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Constant Current Charging a Battery by using Proportional Controller

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***Abstract*— The charging method, in general, is the process that dictates the method by which energy would be returned to the battery. If the energy is not returned to the battery in a way that it is appropriate with the chemistry, the recharge can cause harm effects on the battery. There are several standard charging methods. As a matter of fact, constant current charging is the simplest method of charging employing single low-level current to the discharged battery. The current is usually selected at ten percent of the maximum rated capacity of the battery. Even though there are many advantages of charging method, the only disadvantage of this charging method is that if the battery is overcharged the gassing and overheating of the battery would occur. The main objective of this project was to maintain constant current charged an AA battery while the voltage across the battery was variable. The Buck converter should be used as a dc source. Moreover, applying any of the methods discussed in class to control the circuit.**

***Keywords*— Constant Current, Charging Battery, Buck Converter, and PID Controller.**

I. Introduction

Batteries are widely adopted in various implementations. The charge mode safely affects the battery life and capacity [1]. As a matter of fact, charging battery is very easy and simple. However, it is very complicated to charge a circuit.

In this project, the Buck converter was employed. The Buck converter is used as a DC- DC converter to provide the controlled output power supply to the batteries. The advantages of the buck converter are highly efficient and performed. Additionally, it has a simple structure needing one MOSFET switch and without any transformers to drop the voltage [2]. Charging a battery with constant current was commanded. In fact, a problem would arise to maintain constant current because the voltage across the battery was not linearly related to the total charge in the battery. The constant-current charge ends when the battery voltage reached 1.5 V. In order to maintain constant current charging a battery, it was necessary to use one of the controllers such as Proportional controller (P), Proportional-Integral (PI) controllers, or Proportional-Integral-Derivative (PID) controllers. In this project, using proportional controller is proposed to assist in reducing the steady state error, therefore, made the system more stable.

II. Proportional (P) Controller

The proportional (P) controller is predominantly applied in first order processes with single energy storage to settle down the unstable process. The primary usage of the P controller is to decrease the steady-state error of the system. When the proportional gain factor K increases, the steady-state error of the system decreases. Nevertheless, in spite of the reduction, P control can never manage to eliminate the steady-state error of the system. As we increase the proportional gain, it gives smaller amplitude and phase margin, faster dynamics satisfying wider frequency band, and larger sensitivity to the noise. The P controller can be used only when our system is tolerable to a constant steady state error. Moreover, it can be simply concluded that applying P controller decreases the rise time and after an absolute value of the reduction in the steady state error, increasing K only leads to overshoot of the system response.

III. Proportional Integral (PI) Controller

Proportional-Integral (PI) controller is mostly used to remove the steady-state error resulting from P controller. This controller is primarily used in areas where the speed of the system is not an issue because it has an adverse impact regarding the speed of the response and overall stability of the system. Besides, it cannot decrease the rise time and eliminate the oscillations because PI controller has no ability to predict the future errors of the system.

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IV. PROPORTIONAL INTEGRAL DERIVATIVE(PID) CONTROLLER

The proportional-integral-derivative (PID) controller has the optimum control dynamics. The need of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. There are a lot of advantages of the PID controller such as zero steady state error, fast response, no oscillations, and higher stability. Additionally, it can be used with higher order processes including more than single energy storage.

V. METHODOLOGY

The project was performed in the following steps:

1) Set up a circuit of buck converter with its parameters, which were DC source voltage, MOSFET switch and diode switch, Inductor (L), Capacitor (C), and load resistor (R).

2) The converter used was to be supplied with a dc source of Vg = 5+5= 10V. Note, each group's voltage was determined by using the equation:
Vg = 5+ (last digit of your ZID). The values of the Inductor (L) and of the capacitor (C) should be determined in terms of 10% current ripple of 0.5 A.

$$V_g = 10v \qquad V_o = 1.5v$$

$$i_L = 0.5A \qquad \Delta i_L = 10\%\ of\ i_L$$

$$\Rightarrow \Delta i_L = 0.05A \qquad \Delta i_{L(max)} = 0.525A$$

$$\Delta i_{L(min)} = 0.475A$$

$$D = \frac{V_o}{V_{in}} = 0.15 \qquad R_0 = 3\Omega$$

$$f_s = 50KHZ$$

$$\Delta i_L = \frac{(V_{in} - V_o) \times D}{L \times f_s} \qquad \Rightarrow L = 510\ uH$$

$$Let\ \Delta V = 0.01 \ \Rightarrow\ \Delta V = \frac{\Delta i_L \times T_s}{8 \times C} \Rightarrow C = 12.5uF$$

$$\Delta i_L = \frac{(V_{in} - V_o) \times D}{L \times f_s} \qquad \Rightarrow L = 510\ uH$$

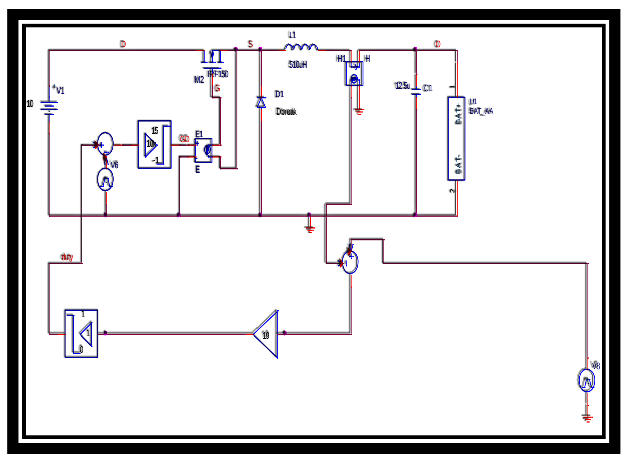
$$\Delta V = \frac{\Delta i_L \times T_s}{8 \times C} \Rightarrow C = 12.5uF$$

3) The PWM switching frequency to be used was 50kHz.

4) Set a voltage reference to have the ripple current values (0.525 - 0.475).

5) The output library (.olb) added to the parts list libraries. And then, the PSPICE library (.lib) added to the library list using "Configure Files" tab in "Edit Simulation Profile".

6) Set up the initial charge to zero. It was done by using the "Configure Files" tab in "Edit Simulation Profile", selected the libraries category, highlight the "batteries.lib" library, Selected edit, Selected the AA battery, Found the C_C1 charge capacitor and set its initial conditions to zero (IC=0).
7) Next, after adjusting the AA battery, the resistor was replaced.
8) Added a sensor current after the inductor to sense a current came from (iL), and connected to a (DIFF) with reference current.



9) The output of the (DIFF) connected to the (Kp) controller.
10) Set G_{pwm} to restrict the limits set by the LO (0) and HI (1).

Fig. 1 DC-DC Buck converter circuit with (Kp) controller.

VI. DISCUSSION

Fig. 2 Simulation output waveforms.

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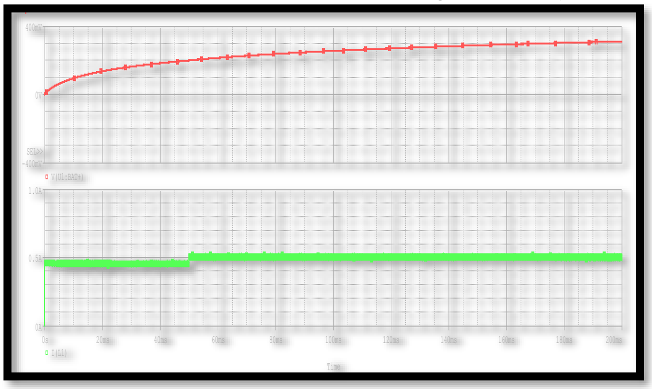


Red- Voltage charging battery; green- current ripple
This graphs shows a current ripple and voltage charging a battery after a simulation.

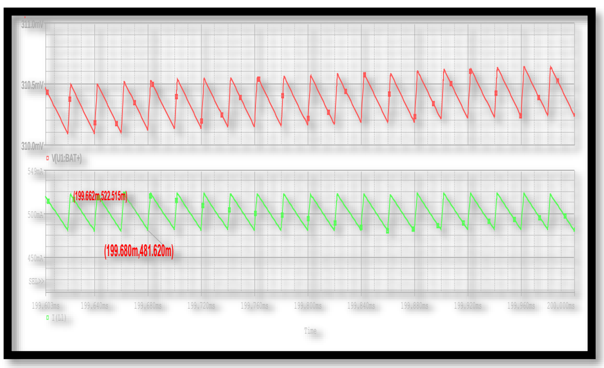


Fig. 3 Simulation output waveforms (zoomed in).

As it can be noticed in Fig. 2, the current ripple is constant, and the voltage increases slowly to charge the battery. Current ripple almost closes to the theoretical results obtained in appendix that $\Delta i = 0.05A$.

$$\Delta i_L = \Delta i_{L(max)} - \Delta i_{L(min)}$$
$$\Rightarrow \quad 0.5225 - 0.4816$$
$$= \quad 0.0409\ A$$

which is very close to the theoretical results.

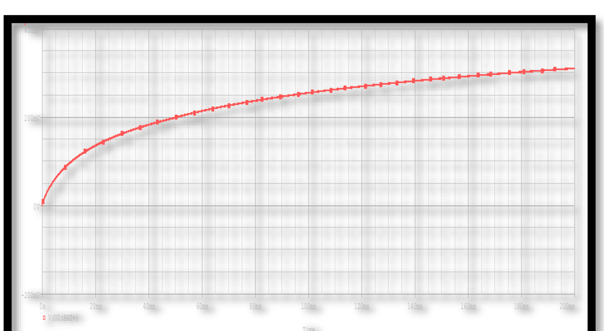
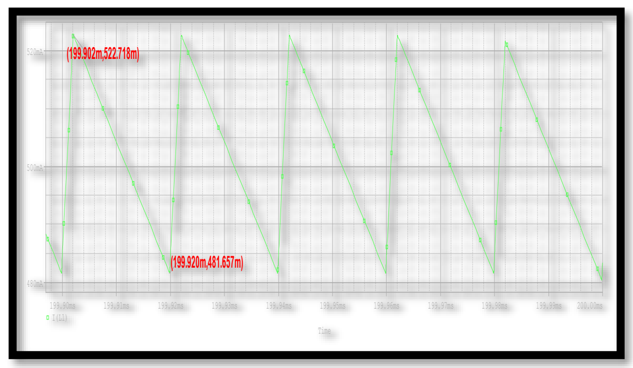


Fig. 4 Output voltage waveform.

This graph shows the output voltage waveform that grows up to reach 1.5V, which is the high value to charge the battery. Indeed, it cannot obtain the maximum voltage in this graph because it needs a long time to reach 1.5V.

Fig. 5 Output current ripple waveform (Zoomed in)

As it can be seen in Fig. 5, the current ripple is maintained



to be constant because of the (Kp) controller that plays a significant role to stabilize the output current ripple and reduce the steady state error.

VII. Conclusion

The project performed showed the correlation between the switching frequencies, output current ripple, controller circuit gain, and the parameters of the LC filter. Based on the objective, maintaining constant current charging a battery was accomplished by using the proportional controller.

References

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