

## Simulation Of Open Loop Current Controller

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### Abstract

This project focused on simulation of open loop current controller for lead acid battery using MATLAB R2013b and Arduino microcontroller software. A current controller is been developed using MATLAB Simulink Toolbox which communicates with Arduino Support Package library in order to generate the pulse width modulation (PWM) signals for converter circuit. The project uses designed Buck-Boost converter circuit with reference voltage of 14V from the battery. The range of buck operation input voltage is between 18V to 15V while boost operation input voltage range is between 10V to 13V. The results of simulation output current slightly increase with the minimum value of 0.38A and the maximum value of 0.73A. As a conclusion, the project is able to communicate between MATLAB and Arduino software.

**Key Words:** battery; rechargeable battery; current control; buck boost converter; matlab; arduino; boost converter; buck converter; gate driver; current sensor

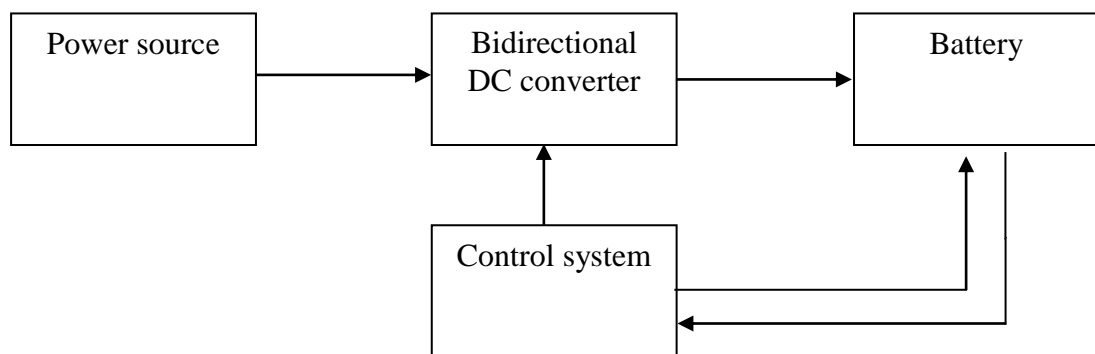
### 1.0 INTRODUCTION

Significant progress in electric propulsion systems and batteries has been made since then resulting in the growing field of electric vehicle, communication, computer, networks, control systems and automatic production lines have increased. Demand for single phase small capacity, high efficiency, high performance, low cost batteries as power management is increasing sophistication to decrease in size and style in performance of data processing equipment. Nevertheless more efforts need to be done and more goals need to be accomplished in order to push the public demand for these power management.

The battery is being rapidly increasing use in a variety of subject areas, such as power sources for telecommunication equipment, car starters, hybrid electrical vehicles, renewable energy storage systems and etc. Furthermore, battery has also been employed as a standby power source when the main power having disturbance of electricity. There is a wide variety of batteries on the market today, which are Nickel Cadmium (NiCa/NiCd), Nickel Metal Hydride (NiMH), Lead acid and Lithium Ion (Li-Ion) batteries. The lead-acid battery is widely used as a supply of power because the maintenance is easy and it's convenient to be used [1]. Battery as the most popular energy storage device has two different types, primary battery and rechargeable battery.

Primary battery also known as disposable battery which have higher density than rechargeable battery. Also have a lower self discharge. The primary battery is not suitable for the energy storage systems since the battery intended to be used once and then discarded. Rechargeable battery which also known as a secondary battery because electrochemical reactions are electrically reversible [2].

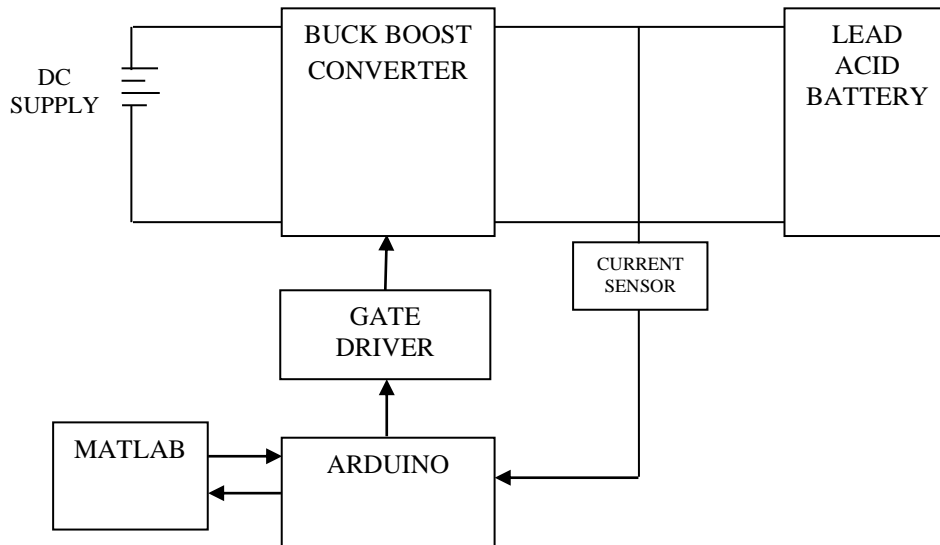
The potential problems that encountered in the battery is the charging technical problem which lead to longer charging time that causing the quality of the battery become poor and shorten the life of the battery [3] [4]. The battery charger requires a converter that able to charge the battery with the variable input voltage and a constant output voltage for charging process. Power conversion system is constructed to improve performance or reliability, or attain a high system rating. The control scheme implements the balancing with the least quantity of switches and cost[5]. Converters are categorized into four categories: AC to DC converter (rectifier), DC to DC converter (chopper), AC to AC converter (cycloconverter) and DC to AC converter (inverter) [6]. Three basics DC to DC converter topologies: Buck converter, Boost converter and Buck-Boost converter. Buck-Boost converter circuit has been decided to use in this project since the converter consists of two modes of operation, Buck and Boost. This project uses software MATLAB as a control while the Arduino serves as a signal processing controller [7]. MATLAB has been chosen for this project due to accessibility this software and can easily modify and improve the code provided. While, Arduino has been selected due to affordable cost and has an easy programming language based on ready C/C++ libraries. Both software should be able to communicate each other in order to receive input and output signal. The purpose of MATLAB R2013b software is to develop repetitive current controller block diagram to create a PWM input signal.



**Figure 1:** Block diagram of battery charger system

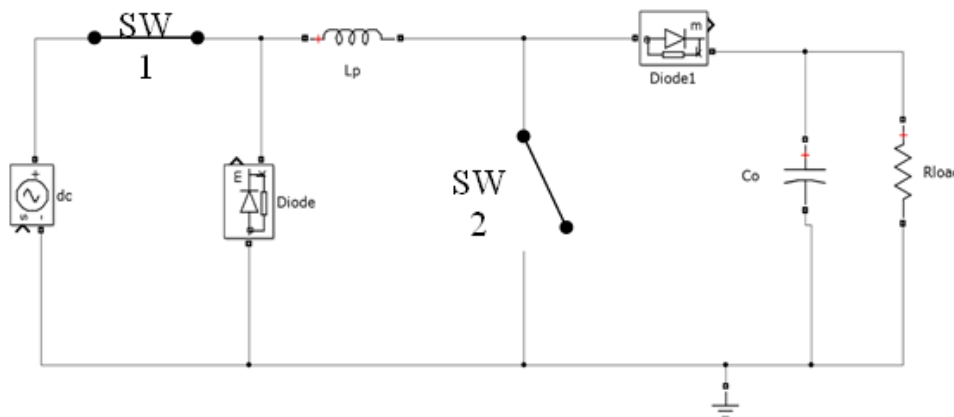
The battery charger system consist of 5 main parts in Figure 1 : DC power source, a bidirectional DC converter (buck-boost converter), a custom data acquisition system (current sensor) and a control system (consist of Arduino, Matlab and gate drive) and output (battery).

## 2.0 MATERIALS AND METHODS



**Figure 2:** Block diagram of the project

The block diagram of the project in Figure 2 starts with DC supply input voltage to the Buck-Boost converter circuit. The output voltage of the converter starts charging the lead acid battery. A current sensor detects the current and send an output signal to the Arduino. The Arduino generates PWM output signals and send through the gate driver to control switching on the Buck-Boost converter circuit.

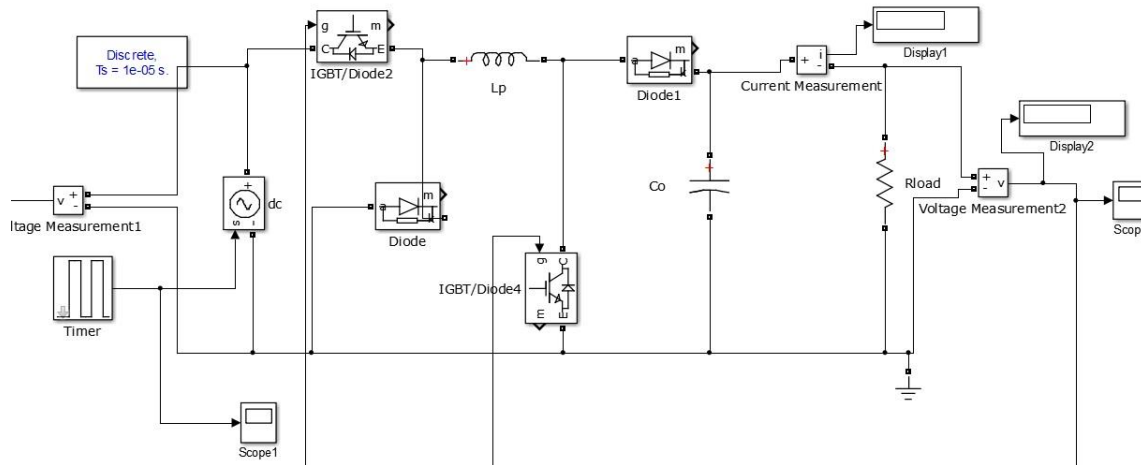


**Figure 3:** Buck Boost converter circuit diagram

The circuit diagram in Figure 3 analysed in two operations: Buck operation and Boost operation. In Buck operation (18V to 15V), switch 1 (SW1) is in PWM mode and switch 2 (SW2) is opened. While in Boost operation (10V to 13V), switch 1(SW1) is closed and switch 2 (SW2) is in PWM mode.

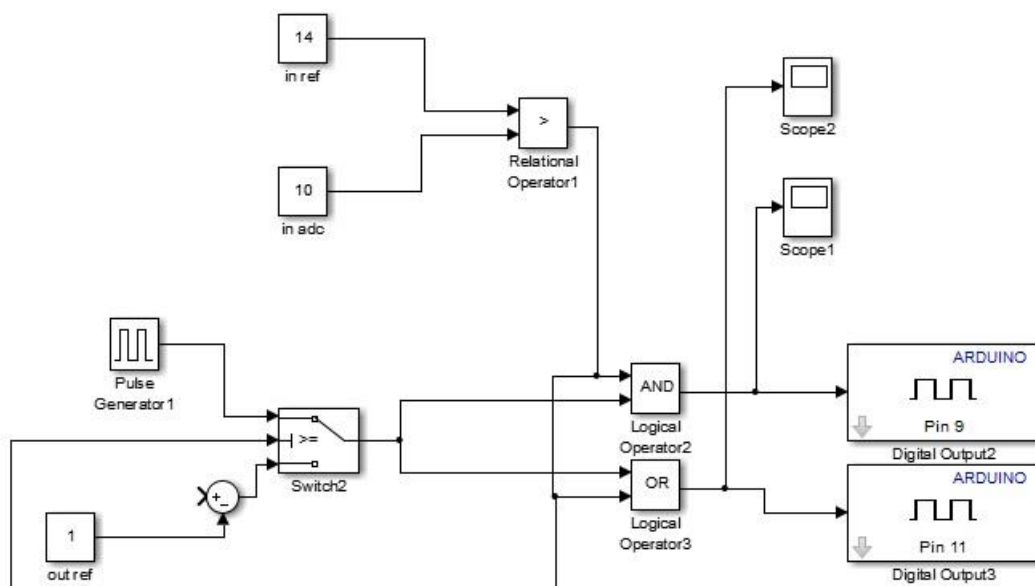
The software used in this project is MATLAB R2013b and Arduino UNO microcontroller which features a maximum clock rate of 16 MHz with 32 KB Flash Memory. The Arduino has 14 digital input and output pins which 6 pins can be used as PWM outputs and another 6 pins used as analog inputs.

A current controller has been developed using MATLAB Simulink Toolbox in order to generate the pulse width modulation (PWM) signals. The Arduino receives PWM output signals and send through the gate driver to control switching on the Buck-Boost converter circuit.



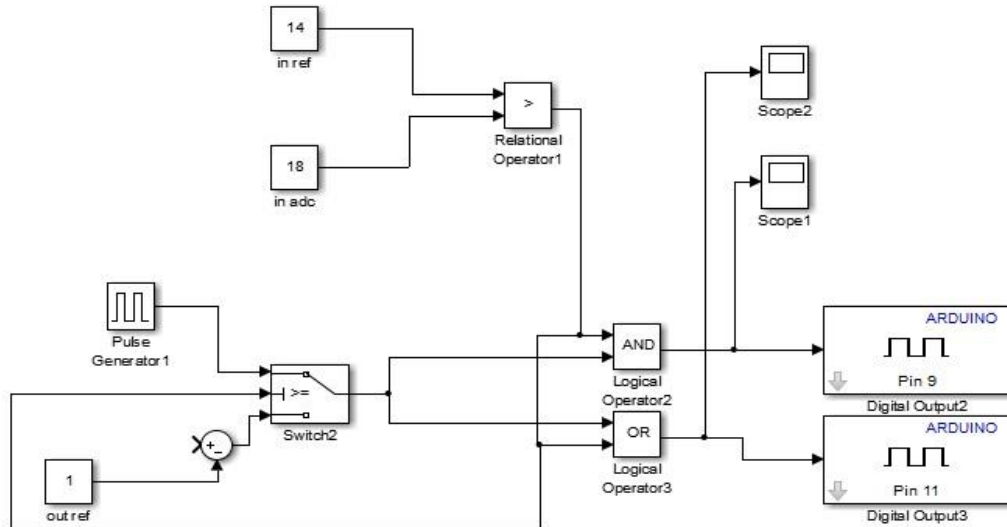
**Figure 4:** MATLAB simulation diagram of Buck-Boost converter circuit

The MATLAB simulation diagram of Buck-Boost converter circuit in Figure 4 shows the components for Buck-Boost converter circuit is a pair of switches, two controlled MOSFET (IRF540) and two uncontrolled diodes (IN4001). The converter also uses one capacitor (47uF), one inductor (10mH) and one resistor (100ohm).



**Figure 5:** Open loop simulation diagram for Boost operation

The open loop simulation diagram in Figure 5 is for Boost operation. Input voltage for Boost operation is 10V and will compare in relational operator with reference voltage 14V. If the input voltage is lower than the reference voltage, the output signal becomes 1, the results are in Boost operation. For this project, two controlled MOSFET used, switch1 and switch 2.



**Figure 6:** Open loop simulation diagram for Buck operation

The open loop simulation diagram for Buck operation is shown in Figure 6. Input voltage for Buck operation is 18V and will compare in relational operator with input reference 14V. If the input voltage is higher than input reference, the output signal becomes 0, the results are in Buck operation.

For Buck and Boost operation, logical operator of AND and OR gate is selected because only these two gates enable to generate PWM signals. By referring Table 1, the truth table of OR and AND gate shown and the simulation of output waveforms is proved.

**Table 1 :** The truth table of OR GATE and AND GATE in Boost operation

A	B	Output switch 1
0	0	0
0	1	1
1	0	1
1	1	1

**OR GATE**

A	B	Output switch 2
0	0	0
0	1	0
1	0	0
1	1	1

**AND GATE**

Input gate A in Table 1 represents the output for relational operator while input gate B represents for PWM signal. For Boost operation, when the input voltage is lower than input reference, the output of relational operator is 1. Therefore, according to the truth table, the output switch 1 shows the switch is close while output switch 2 shows the switch is in PWM signal.

**Table 2:** The truth table of OR GATE and AND GATE in Buck operation

A	B	Output switch 1
0	0	0
0	1	1
1	0	1
1	1	1

**OR GATE**

A	B	Output switch 2
0	0	0
0	1	0
1	0	0
1	1	1


**AND GATE**

Input gate A in Table 2 represents the output for relational operator while input gate B represents for PWM signal. For Buck operation, when the input voltage is higher than input reference, the output of relational operator is zero. By referring the Table 2, the truth table of OR and AND gate, the output switch 1, shows the switch is a PWM signal while output switch 2, shows the switch is open.

### 3.0 RESULTS AND DISCUSSIONS


Open loop analysis is the combined response of the power supply, an Arduino board, gate driver and buck-boost converter. When the power supply is set within 10V to 13V range, the circuit will be in Boost condition which increases the voltage level from an input DC source. The SW1 switch always gives a signal constant '1' and the SW2 switch will give a PWM signal from the Arduino board shows in Table 3. Thus, relate to the truth table of OR GATE and AND GATE in Boost operation in Table 1.

**Table 3:** Switch condition for Boost operation

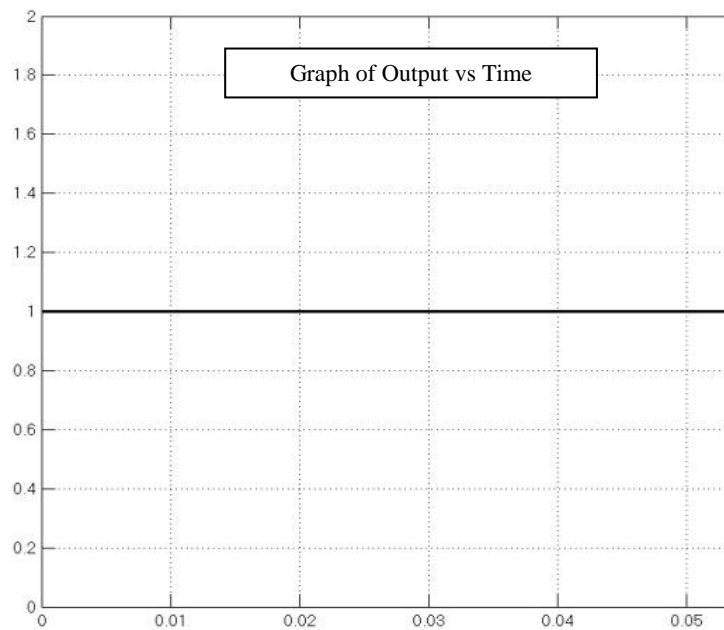
No.	Switch	Condition
1.	SW1	Constant 1
2.	SW2	PWM 

When the power supply is set range within 15V to 18V range, the circuit will be in Buck condition which decreases the voltage level from an input DC source. The SW1 switch always gives a PWM signal and the SW2 switch will gives zero signals from the Arduino board shows in Table 4. Thus, relate to the truth table of OR GATE and AND GATE in Buck operation in Table 2.

**Table 4:** Switch condition for Buck operation

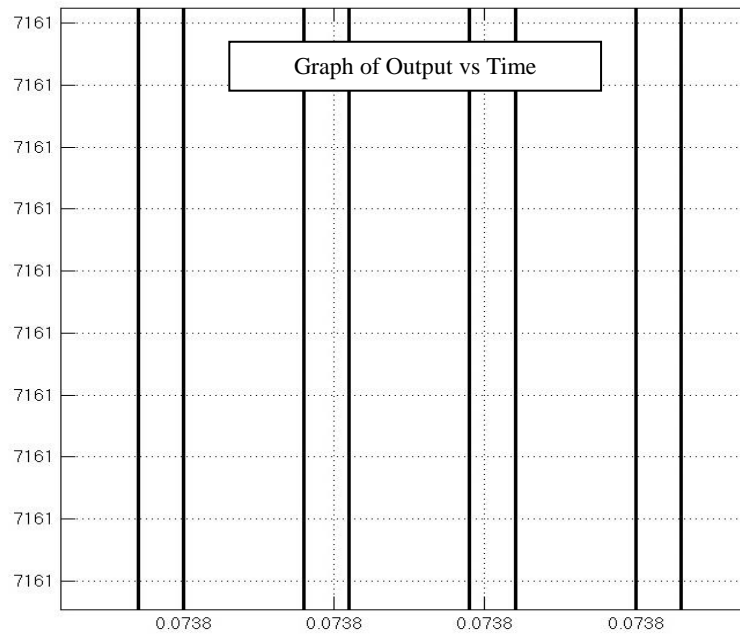
No.	Switch	Condition
1.	SW1	PWM 
2.	SW2	Zero

The open loop simulation diagram is analyzed from MATLAB Simulink Toolbox. For open loop simulation, the circuit use 14V as a reference voltage that will compare with input voltage. If input voltage lower than the reference voltage, the results are in Boost operation. Hence, if the input voltage greater than the reference voltage, the results is in Buck operation.



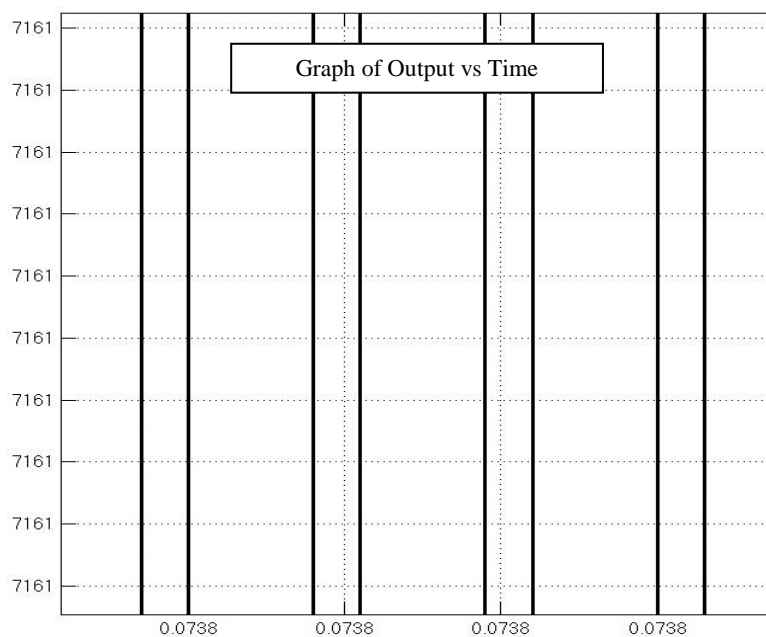
**Figure 7:** Switch 1 Boost operation

The output simulation signal of switch 1 when the converter in Boost operation is shown in Figure 7. The output signal becomes 1 meaning the switch 1 is close.



**Figure 8:** Switch 2 Boost operation

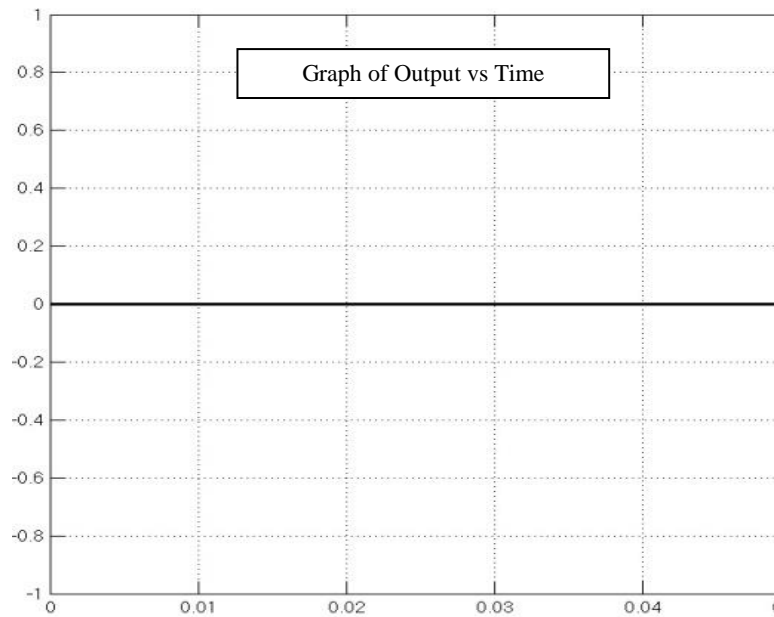
While for switch 2 in Figure 8, the output signal becomes a PWM signal meaning the switch 2 is open and closes continuously.



**Figure 9:** Switch 1 Buck operation

The output simulation signals of switch 1 for Buck operation shows in Figure 9 where the output signal becomes a PWM signal and it means the switch 1 is open and close continuously.





**Figure 10:** Switch 2 Buck operation

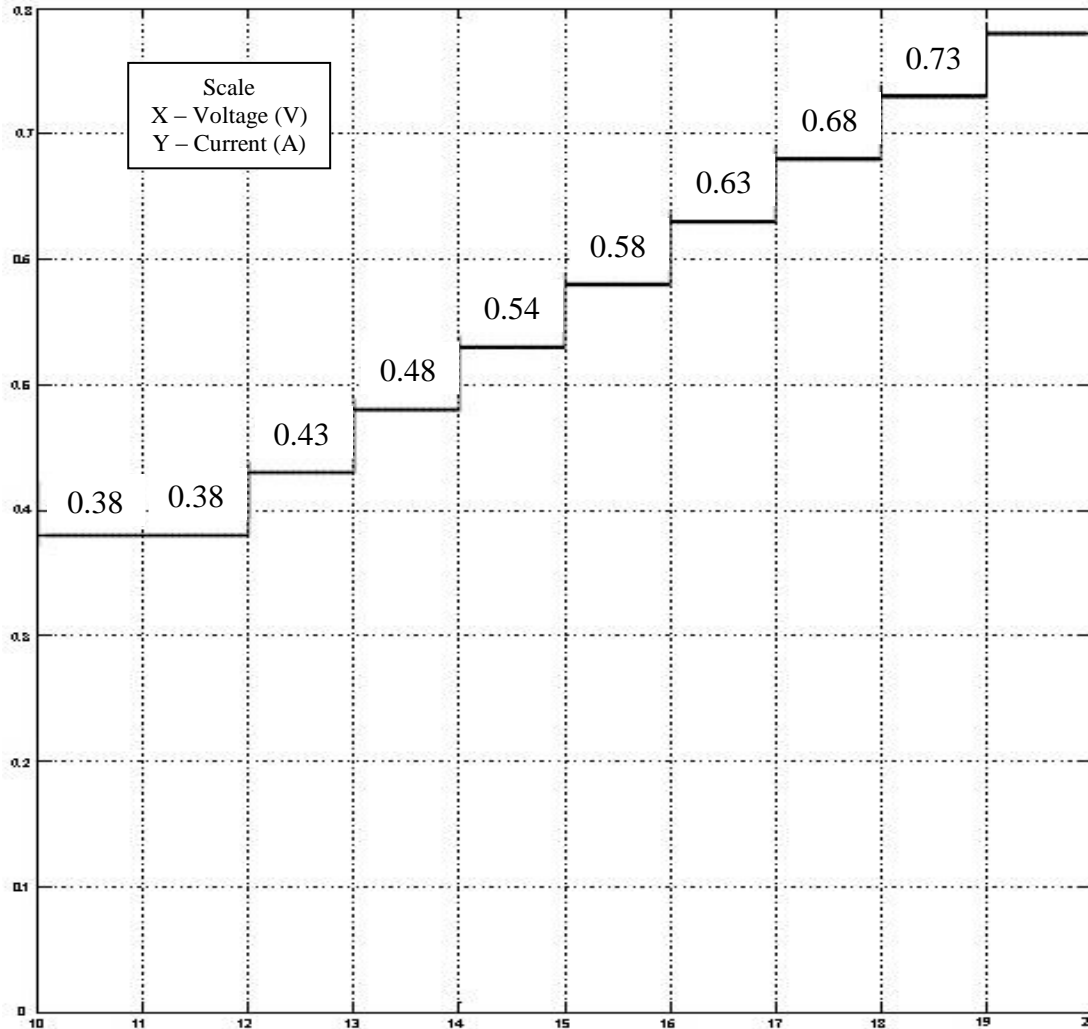
While for switch 2 in Figure 10 is when the converter in Buck operation. Output signal becomes 0 meaning the switch 2 is open.

The results shows in Table 5 is obtained from open loop MATLAB simulation diagram of Buck-Boost converter circuit.

**Table 5:** Results from open loop simulation in Buck-Boost operation

Input Voltage (V)	Output Current (A)
10	0.38
11	0.38
12	0.43
13	0.48
15	0.58
16	0.63
17	0.68
18	0.73

Input voltage in Buck-Boost operation starts with 10V to 18V with reference voltage 14V. The maximum output current is 0.73A and the minimum output current is 0.38A.



**Figure 11:** Graph of Open loop simulation result in Buck-Boost operation

The graph of the open loop simulation result in Buck-Boost operation is shown in Figure 11. The X-axis represents the Buck-Boost input voltage between 10V to 18V while Y-axis represents the value of output current from the converter. The graph is a linear relationship between the input voltage and output current which is when the input voltage at X-axis is increased, the output current at Y-axis also increased.

#### 4.0 CONCLUSION

The simulation of open loop current controller using MATLAB and Arduino software is successfully analyzed with minimum value of output current 0.38A and the maximum value is 0.73A. The higher output current, the faster charging process for lead acid battery. The project is also able to communicate between MATLAB and Arduino software in order to receive input and output signal.

## 5.0 REFERENCES

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