Exploration on Student Project Cases with Power Electronics Converter Application

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Abstract: This project is to explore the capability of Universiti Tun Hussein Onn Malaysis (UTHM) student especially in FKEE to apply the power electronics converter in simulation application. It has been conducted during the Final Year Program on COVID19 situation in year 2020. The single phase inverter model has been modeled for the first case. This inverter used current control feedback model. As for the second case, it is to control of voltage controlled feedback for the bidirectional DC-DC converter system. The bidirectional model is to charge the battery and then to discharge back to the load. Both projects using the Proportional Integral (PI) controller in order to minimize the error between the target and output signal. From the inverter result part, the input current reference is set at 2A and the output the current reference also at 2A where it shows the controller is working. As for the second projects, in various input and output voltages during the charging and discharging mode at the battery have been observed. At the end, the students have managed to complete and understand the important of power electronics converters.

Keywords: Power Electronics Converter, Sinusoidal Pulse Width Modulation, Single Phase Inverter

1. Introduction

In order to change the direct current (DC) to alternating current (AC), a converter known as inverter needs to be used as to generate the AC output waveforms such as square wave, modified sinewave and pure sinewave [1]. Inverter is used to provide uninterrupted AC supply to the load. It performs the reverse role from rectifier where the AC power is converted into DC power and functions by chopping the DC voltage through various means [2].

Inverter has been commonly used for applications, ranging from small switched computer power supplies to high voltage utility applications to transfer bulk power [3]. Inverter is available in different 'size ratings' from 50 VA up to 50,000 VA. Paper [4] explained on developing a single phase inverter

using voltage control for Sinusoidal Pulse Width Modulation (SPWM) switching and a capacitor to be the supply conditioner. However, in [5], the inverter is connected to the grid where it use to active and reactive output current control for maintaining high power quality levels and achieving relative immunity to grid disturbance which required more advanced theory. The inverter is not only for single phase only; however, it can be extended to 3 phase system. Paper [6] implemented the 3phase system using voltage control and paper [7] used the current control topology as the control mechanism.

The DC-DC converter can be operated as bidirectional power flow capability for increasing or decreasing the voltage level between its inputs and outputs along with power flow directions for ways [8]. The bidirectional DC-DC converters (BDCs) have bidirectional power flows capabilities and its gain a lot of attention in systems that require two-way power flows [9] [10] [11] that is been used for this exploration. As general theory, the buck type is to store energy storage on the high voltage side, and the boost type is to place it on the low voltage side [12]. By using a bidirectional pulse switching modulation (PWM) with switching state the power flows in both directions can be made simpler and cheaper [13].

In this project, both converters are being developed using the MATLAB-Simulink software. The software is able to create the converters structure and the control system more easily and it ready to be applied by the undergraduate student. The first configuration for the first case is shown in Figure 1. Figure 1 shows the single phase inverter block diagrams. It consists of current feedback loop that will be applied with the current proportional integral (PI) control system as the feedback.
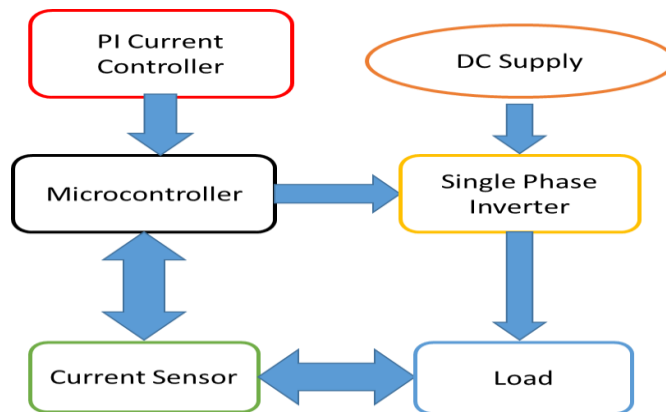

Figure 1: Inverter model for case 1

As for the second case, it is based on the DC-DC converter, the block diagram is shown in Figure 2. The model used the bidirectional converter for making sure the power can flow between the battery and dc supply or vice versa. In here the state of charge (SOC) of the battery needs to be maintained during charging and discharging mode of the converter. The voltage PI control loop is bee used as it feedback.
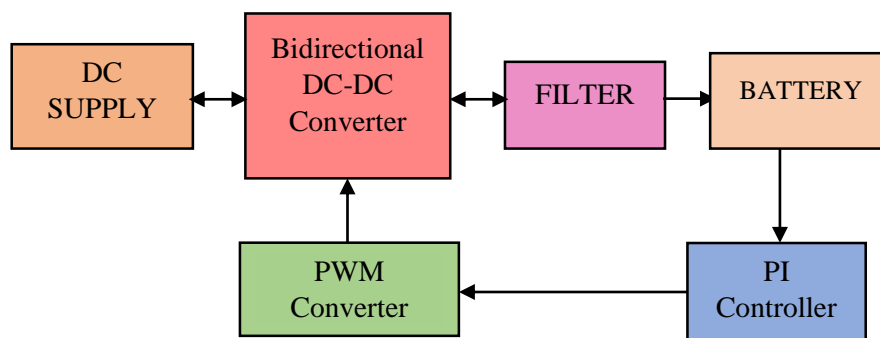

Figure 2 : DC-DC bidirectional model for case 2

2. System Development

In this section, the system developments are to give the understanding for the models and software developments. The models are being developed in MATLAB based on the converters configuration. At the same time the control strategies are also been developed in the MATLAB. The software configuration is when the process flow of the models is being applied. Therefore, system is been separated into two cases as been discussed in this section.

Case 1: Inverter Software Development

Figure 3 shows the flows of simulation development for the single phase inverter model from start to the end. It is a closed loop system, as there is a feedback from the current output on order to be controlled. In this case, there are few steps that need to do in order to developed the MATLAB-Simulink.
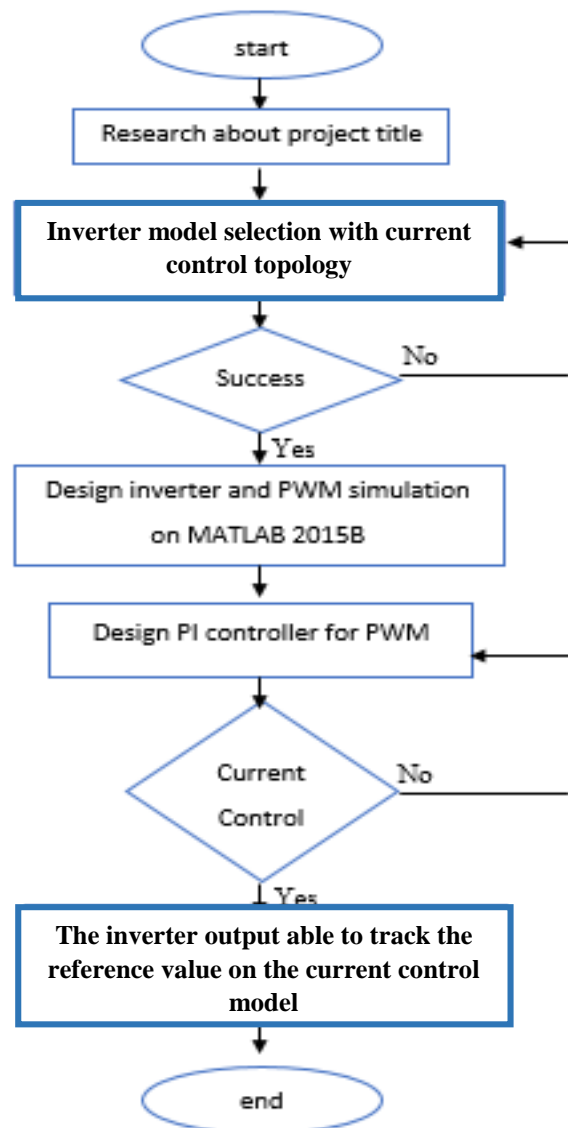

Figure 3: Software Development Flowchart for Inverter

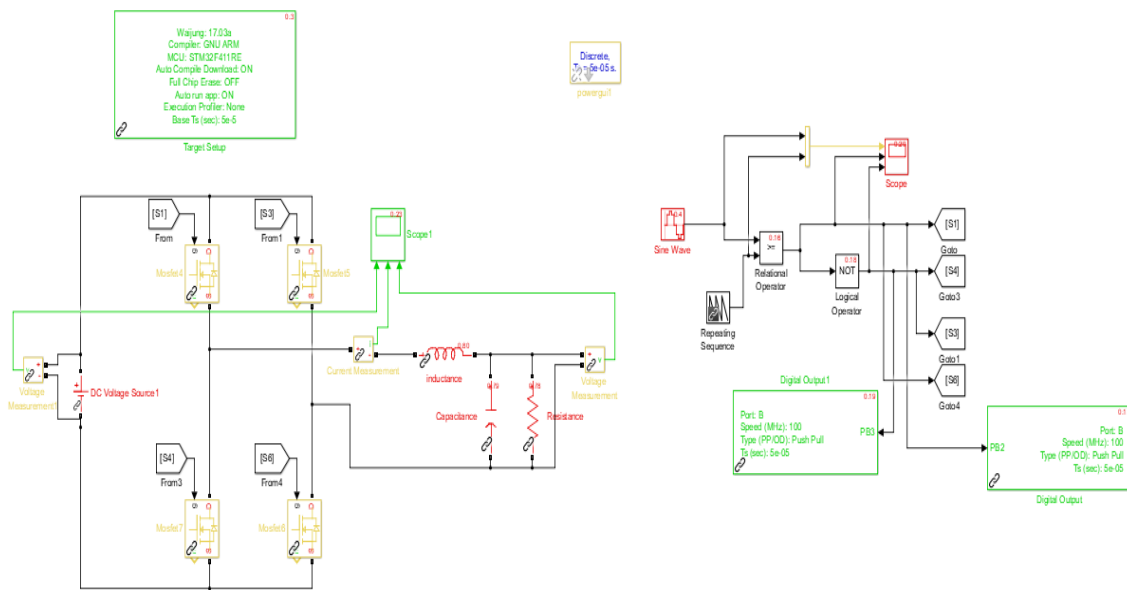The complete circuit diagram is shown in Figure 4.


Figure 4: Single phase inverter

After the development has been succeeded, the process is continued with the design of control and SPWM models in MATLAB Simulink. The filter is used in order to change the square wave signal at the inverter output to sinusoidal signal after the filer. The next step is to model the PI current controller model. The structure of the PI control is based from paper [14]. The gains for the PI control are determined by using try and error method. The SPWM model is used to create the switching pattern for the inverter. The role of the controller is to compare the reference current to the feedback current. By using the try and error method for the determining the PI gains before the required results can be collected. Table 1 shows the PI gain values for this case.

Table 1: The component of PI controller

| Component	Value
Gain P	2.667
Gain I	0.667
Integrator	1/s

Case 2: DC-DC converter Development

Figure 5 shows a system development for PI control feedback flow chart for the bidirectional comnverter. The PI control is needed to be initially for the Pulse Width Modulation (PWM) signal is produced after the setting as mentioned in [15]. The feedback voltage is then pass through the input of the controller which takes places before transmitted to the PI control gain. The PI controller receives the signal and compares the feedback voltage with the reference voltage. The condition of ($V_{out}=V_{ref}$) is begin here, if ($V_{out}\neq V_{ref}$) the PI controller needs to be set again to the appropriate value until it gets the value ($V_{out}=V_{ref}$). Then the PWM signal adjustment was produced and this system is repeated until the output voltage gets the same result as reference voltage.
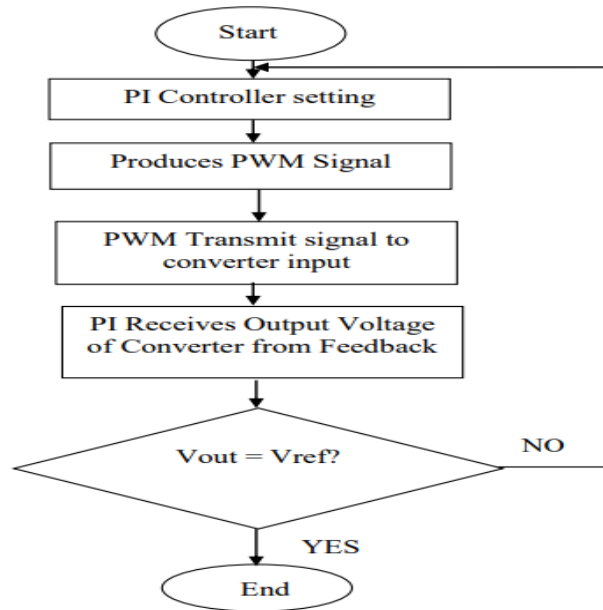
Figure 5: Bidirectional software development

The Simulink model in Figure 6 demonstrated a Bidirectional DC-DC Converter with PI voltage control that been used for battery charging and discharging application. The proposed bidirectional converter consists of a DC voltage source, capacitor C1, two power MOSFET which are MOSFET1 and MOSFET2, filtering inductor L1, output capacitor C2 and lead acid battery that available in the MATLAB. The charging and discharging modes are control by the charge and discharge setting block where a positive current set the converter to discharging mode and a negative current set the converter to charging mode. Energy converters are an integral part of many electrical systems that require energy transfer between one voltage level to another voltage, as the required voltage may vary with voltage supplied.
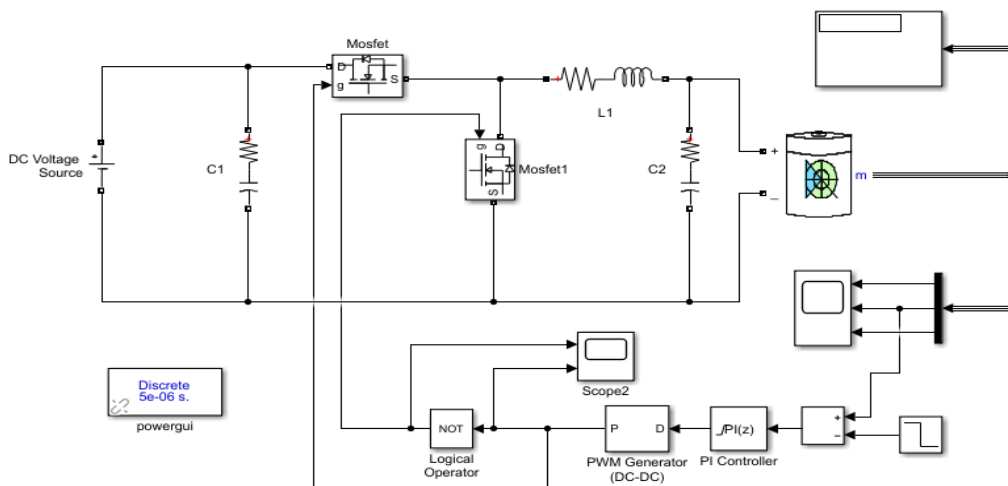
Figure 6: Bidirectional model with battery load

3.   Results and Analysis

In this section the results for each case will be explained. All the results are collecting from MATLAB-Simulink software. For each case the closed loop and open loop simulation results will be shared. From all the results its show the students are able to explore the MATLAB software in very short time due to COVID19 restriction.

Case 1: Open and Closed Loop Inverter Simulation

The first trial is when the single phase inverter is running in the open loop system. The open loop test is when the current feedback and the PI control are not being connected to the inverter. The generation of the SPWM is based on reference voltage which is set at 50Hz and 1V magnitude. Figure 7 shows the results of waveform in Io and Vo. As known the inverter must be connected to the low pass filter in order to improve the signal output from square signal to sinusoidal wave signal. Therefore, the low pass filter is R=30Ω, L=100mH and C= 100uF.
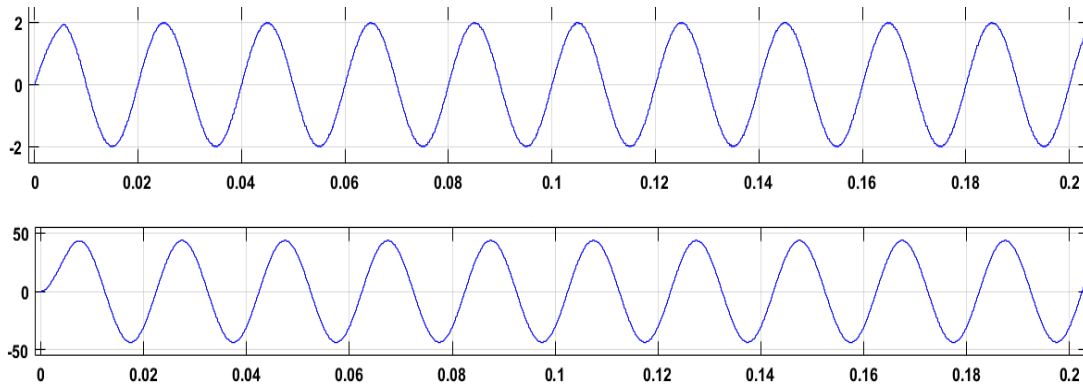

Figure 7: Current and voltage output

Closed loop is the system that running the circuit with feedback is shown in Figure 8. In this simulation, the feedback PI current controller and ADC in SPWM switching pattern. Output current from the inverter will be injected back to the PI controller for producing switching frequency with the comparison of a reference voltage. Figure 8 shows the closed loop result for the inverter output current when the reference current is set at Table 2.
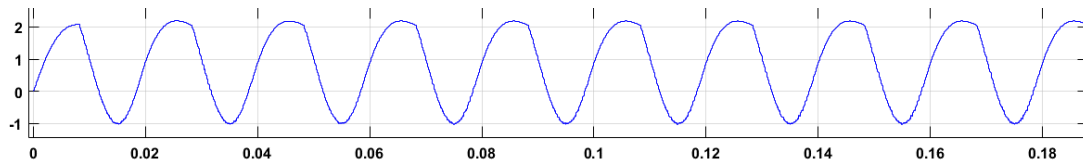

Figure 8: Inverter output current

Table 3: Reference current vs Output current

| Current reference (A)	
I ref	Io
2	2

Case 2: Closed Loop DC-DC Simulation with charging and discharging mode operation

The result shows in Figure 9 show the load voltage when the reference is set at 12V. It is where the PI controller receives the signal and compared the feedback voltage with reference voltage. The result shows the response of the load is maintained at 12V after 1.462 seconds. The result show that the output voltage successful controlled by references voltage.
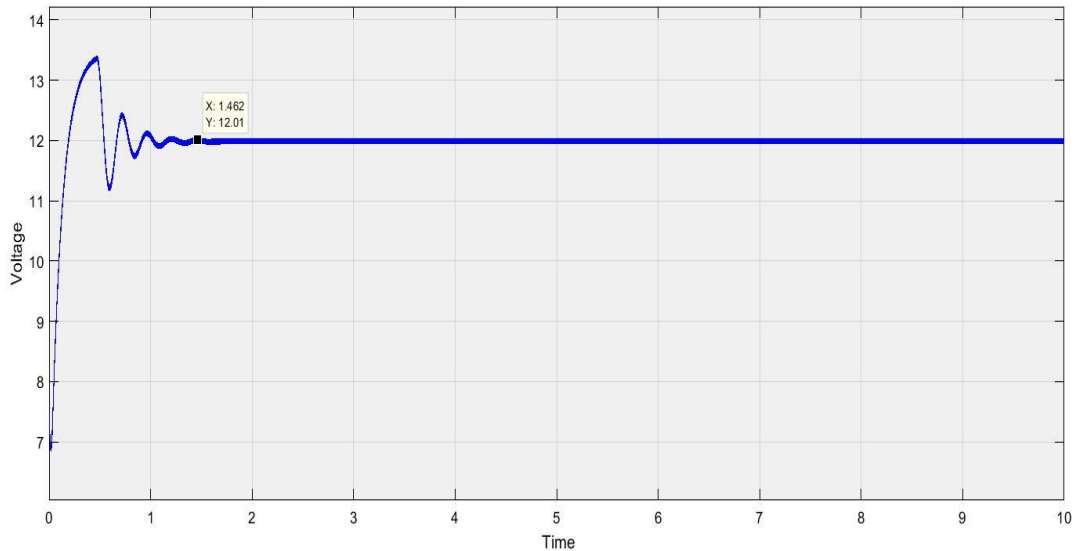
**Figure 9: Load voltage during closed loop (12V$_{ref}$)**

As for the response on the charging and discharging respond the state of charge (SOC) of the battery is been considered. Figure 10 shows the battery state of charge (SOC), output voltage and current waveform in charging mode. The SOC shows the waveform keep increasing due to charging mode after 1.502 seconds. Based on the graph, the current remains negative indicating the circuit is in charging mode. Battery is charged by constant voltage and constant current methods as shown in the Figure 10.
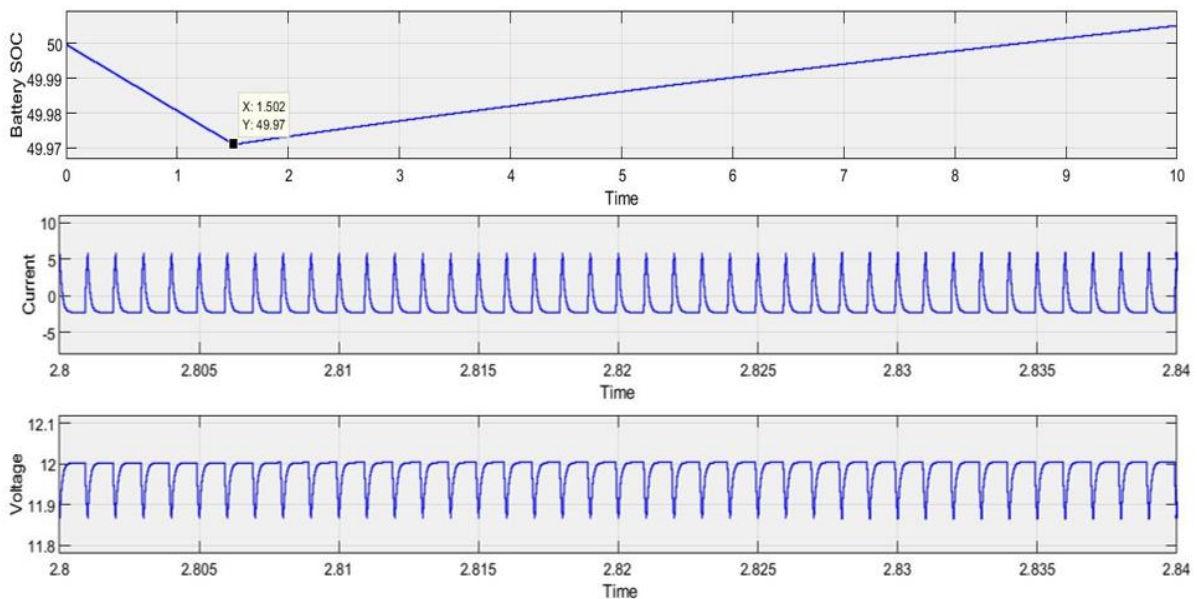
Figure 10: Charging mode status at SOC

Meanwhile Figure 11 shows the output waveform of the bidirectional converter in discharging mode which is transfer the energy from output voltage to input voltage. In this situation, the battery shows the waveform is decrease due to discharging mode. Based on the current waveform, the current value is in positive value it means the battery is discharging. Battery is discharged by constant voltage, constant current methods.
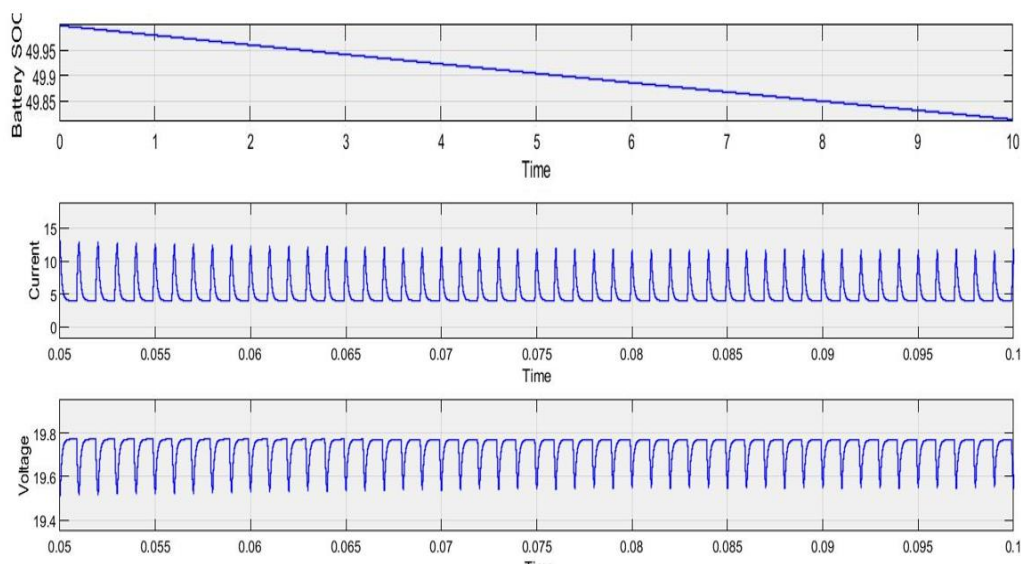
Figure 11: Discharging mode status at SOC

4. Conclusion

As a conclusion, these projects are to exploring the student to be familiar with the power electronics converter and the simulation process. The combination of the PI control model for current and voltage control are also been used. The PI control model is to make sure the controller can make the output of the converters to follow the target values that are required. The open loop and closed loop simulations analysis have been applied to get the output result from the inverter to control the current reference in simulation mode. The open loop circuit is about to testing the whole circuit without the feedback which is the current sensor. The output from open loop was the current reference to make it same with SPWM current control. As for the DC converter, the result for charging and discharging modes are successful generated and also able to maintain the battery voltage at the required value. Thus, the power flow direction of the circuit is from the DC voltage source to the battery bank to charge the battery with output current and the output current is in positive. At the end it shows that the UTHM students are able to adapt quickly on the change of the project requirement due to COVID-19 situation.

Acknowledgement

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