SIMO Converter Design as Emergency Power Supply Multi Output for Disaster Areas

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Abstract. This paper discusses the design of emergency power supply systems in disaster affected areas. Communication and information on post-disaster conditions is very important to be known by the family or authorities. However, a condition that often occurs after a disaster is that the communication system is cut off due to loss of electricity sources. The proposed system aims to provide backups of electrical energy especially in communication equipment such as cellphone chargers and Backup Battery systems on BTS. The flyback converter topology applied provides a multi output voltage of 5 volts for cellphone chargers and 13 volts for Battery systems on BTS, where each system is able to provide an SOC of 20-40%.

1. Introduction
Disasters often occur in Indonesia. In the last two years two major disaster events have been recorded, namely the Lombok earthquake and the hammer. The impact of these events caused damage to infrastructure both private and state owned. Post-disaster, communication and information systems become very important to find out the latest information and information related to the situation in the place affected by the disaster. However, the phenomenon that is happening right now is that the communication system and information cannot be used properly because of the access to the electricity system that went out after the disaster. Like BTS, this signal transmitter system will turn off when the power goes out. Even though the new BTS system has backup storage using batteries, the energy produced will not be able to last long. The next problem is when the BTS is still active (on) but the communication device (cellphone) used cannot function due to low battery so it cannot communicate or provide information to families or authorities regarding post-disaster conditions [1]. Based on these problems, this paper will discuss the design of emergency power supply for single input multi output (SIMO) converters in disaster areas as HP supply and storage battery (Accu) using the Flyback converter topology [1-3].

2. Flyback Topology
Converter can classified as an isolated and non isolated. Flyback is one of converter which have isolated topologies [1], [4].
Figure 1 is a basic flyback converter topology, which is a development of the boost converter topology. In the boost converter topology using a temporary inductor on the flyback, the inductor component is replaced using a transformer so that it can function as a galvanic insulation insulation. In the flyback topology, the converter gain is controlled by PWM. The magnitude of the input voltage gain and output voltage are formulated as follows [1], [4-7].

\[
D = \frac{(V_{out} - V_{Diode})}{(V_{in} - V_{Transistor} + (V_{out} - V_{Diode}))} \times \frac{N_p}{N_s} \tag{1}
\]

\[
V_{out} = \frac{D \times (V_{out} - V_{Diode})}{(1 - D)} \times \frac{N_p}{N_s} + V_{Diode} \tag{2}
\]

Where \(N_p / N_s\) is the turn ratio, the winding between primary and secondary. The advantage of the flyback converter is that it is easy to design a control system, the number of electronic components both passive and active is not far with a non-inverting buck / boost topology, accessible to regulate bi-directional current flow, suitable for medium power applications 50 ~ 250 watts, Input maximum voltage and gain are quite wide, some input / output can be configured and the safety aspect is quite good because of the galvanic isolation feature. On the other hand the flaws of the flyback topology are low power density, high enough component voltage, large filter capacitors are needed because the output voltage ripple is high enough and efficiency will decrease drastically if operated at high frequency [1],[4].

2.1. Circuit Analysis
Flyback converter is a converter that consists of a transformer including a magnetization inductor \(L_m\), a switch (MOSFET) connected to the primary ground side. The transformer used is not like an ideal transformer because current cannot flow simultaneously on the secondary side because the polarity of the transformer is reversed. The flyback converter works when the source voltage \(V_s\) is stored at the magnetization inductor when the switch is on and supplies it to the load when the switch is off [8]. When the switch is on / closed the transformer primary voltage is:

\[
V_1 = V_s + L_m \frac{di_{m}}{dt} \tag{3}
\]

\[
\frac{di_{m}}{dt} = \frac{\Delta i_{m}}{\Delta t} = \frac{\Delta i_{m}}{\Delta T} = \frac{V_s}{L_m} \tag{4}
\]

So the change in current at the magnetization inductor is:

\[
(\Delta i_{m})_{closed} = \frac{V_m DT}{L_m} \tag{5}
\]
While on the secondary side:

\[ V_2 = V_1 \left( \frac{N_2}{N_1} \right) = V_s \left( \frac{N_2}{N_1} \right) \]  \hspace{1cm} (6)

\[ V_D = -V_o - V_s \left( \frac{N_2}{N_1} \right) < 0 \]  \hspace{1cm} (7)

\[ i_2 = 0, \quad i_1 = 0 \]  \hspace{1cm} (8)

Because the diode is off, then \( i_2 = 0 \). During this interval the current at the magnetization inductor increases linearly and energy is stored at this inductor as shown in Figure: [9-10]

![Figure 2. Flyback Converter Circuit When the Switch Condition is Closed](image)

During the switch off and the conduction diode. The flyback converter circuit is seen in Figure 3. The \( I(L_m) \) current goes through the undotted terminal on the primary side and must exit at the secondary side dotted terminal, this causes the diode current to become positive [9-10].

![Figure 3. Flyback Converter Circuit When the Switch Condition is Open](image)

Primary Voltage:

\[ V_1 = -V_o \left( \frac{N_2}{N_1} \right) \]  \hspace{1cm} (9)

Secondary Voltage:

\[ V_1 = -V_o \]  \hspace{1cm} (10)

\[ V_1 = V_1 \left( \frac{N_2}{N_1} \right) = -V_o \left( \frac{N_2}{N_1} \right) \]  \hspace{1cm} (11)

\[ L_m \frac{di_m}{dt} = V_1 = -V_o \left( \frac{N_2}{N_1} \right) \]  \hspace{1cm} (12)
\[
\frac{\Delta I_{lm}}{dt} = \frac{\Delta I_{lm}}{dt} = \frac{\Delta I_{lm}}{(1-D)T} = -\frac{V_o}{L_m} \left(\frac{N_2}{N_1}\right) \tag{13}
\]

So the change in magnetization inductor current is

\[
\left(\Delta I_{lm}\right)_{open} = -\frac{V_o (1-D)T}{L_m} \left(\frac{N_1}{N_2}\right) \tag{14}
\]

Because the change in the magnetizing inductor current in one period is zero then:

\[
\frac{V_s D T}{L_m} - \frac{V_o (1-D)T}{L_m} \left(\frac{N_1}{N_2}\right) = 0 \tag{15}
\]

Then:

\[
V_o = V_s \left(\frac{D}{1-D}\right) \left(\frac{N_1}{N_2}\right) \tag{17}
\]

The power absorbed by the load resistor must be the same as the load supplied by the source under ideal conditions, so:

\[
P_s = P_o \tag{18}
\]

\[
V_s I_s = \left(\frac{V_o^2}{R}\right) \tag{19}
\]

The average current source \(I_s\) is related to the average current of the \(I_{lm}\) magnetization inductor:

\[
I_s = \frac{I_{lm} DT}{T} = I_{lm} D \tag{20}
\]

Substitution equation (7) to equation (8) results in a solution for \(I_{lm}\):

\[
V_s I_{lm} D = \frac{V_o^2}{R} \tag{21}
\]

\[
I_{lm} = \frac{V_o^2}{V_s DR} \tag{22}
\]

Using equation (9) for \(V_s\), the average inductor current is:

\[
I_{lm} = \frac{V_o D}{(1-D)^2 R} \left(\frac{N_2}{N_1}\right)^2 - \frac{V_o}{(1-D)R} \left(\frac{N_2}{N_1}\right) \tag{23}
\]

\[
I_{lm, max} = I_{lm} + \frac{\Delta I_{lm}}{2} = \frac{V_o D}{(1-D)^2 R} \left(\frac{N_2}{N_1}\right)^2 + \frac{V_s DT}{2L_m} \tag{24}
\]

\[
I_{lm, min} = I_{lm} - \frac{\Delta I_{lm}}{2} = \frac{V_o D}{(1-D)^2 R} \left(\frac{N_2}{N_1}\right)^2 - \frac{V_s DT}{2L_m} \tag{25}
\]

Continuous operation requires the condition that \(I_{lm, min} > 0\) in equation (I2) At the boundary between continuous and non-continuous conditions:

\[
\frac{V_s D}{(1-D)^2 R} \left(\frac{N_2}{N_1}\right)^2 = \frac{V_s DT}{2L_m} = \frac{V_o D}{2L_m f} \tag{26}
\]

If \(f\) is the switching frequency then the minimum inductance is:

\[
L_m = \frac{V_s DT}{\Delta I_{lm}} = \frac{V_o D}{2L_m f} \tag{27}
\]
3. Design Systems
The application of a multi-load charging system using a battery source with the Flyback Converter proposed in this study consists of several equipment used such as portable solar panel, batteries, microcontrollers, converters, mobile phones and other components as shown in the picture:

![Diagram of Systems](image)

**Figure 4. Block of Diagram Systems**

Figure 4 showing the flyback converter receives electrical energy from the portable solar panel which then supplies electronic equipment. The flyback converter will be modified to be multi output which means it can supply the voltage of the mobile device and battery at the same time. The charging or charging control of the battery load is controlled by the PI control so that the flyback converter will adjust the battery voltage / capacity at certain times. There is a current sensor function to monitor the converter output in the system. The results of the readings from these sensors will be processed in a microcontroller and displayed on an LCD screen in the form of notification parameters during the charging process to the Emergency Power Supply Multi Output user [9-10].

4. Experimental Result
Flyback converter functions to reduce the voltage of the battery. This converter aims to supply two loads. The value of the flyback converter output voltage is controlled based on the magnitude of the duty cycle of the PWM signal by the microcontroller that drives the MOSFET switching section. The results of the Flyback Converter Multi Output research are carried out as in the following table:

| D (%) | Pin (W) | Pout (W) | Efficiency (%) |
|-------|---------|----------|----------------|
| 10,2  | 0,72    | 0,36     | 49,75          |
| 15,2  | 2,41    | 0,80     | 33,36          |
| 20,3  | 4,12    | 1,25     | 30,40          |
| 25,1  | 5,78    | 2,01     | 34,73          |
| 30,2  | 7,31    | 2,94     | 40,25          |
| 35,2  | 9,38    | 5,59     | 59,65          |
| 40    | 12,02   | 7,80     | 64,91          |
| 45    | 16,77   | 12,21    | 72,78          |
| 50    | 23,77   | 19,74    | 83,08          |

The results of Table 1 aim of this test are to determine the converter response to changes in input duty cycle and how the performance of the flyback converter is seen from the error value and also its
efficiency. The quality resulting from the flyback converter circuit cannot be separated from the appropriate calculation and selection of components to support the expected output. The average efficiency of the flyback converter is 52.55%.

Figure 5. Integrated System

Figure 5 is a flyback converter testing system with a control that aims to determine the suitability of the multi-load response graph in the form of a battery and cellphone presented in the following table and figure:

| Time (Minute) | Duty (%) | Vout Accu (Volt) | Iout Accu (A) | Vout Hp (V) | Iout HP (A) |
|---------------|----------|------------------|---------------|-------------|-------------|
| 20            | 50       | 13               | 2,31          | 4,15        | 0,5         |
| 40            | 50       | 13,86            | 2,21          | 4,09        | 0,5         |
| 60            | 50       | 13,81            | 60            | 3,96        | 0,48        |
| 80            | 50       | 13,81            | 2,03          | 3,87        | 0,46        |
| 100           | 50       | 13,83            | 1,94          | 3,86        | 0,44        |
| 120           | 50       | 13,8             | 1,8           | 3,86        | 0,42        |

Detailed graphic response of the battery load and cell load when the system is operated using PI control

Figure 6. The Graph of Proposed System. (a) Voltage Load Output Accu Graphic of System with Control. (b) Current Load Output Accu Graphic of System using Control.
Figure 7. The Graph of Proposed System. (a) Voltage Load Output Handphone Graphic of System using Control. (b) Current Load Output Handphone Graphic of System using Control

Figure 6 and Figure 7 is a test system with control and carried out for 2 hours and data collection is done every 20 minutes. The set point in this control system is the flyback converter output voltage at the battery load can be constant at 13.8 Volts. From the experimental system with a flyback converter control it can produce a stable output voltage. So it is said that the PI control can work well in maintaining the set point output value of the flyback converter.

Figure 8. Measurement of SOC. (a) Initial SOC Value Of AccuBeforeCharging. (b) Final SOC Value of AccuAfter Charging

The initial SOC value on the battery is 11.69 Volts, due to the process of charging the battery, the Final SOC value is 12.48 Volts, so there is an increase in the voltage measurement on the battery, indicating that the flyback converter is able to charge the battery properly. Furthermore, in testing the charging of the cellphone load using IC L7805CT which functions to maintain a constant voltage output of the cellphone load of 5 Volts. A voltage drop occurred during operation due to the flyback transformer design, here is a picture of the change in the SOC of the hand phone battery.
Figure 9. Battery monitoring systems. (a) Initial SOC Value before Charging. (b) Final SOC Value after Charging

Figure 9 explains the change in the HP SOC value. For the initial SOC value on the hp battery is 25 percent, there is a change in the Final SOC value on the hp battery after the charging process becomes 50 percent. The characteristics in Figure 7 show that the charging system can work constantly well, that is, it can maintain a charging voltage of 5 volts. Can be seen in Figure 7 Graph c constant charging voltage around 5 volts. The charging current in the system can also be seen in Figure 7. Graph d has decreased the value of the charging current because the longer charging process, the SOC of the HP battery will increase and the charging current will decrease.

5. Conclusion
The PI control on the Flyback Converter can charge multiple outputs with a battery and cellphone. The power generated from the Flyback Converter is 32.5 Watt with a duty cycle value of 50%. SOC of the battery increases by 30% - 40% and SOC of the cellphone increases by 20% with a charging time of 2 hours. When using PI Control the maximum power obtained is 19.74 Watt with a duty cycle value of 50%. The PI control manages to increase the performance of the Flyback Converter in the charging process by comparing data charging without control and using controls. PI control can operation in 0% SOC battery charging control. When this Converter works in multi output, there is no disturbance when both loads are charging. Conclusions that have been outlined in discussions for the public that have been published about disasters for those who save batteries that contain important and emergency communications in disaster areas. SIMO Converter provides a practical energy source and the charging process is easy because the process of charging the two loads with different voltage values.

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