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# 600W DC-DC Converter Design Using Flyback, Half Bridge, Full Bridge LLC Topologies and Comparison of Simulation Results

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**Abstract**: This paper presents design and simulation of typical DC-DC converter topologies such as Flyback, half bridge, full bridge LLC, using the PLECS simulation tool. Requirements are chosen to be 600 W power rating and 250 kHz switching frequency with high efficiency and reduced built size. MOSFET is used as the switching element. According to the simulation results, optimum design with the lowest fluctuations in output voltage and current are achieved using the full bridge LLC converter topology. Thanks to the resonant coil and resonant capacitor in its structure, reduced switching losses have been observed in this converter design, which provides soft switching and high switching frequency.

**Keywords:** DC-DC converter, Switching, Half bridge, FlyBack, Full bridge LLC

## Introduction

DC-DC converters are electronic circuits that convert -increase/decrease- a DC voltage level to another level. It accumulates energy in the coil by switching the switching element in its structure at appropriate times. It provides the desired power and voltage level by transferring this energy to the output. They are widely used in variety of applications such portable electronic devices, automotive, military, aerospace, energy and medical systems in which requires continuous and multiple voltage levels. Therefore, they have great importance in the industry. There are many different topologies in DC-DC converters for different purposes such as extra security, control method, desired power, type of load. In industry, the aim is to provide the desired quality at the cheapest cost. Resonance converters transfers power with resonance in contrast to conventional DC-DC converters that operating according to the principle of energy stored in the inductor. DC-DC converters based on resonance power transmission provide soft switching, so switching losses are significantly reduced, efficiency and frequency are increased, thus reducing costs. Hence, resonant converters are common in the industry. (Mohan, 1995; Rashid, 2001).

The key objectives in converter design are high power density, high efficiency, and optimum built size. Switching frequencies are increased in order to provide high power density and optimum size among these. The increase in the switching frequency reduces the size of the elements such as transformers, coils and capacitors in the converter. However, high switching frequency brings high switching losses. Switching losses cause decreased efficiency, shortened life of materials and excessive heat. Therefore, soft switching techniques are used in high switching frequency converters. Soft switching reduces the switching losses through the components connected to the switching elements. Zero voltage switching (ZVS), zero current switching (ZCS), zero voltage transition (ZVT) and zero current transition (ZCT) are the most common soft switching methods (Çetin, 2017; Kubilay, 2020, İşbilir, 2005; Polat, 2017).

Zero voltage switching reduces the rapid rise in voltage during switching by a capacitor connected in parallel with the switching element. Zero current switching reduces the rapid rise in current during switching, thanks to the coil connected in series with the switching element. Zero-current transition and zero-voltage transition also provide a delay in voltage and current spikes during switching (Mohan, 1995; Rashid, 2001; İşbilir, 2005; Saydı, 2017; Polat, 2017).

DC-DC converters are classified as isolated and non-isolated converters. Transformers provide galvanic isolation between input and output. Hence, converters using a transformer such as full bridge, half bridge, forward, flyback and push-pull converters are called isolated DC-DC converters. Converters without a transformer such as boost, buck, buck-boost, CUK, SEPIC and ZETA are called non-isolated DC-DC converters. In isolated converters, the energy flow is provided through the transformer (Mohan, 1995; Rashid, 2001; İşbilir, 2005; Saydı, 2017; Polat, 2017; Yılmaz, 2020).

## DC-DC Converter Design

### *Flyback Converter Design*

Flyback converters are frequently preferred converter topology due to their galvanic isolation and simple design. They can be used where the input voltage is lower or higher than the output voltage. Transformer winding ratio and switching element duty cycle time determine the relationship between input and output voltages. The flyback converter topology is shown in figure 1. When the switch S is on, the input voltage transfers energy to the coil. The load is energized from capacitor. When the S switch goes off, the diode turns on and the energy on the coil is transferred to both the capacitor and the load (Mohan, 1995; Rashid, 2001; İşbilir, 2005; Yılmaz, 2020).

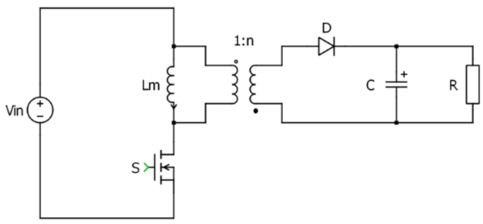


Figure 1. Flyback converter topology

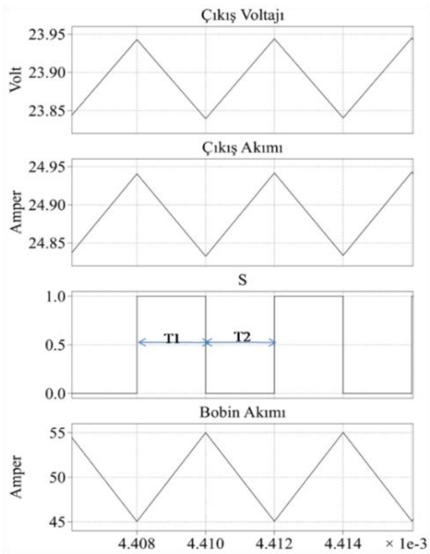


Figure 2. Flyback converter simulation results

A flyback converter with 600 W of power rating was designed. The output voltage is 25 V and output current is 25 Simulations were made using the PLECS tool. Output voltage waveform, output current waveform, current drawn from the primary winding of the transformer and switching are shown in figure 2.

The ratio of the time that the switching element is on to the switching period gives the duty cycle time (*D*). The relationship in between transformer winding ratios (*n*) and input ($V_i$) and output ($V_o$) voltages shown below.

$$D = \frac{T1}{T1+T2} \quad (1)$$

$$n = \frac{Seconder\ sarım\ oranı}{Primer\ sarım\ oranı} \quad (2)$$

$$V_o = n \times \frac{D}{1-D} \times V_i \quad (3)$$

The following relationship exists between the input ($I_i$) and output ($I_o$) currents in ideal conditions,

$$I_i = n \times \frac{D}{1-D} \times I_o \quad (4)$$

The value of capacitor *C* can be found with the following formula. $F_s$ is the switching frequency. $\Delta Vo$ is the output voltage fluctuation value.

$$C = \frac{Io\ x\ D}{\Delta Vo\ x\ Fs} \quad (5)$$

Flyback converters are used in low power applications. In high power applications, the transformer must have a large air gap to store energy. Large air gap increases leakage in flux and causes inefficiency.

## Half Bridge Converter Design

Half Bridge converters are used at power rating up to 500 W. Since it contains fewer switching elements compared to the full bridge structure, the switching losses are less. Half bridge converter topology is shown in figure 3.

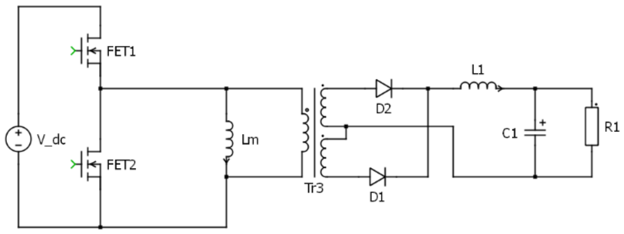


Figure 3. Half Bridge converter topology

Output voltage waveform, output current waveform, L1 coil current waveform and switching are shown in figure 4 for the designed half bridge converter with 600 W power rating.

As seen in Figure 4, there is 0.7 V fluctuation in voltage and 0.7 A in current. When the S switch is on, energy accumulates in the coil, when the S switch is off, the energy in the coil is transferred to the output. The relationship in between input and output voltages and currents is shown below.

$$V_o = n \times D \times V_i \quad (6)$$

$$I_i = n \times D \times I_o \quad (7)$$

*L1* and *C1* are used for filtering. It is found with the following equations. $\Delta Il$ is the desired current fluctuation value on the *L1* coil. $F_s$ is the switching frequency. $\Delta Vo$ is the output voltage fluctuation value.

$$L1 = \frac{\left(\frac{Vi}{n} - Vo\right) xD}{\Delta Il x 2 x Fs} \quad (8)$$

$$C1 = \frac{\Delta Il}{8 x \Delta Vo x 2 x Fs} \quad (9)$$

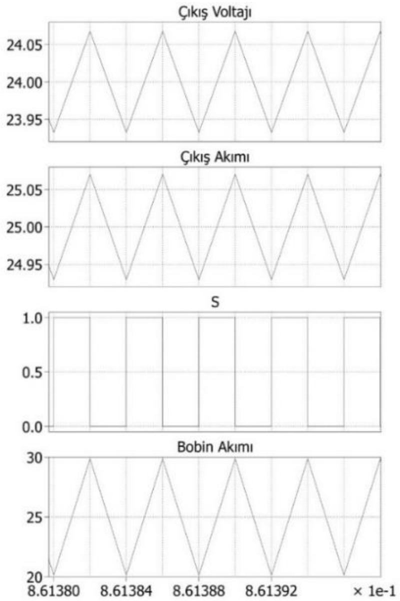


Figure 4. Half Bridge converter simulation results

**Full Bridge LLC Converter Design**

Full Bridge LLC converters work with the resonant converter principle. The resonant coil and resonant capacitor resonate with the square wave coming from the switching elements and transfer the energy to the transformer. Energy flow is provided through the transformer. Unlike the classical PWM method, the appropriate control signal is provided by the frequency modulation technique. Resonant converters consist of switching network, resonant tank and rectifier network shown in figure 5 (Mohan, 1995; Kubilay, 2020; Seminar Notes, 2018).


Figure 5. Resonant converter structure

The switching network generates a square wave to excite the resonant tank. The resonant tank generates resonance wave according to the appropriate resonance frequency and is transmitted to the rectifier network via transformer. In the rectifier network, the wave is rectified. DC voltage is transmitted to the output by filtering process. Control is provided by changing the switching frequency in full bridge LLC converters. Maximum efficiency and power flow is achieved where the switching frequency and the resonant frequency are equal. The resonance coil and resonance capacitor value are determined according to this principle (Mohan, 1995; Kubilay, 2020; Seminar Notes, 2018).

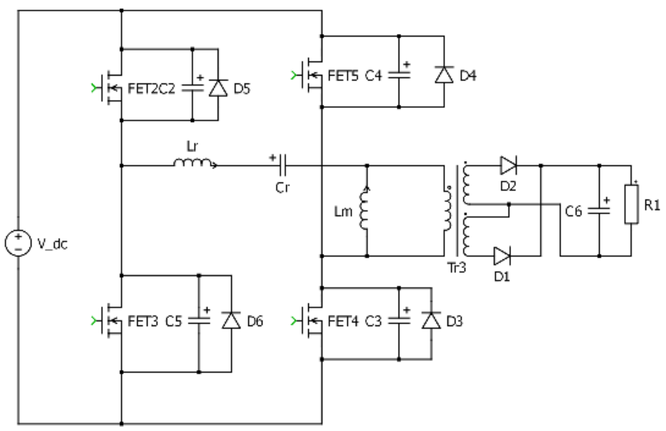


Figure 6. Full Bridge LLC converter topology

The Full Bridge LLC Converter topology is shown in Figure 6. The square wave produced by the switches is transmitted to the transformer by changing the gain with the resonant tank elements.

The output voltage and current waveforms, switching and resonant coil current waveform are as shown in figure 7. Fluctuation in output voltage is seen as 0.05 V in the converter, which has an output voltage of 24 V. In addition, the fluctuation in output current is 0.05 A. Since the current drawn from the coil is close to the full sinus format, it is understood that the resonant frequency is close to or equal to the switching frequency. For this reason, it is observed that there is maximum efficiency and minimum fluctuation.

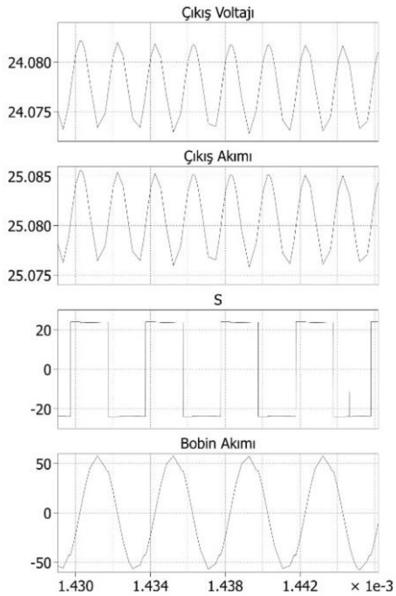


Figure 7**.** Full Bridge LLC converter simulation results

## Results

In this paper, 3 DC-DC converter topologies were designed, and simulation results were obtained by using the PLECS tool. Switching frequencies were chosen as 250 kHz. Output voltage fluctuation, output current fluctuation, current drawn from the coils are examined. The lowest fluctuation in output current and voltage is seen in the full bridge LLC converter design. Thanks to the resonance coil and resonance capacitor in its structure, soft switching is provided. Thus, switching losses are reduced. Additional components must be added to provide soft switching to other converter topologies. Considering these reasons, it is seen that the optimum topology for 600 W DC-DC converter design is full bridge LLC structure.

## Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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