

Simulation of A Buck-Boost DC-DC Converter for Battery Starter and Battery Storage in Fuel Cell Power System

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Abstract: A buck-boost DC-DC converter is used to control the charge current and discharge of the battery. In a buck mode, the converter will charge the battery while in boost mode it will discharge the battery using a voltage from the fuel cell. Components include a DC power source (in this case, a fuel cell), controlled switches, diodes, inductors and capacitors. This converter uses to investigate which battery is best to use while the battery is being charged and discharged. Based on the result achieved, it shows that each battery has the own their own advantages and disadvantages when using this buck-boost DC-DC converter.

Keywords: DC Converter, Battery, Fuel Cell, Buck-Boost

1. Introduction

In this new era of technology, the world that society lives in these days is changing and revolutionizing for the greater development of the nation. Power supply systems are one of the developments that need to be taken seriously. The power supply converts the power from the source into the proper voltage and format. Because there are so many alternatives, the specific power supply function is determined by whether it needs to control or convert energy [1]. The increasing consumption of power supply is used widely in the world. A lot of industries depend on the power supply to work their machine. One of the recently used DC power supplies is a hybrid fuel cell. Fuel cells are electrochemical devices that transform chemical energy directly into electricity and heat from reactants. An electrolyte layer is in contact with a porous anode and cathode on both sides of the device [2]

Therefore, to ensure that the hybrid fuel cell can be used for the load, a battery starter and battery storage is needed in the power system. The main problem is when the battery is directly parallel with the dc bus, the charge and discharge current cannot be controlled and if the load change significantly, the rush current will destroy the battery. DC converter is one of the solutions to solve the problem. There are a few types of DC converters such as buck converter, boost converter, and buck-boost converter. This project purposely is to simulate a buck-boost DC-DC converter to use for a battery to

control the charge and discharge current. In buck mode, the converter will charge the battery while in boost mode the converter will discharge the battery. Buck-boost DC-DC converter also simulates to determine which type of battery is good to use for battery starter and battery storage in fuel cell power systems. This converter will prove which battery will be the best to use when the battery is being charged and discharged. Other than that, this converter also will show what type of battery will reach full charge faster when being charged using the voltage from the fuel cell. Three types of batteries that will be tested are the lead-acid battery, lithium-ion battery and nickel-cadmium battery.

2. Materials and Methods

The initial design for this project requires some careful reading so that the values to be used are accurate. This project is designed using the software MATLAB 2018 because it is a medium that is easy to simulate and understand. There are two major parts that are designed that are the circuit for the buck-boost DC-DC converter and the fuel cell circuit. The overall design and analysis procedures for implementing the Simulation of the buck-boost DC-DC converter can be simplified by using a flowchart as illustrated in Figure 1.

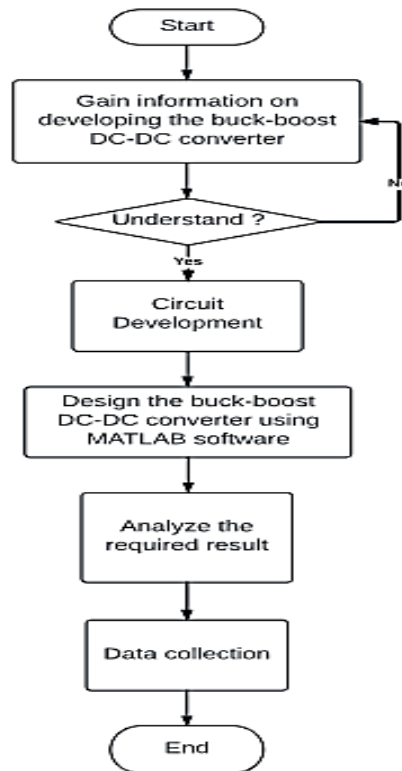


Figure 1: Flowchart for buck-boost DC-DC Converter

Figure 2 shows the power flow for the converter. The power flow can be divided into two that are battery discharging and battery charging. When a battery is discharging, its supplies power to the load through the buck-boost DC-DC converter. This process only happens for 7 seconds because the fuel cell is going through the cold start mode. After 7-second the fuel cell immediately supplies power to the load while charging the battery. Due to the natural electrochemical reactions required for enthalpy balance, fuel cells have a very delayed response [3]. The first thing that happens when the system start is, that the fuel cell required a few times to self-heat [4].

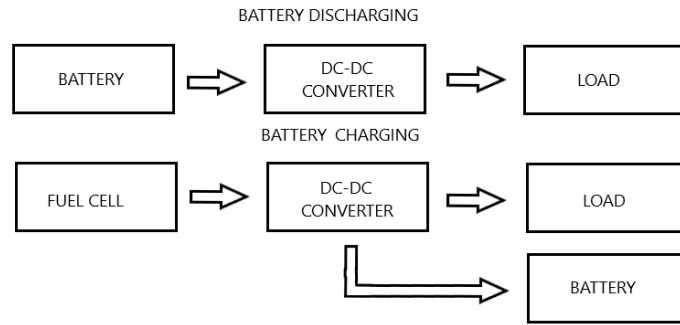


Figure 2: Power Flow for the Converter

To build a buck-boost DC to DC converter for the battery starter and storage, various components in the MATLAB Simulink were required. The components include a DC power source (in this case, a fuel cell), a range of battery types, a controlled switch, a diode, an inductor, a capacitor, and load resistance. Three types of battery use are lead-acid, lithium-ion, and nickel-cadmium batteries. Lead acid batteries consist of several parts such as a container, plate, active materials, separator and battery terminal to produce the voltage [5]. A lithium-ion battery is an advanced battery technology that uses lithium-ions as a key component of its electrochemistry [6]. The chemical symbols for nickel (Ni) and cadmium (Cd) are used to create the nickel-cadmium battery [7]. To switch the load and switching controller, a few components must be used. The best option for switching is to use MOSFET. The MOSFET receives its input signal from the PWM signal. Because the PWM output is insufficient to drive the MOSFET, a PID controller is utilized to amplify the PWM output and connect it to the MOSFET gate. Figure 3 shows the simulation of the buck-boost DC-DC converter using MATLAB

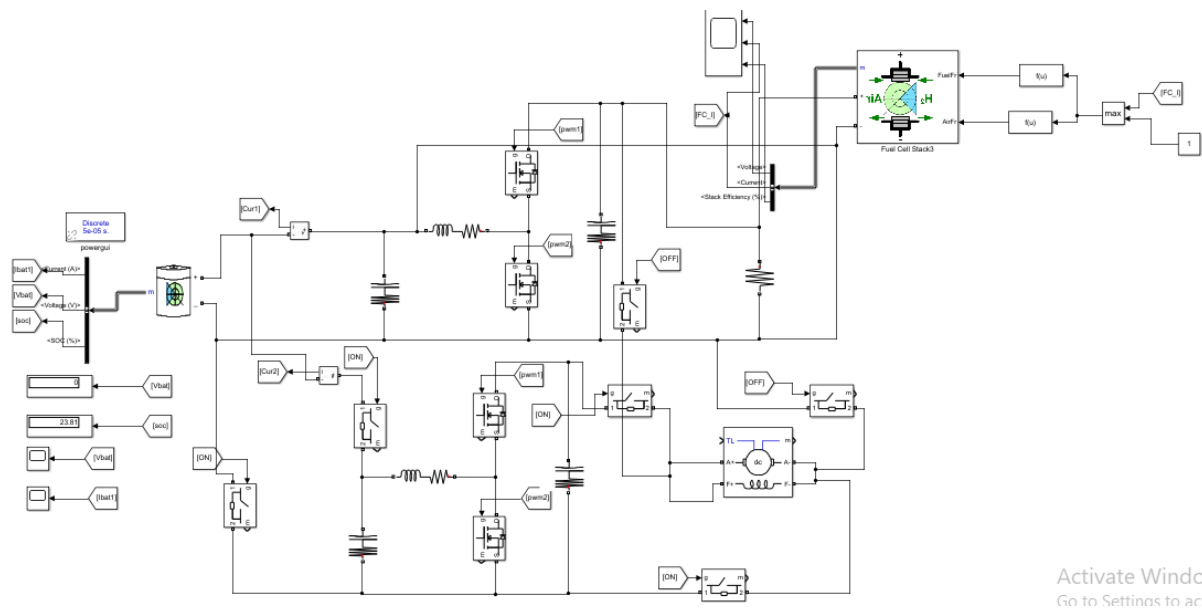


Figure 3: Simulation of Buck-boost DC-DC converter using MATLAB

3. Results and Discussion

The results of the analysis performed by the buck-boost DC-DC converter simulation made using MATLAB software were collected by testing a few types of batteries. The outcomes of the result will determine whether the project's aims and objectives were met successfully.

3.1 Battery Charge and Discharge Result

The voltage graph for the battery in charge and discharge mode is shown in Figure 4. The graph indicates that when the battery is used to power a load, it is discharged for 7 seconds. The battery is used in this situation since the fuel cell is in the cold start and unable to power the load. The fuel cell is used to power the load and recharge the battery after 7 seconds. Figure 5 depicts a graph of the charge and discharge current for the batteries. The graph demonstrates how the battery current increases when it is being charged while dropping when it is being discharged.

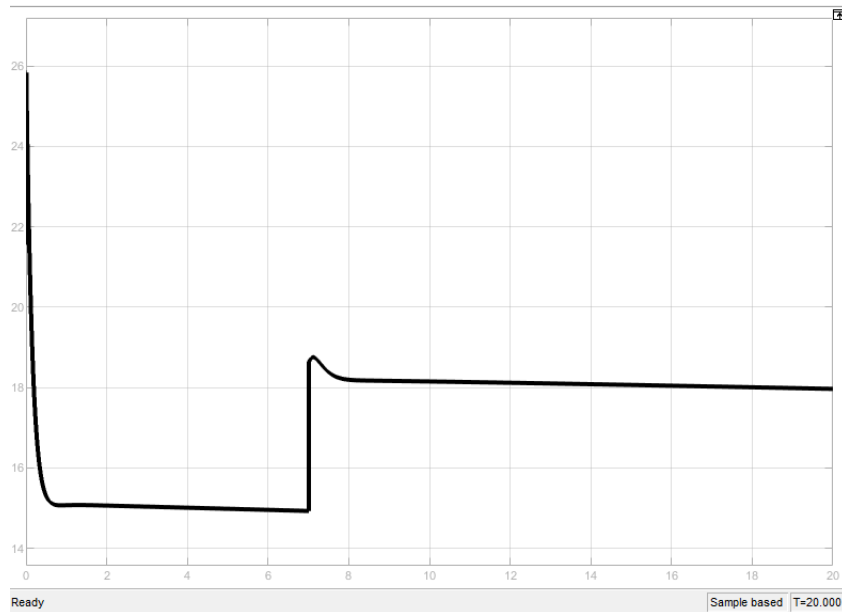


Figure 4: Battery Charge and Discharge Voltage Graph

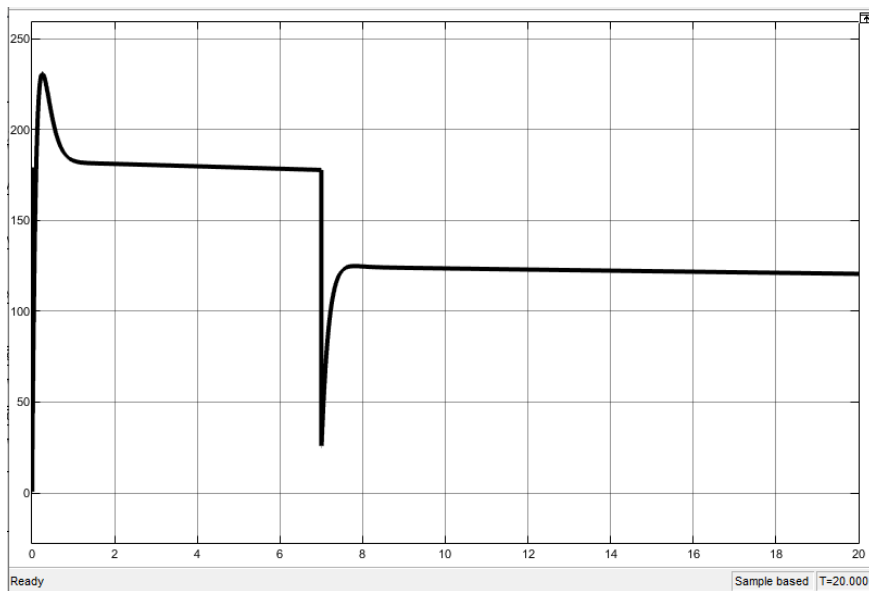


Figure 5: Battery Charge and Discharge Current Graph

After a 13-second charge, the state of charge for the battery is shown in Figure 6. The display block will show the percentage for battery charging and discharging.

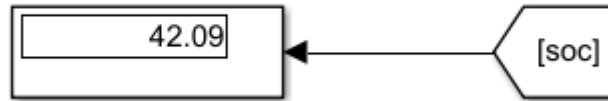


Figure 6: State of Charge display for battery

3.2 Discharge Characteristics of Battery

The model parameters are taken from the type of battery discharge characteristics that is from the battery. The discharge curve of the battery model is been plotted in voltage versus Time (hours) in Figure 7, battery and it indicates that the discharge curve is made up of three sections: an exponential area, a nominal area, and a discharge curve. When the battery is discharged, the voltage drops exponentially, resulting in an exponential area. For the first section region, the voltage drops quickly, depending on the battery type utilized. The nominal area is the second part and it is the standby area before it reaches the discharge curve.

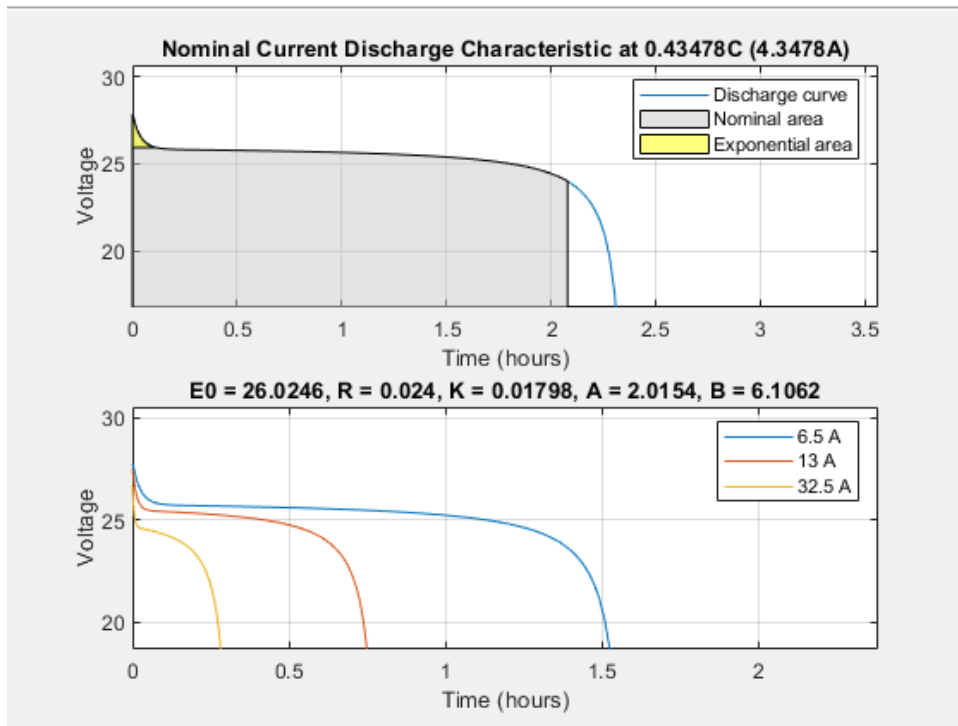


Figure 7: Discharge Characteristics of Battery

3.3 Comparison of battery performance

Table 1 shows the comparison of battery performance for three types of battery that is the lead-acid battery, lithium-ion battery and nickel-cadmium battery. The table show state of charge for the battery after being charged for 13 seconds. The initial state of charge for the battery is 50%, but after discharge, the percentage of the state of charge is decreasing and it will increase back when the battery is charging. It shows that lithium-ion has the lowest state of charge compared to other batteries and can be concluded that lithium-ion battery needs still to charge longer until it reaches an initial state of charge of 50%. Lead acid has the highest percentage of the state of charge which is 46.09 % during 13 seconds of charging and proves that lead acid is the fastest chargeable battery when using the converter. The table shows that nickel-cadmium batteries have the longest time taken to fully discharge based on the battery characteristic and lithium-ion batteries have the shortest time taken to fully discharge based on the

battery characteristic. Lithium-ion batteries only need 2.4 hours to fully discharge while the lead-acid battery and nickel-cadmium battery need a longer time to fully discharge. This is the weakness of lithium-ion batteries because when a battery is fast discharged it will cause the charging process to become more frequent compared to when using lead-acid batteries and nickel-cadmium batteries.

Table 1: Comparison of Battery Performance

| Battery Type | State Of Charge After charge for 13 second | Time Taken To Fully Discharge Based On Battery Characteristic |
|----------------|--|---|
| Lead-Acid | 46.09 % | 5.1 Hours |
| Lithium-Ion | 42.09 % | 2.4 Hours |
| Nickel-Cadmium | 44.19 % | 5.8 Hours |

4. Conclusion

There are three objectives in this study that have been archived. The first objective is to simulate a buck-boost DC-DC converter using MATLAB simulation. There are a few components used to successfully develop the buck-boost DC-DC converter including a DC power source (in this case, a fuel cell), a range of battery types, a controlled switch, a diode, an inductor, and a capacitor. The Second objective in this project also has been achieved because the simulation of the buck-boost DC-DC converter can control the charge and discharge of three types of battery that are lead-acid battery, lithium-ion battery, and nickel-cadmium battery. Each battery has been given the same nominal voltage before being tested by using the buck-boost DC-DC converter. Last but not least, to investigate the battery performance using a buck-boost DC-DC converter. Based on the result achieved, it shows that each battery has the own their own advantages and disadvantages when using this converter. For example, from table 1, the advantages of a nickel-cadmium battery are it takes the longest time to fully discharge and the charging process is less frequent. Also, the lead-acid battery has the highest percentage for the state of charge and it proves that the lead-acid battery is the fastest rechargeable battery compared to other batteries when using this converter.

Acknowledgement

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