ANALYSIS OF HARMONICS IN DIMMABLE LED DRIVER

A report submitted

In the partial accomplishment for the degree of Master of Technology in Illumination science, Engineering & Design

by

Subinay Sarkar

Under the guidance of

Prof. Susanta Ray

Associate Professor

Department of Electrical Engineering

School of Illumination Science Engineering and Design

Faculty of Interdisciplinary

studies law and management (FISLM)

Jadavpur University

West Bengal

Kolkata-700098

August, 2022

JADAVPUR UNIVERSITY

FACULTY OF INTERDISCIPLINARY STUDIES LAW AND MANAGEMENT

Certificate

This is to certify that the thesis titled “Analysis of Harmonics in Dimmable LED Driver” carried out by Mr. Subinay Sarkar under My supervision during session 2019-2022 in the department of Electrical Engineering, Jadavpur University is an authentic work and can be accepted in the partial fulfilment of the requirement of the degree of Master of Technology in Illumination science, Engineering & Design.

____

Prof. Susanta Ray

Associate Professor

Electrical Engineering Department

Jadavpur University

____

Prof. Subenoy Chakraborty

Dean of, Faculty of Interdisciplinary

studies law and management (FISLM)

Jadavpur University

____

Prof. Parthasarathi Satvaya

Director,

Illumination science, Engineering & Design,

Jadavpur University

JADAVPUR UNIVERSITY

FACULTY OF INTERDISCIPLINARY STUDIES LAW AND MANAGEMENT

Certificate of Approval The forgoing thesis titled “Analysis of Harmonics in Dimmable LED Driver” is hereby approved as a creditable study of an Engineering subject carried out and presented in a manner that fulfil its acceptance as a prerequisite to the degree for which it is submitted. It is understood that by this approval, the undersigned doesn’t necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein but approves the thesis only for the purpose for which it is submitted.

____

Signature by the Examiner

____

Prof. Susanta Ray

Associate Professor

Electrical Engineering Department

Jadavpur University

ACKNOWLEDGEMENT

With the submission of my thesis work I would like to extend my deep gratitude and sincere thanks to my guide Dr. Susanta Ray, Professor, Electrical Engineering department, Jadavpur University, without whose proper guidance and support this work could not been possible. His continuous encouragement, support, suggestions and technical expertise helped me a lot to overcome the difficulties during the course of work.

We are grateful to the all-other faculty members for their cooperating, good will and support throughout the project.

I am thankful to all my classmates and the department research scholars for their cooperation and unfailing help during the Thesis work.

Again, the contribution made by out laboratory assistant and Illumination Engineering staff is unmatchable. They helped me time to time opening the Illumination lab for me to providing necessary things required during the course of work.

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his M. Tech in Illumination Technology and Design studies during academic session 2019-2022

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and result that are not original to this work.

NAME: - SUBINAY SARKAR

ROLL: - M6ILT22004

REGISTRATION NO: - 150171 of 2019-2020

DATE SIGNATURE

Abstract

Now a days compact fluorescent lamp (CFL) and light emitting diode (LED) are becoming more popular when in early days incandescent lamp are used. CFL and LED are more efficient than incandescent lamp. In 2022 CFL and LED especially LED'S have spread everywhere.in very few places incandescent lamps are used. But in case of load analysis, two types of loads, those are linear and non-linear. As CFL and LED'S are highly non-linear load, it produced highly distorted current and it will generate harmonics in the system also poor power quality.

By running the LED and CFL lamp load it is necessary to improve the harmonics by design a filter. (Single tuned passive filter) That is also known as notch filter. That filter will reduce the harmonics as standard (IEEE 519 – 2014) that is constant voltage harmonics range 2.2% - 5%. And current harmonic range is 30%.

This single tune filter can reduce 3rd, 5th & 7th harmonics and also decrease THDi. A large number of LED are using domestic, industrial lighting could causes power quality problem. Ans when we are talking abought energy savings dimming is one of key process. When dimming is done in a particular LED driver, that harmonics filter is no longer kept the THD level as standard.

So, in this paper I tried to solve this problem by using interlevel integrated buck flyback converter to fixed the THD 5%, at minimum dimming up to 10%.

Abbreviation & Acronyms

AC = Alternating Current

DC = Direct Current

THD = Total Harmonics Distortion

LED = Light Emitting Diode

IEEE = Institute of Electrical & Electronics Engineers

CFL = compact Fluorescent Lamp

GaAsP = Gallium arsenide Phosphide

InGaN = Indium Gallium Nitride

PWM = Pulse Width modulation

PF = Power Factor

ESR = Equivalent series resistance

V_F = Knee Voltage

MOSFET = Metal Oxide Silicon Field Effect Transistors

IC = Integrated Circuit

PIV = Peak Invers Voltage

KVL = Kirchhoff's Voltage Law

CCM = Continuous Conduction Mode

DCM = Discontinuous Conduction Mode

FF = Form Factor

VRF = Voltage Ripple Factor

g = Distortion Factor

DPF = Displacement Power Factor

IIBFC = Interleaved Integrated Buck Flyback Converter

List of Symbols

α = conduction angle.

β = It depending upon at what time I_L = 0.

ω = Angular frequency.

Δ = small change.

List of Figures

Table of Contents

CHAPTER 1

Introduction

1.1 Motivation of the Work

LED are so popular now a days because of its reliability, low power consumption, environment friendly, operate in cold condition, higher efficiency and longer life. But to design a LED driver circuit many non-linier components are used. Though LED drives in DC Voltage and our domestics supply is in AC, so 1st we have to rectify the AC in to DC. After that for constant current or constant Voltage drive, we have to filter the pulsating DC into smooth DC, then reduced the DC voltage using DC-DC converter.

But the problem is by using those components our input source current and voltage is no longer sinusoidal. (non-sinusoidal but periodic) So Harmonics is present the system. To solve this issue just place a harmonics filter which is also known as Knoch filter, (Series inductor with supply & parallel Capacitor across supply) by calculating the value at a particular power we can easily design the input inductor, Resistance and capacitor.

But now a days energy savings is one of the keys concerned in the planet. In case of lighting load, the energy savings means dimming. But whenever we are trying to dim out LEDs the power is change, due to the change in the power, input filter is no longer works properly to maintain the Current harmonics.

My objective is to design something that we can change the intensity of light according to our need with minimum input current THD.

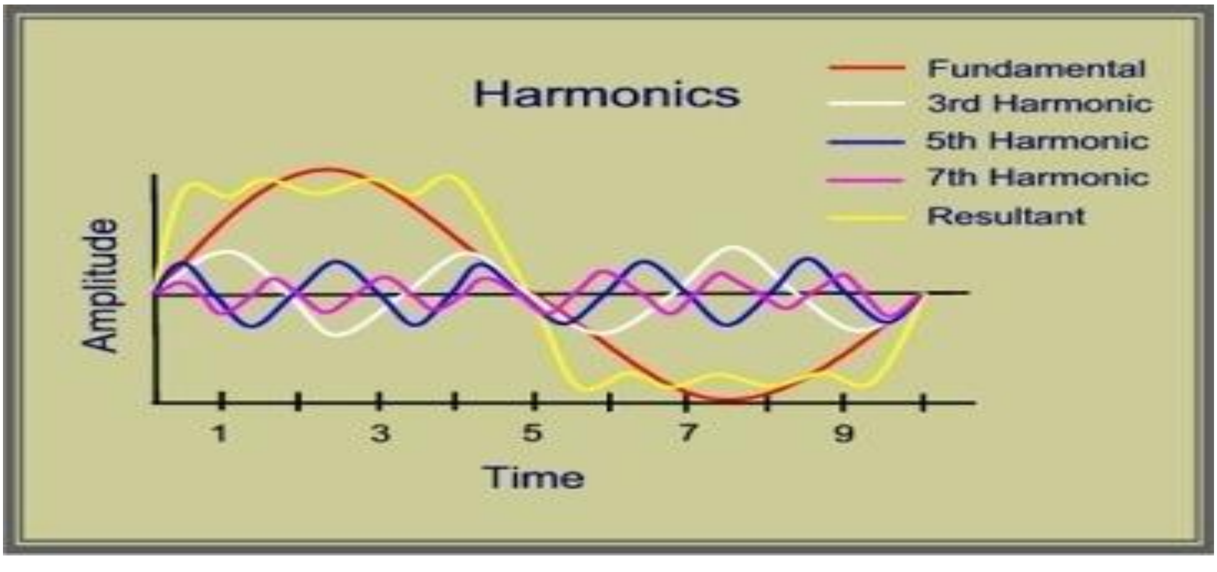


figure 1.1 harmonics [1]

Electrical loads which draw sinusoidal current from sinusoidal voltage are called linear load. Those are consisting of passive element such as resistance, inductance & capacitance.

Where non-sinusoidal load draws non-sinusoidal waveform from an input sinusoidal voltage source. In order to show the non-sinusoidal effect. Harmonics definition was introduced by IEEE (Institute of Electrical & Electronics Engineers) in the year of 1981.

Acceding to IEEE harmonics is known as "A sinusoidal component of a periodic signal which consist of a frequency that is an integer multiple of the fundamental frequency. In other words, we can also say that the harmonics is the sum of the sinusoidal waveform in different frequency by Fourier series.

The non-linier loads will cause distorted voltage and current waveform. Total harmonic distortion (THD) is the addition of individual harmonics components of the voltage & current with the Respect to the fundamental voltage & current.

1.2 Literature Review

Not only at present time of engineering development, researches and experiments were conducted even before the beginning of science development. By finding the sources of thesis works it is very important to study as many papers as can. After knowing all the advantages, disadvantages, scope of improvement etc we can start our project. Hare, I have studied many journal & conferences papers those are given as follows.

An Analysis of Harmonics from Dimmable LED Lamps [2] that is published by IEEE 2012 International power engineering and optimization conference, hare the nobility of this paper is all LED lamps generate very high levels of harmonics during dimming operation which may affect the power quality of AC mains. Analysis this thing by using Tapping the load current behaviour under different conditions**.** Frequency domain analysis is performed to investigate the generated Harmonics.

In this paper Analysis of Harmonic Emission from Dimmable Compact Fluorescent Lamps published [3] by 2011 International Conference on Electrical Engineering and Informatics, it shows that the dimmable CFLs produce more harmonics compared to incandescent lamps and non-dimmable CFLs by using A phase-control circuit with triac to vary the conducting period of each half cycle of lamp currents.

Study of the Lamp's influence on the power Quality based on voltage and current analysis [4] THE 9th INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING May 7-9, 2015 Bucharest, Romania was published. The main moto of the paper is experimental study highlights that compact fluorescent lamp produce harmonics as a result of their operation. These harmonics lead to notable increased levels of the current total harmonic distortions value and they are using 6 lamps 2 incandescent lamps & 4 CFL'S, a power quality analyser (C.A.8230) and a computer for data storing (Harmonics analyser) by using the acquired data, the waveforms of voltages and currents have been observed.

Analysis of the current harmonics injected into the power grid by dimmable LED lamps [5] the paper contains of the harmonic content introduced by dimmable LED lamps of different brands is experimentally investigated and analysed by check the dimmable LED harmonics they are using adjusting flux control method for dimming method this paper was published on 2016 AEIT International Annual Conference (AEIT).

HARMONIC MODEL FOR THE FLUORESCENT LAMP [6] 1st introduced 1998 8u International Conference on Harmonics and Quaiio of Power, Method for modelling harmonic currents injected by fluorescent lamps. A simulation method with the ability to analyse non-linear networks is needed for this model is the mobility of this paper and the using technique was developed using tube and ballast non linearities and their dependence on source voltage variations. A harmonic analysis algorithm is used.

The Study of Harmonics from Dimmable LED Lamps, using CompactRIO [7] 13th International Conference on DEVELOPMENT AND APPLICATION SYSTEMS, 2016, A software application in LabVIEW programming environment for both cRIO processors that allows the acquisition of current and voltage signals and harmonic analysis in real time using reconfigurable CompactRIO system to build an embedded control and acquisition system that can analyses the harmonics from dimmable LED lamps.

The Effect of Dimming and non-Dimming LED Lights on the Quality of the Electrical Grid [8] by 2019 20th International Scientific Conference on Electric Power Engineering tropology was Gradual dimming by changing the voltage that and also controlled by an external PWM module by using this they get measured data from several variants of the LED lights dedicated to different applications for household or for industry.

Flicker Distortion Power Factor Analysis in Lighting LEDs [9] was another paper which was published on 2017 IEEE 23rd International Symposium for Design and Technology in Electronic Packaging. Mobility is Distorted sinusoidal regime for LEDs and different lamps, also the effect of dimming process on light flicker, situation in which the distortion is produced by simultaneously distortion of LED voltage and current using A proper FFT algorithm, intended to offer useful information regarding the presence of harmonics.

Some specifics of using LED drivers in dimming mode [10] 2018 Seventh Balkan Conference on Lighting (Balkan Light) mobility is Deep dimming may cause the LED drivers to generate harmonics. The harmonic content in the supply current may result in other equipment interference using A deep dimming technique is used to analysis the PF and THD.

The Analysis of TRIAC Dimming LED Driver by Variable Switched Capacitor for Long Life and High Power-Efficient Applications [11] published on 9th International Conference on Power Electronics and ECCE Asia 2015. Using tetralogy for the paper was the analysis of the proposed TRIAC dimming LED driver, which adopts a variable switched capacitor.

A simple dimmer using a MOSFET for AC driven lamp [12] in this paper they are using control method of the proposed dimmer is pulse width control (PWM) method. Compared with the conventional phase-controlled dimmer its main advantages are MOSFET is free from latching & holding current, the proposed dimmer using a MOSFET has wide dimming range and the proposed control method does not amplify the light flicker due to independence of the input voltage. It was publishing on 2011, 37th Annual Conference of the IEEE Industrial Electronics Society

An Improved Power Quality Evaluation for LED Lamp Based on G1-Entropy Method [13], the main objective is to investigation harmonic emission from several LED drivers and improved the power quality of distribution network.it was published on 2021. In this paper the main methods are G1 weight assignment method and entropy methods to Harmonics evaluation approach of LED lamps. Innovation of the paper is to get 4 primary indicators are assigned using G1 methods and objective weight for 28 secondary indicators using the entropy weight method. The main advantages of the journal are to improve the structure of LED lamp drives, decrease grid harmonics and reduce harmonic fires.

Harmonic Characteristics Data-Driven THD Prediction Method for LEDs Using MEA-GRNN and Improved-AdaBoost Algorithm were this paper predicts of Total Harmonic Distortion (THD) for LED's by using Artificial Intelligence [14]. Experiment was done by using LED lamps with different driving current were tested, then the data of each harmonic were sampled and analysed. After that THD protection method based on an improved AdaBoost algorithm is proposed. In this journal paper, the main thing is to get the integration algorithm and optimized algorithm in machine learning. Also proposed an adaptive factor method to improve the threshold selection in AdaBoost algorithm.

Characterization of Commercial LED Lamps for Power Quality Studies in this paper the focus is characterization of commercial dimmable LED lamps and their impact on power quality parameters by using ac power supply [15] (Keysight AC6801A) is used to provide different ac voltage levels to the LED. Output can be controlled by an external reference signal from a function generator; thus, it can simulate different voltage quality issues. The execution of light intensity, harmonic current contents, and voltage measurement of commercial LED lamps. Data processed using the MATLAB software tool have been used to analyse the results. The main advantage is improvement of power quality by generating less harmonics.

Analysis and Experimentation on a New High Power Factor Off-Line LED Driver Based on Interleaved Integrated Buck Flyback Converter this is most important paper [16]. The main objective is to achieve high power factor and less total harmonic distortion with dimming LED driver. The converter is tested to work under the quasi-resonant flyback technique. By using an interleaved capacitor, the line current conduction angle is increased for that power factor is also increased and THD value decreases. The main advantage of the paper is THD is very low 2.5 %. And power factor is nearly unity 0.997. Also, it meets the IES-61000-3-2 standard at any dimming ratio.

1.3 Organization of the Thesis

The content of this Thesis is organized into 6 chapters.

Chaptor 1 Provides an introduction to this thesis, motivation work, literature review, and aim of my work.

Chaptor 2 deals with the basic application of LEDs, light measurement, the equivalent circuit of LEDs finally the V-I characteristics of LEDs.

Chaptor 3 starts with the LEDs driver like voltage source, current source, testing of LEDs and the common mistake we are made.

Chaptor 4 discusses the basic principle of diode LC circuit with zero and initial condition, discharging of LC circuit, type of load, rectifier, DC-DC converter. In DC-DC converter Buck and flyback converter are mention hare.

Chaptor 5 describes the concept of harmonics, source of harmonics, mathematical analysis, problem, effect and Fourier series to analysis of harmonics.

Chaptor 6 starts with why I am chousing IIBFC, the advantages of the tropology. Finally, the result and discussion. Flow chart and the Algorithm of soft switching and summary of the hole paper.

CHAPTER 2

Characteristics of LEDs

Maximum semiconductors are made by doping silicon via a material that creates free positive charge (P-type) or negative charge (N-type). The fixed atoms have positive and negative charges. These two materials, the free charges combine together and this creates a small region devoid of free charge, at the junction. ‘Intrinsic region’ which opposes further free charge combination, now has the positive and negative charge of the fixed atoms. For that, there is an energy barrier formed, we have a diode junction.

For a P-N junction to conduct, we must make P-type material more positive than N-type. These forces have more positive charge into P-type material and sufficient amount of negative charge into the N-type material. Conduction takes place when there is about 0.7 V potential difference across the junction (P-N). To conduct, this potential difference gives electrons adequate energy.

An LED is also made from P-N junction, but silicon is out of place because the energy barrier is too low. First LED was made by GaAs (gallium arsenide) and turn out infrared light at almost 905 nm. The energy difference between the conduction band and the valence band is the reason for producing the colour. Electrons are given sufficient energy to jump into the conduction band and current flows. When an electron loses its energy and goes back into the low energy state which is valence band, a photon (nothing but light) is generally emitted, when a voltage is supplied across the LED. See Figure 2.1.

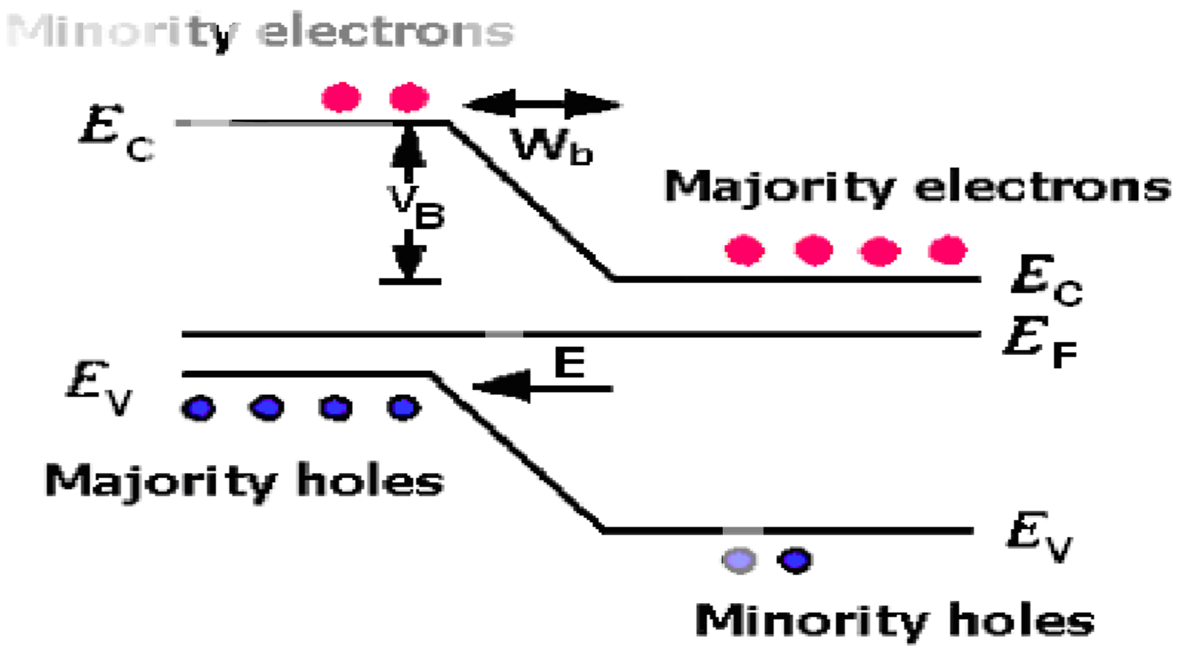


Figure 2.1: Band Diagram of P-N Junction Semiconductors [17]

2.1 Applications for LEDs

New a day's semiconductor materials were developed and gallium arsenide phosphide (GaAsP) was used to make LEDs. So, the light wavelength is shorter because the energy gap in GaAsP material is higher than GaAs. These LEDs are produced a red colour light and were first just used as indicators. The most typical application was to show that equipment was powered, or in a radio that some feature such as 'stereo' was active. In fact, it was mainly consumer products like radios, tape recorders and music systems that used large numbers of red LEDs. When green and yellow LEDs available, the number of applications of this increased. To give additional information, or could indicate more urgent alarms, the colour could change now. For example, Green = OK, Yellow = requires attention, Red = faulty [2]. Most important was the capability to have LED lamps in traffic lights. One characteristic of the light from an LED is that the colour is fairly pure; it occupies a narrow spectrum about 20 nm wide. By contrast, a semiconductor laser used for telecommunications to occupy a spectrum about 2 nm wide. The very narrow spectrum of a laser is important because, the narrow spectral width allows a wide system bandwidth, when used with optical fibre systems. In general-purpose LED applications, the spectral width has very less effect.

A special important characteristic of LED light is that current is converted into light (photons). This means that increase of the current, the light amplitude will also increase. Via dimming lights, lowering the current is possible. It should be noted that the specified wavelength emitted by an LED is at a certain current; the wavelength will change a little if the current is higher or lower than the specified current. Dimming by PWM is a viable alternative used by several places. To turn the LED on and off, PWM dimming uses a signal, typical frequency 100 Hz–1000 Hz. The pulse width is basically reduced to dim the light, or increased to brighten the light. The 'holy grail' was blue LEDs, which are formed from indium gallium nitride (InGaN). When adding coloured light, red, green and blue make light that appears white to the human eye. The eye has receptors (cones) that detect red, green and blue, that is the reason for only 'appearing' white.

There are big gaps in the colour spectrum, but the eye does not notice. White LEDs are sometimes formed using blue LEDs with a yellow phosphor coting over the emitting surface. The yellow phosphor creates a wide spectrum and, when it combined with the blue, appears white. An interesting use for blue LEDs is in dentistry. The 465 nm wavelength has been found to be close to adjective for this application, although the intensity of this light must be very high to go into the resin. Few interesting applications rely on the purity of the LED colour. The illumination of fresh food is very suitable with LEDs, because LEDs doesn't emit ultraviolet light. Photographic dark rooms can use colours where film is insensitive – traditionally dark rooms have been illuminated by red-coloured incandescent lamps. Even traffic lights must emit a limited range of colours, which are specified in national standards. It should be noted that the colour of an LED would change as the LED's temperature changes. The temperature can differ due to ambient conditions, such as being housed adjacent to hot machinery, or due to internal heating of the LED due to the high amount of current flowing through it. If we want to control the ambient temperature the only way is to add a cooling fan, or by placing the LED away from the source of heat. Mounting the LED on a good heatsink can control internal heating.

The early LEDs were all rated at 20 mA and the forward voltage drop was about 2 V for red, higher for other colours; later low current LEDs were created that operated from a 2-mA source.

Over time the current rating has increased, so that 30 mA, 60 mA and even 100 mA are fairly common. Lumileds was developed by HP and Philips in 1999 and produced the 1st 350 mA LED. Now a days there are a number of power LED manufacturers, rating is, 350 mA, 700 mA, 1 A and more. Power LEDs are being used in increasing numbers; in channel lighting (signage), traffic lights, street lights, automotive, mood lighting (colour changing 'wall wash'), and also in theatres for lighting steps and emergency exits. Channel lighting is so called because the LEDs are use in a channel; see Figure 2.2. for illuminated company signs, this channel is used to form letters. In the past, channel lighting used in cold-cathode or fluorescent tubes, but these had several problems. Safety & Health legislation, like the RoHS Directive, banned some materials which is mercury that is used in the construction of cold-cathode tubes. So, to cope with the size and environmental conditions, the most viable technology is LED lighting

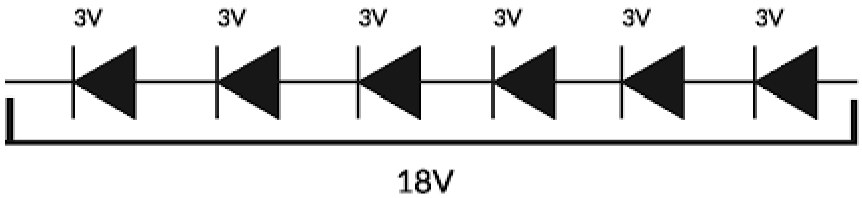


Figure 2.2: Channel Lighting

Traffic lights have used low power LEDs for few years, but now a days some manufacturers are using a few high-power LEDs. One problem with traffic lights is controlling the wavelength of the yellow (amber) light. Yellow LEDs suffer from a greater wavelength shift than other colours, and this can cause them to operate outside their permitted spectral range. Another problem is making them fail-safe – authorities permit some degree of failure, but if more than 20% of the LEDs fail, the entire lamp must be shut down and a fault reported to maintenance teams. High ambient temperatures inside the lamp can make LED driver failures. So we need to dissipated the heat. This is particularly true if the LED driver circuit contains electrolytic capacitors, which vent when hot and eventually lose their capacitance. Some novel LED drivers have been developed, which do not need electrolytic capacitors and can run for several years at high temperatures. Failing LED, can give LED lights a bad name. Street lights have been made to using medium and high-power consumption LEDs.

Although this is simple application, in high ambient temperatures and high-power LEDs can created to driver problems. In some application, white and yellow LEDs are used together to formed a 'warm-white' light. The problem with white LEDs, made using a blue LED with a yellow coting of phosphor, this high blue content produces a 'cold-white' light. There are many applications for automotive lighting like; internal lights, stoplights, headlights, daylight running lights (DRL), rear and front fog lights, cornering light, reversing lights, etc. The biggest problem with automotive applications is that, EMI specifications demand is very low levels of emissions, which are very difficult to meet with a switching circuit. If the efficiency is not a critically requirement, then linear drivers are sometimes used to dissipate heat generated by Connecting a linear driver to the metal surface of the vehicle. Automotive stoplights using LEDs have a very high safety advantage over the filament lamps. Current flowing to light output in an LED is measured in nanoseconds (ns). A filament lamp has the response time is about 300 ms. Assume, at 100 km/h, a vehicle travels 1.6 km per minute In 300 ms, a car will cover over 8 meters. But stopping 300 ms earlier, having seen the previous car's brake lights earlier, could avoid death or injury. Also, LED brake lights are hardly failed.

Mood lighting is an effect caused by changing the colour of a surface and uses human psychology to control people's feelings. It is used in medical facilities to calm patients, and on aircraft to relax (or wake up!) passengers. Generally, mood lighting systems use red, green and blue (RGB) LEDs in a 'wall wash' projector to create any colour in the spectrum. Other applications for these RGB systems used in disco lights! In case of backlighting displays, such as flat screen televisions, RGB LED arrays is also used to create a 'white' light. In this case the colour changes little – ideally not at all. To carefully control the amount of red, green and blue, to create the exact mix for accurate television reproduction, a control system is required, however, cold cathode tubes are sometimes used to backlight computer screens, but here the exact colour is not important.

2.2 Light Measure

Lumens is the unit of total luminous flux. It is the photometric equivalent of 1 watt, weighted to match the normal human eye response. At 555 nm, 1W= 683 lumen in the green-yellow part in the spectrum where the eye is most efficient. Another term candela the unit of intensity, is also been used. This is the light produced by a lamp, to produce 1 lumen per steradian radiating in all directions equally. We know, 1 cd= 1 lm/sr [18].

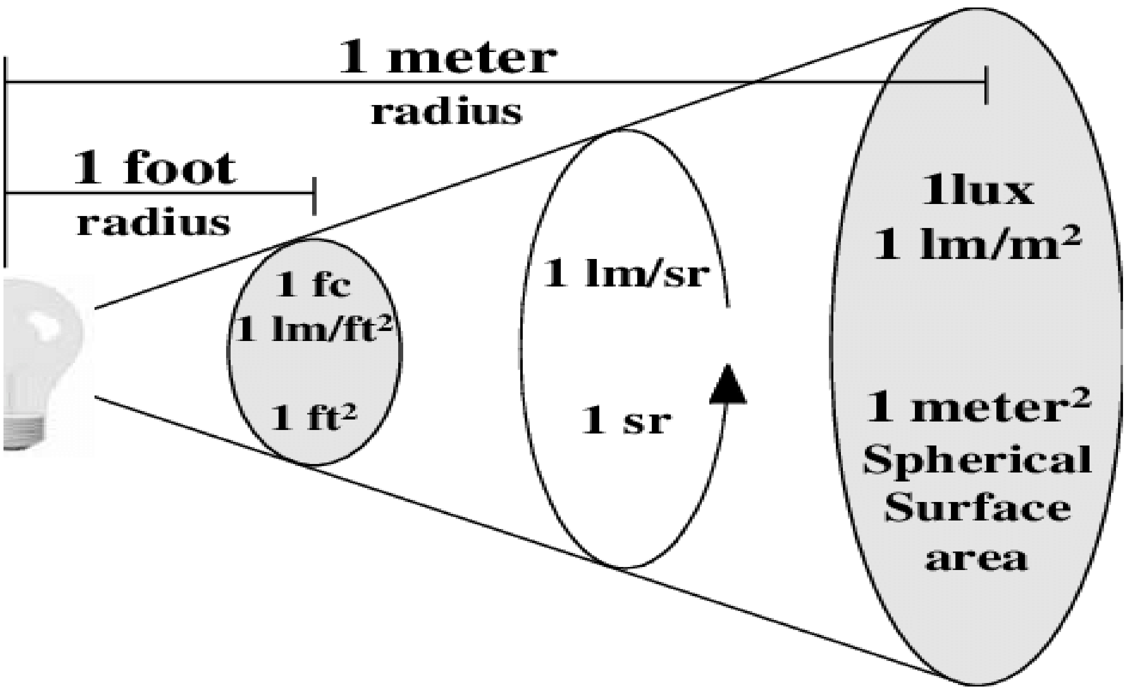


Figure 2.3: Light Measurement [19]

A steradian, unit of solid-angle has a projected area of 1 square meter at a distance of 1 meter from the source. The light from a 1 cd source, at meter distance, is 1 lux, or 1 lm/m2 this is also known as illuminance, see Figure 2.3.

Light emission efficiency (luminous efficacy) from all light source is described in terms of lumens per watt. To get the highest luminous efficacy, there is some competition between LED manufacturers, but when comparing results, it is important to make a note of the electrical power levels used. It is very easy to make an efficient 20 mA LED, rather than an efficient 700 mA LED.

2.3 LED Equivalent Circuit

We can describe an LED as a constant voltage load. The voltage drop of LED depends on the internal energy barrier for the photons of light to be emitted. This energy barrier depends on the colour; so, the voltage drop also depends on the colour. Now the question is, every red or same colour LED have the same voltage drop? The answer is No, because production variations will mean that the wavelength will not be the same for all, and thus the voltage drop will have differences although it is same colour. The peak wavelength has typically almost a 10% variation.

If there are temperature differences in between two LEDs, this will provide a colour change and also differences in voltage drop. As the temperature rises, it is very easy from the electrons to cross the energy barrier. Thus, the voltage drop reduces by almost 2 mV per degree as the temperature rises.

We know that the semiconductor material is not a perfect conductor, some resistance is in series with this constant voltage load are there, see Figure 2.4. This means that the voltage drop will increase with increasing current.

The ESR (equivalent series resistance) of a low power 20 mA LED is about 20 ohms, but a 1W 350 mA LED has an ESR of about 1 to 2 ohms depending on the semiconductor material is used. The ESR is inversely proportional to the current rating of the LED. The ESR will also have production variations. The ESR can be calculated by, the increase in forward voltage drops, with the respect to the increase in current. For example, if the forward voltage drops increases by from 3.5 V to 3.6 V when the forward current goes from 15 mA to 25 mA, the ESR will be 100 mV/10 mA = 10 ohms.

The Zener diode is shown as a perfect device In Figure 2.4. In reality, in Zener diodes it also has ESR, which can be more than the ESR of an LED. For initial testing of an LED driver, a 5 W, 3.9 V Zener diode can be used in place of the (white) LED. If the driver is not working as per requirement the Zener diode may be destroyed, but this is very less in terms of cost than destroying a power LED. Since the Zener diode does not have any emitting surface, the test engineer will not be dazzled.

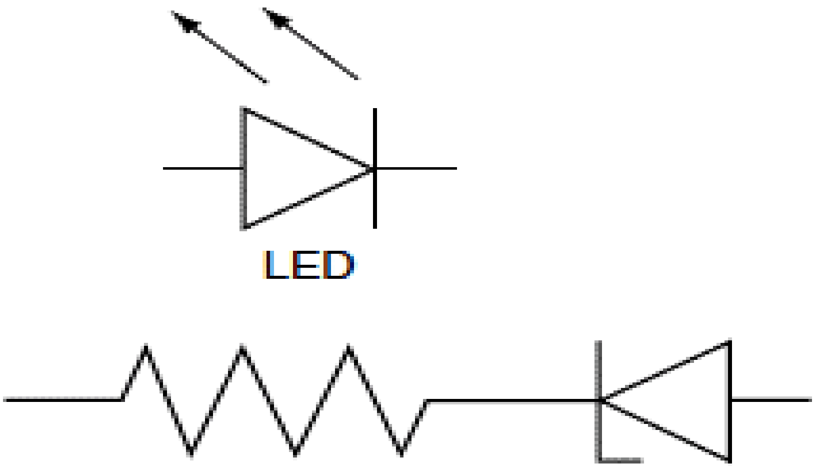
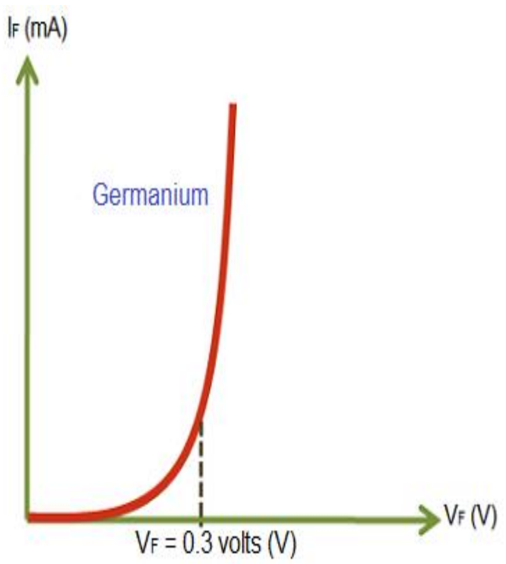


Figure 2.4: Equivalent Circuit for an LED.

2.4 V-I Characteristics of LED

The V-I Characteristics of LED are almost same as Silicon & Germanium Diode. For a silicon diode the threshold voltage is 0.7 V and for Germanium Diode threshold voltage is almost 0.3.



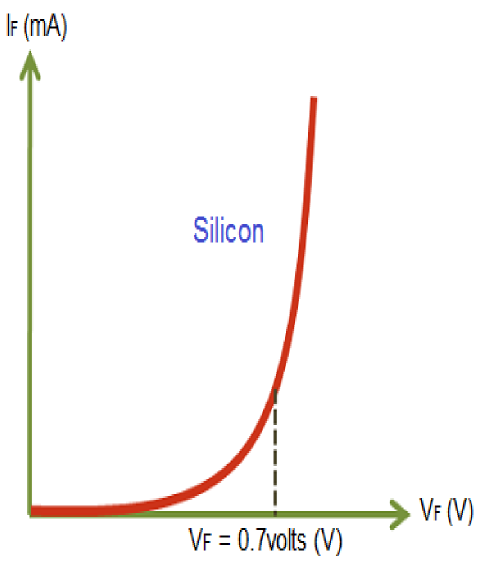


Figure 2.5: V-I Characteristics of Germanium Diode [20]   Figure 2.6: V-I Characteristics of Silicon Diode [21]

The graph in, Figure 2.7 shows, how the forward voltage drop depends on the light colour and on the LED current. At the point where conduction begins, the forward voltage drop, Vf, is about 2 V for a red LED and about 3.5 V for a blue LED. Because of different dopant materials and wavelengths, the exact voltage drop depends on the manufacturer. The voltage drop at a particular current will also depend on initial Vf, but also on the ESR.

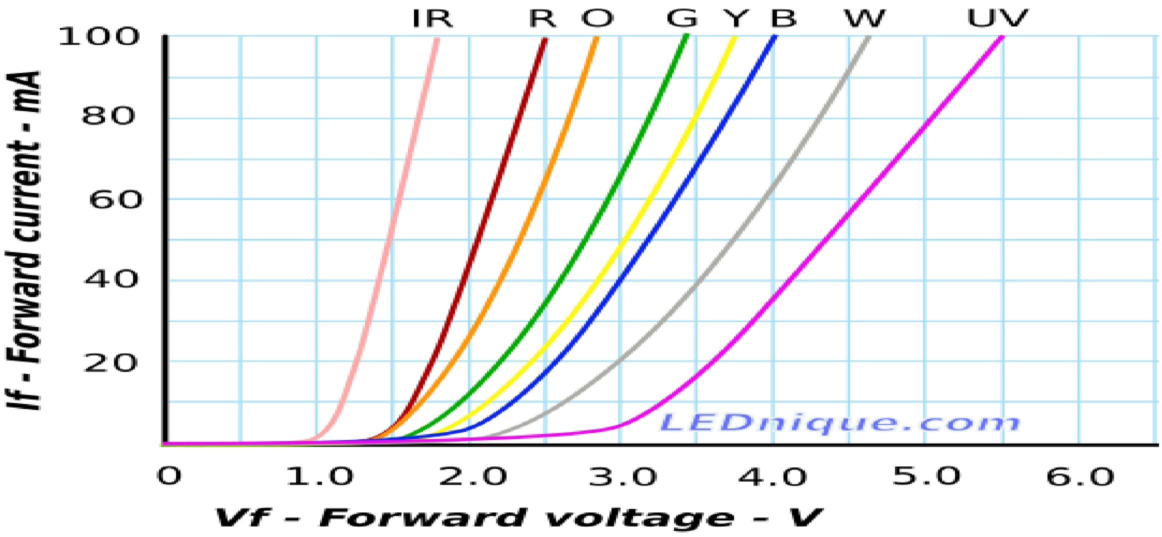


Figure 2.7: Forward Voltage Drop Versus Colour and Current. [22]

CHAPTER 3

Driving LEDs

3.1 Voltage Source

We have already seen in Chapter 2 that an LED behaves almost like a constant voltage load, with a low equivalent series resistance (ESR). This behaviour is nearly same like a Zener diode – in fact Zener diodes make a good test dummy load, rather than using expensive high-power LEDs!

Driving constant voltage load from a constant voltage supply, is not so easy, because it is only the difference between the load voltage and supply voltage, that is dropped across the ESR. But it has very low value, so the voltage drop will also be less. A slight variation in the load voltage or the supply voltage, will cause a very high change in current; see curve A in Figure 3.1.

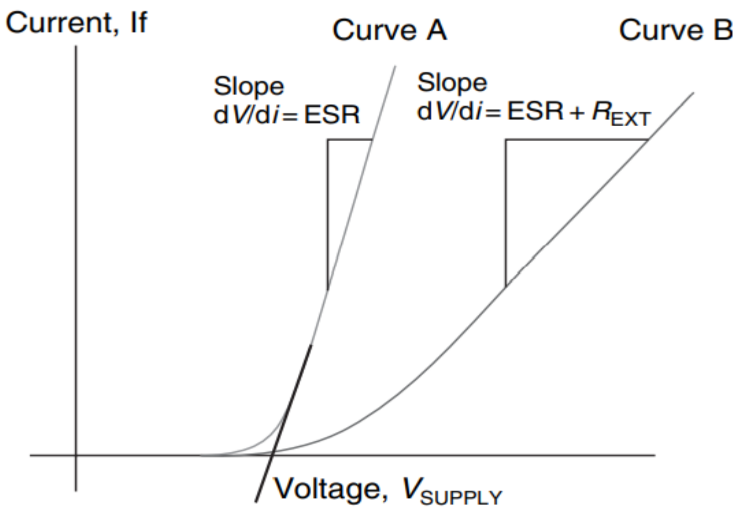


Figure 3.1: LED Current Versus with Voltage. [23]

If the variation in supply voltage and forward knee voltage (V_f) is known to us, the variation in current can be calculated. Remember that there are variations in LED voltage drop due to manufacturing tolerances (chapter 2) and operating temperature. Most supply voltages from regulated supply have a 5% tolerance, but from unregulated supplies like automotive power source, the tolerance is far more.

$$\boldsymbol{I_{min} = \frac{V_{source\_Min} - V_{F\_Max}}{ESR}} \quad \text{-----------(1)}$$

$$\boldsymbol{I_{max} = \frac{V_{source\_Max} - V_{F\_Min}}{ESR}} \quad \text{-----------(2)}$$

These equations (1) & (2) assume that ESR is constant. In practice, the voltage drops across ESR and V_f are combined, since manufacturers lifting the voltage drop at a certain forward current. The actual V_f can be composed from graphs, or measured.

If there is a large difference between the load and source voltage, also high ESR, there is very small difference between the minimum & maximum LED current. This may be adequate for low current LEDs, such as 50 mA. However, in high power LED circuits, a large voltage drop across series resistor will be less efficient and may cause I^2*R problems. Also, the ESR of LEDs is very less as the power rating increases. A standard 25 mA LED may have an ESR of 20 ohms, but a 300 mA LED will have an ESR of 1–2 ohms. Thus a 1 V difference in supply voltage, could increase the LED current by almost 1 A in a power LED. Even in low current LEDs circuit, the proportional change in current can be high.

3.1.1 Passive Current Control

Although the LED voltage drop moves from the right of the graph Figure 3.1, the slope of the graph is present due to the ESR. Low output current can have a cause of high value resistance added in series, in order to reduce the slope, current versus voltage graph; see curve B in Figure 3.1.

We can easily calculate the variation in current by adding a series resistor, provided that the variation in load voltage & supply voltage is known. In the equations below (3) & (4), the load voltage adds the voltage drop across ESR, at the rated current, so only the external resistor value we have to find out.

$$I_{min} = \frac{V_{source\_min} - V_{load\_min}}{R_{ext}} \quad \text{-----------(3)}$$

$$I_{max} = \frac{V_{source\_max} - V_{load\_max}}{R_{ext}} \quad \text{-----------(4)}$$

When multiple LEDs are used to impart lighting for an application, they are commonly connected in an array, include of parallel strings of series connected LEDs. Since the LED strings are in parallel the voltage source for all the strings is same. However, due to difference in forward voltage for each LED total voltage drop of each string varies from the other strings in the same array. The forward voltage depends on the ambient temperature. To make sure uniform light output for all LEDs current should be equally designed to flow through each string of LEDs.

The common way is to connect a current limiting resistor in series with each string then power all the strings using a single voltage source. A considerable voltage needs to be dropped across the resistor to make sure that the current will stay within the range in the presence of device-to-device voltage variations as well as temperature. This method is very inexpensive, but it suffers from power inefficiency also heat dissipation. It also needs a stable voltage source. An efficient way of powering the LED array is to regulate the total current through all the strings present in the driver and devise a means to divide that total current equally among the LED strings. This is known as active current control and is the subject of the next subsection 3.1.2.

3.1.2 Active Current Control

Adding a series resistor is not a good current control method, mainly when the supply voltage has a wide tolerance, we will now look at active current control. In active current control transistors and feedback are used to regulate the current. Here only consider limiting LED current when the energy is supplied from a voltage source, driving LEDs using energy from current sources will be discussed in 3.2 section.

A current limiter has some certain functional elements like, a regulating device that is MOSFET or bipolar transistor, a current sensor with a low value resistor, and some feedback path with gain or without gain, from the current sensor to the regulating device. Figure 3.2 shows these all functions.

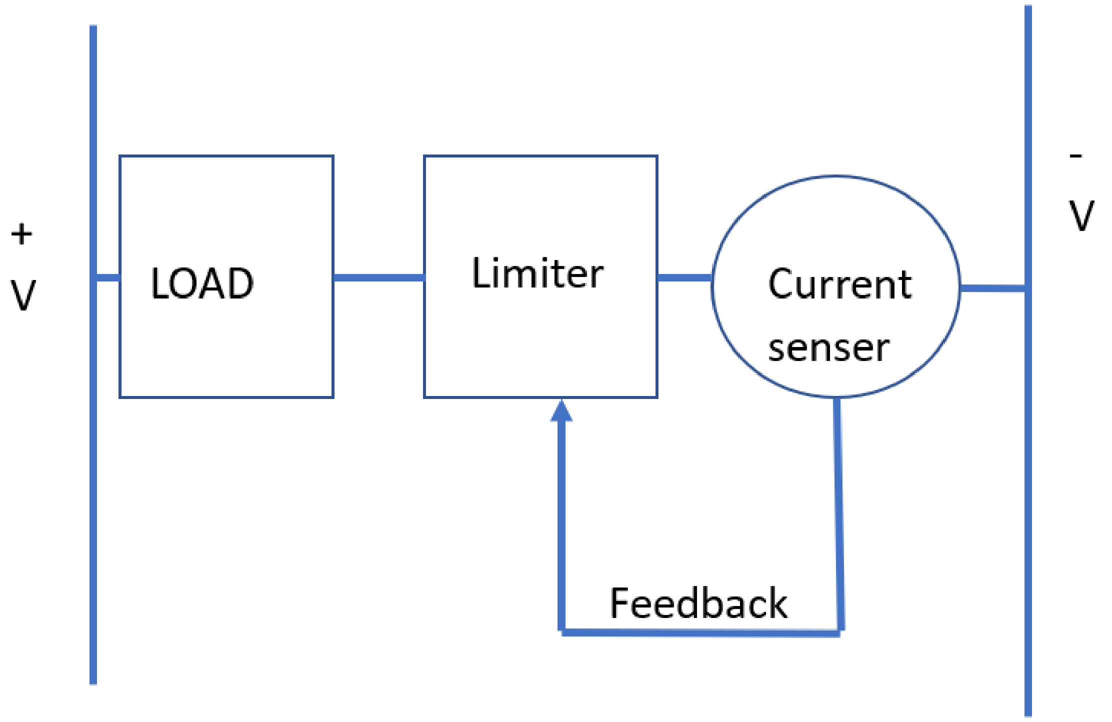


Figure 3.2: Current Limiter Functions

One of the simplest current limiters is a depletion mode MOSFET; it has three terminals called source, gate and drain Conduction of the drain to source channel is controlled from the gate-source voltage like any other MOSFET. However, an enhancement MOSFET, a depletion mode MOSFET is ‘normally-on’ so current flows when the gate to source voltage is zero. When the gate voltage becomes negative with respect to the source voltage, the device turns off.

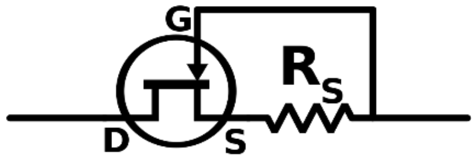


Figure 3.3: Depletion MOSFET Current Limiter

A current limiting circuit plus a depletion mode MOSFET uses a resistor in series with the source to sense the circuit current Figure 3.4. The gate is connected to the negative supply side (0 V). As current flows through the resistor, the voltage drop across it will increase. The voltage at this MOSFET source will increased in potential compared to the 0 V rail and the MOSFET gate. In other words, we can say, if we compared to the MOSFET source, the gate becomes more negative. At a certain point where the voltage drop approaches the MOSFET pinch-off voltage, the MOSFET will tend to shut down and thus regulate the current.

3.1.3 Short Circuit Protection

The current limiting circuits described in the previous section and it will provide automatic short circuit protection. If the LED goes short circuit, a large voltage will be placed across the current limiter. Power dissipation is one of the main issues that needs to be addressed. If the power dissipation cannot be tolerated, when the load goes short circuit, we need a voltage monitoring circuit. When a higher-than-expected voltage is placed across the current limiter on that time current must be reduced to protect the circuit. In the LM317 circuit previously described, the regulator itself has the thermal shutdown option.

3.1.4 Failures

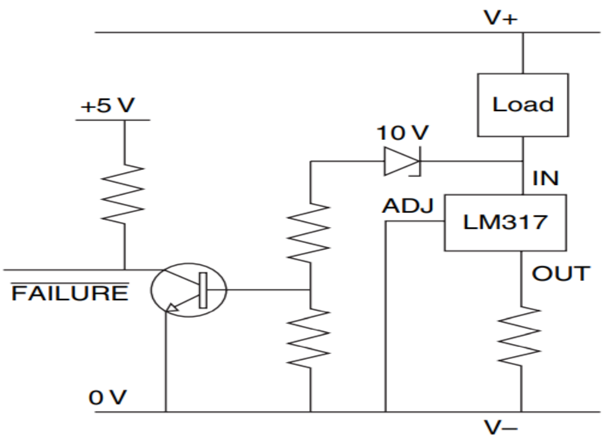


Figure 3.4: Shorted Load Indication [24]

If we have short circuit condition in the LEDs, the voltage across the current limiter will increase that thing will discuss earlier. We can use this change to detect the failure. In the circuit shown in Figure 3.4, a 10 V Zener is used in series with the base of an N-P-N transistor. When the voltage at the 'IN' terminal of the LM317 reaches about more than 10 V, the Zener conducts and turns on the switch which is transistor. This thing pulls the 'FAILURE' line to 0 V and indicates a short circuit across the lamps.

3.2 Current Source

Since an LED reacted like a constant voltage load so it can directly connect to a current source. The voltage across the LED, or the string of LEDs, will be classified by the characteristics of the LEDs used. A pure current source will not limit the voltage for that some care must be taken to provide some limits like this will be covered in more detail in the next subsection. If the current source generated much more current than the LED needs, current-sharing circuits will be needed. Current mirror is the simplest of these, which divide the current equally in between strings, that is based on the current flowing through the primary string.

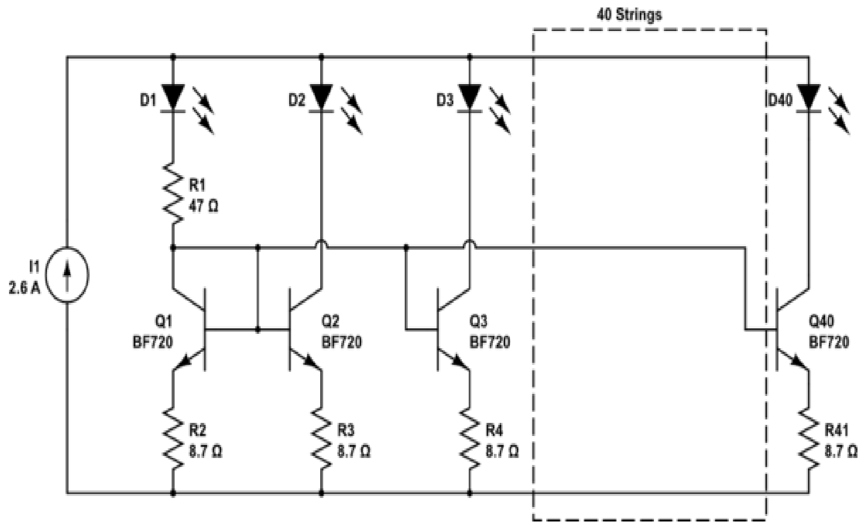


Figure 3.5: Current Mirror [25]

Figure 3.5 shows simple current mirror. The basic principle is relying on the fact that matched transistors will have the same collector current if their base-emitter junctions have the same voltage across them. By connecting all the bases together and all the emitters together, all base-emitter junction voltage must be equal and therefore every collector current must be same. The primary LED string is the one that decided and controls the current through the other strings. The collector and base of transistor Q1 are connected, the transistor will be totally conducting until the collector voltage falls low enough for the base emitter current to limit. Other transistors on that time (Q2 - Q40) have their base connections joined to Q1, and will conduct exactly the same collector current as Q1 since the transistors are matched. The total current through Q1 to Q40 will same for the current source limit.

The voltage drop across the LEDs in the primary string must be large than any other string in order for the current mirror to work smoothly. In the slave strings, some voltage will be dropped across the collector to emitter junction of the transistors Q2 – Q40. The slave circuits adjust the current by increasing or lowering this surplus voltage drop across the transistor.

3.2.1 Voltage Limiting

Theoretically we know, the output voltage of a constant current driver is not limited. The voltage will be the product of the load resistance and current in the case of a linear load. In the case of an LED lamp load, the voltage limit will depend on the number of LEDs in a string. practically, there will be a maximum output voltage, because components in the current source finally will break down. Limiting the LED string voltage is mandatary to prevent circuit damage and the voltage level will depend on the particular circuit.

3.2.2 Open Circuit Protection

Especially switching boost converters, will produce a sufficiently high voltage to destroy the driver circuit Some constant current drivers. For these types of drivers, a shutdown system is needed. when the output voltage exceeds a certain limit is the standard method, using a Zener diode to give feedback. Before LED driver functions are enabled, some over-voltage detectors within integrated circuits (ICs) have a latched output, requiring the power supply to be shut down and then, on again. When the open circuit condition is removed other circuits will automatic starting (i.e., when the LEDs are reconnected). Some integrated circuits have an over-voltage detector (internal comparator) that disables the LED driver circuit when the voltage at the input exceeds the reference voltage. A potential divider comprising two resistors are usually used to measure the output voltage to the reference voltage level.

3.2.3 LED Failures

In a constant current circuit, a failure of an LED can mean either the total string is off (open circuit LED) or a single LED is off (short circuit LED). The load is removed, in the case of an open circuit LED and so the output voltage from the current source increases. The increasing values in voltage can be detected and used to signal a failure. This can be used to indicate a failure, where over-voltage protection is fitted, in circuits. If we use a current mirror to drive an array of LEDs with number of strings, the result of an open circuit LED will allows depend on which string the LED is located. In a basic current mirror, in Figure 3.7, a failure in the primary string will cause all the LEDs to have no current flow through them. If the failure were in a secondary string, detection of the increasing values in output voltage would be a solution, however, there would be higher current flowing in the other strings and the output voltage would not increase very much (only due to the extra current flowing through the ESR). The voltage at the transistor collector of the broken string would fall to zero since there is no link to the positive supply, and this could be detected.

Another technique, is to connect the LED of an opto-coupler in series with the LED string, for low current LEDs. A basic opto-coupler has an LED & a photo-transistor in the same package. Current through the opto-coupler LED causes the photo-transistor to conduct. Thus, the opto-coupler’s internal LED, when current is going through the LED string, the photo-transistor is conducting. If the string goes open-circuit, the photo-transistor does not conduct and there is no current through the opto-coupler’s LED.

3.3 Testing LED Drivers

Although the testing of an LED driver with the actual LED load is necessary, it is wise to use a dummy load first. There are two main reasons for this: (A) cost of an LED, can be greater than the driver circuit, especially high-power devices and (B) operating high brightness LEDs for long time under testing conditions can cause strain of eye and temporary sight impairment when LEDs viewed at close range. Another reason is that some dummy loads can be set to limit the current and so enable fault-finding to be made easier.

3.3.1 Zener Diodes as a Dummy Load

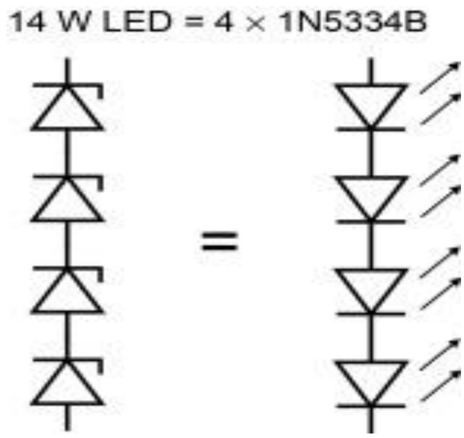


Figure 3.6: Zener Diode Dummy Load. [26]

Figure 3.6 shows how Zener diodes can be used as a dummy load. This is the simplest and cheapest load. The 1N5334B is a 3.6 V, 5W Zener diode (3.6 V typical at 350 mA). This is not the perfect dummy load. This reverse voltage is slightly higher than the typical forward voltage of 3.42 V of a Lumileds 'Luxeon Star' 1 W LED. The 1N5334B has a dynamic impedance of 2.5 ohms, which is higher than the Luxeon Star's 1 ohm impedance [24]. Some switching LED drivers that have a feedback loop, will have an effect on impedance. The impedance only has a small effect, for simple buck circuits. An active load is more precise. A constant voltage load will have (in theory at least) zero impedance, so simply adding a little value series resistor will give the correct impedance. Commercial active loads can be set to have constant current or constant voltage – a constant voltage setting is required to simulate an LED load.

3.4 Common Mistakes

The most common mistake is to use expensive high-power LEDs when testing a prototype circuit. Instead, 3.6 V, 5 W Zener diodes should be used in place of each LED. Only once the circuit has been tested under all possible conditions should LEDs be used.

CHAPTER 4

Power conversion in LED Driver

In my tropology I am using various power conversion process such as, AC to DC, DC to DC. In Dc-to-DC conversion buck converter, flyback converter etc.so I am trying to gone through all the basic things to understand very easily.

We have studied the operation and V/I characteristics of a PN junction diode in the previous chapter. We have also seen that the diode can conduct only when it is forward biased, blocks when it is reversed biased. This property of diode makes it an important component of DC power supplies which are used to power electronic system. The block diagram of a typical DC power supply is shown in Fig 4.1

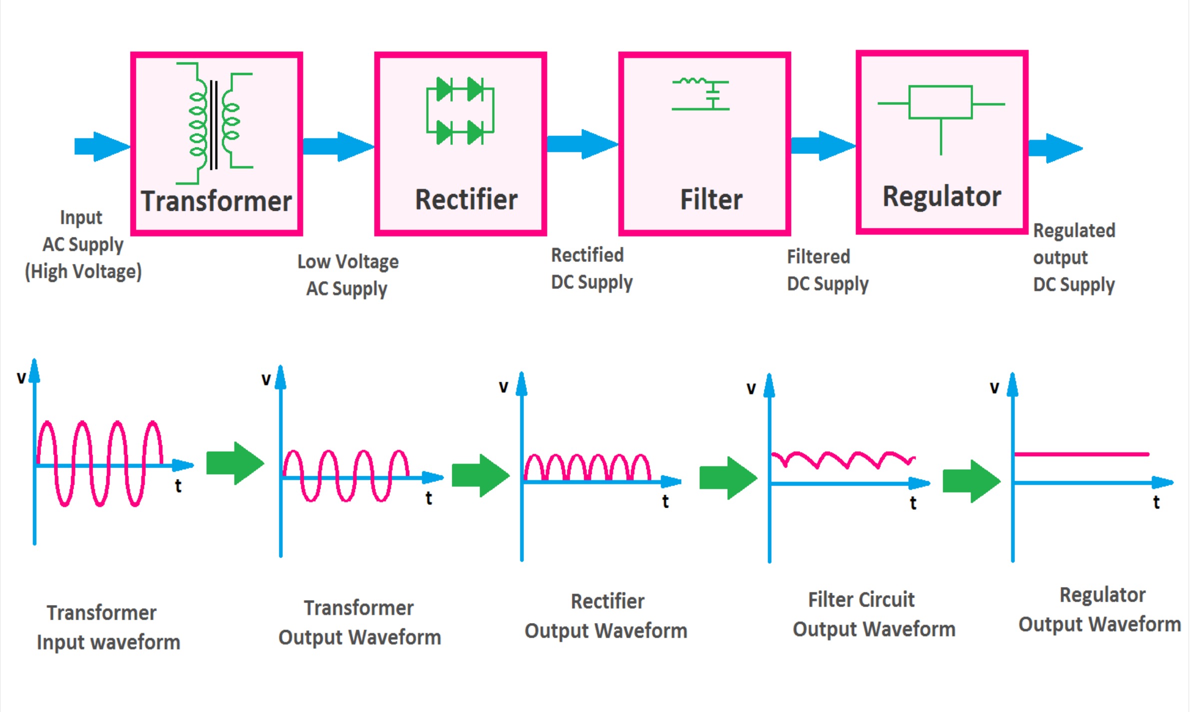


Figure 4.1: block diagram of a typical DC power supply [27]

The transformer is used to step down the AC voltage to desired voltage level by depending upon the turn's ratio N2:N1. The transformer also provides electrical isolation to the power electronics circuit. Fast the rectifier converts AC voltage to pulsating DC, then the pulsating dc is smoothened by filter circuit. Finally, we get the almost constant waveform.

4.1 Diode LC circuit with Zero initial condition

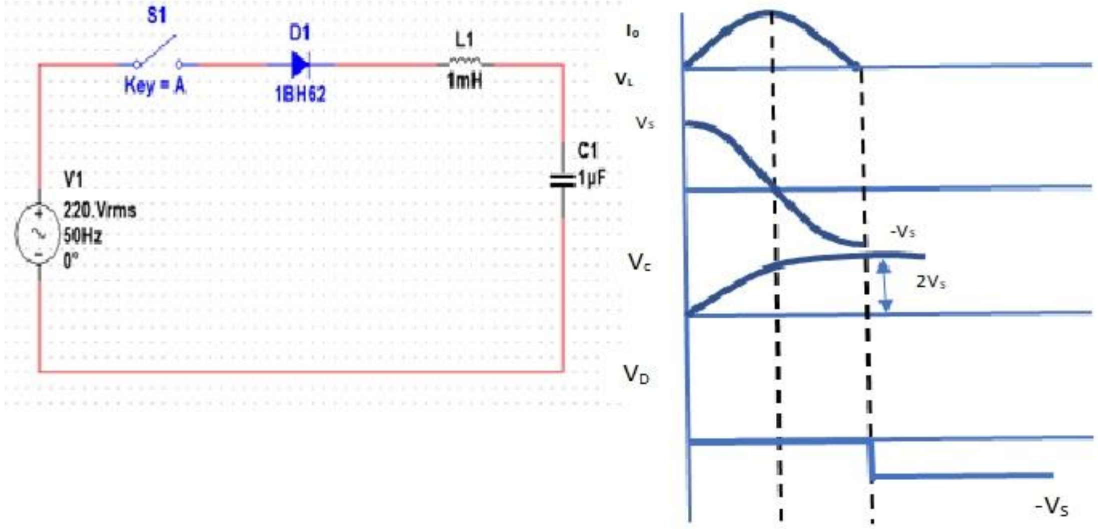


Figure 4.2: LC series circuit with zero initial condition different waveform.

In the figure 4.2 Zero initial condition means V_{C0} = 0. At t =0, the switch S1 is on, and the diode is in forward bias. Then the circuit behaves like LC series. In case LC series circuit the voltage and the current equitation is

$$V_C(t) = V_S(1 - Cos\omega_0 t) + V_{C0}Cos\omega_0 t \quad \text{-------------- (1)}$$

$$I_L(t) = (V_S - V_{C0})\sqrt{\frac{C}{L}}Sin\omega_0 t \quad \text{-------------- (2)}$$

Now put V_{C0} = 0, in both the equation and finally we get,

$$V_C(t) = V_S(1 - Cos\omega_0 t) \text{ -------------- (3)}$$

$$I_L(t) = V_S\sqrt{\frac{C}{L}}Sin\omega_0 t \quad \text{-------------- (4)}$$

The voltage across inductor $V_L(t) = L\frac{di}{dt}$. Now put $I_L(t)$ value in the $V_L(t)$

Equitation,

$$V_L(t) = L\frac{d}{dt}[\,V_S\sqrt{\frac{C}{L}}Sin\omega_0 t] \quad \text{by solving this we get,}$$

$$V_L(t) = V_S Cos\omega_0 t \quad \text{-------------- (5)}$$

The current through the circuit is sinusoidal, from π to 2π current should change its polarity. Due to the diode D1 we get only the current value up to π.

Finally, we get 3 different equations, {(3), (4), (5)} by putting 2 different condition we can easily analysis the responses.

1st put $\omega_0 t = 0$, so the voltage across capacitor is,

$$V_C(t) = V_S(1 - Cos\ 0)$$

$$V_C(t) = V_S(1 - 1)$$

$$\boldsymbol{V_C(t) = 0} \text{ -------------- (6)}$$

The current through the inductor,

$$I_L(t) = V_S\sqrt{\frac{C}{L}}Sin0$$

$$\boldsymbol{I_L(t) = 0} \text{ -------------- (7)}$$

Inductor voltage

$$V_L(t) = V_S Cos0$$

$$\boldsymbol{V_L(t) = V_S} \text{ -------------- (8)}$$

At t=0 we only get inductor voltage which is equal to the supply voltage.

In 2nd condition put $\omega_0 t = \pi$, so the voltage across capacitor is,

$$V_C(t) = V_S(1 - Cos\ \pi)$$

$$V_C(t) = V_S(1 + 1)$$

$$\boldsymbol{V_C(t) = 2V_S} \text{ -------------- (9)}$$

The current through the inductor,

$$I_L(t) = V_S\sqrt{\frac{C}{L}}Sin\ \pi$$

$$\boldsymbol{I_L(t) = 0} \text{ -------------- (10)}$$

Inductor voltage

$$V_L(t) = V_S Cos\ \pi$$

$$\boldsymbol{V_L(t) = -V_S} \text{ -------------- (11)}$$

At t= π we can see that the capacitor voltage is two times than supply voltage & inductor voltage which is equal to the supply voltage but in opposite polarity.

4.2 Diode LC circuit with initial condition

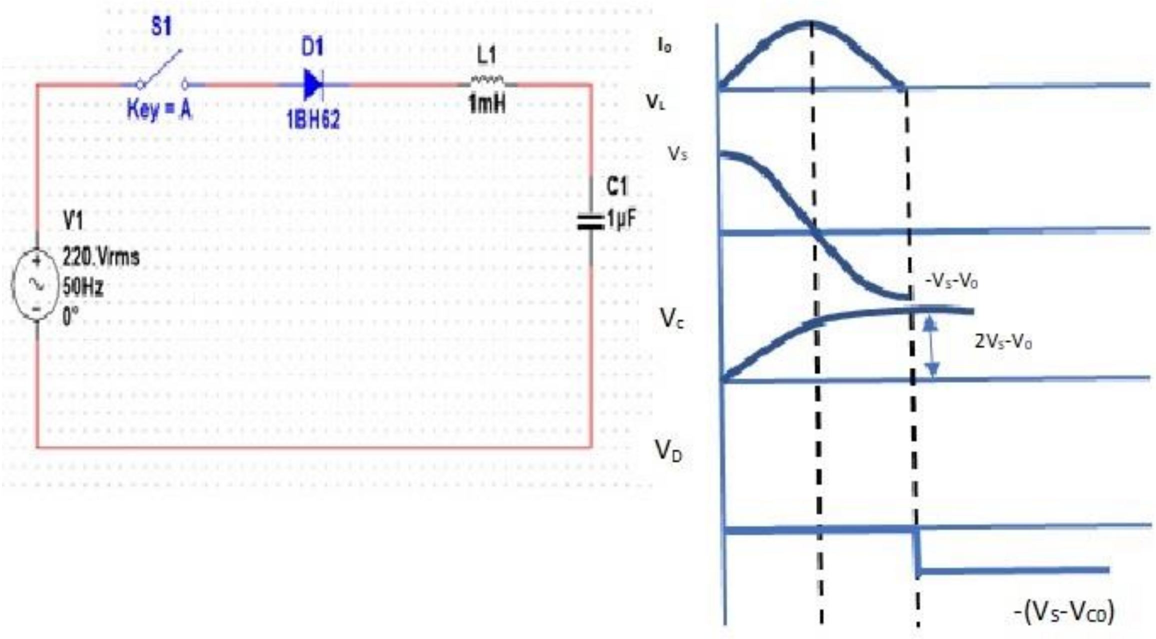


Figure 4.3: LC series circuit with initial condition & different waveform.

If we take the initial condition across the capacitor V_0, so we can write $V_c(0)=V_0=V_{c0}$ where $V_0 < V_s$ and the D_1 diode are in condition mode. If S_1 is on at T=0 it works as a LC circuit with DC excitation. In case LC series circuit the voltage and the current equitation is

$$V_C(t) = V_S(1 - Cos\omega_0 t) + V_{C0}Cos\omega_0 t \quad \text{-------------- (12)}$$

$$I_L(t) = (V_S - V_{C0})\sqrt{\frac{C}{L}}Sin\omega_0 t \quad \text{-------------- (13)}$$

The voltage across inductor $V_L(t) = L\frac{di}{dt}$. Now put $I_L(t)$ value in the $V_L(t)$

Equitation,

$$V_L(t) = L\frac{d}{dt}[\,(V_S - V_0)\sqrt{\frac{C}{L}}Sin\omega_0 t] \quad \text{by solving this we get,}$$

$$V_L(t) = (V_S - V_0)Cos\omega_0 t \quad \text{-------------- (14)}$$

We will get I_L up to π. Finally, we get 3 different equations, {(12), (13), (14)} by putting 2 different condition we can easily analysis the responses.

1st put $\omega_0 t = 0$, so the voltage across capacitor is,

$$V_C(t) = V_S(1 - Cos\ 0) + V_{C0}cos0$$

$$\boldsymbol{V_C(t)} = V_{C0} \quad \text{-------------- (15)}$$

The current through the inductor,

$$I_L(t) = (V_S - V_{C0})\sqrt{\frac{C}{L}}Sin0$$

$$\boldsymbol{I_L(t) = 0} \text{ -------------- (16)}$$

Inductor voltage

$$V_L(t) = (V_S - V_{C0})Cos0$$

$$V_L(t) = (V_S - V_{C0}) \text{ -------------- (17)}$$

In 2nd condition put $\omega_0 t = \pi$, so the voltage across capacitor is,

$$V_C(t) = V_S(1 - Cos\,\pi) + V_{C0}Cos\pi$$

$$\mathbf{V_C(t) = 2V_S - V_{C0}} \text{ -------------- (18)}$$

The current through the inductor,

$$I_L(t) = (V_S - V_{C0})\sqrt{\frac{C}{L}}Sin\,\pi$$

$$\boldsymbol{I_L(t) = 0} \text{ -------------- (19)}$$

Inductor voltage

$$V_L(t) = V_S Cos\,\pi$$

$$\boldsymbol{V_L(t) = -(V_S - V_{C0})} \text{ -------------- (20)}$$

Now we can understand all the condition except voltage drop across diode, to find out this we have to apply KVL in Figure 4.3.

After applying KVL we get,

$$-V_S + V_D + V_L + V_C = 0$$

$$V_D = V_S - V_L - V_C$$

In the equitation 18 we get $V_C = \mathbf{2}V_S - V_{C0}$,and inductor voltage = 0 as current through the inductor I_L=0 at π^+

$$V_D = V_S - (\,\mathbf{2}V_S - V_{C0})$$

$$\boldsymbol{V_D = -(V_S - V_{C0})} \textbf{ -------------- (21)}$$

This V_D is also known as peak invers voltage (PIV). With the respect to zero initial condition the equitation is almost same, but the main difference is adding a ($-V_{C0}$). That means the amplitude will be decreasing with the respect to zero initial condition.

4.3 Discharging LC circuit

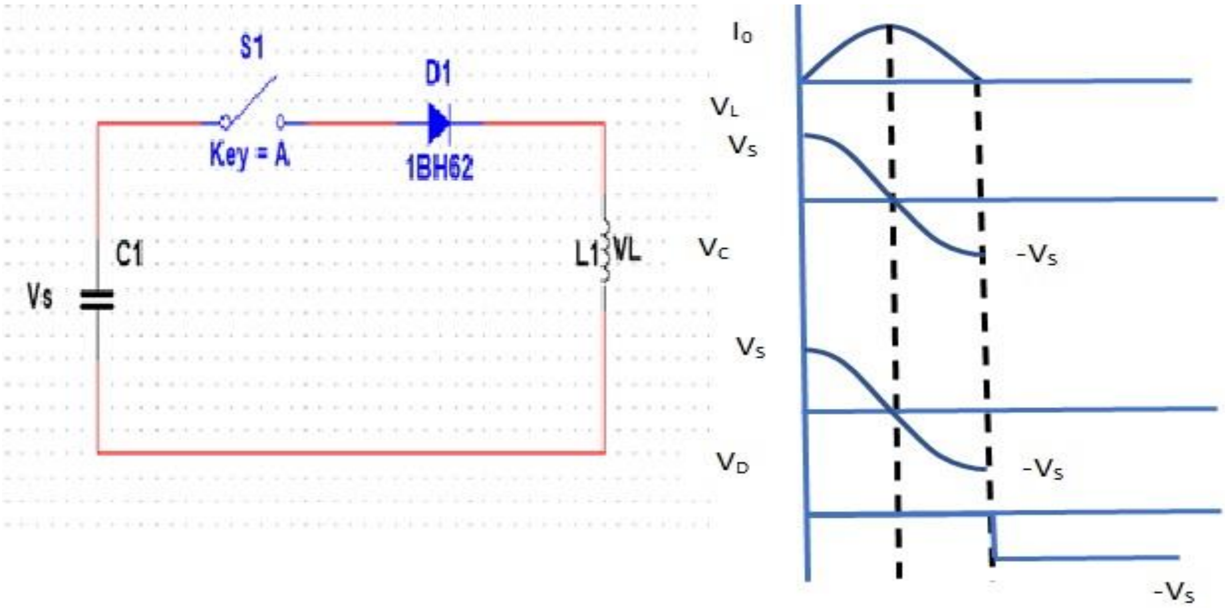


Figure 4.4: Discharging LC circuit & different waveform

Now we will understand the discharging phenomena of LC circuit. Initially the capacitor C_1 is charging up to V_S, so we can write $V_{C0}=V_S$. After that we adding a diode D_1 & S_1 switch is on at t = 0. Then the capacitor will discharge across the inductor L_1. Then capacitor will charge the inductor.

Here that inductor behave like a current source and also charge the capacitor in opposite polarity.

So, in equitation 1, 2 & 3 this is the main equitation we will put $V_S=0$ as it is source free.

$$V_C(t) = 0(1 - Cos\omega_0 t) + V_{C0}Cos\omega_0 t$$

$$V_C(t) = V_S Cos\omega_0 t \quad \text{-------------- (22)}$$

{$V_{C0}=V_S$, V_S is not the source}

$$I_L(t) = (0 - V_{C0})\sqrt{\frac{C}{L}}Sin\omega_0 t$$

$$I_L(t) = V_S\sqrt{\frac{C}{L}}Sin\omega_0 t \quad \text{-------------- (23)}$$

$$V_L(t) = V_S Cos\omega_0 t \quad \text{-------------- (24)}$$

Finally, we get 3 different equations, {(22), (23), (24)} by putting 2 different condition we can easily analysis the responses.

1st put $\omega_0 t = 0$,

$$V_C(t) = V_S$$

$$I_L(t) = 0$$

$$V_L(t) = V_S$$

In 2nd condition put $\omega_0 t = \pi$,

$$V_C(t) = -V_S$$

$$I_L(t) = 0$$

$$V_L(t) = -V_S$$

Now we can understand all the condition except voltage drop across diode, to find out this we have to apply KVL in Figure 4.4.

After applying KVL we get,

$$V_D + V_L + V_S = 0$$

$$V_D = -V_S - V_L$$

As the inductor current is zero so the voltage across inductor also be zero, $V_L = 0$

$$\boldsymbol{V_D = -V_S} \text{ -------------- (25)}$$

4.4 Type of Load

Before going to the rectifier analysis, it is very important to understand the types of loads & according to those loads how power is calculated.

In case of load, two types of loads are present voltage stiff type load and current stiff type load. In voltage stiff type load the nature of voltage and current waveform are same. For resistive load power can be calculated as $\mathbf{P_0 = I^2_{rms} R}$, and for RE load,

$$\mathbf{P_0 = I^2_{rms} R + E\ I_{rms}.}$$

when we are talking abought the current stiff type load, here I_0 doesn't change suddenly, means RL, RLE type of load are present. To find out the power we must take average value of voltage and current because I_0 is not follow the sine wave, calculate rms value is a bit of challenging. For that allows take the average value to find out power.

$$\mathbf{P_0 = V_{0\ avg} * I_{0\ avg}}$$

4.5 Rectifier and its classification

Basically, rectifier is a power electronics circuit which convert any AC signal to DC signal. If we talking abought the classification of rectifier, we have three types A) uncontrolled rectifier, we can use diode and we get the fixed DC. Hare we cannot controlled the output. B) fully controlled rectifier. In fully controlled rectifier we get the variable DC by using thyristors. C) Semi-controlled rectifier, it consists of diode and thyristors. we also get the variable DC.

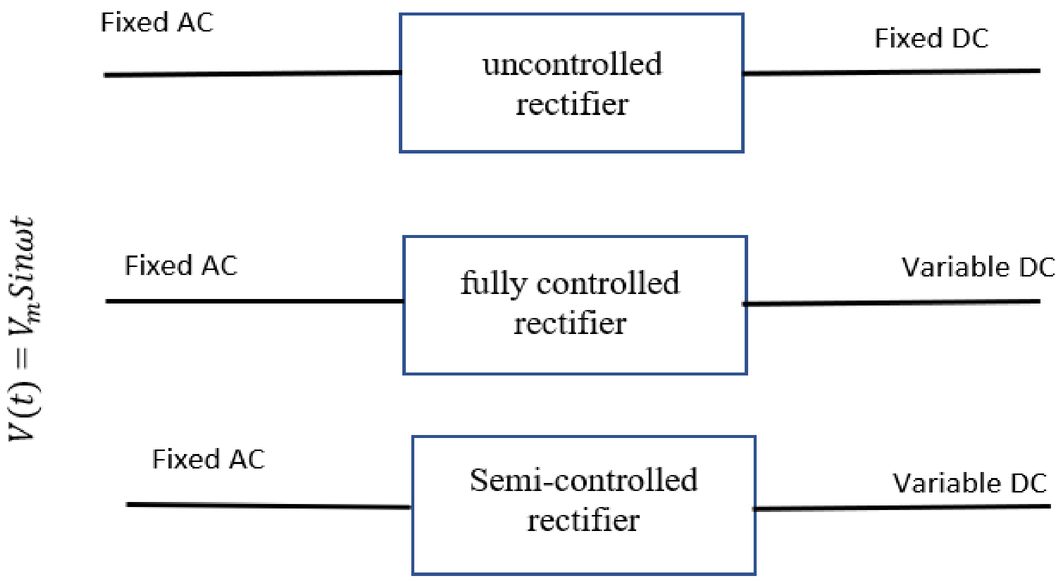


Figure 4.5: Block diagram of all type's rectifier

We know in power electronics circuit; practical loss is very less. We can say that $P_{in} = P_{out}$. $V_{S}*I_{S}*\cos\phi = P_{out}$. Where the output power is depending upon the type of load, voltage stiff type or current stiff type.

Another type of classification of rectifier is based on number of pulses. We are given the input as AC, for one cycle of AC the number of pulses we get in dc is known as pulse converter. If we will talk about harmonics analysis, means Fourier series of one and two pulse converter, one pulse converter harmonics contain will more than two pulse. For that we can say as we increased the number of pulses the harmonics will reduced because the ripple voltage will decrease.

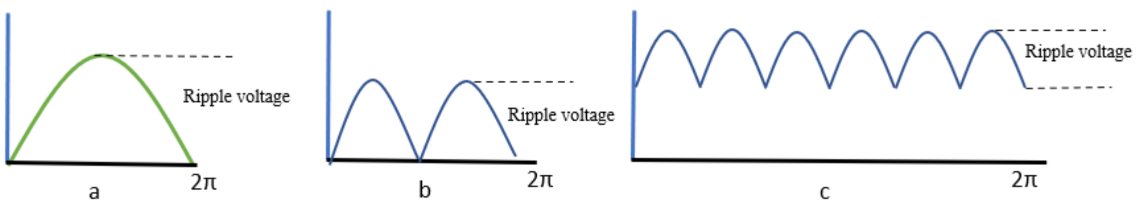
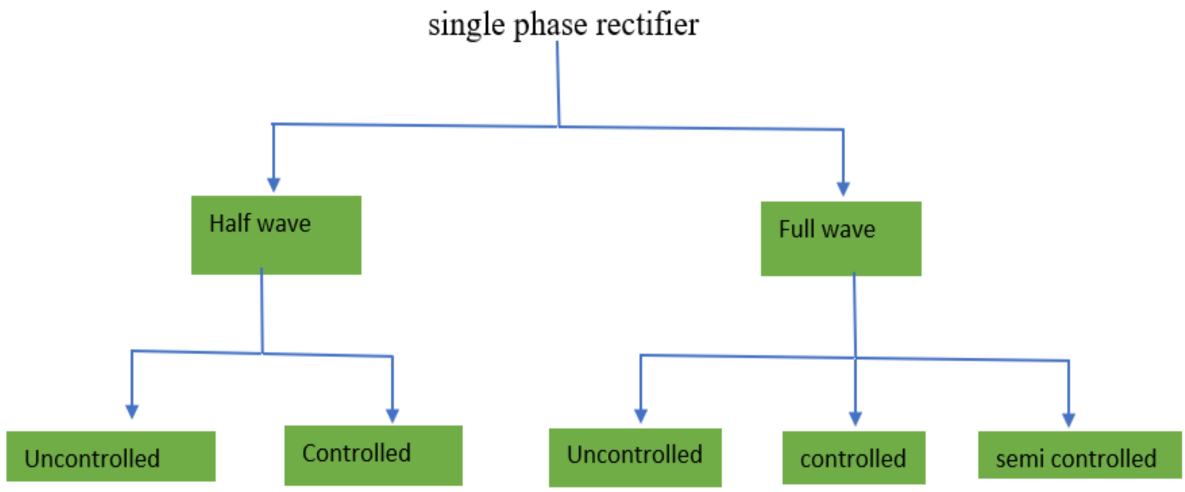


Figure 4.6: a) one pulse converter, b) two pulse converters, c) six pulse converters



Hare we only discuss full wave-controlled bridge rectifier though in our circuit we are using full wave uncontrolled bridge rectifier. The main difference is that the firing angle is zero w.r.t full wave-controlled bridge rectifier. Controlled rectifier is most complicated thing if we compare to this to uncontrolled rectifier, so we try to understand full wave-controlled bridge rectifier.

4.5.1 Full Wave Controlled Bridge Rectifier

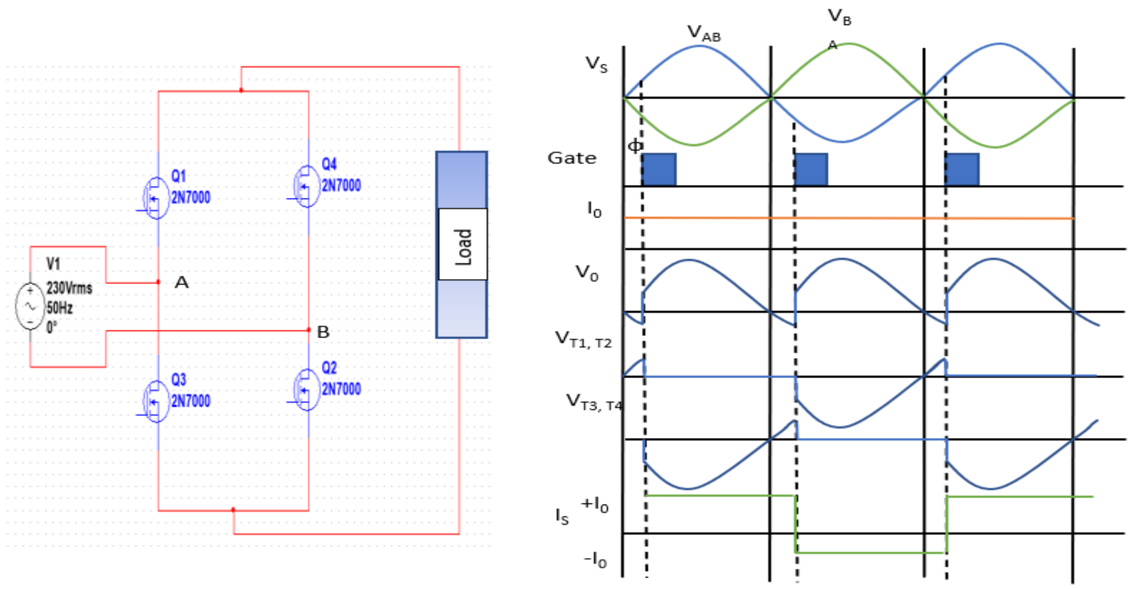


Figure 4.7: full wave control bridge rectifier with waveform

We know that $V_1 = V_{AB} = V_m \sin\omega t$. And let us consider that the load current I_0 is constant, that means the load is highly inductive type.

$V_1 = V_{AB} = V_m \sin\omega t$, we can also write $V_{BA} = - V_m \sin\omega t$.

Input supply is given and we are trigger the Q_1 & Q_2 switch on at an angle of ϕ. Now from ϕ to $\pi+\phi$, Q_1 and Q_2 both the switch is conducting and other pair of switches are closed means open circuited. Finally, the equivalent circuit look like that Figure 4.8

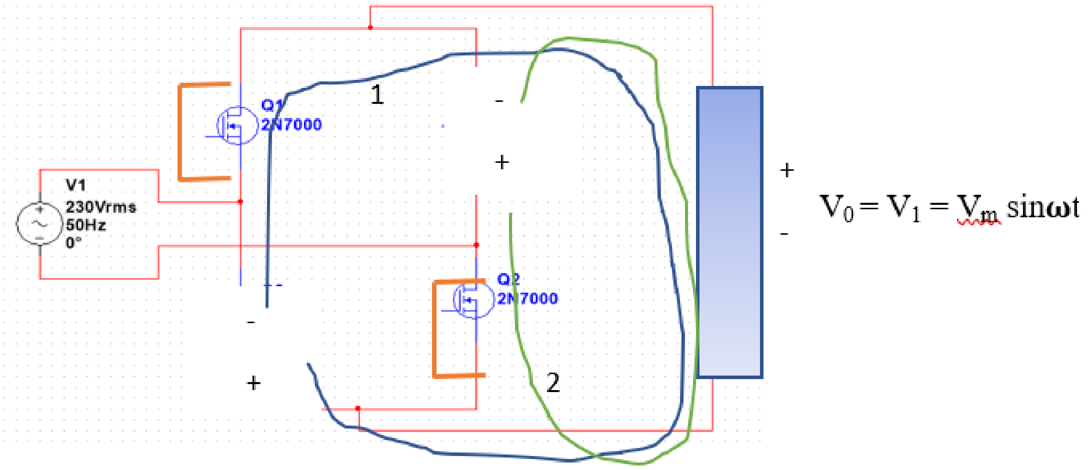


Figure 4.8: equivalent circuit of full wave control bridge rectifier with +ve half cycle

After π supply voltage is getting revers, that means Q_1 and Q_2 must go into rivers bias and it can be replaced by open circuit Figure 4.8. Wea are assumed that load is almost constant and we are not trigging Q_3 and Q_4 after π. So, this means to turn off this Q_1 and Q_2 switches I_0 must be less than or equal to holding current ($I_0 <= I_H$). But load current is constant so even after reversing the supply voltage this Q_1 and Q_2 has to conduct after π, and it will continue to conduct from ϕ to $\pi+\phi$.

When Q_1 and Q_2 conducting then the voltage drops across Q_3 and Q_4 we can find by using KVL Figure 4.8.

Apply KVL across loop 1 in Figure 4.8 we get,

$$+V_{T3} + V_0 = 0$$

$$V_{T3} = - V_0$$

Apply KVL across loop 2 in Figure 4.8 we get,

$$+V_{T4} + V_0 = 0$$

$$V_{T4} = - V_0$$

So, we can say that when Q_1 and Q_2 are conducting at this time voltage drop across Q_3 and Q_4 is – V_0. From ϕ to $\pi+\phi$ output voltage will follow the input voltage & the voltage drop across Q_3 and Q_4 are same as output voltage but in opposite polarity.

The moment $\omega t = \pi+\phi$, Q_3 and Q_4 are trigger, so on that same time Q_1 and Q_2 are go into off mode and it will stop conducting Figure 4.9 is the equivalent circuit diagram.

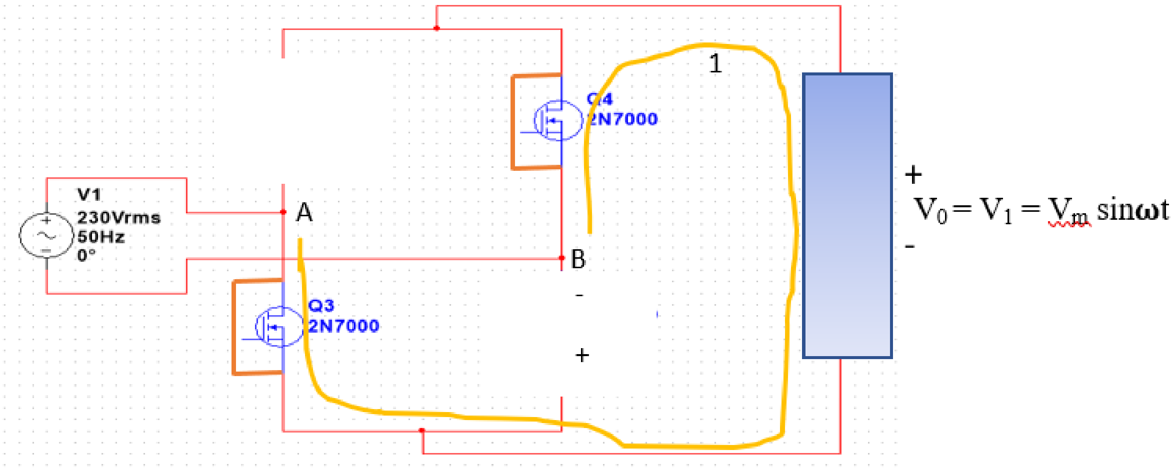


Figure 4.9: equivalent circuit of full wave control bridge rectifier with -ve half cycle

Apply KVL across loop 1 in Figure 4.9 we get,

$$+V_{AB} + V_0 = 0$$

$$V_{AB} = - V_0$$

$$V_{BA} = V_0$$

So, for $\pi+\phi$ to $2\pi+\phi$ output voltage we get V_{BA}. Also, the voltage drops across Q_1 and Q_2 is same as before $V_{T1} = V_{T2} = - V_0$.

Now we want to check the source current from ϕ to $\pi+\phi$ when Q_1 and Q_2 is turned on by looking at the equivalent circuit in Figure 4.8 we can find that $I_S = I_0$. And from $\pi+\phi$ to $2\pi+\phi$ when Q_3 and Q_4 is turned on by looking at the equivalent circuit in Figure 4.9 we can find that $I_S = - I_0$.

Output average voltage ($V_{0\ avg}$) = $\frac{1}{\pi}\int_{\phi}^{\pi+\phi} V_m sin\omega t d\omega t$

$$V_{0\ avg} = \frac{2V_m}{\pi} Cos\phi \text{ -------------- (26)}$$

$V_{0\ avg}$ is depending upon ϕ (conduction angle), If $\phi < 90$, $V_{0\ avg} > 0$ and $I_0 > 0$ so power is also > 0. We can say that power is transfer source to load. But if $\phi > 90$, $V_{0\ avg} < 0$ and $I_0 > 0$ (as constant current) so power is also < 0. We can say that power is transfer load to source.

Circuit turns off time (t_c) = $\frac{\pi-\phi}{\omega}$, and each switch is conducting for the period of $\pi+\phi-\pi = \pi$.

Average switch current ($I_{T\ avg}$) = $I_0 \frac{\pi}{2\pi} = \frac{I_0}{2}$. -------------- (27)

And the RMS switch current is $\frac{I_0}{\sqrt{2}}$ -------------- (28)

Now we want to analysis the harmonics of source current, we should know how much harmonics is present in source current because of rectifier circuit. Source current (I_S) is not sinusoidal, it is a rectangular pulse repeating from + I_0 to – I_0.

$$I_0(S) = \sum_{n=1,3,5}^{\phi} \frac{4I_0}{n\pi} \sin(n\omega_0 t - n\phi) \quad \text{-------------- (29)}$$

Equitation 29 is the furrier series of source current (in chapter 5, article 5.5 the complete derivation is their) From hare we can easily get fundamental RMS of source current by putting n = 1 in this (29) equation.

$$I_{S1\,rms} = \frac{\frac{4I_0}{\pi}}{\sqrt{2}} = \frac{2\sqrt{2}\,I_0}{\pi} \quad \text{-------------- (30)}$$

The distortion factor (g) = $\frac{I_{S1}}{I_S} = \frac{2\sqrt{2}}{\pi} = 0.9$. By getting distortion factor we can easily find out T.H.D = $\sqrt{\frac{1}{g^2} - 1}$ = 48.34.

Now finally the input power factor (IPF) can be calculated by multiplying distortion factor (g) and fundamental displacement factor (FDF). Fundamental displacement factor is the cos of angle between fundamental voltage and fundamental current. Hare the angle is ϕ. So, the FDF= cosϕ.

$$\text{IPF} = \frac{2\sqrt{2}}{\pi} cos\phi \quad \text{-------------- (31)}$$

4.6 DC-DC Converter

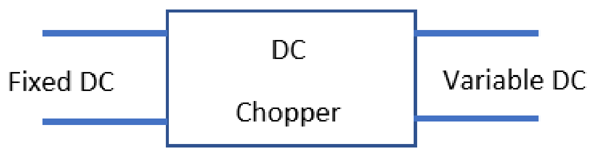


Figure 4.10: Block diagram of DC -DC converter

In case of LED driver circuit after rectification according to our need we can change the DC voltage by stepping up or down. DC-DC converters are also known as Choppers.

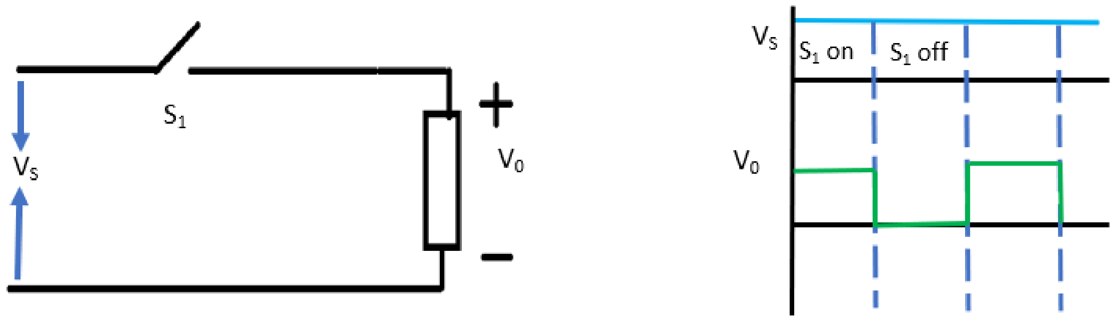


Figure 4.11: DC- DC only using a switch and its wave form.

In figure 4.11 this is the simple dc circuit with a switch S_1, where V_S is the supply voltage and V_0 is the output voltage. When S_1 is on then $V_S = V_0$. And when the switch is open then $V_0 = 0$. So, the average voltage is $V_{0\,avg} = V_S * \left(\frac{T_{On}}{T}\right)$. We can also write $V_{0\,avg} = V_S * D$, D is known as duty cycle. Depending upon the duty cycle we can vary the output voltage.

Hare, we get the output voltage but the voltage ripple is very high. (Figure 4.11 V_0 graph) Due to this ripple it will produce harmonics. So, we can't directly connect load in the circuit because harmonics has AC as well as DC component. For that we put a capacitor parallel with load for voltage ripple and place an inductor in series with load for current ripple see figure 4.12

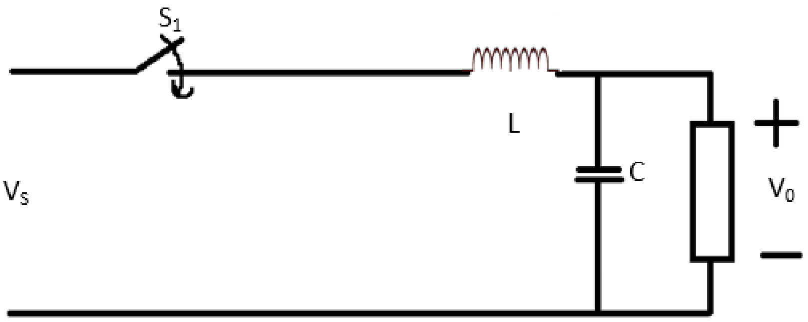


Figure 4.12: DC- DC using L & C

Still, we can't use this circuit in practical purpose. (Figure 4.12) The main reason is when the switch is on inductor L charged and it store some energy that is not an issue but, when the switch is off inductor has no path to discharge so a spark will produce across the switch. So, we must connect a diode D_1 to provide the discharge path of that inductor. Figure 4.13.

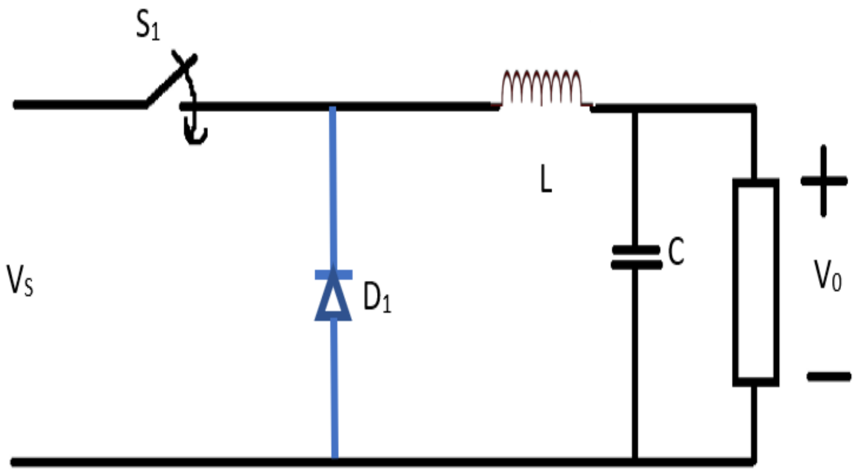


Figure 4.13: practical DC-DC Converter

Here we will look at the Step-Down Chopper that is also known as Buck converter which reduces the input DC voltage to a specified output DC voltage.

Mainly, three types of converters are their buck, boost, buck-boost. By inter-changing the components we can make buck, boost or buck-boost.

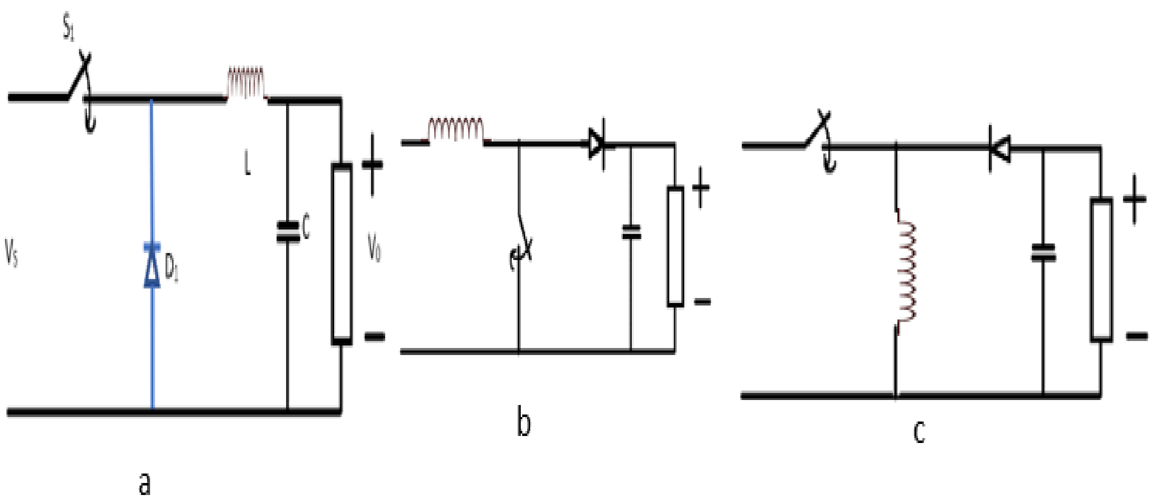


Figure 4.13: a) Buck Converter, b) Boost Converter c) Buck-Boost Converter

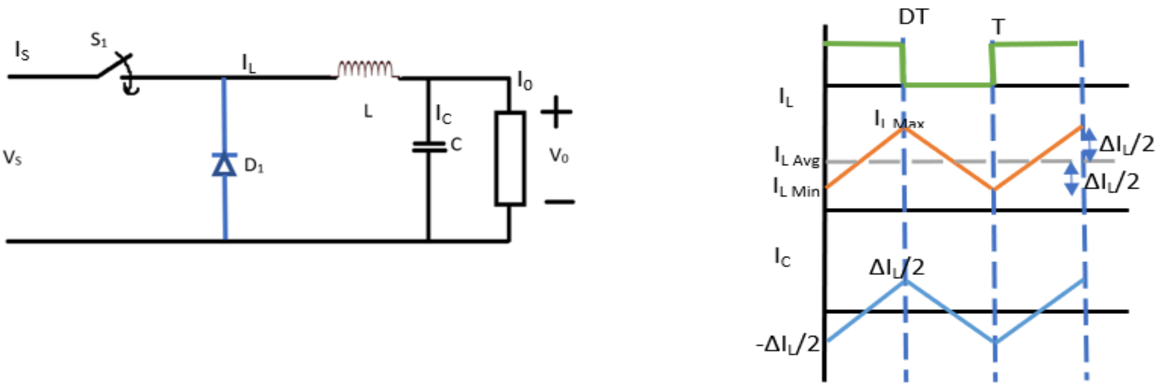


Figure 4.14: Buck Converter with waveform

When S_1 is on at t = 0, switch behave like short circuit and the diode D_1 is open circuit. On that condition L stored the energy equivalent circuit shown in figure 4.15 (a). At steady state condition L has min current that is $I_{L\ Min}$ so, I_L will increase from minimum to maximum. In between min and max level, we get the average I_L which is constant. (Figure 4.14 graph)

When S_1 is off L behave like a current source and I_L discharge through load and diode on that time this diode is in forward bias and supply is cut off. equivalent circuit shown in figure 4.15 (b)

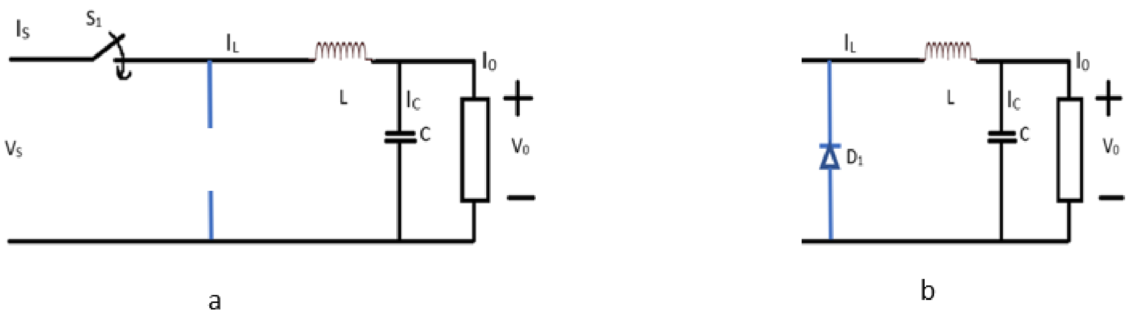


figure 4.15 (a) equivalent circuit of buck converter when S_1 on b) equivalent circuit of buck converter when S_1 off.

When S_1 is on the apply KVL in the equivalent circuit figure 4.15 (a) to find out voltage across inductor,

$$-V_S + V_{L\ ON} + V_0 = 0$$

$$V_{L\ ON} = V_S - V_0 \text{ -------------- } (32)$$

When S_1 is on the apply KCL in the equivalent circuit figure 4.15 (a) to find out current through capacitor,

$$I_L = I_{C\ ON} + I_0$$

$$I_{C\ ON} = I_L - I_0 \text{ -------------- } (33)$$

When S_1 is off the apply KVL in the equivalent circuit figure 4.15 (b) to find out voltage across inductor,

$$V_{L\ OFF} + V_0 = 0$$

$$V_{L\ OFF} = - V_0 \text{ -------------- } (34)$$

When S_1 is off the apply KCL in the equivalent circuit figure 4.15 (b) to find out current through capacitor,

$$I_L = I_{C\ ON} + I_0$$

$$I_{C\ ON} = I_L - I_0 \text{ -------------- } (35)$$

If we calculated volt -sec balance we get,

$$V_{L\ ON}\ T_{ON\ +}\ V_{L\ OFF}\ T_{OFF} = 0$$

$$(V_S – V_0)\ DT – V_0\ (1\text{-}D) *T = 0$$

$$V_0 = D*V_S \text{ -------------- } (36)$$

Using ampere – Sec balance,

$$I_{C\ ON}\ T_{ON\ +}\ I_{C\ OFF}\ T_{OFF} = 0$$

$$(I_L – I_0)\ DT – I_L\ \text{-}I_0\ (1\text{-}D) *T = 0$$

$$I_L = I_0 \text{-------------- } (37)$$

We can say that in case of buck converter $I_{L\ Avg}$ current is equal to the output current.

Now we are trying to find ripple inductor current for that during on stage $V_{L\ ON} = V_S - V_0$ equitation (35)

$$V_{L\ ON} = V_S - V_0$$

$$L * \frac{di_{on}}{dt_{on}} = V_S - V_0$$

In our graph di_{on} is nothing but ΔI_L change in current & dt $_{ON}$ is nothing but the time up to the switch is on.

$$L * \frac{\Delta I_L}{DT} = V_S - DV_S$$

$$\Delta I_L = \frac{D(1-D)V_S}{fL} \text{ -------------- } (38)$$

For maximum & minimum inductor current we can easily be calculated by the graph in figure 4.14.

$$I_{L\ Max} = I_{L\ Avg} + \frac{\Delta I_L}{2}$$

$$I_{L\ Max} = I_0 + \frac{\Delta I_L}{2} \text{ -------------- } (39)$$

$$I_{L\ Min} = I_0 - \frac{\Delta I_L}{2} \text{ -------------- } (40)$$

To find out the source current allows put $P_{IN} = P_{OUT}$.

$$V_S\ I_S = V_0\ I_0$$

$$I_S = \frac{V_0 I_0}{V_S} \text{ -------------- } (41)$$

Calculated switch average current & RMS current,

$$I_{sw\ Avg} = \text{max current x (time for getting current / total time)}$$

$$I_{sw\ Avg} = I_0 * \frac{DT}{T}$$

$$I_{sw\ Avg} = I_0 * D \text{-------------- } (42)$$

$$I_{sw\ RMS} = I_0\sqrt{\frac{DT}{T}}$$

$$I_{sw\ RMS} = I_0\sqrt{D} \text{-------------- } (43)$$

When S_1 is off then the diode D_1 will conduct. So, only that period of time we will get diode current. So average diode current is,

$$I_{D\ Avg} = I_0\frac{(T-DT)}{T}$$

$$I_{D\ Avg} = I_0(1-D) \text{ -------------- } (44)$$

Now the RMS diode current is

$$I_{D\ RMS} = I_0\sqrt{\frac{(1-D)T}{T}}$$

$$I_{D\ RMS} = I_0\sqrt{(1-D)} \text{ -------------- } (45)$$

Our main moto is harmonics analysis so the ripple in capacitor has to be calculated, by applying KCL we get $I_C = I_L – I_0$. We know Q = CV,

$$\Delta Q = C\Delta V$$

$$\Delta V = \frac{\Delta Q}{C}$$

When I_C is grater than zero 4.14 then the capacitor will share the charge and if I_C is less than zero capacitor will discharge. So, the area is, $\Delta Q = \frac{1}{2} * \frac{\Delta I_L}{2} * \frac{T}{2}$

$$\Delta Q = \frac{\Delta I_L}{8f}$$

Finally, the ripple in capacitor $\Delta V = \frac{\Delta I_L}{8fC}$

$$\Delta V = \frac{D(1-D)V_S}{8f^2LC} \text{ -------------- } (46)$$

After getting the ripple in capacitor voltage now if we want to calculated duty cycle at max ripple

$$\Delta V = \frac{D(1-D)V_S}{8f^2LC}$$

$$\frac{d\Delta V}{dV} = \frac{d}{dD}\left(\frac{D(1-D)V_S}{8f^2LC}\right)$$

D = 0.5 -------------- (47)

Two types of operation are there, continuous conduction mode (CCM) and dis-continuous conduction mode (DCM). To choose the operation is CCM or DCM critical inductance (L_C) and critical capacitance (C_C) has to be calculated.

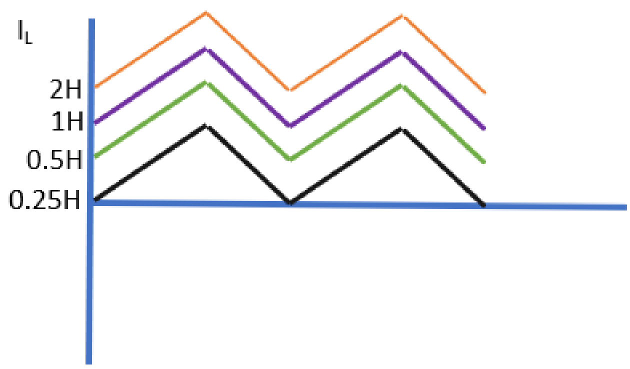


figure 4.16 min inductance value for CCM

Min value of inductor for which I_L is just continuous. If we will make L_C less than critical value, (critical value is 0.25 in figure 4.16) then we will get DCM operation.

$$I_{L\,Min} = 0$$

From equitation no 40 we get $I_{L\,Min} = I_0 - \frac{\Delta I_L}{2}$

$$I_0 = \frac{\Delta I_L}{2} \quad [I_0 = \frac{V_0}{R}\ if\ R\ load\ is\ present]$$

$$\frac{V_0}{R} = \frac{D(1-D)V_S}{2fL_C} \quad [\text{put } V_0 = DV_S]$$

$$\frac{DV_S}{R} = \frac{D(1-D)V_S}{2fL_C}$$

$$L_C = \frac{R(1-D)}{2f} \quad \text{-------------- (48)}$$

And in case of critical capacitor (C_C) value means for which the output voltage is just continuous

$$\Delta V_{C\,Min} = 0$$

$$\Delta V_{C\,Min} = V_0 - \frac{\Delta V_C}{2}$$

$$C_C = \frac{(1-D)}{16f^2L_C}$$

$$C_C = \frac{1}{8fR} \text{ -------------- } (49)$$

4.6.1 Buck converter in DCM

In this tropology I am using DCM of operation because in DCM of buck and flyback splits the off state into three different intervals.

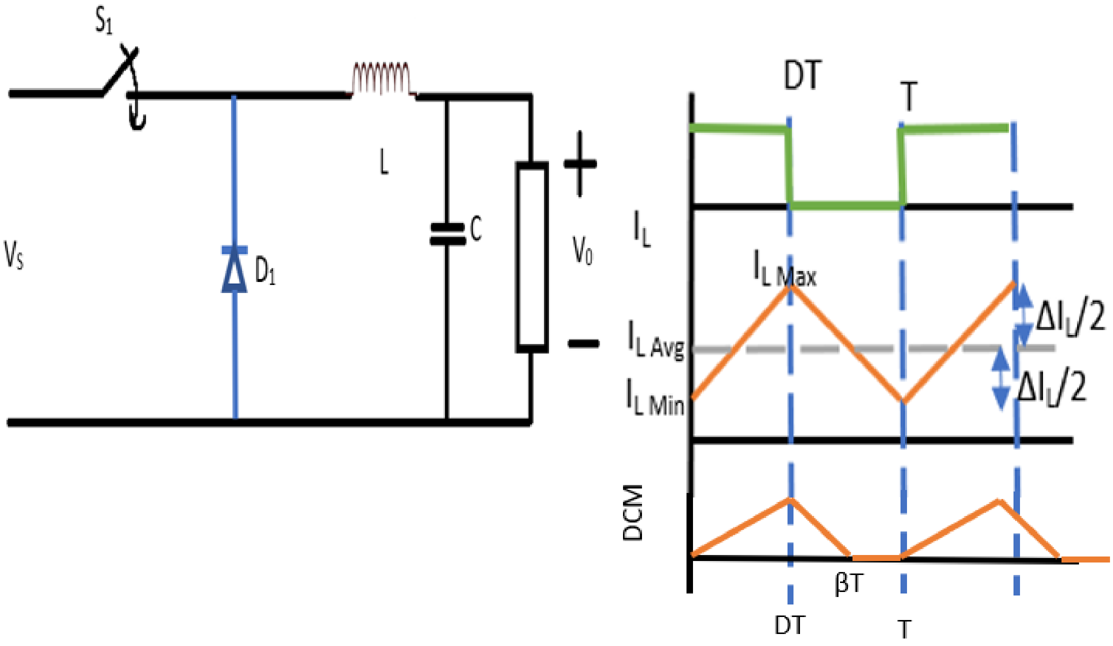


figure 4.17 Buck converter in CCM & DCM with waveform

Hare β is the value depending upon at what time $I_L = 0$. In CCM $V_0 = DV_S$ and in case of DCM when switch is on, $V_{L(ON)} = (V_S - V_0)$ & $T_{ON} = DT$.

When switch is off, $VL_{(OFF)} = - V_0$ & $T_{OFF} = \beta T - DT$.

For volt- sec balance method we get,

$$(V_S - V_0)\, DT - V_0\, (\beta - D) * T = 0$$

$$V_0 = \frac{DV_S}{\beta} \text{ -------------- } (50)$$

This is the output voltage for DCM of operation.

4.7 Flyback Converter

It is DC-DC converter with provide isolation in between input and output. In figure 4.18.

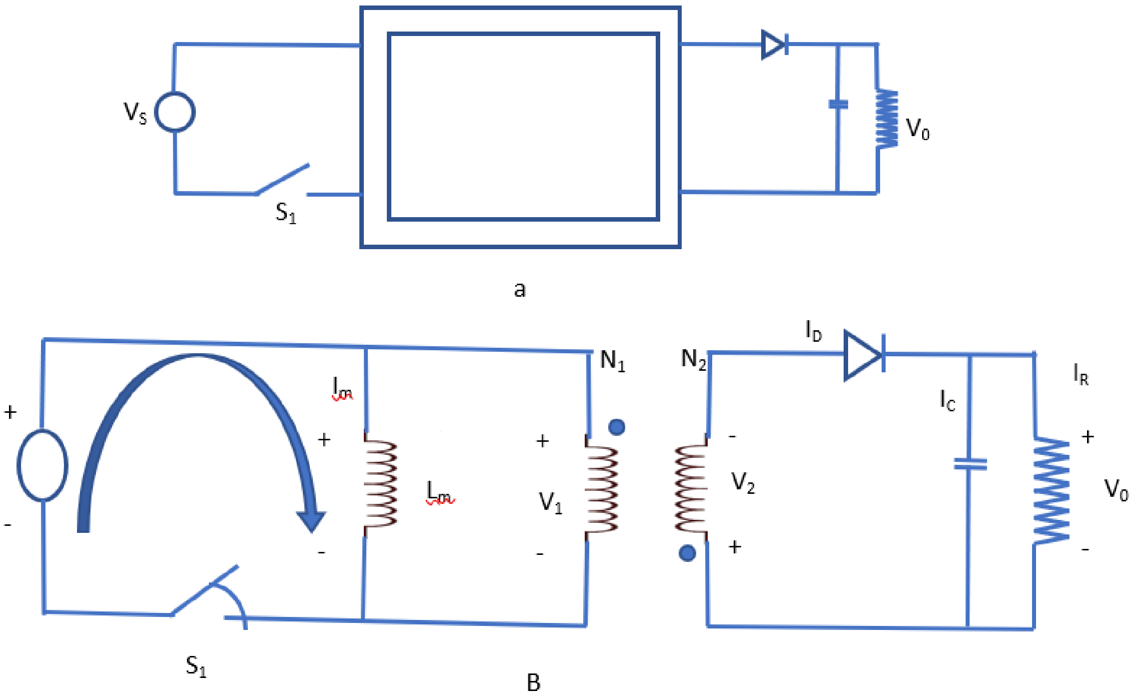


figure 4.18 a) DC-DC isolation converter b) equivalent circuit

Primary winding takes the energy from the source when S_1 switch is on. And when switch is off then store energy is transfer in secondary. In figure 4.18 (b) L_m is the magnetizing inductances. Consider that the transformer loss is negligible and V_0 voltage is almost constant. Also, one more thing that ideal switch is use.

We know, $D = \frac{t_{ON}}{T}$

$t_{ON} = DT$

And $t_{OFF} = (1\text{-}D)\ T$

$t_{OFF} = D'T$

we will divide into 2 mode 1) switch is on, 2) switch is off.

When S_1 is on current through L_m and the L_m polarity same as supply voltage polarity as it is parallel to V_S shown in figure 4.18 (b). Throughout the operation the N_1 top is doted so it is positive. It means the current is entering from dot terminal in N_1 side and it must leave from doted terminal from N_2. For that reason, N_2 top side is (-ve) so the output diode is rivers bias & it's represented as open circuit.

As secondary side is open circuit no current is passing through secondary as well as primary. The current will be present at L_m. On that time output capacitor provide power to the load.

Analysis when S_1 on,

$$V_1 = V_S = L_m \frac{di_{Lm}}{dt}$$

$$\frac{V_S}{L_m} = \frac{di_{Lm}}{dt} \qquad [\Delta t = DT \text{ as we consider on stage}]$$

$$\frac{di_{Lm}}{dt} = \frac{\Delta I_{Lm}}{DT} = \frac{V_S}{L_m}$$

So, the change of the current on the DT through the magnetizing inductance,

$$(\Delta I_{Lm})_{close} = \frac{V_S\, DT}{L_m} \quad \text{--------------} \ (51)$$

If we talk abought secondary side, we found that $I_2 = 0$, for that I_1 is also 0 because it is ideal transformer. Secondary voltage is

$$V_2 = V_1 \frac{N_2}{N_1} = V_S \frac{N_2}{N_1}$$

Voltage across the diode

$$V_D = -V_0 - V_S \frac{N_2}{N_1}$$

when S_1 off,

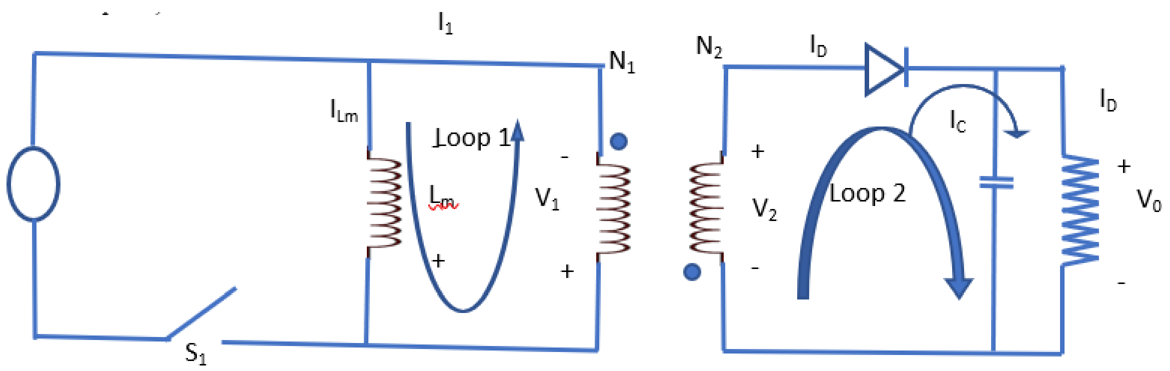


figure 4.19 DC-DC isolation converter when S_1 off

S_1 off, the I_{Lm} current will flow through loop 1 in figure 4.19. It is entering from non doted end. So, in secondary it should leave from non doted end and for that the output diode is in action. Now there will be flow of current through diode the high frequency ripple current go through capacitor and the average current will go to load resistance. Now the secondary winding parallel with load so, V_2 & V_1 are same & the voltage will be reflected back to primary according to turns ratio, but the polarity is change.

$$V_1 = -V_0 \left[\frac{N_1}{N_2}\right]$$

$$V_2 = -V_0$$

So,

$$V_1 = V_2 \left[\frac{N_1}{N_2}\right]$$

We know VL = $L_m \left[\frac{di_L}{dt}\right]$ in this stage $V_L = V_1$ so we can write,

$$L_m \left[\frac{di_L}{dt}\right] = -V_0 \left[\frac{N_1}{N_2}\right]$$

$$\left[\frac{di_L}{dt}\right] = \frac{-V_0}{L_m} \left[\frac{N_1}{N_2}\right]$$

$$\left[\frac{di_L}{dt}\right] = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = -\frac{V_0}{L_m} \left[\frac{N_1}{N_2}\right]$$

$$(\Delta i_L)_{open} = -\frac{V_0(1-D)T}{L_m} * \left[\frac{N_1}{N_2}\right] \text{ ------------- (52)}$$

In figure 4.20 this is the complete waveform of flyback converter when the switch is on the magnetizing inductor current build up linearly and it is same as supply current. on that time output diode vis open so diode current is zero. Also, primary winding voltage is same as supply voltage.

When we turn off the switch magnetizing inductor current fail down linearly, so the source current is zero. But now output diode is conducting so the diode current shape is same as magnetizing inductor current. If we talk abought voltage across primary winding, as current change its polarity it should be $-V_0 (N_1/N_2)$.

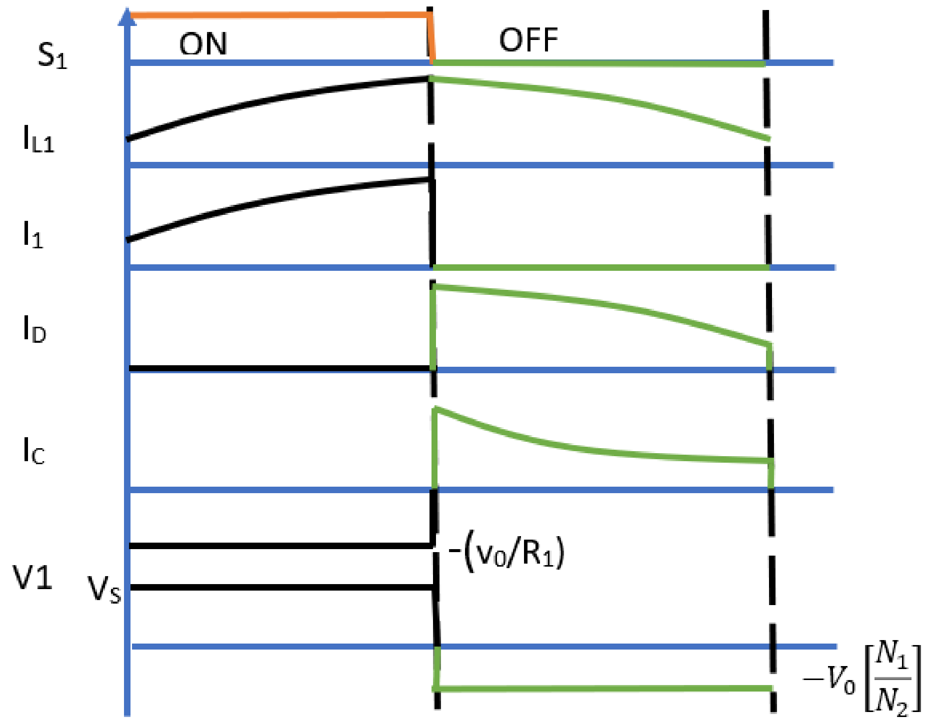


figure 4.20 DC-DC isolation converter waveform

CHAPTER 5

Harmonics In LED Driver

5.1 Harmonics

Harmonic signals are those type of signal which having frequency other than the fundamental frequency. We split this into two-part A) Current harmonics, B) Voltage harmonics

There are many effects due to current harmonics like, additional copper loss, additional core loss due to increased eddy current & also, electro-magnetic interference with closes communication circuit will increased.

And in case of voltage harmonics the effect is dielectric stress on insulator will increased, Electro-static interference with nearby communication circuits also be affected.

5.1.1 Sources of harmonics

We know that in case of non-linear load like power electronic converters, electronic devices, TV, Computer, Motor drives, Choke of tubular light those are the main reason for generating harmonics in system.

5.2 Mathematical Analysis of Harmonics

Due to switching harmonics injected into system. The non-fundamental component of voltage, current or power.

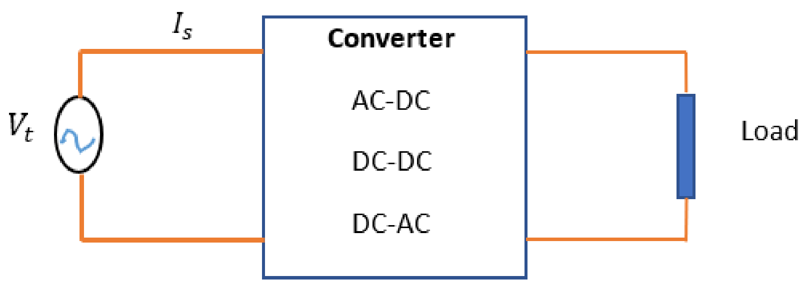


Figure 5.1 converter block

$V_t = V_m sin\omega t$,

$I_s(t) = non - sinusoidal\ but\ periodic,$

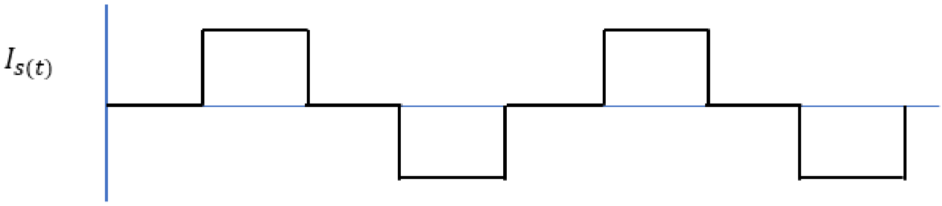


Figure 5.2 $Current\ Waveform\ non-sinusoidal\ \ periodic$

Any non-sinusoidal periodic function can be represented by Fourier series to analysis which harmonic component are present.

$I_s(t) = I_0 + I_{m1} sin\omega t + I_{m2} \sin 2\omega t + \ I_{m3} \sin 3\omega t + \ldots$

$I_s(t) = non - sinusoidal\ but\ periodic$

$I_0 = DC$,

$I_{m1} sin\omega t = 1st\ fundamental$

$I_{m2} sin\omega t = 2nd\ fundamental$

$I_{m3} sin\omega t = 3rd\ fundamental$

5.2.1 Disadvantage of Harmonics

1. Rms current will increase, because it has Dc with all fundamental components (1^{st},2^{nd},3^{rd}, etc)

$$\boldsymbol{I_{rms}} = \sqrt{(\boldsymbol{I_0})^2 + \frac{\mathbf{1}}{\mathbf{2}}\left(\boldsymbol{I_{m1}}^2 + \boldsymbol{I_{m2}}^2 + \boldsymbol{I_{m3}}^2 + \cdots\right)}$$

2. As I_{rms} increases cupper loss also increases
3. Power factor also go down as we know that $P = V * I * cos\emptyset$.
4. Problem arises on rotating machines, transformer, relay etc.

5.2.2 Type of Harmonics

Two types of harmonics are there.

A. DC Harmonics
B. AC Harmonics

5.2.2.1 Dc Harmonics:

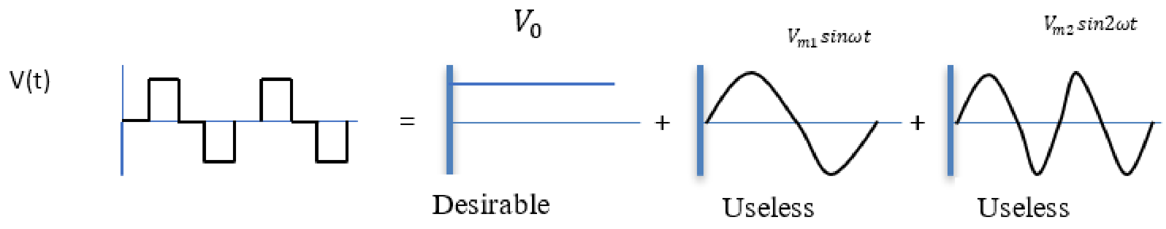


Figure 5.3 DC harmonics Waveform analysis

In case of DC harmonics in the equitation

$$I_s(t) = I_0 + I_{m1} sin\omega t + I_{m2} \sin 2\omega t + \ I_{m3} \sin 3\omega t + ...$$

We want only dc component.
The full wave Rectifier wave form is represented by,

$$V_0(t) = a_0 + \sum_{n=1}^{\infty} a_n cos\ n\omega_0 t + b_n sin\ n\omega_0 t$$

$$V_0(t) = a_0 + \sum_{n=1}^{\infty} c_n \sin\ (n\omega_0 + \emptyset_m)$$

$$c_n = \sqrt{{a_n}^2 + {b_n}^2} \qquad \& \qquad \emptyset_m = \tan^{-1} \frac{a_n}{b_n}$$

If we want to find out V_{Rms},

$$\boldsymbol{V_{rms}} = \sqrt{(\boldsymbol{a_0})^2 + \frac{\mathbf{1}}{\mathbf{2}}({\boldsymbol{C_1}}^2 + {\boldsymbol{C_2}}^2 + {\boldsymbol{C_3}}^2 + \cdots)}$$

In the DC harmonics, $\boldsymbol{a_0}$ is desirable (useful in dc load) and ${\boldsymbol{C_1}}^2 + {\boldsymbol{C_2}}^2 + {\boldsymbol{C_3}}^2 + \cdots$ those are useless in Dc load.

$$\boldsymbol{V^2}_{\boldsymbol{rms}} = (\boldsymbol{a_0})^2 + \frac{\mathbf{1}}{\mathbf{2}}({\boldsymbol{C_1}}^2 + {\boldsymbol{C_2}}^2 + {\boldsymbol{C_3}}^2 + \cdots)$$

$$\boldsymbol{V^2}_{\boldsymbol{rms}} - (\boldsymbol{a_0})^2 = \frac{\mathbf{1}}{\mathbf{2}}({\boldsymbol{C_1}}^2 + {\boldsymbol{C_2}}^2 + {\boldsymbol{C_3}}^2 + \cdots)$$

$$\sqrt{\boldsymbol{V^2}_{\boldsymbol{rms}} - (\boldsymbol{a_0})^2} = \sqrt{\frac{\mathbf{1}}{\mathbf{2}}({\boldsymbol{C_1}}^2 + {\boldsymbol{C_2}}^2 + {\boldsymbol{C_3}}^2 + \cdots)}$$

Now,

$$\left[\sqrt{\frac{1}{2}\left({C_1}^2 + {C_2}^2 + {C_3}^2 + \cdots\right)} = Harmonic\ voltage = V_{Oh}\right]$$

$$\sqrt{V^2{}_{rms} - (a_0)^2} = V_{oh} \qquad (1)$$

That equitation (1) divides with a_0,that is desirable.

So, we get,

$$\sqrt{\left(\frac{V_{rms}}{a_0}\right)^2 - \left(\frac{a_0}{a_0}\right)^2} = \frac{V_{oh}}{a_0}$$

$$\sqrt{\left(\frac{V_{rms}}{a_0}\right)^2 - 1} = \frac{V_{oh}}{a_0} \qquad (2)$$

$\frac{V_{oh}}{a_0}$ *is also known as, "Voltage Ripple Factor"* (VRF)

And $\frac{V_{rms}}{a_0}$ known as "Form Factor" (FF).so we can also write the equitation (2),

$$VRF = \sqrt{(FF)^2 - 1}$$

5.2.2.2 AC Harmonics

If we consider the inverter waveform, that is non-sinusoidal wave but it's periodic

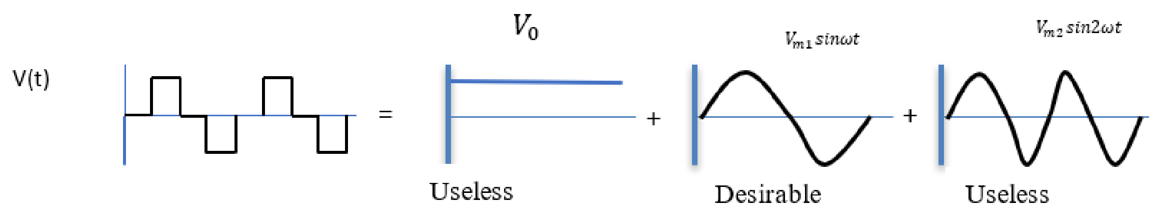


Figure 5.4 AC harmonics Waveform analysis

We know,

$$V(t) = V_0 + V_{m1}sin\omega t + V_{m2}\sin 2\omega t + \ V\sin 3\omega t + \ldots$$

$$V_{rms} = \sqrt{(V_0)^2 + \frac{1}{2}\left({V_{m1}}^2 + {V_{m2}}^2 + {V_{m3}}^2 + \cdots\right)}$$

In the AC harmonics, $\boldsymbol{V_{m1} sin\omega t}$ is desirable (useful in ac load) and $\boldsymbol{V_0}^2, \boldsymbol{V_{m2}}^2, \boldsymbol{V_{m3}}^2$ ... those are useless in Ac load.

$$\boldsymbol{V^2}_{rms} = (\boldsymbol{V_0})^2 + \frac{\boldsymbol{1}}{\boldsymbol{2}}\left(\boldsymbol{V_{m1}}^2 + \boldsymbol{V_{m2}}^2 + \boldsymbol{V_{m3}}^2 + \cdots\right)$$

$$\boldsymbol{V^2}_{rms} = (\boldsymbol{V_0})^2 + \frac{\boldsymbol{1}}{\boldsymbol{2}}\left(\boldsymbol{V_{m1}}^2 + \boldsymbol{V_{m2}}^2 + \boldsymbol{V_{m3}}^2 + \cdots\right)$$

This is($\frac{1}{2}\left(\boldsymbol{V_{m1}}^2 + \boldsymbol{V_{m2}}^2 + \boldsymbol{V_{m3}}^2 + \cdots\right)$) in turms of max value.we can represent it in RMS value.

$$\boldsymbol{V^2}_{rms} = (\boldsymbol{V_0})^2 + \left(\boldsymbol{V_{rms\,m1}}^2 + \boldsymbol{V_{rms\,m2}}^2 + \boldsymbol{V_{rms\,m3}}^2 + \cdots\right)$$

$$\boldsymbol{V^2}_{rms} - \boldsymbol{V_{rms\,m1}}^2 = (\boldsymbol{V_0})^2 + \left(\boldsymbol{V_{rms\,m2}}^2 + \boldsymbol{V_{rms\,m3}}^2 + \cdots\right)$$

$$(\boldsymbol{V^2}_{\boldsymbol{0}} + \boldsymbol{V_{rms\,m2}}^2 + \boldsymbol{V_{rms\,m3}}^2 += \text{Harmonics voltage} = V_{oh})$$

$$\boldsymbol{V^2}_{rms} - \boldsymbol{V_{rms\,m1}}^2 = \boldsymbol{V_{oh}} \quad \text{-----------------(1)}$$

That equitation (1) divides with $\boldsymbol{V_{rms\,m1}}$,that is desirable.
So, we get,

$$\sqrt{\left(\frac{\boldsymbol{V_{rms}}}{\boldsymbol{V_{rms\,m1}}}\right)^2 - \left(\frac{\boldsymbol{V_{rms\,m1}}}{\boldsymbol{V_{rms\,m1}}}\right)^2} = \frac{\boldsymbol{V_{oh}}}{\boldsymbol{V_{rms\,m1}}}$$

$$\sqrt{\left(\frac{\boldsymbol{V_{rms}}}{\boldsymbol{V_{rms\,m1}}}\right)^2 - 1} = \frac{\boldsymbol{V_{oh}}}{\boldsymbol{V_{rms\,m1}}} \quad \text{-----------------(2)}$$

$$\frac{\boldsymbol{V_{oh}}}{\boldsymbol{V_{rms\,m1}}} = Total\ Harmonic\ Disturtion(THD)$$

THD is harmonic current or voltage by fundamental current or voltage.
THD will give us the amount of deviation are present in any kind of electrical output.

$$\frac{\boldsymbol{V_{rms\,m1}}}{\boldsymbol{V_{rms}}} = Disturtion\ Factor = g$$

So, we can write,

$$\sqrt{\left(\frac{1}{g}\right)^2 - 1} = \frac{\boldsymbol{V_{oh}}}{\boldsymbol{V_{rms\,m1}}}$$

$$\sqrt{\left(\frac{1}{g}\right)^2 - 1} = \boldsymbol{THD}$$

Displacement power Factor (DPF) or Fundamental Power Factor (FPF) is the cosine of the angle between fundamental voltage ($\boldsymbol{V_{rms\,m1}}$) to fundamental Current ($\boldsymbol{I_{rms\,m1}}$).

5.3 Problems of Harmonics

Some of the problems associated with the harmonic interface are as follows:
1. Increase losses in the supply transformer.
2. Unwanted tripping of circuit breakers.
3. Possible cause of system resonance when power factor correction equipment is present on the system. This may impose high voltages, currents on the system which can be dangerous.
4. Premature ageing of electrical insulation.
5. Premature failure of power factor correction capacitor installations
6. Malfunctions or failure of some electrical circuits.
7. Efficiency loss in transmission and distribution depending on RMS current increase in lines.

5.4 Effects of Harmonic

Harmonic distortion causes various problems towards the power system. Over voltage problems, instability of zero voltage crossing firing circuits, overheating of neutral conductors and transformers and communication interferences are some of the current problems which found from harmonic distortion due to non -linear loads.

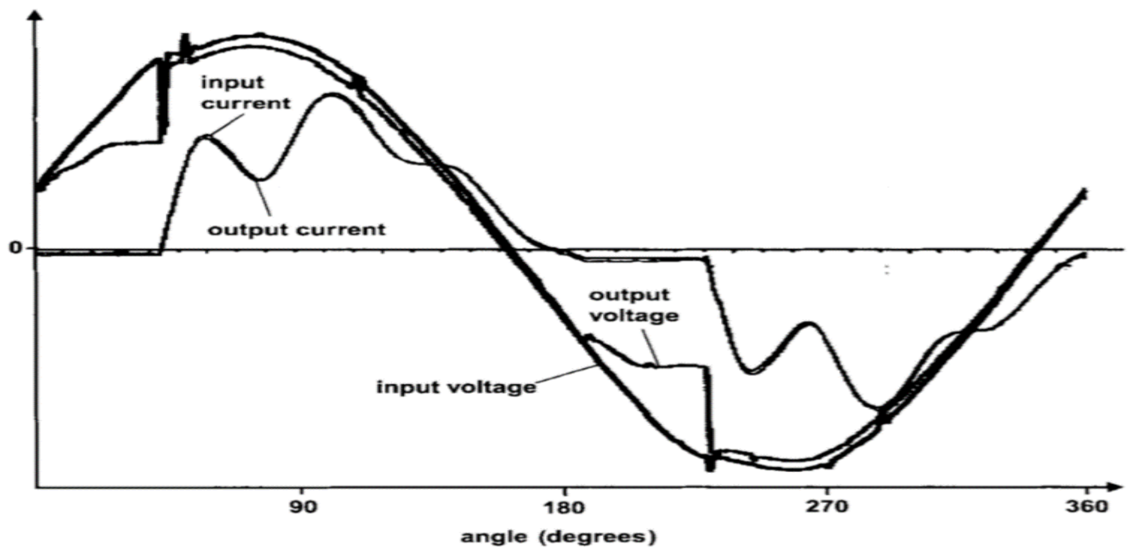


Figure 5.5 Effect of harmonics

5.5 Fourier Series to analysis of Harmonics

$$V_0(t) = a_0 + \sum_{n=1}^{\infty} a_n cos\, n\omega_0 t + b_n sin\, n\omega_0 t$$

It is the representation of any non-sinusoidal periodic function in sine or co-sine waveform.

Where,

$a_0 = \frac{1}{2\pi}\int'_{<2\pi>} f(t)dt$ &

$a_n = \frac{1}{\pi}\int'_{<2\pi>} f(t)cos\, n\omega_0 t d\omega_0 t$,

$b_n = \frac{1}{\pi}\int'_{<2\pi>} f(t)sin\, n\omega_0 t d\omega_0 t$

If our source voltage is rectangular and we want to make Fourier series of this waveform figure 5.6

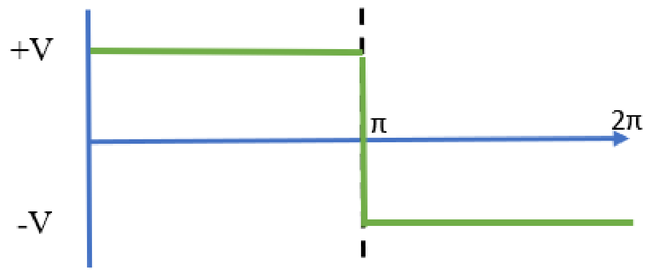


figure 5.6 Reference source voltage

This is the rectangular waveform which is odd function & in case of odd function we know,

$$a_0 = a_n = 0$$

So, we only get b_n,

$$b_n = \frac{1}{\pi}\int'_{<2\pi>} f(t)sin\, n\omega_0 t d\omega_0 t$$

In this waveform if we split this into 2 sections +ve half & -ve half we will get something like

$$b_n = \frac{2}{2\pi}\int_{\pi}^{0} Vsin\, n\omega_0 t d\omega_0 t + \int_{\pi}^{2\pi} -Vsin\, n\omega_0 t d\omega_0 t$$

$$b_n = \frac{V}{\pi}\left[\left(-\frac{cosn\omega_0 t}{n}\right)_{\pi}^{0} + \left(\frac{cosn\omega_0 t}{n}\right)_{\pi}^{2\pi}\right]$$

$$b_n = \frac{V}{n\pi}\{cosn\pi - (-cosn0)\} + \{cos2n\pi - (cosn\pi)\}$$

$b_n = \frac{2V}{n\pi}\{1 - cosn\pi\}$ -----------------(3)

Now in equitation 3 if we take two cases, when n is even (2,4,6…) then,

$$b_n = \frac{2V}{n\pi}\{1 - cosn\pi\}$$

$$b_n = 0$$

And in case of odd (n=1,3,5…)

$$b_n = \frac{2V}{n\pi}\{1 - cosn\pi\}$$

$$b_n = \frac{2V}{n\pi}\{1 - (-1)\}$$

$$b_n = \frac{4V}{n\pi}$$

So finally, we get

$$V_0(t) = \sum_{n=1,3,5}^{\alpha} \frac{4V}{n\pi} sin\ n\omega_0 t \text{ ----------------- (4)}$$

CHAPTER 6

Power Converter Tropology to Reduced THD

6.1 Select IIBFC tropology

In previous five chapter we have already discuss about all the tropology that we are suppose to use in this thesis paper in brief. Now it is time to implement those and trying to reach our objective that is control the input current harmonics (THD).

Fastly, we have to quickly compare our tropology with some other basic tropology. As we already know that for LEDs, we need DC supply. There are plenty of options to make DC power supply. Just using a step-down transformer with a rectifier in figure 6.1.

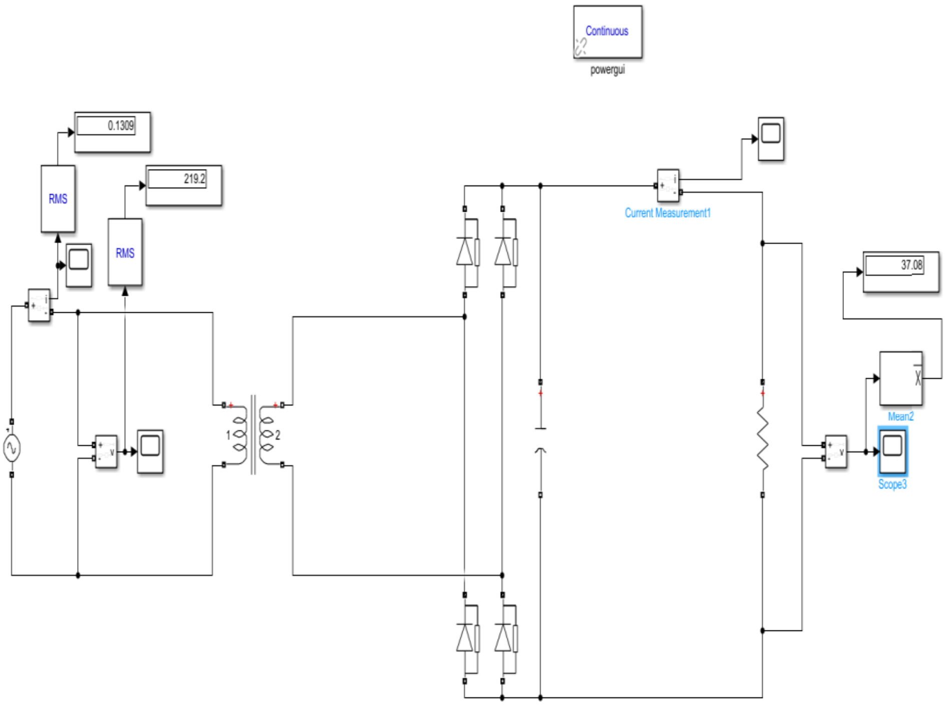


figure 6.1 Basic Rectifier with a step-down transformer

this is very old and basic DC power supply. But the main problem is the losses, and the supply current is no longer sinusoidal.it will contain 25.69% of THD. Figure 6.2

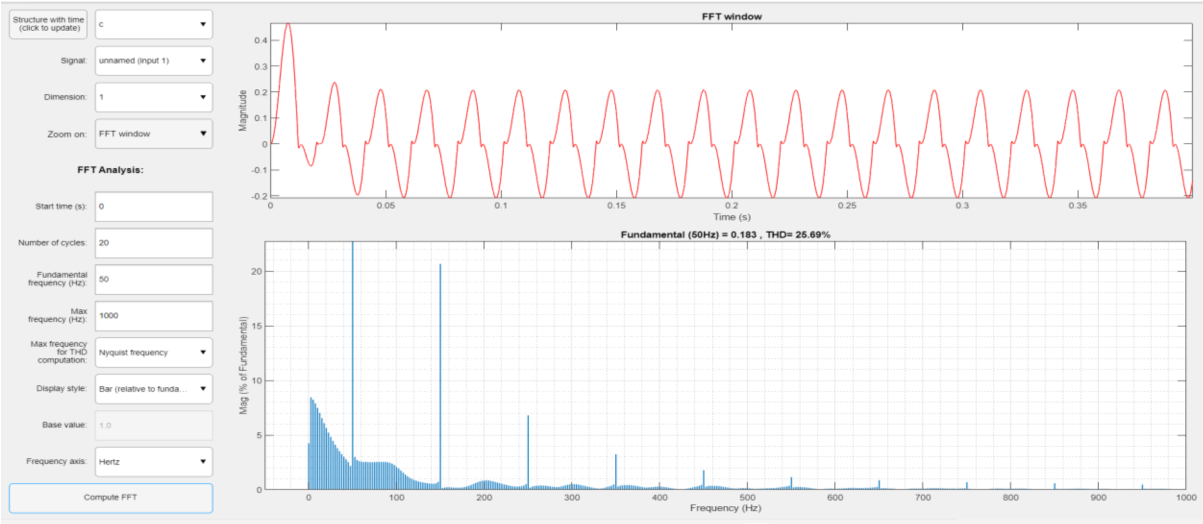


figure 6.2 Basic Rectifier with a step-down transformer THD analysis

Then we can omit the step-down transformer and use a buck converter for DC supply figure 6.3. Hare the THD level is improved 19.08% but it's doesn't match our objective in figure 6.4.

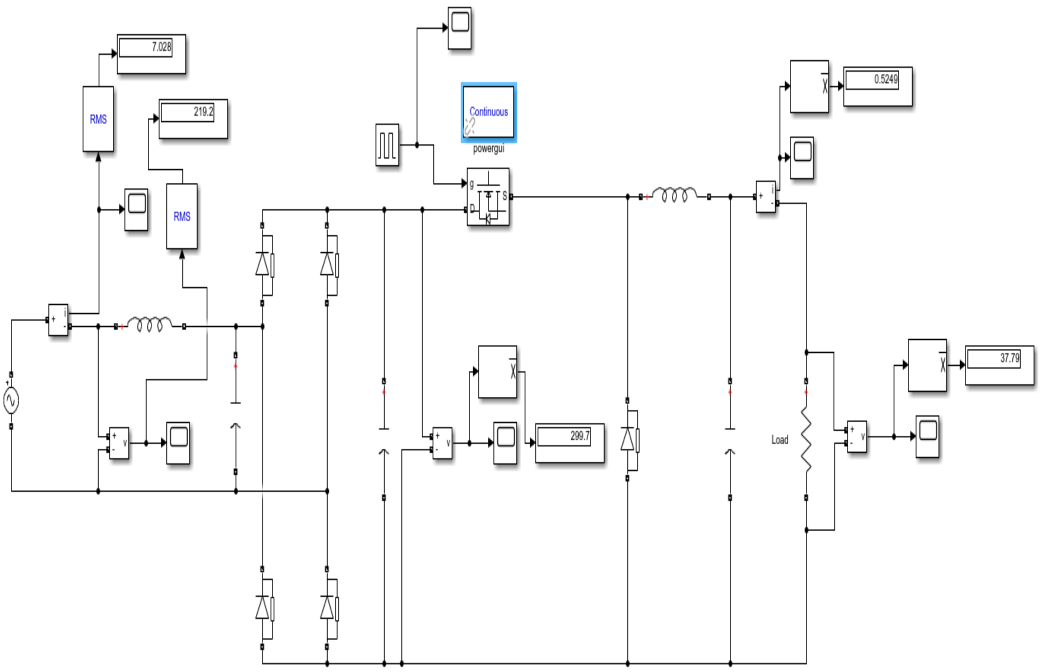


figure 6.3 Buck converter

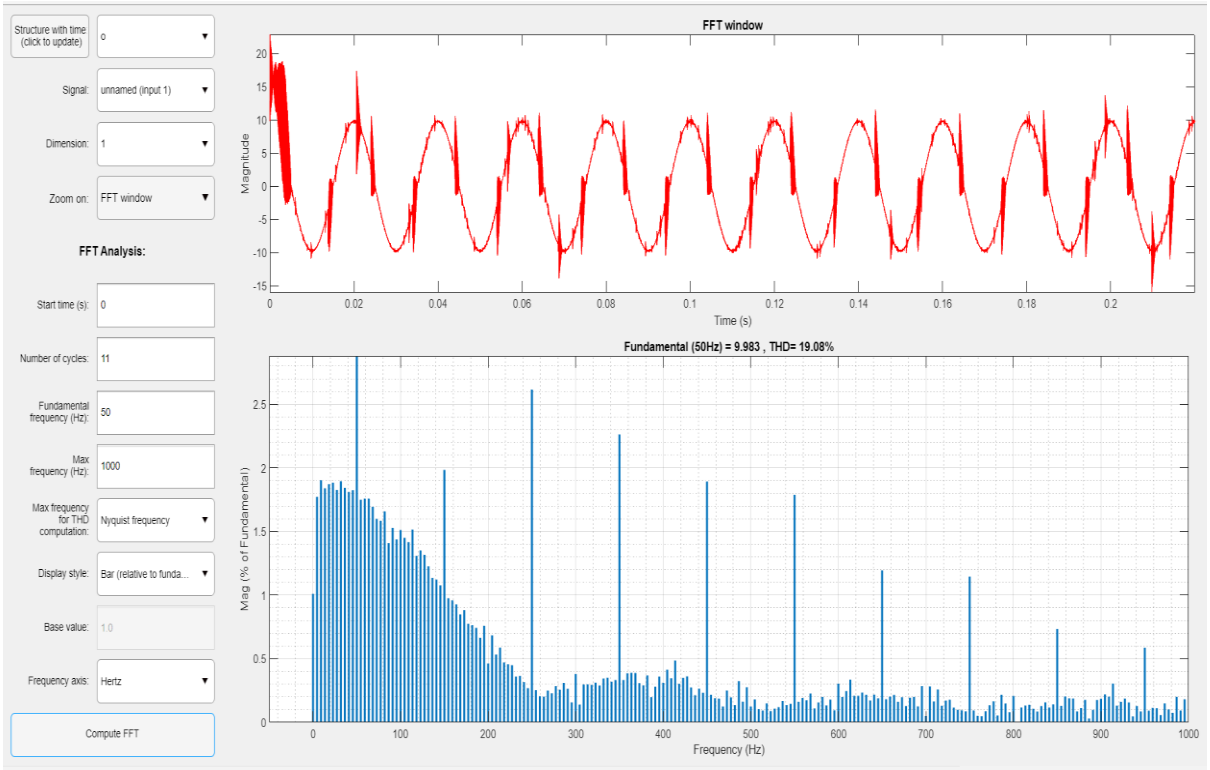


figure 6.4 Buck converter THD analysis

In figure 6.3 it lags the isolation between input and output so next we use transformer with DC-DC buck converter in figure 6.5.

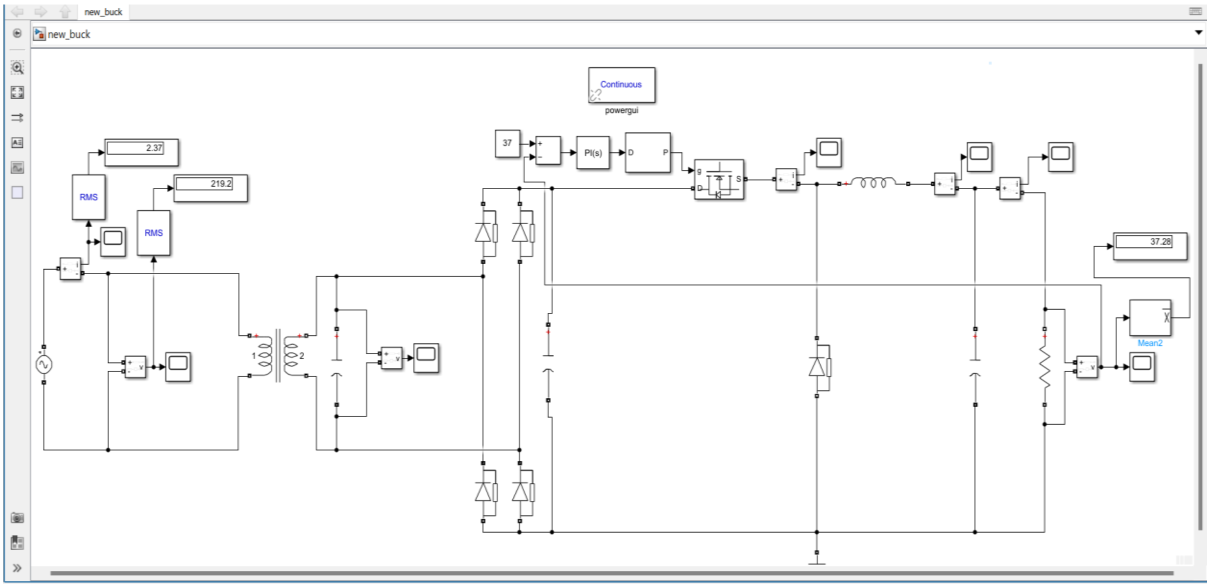


figure 6.5 Isolated Buck converter

in this configuration THD level is 7.66% in figure 6.6. but it is still not up to the mark.

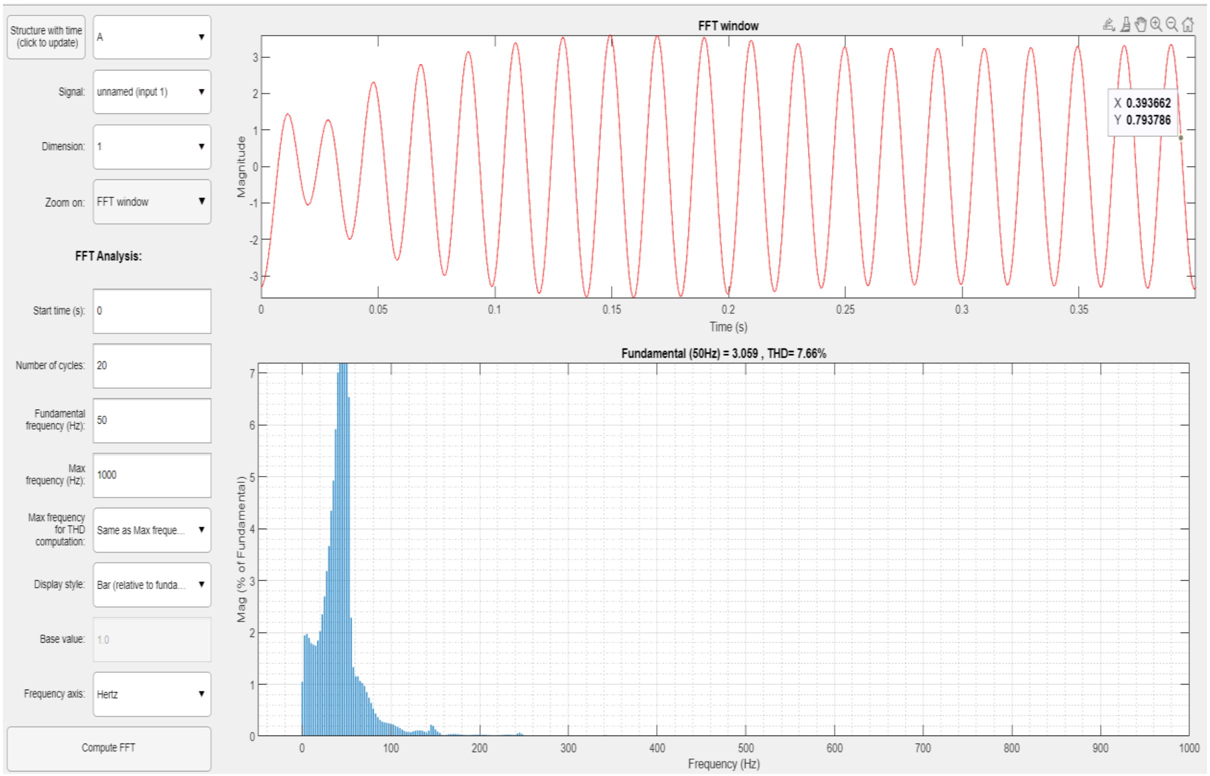


figure 6.6 Isolated Buck converter THD analysis

For this we can use Integrated Buck Flyback Converter (IBFC). This is very similar to figure 6.5 with interchanging some component and add a polarised transformer. In IBFC the buck converter and the Flyback converter works in a cascade mode figure 6.7. This IBFC presents several good features like fast output regulation, low current through the main switch and low voltage at buck output. But it's showing a limitation in THD and PF. When dimming is applied it became worst.

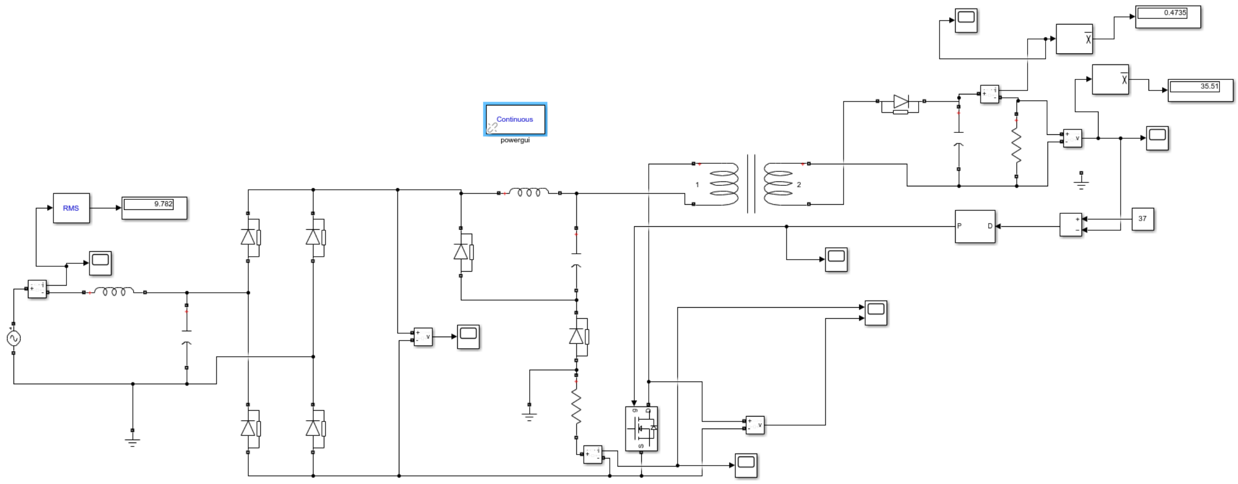


figure 6.7 Integrated Buck Flyback Converter (IBFC)

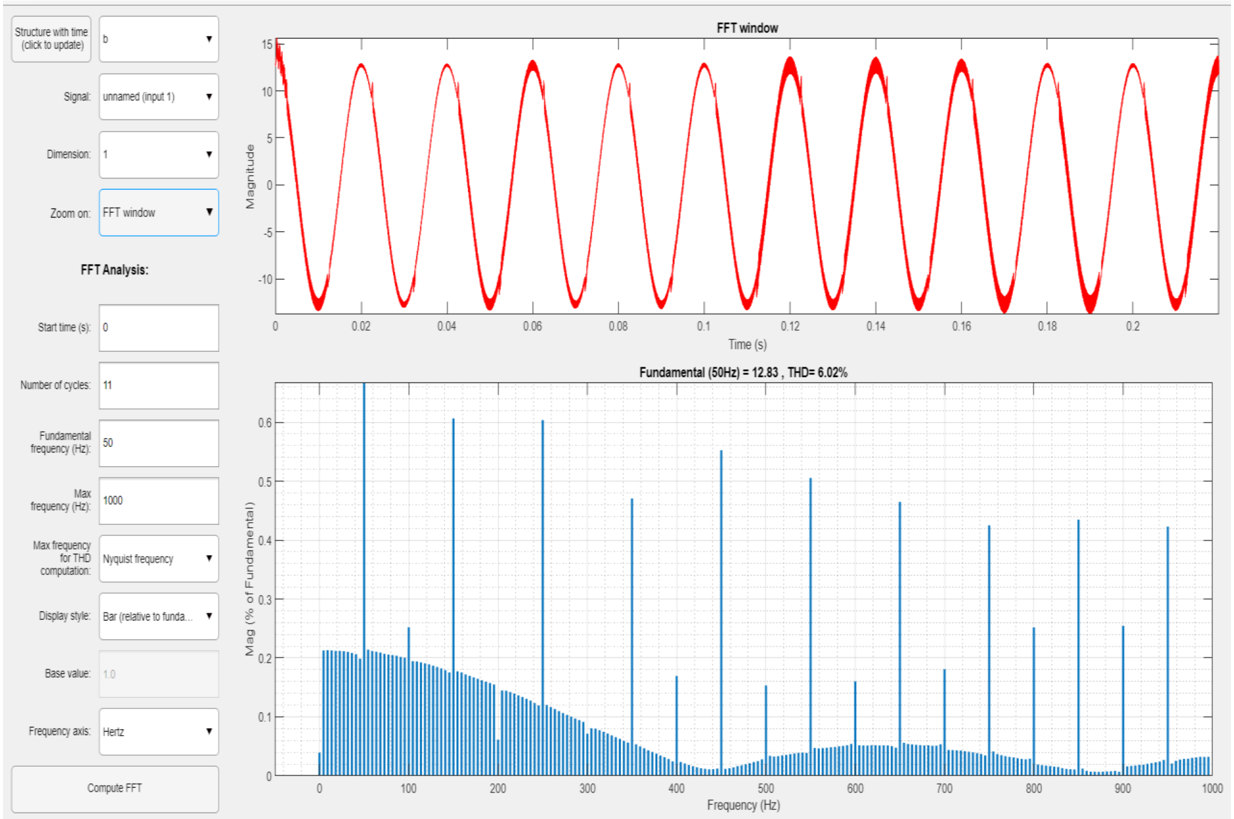


figure 6.8 Integrated Buck Flyback Converter (IBFC) THD analysis

By solving this issue Interleaved Integrated Buck Flyback Converter (IIBFC) tropology is used. In this tropology adding a capacitor between the diode bridge & IBFC also add a third winding to the flyback transformer with same polarity. Figure 6.9

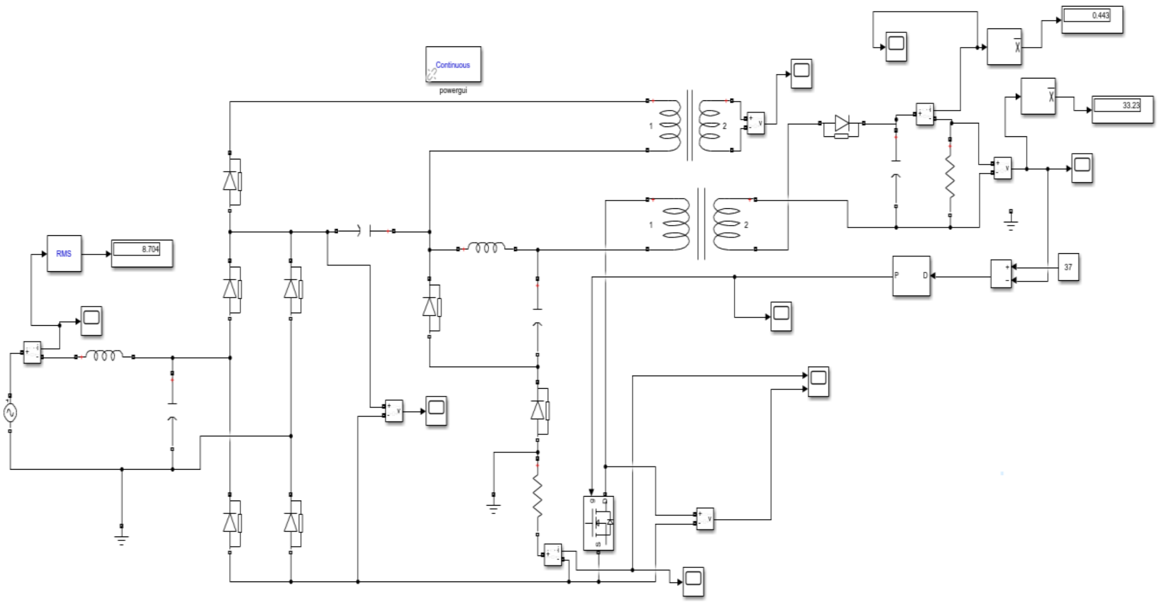


figure 6.9 Interleaved Integrated Buck Flyback Converter (IIBFC)

Finally, we can improve the THD level 2.52% in figure 6.10(a). This is done by inserting an interleaved capacitor. The interleaved capacitor voltage is fixed by a third winding added to the flyback tr. That's why IIBFC reduces the ripple. Figure 6.10(b) is the output current top and bottom is the output voltage waveform.

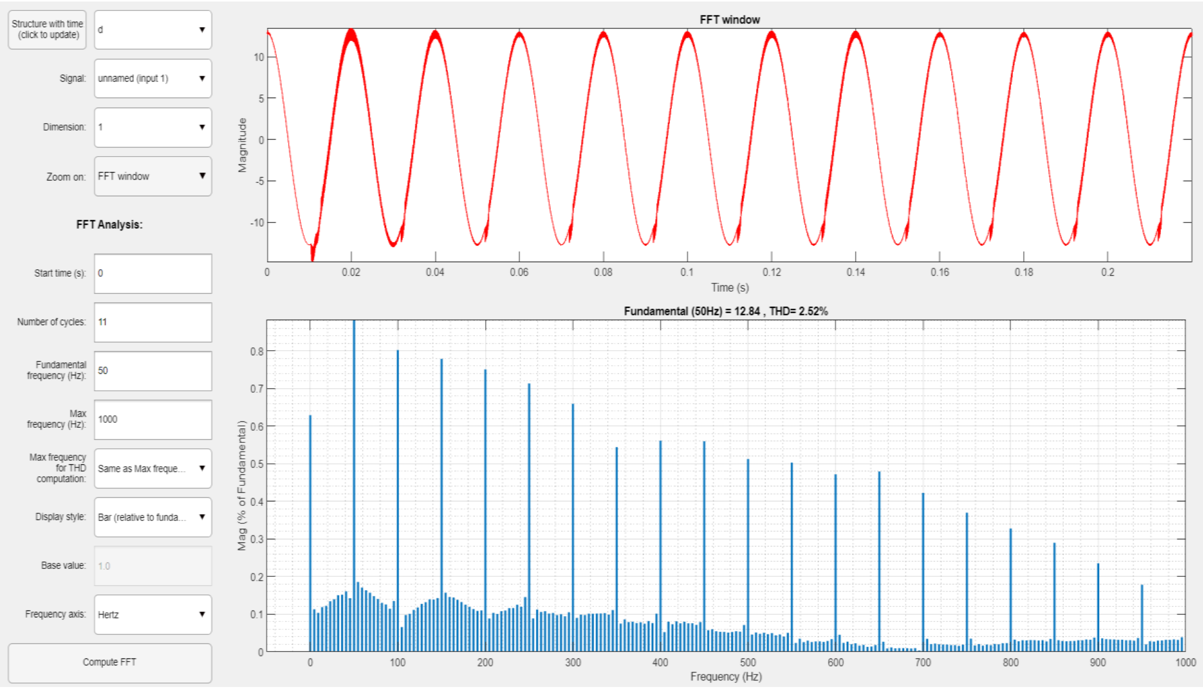


figure 6.10(a) Interleaved Integrated Buck Flyback Converter (IIBFC) THD analysis

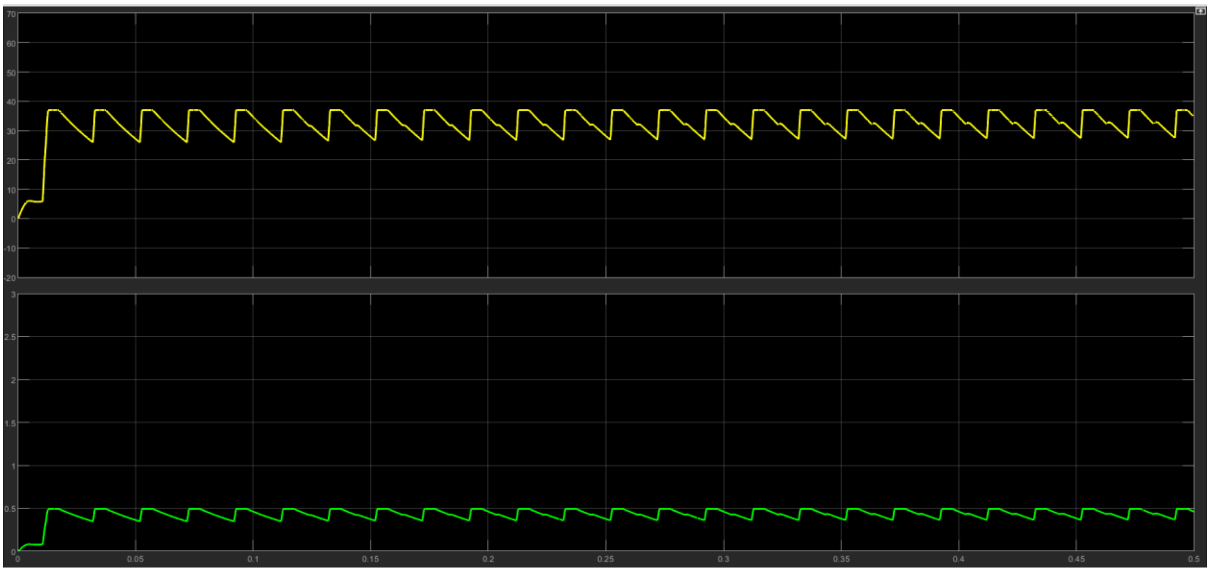


Figure 6.10(b) output Voltage top and bottom is the output Current waveform.

6.2 Result and Discussion

By using the Interleaved Integrated Buck Flyback Converter which is shortly known as IIBFC we can get several advantages like It is a single switch driver so the switching loss is less and easy to control, very low THD at dimming condition, Lower ripple compared to IBFC, so lower value of capacitor is needed to design the tropology and for all reason the driver has a more compact in size & lower cost

For simulation, I am using MATLAB Simulink software and Ni-Multisim. Though it is the control of dimmable Driver's harmonics for dimming I am using voltage control dimming. In Interleaved Integrated Buck Flyback Converter, we can vary the output voltage by controlling the switch, though it is a one switch devices the losses are batter.

In Simulink the controlling of switch is in figure 6.11. I am simply using the output voltage and r reference voltage which we suppose to achieved. By comparing this two voltages DC-DC signal generator generated PWM signal, and control the switch.

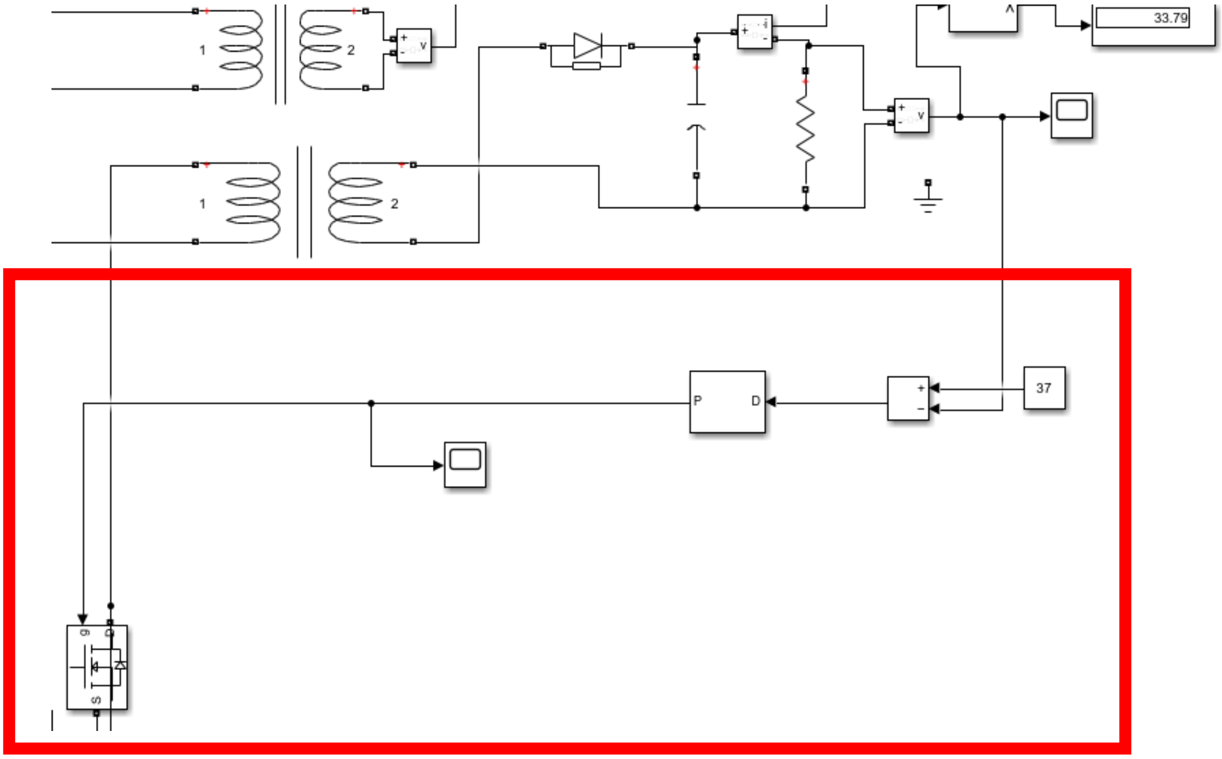


figure 6.11 switching of MOSFET

In practically we can use a modern switching tropology that is known as soft switching by using quasi resonant technique. In this technique when the power switch is on, apply input voltage across transformer primary. So, energy is store in transformer primary. Peak current starts from zero and ramp up to peak value, then compare it to the voltage & we turn off our switch.

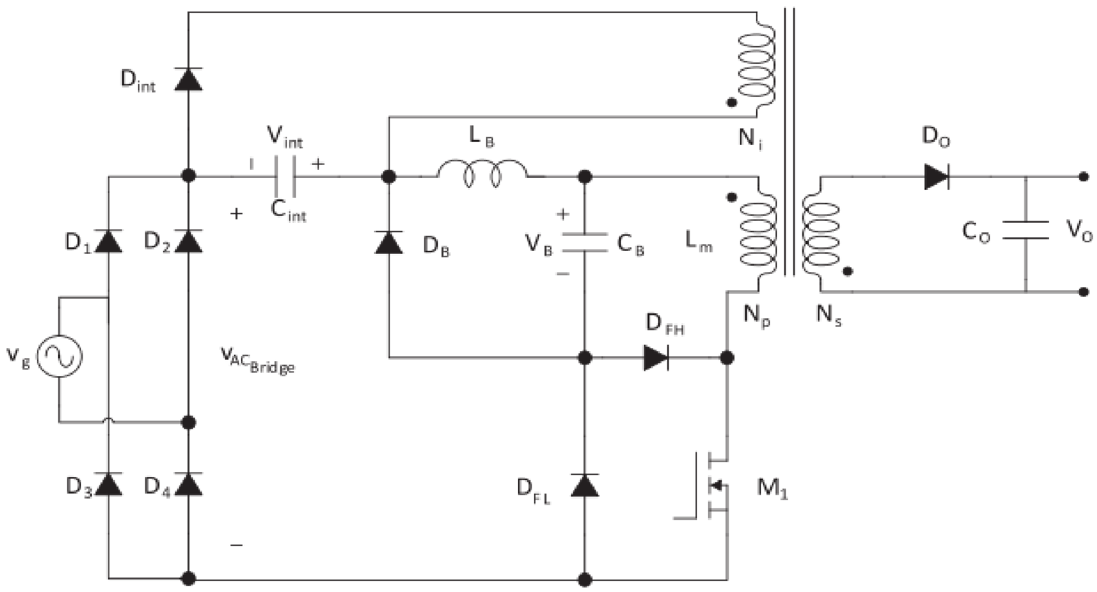


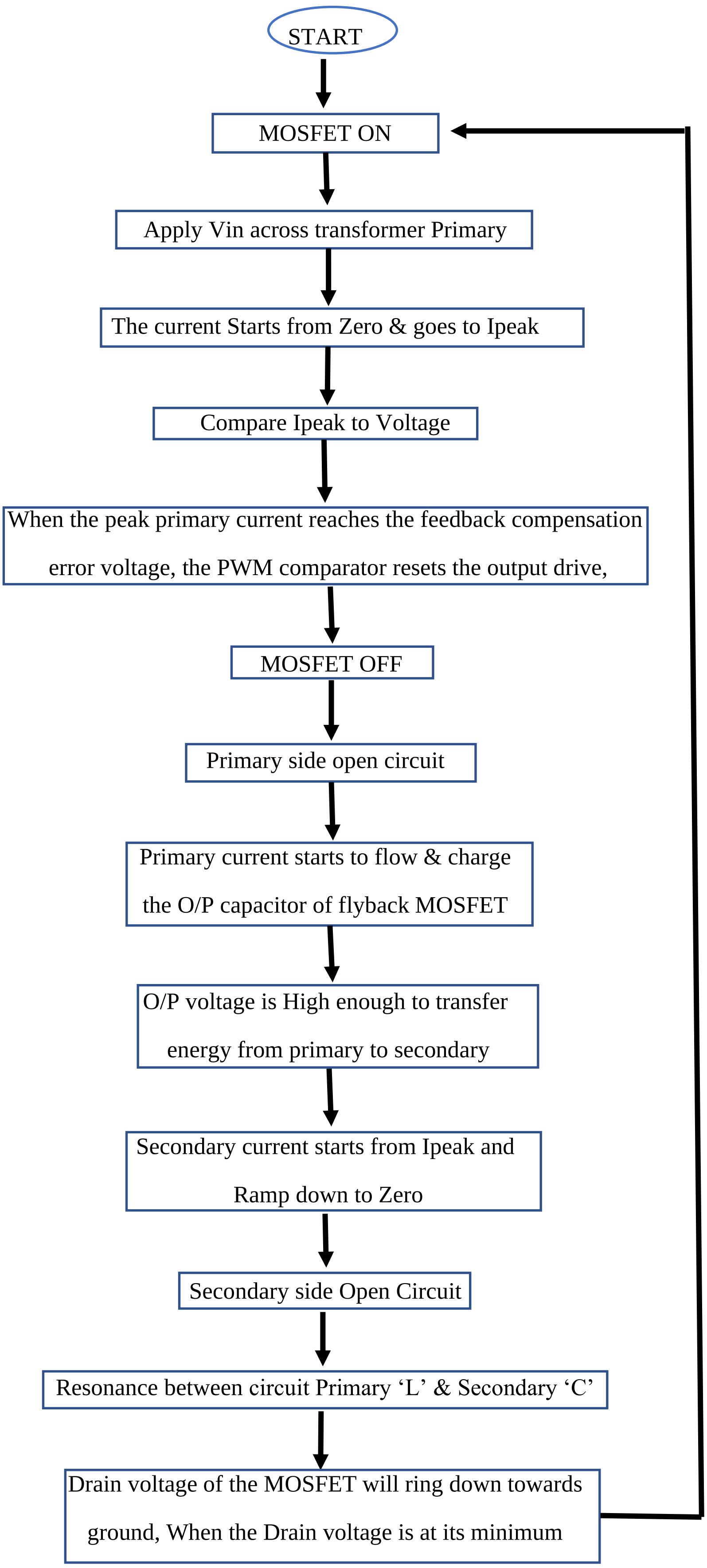
figure 6.12 Interleaved Integrated Buck Flyback Converter (IIBFC) schematic diagram

At this point primary current continues to flow but it will not charge the output capacitor of our MOSFET. At the same time the o/p voltage is high to conduct the o/p diode & transfer the energy from primary to secondary.

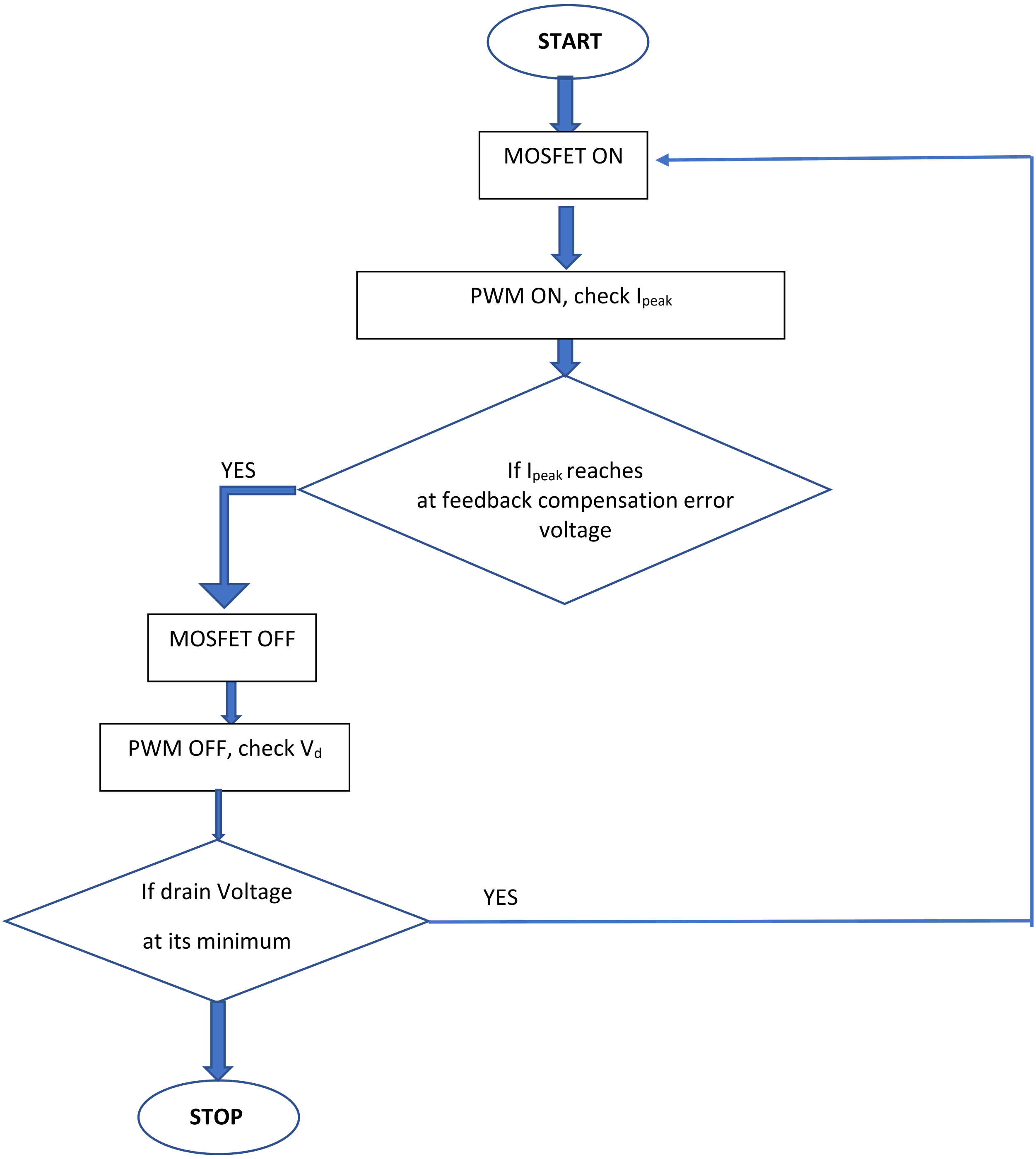
Once we take a look at the secondary current it will start at a peak and it will ramp down to zero. At zero transformer all energy from primary to secondary. when the secondary is zero, we have an open circuit in secondary. So now we have a resonance tank circuit which is the primary inductance and o/p capacitors of MOSFET.

For the resonance tank circuit once all the energy is transferring the drain voltage is get down to zero volt, when this happens, we will turn the switch on. Because if we turn the switch on at zero volt, we reduced the switching loss, and overall efficiency will improve.

6.2.1 Flow Chart of soft switching



6.2.2 Algorithm of soft switching



In figure 6.13 I made IIBFC in NI-Multisim, and tries to make the soft switching using two 741 op-Amp, one is for the MOSFET voltage and other is for the inductor current.

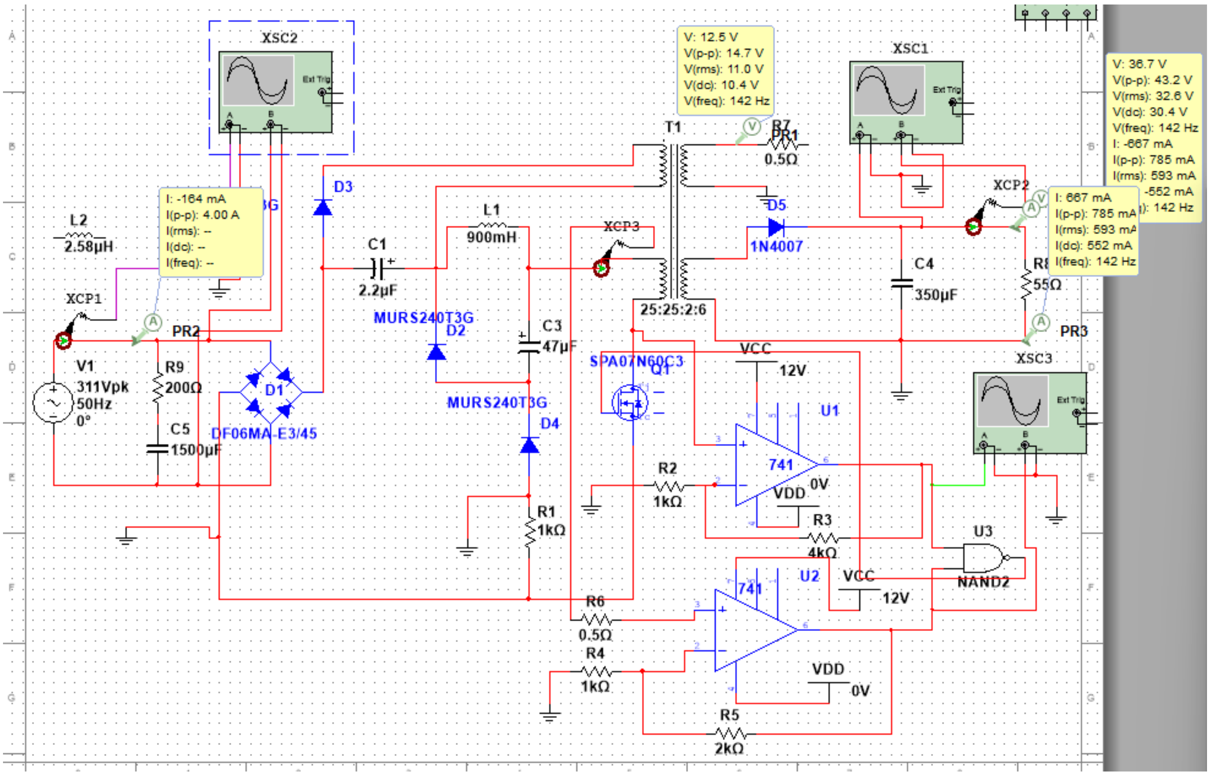


figure 6.13(a) Interleaved Integrated Buck Flyback Converter in Multisim

figure 6.13(b) IIBFC soft switching

In figure 6.13(b) red one is the voltage and the green one is the flyback current.

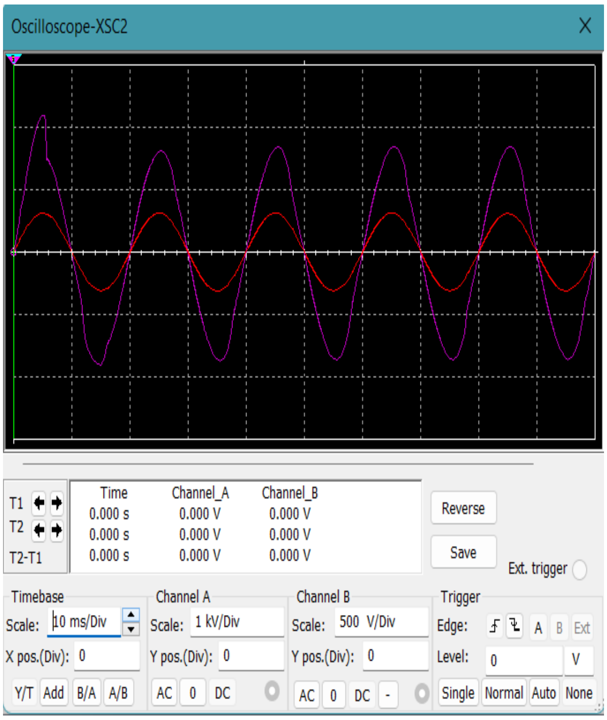


figure 6.13(c) IIBFC input voltage and current

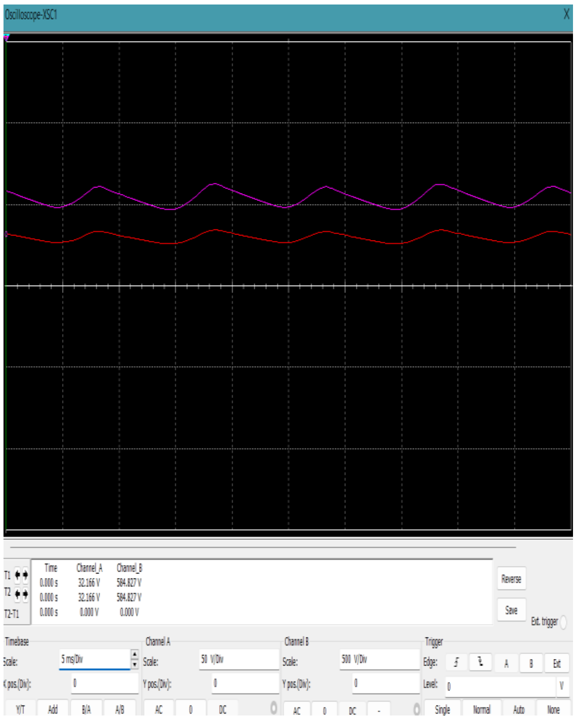


figure 6.13(d) IIBFC output voltage and current

In figure 6.13(c) red one is the input voltage and the purple one is the input current. In figure 6.13(d) red one is the output voltage and the purple one is the output current. If we measured the THD we can get 4.98% in figure 6.13(e).

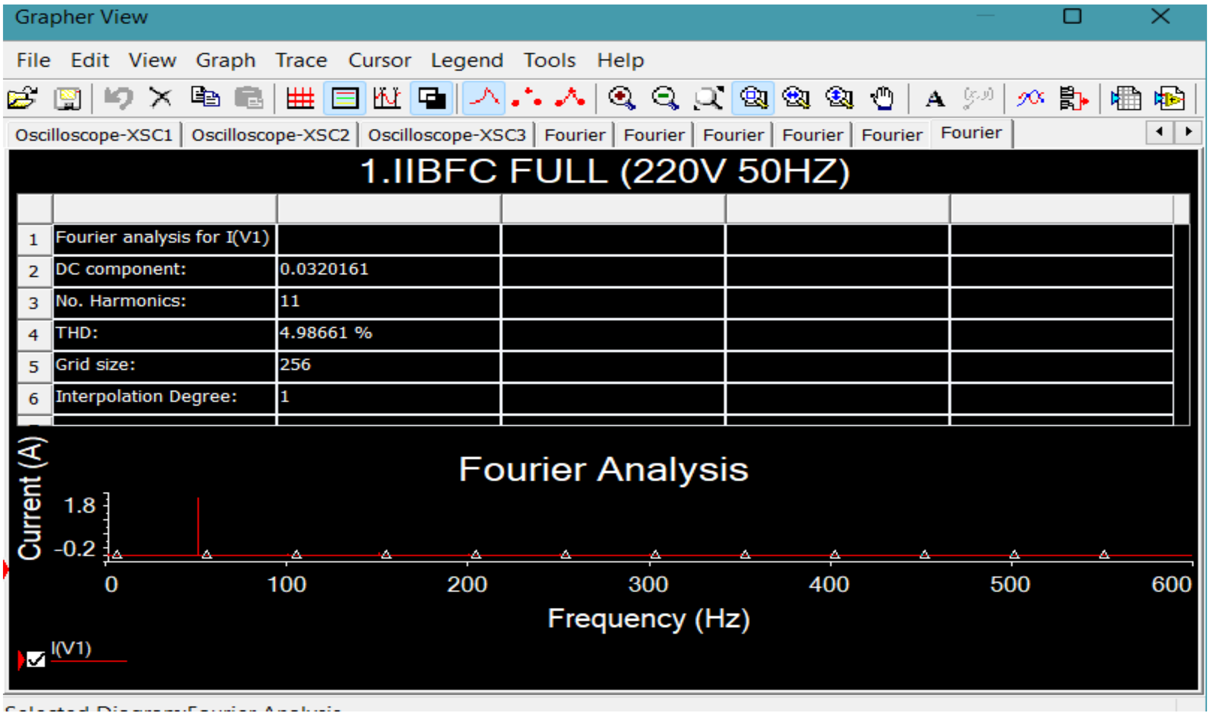


figure 6.13(e) IIBFC THD analysis

in figure 6.9 we get the THD value of 2.52%. But as we talking about dimming condition, reducing the output voltage we can change the power level. As we are setting the voltage to 25V in figure 6.14 we can see that the THD level is in the range 2.03% in figure 6.15.

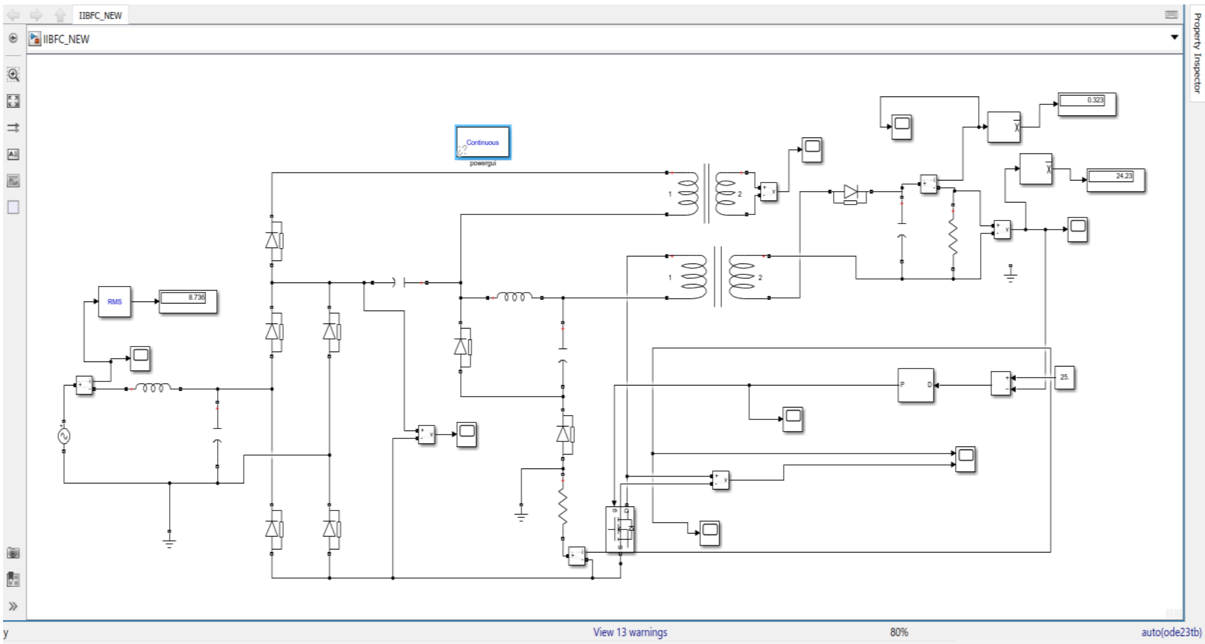


figure 6.14 IIBFC Dimming condition 25V O/P

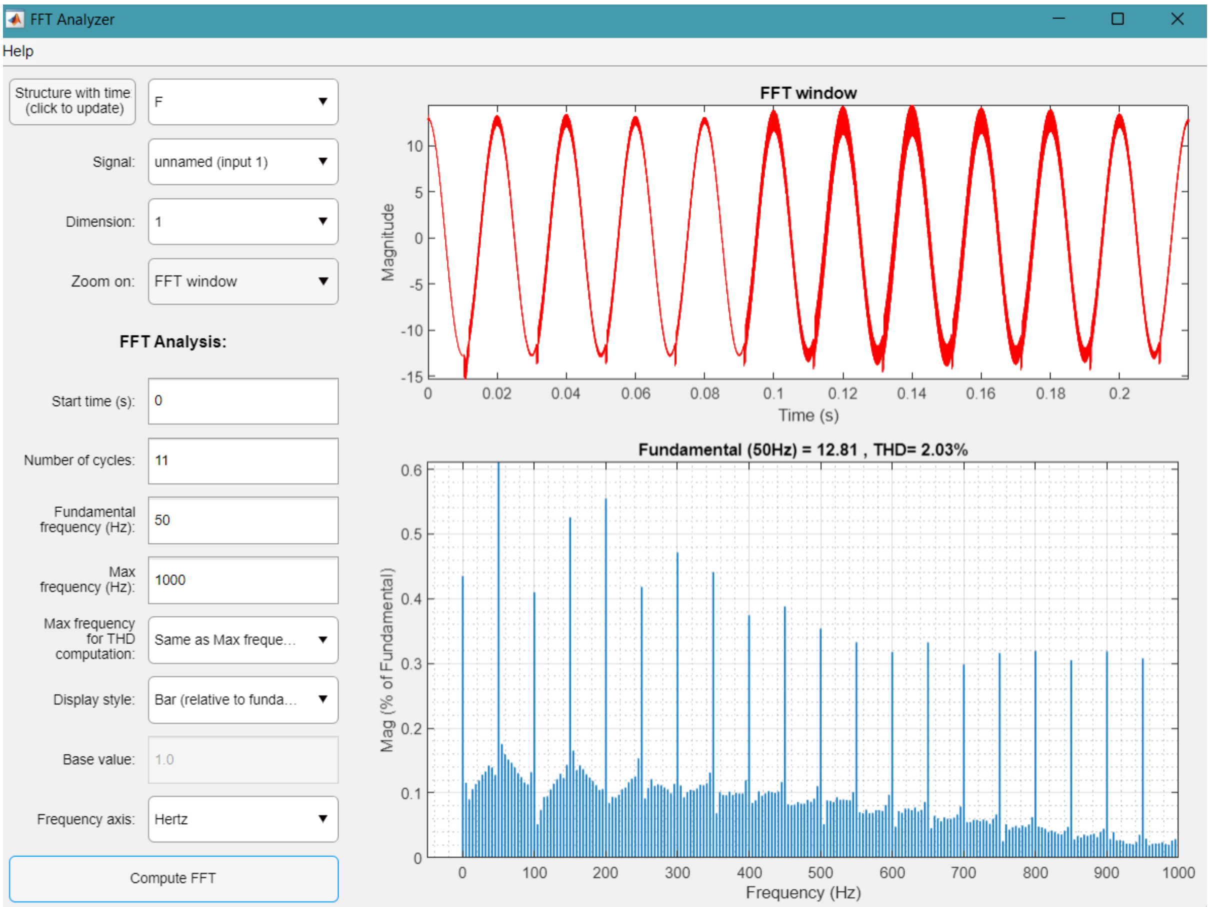


figure 6.15 IIBFC Dimming condition 25V O/P THD Analysis

6.3 Summary

Using the Interleaved Integrated Buck Flyback Converter which is known as IIBFC we can get many advantages like It is a single switch driver so the switching loss is less and easy to control, very low THD at dimming condition, Lower ripple compared to IBFC, so lower value of capacitor is needed to design the tropology and for all reason the driver has a more compact in size & lower cost. The main drawback in this paper is the output voltage is not smooth enough. There are some ripples in the output voltage if further it could be negated the input current THD will more efficient, and another challenging issue is for the controlling purpose. There are so many blocks has been used in simulating the diagram, due to that ripple are little more. Instate of so many blocks it is preferable to use a simple IC which has a feature of soft switching.

Reference

[1] https://www.electricalindia.in/harmonics-in-power-system/

[2] S. Uddin, H. Shareef, A. Mohamed and M. A. Hannan, "An analysis of harmonics from dimmable LED lamps," 2012 IEEE International Power Engineering and Optimization Conference Melaka, Malaysia, 2012, pp. 182-186, doi: 10.1109/PEOCO.2012.6230857.

[3] Khodijah Mohamed, Hussain Shareef, Azah Mohamed “Analysis of Harmonic Emission from Dimmable Compact Fluorescent Lamps” in the proceedings of *2011 International Conference on Electrical Engineering and Informatics*. Bandung, Indonesia, 17-19 July, 2011

[4] M. Iorgulescu, "Study of the lamp's influence on the power quality based on voltage and current analysis," 2015 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 2015, pp. 729-734, doi: 10.1109/ATEE.2015.7133901..

[5] S. Di Mauro, S. Musumeci, A. Raciti and G. Vasta, "Analysis of the current harmonics injected into the power grid by dimmable LED lamps," 2016 AEIT International Annual Conference (AEIT), 2016, pp. 1-6, doi: 10.23919/AEIT.2016.7892796.

[6] C. Carrillo and J. Cidras, "Harmonic model for the fluorescent lamp," 8th International Conference on Harmonics and Quality of Power. Proceedings (Cat. No.98EX227), 1998, pp. 1211-1217 vol.2, doi: 10.1109/ICHQP.1998.760212..

[7] G. Rata and M. Rata, "The study of harmonics from dimmable LED lamps, using CompactRIO," 2016 International Conference on Development and Application Systems (DAS), 2016, pp. 180-183, doi: 10.1109/DAAS.2016.7492570.

[8] M. Taraba, J. Adamec, M. Danko and P. Drgona, "The Effect of Dimming and non-Dimming LED Lights on the Quality of the Electrical Grid," 2019 20th International Scientific Conference on Electric Power Engineering (EPE), 2019, pp. 1-5, doi: 10.1109/EPE.2019.8778175.

[9]. C. Ionescu, M. Dima and D. Bonfert, "Flicker distortion power factor analysis in lighting LED's," 2017 IEEE 23rd International Symposium for Design and Technology in Electronic Packaging (SIITME), 2017, pp. 280-285, doi: 10.1109/SIITME.2017.8259908.

[10]. Dimitar Bogdanov, Angel Pachamanov, Kamen Georgiev " Some specifics of using LED drivers in dimming mode" 2018 Seventh Balkan Conference on Lighting (Balkan Light). Sofia, Bulgaria

[11] E. S. Lee, B. H. Choi, D. T. Nguyen and C. T. Rim, "The analysis of TRIAC dimming LED driver by variable switched capacitor for long life and high power-efficient applications," 2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), 2015, pp. 54-59, doi: 10.1109/ICPE.2015.7167766..

[12] Jong-Hyun Kim, Jee-Hoon Jung, Myung-Hyo Ryu and Ju-Won Baek, "A simple dimmer using a MOSFET for AC driven lamp," IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society, 2011, pp. 2872-2876, doi: 10.1109/IECON.2011.6119608.

[13] J. Dou, H. Ma, J. Yang, Y. Zhang and R. Guo, "An Improved Power Quality Evaluation for LED Lamp Based on G1-Entropy Method," in IEEE Access, vol. 9, pp. 111171-111180, 2021, doi: 10.1109/ACCESS.2021.3103052.

[14] J. Yang, H. Ma, J. Dou and R. Guo, "Harmonic Characteristics Data-Driven THD Prediction Method for LEDs Using MEA-GRNN and Improved-AdaBoost Algorithm," in IEEE Access, vol. 9, pp. 31297-31308, 2021, doi: 10.1109/ACCESS.2021.3059483.

[15]. Radwa M. Abdalaal, Carl Ho "Characterization of Commercial LED Lamps for Power Quality Studies" April 2021.

[16] G. Z. Abdelmessih, J. M. Alonso and W. Tsai, "Analysis and Experimentation on a New High Power Factor Off-Line LED Driver Based on Interleaved Integrated Buck Flyback Converter," in IEEE Transactions on Industry Applications, vol. 55, no. 4, pp. 4359-4369, July-Aug. 2019, doi: 10.1109/TIA.2019.2910785.

[17]. https://www.semanticscholar.org/paper/Chapter-1-Semiconductor-Pn-Junction-Theory-and-1.0/72bff9944a2cdd5cde17265fec09332b159d801b/figure/29

[18]. https://www.edn.com/the-nuts-bolts-of-leds-part-i/

[19]. https://www.researchgate.net/figure/Units-of-light-The-candela-cd-is-the-SI-unit-for-the-total-amount-of-light-produced-by_fig4_222833918

[20]. https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/semiconductor-diodes/vicharacteristicsofdiode.html

[21]. https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/semiconductor-diodes/vicharacteristicsofdiode.html

[22]. http://lednique.com/current-voltage-relationships/iv-curves/

[23] https://www.edn.com/the-nuts-bolts-of-leds-part-iii/

[24] https://www.edn.com/the-nuts-bolts-of-leds-part-iv

[25] https://electronics.stackexchange.com/questions/564190/current-mirror-led-circuit-with-constant-current-source

[26] https://www.sciencedirect.com/topics/engineering/dummy-load

[27]. https://www.etechnog.com/2021/11/regulated-power-supply-block-diagram-working.html