# Design And Application of 2 Switch Forward Converter Based Switch Mode Power Supply

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***Abstract*** – In this paper, a 2 switch forward converter based switch mode power supply design and application with an increased efficiency is proposed.The converter has all the advantages of two switch forward topology and PWM control, furthermore AC-DC converter works with current mode so it has low cost comparing the voltage control mode applications, also application does not need external control voltage and includes high voltage protection. The methods used in the operating modes analysis and design considerations of the proposed converter are explained in detail. Theoretical analyzes are verified with a simulation and prototype having 50kHz switching frequency, 80V output voltage, 3A output current.

*Keywords – AC-DC Converter, PWM Two Switch Forward, Peak Current Control, High Voltage Protection, Low Cost*

## I. INTRODUCTION

Today, with the development of technology, the need for electrical energy has increased; for this reason, the importance of using energy in the most efficient way has increased. PWM DC-DC converters are used in electric vehicle battery chargers, renewable energy sources, defense industry and health sector etc. widely used. It is now a necessity for the designed converters to work with high efficiency[1].

Efficiency and power density studies for these converters have gained great importance in recent years and heavy studies have been carried out. An increase in power density results from a decrease in switching losses and a smaller filter size. As the switching frequency increases, the filter sizes can be smaller, but switching losses must be considered at this time[2]. However, this paper will focus not on switching losses, but on an efficient, easy-to-control design.

Switched power supplies (SMPS) converters and their derivatives have attracted great attention in the field of power electronics since the 20th century with their analysis, operational principles, controls and designs[3]. Switched power supplies (SMPS) are preferred instead of linear power supplies for high efficiency, power density and similar purposes. The basic working principle of SMPS is based on inductance energy transfer.Switched mode power supplies are divided into two parts, isolated and non-isolated. Switched mode power supplies are examined in two parts, insulated and non-insulated, and forward converters can be examined in the insulated part. Forward converters have advantages such as simple circuit structure, low cost and high efficiency, in addition to these transfers energy directly compared to flyback converters. Forward converters are widely used for low voltage and high current applications with power levels up to 250W[3-8].

Past days, it was really difficult to implement this topology for high voltage applications, because of high switching frequencies is difficult to use in high voltage applications. Unlogical to use two switch forward low frequency applications because, lower frequency means a large transformer and in these days it is really important to reducing converter’s sizes. But nowadays, it has been talked that the specialities of the SiC make it suitable to use in high voltage applications[9].

In basic forward converters, a third winding is added or a RCD snubber structure needed to reset the magnetizing current or in other words to discharge the energy store. These structures increase the complexity of the design.

In two switch forward topology, voltage stress on the power switches reduced and circuit structure provides an advantage which is the transformer’s leakage inductance can release its charging energy to the input source[10].

Instead of adding a third winding or using an RCD snubber structure, a two switch forward topology has been developed by adding a switching element and reset diodes.

In recent years, resonant power converters have become fashionable to reduce high switching losses. Increasing the operating frequency is necessary to reduce component sizes. However, the complex control of resonant converters is a disadvantage. However, with the use of SiC in recent years, it has become possible to use the Two Switch Forward topology at high frequencies[11]. On the other hand SiC semiconductors, have some reliability issues. SiC is generally by its smaller conduction-band offset compared with Si, which means that these semiconductor switching elements have lower voltage ranges and are more noise-resistant than Silicon switching elements[12].

Two Switch Forward PWM AC-DC converters are frequently preferred in medium to high power applications due to their advantages such as isolation, easy control and low power losses and noise. TSF PWM AC-DC converters have many applications such as battery charging systems, power factor regulator, renewable energy systems, telecommunication equipment and welding machines [13].

This topology has some advantages and drawbacks.

**Advantages**

- The circuit structure has a self-resettable transformer with freewheeling diodes, hence no third winding or snubber structure is required.
- It has an easy to control structure.
- The power loss is low and efficiency high because when the switching elements go cut, the stored energy will be transferred back to the input via the freewheeling diodes.
- It transfers energy directly.
- When the switches turn off, besides the magnetization inductance, the leakage inductance energy is transferred back to the input and system noise is reduced with this advantage.
- Since there are two series switch elements, the voltage stress on the switch element is reduced.
- Two switch forward topology, comparing to the other topologies, has a lower common mode noise because its symmetric structure of primary side circuit so that it has two out of phase dv/dt's that cancel each other[14].

**Disadvantages**

- In order for the transformer to be reset, our Duty must be less than 0.5.
- Since it has a structure that transmits power in one direction, the size of the Transformer sizes increase
- The number of switching elements is high and the number of components increases, so the cost increases.
- Switching losses are higher than single-switched circuits.
- Two Switch topology requires a high side gate drive.

In this study, Two Switch Forward DC-DC converter design with peak current control is proposed.

**Advantages of Peak Current Control**

- Since the number of components will be less, the cost is less than voltage control.
- It is easy to control.
- Feedback response is faster than applications using voltage control.[15]

In recent years, new control techniques have been developed to obtain high power factor. Continuous Conduction Mode, Discontinuous Conduction Mode and critical conduction mode are among these techniques. It is very important to choose the appropriate control mode for the application[16]. The converter mentioned in this paper works in Continuous conduction mode. The advantages of continuous conduction mode are:

**Advantages of Continuous Conduction Mode**

- Lower Conducted Noise.
- Lower Conduction Loss.
- Lower Inductor Core Loss.
- Low dv/dt, di/dt ratio.[16]

The circuit diagram of the two switch forward is given in figure 1.

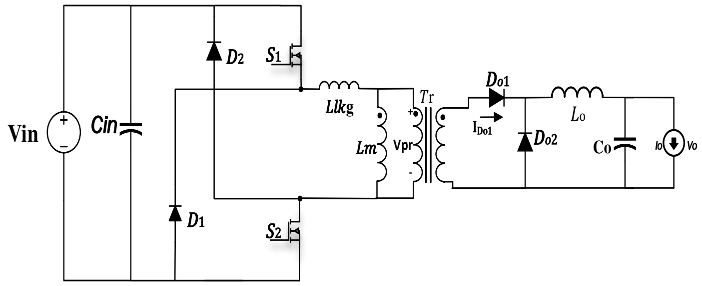


**Figure1.** Two Switch Forward DC-DC Converter

## II. Materials and Method

### Operating Principles and Analysis of Proposed Converter

The following equations have been used while performing the proposed converter analysis.

i. $S_1$ and $S_2$ are the main switches of the converter.

ii. $D_1$ and $D_2$ are the main diodes of the converter, $D_{o1}$ and $D_{o2}$ are the output diodes of the converter.

iii. $C_{in}$ is the input capacitor, and the $C_O$ is the output capacitor of the converter.

iv. $L_o$ is the output inductance of the converter.

v. $T_r$ is the power transformer, n is the turns ratio, $L_m$ is the magnetizing inductance of the transformer and $L_{lkg}$ is the leakage inductance of the transformer.

vi. $V_{in}$ is the input voltage and $V_o$ is the output voltage.

vii. Semiconductor power elements are ideal.

viii. The input voltage and output current of the circuit are constant over a switching period.

The circuit operating occurs in a total of 2 modes. The analyzes of the operating modes are made for the case where the gate signals are applied to the switches $S_1$ and $S_2$ . The operation wave forms of the designed circuit are given in Figure 2 in below.

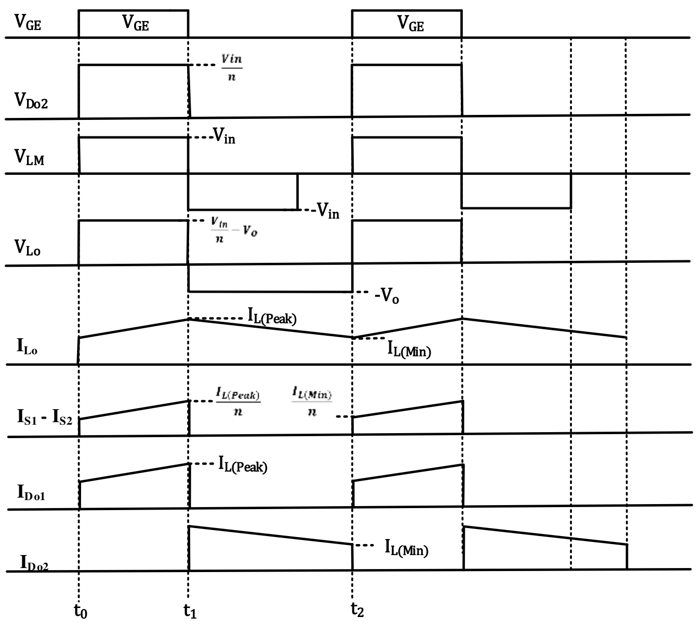


**Figure 2.** Operation wave forms of the proposed converter.

### Stage 1: Conduction Mode ($t_0 - t_1$)

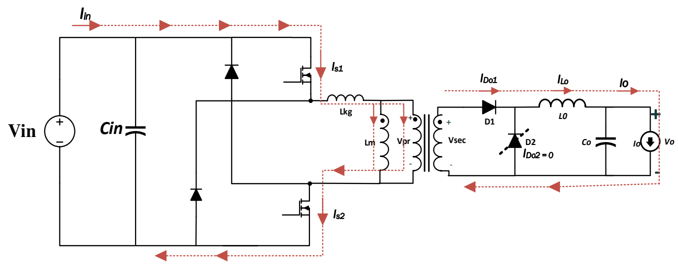


**Figure 3.** Conduction Mode Of The Proposed Converter

The signals of the switches $S1$ and $S2$ start to be applied at the moment t = $t0$ ,$t1$ and these switches transmit simultaneously. The transformer charges for the duration of the DxT. Voltage $Vin$ is applied on $Llkg$ and $Lm$ leakage inductance current $ilkg$ starts to increase linearly. If we ignore the leakage inductance effect, Vin voltage will be applied to our Magnetizing inductance. At the same time, the switch currents ($I_{S1}$ and $I_{S2}$), the output inductor current ($I_{Lo}$), and the $I_{DO1}$ current will increase.

The $t_0 - t_1$ interval is given above in figure 3.

**Values in Stage 1 are given as:**

$V_{pr} = V_{in}$ $\quad V_{Sec} = \frac{V_{in}}{n}$ $\quad V_{Lm} = V_{in}$ $\quad V_{Lo} = \frac{V_{in}}{n} - V_o$ $\quad V_{Do2} = \frac{V_{in}}{n}$ $\quad V_{Do2} = \frac{V_{in}}{n}$

$I_{Lo} = I_{DO1}$ $\quad I_{S1} = I_{S2} = \frac{I_{LO}}{n}$

### Stage 2: Cutt off Mode ($t_1 - t_2$)

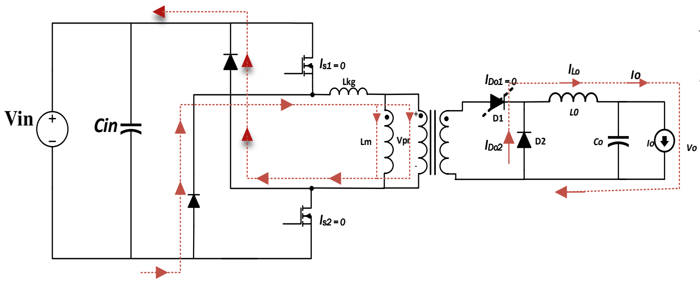


**Figure 4.** Cut off Mode Of The Proposed Converter

In the range $t_1$ - $t_2$, the signal applied to the switching elements is cut off and the switching elements go off. The energy on the $L_m$ and $L_{lkg}$ inductances in the transformer is transferred to the input. The transformer is discharged during the (1-D)xT period. If we ignore the leakage inductance effect, $-V_{in}$ voltage will be applied to our Magnetizing inductance because of freewheeling diode is conducting in this stage. The current in the switching elements are zero. The output inductor current ($I_{Lo}$) will drop by the amount of Ripple. The $t_1 - t_2$ interval is given above in figure 4.

### Values in Stage 2 are given as:

$V_{Lo}= -Vo$ $\quad$ $V_{Do2}= 0$

$I_{LO} = I_{DO2}$ $\quad$ $I_{S1} = I_{S2} = 0$

## A. *Design Considerations*

### Determination of $C_{in}$

In practice, assuming we get our input power from the grid which is 50Hz 230Vrms sin wave ; we should consider the efficiency value to determine the input capacitor capacitance value, the worst case of the input voltage, so that the transformer is not saturated. In figure 4, rectified capacitor voltage is given.

In our application, the output power is 250 Watt and the efficiency value is 0.95.

$P_o$ denotes output power when n denotes the efficiency.

Input power Pin calculated in below :

$$P_{in} = \frac{P_o}{n} = \frac{250W}{0.95} = 265W$$

Let's set a tolerance for the worst case of the electrical grid.

$$230 \pm \%10 \rightarrow 207V_{rms} < V_{in} < 253V_{rms}$$

$$207x\sqrt{2} = 292.74\,Volt\ Peak$$

$$292.74x0.8 = 233\ Volts$$

**Δt** denotes capacitor decharging time, hence if we choose **Δt= 7ms**

We can determine our capacitor current from the average voltage and input power of the capacitor.

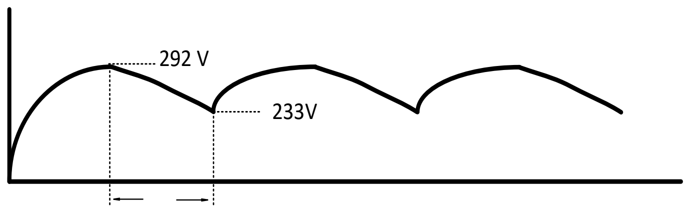


**Figure 4.** Rectified Input Voltage

$I_c$ is the capacitor current, $V_{av}$ is the capacitor voltage.

$$I_C = \frac{P_{in}}{n} = \frac{(265W)}{\frac{292+233}{2}} = 1Ampere\ rms$$

Then ΔV is denotes the voltage change in volts on capacitor. Where Δt=7ms and ΔV = 292-233=55V

$$\frac{Cdv}{dt} = I \rightarrow C = \Delta t\frac{I}{\Delta V} \rightarrow C_{min} = 120uF$$

### Determination of Winding Ratio

The following formula is used to find the turn ratio. While the winding ratio is found from this formula, the duty cycle is designed to be less than 0.5 in case the input voltage is the worst, that is, the lowest. The input voltage will be the minimum of the lowest capacitor voltage. D is the duty cycle.

$$V_O = \frac{V_{in}}{n}D$$

D=0.4 is taken to prevent the transformer from saturating.We calculate the winding ratio:

$$n = \frac{233}{80}x0.4 = 1.165$$

### Determination of $L_O$ Inductance

In order for the application to work in continuous conduction mode, the output inductance must be greater than the critical inductance value. For this reason, the selection should be made according to the following equation for this case. $L_C$ denotes the critical inductance value.

$$L_O > L_C \quad that\ is \quad L_O > \frac{V_{sec} - V_O}{2I_{O(av)}}$$

T is the switching period, $V_{sec}$ is the secondary voltage, when $I_{o(av)}$ is the average output current.

Where output voltage $V_O = V_{sec}xD$

$$Lc = \frac{(200-80)x0.4x20X10^{-6}}{2x3} = 160uH$$

While designing, the inductance value must be greater than critical inductance value.

When finding the output inductance, an inductor current ripple must be determined according to the application. The smaller the inductor current ripple, the larger the coil that will be used in the design. The output inductance is calculated with the following formula by taking the current ripple of 20%.

$$\Delta I_{LO} = \frac{V_{sec} - V_O}{L} DT$$

$$\Delta I_{LO} = I_O \text{ x } 0.2 = 0.6A$$

Then the inductance value is calculated below:

$$L_o = \frac{V_{sec} - V_O}{\Delta I_{LO}} DT = \frac{200-80}{0.6} 0.4x20x10^{-6} = 1.6mH$$

Where $V_{secondary}$ is $V_{sec} = V_o x D$.

**Determination of $C_o$ Capacitor**

The output capacitor value is found by considering the ripple of the output current and the desired ripple of the output voltage. As can be seen in the figure below, the ripple of the output current is taken into account, the total charge change and the output capacitor from this charge change.

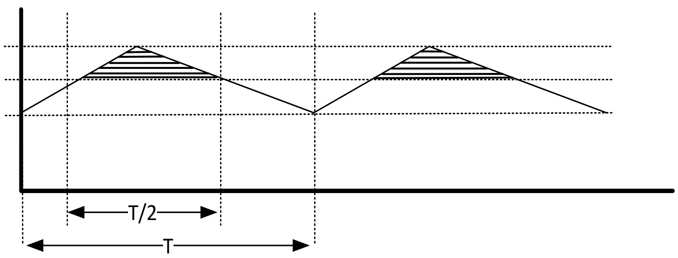


**Figure 5.** Output Inductor Current

The value of the shaded area given in Figure 5 is equal to the current change. The area of the triangle is calculated from the formula:

$$Q = \frac{\Delta I_{Lo}}{2} x \frac{T}{2} X \frac{1}{2}$$

$$\Delta I_{Lo} = \Delta I_{L(Peak)} - \Delta I_{L(Min)}$$

Where Q is the charge, ΔILo is the inductor current change,T is the period. ΔILo is calculated in previous section.

$$Q = \frac{0.6}{2} x(20x10^{-6})x0.5 = 0.03Coulumbs$$

The capacitor charge change formula is given below. We find the output capacitance by choosing the output ripple value we want in our application. The output voltage ripple is selected as 20%. The total capacitor voltage change in the T/2 period will be 8 Volts.

$$\Delta V = 80x0.1 = 8 \text{ Volts}$$

$$C_o = \Delta VxQ \rightarrow C_o = 8x\, 0.03 = 375uF$$

With this method, the output voltage ripple can be adjusted.

*B. Figures and Tables*

**Simulation And Application Results**

In this part of the paper, the application results will be given.The simulation of the proposed Two Switch Forward PWM converter has been made. Figure 6 shows the simulation schematic and Table 1 shows the basic parameters of the converter and the selected values. Figure 7 shows the application of the proposed converter.

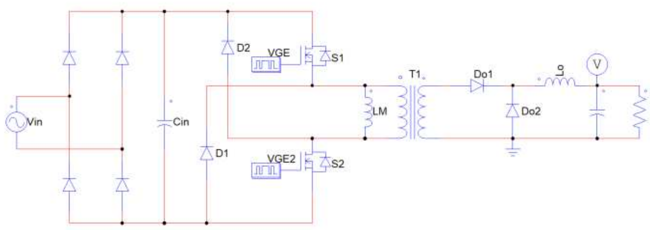


**Figure 6.** Simulation schematic of proposed converter.

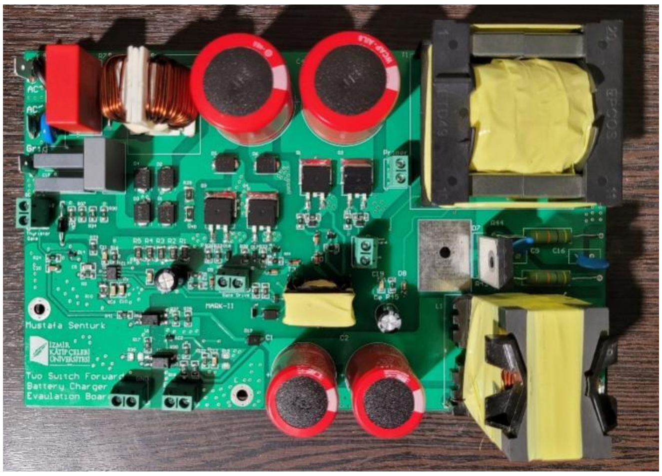

**Figure 7.** Application of proposed converter.

**Table 1.** Simulation Parameters of the proposed converter

| **Parameters** | **Values** |
|---|---|
| $V_{in}$ | 207Vrms |
| $V_0$ | 80Vrms |
| $T_r$ transformation ratio | 1.165 |
| Switching frequency | 50kHz |
| Output Current | 3 Ampere rms |
| $C_o$ | 375uF |
| $C_{in}$ | 120uF |
| $L_O$ | 1.6mH |

Application parameters of the proposed converter is given below in the table 2. In the application, the input capacitor and output capacitor values have been changed. Since high frequency ripple currents are taken into consideration while choosing the capacitor, the appropriate capacitance for these currents is selected in the application.

**Table 2.** Application Parameters of the proposed converter

| **Parameters** | **Values** |
|---|---|
| $V_{in}$ | 230Vrms |
| $V_0$ | 81Vrms |
| $T_r$ transformation ratio | 1.165 |
| Switching frequency | 50kHz |
| Output Current | 3 Ampere rms |
| $C_o$ | 440uF |
| $C_{in}$ | 200uF |
| $L_o$ | 1.6mH |

In Figure 8-a and 8-b, simulation and application results of the output voltage is given. It is obvious that the output voltage has a 20% ripple.

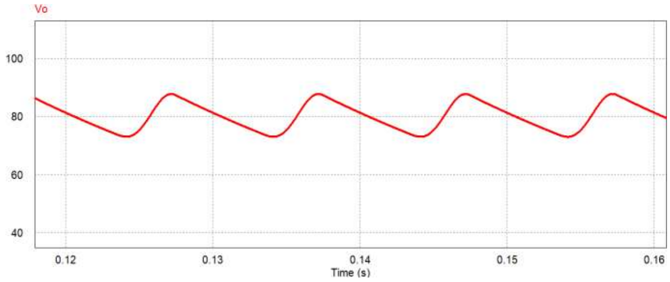


**Figure 8-a.** Simulation result of the output voltage

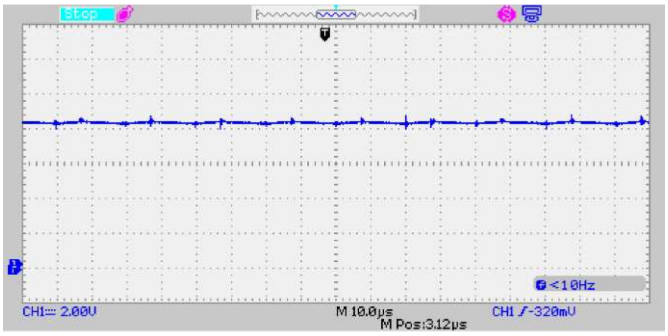


**Figure 8-b.** Application result of the output voltage when the probe is 10x.

It is clearly seen from the measurement results, the simulation and application results are the same.

Gate Source and Drain Source signal measurements of simulation and application are given in figure 10-a and 10-b. It can be seen from the results of the measurement that the frequency is 50kHz.

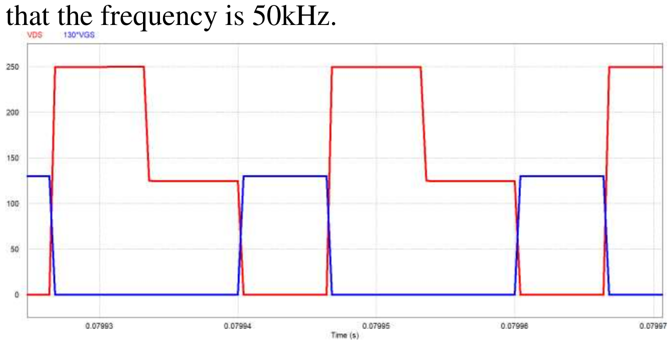


**Figure 10-a.** Simulation result of the output current. Channel 1 and channel 2 are Gate Source And Drain Source Signals.

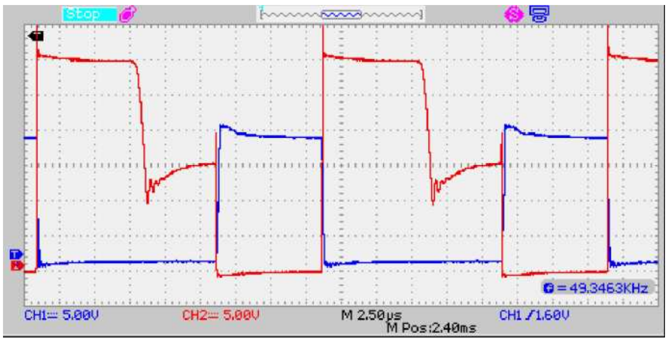


**Figure 10-a.** Simulation result of the output current. Channel 1 and channel 2 are Gate Source And Drain Source Signals.

Gate Source signal measurements of simulation and application are given below in figure 11-a and figure 11-b.

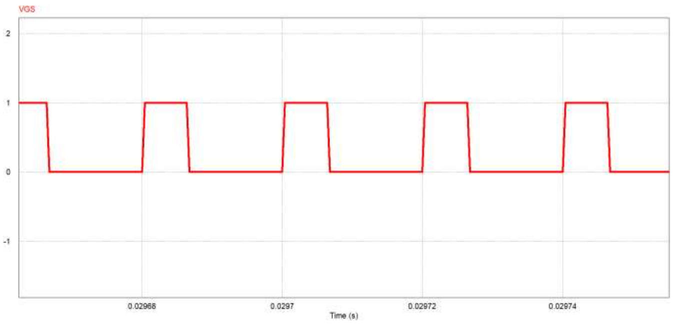


**Figure 11-a.** Gate-Source Signals of Simulation Results

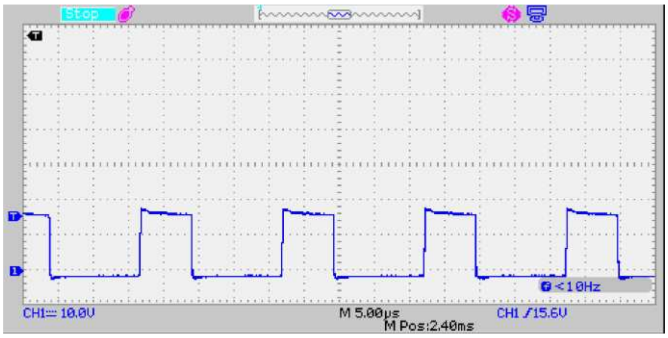


**Figure 11-b.** Gate-Source Signals of Application

Gate Source signal measurements of simulation and application are given below in figure 12-a and 12-b .

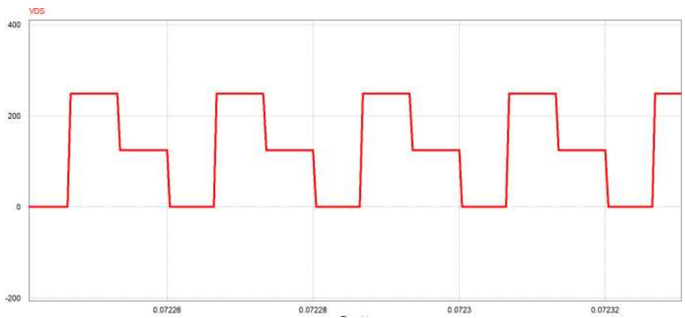


**Figure 12-a.** Drain-Source Signals of Application

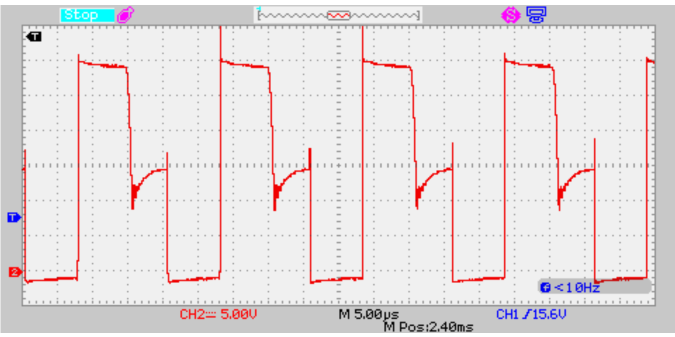


**Figure 12-b.** Drain-Source Signals of Application

Primer Voltage measurements of simulation and application are given in figure 13-a and 13-b. If we look at the results of the application compared to the simulation, damping was observed in the primary voltage due to the L-C structure connected in series in the primary.

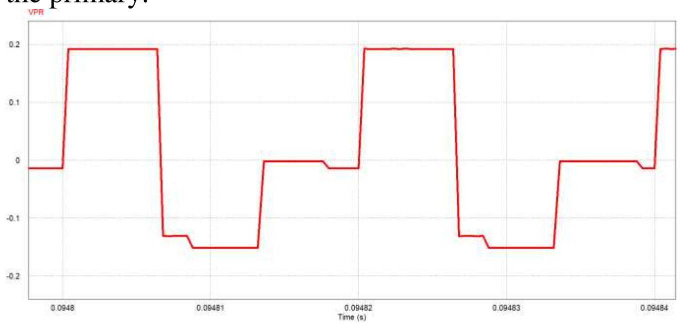


**Figure 13-a.** Primer Voltage result of simulation

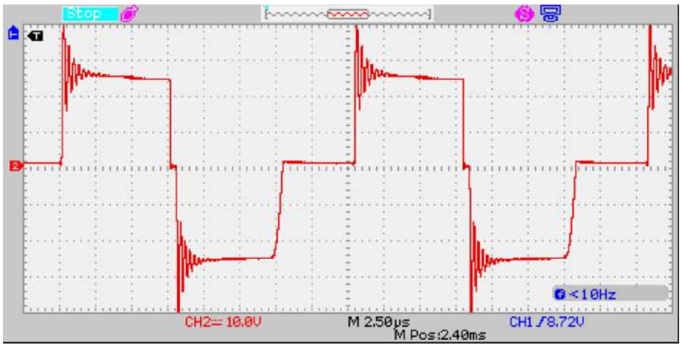


**Figure 13-b.** Primer Voltage with load. Primer Voltage measured with 10x probe.

Gate Source signal and primer voltage measurements of application are given in figure 14-a and figure 14-b below. It can be seen from the following two figures that when the load Seconder voltage measurements of simulation and application are given in figure 15-a and figure 15-b below.

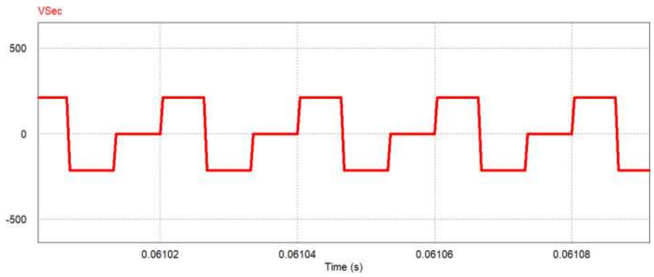


**Figure 15-a.** Seconder Voltage simulation result.

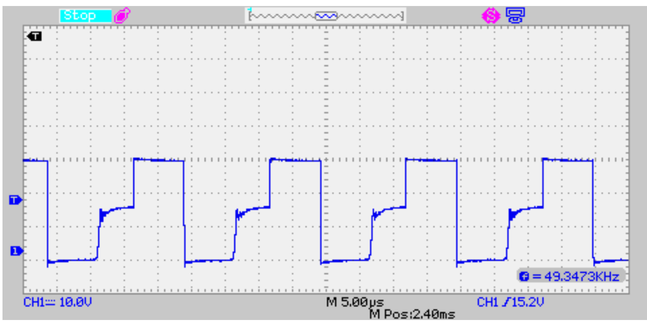


**Figure 15-b.** Seconder Voltage applicaton result. Seconder voltage measured with 10x probe.

Output diode measurements of simulation and application are given in figure 16-a and 16-b.

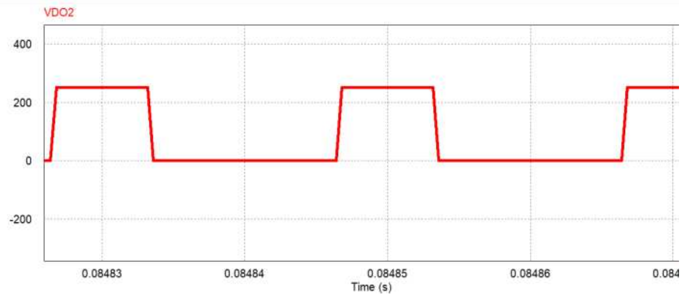


**Figure 16-a.** Output Diode Voltage Simulation Result

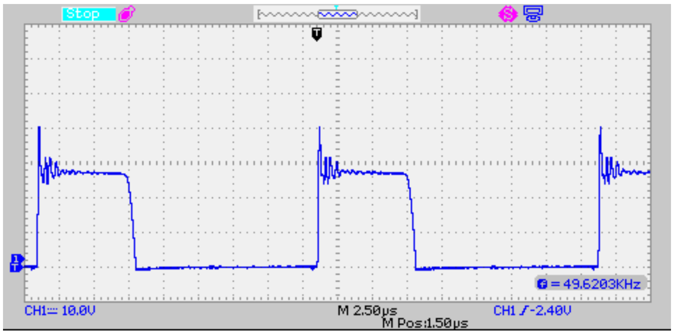


**Figure 16-b.** Output Diode Voltage Application Result

## III.RESULTS

In this paper, some parameters had to be changed in the simulation and application of the proposed converter. Compared to the simulation, the values of the input and output capacitors were chosen larger in the application. The reason for this is that there is no capacitor that can withstand the desired values in the application. It has been observed that as the capacitance value of the input capacitor increases, the losses decrease and the efficiency increases, and as a disadvantage, the peak value of the input current increases. In the transformer and output inductor winding of the application mentioned in this paper, an air gap is left to prevent saturation of the transformer. In this way, the slope of the B-H curve has been reduced. However, we know that such methods reduce the average performance of the circuit, because leakages in the transformer increase, etc[17]. Compared to the simulation, 2 parallel MOSFETs, a total of 4 MOSFETs, are used instead of a switching element as a switching element in the application circuit, the reason being that no heatsink is used. Gate drive transformer is used to drive the mosfets. As a result, it has been observed that the gate drive structure and circuit control are easy, noise is low and efficiency is high. It is clear that the number of components has increased considerably. All of the advantages and disadvantages given in the introduction have been observed in the application.

## IV.CONCLUSION

In this study, a PWM Two Switch Forward AC-DC converter with high efficiency is proposed. The proposed converter is very advantageous thanks to its features such as easy applicability and no need for additional control signals. Theoretical analyzes and operating stages of the presented PWM converter were explained in detail and supported by relevant visuals. Afterwards, the theoretical analyzes of the converter were verified with a simulation circuit with 50 kHz switching frequency, 80V output voltage and 3 A output current values. After the simulation, It has been clearly observed that the output voltage and output current have the desired ripple and desired values.

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