Middle East Technical University
EE464 Power Electronics II

Project 1 Report

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supervised by

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Contents

1 Introduction

In this project, we are supposed to design a Cuk converter and a full bridge DC to DC converter. Cuk converter is supposed to convert 12 volts DC plus 2 volts AC with a frequency of 300 Hz into -15 volts DC. Note that 2 volts AC with a frequency of 300 Hz represents the ripple on the input end of the Cuk converter. Whereas, full bridge converter is supposed to convert 48 volts DC into -15 volts DC. Additionally, we need to add a controller circuit when designing the Cuk converter. The reason behind this purpose is to minimise the ripple on the output end of the Cuk converter.

2 Cuk Converter

First of all, we have designed our Cuk converter by without having any ripple on the input end of it. Therefore, our only input has been a 12 volts DC supply. Since we needed to obtain -15 volts DC on the output end of the converter, the duty cycle of the gate driver is set to 5/9 with a (-) reference input.

Just after we have obtained -15 volts DC on our Cuk converter, we were required to design another Cuk converter whose input would be 12 volts DC plus 2 volts AC with a frequency of 300 Hz keeping the output voltage in the given spec. In other words, the input would be rippling between 10 volts and 14 volts with a frequency of 300 Hz. However, the ripple on the input would also affect the output. To put another way, there would also be some ripple on the output end of our design. Therefore, we have needed to deisgn a voltage controller between the input and output ends of the converter, which would stabilise the voltage on the output by minimising the ripple.

2.1 a. Design

The selection of the components were done such that the operation is on the edge of CCM and DCM. It was assumed that the circuit is an ideal one with no power loss. Hence for the desired 60 W power, the output will have 4 Ampers current flowing while the input side will have 5 Ampers current. Te operation of the cuk converter relies on

the energy strorage from the input via the inductor to the capacitor and that capacitor being discharged to the output inductor. Hence the amount of energy transfer of the two inductors are same. Hence, they will have the same ripple if their inductances are selected equal, their graphs will have similar risng and falling current waveform only with the difference of the mean current being 4 for the output and 5 for the input sides. For the required operation, the ripples are 8 or 10 Ampers. The inductance values are selected as 4.7 μH and 6.8 μH in order to find the components commercially in the market. The calculation of the inductances are done through the equation 1

$$\frac{\Delta I}{\Delta T} = V/L \tag{1}$$

For DTs, the ripple is 10 A for the input side with 12 V voltage and 8 A for (1-D)Ts for 15 V output voltage. Since we want small ripple, we want the system to respond fast enough for charging and discharging and be able to keep the output constant. Hence, C1 determines the response time so its value is set to 1 μF . The output capacitance is selected as 47 μF so that the ripple is small enough. With these values in hand, the ripple is 0.06 for 15 V mean giving 0.4 % ripple. Resistor is selected as 3.75 Ω.

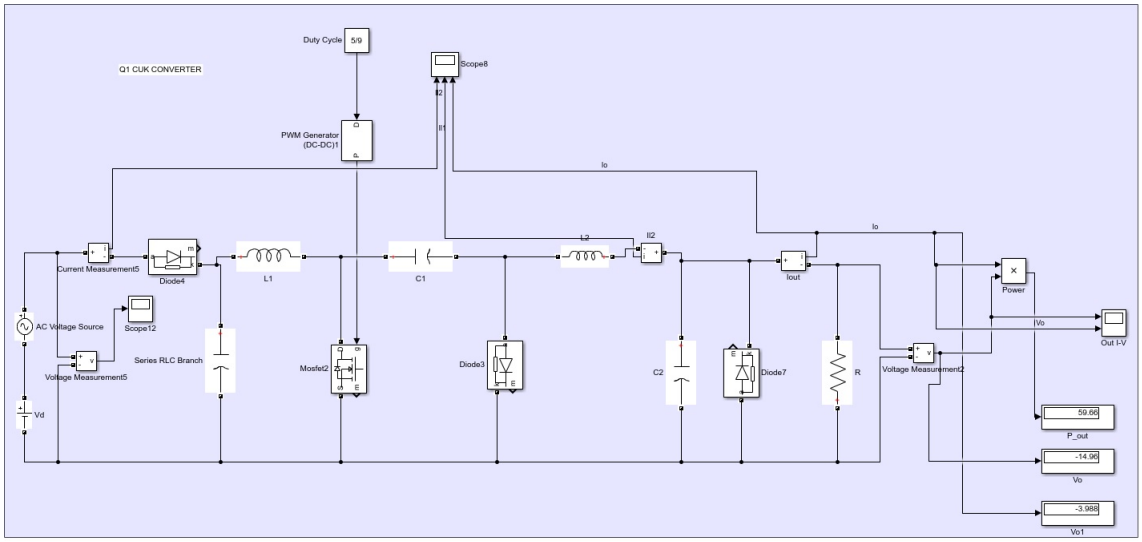


Figure 1: Circuit Implementation of Cuk Converter Without a Controller

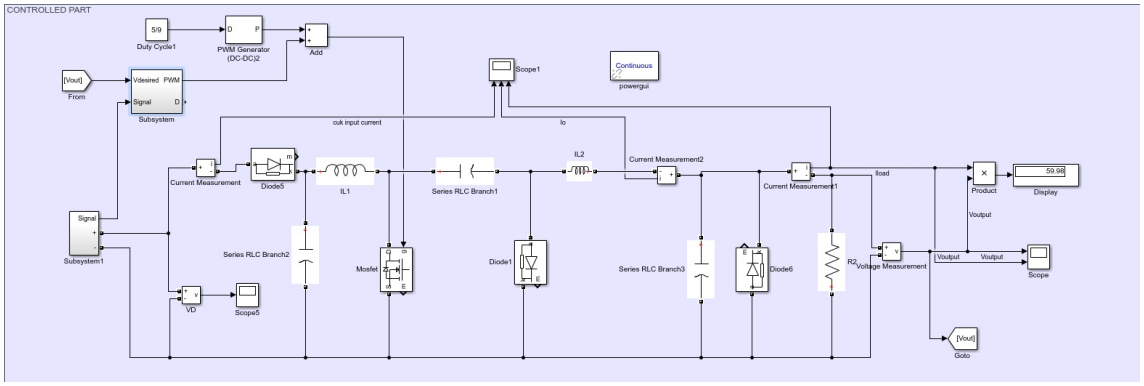


Figure 2: Circuit Implementation of Cuk Converter With a Controller

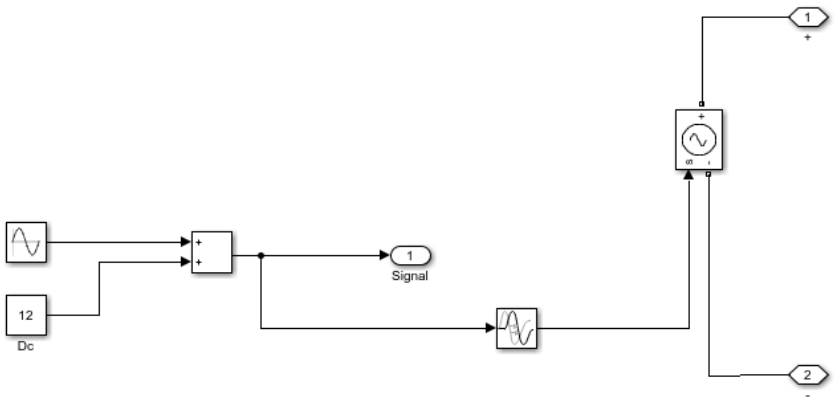


Figure 3: Signal Generator for Controlled Cuk Converter

For the selection of the components, the current and voltage rating are taken into consideration:

DRQ125-6R8-R - INDUCTOR, DUAL, SMD, 6.8UH, 6.64A

Figure 4: http://tr.farnell.com/eaton-coiltronics/drq125-6r8-r/inductor-dual-smd-6-8uh-6-64a/dp/2075633

7448990047 - Inductor, Coupled, Molded, 4.7 µH, 0.04 ohm, 5.9 A,

Figure 5: http://tr.farnell.com/wurth-elektronik/7448990047/inductor-coupled-4-7uh-5-9a-20/dp/2842131

C1608X7R1V105K080AC - SMD Multilayer Ceramic Capacitor, 0603 [1608 Metric], 1 µF, 35 V, ± 10%, X7R, C Series

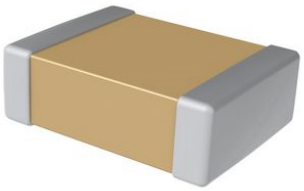
TDK

Üretici:	TDK
Üretici Parça No.:	C1608X7R1V105K080AC
Sipariş Kodu:	2346909
Ürün Çeşitleri	C Series
Teknik Bilgi Formu:	(EN)

Tüm Teknik Belgeleri Görüntüleyin

Figure 6: http://tr.farnell.com/tdk/c1608x7r1v105k080ac/cap-mlcc-x7r-1uf-35v-0603/dp/2346909

C1210C476M4PACTU - SMD Multilayer Ceramic Capacitor, 1210 [3225 Metric], 47 µF, 16 V, ± 20%, X5R, C Series

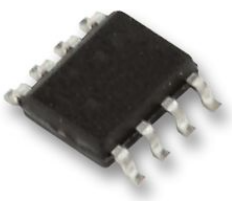


Electronic Components KEMET CHARGED.

Üretici:	KEMET
Üretici Parça No.:	C1210C476M4PACTU
Sipariş Kodu:	1838761
Ürün Çeşitleri	C Series
Diğer Adıyla:	C1210C476M4PAC7800
Teknik Bilgi Formu:	(EN)

Figure 7: http://tr.farnell.com/kemet/c1210c476m4pactu/cap-mlcc-x5r-47uf-16v-1210/dp/1838761

IRF7425PBF - MOSFET Transistor, P Channel, 15 A, -20 V, 8.2 mohm, 4.5 V, 1.2 V



Infineon

Üretici:	INFINEON
Üretici Parça No.:	IRF7425PBF
Sipariş Kodu:	1298554
Diğer Adıyla:	SP001563588
Teknik Bilgi Formu:	(EN)

Tüm Teknik Belgeleri Görüntüleyin

Figure 8:

SMA (DO-214AC)

PRIMARY CHARACTERISTICS	
V_{WM} (uni-directional)	5.8 V to 459 V
V_{WM} (bi-directional)	5.8 V to 185 V
V_{BR} (uni-directional)	6.8 V to 540 V
V_{BR} (bi-directional)	6.8 V to 220 V
P_{PPM}	400 W, 300 W
P_D	3.3 W
I_{FSM} (uni-directional only)	40 A
T_J max.	150 °C
Polarity	Uni-directional, bi-directional
Package	SMA (DO-214AC)

Figure 9: http://www.vishay.com/docs/88367/p4sma.pdf

2.2 b. Waveforms and Comparison

Here, a buck-boost converter seen in 10 is designed with the same output power and specifications using 22 μH inductor and 63 μF capacitor with 3.75 Ω resistance . When we look at their input currents (11) we see that for the buck-boost design, the waveform is not continuous and it is the current on the MOSFET. Whereas, for the cuk converter, there is an inductance hence the current is continuous. Their mean values are same. The current output for the buck boost is not a desired output and would cause switching problems due to abrupt current changes and would create high frequency harmonics.

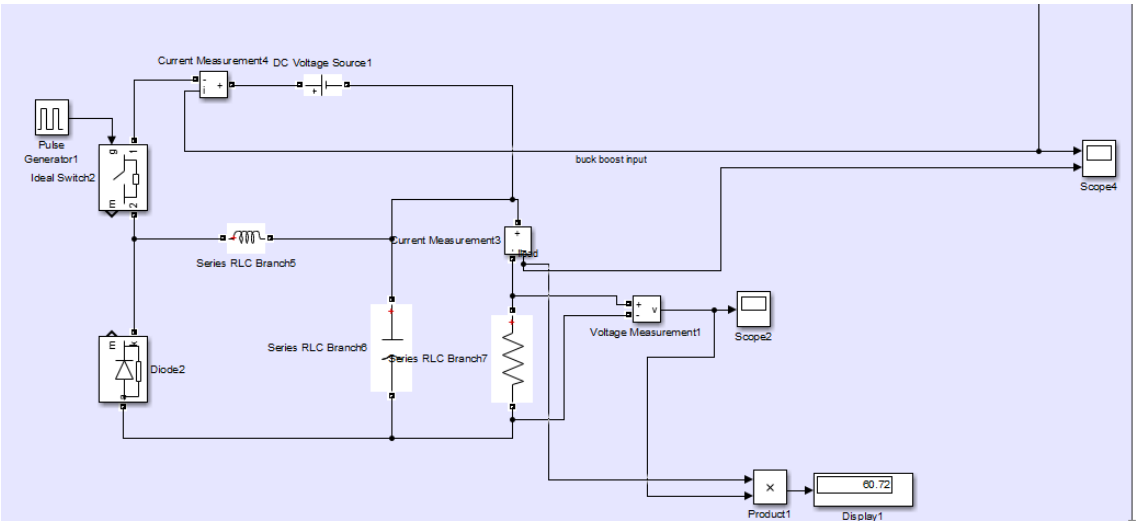


Figure 10: Buck Boost Design

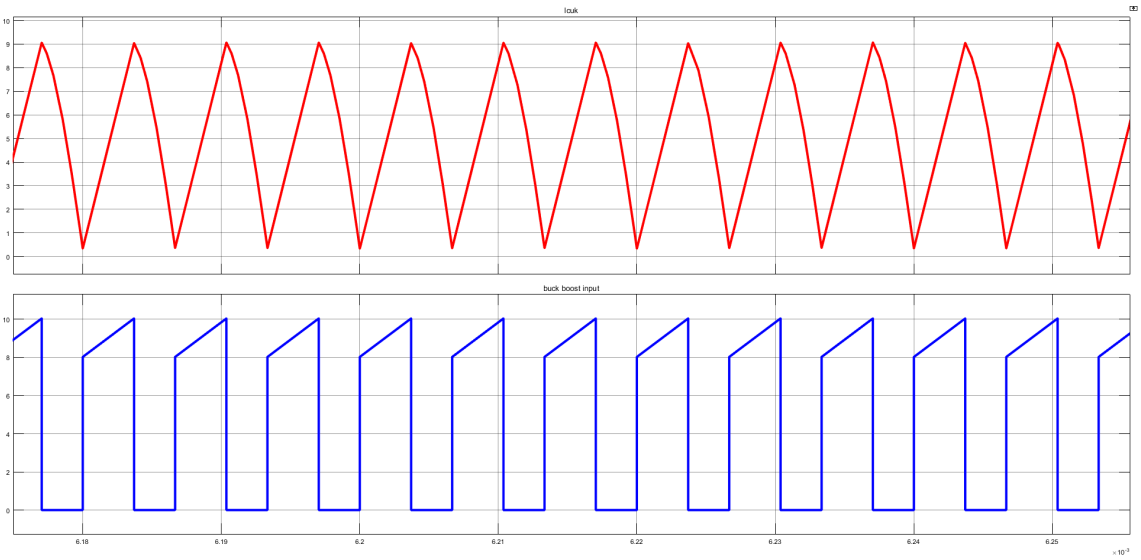


Figure 11: Cuk and Buck-Boost Input Current Waveforms

2.3 c. Control

Even though some voltage ripple might occur on the input end of the converter, the output needs to stay roughly the same in order not to burn or destroy the device which Cuk converter is connected to. Therefore, we have designed a controller circuit which is going to maintain the output voltage. For this purpose, a controller circuit has been implemented and integrated into our Cuk converter. The control is managed by measuring the input and using a linear system block shown in 3 which calculates the duty cycle that needs to be fed to the system.

Here, it is important to note that the system response time is highly controlled by the capacitor that is located in-between the input and output sides. Hence, in order for the system to respond fast to the input changes, the capacitance value must be selected accordingly. Then, this system gives us the output shown in **??**

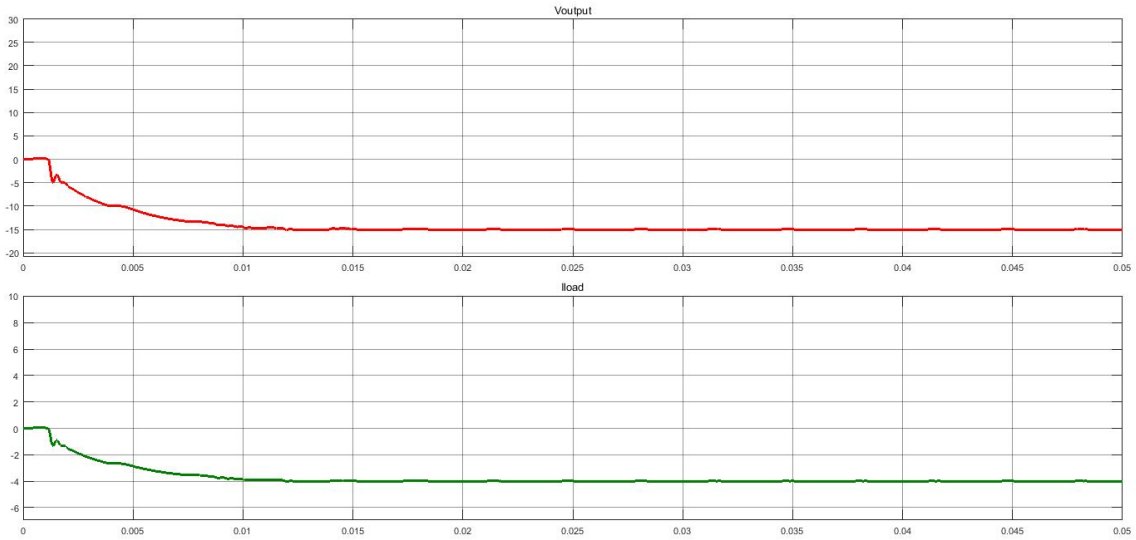


Figure 12: Controlled Output

Since $Vout/Vin = D/(D-1)$ when implementing a Cuk converter, we have designed our feedback loop accordingly.

$$D = V_{out}/(V_{out} + V_{in}) = V_{desired}/(V_{desired} + Signal) \tag{2}$$

This gives us the result seen in 14, with a very small ripple value. It is important here to note that implementing a controller with a PID representation is very hard since we do not have the system's overall transfer function and the system input is a sinusoidal function with a rather different than a step representation in Laplace domain, which we are used to solve for control design problems. Tuning by hand is nor an efficient (by means of time and insight) way neither a very engineering sort of manner to handle this problem.

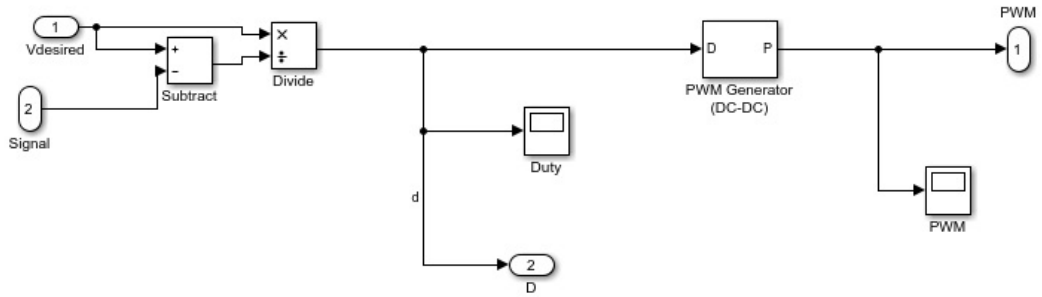


Figure 13: Controller Circuit

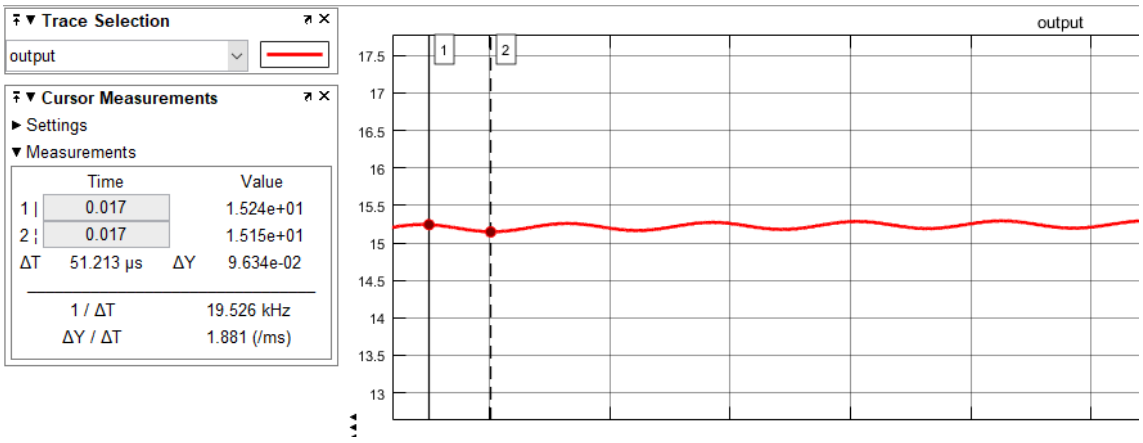


Figure 14: Control Output of Cuk Converter

3 Full Bridge DC-DC Converter

3.1 a. Bipolar Switching

As required two example situations for demonstrating the bi-polarity of the output is done with positive and negaitve reference voltage comparisons as shown in the figures 16 and 15 below.

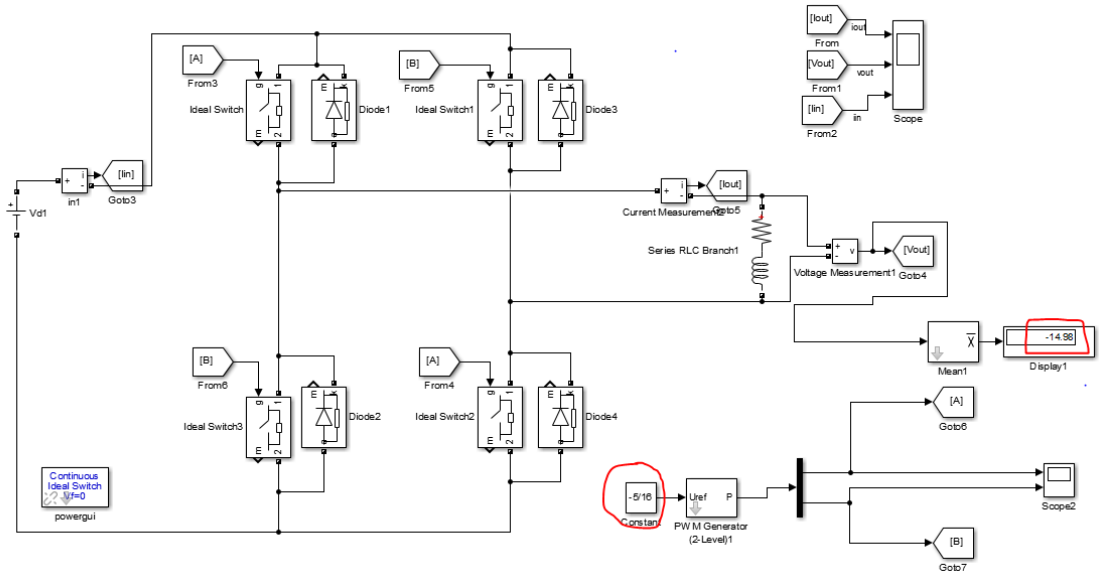


Figure 15: Negative Out Bipolar Switching

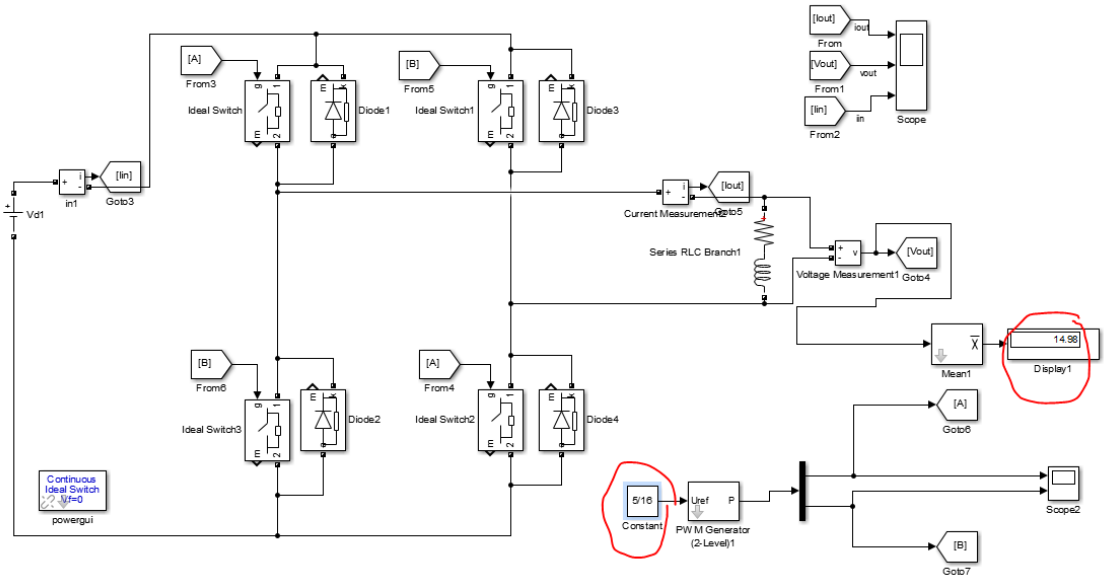


Figure 16: Positive Out Bipolar Switching

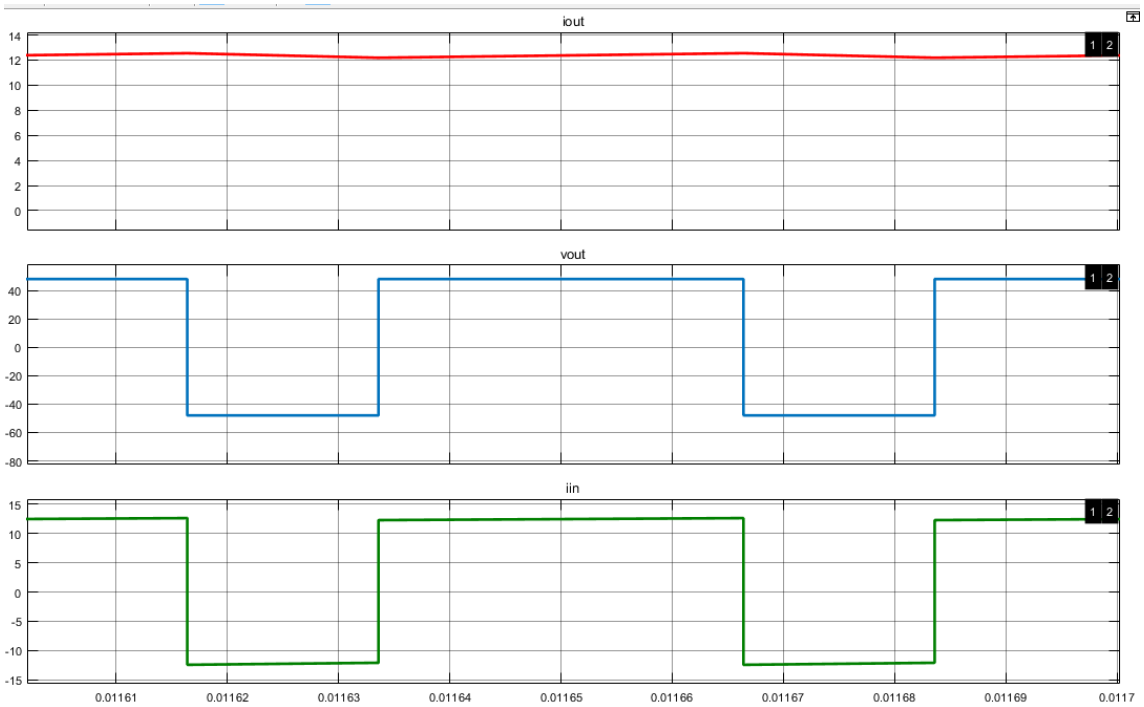


Figure 17: Output Waveforms for Bipolar Switching

3.2 b. Unipolar Switching

Same voltage can be obtained by applying unipolar switching. A and B legs are fed with the PWMs of different reference comparisons and the resultant waveforms for the output voltage and current with the same rms value is shown in figures 18 and 19. As seen with the comparison of 17 and 19, the frequency is doubled and the result is unipolar.

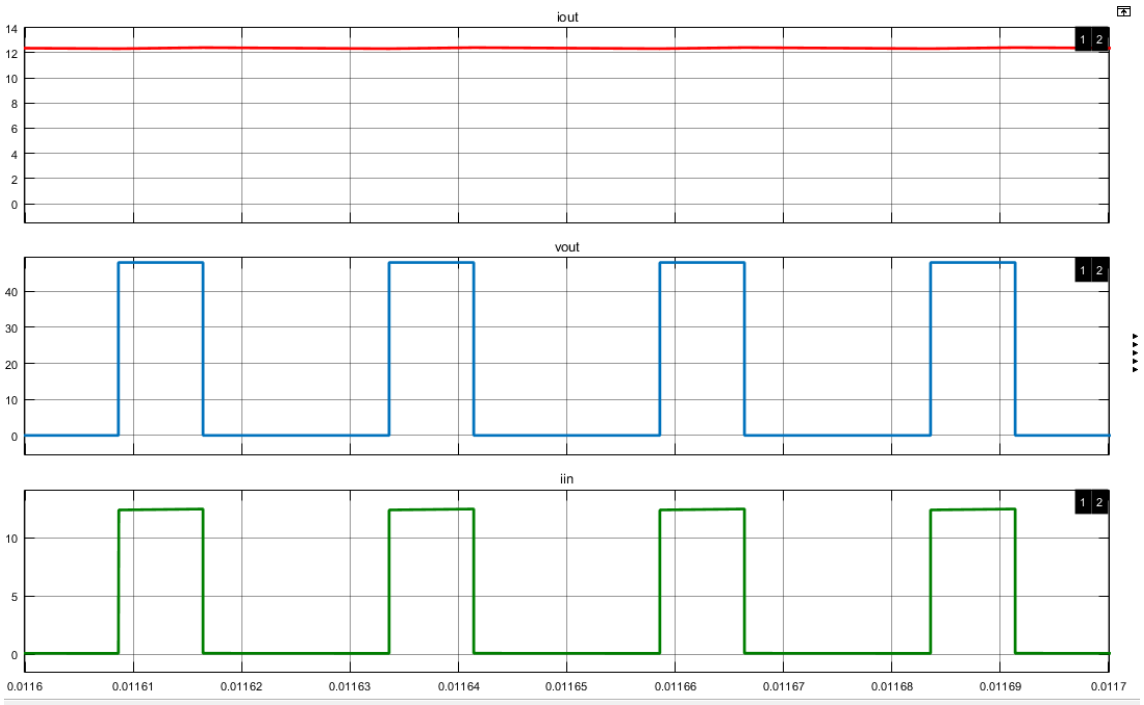


Figure 18: Output Waveforms for Unipolar Switching

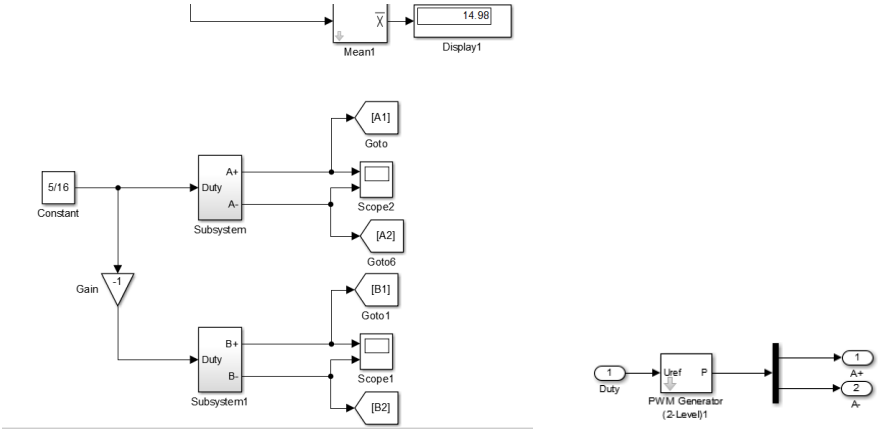


Figure 19: Switching Implementation and the resultant rms

3.3 c. FFT Analysis

The FFT Analysis for both switching types are shown in Figure 20 and Figure 21. The FFT analysis for bipolar switching shows that the THD is better, whereas for unipolar switching the result is a bit larger than the former. The output waveform of the unipolar is like a DC shifted square wave hence, it has a dc component and this dc shows its affect at the THD more. However, the resultant waveform of uniploar is more like a squarewave hence we see the effects of higher order harmonics less.

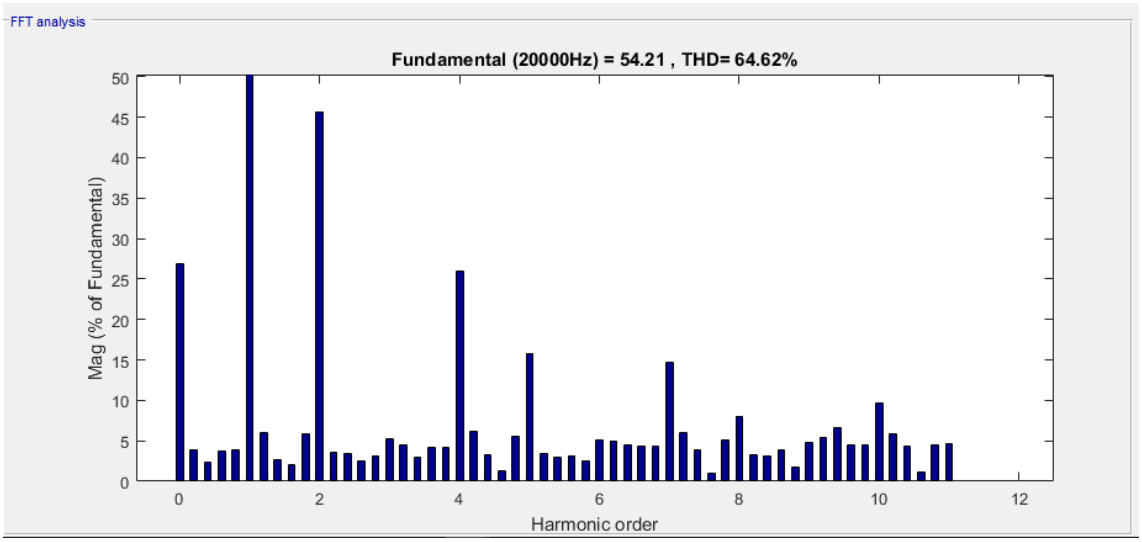


Figure 20: FFT Analysis for Bipolar Switching

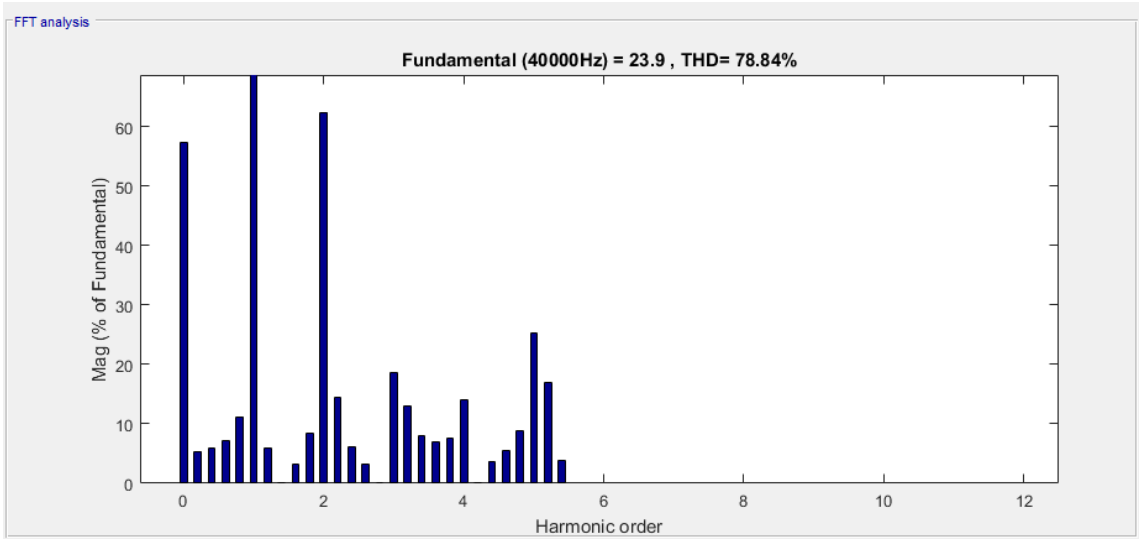


Figure 21: FFT Analysis for Unipolar Swithing

3.4 d. Dead Time

Dead time is added to the circuit with an "on deadtime" block of Simulink. The output voltage mean is 11.99 for the model without deadtime whereas it is 8.149 for the deadtimeed version. The deadtime in the signal can be observed in figure 22. This result is expected since the total area under the switching output voltage waveform decreases.

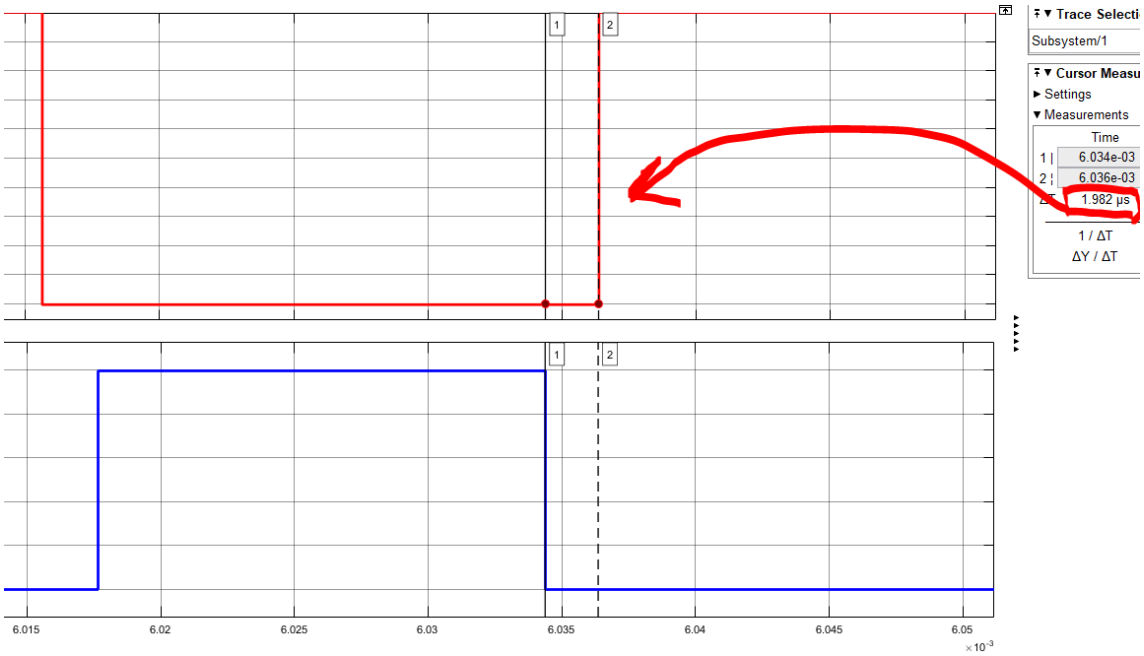


Figure 22: 2 μsec deadtime between on and off times

3.5 e. Sinusoidal Output

Simulation for both cases are conducted using bipolar switching method. Using an RLC filter the output is filtered perfectly. R is added in order to put a damping. Yet, when a deadtime is put, the peak magnitude drops for the same damping ratio. Hence, R value is increased to decrease the damping in order to generate the desired peak voltage. The resultant waveforms are shown in Figures 23 and 24, 25. In order to generate a sinusoid, instead of using a constant as a reference, a sinusoid is used. Moreover, the filter values are tabulated (1).

Table 1: Filtering Values

deadtime	Inductance	Capacitance	Resistance	Peak Voltage
No	1.6mH	0.1 mF	4 Ω	35.87
Yes	1.6mH	0.1 mF	4 Ω	32.2
Yes	1.6mH	0.1 mF	4.5 Ω	36.11

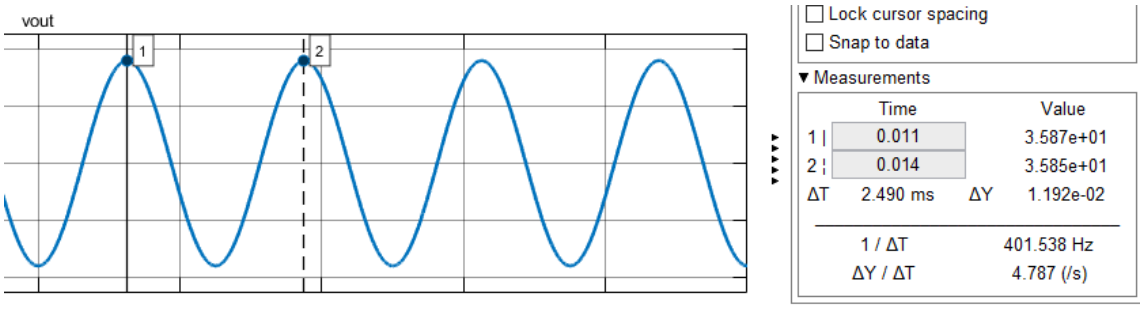


Figure 23: Filtered Sinusoidal Output Voltage without deadtime

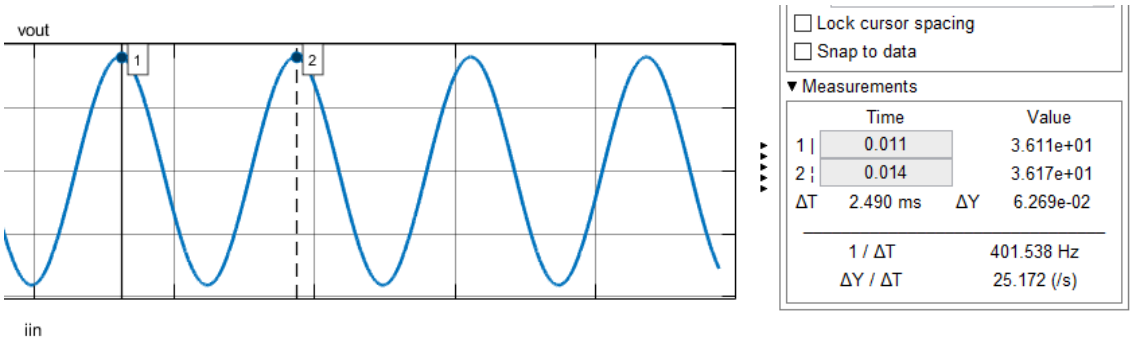


Figure 24: Filtered Sinusoidal Output Voltage with 2 μsec deadtime between on and off times

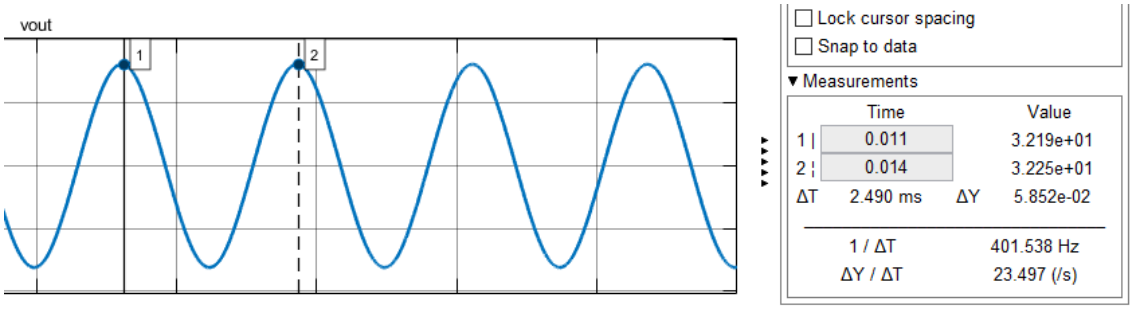


Figure 25: Filtered Sinusoidal Output Voltage with 2 μsec deadtime between on and off times filter redesigned

3.6 f. FFT Analysis

Below two different cases will be shown for the fft analysis of the inverter. The first part shows the results without any filtering components in order to highlight the deadtime effect on the harmonics and the second part shows the filtered output for harmonics.

Unfiltered FFT Analysis

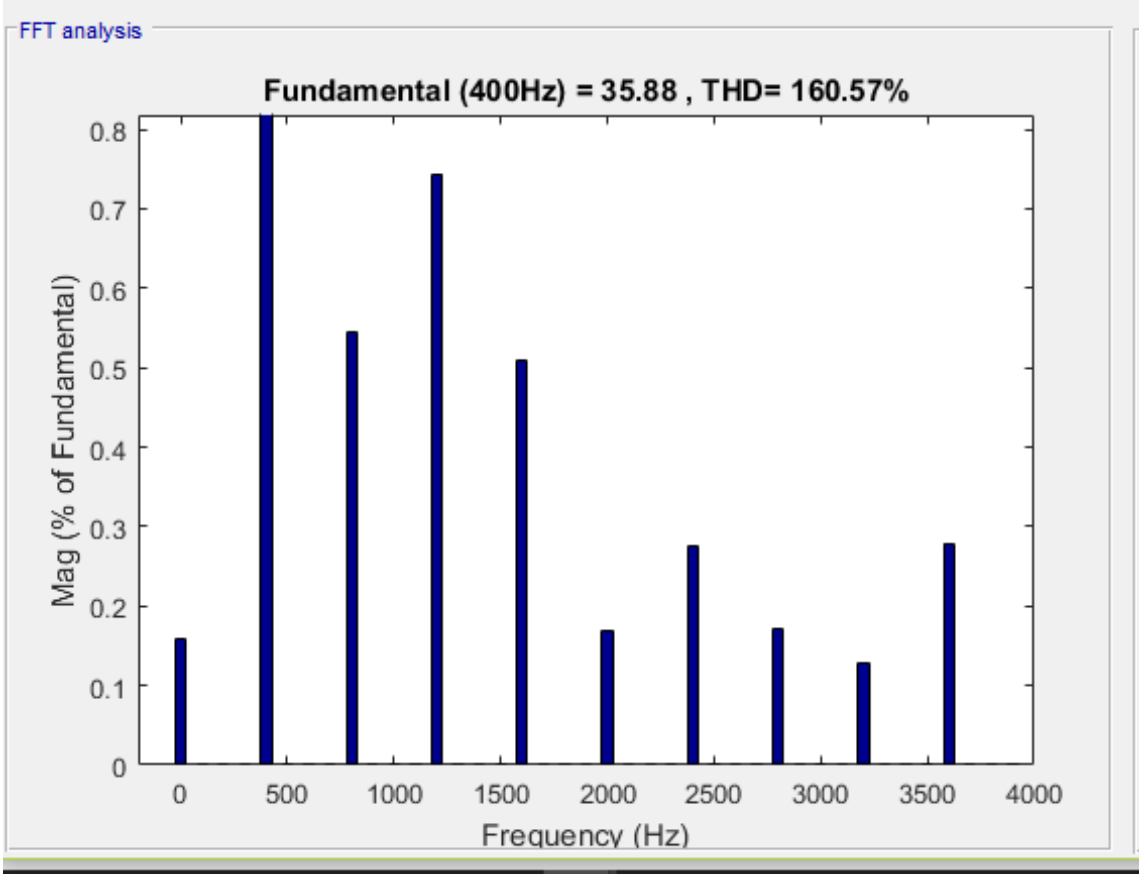


Figure 26: FFT Analysis of sinusoidal voltage without deadtime

Figure 27: FFT Analysis of sinusoidal voltage with deadtime

The figures show that deadtime introduces some harmonic components except the orders of fundamental frequency. The magnitude of the fundamental frequency remains nearly the same.

Filtered FFT Analysis

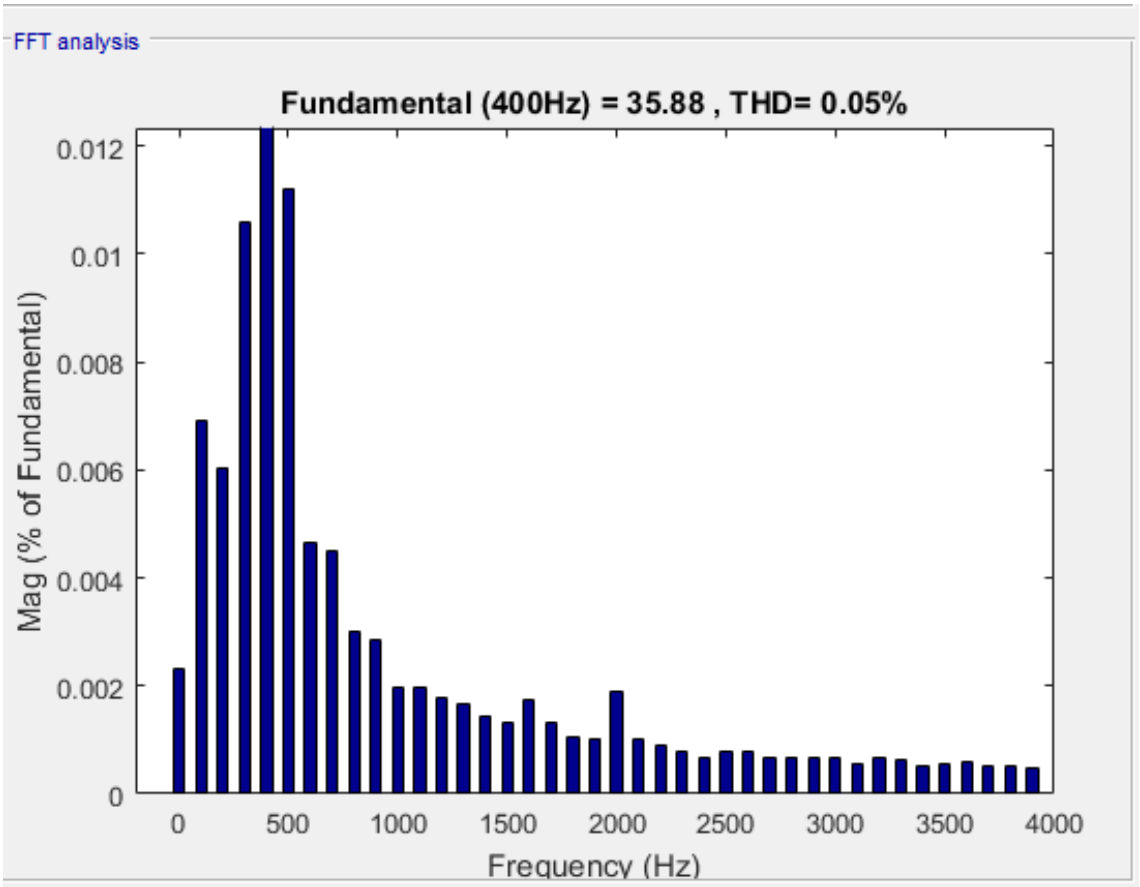
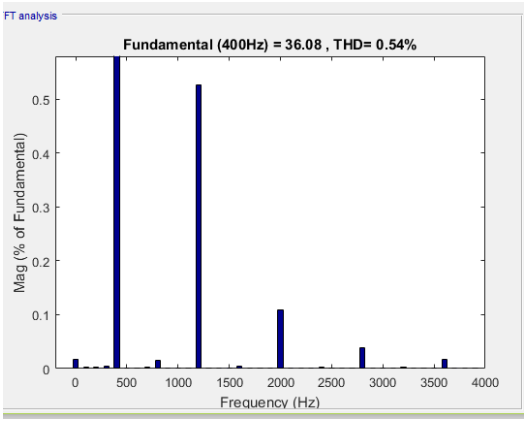


Figure 28: FFT Analysis of sinusoidal voltage without deadtime



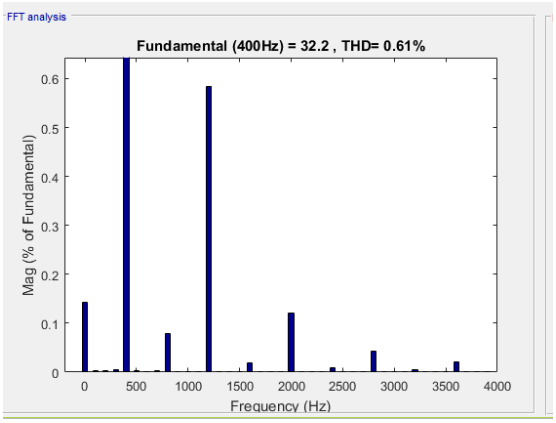


Figure 29: FFT Analysis of sinusoidal voltage with deadtime (a)Left, 36 V peak with redesigned filter (b)Right, 32 V peak with the filter used for nondeadtime case

Here, the distribution of the frequency components should not mislead the reader, the contribution of the frequencies other than the fundamental are very small and the magnitude of the fundamental remains same for filtered and nonfiltered cases.This is true for the deadtime datas as well.