A Smart Universal Charger

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Approval Sheet

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Dedicated to

My Parents, My Supervisor & My friends

Abstract

The objective of this project is to develop a novel universal charger that can able to charge different electronic gadgets like laptops, smart phones, tablets etc. Conventionally different types of chargers or adapters are required for different types of gadgets as voltage rating of their batteries are different. At the same time it is cumbersome to carry all the chargers during our journey. So to avoid all these issues, in this project a universal charger has been developed which can take both AC (with any frequency) and DC as input with a wide range of voltage at the same time it can able to charge the battery with desired voltage level. Here in the proposed universal charger a Flyback converter has been cascaded with multilevel buck DC-DC converter. Multilevel buck DC-DC converter has been used to reduce the voltage and current rating of the power electronics switches as well as to reduce the magnetic requirement. A TOP227Y switch has been used to control the Flyback converter, whereas ARDUINO UNO micro-controller based board has been used to sense the voltage level required for electronics gadget and to control the output of multilevel buck converter based on the sensed voltage. Keeping view on distributed generation system the charger has been developed so that it can take both AC as well as DC as input. The charger has been simulated using Matlab Simulink to verify the proposed charger circuit. A laboratory prototype also has been developed and verified with admissible accuracy.

Nomenclature

CCM	:	Continuous conduction mode
DCM	:	Discontinuous conduction mode
PIV	:	Peak Inverse Voltage
I_p	:	Peak Current
I_R	:	Ripple current
I_{avg}	:	Average current
V_{acmin}	:	Minimum AC input voltage
V_{acmax}	:	Maximum AC input voltage
f_S	:	Switching frequency
f_L	:	Line frequency

Contents

Chapter 1

Introduction

1.1 Motivation

Day by day trend towards using the elements with smart feature are increasing remarkably. Keeping view on this, research are focused towards developing smart products to make human life much simpler. It has been studied from the survey of different reputed organization like Business Insider Intelligence, Gartner, World Bank etc. that the use of Electronic gadgets like PC (or Laptops), Smart phones, Tablets etc. has been increased quite significantly in the present decade as shown in Figure 1.1 [4].

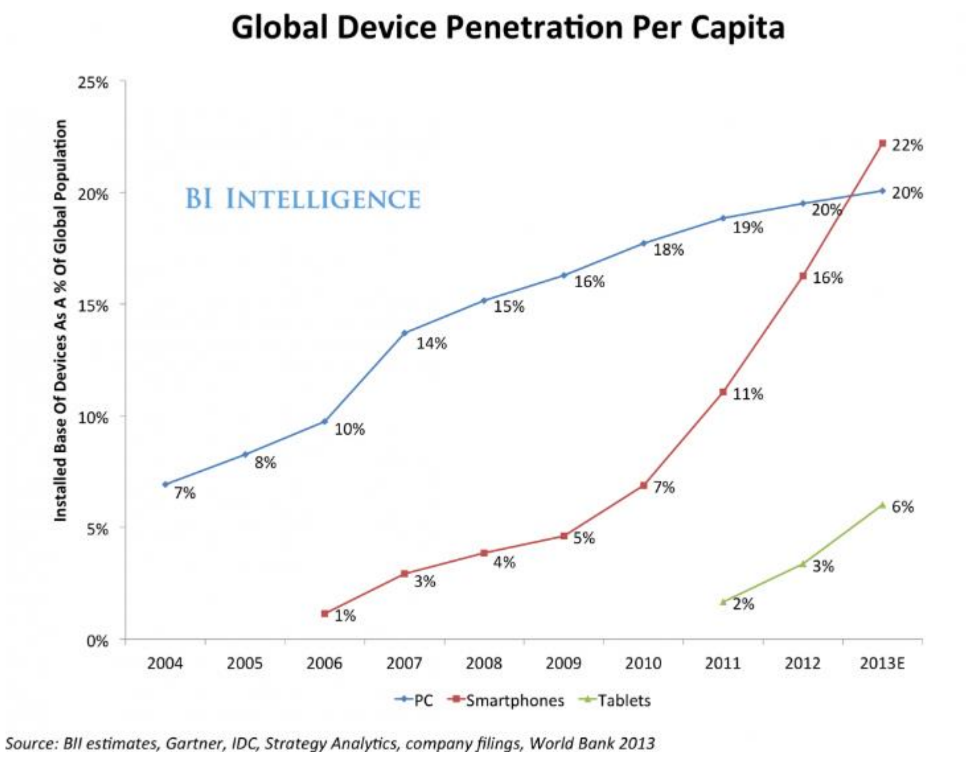


Figure 1.1: Survey report on penetration of Electronics

But, these Electronic gadgets require different type of AC adapter or battery charger based on the voltage and power rating of the battery [18]. So, it is cumbersome to carry all the charger or adapter while travelling.

At public places like Airports, Railway stations we have various chargers for different gadgets at charging points. However, owing to variable demand for different chargers there is a possibility of longer waiting periods for users of certain devices.

Another issue is these adapter requires AC supply as input for charging the battery. But, in present days to meet the energy crisis research are focused towards the distributed generation of power from renewable energy sources like PV system, Wind turbine, Fuel cell etc. [19-21]. To control the power flow from these generation to load micro-grids are formed [22].These micro-grid are mainly of three types like AC micro-grid, DC micro-grid, AC-DC hybrid micro-grid [23-24]. Currently most of the major loads like air-conditioner, fan, washing machine etc. require AC supply whereas, electronics load like TV, Laptop, Smart phone, Tablets etc. require DC supply. In order to increase the efficiency of the system AC-DC hybrid micro-grid is preferable in present scenario [25]. But, presently the available adapter with the Electronic gadgets are designed only for AC input which may not be used for the DC system.

With the increase in Electronic beverages e-waste management is the need of the hour. One of the major concern is if, one of the gadget stops working or lost somewhere, then the adapter associated with it to charge the battery may not come in use which lead to increase in e-waste.

1.2 Important Features:

So, in order to address the above issues, a universal smart charger has been developed, which is capable of charging different electronic gadgets like smart phones, tablet pcs, iPad, Laptops etc. based on their voltage ratings. It can take both AC (any frequency) as well as DC as input supply with a wide range of voltage variation. It can communicate with the electronic gadgets, to get the information regarding voltage level required for charging the corresponding batteries. It can able to charge the batteries with required voltage within tolerable limit.

1.3 System Description

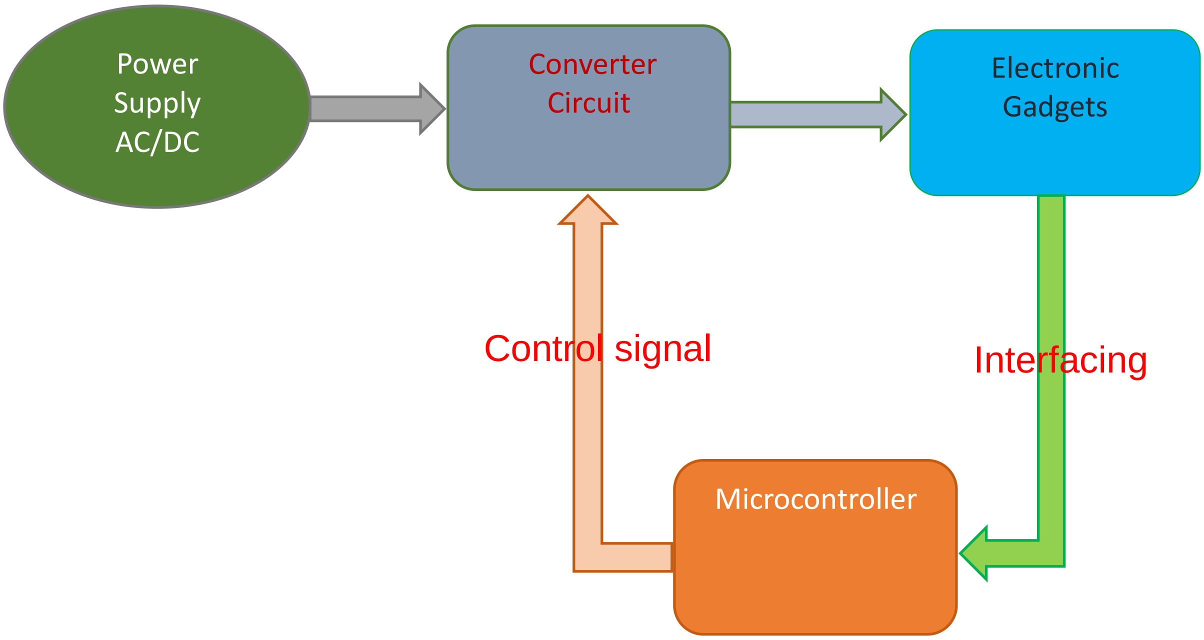


Figure 1.2: Block Schematic of the system

The block diagram given in Figure 1.2, describes the overall system. The electronic gadgets voltage levels are lower than the supply which is available. So a converter is required to fulfill the load requirement. As these loads are DC loads, DC-DC converter is required for transferring of power from source to load. To control the converter for getting the required output, control signal is required which is given by a microcontroller.

The microcontroller communicates with the gadgets to get the reference voltage for that device. It is like an interface between load and converter. After getting the information about the voltage of the device, it does some calculation and gives the control signal to the converter. The converter gives power, with required voltage level to the load after getting the control signal. So the microcontroller should able to communicate with electronic device.

Chapter 2

Proposed Circuit Analysis, Design &Control

The proposed system is comprised of converters like rectifier, Flyback converter and a multilevel buck converter. A controller is used in the system to sense and control the required voltage level for charging the Electronic gadgets. The complete block diagram of the converter circuit is given in Figure 2.1 (a). Single phase rectifier is used for converting AC to DC and then both Flyback converter and the buck converter are used for converting DC to DC. It will be very difficult, if only Flyback converter will be used. Because we need different voltage level output for different load, normally Flyback converter is designed for a particular load with fixed output voltage. If we want output which is different from the designed output then it will be very difficult to control the Flyback converter, as its input and output voltage relation is not linear.

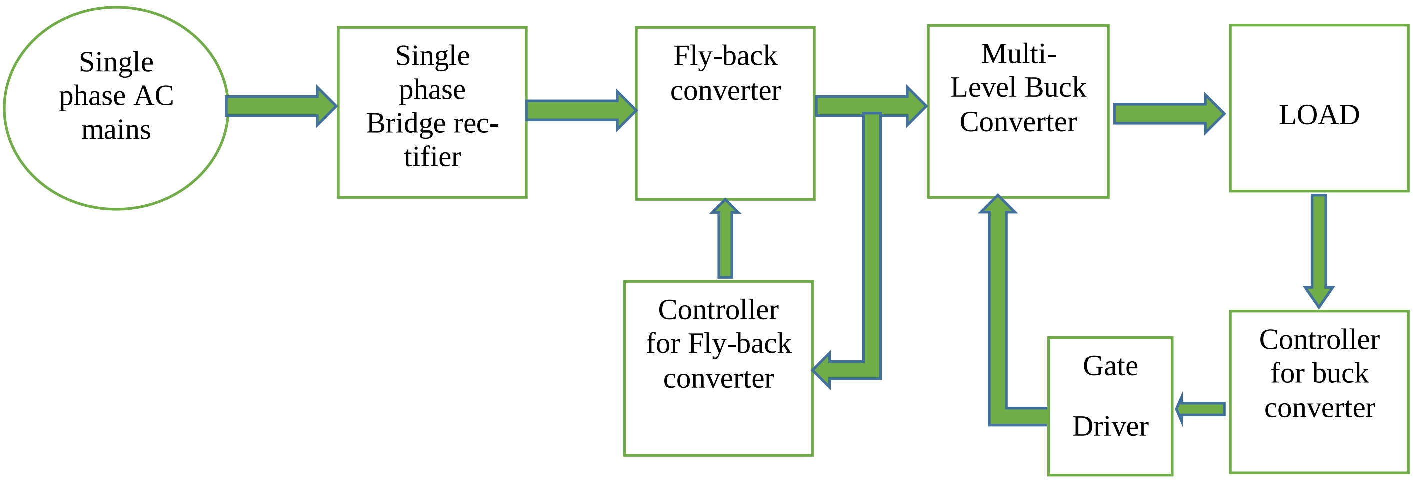


Figure 2.1 (a): Block Diagram of Converter circuit

So a buck converter is used in between load and Flyback converter. Also only simple buck converter cannot be used, because its voltage gain is not that much high.

Flyback converter is used for stepping down the input voltage to a value such that the buck converter can give required output voltage. To make the input voltage for buck converter constant the output voltage of the Flyback converter needs to be constant, so a feedback circuit is used for Flyback converter to make the output voltage constant. This thing will be discussed later in this chapter.

The schematic of the proposed charger circuit is shown in Figure 2.1 (b). This circuit consists of two converter, a multiple output Fly-back converter and a multi-level buck converter. The function of these converters are same as that of conventional DC-DC converter, which have been discussed earlier. This converter can take input as ac supply or dc supply. From Figure 2.1 (b) we can see that Flyback converter has two output, the reason is that a multilevel buck converter is used which has two inputs.

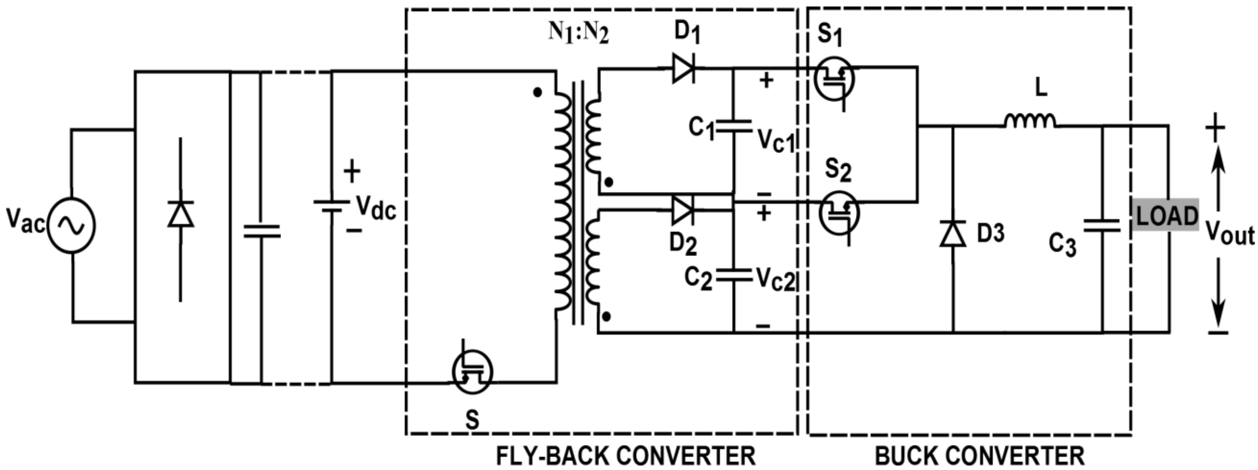


Figure 2.1 (b): Schematic of Proposed Charge Circuit

2.1 Analysis of the circuit

The circuit operation is explained in two parts

- Fly-back Converter circuit operation
- Buck Converter circuit operation

2.1.1 Fly-Back Converter operation:

The multilevel buck converter which is used in this system, requires two input. So there is need of a multiple output Flyback converter. Multiple output Flyback converter operation is similar as the conventional Flyback converter [1]. The Flyback converter can be operated in continuous conduction mode (CCM) or discontinuous conduction mode (DCM) [2]. Here the converter operates in CCM. Operation of this circuit is described in two modes of operation

- Mode-1 : Switch On
- Mode-2 : Switch Off

Mode-1: In this mode of operation the switch 'S' is turned on for some time ie. Turn On period (T_{on}). It can be seen from the fig.2.1 that when 'S' is on the primary winding of the transformer gets connected to the input supply with dotted end connected to positive side. At the same time the diodes 'D_1' and 'D_2' are connected in series with secondary windings and due to the induced voltage on the secondary sides the diodes get reverse biased, because the dotted end of the secondary side is at higher potential than the other end, where anode of diode is connected [8]. Sum of the output voltage and the induced voltage in the secondary side will come across the diode, and make diodes reverse biased. So the current will flow in primary winding only after turning on the switch 'S' and secondary winding current is '0'. We know that if secondary current is zero, primary current is only magnetizing current. Now the flux will be established in the transformer core [16]. In the Figure 2.2 (a) the arrow mark shows the current carrying path of the circuit and the Figure 2.2 (b) is the equivalent circuit of the mode-1 circuit operation. In the equivalent circuit the conducting switch is replaced by short circuit and the non-conducting diode is replaced by open circuit as we have assumed that the switch and diode are ideal, zero voltage drop during conduction and zero leakage current during off state. But in practical there will be voltage drop across the switch while conducting [6]. Let that voltage drop across switch is V_S and across diodes are V_{D1}, V_{D2}.

Voltage across the primary winding is given below (ideal condition)

$$V_{in} - V_{pri} = 0$$

$$\Rightarrow V_{pri} = V_{in} \qquad (2.1)$$

If we'll consider the forward voltage drop across switch, then the voltage across primary winding will be:

$$V_{pri} - V_{in} + V_S = 0$$

$$\Rightarrow V_{pri} = V_{in} - V_S \qquad (2.2)$$

Voltage across secondary winding 1 is

$$V_{sec1} = V_{pri} \times \frac{N_2}{N_1} \qquad (2.3)$$

Similarly voltage across secondary winding 2 is

$$V_{sec2} = V_{pri} \frac{N_2}{N_1} \qquad (2.4)$$

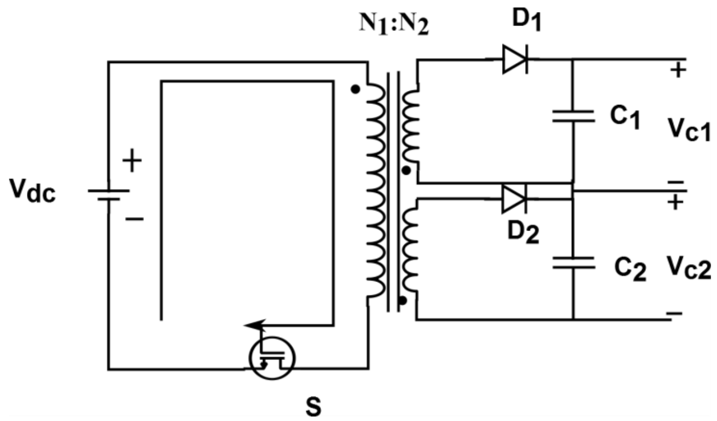


Figure 2.2 (a): Current path during Mode-1 operation

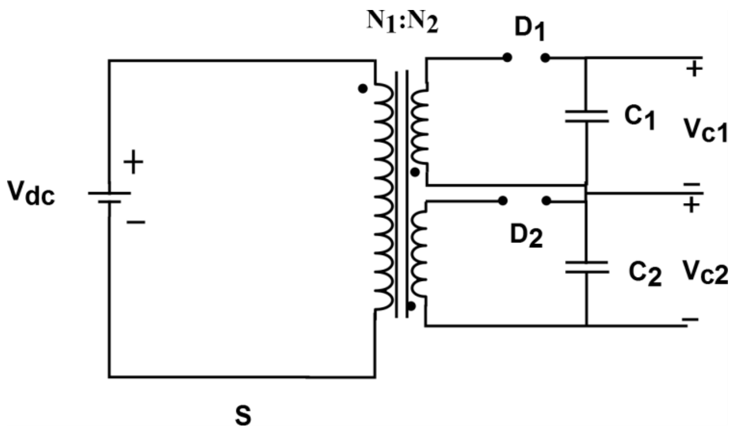


Figure 2.2 (b): Equivalent circuit in mode-1 operation

Mode-2: This mode of operation will start when the switch ‘S’ is turned off after conducting for some time. In this mode the switch ‘S’ will be turned off for remaining time of the total time period of each cycle. When the switch ‘S’ is turned off, current in the primary winding does not flow and according to laws of magnetic induction, the voltage polarity across the inductor will be reversed [6]. Reversal of voltage polarities makes the diode in the secondary circuit forward biased. The current path in Mode-2 operation is shown in Figure2.3 (a) by arrow mark and Figure2.3 (b) is the functional equivalent of the circuit during Mode-2.

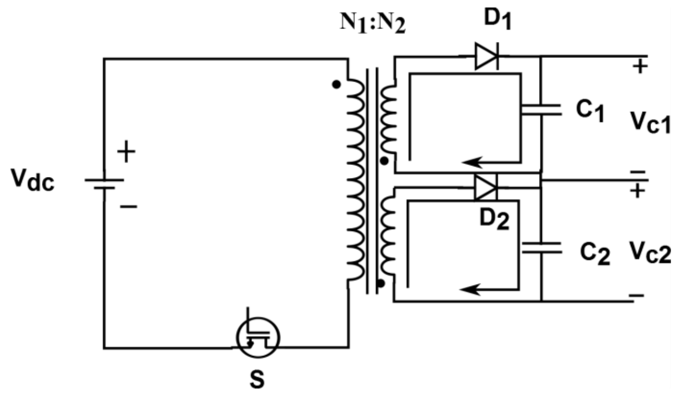


Figure 2.3 (a): Current path during Mode-2 operation

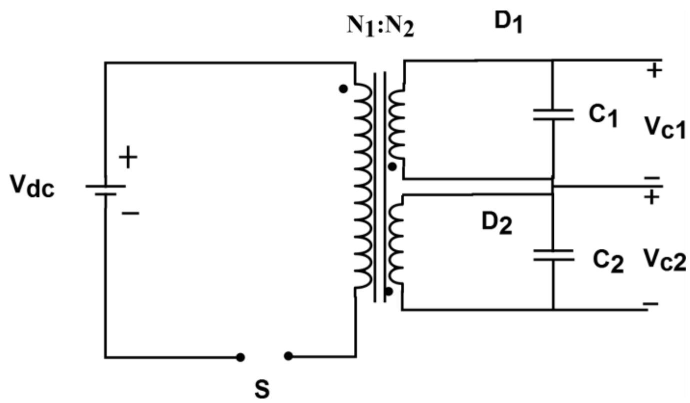


Figure 2.3 (b): Equivalent circuit in Mode-1 operation

Voltage across the secondary winding 1:

$$V_{sec1} + V_{c1} = 0$$

$$\Rightarrow V_{sec1} = -V_{c1} \quad (2.5)$$

Voltage across secondary winding 2:

$$V_{sec2} + V_{c2} = 0$$

$$\Rightarrow V_{sec2} = -V_{c2} \qquad (2.6)$$

If we will consider the forward voltage drop of diodes then secondary winding 1 voltage:

$$V_{sec1} + V_{D1} + V_{c1} = 0$$

$$\Rightarrow V_{sec1} = -(V_{D1} + V_{c1}) \qquad (2.7)$$

Similarly for secondary winding 2:

$$V_{sec2} = -(V_{D2} + V_{c2}) \qquad (2.8)$$

Reflected voltage in primary winding:

$$V_{pri} = V_{sec1} \times \frac{N_1}{N_2} \qquad (2.9)$$

Practical Issues in Fly-Back converter:

The fly-back converter discussed in the previous sections neglects some of the practical aspects of the circuit. The simplified and idealized circuit considered above essentially conveys the basic idea behind the converter. However a practical converter will have device voltage drops and losses, the transformer shown will also have some losses. The coupling between the primary and secondary windings will not be ideal, so there will be leakage inductance. The loss part of the circuit is to be kept in mind while designing for rated power. The designed input power (P_{in}) should be equal to P_0/η, where P_0 is the required output power and η is the efficiency of the circuit [17]. Similarly one needs to counter the effects of the non-ideal coupling between the windings. Due to the non-ideal coupling between the primary and secondary windings when the primary side switch is turned-off some energy is trapped in the leakage inductance of the winding [15]. The flux associated with the primary winding leakage inductance will not link the secondary winding and hence the energy associated with the leakage flux needs to be dissipated in an external circuit [5]. Unless this energy finds a path, there will be a large voltage spike across the windings which may destroy the circuit. So there should be proper designing of the converter [16].

In the proposed circuit, fly-back converter has multiple outputs and input is also not constant, the converter should give a constant output voltages for wide range of input variation. This is possible by controlling the switch 'S', and by taking the voltage or current feedback from the output. Designing an off-line switching power supply involves many aspects of electrical engineering: analog and digital circuits, bipolar and MOS power device characteristics, magnetics, thermal considerations, safety requirements, control loop stability, etc. There are many PWM controller which are dedicated for fly-back converter operation. In the proposed circuit a *TOPSwitch* is used for fly-back converter operation. The designing of the multiple output fly-back converter with *TOPSwitch* is given below.

Complete Design of Fly-Back converter with *TOPSwitch*

When compared to single output fly-back supplies, multiple output applications demand further design considerations to optimize the performance. The design of a switching power supply, by nature, is an iterative process with many variables that have to be adjusted to optimize the design. The design of the fly-back converter is described step by step.

Step-1. Determine system requirements: V_{acmax}, V_{acmin}, f_L, f_S, V_O, P_O, η, Z:

The step-by-step procedure uses predetermined parameter values such as input ac voltage (V_{acmax}, V_{acmin}), minimum dc voltage (V_{dcmin}), reflected voltage from secondary side while switch 'S' is in turned OFF condition (V_{OR}) and clamping voltage (V_{CLO}) for most commonly encountered input voltage ranges: 85 to 132 V_{ac} for 100/115 V_{ac}, 195 to 265 V_{ac} for 230 V_{ac} and 85 to 265 V_{ac} for universal input. Applications with a different input voltage range can be handled by following the information and methods provided in Step 3, 4 and 5 of this in-depth information section to derive appropriate values for C_{in}, V_{OR}, V_{CLO} and V_{dcmin}.

Switching power supply efficiencies typically range from 75% for supplies delivering most of their power at low voltage outputs (5 or 3.3V) to 85% for those supplying most of their power through higher voltage outputs (12V and above). If anything is not given, then typically 80% we can take [9].

For output power P_0 and efficiency η, P_0 (1- η)/ η [17] power is lost somewhere in the system: part in the secondary circuits, and the balance in the primary circuits. The ratio of the secondary loss to the total loss is defined as the loss allocation factor, Z, which should be set based on experience. A value of 0.5 should be used if no reference data is available [8].

Step 2. Decide on a Feedback/sense circuit and bias voltage V_B:

Feedback is taken from the main output winding. The control pin will control the main winding output voltage and other winding output voltage will be determined by turn's ratio. Three types of feedback/sense circuits are mostly used.

1. **Primary feedback:** The primary feedback circuit is the least expensive but has lower absolute accuracy and regulation and is suitable only for low power and higher output voltage (VO >5V) [9]. The output is indirectly sensed by the primary bias winding. The output voltage is determined by the *TOPSwitch* control pin voltage. Figure2.4 (a) shows schematic diagram of primary feedback design [8]. The bias winding is rectified and filtered by D_3, R_1 and C_2 to create a bias voltage to the *TOPSwitch*. C_2 also filters internal MOSFET gate drive charge current spiked on the control pin, determines the auto-restart frequency, and together with R_1, compensates the control loop.

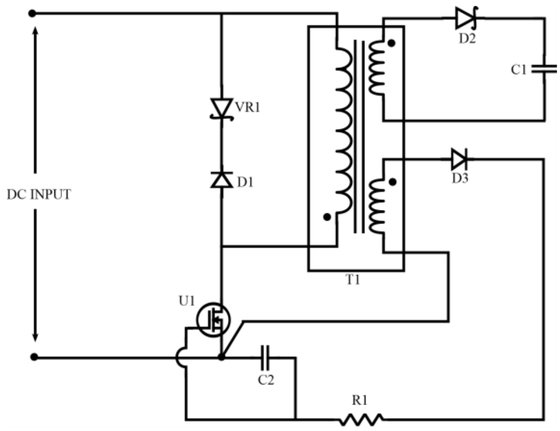


Figure 2.4: Schematic diagram of Primary feedback power supply

2. **Opto/zener feedback**: This circuit also less expensive. The main output is directly sensed by optocoupler and Zener diode. This is suitable for medium power level (up to 30 watt). The output voltage is determined by the Zener diode (voltage and the voltage drops across the optocoupler photodiode and resistor R1. Other output voltages are also possible by adjusting the transformer turns ratios and value of Zener diode. In the Figure 2.4 (b), R2 and VR2 provide a slight pre-load on the output to improve load regulation at light loads [8].

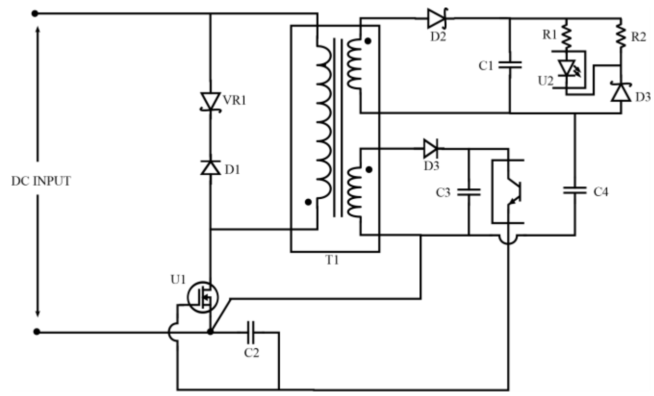


Figure 2.4 (b): Schematic diagram of Opto/Zener power supply

3. **Opto/TL431feedback:** Output voltage is directly sensed and accurately regulated by a secondary-referenced error amplifier. The error amplifier drives a current error signal through an optocoupler into the *TOPSwitch* Control pin to directly control *TOPSwitch* duty cycle. The TL431 shunt regulator integrate an accurate 2.5volt bandgap reference, op amp, and driver into a single device as a secondary reference error amplifier. Output voltage is sensed, divide by R4 and R5, and compared with the internal reference. C9 and r4 determine error amplifier frequency response [8]. R1 limits LED current and sets overall control loop dc gain. This provides high accuracy and slightly added cost. It is applicable to all power and voltage range.

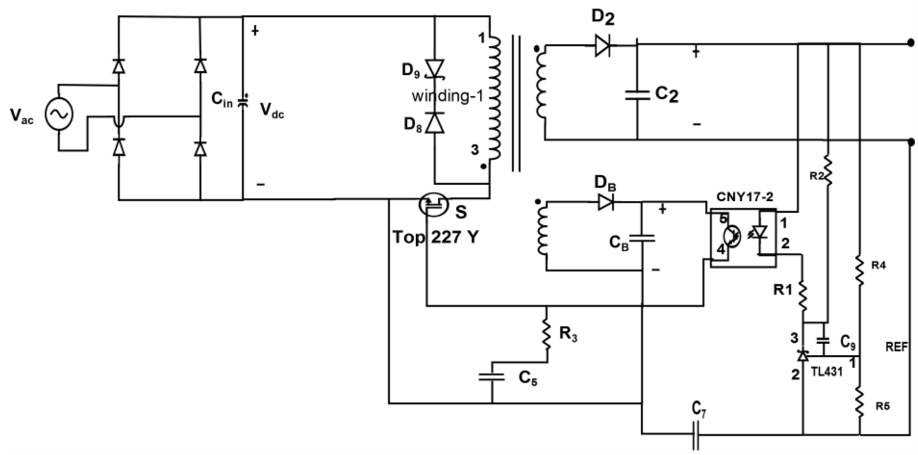


Figure 2.4 (c): Schematic diagram of Opto/TL431 power supply

Table-1.1:

Feedback Circuit	VB (Volt)	Output Accuracy
Primary/basic	5.7	± 10%
Opto/Zener	12	± 5%
Opto/TL431	12	± 1

Step 3. Determine input storage capacitor C_{in} and minimum DC input voltage Vdcmin based on input voltage and P_0:

The rectified voltage is filtered out by input capacitor C_{in}. But there is some ripple in the output voltage. The minimum DC voltage Vdcmin occurring at the lowest line voltage V_{ac-min} is an important parameter for the design of the power supply. A rule of thumb on choosing the C_{in} value is to use 2 to 3 µF per watt of output power for 100/115 VAC or universal input, and 1 µF/Watt for 230VAC. Higher values of Cin increase capacitor cost but reduces ripple voltage, whereas lower values of Cin result in significantly lower Vdcmin increasing TOPSwitch cost due to increased peak operating current demand.

The accurate calculation of V_{dcmin} for a given C_{in} (or vice versa) is a very complicated task which involves the solving of an equation with no closed form solution. The equation shown below represents a good first order approximation which is accurate enough for most situations [10].

$$V_{dcmin} = \sqrt{(2 \times V^2_{acmin}) - \left(\frac{2 \times P_0 \times (\frac{1}{2 \times f_L} - t_c)}{\eta \times C_{in}}\right)} \qquad (2.10)$$

Step 4. Determine reflected output voltage V_{OR} and clamp Zener voltage V_{CLO}:

A typical fly-back circuit using TOPSwitch is shown in Fig.2.4. When the TOPSwitch is off and the secondary is conducting, the voltage on the secondary is reflected to the primary side of the transformer by the turn's ratio. This reflected voltage V_{OR} adds to the input DC voltage at the *TOPSwitch* drain node. Worst case voltage at the drain occurs at high line when the DC input voltage is at its maximum value. The maximum DC input voltage can be calculated as:

$$V_{dcmax} = \sqrt{2} \times V_{acmax} \qquad (2.11)$$

When the switch 'S' is turned off, the voltage across primary winding will be the sum of V_{dcmax} and the reflected voltage from secondary side (V_{OR}) in addition to that voltage spike will come due to the energy stored in the leakage inductance. This thing discussed previously. To avoid this spike a snubber circuit/clamp circuit is used. In Fig.2.4, diode (D_8), zener clamp (D_9) forms the clamp circuit. A Zener clamp as shown in Fig.2.4 is highly recommended over the usual RCD clamp as it is much more effective in clamping the leakage energy during start up transients. RCD clamp circuits are not recommended because clamping voltage varies with load current. RCD clamp circuits may allow the drain voltage to exceed the data sheet breakdown rating of *TOPSwitch* during overload operation or during turn on with high line AC input voltage. The value for the zener clamp voltage is decided based on the reflected secondary voltage. Normally 50% of V_{OR} is taken. The nominal clamp Zener voltage V_{CLO} is usually specified at low current values and at room temperature. High voltage Zener have a strong positive temperature coefficient and are quite resistive. Consequently, the clamp voltage at high current and high temperature V_{CLM} can be much higher. Experimental data has shown that the V_{CLM} can be as high as 40% above the specified V_{CLO} [10].

$$V_{CLM} = 1.4 \times V_{CLO} \qquad (2.12)$$

Voltage across the switch 'S' during turn OFF period is given below:

$$V_S = V_{dcmax} + (1.4 \times 1.5 \times V_{OR}) + 20 \qquad (2.13)$$

This 20 volt is taken for safety factor. Because there may be some spike due to the forward recovery time of the blocking diode in series with zener clamp. This is the maximum voltage ratings of the switch. The current ratings of the switch is the peak primary current.

Step 5. Determine maximum duty cycle at low line D_{MAX} using V_{OR} and V_{dcmin}

D_{MAX} is calculated by using V_{OR} and V_{dcmin} [10].

$$D_{MAX} = \frac{V_{OR}}{V_{OR} + (V_{dcmin} - V_{DS})} \qquad (2.14)$$

Step 6. Set ripple current I_R to peak current I_P ratio K_{RP}:

$$K_{RP} = \frac{I_R}{I_P} \qquad (2.15)$$

Ripple current and peak current is shown in Fig.2.5. K_{RP} value decides the mode of operation i.e. CCM or DCM. If K_{RP} = 1, then it is a DCM operation. But in DCM mode the switch ratings will be increased so it will be better to operate in CCM mode. A K_{RP} of 0.4 is recommended for 100/115 V_{ac} and universal input [9].

Step 7. Determine primary waveform parameters I_{avg}, I_P, I_R, I_{RMS}:

The values of the currents is very important for switch selection. The average current in the primary side (I_{avg}) is

$$I_{avg} = \frac{P_0}{\eta \times V_{dcmin}} \qquad (2.16)$$

V_{dcmin} is used for calculating maximum possible average current in primary side of the circuit.

From the Fig.2.5 we can calculate I_P, I_R and I_{RMS}.

$$I_P = \frac{I_{AVG}}{(1-\frac{K_{RP}}{2}) \times D_{MAX}} \qquad (2.17)$$

$$I_R = I_P \times K_{RP} \qquad (2.18)$$

$$I_{RMS} = I_P \times \sqrt{D_{MAX} \times (\frac{K^2_{RP}}{3} - K_{RP} + 1)} \qquad (2.19)$$

Step 8. Select *TOPSwitch* based on *TOPSwitch* data sheet minimum I_{LIMIT} specification and required IP such that $0.9 \times I_{LIMIT} \geq I_P$

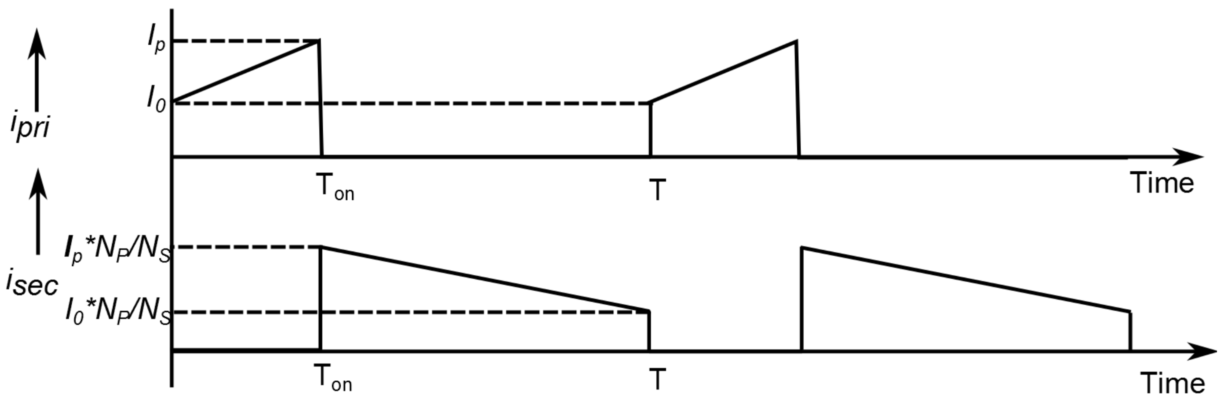


Figure 2.5: Current wave form of primary and secondary of Fly-back Transformer

Step 9. Determine primary inductance L_{PRI}

Primary winding inductance value is one of the important parameter. Its value decides the ripple current, peak current. The primary inductance LP can be expressed as a function of I_P, K_{RP}, f_S, P_O, η and Z [10].

$$L_{pri} = \frac{P_0}{I^2{}_P \times K_{RP} \times (1-\frac{K_{RP}}{2}) \times f_S} \times \frac{Z \times (1-\eta)+\eta}{\eta} \quad (2.20)$$

L_{pri} is in Henry (H), η is the efficiency and Z is the loss allocation factor. If Z=1, all losses are on the secondary side. If Z = 0, all losses are on the primary side. Z is simply the ratio of secondary loss to total loss. If no better reference information is available, Z should be set to 0.5. Primary inductance L_{pri} can also be determined from a simple function of ripple current I_R, effective primary voltage (V_{dcmin}-V_{DS}), maximum duty cycle D_{MAX}, and switching frequency f_S, which is derived below. But the resulting value for primary inductance may be slightly different due to the selected value for loss allocation factor Z.

From equation (1.1)

$$L_{pri} \frac{d}{dt} i_{pri} = V_{DC}$$

$$\Rightarrow \frac{di_{pri}}{dt} = \frac{1}{L} V_{DC} \quad (2.21)$$

Where i_{pri} = instantaneous primary winding current.

From the primary winding current waveform fig.2.5

$$\frac{I_P - I_0}{T_{on}} = \frac{1}{L_{PRI}} \times (V_{DC} - V_{DS})$$

$$\Rightarrow \frac{I_R}{D_{MAX} \times T_S} = \frac{1}{L_{PRI}} \times (V_{DC} - V_{DS})$$

$$\Rightarrow L_{PRI} = \frac{V_{DC} - V_{DS}}{I_R} \times D_{MAX} \times T_S \quad (2.22)$$

$$\Rightarrow L_{PRI} = \frac{V_{DC} - V_{DS}}{I_R \times f_S} \times D_{MAX} \quad (2.23)$$

Here $V_{DC} = V_{dcmin}$

Step 10. Set value for number of secondary turns N_S: We have to set at least one secondary winding turns.

Step 11. Calculate number of primary turns NP, other secondary turns and number of bias turns N_B: While calculating the primary turns or bias turns, we have to consider the diodes forward voltage drop.

$$N_P = N_S \times \frac{V_{dc\min} - V_{DS}}{V_0 + V_D} \times \frac{D_{MAX}}{1 - D_{MAX}} \qquad (2.24)$$

The number of bias winding turns N_B is calculated from the output voltage V_O, output diode voltage V_D, secondary number of turns N_S, target bias voltage V_B, and bias diode voltage V_{BD}.

$$N_B = \frac{V_B + V_{BD}}{V_0 + V_D} \times N_S \qquad (2.25)$$

Similarly other secondary windings (N_X) turns can be calculated.

$$N_X = \frac{V_X + V_{DX}}{V_0 + V_D} \times N_S \qquad (2.26)$$

Step 12. Determine secondary parameters I_{SP}, I_{SRMS}, I_{SR}:

The secondary currents can be calculated from the primary currents. The secondary currents are the reflected version of the primary current with duty cycle (1-D).

$$I_{SP} = I_P \times \frac{N_P}{N_S} \qquad (2.27)$$

$$I_{SRMS} = I_{SP} \times \sqrt{(1 - D_{MAX}) \times (\frac{K^2_{RP}}{3} - K_{RP} + 1)} \qquad (2.28)$$

Step 13. Determine maximum peak inverse voltages PIVS, PIVB for secondary and bias windings: Maximum peak inverse voltage PIVS for the output rectifier is determined by transformer primary and secondary number of turns N_P and N_S, maximum DC input voltage V_{dcmax}, and output voltage V_O.

$$PIV_S = V_0 + (V_{dcmax} \times \frac{N_S}{N_P}) \qquad (2.29)$$

Peak inverse voltage of the bias winding can be calculated by using bias voltage, bias turns and primary or secondary turns.

$$PIV_B = V_B + (V_{dcmax} \times \frac{N_B}{N_P}) \qquad (2.30)$$

Additional or auxiliary output winding rectifier diode peak inverse voltage PIV_X can be determined from the desired value for auxiliary output voltage V_X, auxiliary rectifier diode forward voltage drop V_{DX}, output voltage V_O, output rectifier diode forward voltage drop V_D, and number of secondary turns N_X.

$$PIV_X = V_X + (V_{dcmax} \times \frac{N_X}{N_P}) \qquad (2.31)$$

From step 4 to step 13 describes the design of the fly-back transformer [8].

Step 14. Select clamp Zener and blocking diode for primary clamping based on input voltage and V_{CLO}: It is described in step-4.

Step 15. Select output rectifier (diodes): Selection of diodes depends upon the peak inverse voltage across that and the value of peak current. From step-12 and step-13, the voltages and currents can be known and from this data the output diode can be selected. The reverse voltage of the diode should be 1.25 times more than the calculated PIV value. The rule of thumb on the diode current rating is to choose one with rated DC current of at least three times the maximum output DC current. Usually fast recovery diodes are used. Reverse recovery time of the diodes should be very less than the switching frequency.

Step 16. Select bias rectifier: This is also done by similar manner how the output diode are selected. Only exception is that it does not require fast recovery diode as it takes very less current.

Step 17. Select Control pin capacitor and series resistor: A 47 μF, 10V low cost standard grade electrolytic capacitor across the Control pin and Source pin of the TOPSwitch takes care of loop compensation for all types of feedback configurations. Low ESR capacitors should not be used for this purpose, as the ESR resistance of the standard grade capacitor (2 W typical) improves the loop stability by introducing a zero. In fact, a 6.2μ resistor in series with this capacitor is recommended to improve phase margin in designs.[9].

Step 18. Select the feedback circuit components: The feedback components depends upon the applications, there is no proper method to choose these values. Selection of these components is totally experimental. It is described later in this chapter.

Step 19. Select Bridge Rectifier: The diode bridge rectifier is selected based on the maximum input voltage and the input R.M.S current.

$$I_{ACRMS} = \frac{P_0}{\eta \times V_{ac\min} \times PF} \qquad (2.32)$$

Where PF is the power factor of the power supply. Typically, for a power supply with a capacitor input filter, PF is between 0.5 and 0.7.

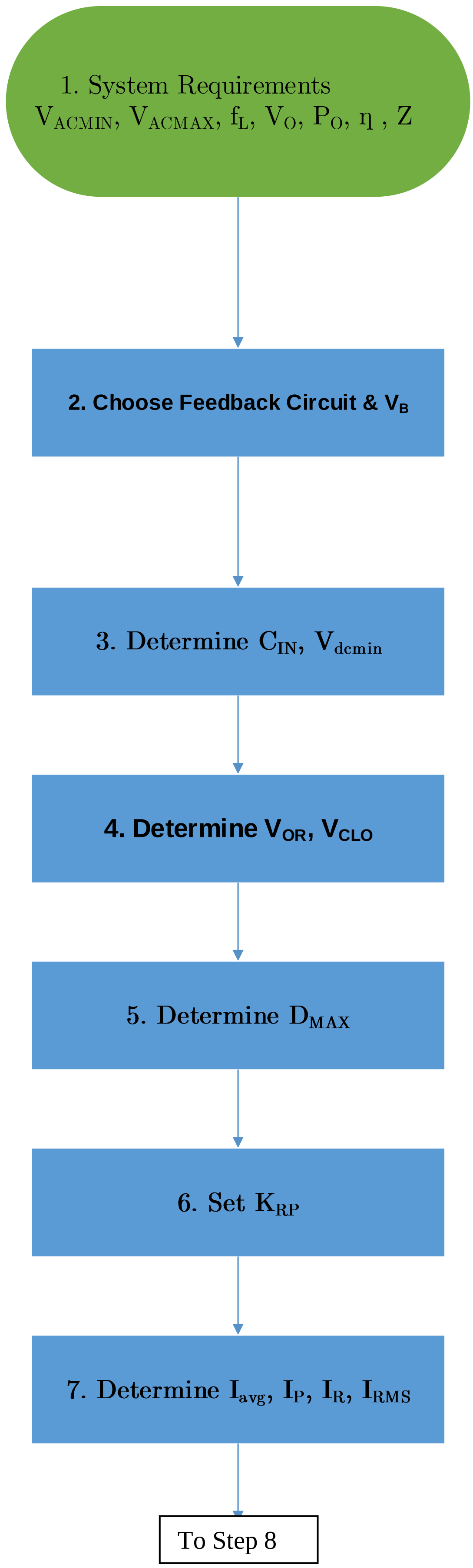
Select the bridge rectifier such that:

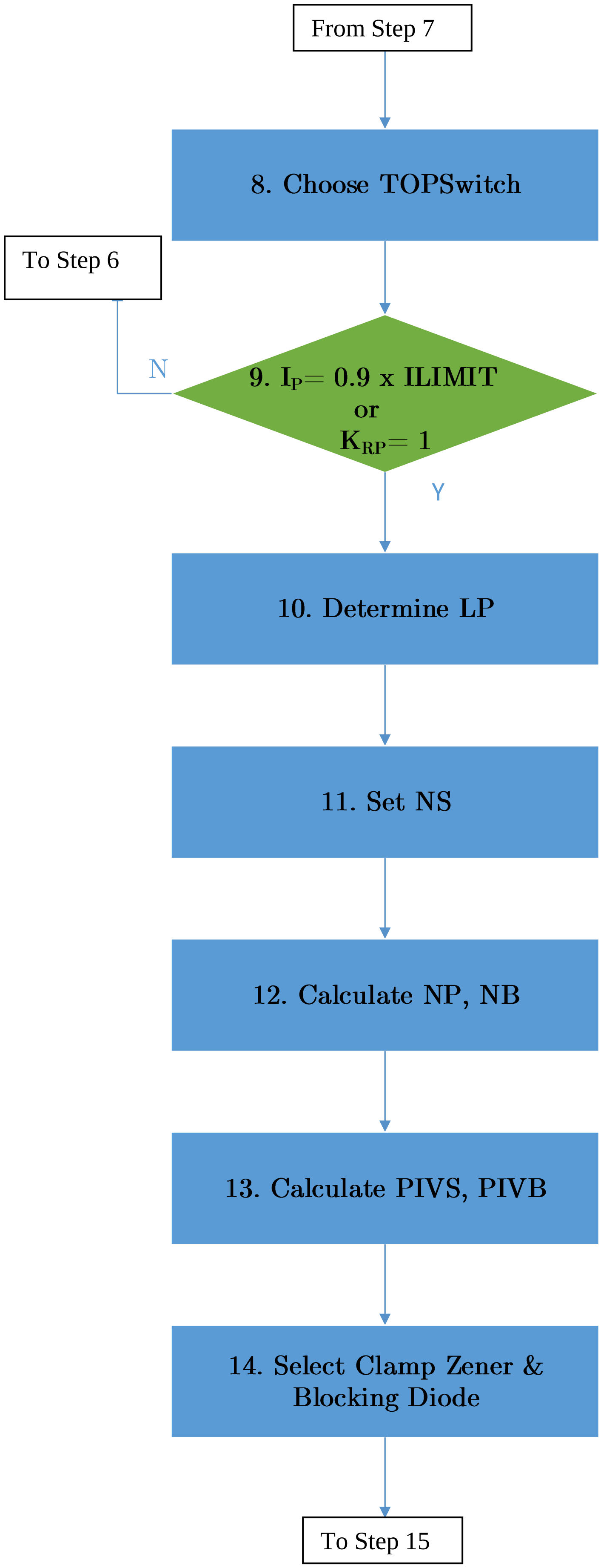
• $I_D \geq 2$ x IACRMS, where ID is the rated RMS current of the bridge rectifier.

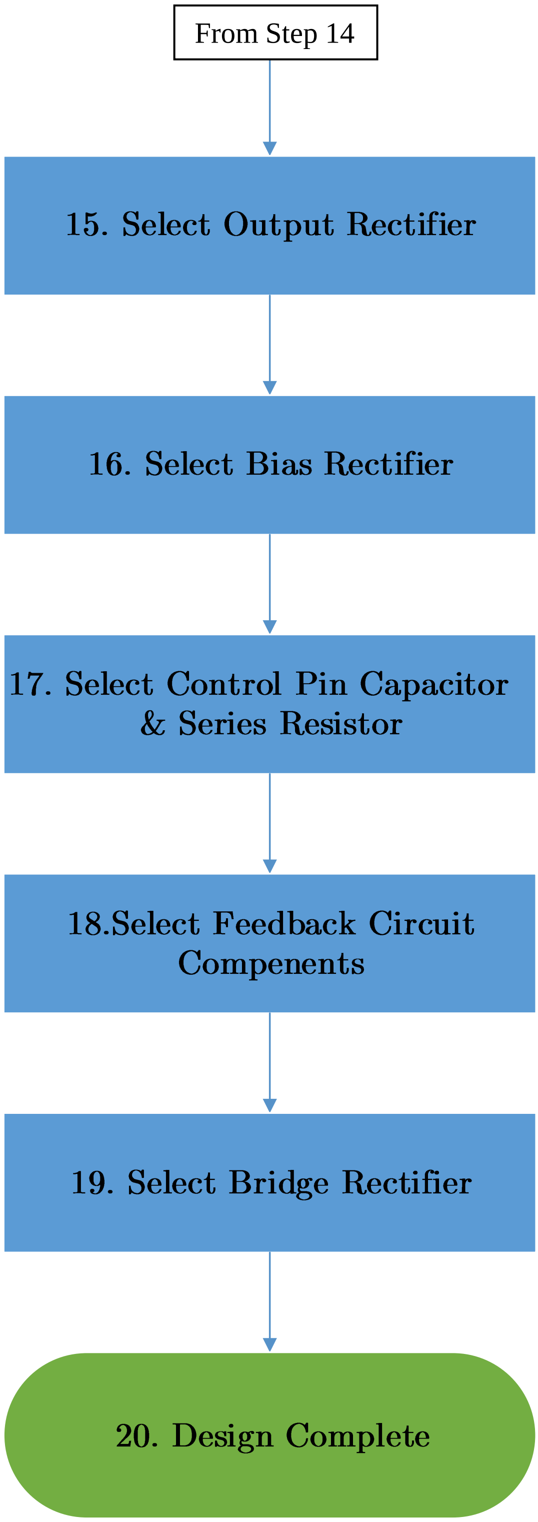
• $V_R \geq 1.25$ x 1.414 x VACMAX; where VR is the rated reverse voltage of the rectifier diode.

Step 20. Design completed: This is the complete design of a fly-back converter with TOPSwitch. All these steps are followed for designing the charger circuit in next chapter (3).A flowchart for this step by step designing is given below.

***TOPSwitch* Flyback design Flowchart**




From Step 7
8. Choose TOPSwitch
To Step 6
N
9. IP= 0.9 x ILIMIT
or
KRP= 1
Y
10. Determine LP
11. Set NS
12. Calculate NP, NB
13. Calculate PIVS, PIVB
14. Select Clamp Zener &
Blocking Diode
To Step 15


From Step 14
15. Select Output Rectifier
16. Select Bias Rectifier
17. Select Control Pin Capacitor & Series Resistor
18.Select Feedback Circuit Compenents
19. Select Bridge Rectifier
20. Design Complete

2.1.2 Buck Converter Operation

It is a dc-dc converter, which steps down the input voltage. It is like a transformer, transfer the same power from input to the output but with different output voltage level [3].

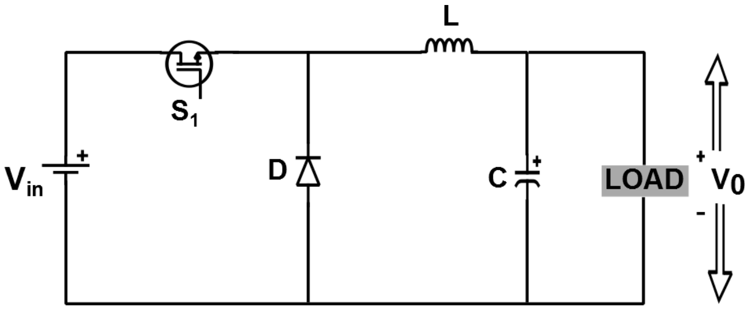


Figure 2.6: Conventional buck converter

It has two mode of operation in CCM

1. Mode-1: Switch ‘ S_1’ turned ON
2. Mode-2: Switch ‘S_1’ turned OFF

Mode-1: In this mode of operation, switch ‘S_1’ is turned for some time in a cycle (T_{on}). When S1 conducts the diode D will be in reverse blocking mode. So the current flows through inductor L and load. During this period inductor L stores energy. Load will get power from source as well as from capacitor. Equivalent circuit diagram for Mode-1 operation is given below Fig.2.7 (a).

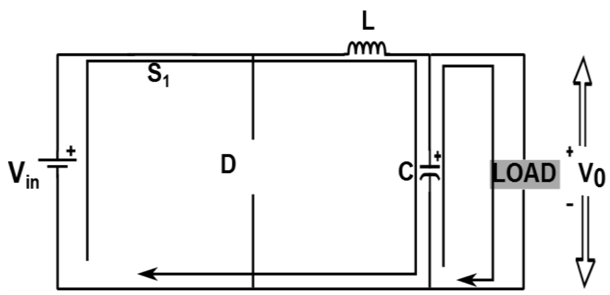


Figure 2.7 (a): Equivalent circuit of Mode-1 operation

Voltage across inductor L (V_L):

$$V_L = V_{in} - V_0 \qquad (2.33)$$

If we will consider the forward voltage drop of switch ‘S_1’ then

$$V_L = V_{in} - V_{DS1} \qquad (2.34)$$

$$V_L = L\frac{d}{dt}i_L \qquad (2.35)$$

Where i_L= instantaneous current through inductor L

Mode-2: This mode of operation will start after turn OFF of switch 'S_1'. When switch is turned off, the voltage polarity of inductor will be reversed and the diode will be forward biased [3]. Now inductor will act as source, it will transfer the stored energy in it, to load [5]. Equivalent circuit is given below in Fig.2.7 (b).

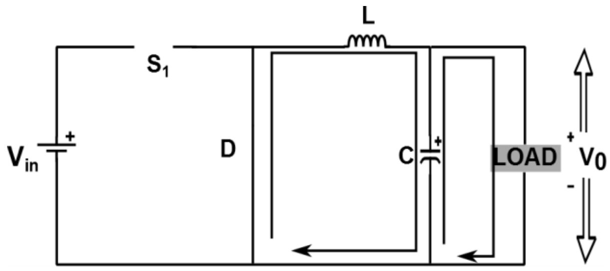


Figure 2.7 (b): Equivalent circuit of mode-2 operation

Voltage across inductor during mode-2

$$V_L = -V_0 \qquad (2.36)$$

If diode forward voltage drop (VD) will be considered, then voltage across inductor:

$$V_L = -V_0 - V_D \qquad (2.37)$$

After applying volt-sec balance across inductor, it can be derived that

$$\frac{V_0}{V_{in}} = D \qquad (2.38)$$

Where D = duty ratio

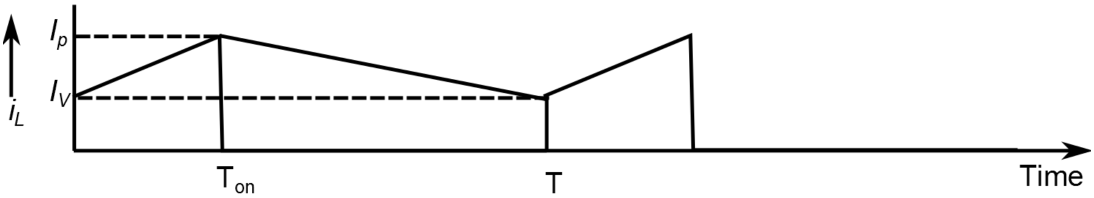


Figure 2.8: Current waveform of inductor

From equation 2.35 and equation 2.37, and from Figure 2.8 we'll get

$$L\frac{d}{dt}i_L = -V_0 - V_D$$

$$\Rightarrow L\frac{I_V - I_P}{(1-D)T} = -V_0 - V_D$$

$$\Rightarrow L\frac{I_P - I_V}{(1-D)T} = V_0 + V_D$$

$$\Rightarrow L\frac{\Delta I}{(1-D)T} = V_0 + V_D$$

$$\Rightarrow L = \frac{V_0 + V_D}{\Delta I}(1-D)T \qquad (2.39)$$

We can see from equation (2.39) that both ripple current and duty ratio are inversely proportional to the inductance. So the gain of the conventional converter cannot be varied with a wide range and the efficiency of buck converter is good within certain limit of duty ratio (0.4<D<0.8) beyond this limit its performance will be degrade. But in our application we need a wide range of voltage variation. If conventional buck converter will be used for this application then a large inductor is needed and the circuit will operate with a duty ratio which may not be within the limit. So it will give poor performance.

For example in some application the required output voltage is in between 5 Volt to 20 Volt and the input available is 24 Volt. For 20 Volt output the duty ratio will be nearly 0.83, so this duty ratio is manageable. But for 5 Volt or 6 Volt output the duty ratio will be nearly 0.25, if the converter will operate with this duty ratio, then its performance will be very poor. A high value of inductor will be needed, size of the inductor will also increase. If inductor value is taken less, then the ripple current will be more, the losses will also be more.

So to avoid such things a multi-level buck converter is used in this application. It is shown in Figure 2.9. Here, the only difference the conventional buck converter and multi-level buck converter two switches 'S_1' and 'S_2' are used instead of one switch, diode is used as usual. This converter needs two dc supply (single source is divided in two source) connected in series, which is given by fly-back converter. For this reason only fly-back converter has two main output winding. These switch operation totally depends upon the out voltage. It is described below.

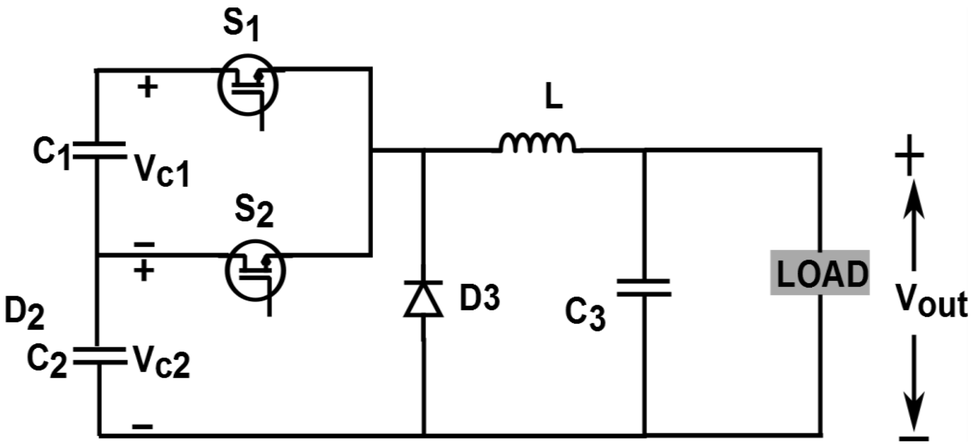


Figure 2.9: Multi-level buck converter

Our objective is to generate wide range of output voltage (from 5 Volt to 20 Volt) depending upon load requirement. For higher voltages both the switch will operate and for lower voltages upper switch ‘S_1’ will remain completely in turned OFF mode. So to decide this, a voltage level is required for differentiating the lower voltage and higher voltage. So 10 volt is the boundary for differentiating the voltages.

If the required output voltage is less than 10 volt , then switch ‘S1’will remain completely off and S2 will be operated. If it is greater than 10 volt, then both the switch will be operated. The circuit operation will be explained in two parts (for ≤ 10 volt and ≥ 10 volt).

- **For V_{out} ≤ 10 Volt:** Here only one switch ‘S_2’ will operate, so it is like a conventional buck converter. The switch ‘S_1’ is permanently turned OFF for all the time. The operation and the equation is same as the conventional buck converter which is explained before. In this circuit both switch ‘S_2’ and diode ‘D_3’ will operate alternatively like conventional buck converter. When switch ‘S_2’ is turned ON, the inductor L stores energy and when it will be turned OFF, the diode ‘D_3’ will get forward biased and starts conducting and inductor will give energy. All the equation from (2.33) to (2.39) are valid. The circuit diagram for two modes of operation (for Turn ON and Turn OFF period of switch ‘S_2’) is given below. This circuit operates for lower output voltage. In this case output voltage is less, at the same time the input voltage for this circuit is also less as compared to the previous case (given example), so the duty ratio will not be very small.

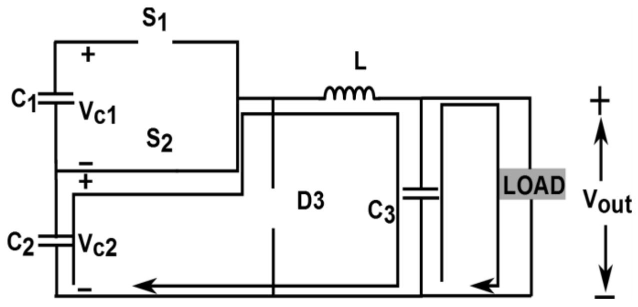


Fig.2.9 (a) Equivalent circuit for mode-1 operation

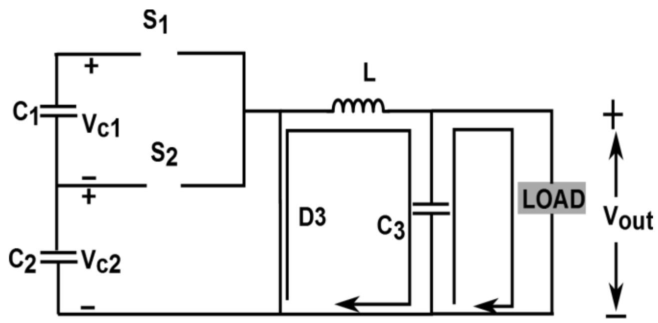


Fig.2.9 (b) Equivalent circuit for mode-2 operation

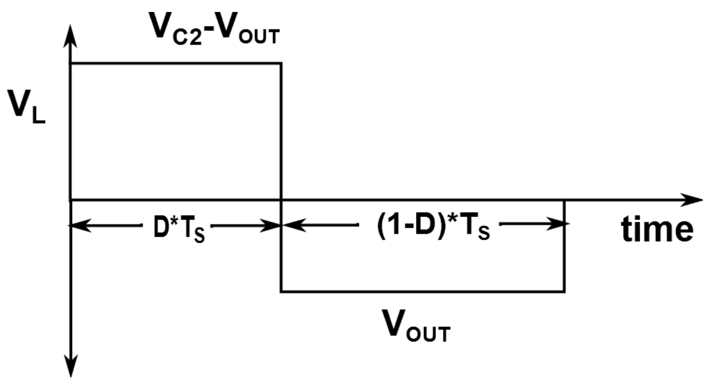


Figure 2.10: Inductor voltage waveform

Voltage across inductor L during both mode of operation is given in Figure 2.10. After applying volt-sec balance, it can be derived that

$$\frac{V_{C1}}{V_{out}} = D \qquad (2.40)$$

- **Output voltage (V_{out}) ≥ 10 Volt:** When required output voltage is greater than 10 Volt then both 'S1' and 'S2' will be operated. It has also two modes of operation.
  - Mode-1
  - Mode-2

Mode-1: In this mode of operation switch 'S_1' will be turned ON for some time (for T_{ON} period). When 'S_1' is turned on, the diode 'D_3' will be reverse biased, so the current will flow through the inductor L. Inductor will store energy during this period. The current through the inductor will rise linearly. The converter is operated in continuous conduction mode, so the current through inductor will not fall to zero. In each cycle it will start from some minimum value (I_V) and it will rise to a peak value (I_P) at the end of this mode. So this difference of minimum to maximum i.e. the ripple current is decided by the inductor value. The equivalent circuit and the current path is shown in Figure 2.11 (a).

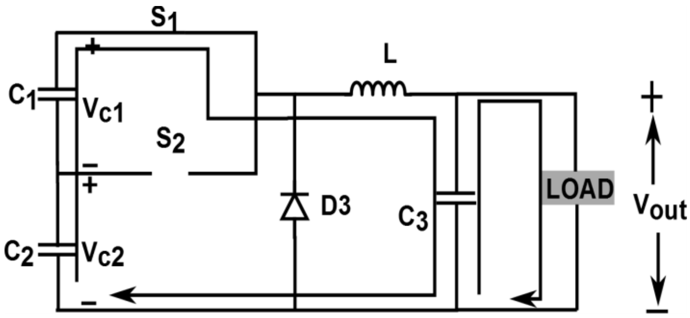


Figure 2.11 (a): Equivalent circuit of Mode-1 operation

Voltage across inductor L (V_L)

$$V_L = V_{C1} + V_{C2} - V_0 \quad (2.41)$$

Voltage across switch 'S_2' (V_{S2})

$$V_{S2} = -V_{C1} \quad (2.42)$$

Voltage across diode 'D_3' (V_{D3})

$$V_{D3} = -(V_{C1} + V_{C2}) \quad (2.43)$$

In this mode of operation, a negative reverse voltage comes across the switch 'S_2'. If that switch is a mosfet, then a diode should be connected in series with the switch 'S_2'. Because Mosfet has inbuilt antiparallel diode, due to negative voltage across the switch 'S_2', the diode may be forward biased, so while switch 'S_1' conducts there may be a circulating current between the switches and source may be short. In this mode both the sources are giving energy to load and the inductor. The voltage across switch and diode is nothing but the peak inverse voltage (PIV). This will help for selection of the switch and diode.

Mode-2: This mode of operation starts after turn OFF of switch 'S_1', but at the same time switch 'S_2' is turned ON. As we know there will be no sudden change in current through inductor, the inductor current flows through switch. The current path and equivalent circuit of this mode of operation is shown in Figure 2.11 (b).When switch 'S_2' will be turned ON, voltage 'V_{C2}' comes across the diode 'D_3' and makes it reverse biased. In this mode of operation diode will not conduct. So throughout the cycle diode 'D_3' completely off. It can be observed that the source is directly connected with the inductor during turn OFF period ('S_1' turned OFF). So source will support inductor for giving energy to load. Now both inductor and source give energy to load. But it does not happen in conventional buck converter, only inductor has to give energy to load during turn OFF period. For higher voltage application, load is also high and it needs more power. For this application, if buck converter will be used, then to make it continuous conduction the inductor should capable of giving energy to load during off period, so it needs a higher value of inductor.

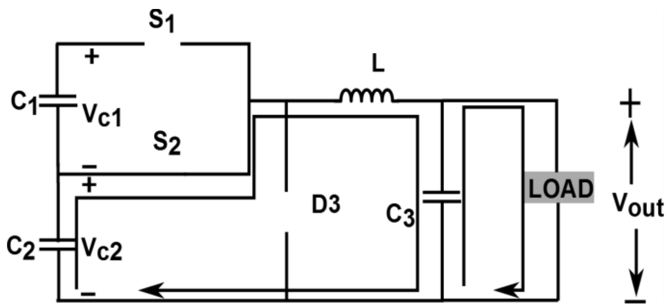


Figure 2.11 (b): equivalent circuit of mode-2 operation

During mode-2 operation, voltage across inductor L is

$$V_L = V_{C2} - V_{out} \quad (2.44)$$

This voltage will be definitely negative, because output voltage (V_{out}) is more than V_{C2}.

Voltage across switch 'S_1' (V_{S1}) during this mode

$$V_{S1} = V_{C1} \quad (2.45)$$

Voltage across diode D_3

$$V_{D3} = -V_{C2} \tag{2.46}$$

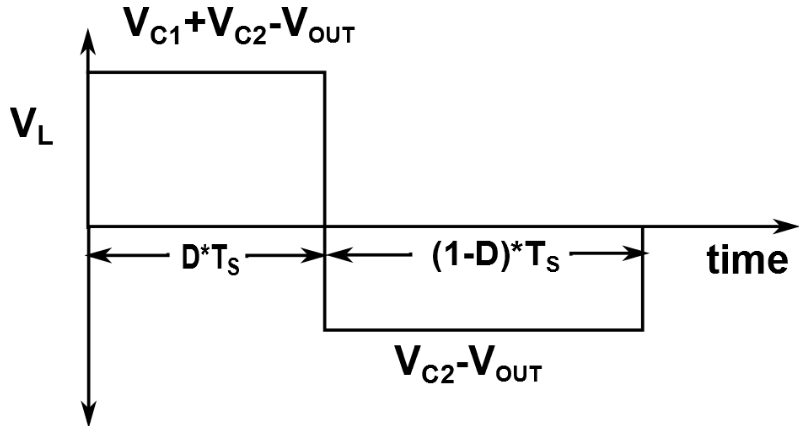


Figure 2.12: Inductor Voltage waveform

The voltage across inductor during the whole cycle is given in Figure 2.12.Here also volt-sec balance across inductor is applicable. From equation (2.41) and (2.44)

$$(V_{C1} + V_{C2} - V_{out}) \times \mathrm{D} \times T + (V_{C2} - V_{out}) \times (1 - D) \times \mathrm{T} = 0$$

$$\Rightarrow V_{C1} \times D + V_{C2} - V_{out} = 0$$

$$V_{out} = V_{C1} \times D + V_{C2} \tag{2.47}$$

Form equations (2.42) and (2.45), it can be observed that the peak inverse voltage i.e. the switching stress is less as compared to conventional buck converter and also current sharing by the switches is also less. So the switch ratings will come down in multi-level buck converter.

2.2 Control of proposed charger circuit

It is necessary to control the switches of every converter to get required output. There are two converters in the proposed circuit. So there is a need of two controller for two different converter.

2.2.1 Fly-back converter Control

Earlier in the section (2.1) it has been discussed that fly-back converter is operated by *TOPSwitch*. To control the switch there are different types of feedback design presents. In the previous section (2.1) three types of feedback design is given, out of those, **Opto/TL431** feedback design is used in this application. In the feedback design, it is very important to choose perfect elements, because every element has some effect on the circuit stability.

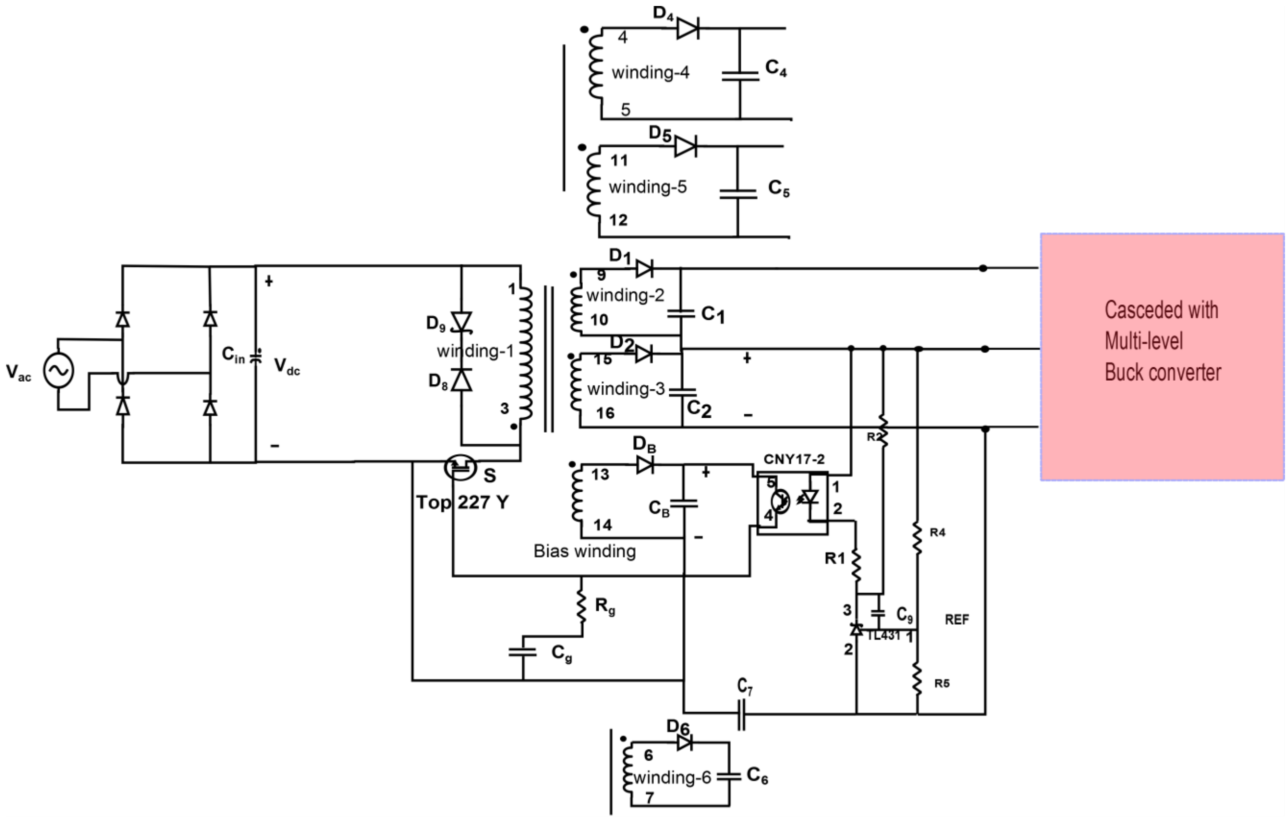


Figure 2.13: Fly-back converter circuit with *TOPSwitch*

The above circuit is used in proposed charger circuit for fly-back converter operation. Opto/TL431 feedback design is used in the above circuit. The components which are used in the feedback circuit, have their own function for operation of the circuit. Those functions are described below.

Auto restart: The capacitor C_g is responsible for auto restart. It determines the amount of time allowed for power supply start-up. When power is first applied, C_g charges to 5.7 Volts before the *TOPSwitch* MOSFET is enabled and the power supply starts. The output voltage must become regulated before C_g discharges from 5.7 V to approximately 4.7 V or *TOPSwitch* will disable the MOSFET and enter the auto-restart mode. C_g may have a series resistor up to 100Ω which has little effect on auto-restart [8].

Low DC input voltage (below 40 V) will cause the auto-restart time intervals to increase and auto-restart frequency to decrease. AC mains voltage is rectified and filtered resulting in a minimum high voltage DC bus of at least 85 V_{DC}. During AC input voltage transients or dropout conditions, input storage capacitor C_{in} can discharge below 40 V which reduces *TOPSwitch* control pin charging current I_C, increases charging time for auto-restart capacitor C_g, and decreases the auto-restart frequency [11]. If input energy storage capacitor C_{in} is not completely discharged and auto-restart capacitor C_g is not discharged below the Control pin internal Power up Reset Voltage threshold. A short delay due to auto-restart will be observed when starting after a short interruption in input power.

Current to Duty cycle conversion: *TOPSwitch* is not a current mode device, it is a voltage-mode device that produces a duty cycle inversely proportional to Control pin current. Increasing Control pin current will linearly decrease the duty cycle down to the minimum duty cycle value. Further increases in Control pin current will have no effect on the duty cycle until reaching the Latched Shutdown Trigger Current threshold at which point *TOPSwitch* shuts down [8]. Resistor 'R_1' is responsible for this. If R_1 is more, then current through LED of optocoupler will be less and duty cycle will increase. It is necessary to choose proper resistance.

Minimum duty cycle operation: It is the case when there is light load or no load across the output of fly-back converter. Shunt resistance or a Zener diode with the proper power rating can simply be added across the output voltage to provide preload current. So R2 is used for this purpose. R2 dissipates the most power when the power supply output is lightly loaded and the TL431 (U3) output is saturated low to decrease *TOPSwitch* duty cycle. During normal operation, when wider duty cycles are necessary, *TOPSwitch* Control pin current is lower, TL431 output voltage is higher, R2 power dissipation is lower, and overall efficiency is improved.

Control loop: The *TOPSwitch* control function has two poles and a zero. One pole is due to an internal RC filter with a typical corner frequency of 7 kHz. This RC network filters switching noise but contributes little phase shift at normal crossover frequencies of 1 to 2 kHz. Due to auto restart capacitor C_g (typically 47µF) and the Control pin dynamic impedance (typically 15 W) contributes the second pole of approximately 226 Hz. C_g has its own series resistance (typically 2 Ω), due to which it creates a zero at approximately 1.7 kHz [9].This compensation method is used for power supplies operating in discontinuous mode or lightly continuous mode at duty cycles of 50%. Additional series resistance R_g (between 2 Ω and 15 Ω) can be added as shown in Figure 2.13 to move the zero lower in frequency. This compensation method is used for power supplies operating in continuous mode.

Soft Start: When a power supply is first switched on, either from the line input switch or by electronic means (say from a TTL logic high signal), there will be a delay while the power and control circuits establish to their correct working conditions. During this period, it is possible for the output voltage to exceed its correct working value before full regulation is established, giving a turn-on voltage overshoot [7]. So Soft Start can be added to eliminate turn-on overshoot in optocoupler feedback applications with a 4.7 μF to 47 μF aluminum electrolytic capacitor (C_{10}) placed across the shunt element as shown in Figure 2.13 [11]. Soft start capacitor C_{10} increases optocoupler current during turn-on to limit the duty cycle and slow down the rising output voltage. C_{10} has minimal effect on the control loop during normal operation. R_2 discharges soft start capacitor C_{10} when input power is removed.
By using all these components which are described above, the fly-back converter can be operated for wide variation of input and constant outputs.

2.2.2 Buck converter control:

We have already discussed that a multi-level buck converter is used for this application. For controlling this converter, it should have information about the required output voltage of load, which can be done by one communicating device, which can communicate with the electronic gadgets and produce the reference voltage and based on that voltage which switch will operate up to what time (as it has two switches 'S_1' and 'S_2' which are operated based on the required output voltage), it should be decided. For this reason one decision making device is required to decide which switch will operate and one computing device is required, which will do all calculation for the duty cycle, which is necessary to generate the required output voltage. All these things can be done by one single microcontroller. Here Arduino Uno (a microcontroller based board) is used, which can communicate with the electronic gadgets to get the reference voltage and generate control signal for the switches to get required output. The equations (1.39) and (1.46), which are derived in previous section, are used for computing the duty cycle in microcontroller.

Overview of Arduino Uno: The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. In the proposed circuit one output winding of Fly-back converter is used for giving supply to the board. The schematic diagram of Arduino Uno is given below in Figure 2.14 [14].

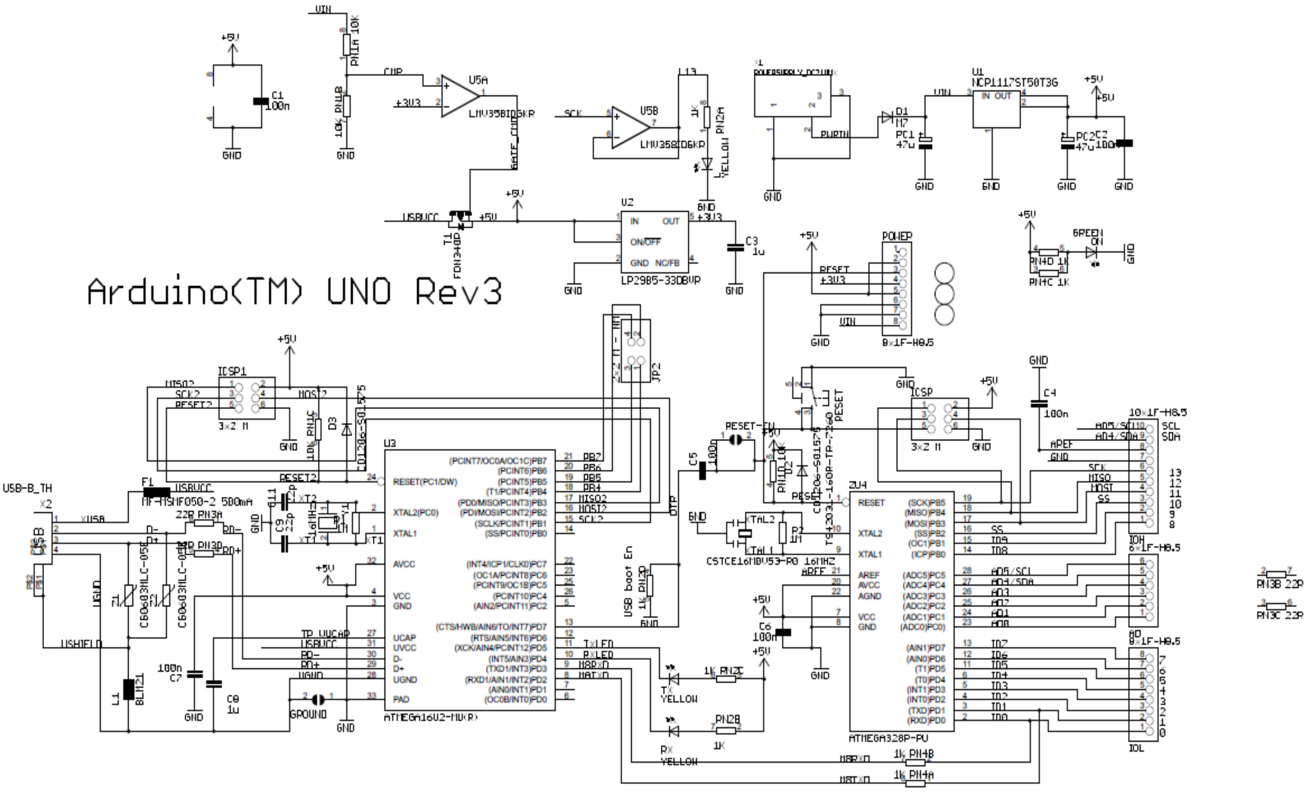


Figure 2.14: Schematic diagram of Arduino Uno

The ATmega328 has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM [13].

Serial Communication of Arduino board: The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other communicating devices. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The Arduino can "talk", (transmit or receive data data) via a serial channel, so any other device with serial capabilities can communicate with an Arduino. It doesn't matter what program/programming language is driving the other device [15].

Chapter 3

Simulation Results

The proposed charger circuit is simulated in Matlab for four different voltage level (5 volts, 9 volts, 15 volts, 20 volts). In simulation the fly-back converter is controlled by a PI controller and the multi-level buck converter is controlled by simple logic gates. The circuit is simulated with ideal condition. The parameters (from Figure 2.1) which are taken for simulation is given in Table 3.1.

Table 3.1:

Parameter	Value
L_{pri}	650 µH
C1,C2	200 µF
L	600 µH
C	100 µF

The results are given below.

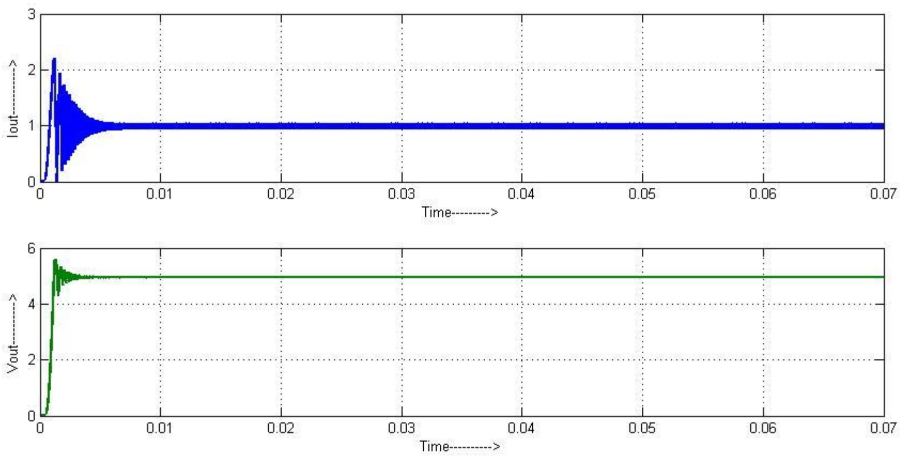


Figure 3.1: Simulation results for 5 volt output

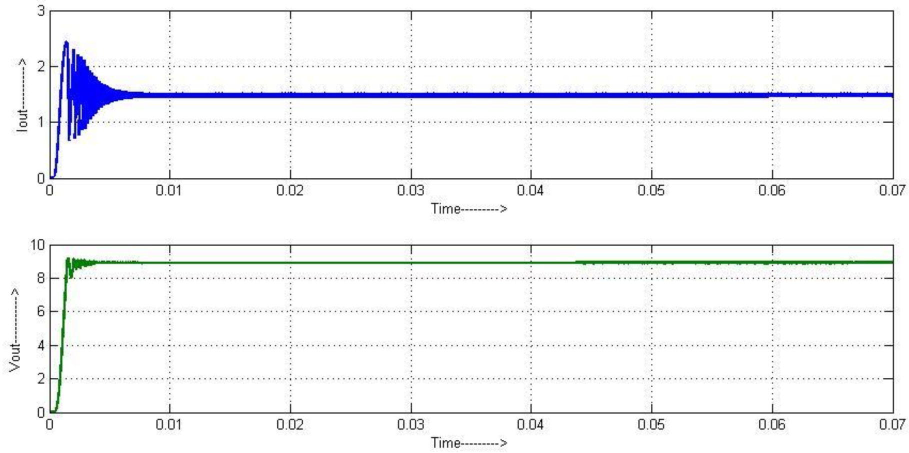


Figure 3.2: Simulation results for 9 volt output

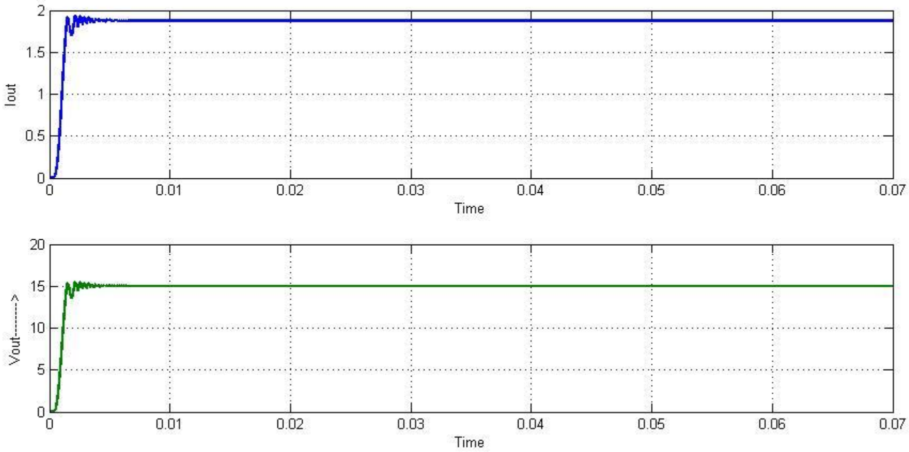


Figure 3.3: Simulation result for 15 volt output

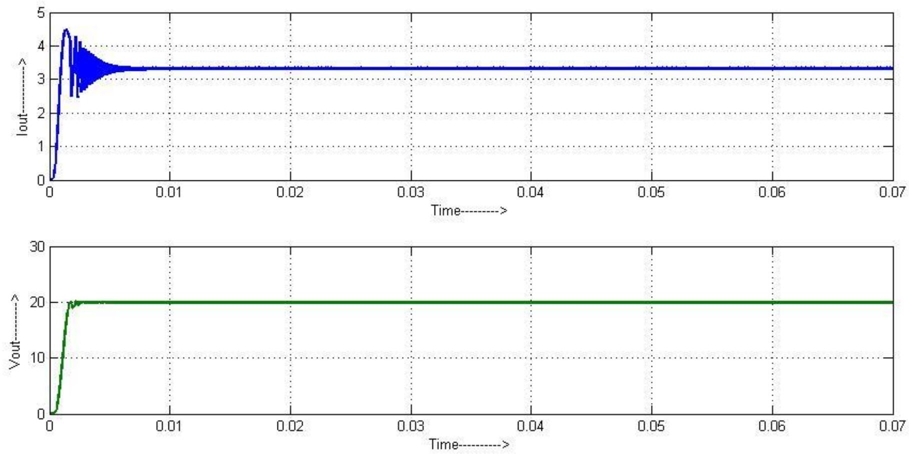


Figure 3.4: Simulation results for 20 volt output

Chapter 4

Hardware implementation and Results

4.1 Hardware Design

Proposed charger circuit is designed for input 90Vac to 240Vac (100Vdc to 340Vdc) and output 5 volt to 20 volt (DC). A proto type of this charger circuit is developed in the laboratory. The schematic of the circuit is given in Figure 4.1.

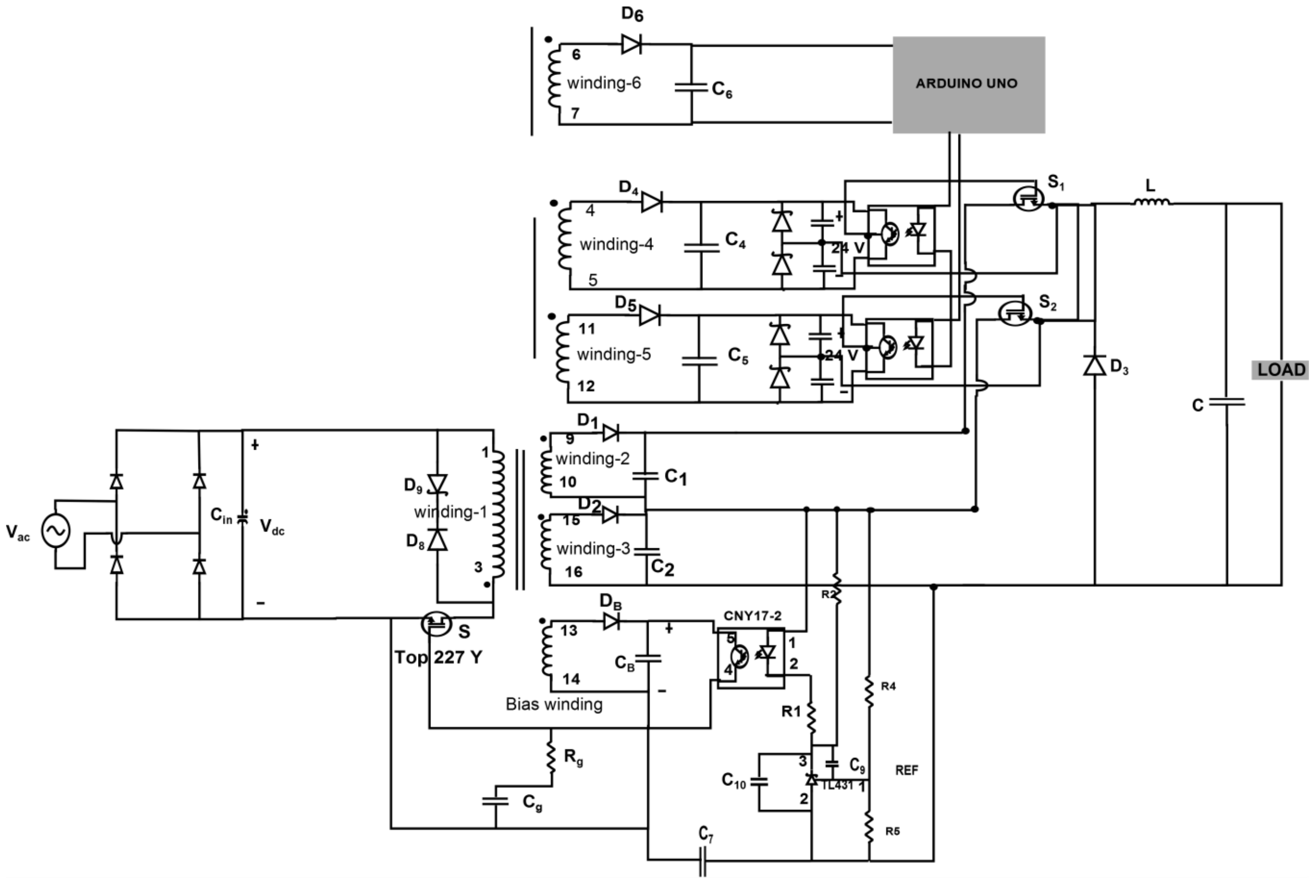


Figure 4.1: Complete circuit diagram of proposed charger circuit

Input to the circuit is given from a single phase auto transformer. As now, the available source is mainly ac, a bridge rectifier is used before the fly-back converter. Fly-back converter has six outputs out of which two outputs are main output, which gives power to load, one is bias winding which is used for feedback purpose and others are auxiliary supply which are used for gate driver circuit of the two switches. Fly-back converter output and their voltage level is given in Figure 4.1.The Flyback transformer which used in this circuit has one primary winding and six secondary winding. The ratings of the windings are given below in Table 4.2. Whatever discussed in the chapter-2 regarding design of the converter, same thing is followed here.

Converter Specification:

Input voltage: 90 Vac – 240 Vac

Output voltage: 5 volt – 20 volt

Switching frequency: 100 kHZ (Flyback converter), 10 kHZ (Buck converter)

From equation (2.11)

V_{dcmax}= 340 Volt

C_{in} =200 µF

From equation (2.10)

V_{dcmin}= 98 volt

D_{MAX} = 0.6

From equation (2.24), for V_{C1} (winding-1)

$$\frac{N_P}{N_{S1}} = 9.2$$

This turn's ratio is same for bias winding and second output (V_{C2}). Similarly we can get turn's ratio for other windings.

$$\frac{N_P}{N_{S4}} = 5 = \frac{N_P}{N_{S5}}, \quad \frac{N_P}{N_{S6}} = 20$$

For selection of output diode rectifier we need to know about the diode PIV. From the equation 2.31 and the turn's ratio, we can calculate the diode PIV. The different output voltage of Fly-back converter and PIV of output rectifier is given below in Table 4.1.

Table 4.1: Output voltages and PIV across diode rectifier of fly-back converter

Output	Voltage	PIV across diode
1 (V_{C1})	**12 volt**	**50 volt**
2 (V_{C2})	**12 volt**	**50 volt**
3 (V_{C4})	**24 volt**	**94 volt**
4 (V_{C5})	**25 volt**	**94 volt**
5 (V_B)	**12 volt**	**50 volt**
6 (V_{C5})	**6 volt**	**23.5 volt**

Table 4.2: Specification of fly-back transformer

Windings	Voltage rating	Current rating	Type
Winding-1	**400 volt**	**1.5 amp**	**Primary winding**
Winding-2	**13 volt**	**4 amp**	**Main output winding of fly-back converter**
Winding-3	**13 volt**	**4.5 amp**	**Main output winding of fly-back converter**
Winding-4	**24 volt**	**0.5 amp**	**Auxiliary winding**
Winding-5	**24 volt**	**0.5 amp**	**Auxiliary winding**
Winding-6	**6 volt**	**0.5 amp**	**Auxiliary winding**
Winding-7	**13 volt**	**0.5 amp**	**Bias winding**

The currents and voltages which are given in the above table, all are calculated by using the equations derived in section 2.1.1.

From the equation the voltage across switch 'S' during turn OFF period is nearly 650 volt. So from the current rating and voltage ratings *TOPSwitch* is selected.

From equation (2.13)

L_{pri} = 700 µH

Where V_{DS}= 10 volt

Earlier we have discussed that the feedback circuit of fly-back converter is important, the elements and their values are given in Table 4.3.

Table 4.3: Feedback circuit elements

Parameter	**Value**
R1	**1 kΩ**
R2	**200Ω**
R_4, R_5	**38kΩ, 10kΩ**
R_g, C_g	**10Ω, 47µF**
C_9, C_{10}	**0.1µF, 22µF**

This is all about the parameters, which are used for operation of the fly-back converter. Now design of the buck converter, which is used in the proposed circuit is given below. As it has been discussed earlier that the buck converter operation will be in two parts, one is above reference voltage and one is below the reference voltage. So we will get different type of values for each component, which is the highest value that is taken in this design. Buck converter parameters and values are given in Table 3.4.

Arduino Uno gives the switching signals to control the buck converter. But it can give only 5 volt output, which is not sufficient to turn ON the switches. So a gate driver circuit is used for driving the switches [1]. So optocoupler TLP250 is used for gate driving.

Table 4.4: Buck converter parameters

Parameter	**Value**
L	**600 µH**
C	**470 µF**

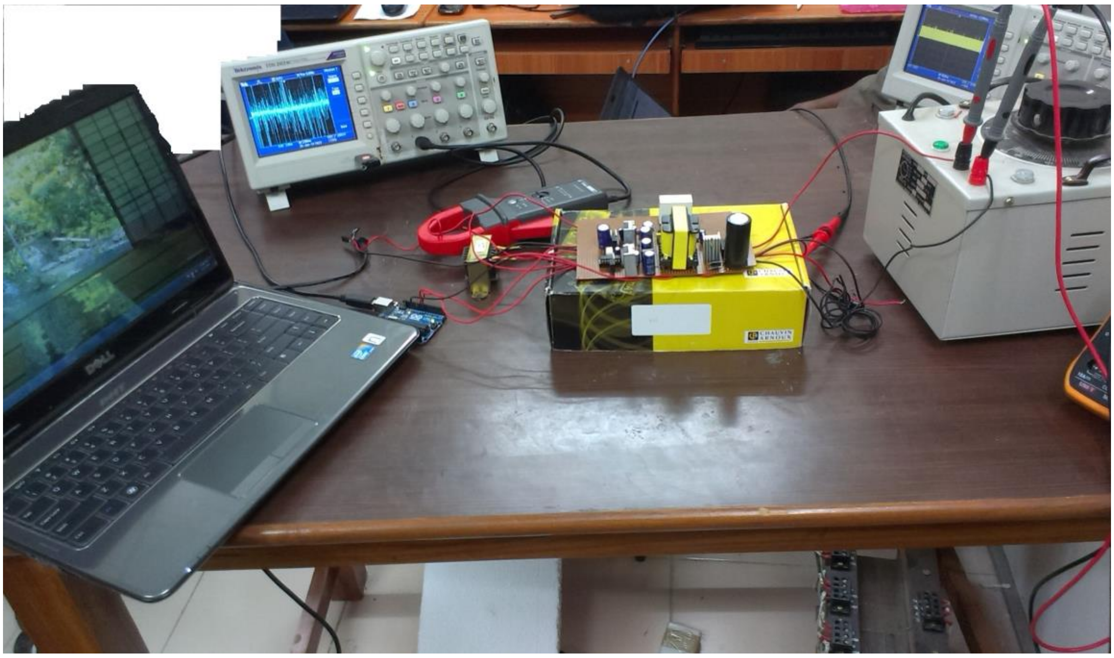


Figure 4.2: Experimental Set up

4.2 Experimental result

A prototype of the charger circuit has been developed in the laboratory to verify theoretical expectation according to the specification given in the previous section. Experiment is done for four different level of voltage (5 volt, 9 volt, 15 volt, 20 volt) with a resistive load. The required voltage is given from the computer and the microcontroller (Arduino Uno) take this voltage and generate PWM for the buck converter switches. The results for different voltage level is given below.

Output voltage < 10 volt:

For experiment 5 volts and 9 volts voltage level has been taken as reference voltage level and for this switch S_2 of the multilevel buck converter has been operated with 10 kHz switching frequency. The output for 5 volts and 9 volts reference voltage level has been found to be nearly 5.03 volts and 9.32 volts is as shown in figure respectively.

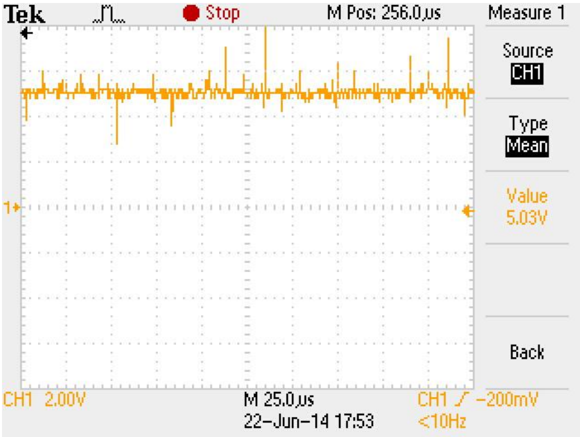


Figure 4.3(a): For 9 volt output voltage

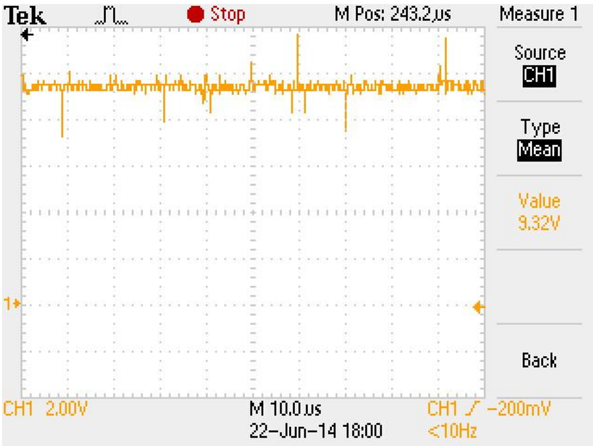


Fig.4.3 (b): For 9 volt output voltage

The ripple content for 5 volts and 9 volts reference voltage level has been found to be 0.04 % and 0.08 % respectively. In the above figures X-axis is the time axis and Y-axis is output voltage axis. The 5 volt output is for Smart phones application and 9 volt output is for Tablets application.

Output voltage > 10 volt:

For experiment 13 volts, 15.5 volts and 20 volts voltage level has been taken as reference voltage level and for this switch S_2 of the multilevel buck converter has been operated with 10 kHz switching frequency. The output for 13 volts, 15.5 volts and 20 volts reference voltage level has been found to be 13.2 volts, 15.8 volts and 20.5 volts is as shown in figure respectively. The ripple content for 13volts, 15.5 volts and 20 volts reference voltage level has been found to be nearly 0.03%, 0.04 % and 0.06 % respectively.

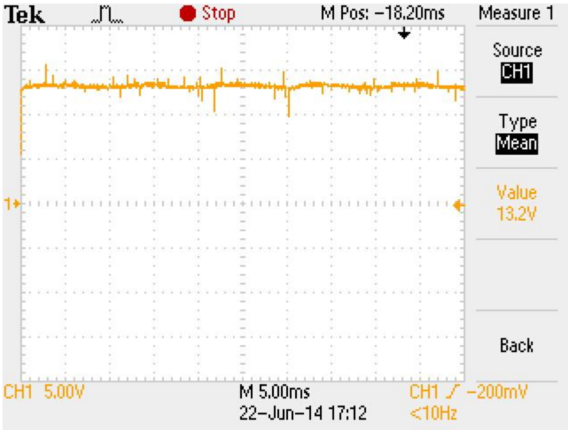


Figure 4.4 (a): For 13 volt output voltage

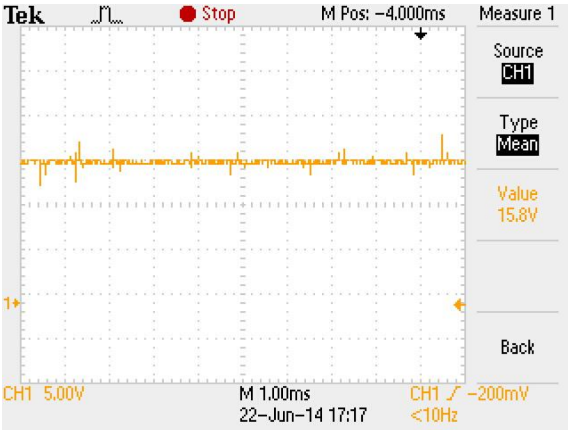


Figure 4.3 (a): For 15.5 volt output voltage

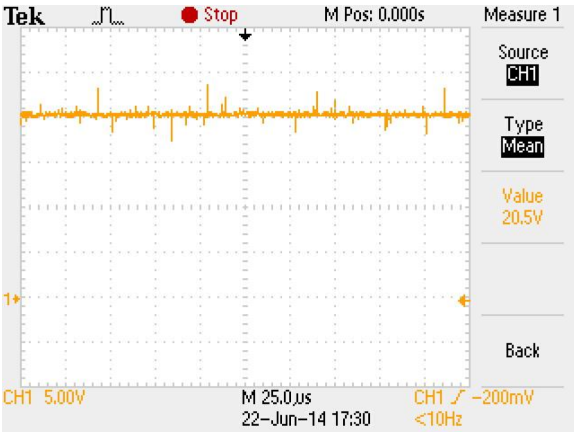


Figure 4.4(b): For 20 volt output voltage

These 13 volts and 15.5 volts voltages are for some notebooks whose battery voltage ratings are varying from 13 volt to 16 volt. The 20 volt output is for laptops. All laptops may not have same voltage ratings, it depends on the laptop manufacturer. Laptop voltage ratings varies from 19 volts to 21 volts.

The experiment is done with a laptop also. The experimental setup is give in Figure 4.2 and the current waveforms is given below Figure 4.5.

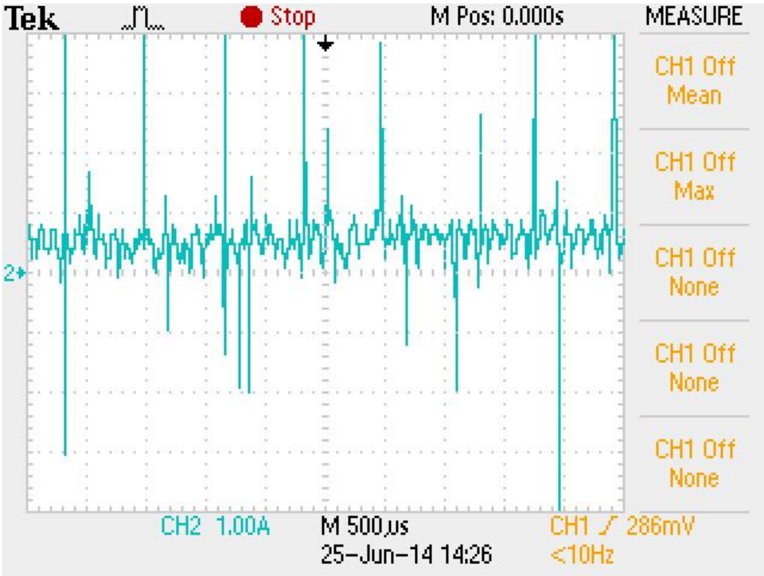


Figure 4.5: Laptop Battery charging current profile

Conclusion

A universal charger circuit has been developed for charging the electronic gadgets with different voltage ratings. It is able to take AC (of any frequency) as well as DC as input with a wide range of voltage variation and can give the required voltage output. So, the user can carry a single charger instead of carrying multiple charger while travelling. This charger circuit can be used in Airport, railway station, bus stand, hotels etc. where different types of gadgets are needed to be charged by the people. As a result their waiting time may reduce for charging their respective gadgets. The proposed charger circuit is simulated using Matlab Simulink and also a laboratory prototype has been built to verify it. During the practical implementation of the universal charger leakage inductance of the Flyback transformer, forward switching drop has been taken into consideration. The laboratory prototype has been tested for different level of voltage reference and based on this switches of the multilevel buck converter has been operated. It has been found that the experimental results are complied with the simulation results within a tolerable limit.

Appendix

A1: Programming code of generating PWM for Buck Converter

```
#include "Arduino.h"
#include "TimerOne.h" // initializing Timer 1
double duty, ref;
void setup()
{
 Timer1.initialize(100); // initializing Timer 1 and set a timer of length 100 microseconds
 Serial.begin(9600);
 pinMode(9, OUTPUT);
 pinMode(10, OUTPUT);
}

void loop(){
 // Main code loop
 if(Serial.available()>0) // if there is data to read
  {
  ref=Serial.read(); // read data from serial port or USB
 if (ref > 10) {
   duty=(ref-12)*1023;
   duty=duty/12; // duty cycle
   Timer1.pwm(10,duty);
   Timer1.pwm(9,duty);
```

```
  Serial.println(ref);
 }
 else {

 duty=ref;
 duty=(12-duty)*1023;
 duty=duty/(12);
 Timer1.pwm(10,duty);
 Timer1.pwm(9,0);
 Serial.println(duty);
 }
   }
}// End of the code
```

A2: PCB Designing

PCB designing for the proposed charger circuit has been done by using the Orcad software. The schematic of the circuit is shown below in Figure A2 (a), and the Layout is shown in Figure A2 (b).

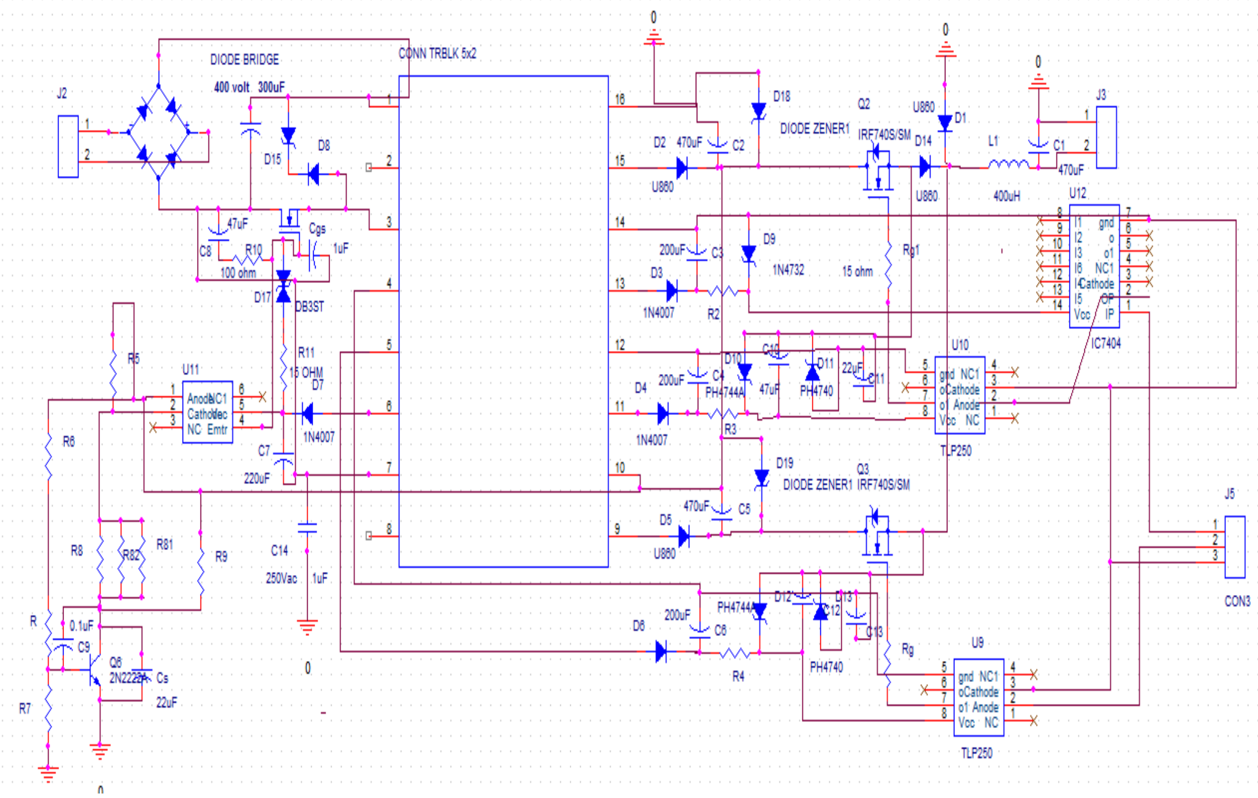


Figure A2 (a): Schematic of charger circuit

PCB Layout Check list: Before designing Layout some points should be taken care which are given below

- The Flyback transformer primary pins, input capacitor C_{in} and the *TOPSwitch* Q1 should be connected very closely to minimize trace length and loop area.
- All the output rectifiers and respective output capacitor should be connected very closely with the secondary pins of the Flyback transformer.
- The gate driver circuit and the gate of the switch, which are used in buck converter should be connected very closely.

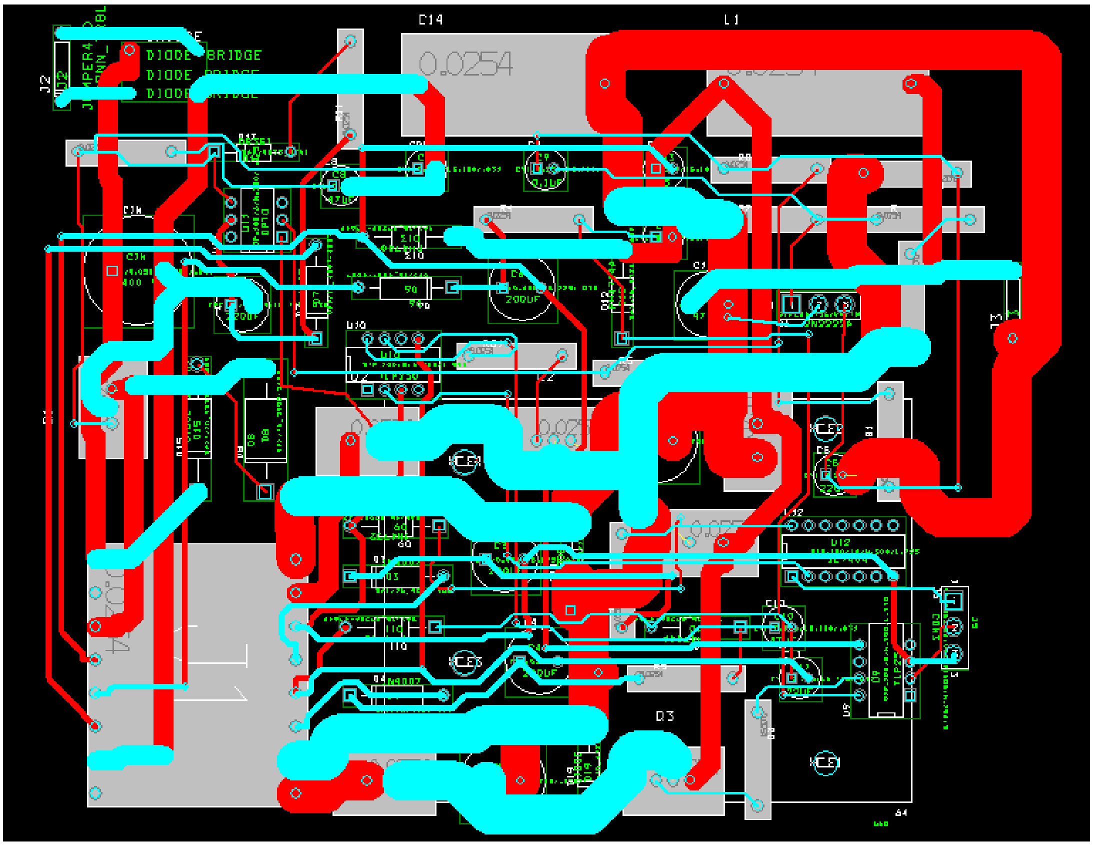


Figure A2 (b): PCB Layout for proposed Charger circuit

For the PCB Layout only two layers has been used ie. top layer and bottom layer.

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