ECEN436

FINAL Report

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Project Summary

The design and building of a flyback converter was the main focus of our semester-long project in the power electronics course. Our lecturer assigned this work to our team of one graduate and two undergraduate students. We were given a pre-designed printed circuit board, complete circuit schematics, and all of the components we needed to get started. The major purpose of this project was to design a dual-output flyback transformer within the converter circuit while sticking to particular test requirements and aiming for an 85% minimum power conversion efficiency.

To build an appropriate transformer for the converter, we experimented with several turn ratios and wire kinds. We began by experimenting with Litz wire and then moved on to the usage of magnetic wire in various gauges. The ratio of leakage inductance to magnetizing inductance (LK/LM) was discovered to be 2.2%.

We used both surface-mount and through-hole components in the circuit construction. Each component was rigorously verified for correctness and potential short circuits after soldering utilizing auditory continuity testing. After that, the dual-output transformer was integrated, and the complete converter was tested for input and output voltage and current at 18VDC and 24VDC inputs. We also used an oscilloscope to examine the current-voltage (I-V) and control switching waveforms. We found the power conversion efficiency to be 85.3% and 85.5% and 85.6% for the 18V, 24V and 30V DC inputs, respectively, after thorough study of our data. These findings confirmed that our research objectives had been met.

Objectives And Description of the Project

The purpose of this course project is to develop, model, build, and test a closed-loop controlled converter using the criteria outlined in TABLE I. The converter, as shown in Fig. 1, is designed to accommodate an input range of 18-30V and provide a 15V.

This also operates at 100 kHz fixed-frequency internal oscillator, allowing fewer magnetic components to be used. A soft-start mode reduces inrush current at starting, current-mode control improves handling of input voltage and output load fluctuations, and cycle-by-cycle current restriction improves safety and performance.

The project aims to achieve an output voltage accuracy within ±5% under the specified input voltages and output load conditions for the power supply system. While the design parameters for most electrical components, like diodes, output capacitors, and control elements, are already finalized, the focal challenge remains in designing, constructing, and validating the flyback "transformer" (essentially a coupled inductor) to meet these stringent requirements.

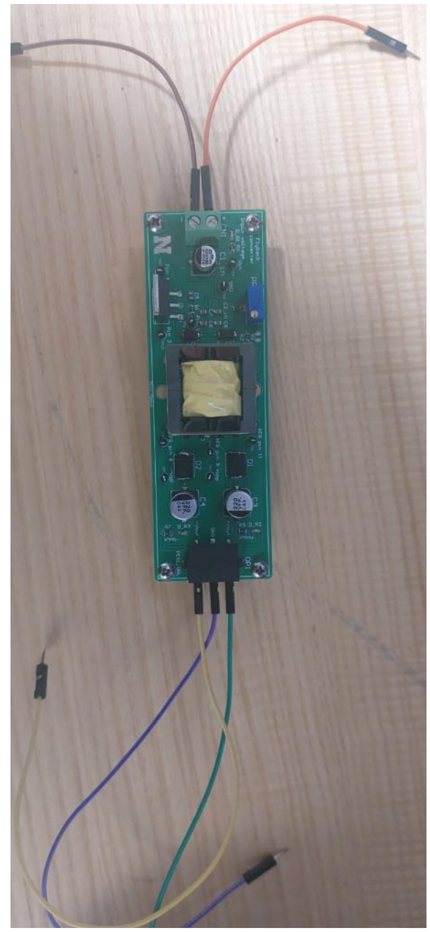


Figure 1.1 The Flyback Converter

1. Introduction

Several applications of flyback power supply demand several outputs to accommodate diverse secondary circuits. These multi-output converters are commonly found in televisions and other consumer devices. Meanwhile, they commonly power both analog and digital low-voltage circuitry in industrial contexts. To efficiently provide half-bridge drivers and control mechanisms in motor control applications, numerous isolated outputs are commonly required.

Multiple-output flyback supply design poses more difficult issues than single-output flyback supply design, necessitating additional design considerations to improve performance. Practical experimentation or breadboarding is generally included in the process of developing multi-output power supply. This is necessary in order to test the efficiency of transformer designs, investigate alternative feedback approaches, and comprehend overall system behavior. This practical approach is critical in ensuring that the final design satisfies the specified standards and functions consistently across a wide range of applications.

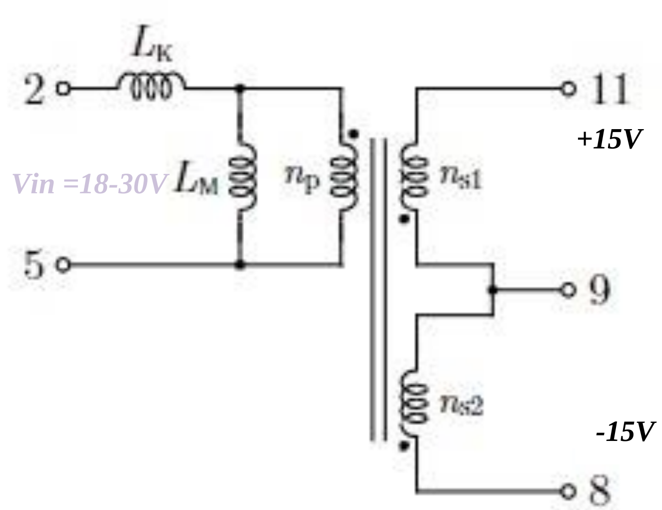


Figure 2.1 The Schematic Diagram of a Dual Output Flyback Converter

2. Design

The process of designing a dual-output power supply is essentially an expanded version of the single-output model. The primary-side circuitry remains identical in both scenarios. The added complexity in dual-output design involves integrating an additional output and then meticulously calculating key parameters such as the Duty Cycle, the transformer's turns ratios, Leakage Inductance, and appropriate wire sizes.

In the realm of transformer construction for dual-output systems, there is a greater scope for customization compared to single-output designs. This flexibility allows designers to employ a variety of winding techniques. These techniques are instrumental in fine-tuning the Leakage Inductance and other critical characteristics to meet specific requirements. This aspect of design provides an opportunity for more tailored and efficient power supply solutions in dual-output applications.

$$V_{\text{s, max}} = V_{\text{in}} + \frac{V_0}{n} \; V_{D_{\max}} = V_0 + nV_{\text{in}}$$

$$65 \geqslant 18 + \frac{15}{n} \; 40 \geqslant 15 + 18n$$

$$n \geqslant 0.319 \; n \leqslant 1.3888$$

$$0.319 \leqslant n \leqslant 1.3888$$

& for $V_{D_3} < 30 : n > 0.5$,

assume $n = 0.8 = \frac{n_2}{n_1}, n_2 = 4, n_1 = 5,\ n_{s_1 = n_{s2} = 4} \quad n_{p_1 = 5}$

$$M = \frac{V_0}{V_{\text{in}}} = \frac{15}{18} = 0.8333$$

$$R = \frac{V_0}{I_0} = \frac{15}{0.3} = 50\Omega, \mathrm{K} = \frac{2L_M}{RT_s},$$

$$\text{Assuming CCM}, I_M = \frac{V_{IN} * M * (M + n)}{R} = \frac{18 * 0.833 * (0.833 + 0.8)}{50} = 0.49\ A$$

$$D_1 V_{in} = D_2 * \frac{n_p}{n_{s1}} * V_o, Assuming\ D3 = 0.1, D1 = 0.36, D2 = 0.54$$

$$L_M = \frac{D_2^2 * T_s * V_o * n_p^2}{2 * n_{s1} * (n_{s1} * I_M + I_o n_{s2})} = \frac{0.54^2 * \frac{1}{100 * 10^3} * 15 * 5^2}{2 * 4 * (0.49 * 4 + 0.3 * 4)}$$

$$= 43.256\mu H, which\ is\ the\ maximum\ for\ DCM, Assume\ Lm = 40\mu H$$

$$I_{D_{Peak}} = \frac{V_{in} * D1 * T_s}{L_m} = 1.62\ A$$

$$I_{P_{\text{rms}}} = I_{T_{PK}} \sqrt{\frac{D_1}{3}} = 0.5612\ \mathrm{A}$$

$$I_{1rms} = I_{2_{rms}} = I_{\text{Dpeak}} \sqrt{\frac{\mathrm{D1}}{3}} = 0.4744\ \mathrm{A}$$

$$I_{\text{total}} = I_{P_{\text{rms}}} + 2nI_{\text{rms}} = 1.31544\ \mathrm{A}$$

$B_{sat} = 0.32T\ and\ B_{\max} \leqslant 60\% B_{\text{sat}}$ assume $B_{\max} = 0.192$

$$lg = \frac{\mu_0 L_M I_{\text{total}}^2}{B_{\max}^2 A_C} * 10^4 = 0.45374$$

$$n_p = \frac{L_M I_{\text{total}}}{B_{\max} A_C} = \frac{224}{5.27} \approx 5 = \sqrt{\frac{L_M \cdot \lg}{\mu_0 A_c}}$$

$$n_{s_1} = n_{s_2} = n_{p*n} = 4.2 = 4$$

$$\#1\ Assume\ \text{lg} = 0.2\ mm$$
$$np = 6$$
$$ns1 = ns2 = 5, n = \frac{5}{6}$$
$$L = \frac{\mu_0 A_c n^2}{lg} > 43.256\mu H, which\ is\ not\ acceptable$$
$$B_{max} = \frac{\mu_0 n I_m}{lg} = 6.88$$
$$\#2\ Assume\ lg = 0.4mm$$
$$np = 8, ns1 = ns2 = 4$$
$$B_{max} = 0.033$$
$$L_M = 10.45\mu H$$
$$\alpha_p = \frac{n_p I_p}{n_p I_{\text{Total}}} = \frac{5 * 0.5612}{5 \times 1.31544} = 0.4266$$
$$\alpha_{s1} = \alpha_{s_2} = \frac{n_1 I_1}{n_p I_{\text{rotal}}} = \frac{4 \times 0.4714}{S_{21} 1.31544} = 0.2867$$
$$A_{W_p} \leqslant \frac{\alpha_p k_u W_A}{np} = \frac{0.3 \times 0.4266 \times .87 \times 10^{-2}}{5} = 0.02227\ \text{cm}^2$$
$$A_{W_{s1}} = A_{W_{s2}} = \frac{\alpha_{s1} * K_u * \alpha_{s1} * W_A}{n_{s1}}$$

The first and second winding

attempted:

$dp \leqslant 0.1684\ \text{cm}(0.0865)$

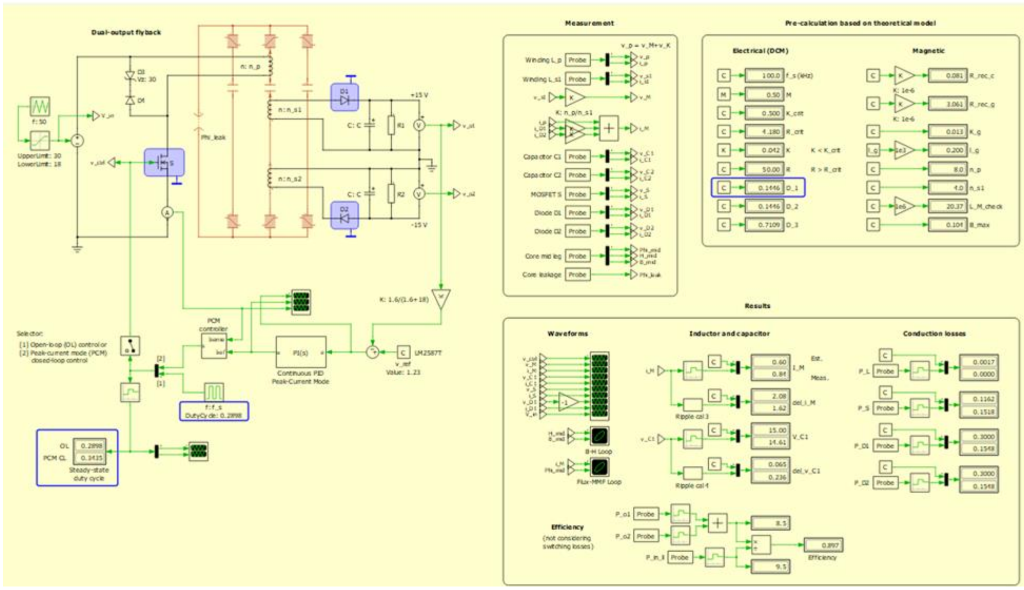
$d_s \leqslant 0.154$ Cm (0.066)

Use 18 AWG for both primary and secondary

Final Trial:

$$np = 8, ns1 = ns2 = 4, lg = 0.4, B_{max} = 0.033T$$
$$L_M = 10.45\mu H$$
$$\alpha_p = 0.4226$$
$$\alpha_{s1} = \alpha_{s_2} = 0.17918$$
$$A_{W_p} = 0.01392\ cm^2$$
$$A_{W_{s1}} = A_{W_{s2}} = 0.01169 cm^2$$
$$dp \leqslant 0.133\ \text{cm}(0.0523^n)\ use\ \ 18\ \text{AWG}$$
$$d_{s_1} \leqslant 0.122\ \text{cm}(0.048^n)\ \text{use}\ 20\ AWG$$

3. PLECS Simulation



4. Construction & Design of the Transformer

4.1 Wire Gauge:

$$\alpha_p = 0.4226$$

$$\alpha_{s1} = \alpha_{s_2} = 0.17918$$

$$A_{W_p} = 0.01392\ cm^2$$

$$A_{W_{s1}} = A_{W_{s2}} = 0.01169 cm^2$$

$$dp \leqslant 0.133\ \text{cm}(0.0523^n)\ use\ \ 18\ \text{AWG}$$
$$d_{s_1} \leqslant 0.122\ \text{cm}(0.048^n)\ \text{use}\ 20\ AWG$$

4.2 Construction of the Transformer

Litz wire selection

In the construction of transformers, the selection of Litz wire plays a critical role, particularly in applications where efficiency and minimizing power losses are paramount. Litz wire is specifically designed to reduce the skin effect and proximity effect losses in conductors used at frequencies up to about 1 MHz.

When selecting Litz wire for transformer construction, several key factors must be considered:

- Frequency of Operation: The effectiveness of Litz wire depends on the frequency of the application. Higher frequencies typically require finer strands to effectively combat skin and proximity effects.

- Strand Count and Size: Litz wire is composed of many thin wire strands, individually insulated and twisted or woven together. The number and size of these strands influence the wire's performance, with more strands generally offering better high-frequency performance.

- Insulation Type: The insulation material of each strand is crucial for preventing short circuits between strands, and its thermal properties determine the wire's heat resistance.

- Current Capacity: It's essential to choose a Litz wire that can handle the expected current load without excessive heating.

- Physical Dimensions: The size and flexibility of the Litz wire must be compatible with the transformer's design, especially when space constraints are a factor.

- Resistance and Efficiency: Lower resistance Litz wire improves efficiency but may be more expensive. The balance between cost and efficiency needs to be considered.

By carefully selecting the appropriate Litz wire, transformer designers can significantly reduce losses due to skin and proximity effects, thereby improving the efficiency and performance of the transformer, especially in high-frequency applications. This selection process is a crucial step in ensuring the overall effectiveness and reliability of the transformer.

Winding Technique:

When constructing transformers, the winding technique is a key consideration that significantly impacts the transformer's performance and efficiency. Different winding techniques are suited to various applications and have their own set of advantages and disadvantages. Below is a discussion of some common winding techniques, followed by a table summarizing their pros and cons.

Common Winding Techniques:

1. Layer Winding: In this technique, the wire is wound in layers, typically with each layer insulated from the next.

2. Sectional Winding: This involves dividing the winding into sections, which can be useful for managing voltage distribution and heat dissipation.

3. Foil Winding: Used primarily in low voltage, high current applications, this technique involves winding with a thin foil rather than wire.

4. Bifilar Winding: Two wires are wound together, which can help in reducing leakage inductance and improving capacitance.

5. Toroidal Winding: The wire is wound around a donut-shaped core, providing high efficiency and low electromagnetic interference.

6. Separate Output Windings: This technique involves having individual windings for each output on the transformer. This method can reduce electrical interference between different outputs but may lead to a more complex and larger transformer design.

7. Stacked Output Windings: In this approach, different output windings are placed on top of each other. This can be space-efficient and ensure good magnetic coupling, but

it can also lead to issues like cross-talk between the windings and challenges in managing heat.

8. Primary Winding with Separation: Here, the primary winding is constructed with a physical separation, often for safety or insulation purposes. This can reduce the capacitive coupling between primary and secondary but might result in a larger overall transformer size and add complexity to the winding process.

Transformer Winding Techniques:

Winding Technique	Advantages	Disadvantages
Layer Winding	Simple construction, good heat dissipation	Higher leakage inductance, not ideal for high frequencies
Sectional Winding	Improved voltage distribution, enhanced heat management	Complex construction, higher cost
Foil Winding	Low resistance, excellent for high currents	Limited to low voltage applications, bulky
Bifilar Winding	Reduced leakage inductance, better capacitance control	More complex to wind, higher cost
Toroidal Winding	High efficiency, low electromagnetic interference	Difficult to wind, core can be expensive
Separate Output Windings	Reduced interference between outputs, flexible design	Increased size and complexity, higher cost
Stacked Output Windings	Efficient use of space, good coupling	Risk of cross-talk between windings, thermal management issues
Primary Winding with Separation	Improved insulation and safety, reduced capacitive coupling	Potentially larger transformer, complexity in winding

Table 1: Transformer Winding Techniques

5. Trials & Attempts

Attempt 1:

However at our first trial, the value of the leakage inductance was too low Lk=0.174 uH and Lp= 4.942 uH so the percentage achieved was 3.52% which is perfect and close to the designed one, however we figured out the winding was not made correctly as the first secondary was firstly winded on bobbin then the second secondary and finally the primar which is then found not to be the correct way.

The transformer looked as the following and was good as for our first trial doing such windings:


Attempt 2:

The second attempt got Lk/Lp = 3.6%, this is super but the problem was that once we connected it into the PCB luckily not soldered entirely, the transformer is burnt because as we think, there was a short circuit inside the transformer so we then redesigned the turns number and the turns ratio to retest again.

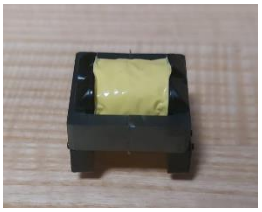
Attempt 3:

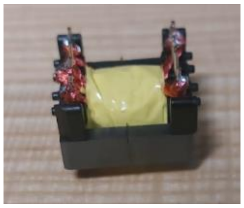
Finally, and successfully, the designed transformer with n = 0.5 and np = 8 and ns1 = ns2 = 4, we got the percentage of Lk/Lp = 0.28/12.69 = 2.2% which is the lowest too far.

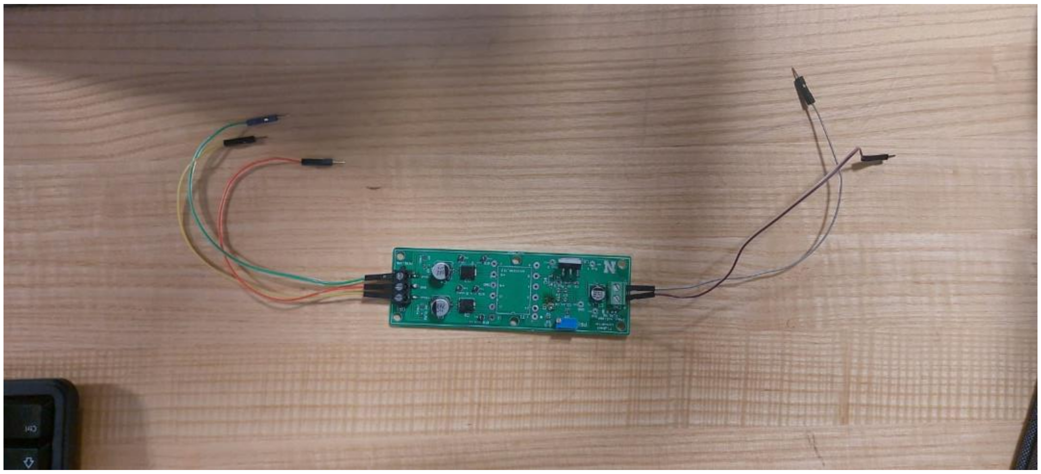
6. Project Construction & Fabrication

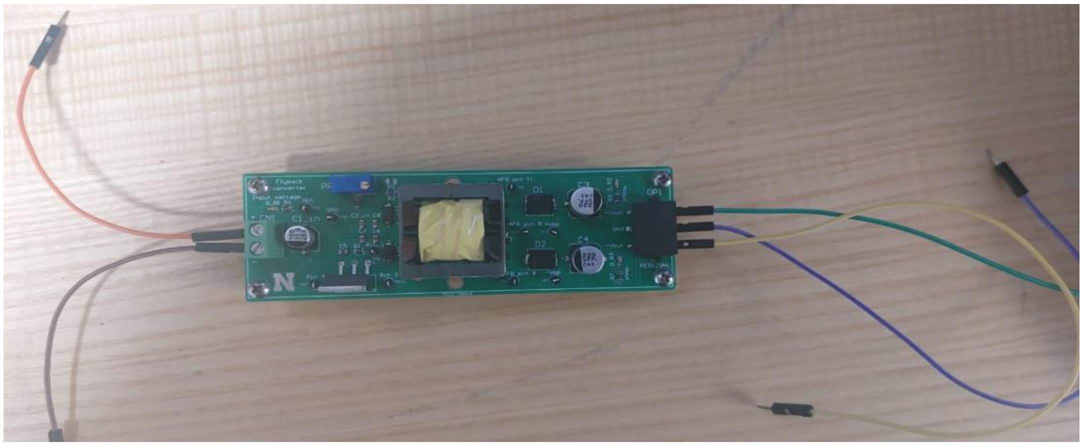
6.1 Transformer Windings:

The primary is coiled around the bobbin first, then insulation tape is used to establish a barrier between the primary and secondary windings. Various ways are used, such as winding the secondary side by side or one over the other. The picture below shows isometric views of the Flyback Transformer, which was built with Litz wire in an 8:4:4 ratio.









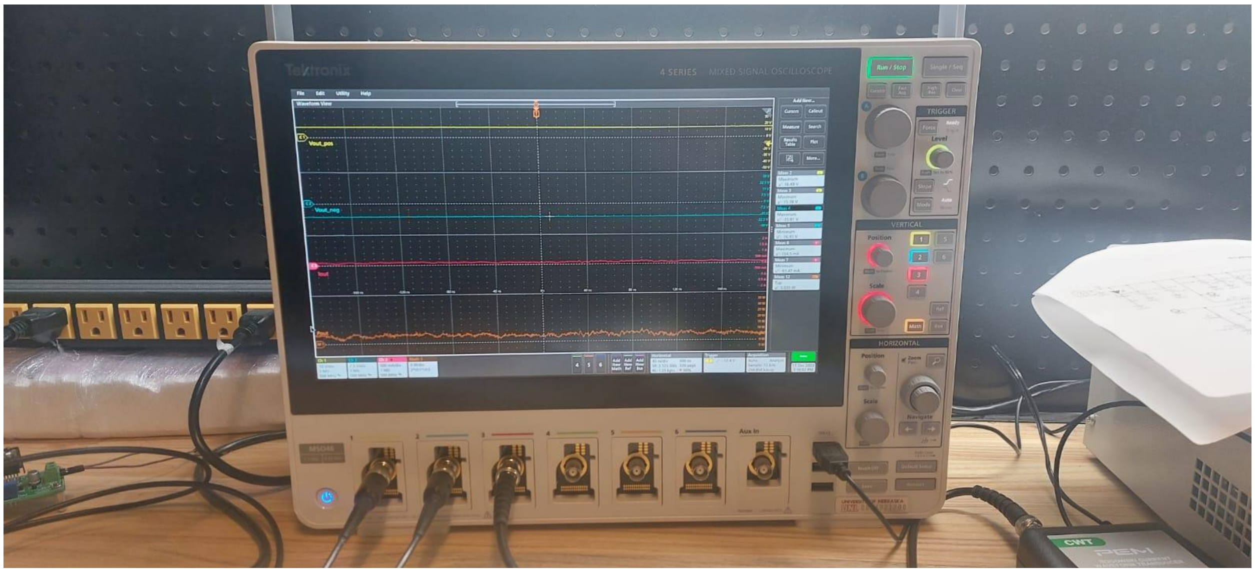
6.2 Soldering of Surface Mount and Through-Hole Devices:

1. Each component is carefully selected based on the requirements supplied, tested with a multimeter for accuracy, and then securely soldered into the board.
2. Following that, all surface mount (SMD) and through-hole components, such as resistors, diodes, terminal blocks, header connectors, capacitors, and the switching controller, are soldered using 67/37 soldering wire with built-in flux to ensure high-quality, low-resistance solder joints.
3. Following the soldering procedure, all connections are thoroughly tested for continuity with audible testing using a digital multimeter.
4. Following the short circuit investigation, each soldering junction is carefully examined under a magnifying lens to determine its quality. Additional solder is applied to any detected cold joints.
5. Finally, the transformer is installed and put through its paces.

7. Final Qualifications Test

7.1 Results:

The final testing demonstrated that the converter operated smoothly and consistently, delivering constant output voltages and currents. However, total efficiency fell short of expectations and fell short of estimates. We are contemplating rewiring the transformer to increase the converter's efficiency by utilizing either a larger wire to minimize winding resistance or a stripped wire to boost performance.



7.2 Efficiency Calculations:

The power conversion efficiency of a power converter is calculated using the formula below.

$$\boldsymbol{\eta} = \frac{\mathrm{P_{IN}}}{\mathrm{P_{OUT}}} \times 100$$

$$\mathrm{P_{IN}} = \mathrm{V_{IN}I_{IN}}$$
$$\mathrm{P_{OUT}} = \mathrm{P_1} + \mathrm{P_2} = \mathrm{V_1I_1} + \mathrm{V_2I_2}$$

When we look at the total power conversion efficiency for various input voltages, we see that it is 85.3% for an 18V input, 85.5% for a 24V input, and 85.6% for a 30V input. These findings are regarded satisfactory since they meet the design specifications.