daire, grafik, renklilik, kırmızı içeren bir resim

Açıklama otomatik olarak oluşturuldu

**MIDDLE EAST TECHNICAL UNIVERSITY**

**ELECTRICAL-ELECTRONIC ENGINEERING DEPARTMENT**

**EE464 – TERM PROJECT REPORT**

**PEAKY CONVERTERS**

Student Names:

Çağlar Umut Özten

Onur Toprak

Student ID: 2375616

# INTRODUCTION

Our term project revolves around the design of an isolated power converter. To achieve this objective, we carefully chose an optimal topology and selected the necessary components. Subsequently, we conducted simulations based on these choices. Additionally, we incorporated magnetic design considerations for both the inductor and transformer into our report. This includes outlining magnetic design parameters and the step-by-step process for designing these components. Furthermore, we addressed controller design aspects, including specifications such as compensator selection, feedback mechanisms, and frequency adjustment. Our report also includes simulation results, circuit schematics, and details on the designed magnetic components.

# TOPOLOGY SELECTION

* **Minimum Input Voltage**: 20 V
* **Maximum Input Voltage**: 40 V
* **Output Voltage**: 12 V
* **Output Power**: 60 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%

According to given specifications, topology is selected as forward converter with third winding. This topology has many advantages. Firstly, we wanted to design two switch forward converter. With this topology, we can get rid of third winding for resetting the transformer and our efficiency was increased. However, less design resources and problems on the simulations, this topology is changed and forward converter with third winding is used.

Advantages of the Forward Converter:

The forward converter is a popular topology in power electronics, offering several advantages along with some limitations:

**Advantages:**

* High Efficiency: Forward converters typically exhibit high efficiency due to their low conduction losses and effective utilization of magnetic components.
* Isolation: Like other isolated converters, the forward converter provides electrical isolation between the input and output, ensuring safety and enabling the converter to be used in a wide range of applications.
* Reliability: Forward converters are known for their simplicity and robustness, resulting in reliable operation over long periods, particularly when designed and implemented correctly.
* Ease of Control: They offer relatively straightforward control schemes, making them easier to design and implement compared to more complex topologies.
* Compact Design: Forward converters can be designed to be relatively compact, making them suitable for applications where space is limited.

**Disadvantages:**

* Complex Transformer Design: The transformer design for a forward converter can be more complex compared to simpler non-isolated topologies due to the need for both forward and reset windings.
* Limited Duty Cycle: The duty cycle of a forward converter is limited by the requirement to prevent transformer core saturation. This limitation can restrict the achievable output voltage range.
* Voltage Stress: The forward converter can subject components to relatively high voltage stresses, particularly during switching transitions, which may necessitate the use of specialized components.
* Potential for EMI: Like many switch-mode power supplies, forward converters can generate electromagnetic interference (EMI), which may require additional filtering or shielding measures to comply with regulatory standards.
* Complex Control for Wide Load Variation: While simple to control under nominal conditions, maintaining stable operation across a wide load range can require more complex control strategies, adding to design complexity.

## TOPOLOGY OPERATION

diyagram, teknik çizim, plan, şematik içeren bir resim

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Figure 1. Selected Topology

Firstly, we will explain selected topology. Forward converter works with 2 operation mode. These modes are listed below:

### MOSFET ON CASE

diyagram, çizgi, plan, teknik çizim içeren bir resim

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Figure 2. MOSFET ON Case

During this phase of operation, the MOSFET switch is turned on, allowing current to flow from the input source directly through the primary winding of the transformer. At this moment, diodes 3 and 2 are reverse biased, preventing current flow in those paths, while diode 1 is forward biased, facilitating the flow of current from the input source and the primary winding.

As current flows through the primary winding, energy is stored in the transformer's magnetic field. Then this energy is transferred to secondary side with secondary winding. The primary current builds up gradually, controlled by the input voltage, the transformer's inductance, and the duty cycle of the switching signal. Meanwhile, on the secondary side of the circuit, the inductor and capacitor are charging.

The duration of this phase is determined by the duty cycle of the converter. The duty cycle represents the fraction of time the MOSFET switch remains on during each switching period. During this on-time, energy is transferred from the input source to the transformer's primary winding, initiating the energy conversion process.

In summary, when the MOSFET is on in a forward converter, current flows from the input source through the primary winding, storing energy in the transformer's magnetic field. Simultaneously, on the secondary side, the load is supplied with power as the secondary winding induces a voltage, charging the output capacitor and providing the necessary current. This phase of operation sets the stage for the subsequent phases in the converter's switching cycle.

### MOSFET OFF CASE

diyagram, çizgi, plan, teknik çizim içeren bir resim

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Figure 3. MOSFET OFF Case

When the MOSFET is turned off in a forward converter with a third winding, the operation enters a critical phase for energy transfer.

MOSFET Turn-off: At the end of the on-time, the MOSFET switch is turned off. This action interrupts the current flow through the primary winding. As a result, stored magnetic energy at the magnetizing inductance disappear on third winding and diode. When this operation occurs, required current is supplied from inductor at secondary side. So, inductor is discharging at this operation mode.

Diode Action: With the MOSFET off, diodes 3 and 2 become forward biased, while diode 1 becomes reverse biased. The voltage induced across the third winding is of opposite polarity to that of the primary and secondary windings. This causes diode 3 to conduct, providing a path for the third winding's energy to circulate back to the input source.

Resetting the Transformer: The collapsing magnetic field causes the transformer's core to reset, preparing it for the next switching cycle. This resetting process is crucial for ensuring efficient energy transfer and preventing transformer saturation.

Control of Duty Cycle: The off-time of the MOSFET, along with the on-time, determines the duty cycle of the converter. Adjusting the duty cycle allows for control over the output voltage and current regulation.

In summary, during the off time of the MOSFET in a forward converter with a third winding, energy transfer continues as the transformer's magnetic field collapses. Diode 3 conducts, providing a path for the energy stored in the magnetizing inductance. This phase of operation ensures efficient energy transfer and proper functioning of the converter.

Operation Waveforms can be seen in Figure 4.

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

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Figure 4. Operation Waveforms

From the resulted waveforms, we can easily say that gain of this converter is calculated as

From these equations, as we know, current changing on inductor should be same at these two operation mode. So, charging period is D \* Ts and discharging time is (1 – D) \* Ts. From these equations we can derivate the output gain like this

Moreover, we should consider duty cycle value. As we discussed, energy on magnetizing inductance should be reset. So, maximum duty cycle should be considered. In this design, we will design our transformer according to this turn ratios:

So, for resetting the third winding maximum duty cycle for this converter type should be 0.5. When switch is on, magnetizing inductance charges on the on period, which is D \* Ts and at the off period magnetizing inductance is discharging. This period is (1 – D) \* Ts. As we discussed above, stored energy on the magnetizing inductance can be determined from inductor current equation. From the equations, we can easily say that maximum duty cycle for the safety operation occurs at 1 – D = D, so maximum duty cycle is calculated as 0.5. These calculations will be discussed more detailed next chapters.

# CALCULATIONS FOR CONVERTER SPECIFICATOINS

As we discussed, converter operation specifications were listed. Maximum duty cycle is calculated as 0.5 in previous chapter. After that, turns ratio of the secondary and primary winding is calculated as limitation on duty cycle.

From the specification, maximum duty cycle occurs at minimum voltage case. So, maximum duty cycle can be calculated as

From this calculation, turns ratio between secondary and primary is selected as 1.5 for designing transformer easily and this selection will decrease the maximum duty cycle and third winding can reset more easily. Non-idealities or errors at controller can be affects the operation and core can go to saturation mode and this situation affects the operation of the converter and desired output and efficiency can not be supposed. So, turns ration between secondary and primary winding selected as 1.5.

From the selected turns ratio, duty cycle at maximum and minimum duty cycle can be calculated as

From this calculations transformer will be designed. After that minimum inductor inductance is calculated. For keeping the converter at continuous conduction mode, minimum inductance value can be calculated. Operation frequency is selected as 100 kHz. From the operation ratings, output current is around 5 A. Minimum inductance can be calculated as

However, designing this inductor with this inductance value causes very large oscillation at the output. So, for reducing the oscillation at output voltage, inductance is selected as 100 µH minimum.

Then, minimum output capacitor value is calculated from the load regulation requirement for this project. Required maximum output voltage regulation is 3%. So, from the equation of capacitor

According to these formulations, component selection and magnetic designs are made.

# COMPONENT SELECTION

# MAGNETİC DESIGN