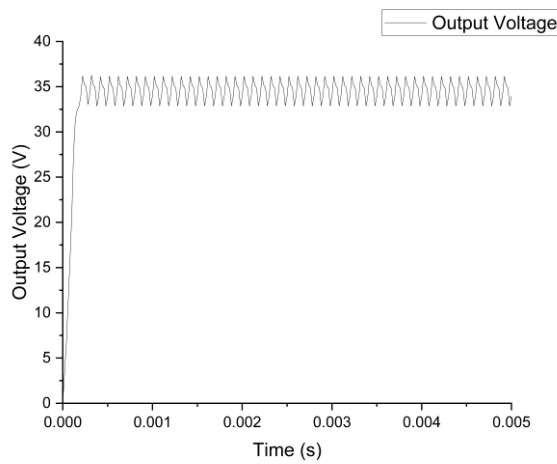


Figure 5: Set 1 to Set 5 Fuzzy Logic Rules Output Voltage Waveform

Figure 6 shows the graph of the output current acquired from the simulation and the average output current acquired from the graphs of all five sets of fuzzy logic rules was 26.8 A whereas the peak output current acquired was 27.9 A.

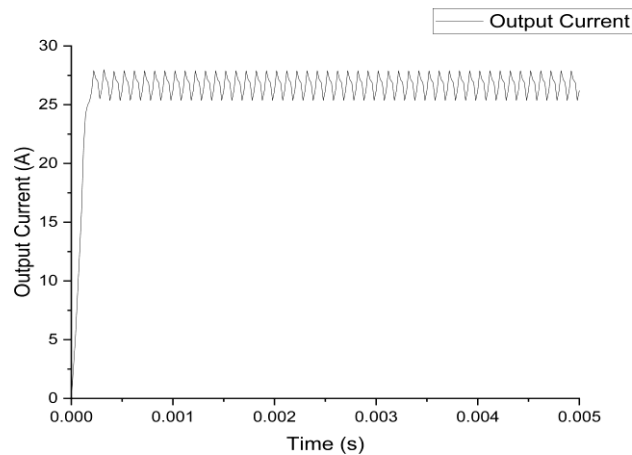


Figure 6: Set 1 to Set 5 Fuzzy Logic Rules Output Current Waveform

Figure 7 shows the output power waveform and the average output power that can be observed from these graphs of all five sets of fuzzy logic rules was 921.3 W whereas the peak output power was 1008.7 W. Having said that, the calculation of the product of the average output voltage and current would show the average output power at 927.3 W.

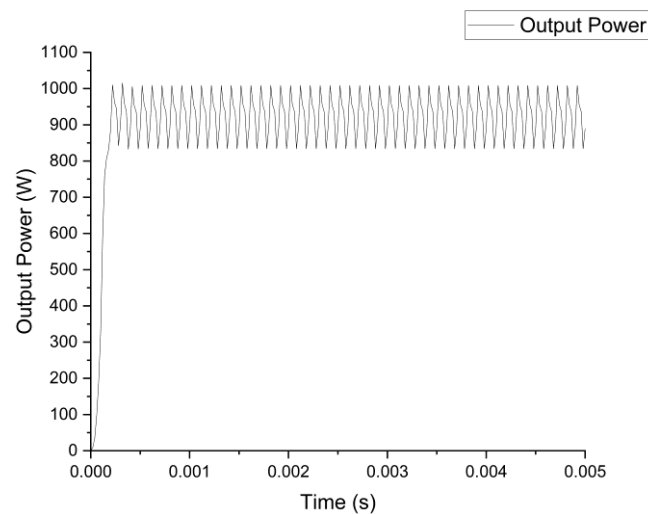


Figure 7: Set 1 to Set 5 Fuzzy Logic Rules Output Voltage Waveform

Based on the results that had been acquired, the output voltage, output current and output power are seen to be in a stabilized waveform but the ripple factor is still quite high as mentioned earlier. Improvements such as increasing the capacitance of the capacitor can reduce the ripple factor. However, this may result in the reduction of the peak power output of 1 kW which was the targeted power output, but the resulting output power produced would be more stable and efficient with the reduction of ripple. In addition to that, it can be observed that the variation of fuzzy logic rules would produce the same outputs no matter the variations of Fuzzy Logic Rules. The values did not matter as long they involve one small value, one medium value and one big value and can cancel each other out in an arithmetic process between the positive and negative values.

4. Conclusion

As a conclusion, all three objectives were able to be achieved. The results were successfully acquired from the simulation and observations and comparisons were made as well. The first objective of analyzing a DC Buck Converter based on a simulation approach had been achieved as the DC Buck Converter had been designed in MATLAB Simulink and was able to run without any issues and could produce a satisfactory output of peak output voltage, current and power of 36.2 V, 27.9 A and 1008.7 W as well as average output voltage, current and power of 34.6 V, 26.6 A, and 921.3 W respectively.

The second objective was to develop a simulation model of a DC Buck Converter that uses different types or sets of fuzzy logic rules to observe if there are any considerable changes in the outputs of the DC Buck Converter. Although five sets of fuzzy logic rules were implemented, the results were the same for every set of fuzzy logic rules. However, the simulated DC Buck Converter was able to run for every set of fuzzy logic rules and produced results without problems or errors.

Finally, for the third objective, the comparison of output performances of the DC Buck Converter with a variation of fuzzy logic rules was completed as well even though the end results are all the same. It seems that the values did not matter as long as one small value, one medium value and one big value were involved and could cancel each other out in arithmetic processes between the positive and negative values.

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