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**EE464 STATIC POWER CONVERSION II**

**Simulation and Magnetic Design Report**

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## Introduction

This report is a combination of both “HW2” and “Simulation and Magnetic Design Report”. The contents include the topology selection, magnetizing inductor calculations, core selection steps, the simulation results and loss analysis. The aim of the report is to prepare a template for the hardware project circuit and face the design problems before implementation.

## Topology Selection

The topology selection is done via comparing the topology types that we learnt during the lectures. The selected topologies to compare are as follows:

* Flyback
* Forward
* Push-pull
* Full Bridge
* Half Bridge

Table 1: A basic comparison between several isolated DC-DC converters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Topology Name | Optimal Power Demand | Efficiency | Number of Components | Voltage Stress | Cost |
| Flyback | Low (<500W) | High | 4 | High | Low |
| Half Bridge | Low (<500W) | High | 7 | High | Medium |
| Full Bridge | High (>1kW) | Medium | 9 | Medium | High |
| Push Pull | High (>1kW) | Medium | 8 | High | High |
| Forward | Low (<500W) | High | 7 | Medium | Low |

Table 2: A more detailed analysis between the topologies

|  |  |  |
| --- | --- | --- |
| Topology Type | Advantages | Disadvantages |
| Flyback | Simplest and most commonly used isolated DC-DC converter | Additional snubber circuit for the leakage inductance di/dt |
| Does not require a separate storage inductor | Relatively lower efficiency |
| Half Bridge | Higher power levels | Need to be careful with the switches not to short the input (leave dead time) |
| The switching stresses are equal to the input voltage | Less suitable for high output currents |
| Full Bridge | Even higher power levels | Need to be careful with the switches not to short the input (leave dead time) |
| Allows the power flow in both directions | Switching losses increase |
| Push Pull | Utilizes the core more efficiently, reaching high power levels | Switching control is a bit difficult |
| Output current is regulated with the output inductor | Switching stresses are high |
| Forward | Can supply high output currents with less di/dt | Extra inductor at the output |
| Gain equation is linear with the duty cycle | Not suitable for high output voltage |

Considering the positives and the negatives, our final topology choice is the flyback converter. The most critical factor is the component number and the cost for us. The control method is also relatively easier. The flyback converter also makes same as the highest efficiency is not required and the project is a low-power project. As a disadvantage, a snubber design is required.

## Flyback Converter Design

Specifications of the project are listed as follows:

* **Minimum Input Voltage**: 12 V
* **Maximum Input Voltage**: 18 V
* **Output Voltage**: 48 V
* **Output Power**: 48 W
* **Output Voltage Peak-to-Peak Ripple**: 3%
* **Line Regulation**(Deviation of percent output voltage when input voltage is changed from its minimum to maximum or vice versa): 3%
* **Load Regulation**(Deviation of percent output voltage when load current is changed from 10% to 100% or vice versa): 3%

Let’s choose duty cycle range as

for safe operation After that, boundaries of turns ratio becomes,

Let’s select turns ratio = N1/N2 = 1/3. After that,

Then,

when N2/N1 = 3.

In order to design convenient transformer, the magnetizing inductance should be decided. Maximum, average and RMS value magnetizing current should be calculated. When the switch is on, input current is equal to magnetizing current. However, input current is equal to 0 when the switch is off.

When the input voltage is equal to 12 V, duty cycle is equal to 0.58. Then,

When the input voltage is equal to 18 V, duty cycle is equal to 0.47. After that,

The ripple current formula is given below as;

We assume that fs = 50 kHz because a lot of controllers work at that frequency. Moreover, we should consider the case of input voltage = 18 V and D = 0.47 because ripple current is larger for larger Vin\*D values for same inductance value. In this case, the maximum ripple current would be equal to 5.67\*2 = 11.34 A to stay at continous conduction mode. Hence,

For the case of input voltage = 12 V, D = 0.58 and ripple current = 6.9\*2 = 13.8 A;

This result also verifies that Lm should be greater than 14.92 uH.

To decide the Lm current ripple we consider the 25% load case. For Vin = 18V, the minimum inductor current should not be dropping to zero. Then;

= 2.835 A

Imax = 6.9 + 2.835/2 = 8.318 A

Iavg\_max = 6.9 A

Then,

For the core selection, we consider magnetic flux, cross sectional area of the core and copper properties. First, we searched the ferrite cores, however, they are not suitable for flyback converter design if we do not use air gap. The reason is that they have large permeability so that they are not convenient for storing energy. Then, we look at Kool Mu cores from Magnetics from the excel table. We prepared Matlab Script that we also added it to the Github repository. We compared different cores from the Excel table that are already in the lab and will come in the May. Moreover, we have benefitted from the Magnetics Powder Core Catalog. We have specifications of;

* Minimum inductance = 59.68 uH
* The maximum current = 8.318 A (without losses)

After that, from the formula of

we moved on the core selector charts. Then, the core 00K4022E090 satisfied the requirements of our project. Moreover, it is also available in the lab.

The inductance factor of the core is AL = 281 nH/T^2. However, it can be as ±8%. Therefore, the minimum inductance factor is calculated as 258.52 nH/T^2.

We have calculated to primary number of turns as;

However, the number of turns should be integer number. Therefore, we have taken as

This number of turns is calculated assuming there are no change in AL. However, since AL changes with MMF, we have calculated MMF when I=.

According to the Typical DC Bias Performance from the datasheet, and assuming it is decreasing linearly from 0 to 420 A-t,

Since it can be as ±8%, AL = 274.19\*0.92=252.26. When we recalculate the turn number with new AL value

Hence the .

Now, we have to calculate the copper losses and core losses.

Approximate length of cable for 1 turn is equal to 2\*(F+C+2\*M)=100.9 mm. Additionally since we are working with 50kHz we choose AWG-23 cable which has and Hence,

Where : number of parallel cables at primary side

: number of parallel cables at secondary side

For core losses B=µ\*H.

Since both equation is related to when , we made iterative solution using MATLAB:

## Ideal Case Simulations

## metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram içeren bir resim Açıklama otomatik olarak oluşturuldu

Figure : Output Voltage vs Time Graph For Vin = 12 V

The average output voltage is 48.64 V and the ripple voltage is 1.23. Therefore,

Which is lower than specification.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Output Current vs Time Graph For Vin = 12 V

The average output current is 1.01 A according to simulation.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Input Current vs Time Graph For Vin = 12 V

The maximum input current is around 8.79 A which is similar to theoretical result.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Output Voltage vs Time Graph For Vin= 18 V

The average output voltage is 47.84 V and the ripple voltage is 1.03. Therefore,

çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Output Current vs Time Graph For Vin = 18 V

The average output current is 0.996 A according to simulation.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Input Current vs Time Graph For Vin = 18V

The maximum input current is around 7.63 A.

## A

Lm =

Vin =12 V

Vin = 18 V

The maximum average transformer current without losses is 6.9 A.

The minimum average transformer current without losses is 1.06 A.

## Component Selection and Practical Case Simulations

Mosfet:

The maximum mosfet voltage is

On the other hand, the maximum switch current is

We have chosen IRF 540 N Mosfet because it has a current rating of 28 A and voltage rating of 100 V. This values guarantees proper operation. Moreover, it has a drain to source resistance of 44 mohm which is quite low.

Diode:

The maximum reverse voltage of the diode is equal to output voltage when the switch is on case and it is 48 V . + 18\*3 = 102 V. Moreover, maximum current on the diode is

For the diode selection, we have chosen BYW29-200 Power diode which has a current rating of 8A and voltage rating of 200V. Moreover, it has a forward voltage drop 0.85 V

Output Capacitor:

The output capacitor is selected from the formula of;

To guarantee proper operation, C is chosen as 10 .

Controller:

1. UC3845 is one of the most used DC-DC switching controller on the market. The application notes include flyback converters as shown in Figure 1. The line and load regulation values are suitable for the design requirements. Also, it can be bought easily from Özdisan. In general, UCxxxx series are looking applicable for the project.

diyagram, metin, plan, teknik çizim içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : UC3845 Controller

[UC3842/3/4/5\_Provides\_Low-Cost\_Current-Mode\_Control (ti.com)](https://www.ti.com/lit/an/slua143/slua143.pdf?ts=1683267662476)

1. OB2269CAP is an alternative to UC models which can also be purchased from Özdisan. The application areas include offline flyback converters. It is also very cost-effective and easy to implement.

diyagram, plan, teknik çizim, şematik içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : OB2269CAP Controller

[Microsoft Word - OB2269C\_DataSheet\_V31.doc (ozdisan.com)](https://cdn.ozdisan.com/ETicaret_Dosya/474255_4348470.PDF)

metin, ekran görüntüsü, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Output Voltage vs Time Graph For Vin = 12 V

The average output voltage is 46.46 V and the ripple voltage is 1.19. Therefore,

çizgi, diyagram, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, paralel içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Output Current vs Time Graph For Vin = 12 V

The average output current is 0.968 A according to simulation.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, paralel içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Input Current vs Time Graph For Vin = 12 V

The maximum input current is around 9.79 A.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Switch Voltage vs Time Graph For Vin = 12V

The maximum switch voltage is 28.18 V according to simulation.

metin, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, çizgi, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Diode Voltage vs Time Graph For Vin = 12 V

The maximum reverse voltage of the diode is 82 V.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, ekran görüntüsü içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Diode Current vs Time Graph,

The maximum diode current is 2.77 A.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Magnetizing Inductance Current For Vin = 12 V

metin, yazı tipi, çizgi, ekran görüntüsü içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : : Output Voltage vs Time Graph For Vin = 18 V

The average output voltage is 45.51 V and the ripple voltage is 0.98. Therefore,

çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram, metin içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Output Current vs Time Graph For Vin = 18V

The average output current is 0.948 A according to simulation.

metin, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, çizgi, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Input Current vs Time Graph For Vin = 18V

The maximum input current is 8.86 A according to simulation.

metin, ekran görüntüsü, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Switch Voltage vs Time Graph For Vin = 18V

The maximum switch voltage is 33.75 V according to simulation.

metin, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Diode Voltage vs Time Graph For Vin = 18V

The maximum reverse voltage of the diode is 80.22 V.

metin, ekran görüntüsü, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, çizgi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Diode Current vs Time Graph For Vin = 18V

The maximum diode current is around 2.34 A.

metin, ekran görüntüsü, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Magnetizing Inductance Current For Vin = 18 V

diyagram, plan, teknik çizim, şematik içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : Simulation Block Diagram

## Efficiency Calculation For Different Loads

Vin = 12 V

100% Load:

Pin = 79.6 W, Pout = 44.95 W that yields 56.47% efficiency.

75% Load:

Pin= 64.5 W, Pout = 44.95 W that yields 53.4% efficiency.

50% Load:

Pin= 49.09 W, Pout = 23.46 W that yields 47.79% efficiency.

25% Load:

Pin= 33.44 W, Pout = 12 W that yields 35.89 % efficiency.

Vin = 18 V

100% Load:

Pin = 93.15 W, Pout = 44.95 W that yields 46.32% efficiency.

75% Load:

Pin= 77.15 W, Pout = 32.79 W that yields 42.5% efficiency.

50% Load:

Pin= 61 W, Pout = 22.16 W that yields 36.33% efficiency.

25% Load:

Pin= 44.77 W, Pout = 11.24 W that yields 25.11 % efficiency.

However, we calculated efficiency theoretically also. As we can sen in part b the core loss and the copper losses are 6.64W and 1.43W. And the efficiency is around 85% without semiconductor losses with full load. It is higher when the load decreases because both copper losses and core loss decreases exponentially. The reason why the efficiency decreases when the load decreases is we assumed Rcu is constant. The efficiency is directly taken from the simulations. When we calculate the conduction loss of mosfet it is equal to 1.93W maximum, switching losses of mosfet equal to 0.39W and diode loss is equal to 1.88W.

Maximum Total Loss = 12.27 W theoretically at full load case and that yields 79.64% efficiency.

## Conclusions

There are different isolated DC-DC converter topologies where basically a trade-off is made. The most used isolated step-up converter is the flyback converter. After deciding on the flyback, there came a lot of different factors when determining the duty cycle and the turns ratio, turn numbers and selecting a proper core. The datasheets do not include sufficient information to be used at the loss calculations, so the catalogs are searched instead. The Steinmetz's equation is used to check with the core characteristics included in the core catalogs. The copper losses are also calculated by hand using the AWG cable catalog, core dimensions and turn numbers. The simulation is run repeatedly with different selections until the desired outcome occurs. The semiconductor losses are not to be ignored as they decrease the overall efficiency significantly. A more proper component and controller selection must be made until the presentation as this iteration of the flyback converter is quite fragile. A snubber design is also strongly suggested for flyback converters, which we also aim to do in the following weeks.

## References

[Switch Mode Power Supply Topologies: A Comparison (we-online.com)](https://www.we-online.com/en/news-center/blog?d=switch-mode-power-supply#:~:text=The%20difference%20between%20flyback%20vs,additional%20storage%20choke%20is%20needed.)

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[DC-DC Switching Voltage Controllers - Hundreds of thousands of electronic components at ozdisan.com with same day shipping advantages. Add to basket with best prices, buy original parts from stock | Özdisan Electronics](https://ozdisan.com/p/213?ids=9964;483221,9964;483241,9964;483212,9964;362756,9964;449480,9964;362782,9964;362754,9964;483195,9964;530082,9964;362753,9964;362773,9964;463997,9964;483254,9964;484779,9964;362770,9964;483231,9964;447555,9964;483199,9964;480483,9964;530077,9964;530083,9964;483202,9964;447557,9964;425005,9964;483911,9964;445898,9964;431833,9964;483218,9964;483235,9964;445894,9964;483209,9964;506831,9964;505093,9964;480481,9964;447553,9964;530078,9964;530080,9964;483249,9964;483225,9964;362750,9964;362759,9964;362762,9964;483247,9964;362744,9964;362748,9964;483250,9964;362739,9964;362735,9964;449484,9964;362778&groupids=9964&propids=483221,483241,483212,362756,449480,362782,362754,483195,530082,362753,362773,463997,483254,484779,362770,483231,447555,483199,480483,530077,530083,483202,447557,425005,483911,445898,431833,483218,483235,445894,483209,506831,505093,480481,447553,530078,530080,483249,483225,362750,362759,362762,483247,362744,362748,483250,362739,362735,449484,362778&sayfaAdedi=20)

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