Design and Simulation of Single-Input Multi-Output (SIMO) Flyback Converter Using PI Controller for Emergency Power Supply

F C Saputri¹, M Z Efendi², F D Murdianto³

¹,²,³Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Keputih Sukolilo, Surabaya, Indonesia

Abstract. The electricity problems in some regions are different, it can be caused by various things e.g power outages and lack of electricity availability. Whereas the need for electrical energy is increasing as human needs increase. The importance of electricity supply for electronic equipment during disaster or emergency condition forces the electricity needs to be fulfilled and supplied continuously. An emergency power supply is commonly used to solve these problems. However, most of the emergency power supply is only intended for single-input single-output needs. This paper refers to a single-input multi-output flyback converter as an emergency power supply that can provide a multi-output system that has two different output voltage levels, which is specified for charging notebook and cell phone using a PI controller as a voltage regulator. Based on the simulation result, the system can obtain the desired output voltage (19 V and 9.5 V) and also can reach the steady-state response in 0.017 s.

1. Introduction

Natural disasters that occur in various regions often have an impact on electricity, one of the impacts is power outages. The importance of electricity supply for electronic equipment during emergency conditions such as PC or notebook and cell phone forces the electricity needs to be fulfilled and supplied continuously. Emergency Power Supply is the solution to overcome the problem.

DC-DC Converter is one of the common electronic devices that is used to provide the required output voltage by using PWM (Pulse Width Modulation). There are various types of DC-DC Converter e.g. buck, boost, and buck-boost converter. These converters have non-isolated converter topologies and single-input single-output only. Whereas to overcome the problem of emergency electricity needs, it is needed a converter that can provide for more than one output with different voltage levels [1]. Flyback Converter has isolate converter topology which isolates the input and the output. Since every isolated converter employs a transformer which would further increase the cost and size, a flyback converter is a reasonable choice for high frequency and low power application due to its easy implementation and simple structure with no additional inductor at the output. Flyback converter also low cost because of low component numbers which uses only one switch component and one transformer [2][3]. Hence the flyback converter is chosen as a multiple output converter that is suitable for variable voltage needs [4]-[6].
This paper proposes a Single-Input Multi-Output Emergency Power Supply as a design of Flyback Converter which developed using batteries as the main source. A simulation using PSIM is attempted to analyze the whole system. This system is designed has 24 V DC input voltage which comes from two series batteries and two DC output for 19 V and 10 V. The output is designed and proposed for charging notebook and cell phone needs, which of the secondary winding that generates 10 V will be lowered to 5 V using DC-DC USB Buck Converter module to suit the cell phone charging specification. The PI controller is designed as a voltage regulator to distribute more stable power from the source to the load in a small-time response as proposed.

2. Design Considerations
Various types of DC-DC Converter can be classified based on the topology i.e. isolated converter and non-isolated converter. One of the isolated converter used in this proposed system is a flyback converter. The topology and the design of the flyback converter will further be explained in the following sections.

2.1. Flyback Converter
Flyback converter is an isolated dc-dc converter with simple topology. The typical topology of the flyback converter is shown in Figure 1.

![Figure 1. Typical Flyback Converter.](image)

Flyback converter has a topology that works as a buck-boost mode with a switching component to set the duty cycle. This converter has dot-ends or polarity of the transformer to determine the operation of the converter. The polarity of the primary winding (Np) and the secondary (Ns) are not the same. The condition of the flyback converter is divided into two, switch on and switch off. These two conditions are shown in Figure 2 and Figure 3.

- **Switch ON**
  When the switch is on, energy absorbed into the primary winding, then transferred to the secondary winding after switch turned off. Since the diode is reverse bias, the load current is supplied by the capacitor.

![Figure 2. Topology of The Flyback Converter When Switch is ON.](image)
• **Switch OFF**
  When the switch is off, energy stored at the air gap of the transformer and transferred to the secondary winding. Since the diode is forward bias, the load current is supplied by the secondary winding (Ns).

![Figure 3. Topology of The Flyback Converter When Switch is OFF.](image)

There are three operation conditions that work on flyback converter i.e CCM (continuous conduction mode), DCM (discontinuous conduction mode), and critical operation mode [7]. For this proposed system, the CCM operation is recommended. In CCM, the current of the secondary winding is greater than zero when the switch turns-on for the next period. The secondary current couldn’t fully discharge and there will be stored energy at the secondary side when the next switch turn-on interval starts.

In this paper, a flyback converter is needed in developing a single-input multi-output emergency power supply. The proposed block diagram system of the flyback converter interfaced with batteries is shown in Figure 4.

![Figure 4. Block Diagram System.](image)

As seen in Figure 4 the flyback converter is used to generate two output 19 V and 10 V DC voltages that suitable for charge the notebook and the cell phone batteries with 3.42 A and 2 A for the current specification. These output voltage can be set by adjusting the winding turn ratio of the transformer. Adjusting the winding turn ratio is not enough yet to get obtain the right output voltage value as designed, so this system still needs a controller to obtain a stable output voltage. PI controller is chosen in this system to control the output voltage. The circuit of the flyback converter is shown in Figure 5.
Critical design parameters are defined initially such as input voltage, output voltage, and switching frequency [8]. These initial designs are effective for the efficiency of the system. In this system we use 50 kHz for the switching frequency as the higher switching frequency we use, the smaller transformer size and weight we get [9]. The Flyback Converter is designed according to the parameters shown in Table 1.

### Table 1. Parameter Of Flyback Converter.

| Parameter                        | Value     |
|----------------------------------|-----------|
| Input Voltage (V<sub>S</sub>)    | 24 V dc   |
| Frequency Switching (f<sub>S</sub>) | 50 kHz   |
| Duty Ratio (D)                   | 0.5       |
| Output Voltage 1 (V<sub>O1</sub>) | 19 V     |
| Output Voltage 2 (V<sub>O2</sub>) | 10 V     |

The basic circuit for a flyback converter can be designed by a standard design procedure [10]. The design of the flyback converter transformer is calculated using equation (1) to (7). Flyback transformer parameters are shown in Table 2.

\[
V_O = V_{S\min} \left( \frac{D}{1-D} \right) \left( \frac{N_S}{N_P} \right) 
\]  

\[
L_m = \frac{\left( V_{S\min} \times D \right)^2}{2 \times P_{in} \times f_s \times Krf} 
\]  

\[
\Delta I = \frac{V_{S\min} \times D}{L_m \times f_s} 
\]  

\[
I_{L\max} = 1.12 \times \left( I_{dc} + \frac{\Delta I}{2} \right) 
\]  

\[
N_{P\min} = \frac{L_m \times I_{L\max} \times 10^4}{B_{max} \times A_c} 
\]  

\[
N_P = 2.5 \times N_{P\min} 
\]
\[ C = \frac{I_0 \times D}{f \times \Delta V_o} \]  

Table 2. Parameter Transformer of Flyback Converter.

| Parameter                  | Value    |
|----------------------------|----------|
| Magnetizing Inductance (L_m) | 31.12 μH |
| Primary Turns (N_p)         | 12       |
| Secondary 1 Turns (N_s1)    | 10       |
| Secondary 2 Turns (N_s2)    | 5        |
| Capacitor 1 (C_1)           | 1800 μF  |
| Capacitor 2 (C_2)           | 2000 μF  |

2.2. PI Controller

The Proportional-Integral PI controller is one of the most popular controllers that is used to control the output voltage of the DC-DC converter due to its simple structure and implementation. A PI controller adjusts the error signal as the feedback of the control loop [11]-[13].

In general, a PI controller has two tuning parameters that need to be determined. That is the proportional gain and the integral gain [14]. The proportional gain of a controller which is called a P controller produces an output that is proportional to the error value. This controller causes elimination of the steady-state error. The purpose of the integral gain or I controller is to remove the steady-state error depends on the magnitude and duration of the error [15]. The block diagram of a PI controller that is used to the proposed system is shown in Figure 6.

![Figure 6. Block Diagram of PI Controller for The System.](image)

In the PI controller, both proportional and integral gains are combined as shown in Figure 6. Error signals are conducted by comparing the set-point or reference signal with the output of the converter that is measured by a sensor as triggering pulses. The error of the controller which is the duty ratio of the converter is then adjusted to the set-point of the system to make the error nearer to zero.

The PI controller that is used in the system is obtained from the simulation response of the flyback converter which uses the predetermined parameters. The open-loop transfer function (OLTf) of the system is shown in equation (8) and the response of the OLTF shown in Figure 7 and the closed-loop transfer function (CLTF) of the system is shown in equation (9) and the response of the CLTF shown in Figure 8.

\[ OLTf = \frac{K}{s^2 + 0.0171 s + 1} = 1.05211 \]
$$CLTF = \frac{K}{\tau s + 1} = \frac{1}{3.42 \times 10^{-3} + 1}$$  \hspace{1cm} (9)

![Open Loop Step Response](image1.png)

**Figure 7.** Step Response of Open-Loop Transfer Function (OLTF).

![Open Loop Step Response](image2.png)

**Figure 8.** Step Response of The Closed-Loop Transfer Function (CLTF).

3. Simulation Result

To analyze the performance of the system proposed, PSIM software is used for the simulation of the flyback converter. Since the design of this system has two proposed output specification as 19 V 3.42 A and 10 V 2 A for charge the notebook and the cell phone batteries, the nominal load of 5.6 Ω and 5 Ω that used are obtained by dividing the voltage and the current specification. This simulation assumes constant input voltage and constant load under steady-state conditions which using 2 batteries 12 V as the input voltage. The simulation diagram of the flyback converter for the closed-loop model is shown in Figure 9. The closed-loop model with the PI controller is simulated with the previously mentioned parameter to suit the constant output voltage as proposed.
Figure 9. Simulation Diagram for The Closed-Loop Model of The Flyback Converter.

The simulation response shows both the output voltage and the output current of the two loads. The response will be compared in open-loop and closed-loop which is shown in Figure 10 – Figure 13. To prove that the controller works on the system, the input voltage will be varied in the range 20 V – 25 V. The results of the simulation are detail mentioned in Table 3.

Figure 10. Simulation Response with 20 V Input Voltage (a) Open-Loop (b) Closed-Loop.
Figure 11. Simulation Response with 22 V Input Voltage (a) Open-Loop (b) Closed-Loop.

Figure 12. Simulation Response with 24 V Input Voltage (a) Open-Loop (b) Closed-Loop.

Figure 13. Simulation Response with 25 V Input Voltage (a) Open-Loop (b) Closed-Loop.
Table 3. Simulation Result of The System With Varied Input Voltage.

| Input Voltage (V) | Output Voltage 1 (V) | Output Voltage 2 (V) | Response Time (s) |
|-------------------|----------------------|----------------------|-------------------|
|                   | Open-Loop Closed-Loop| Open-Loop Closed-Loop| Open-Loop Closed-Loop |
| 20                | 16.59 19.0           | 8.29 9.5             | 0.044 0.017       |
| 22                | 18.33 19.0           | 9.17 9.5             | 0.045 0.017       |
| 24                | 20.01 19.0           | 10.0 9.5             | 0.049 0.017       |
| 25                | 20.83 19.0           | 10.4 9.5             | 0.054 0.017       |

The simulation result shows that the PI controller stabilizes the voltage at 19 V in a shorter time period than with no controller. Despite the input voltage is varied from 20 – 25 V, the PI controller always brought the output voltage of the flyback converter back to the set-point 19 V in a very short time period at 0.017 s.

However, the flyback converter has only one switch to control the output voltage, the PI controller can only obtain one desired set-point in one selected output side, while the other output side follows the regulation that is set by the PI controller. This statement is mentioned and shown in Table 4 by the simulation result that use the second output voltage (10 V) as the feedback of the controller.

Table 4. Simulation Result of The System With The Second Output Voltage (10 V) as The Feedback.

| Input Voltage (V) | Output Voltage 1 (V) | Output Voltage 2 (V) | Response Time (s) |
|-------------------|----------------------|----------------------|-------------------|
|                   | Open-Loop Closed-Loop| Open-Loop Closed-Loop| Open-Loop Closed-Loop |
| 20                | 16.59 20.0           | 8.29 10.0            | 0.044 0.035       |
| 22                | 18.33 20.0           | 9.17 10.0            | 0.045 0.035       |
| 24                | 20.01 20.0           | 10.0 10.0            | 0.049 0.035       |
| 25                | 20.83 20.0           | 10.4 10.0            | 0.054 0.035       |

The simulation result of the system with the second output voltage as the feedback using the same input nominal conducts the output voltage at 20 V and 10 V in 0.035 s. It has proven that the flyback converter which has only one switch can only obtain one desired set-point in one selected output side as the regulation of the PI controller.

Comparison of the two simulation result in different feedback parameter conducts that the closed-loop model that uses the PI controller has a better response to obtain the steady-state output voltage as proposed than the open-loop model. It shows that the system of Single-Input Multi-Output (SIMO) Flyback Converter Using PI Controller for Emergency Power Supply can obtain the desired output voltage in stable condition as the designed for charging the notebook and the cell phone needs.

4. Conclusion

According to the simulation result, a comparison of both the open-loop model and the closed-loop model of the flyback converter has proven that the closed-loop model that uses the PI controller has a better response to obtain the steady-state output voltage as proposed. The obtained output voltage of the closed-loop system with the feedback control from the first output voltage is 19 V and 9.5 V in 0.017 s, while the output voltage of the closed-loop system with the feedback control from the second output voltage is 20 V and 10 V in 0.035 s. The efforts for getting the output voltage as desired are hindered by the fact of a flyback converter has only one switch to control the output voltage only in one selected output side of the converter. However overall simulation result of Single-Input Multi-Output (SIMO) Flyback Converter Using PI Controller can be applied as an Emergency Power Supply for the notebook and the cell phone charging needs.
References

[1] M Tahan, D Bamgboje, and T Hu 2018 9th Int. Symp. on Power Electronics for Distributed Generation Systems (PEDG) (Charlotte, NC: IEEE) pp 1-8

[2] G Niveditha M, Karanam V, Durga P, Satish S 2017 Int. J. of Innovative Research in Computer and Communication Engineering (IJIRCEE) 5 7675-83

[3] N Coruh, S Urgun, and T Erfidan 2010 5th Conf. on Industrial Electronics and Applications (Taichung: IEEE) pp 1189-1193

[4] Subhrabajoti M, Goutam K P, Pradip K S, Sankar D 2015 Int. J. of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE) 4 289-97

[5] M Alam, K Kumar, and V Dutta 2019 1st Int. Conf. on Energy, Systems and Information Processing (ICESIP) (Chennai: IEEE) pp 1-4

[6] G Tosun, O C Kivanc, E Oguz, O Ustun, and R N Tuncay 2015 9th Int. Conf. on Electrical and Electronics Engineering (ELECO) (Bursa: IEEE) pp 1102-1108

[7] T E Salem, C W Tipton, D Porschet 2006 Proc. Of The Thirty-Eight Southeastern Symp. on System Theory ( Cookeville, TN: IEEE) p 406 - 409

[8] Marian K Kazimierczuk 2012 Pulse-width Modulated DC–DC Power Converters (WILEY) pp 189-237

[9] C M Wang, C H Su, and C H Yang 2006 Proc. Electric Power Applications (IEEE) pp 116-122

[10] D W Hart 2015 Power Electronics (New York, NY: McGraw-Hill Education)

[11] O Rabiaa, B H Mouna, S Lassaad, F Aymen, and A Aicha 2018 Int. Symp. on Advanced Electrical and Communication Technologies (ISAECT) (Rabat: IEEE) pp 1-5

[12] A Elnady 2019 Advances in Science and Engineering Technology Int. Conf. (ASET) (Dubai: IEEE) pp 1-6

[13] T Halder 2014 6th India Int. Conf. on Power Electronics (IICPE) (Kurukshetra: IEEE) pp 1-6

[14] A Alganidi and A Kumar 2019 Canadian Conf. of Electrical and Computer Engineering (CCECE) (Edmonton, AB: IEEE) pp 1-4

[15] D Vasanthakumar and Srikanth V 2014 Int. Conf. on Computation of Power, Energy, Information and Communication (ICCPEIC) (Chennai: IEEE) pp 245-249