Portable Refrigerator Using Peltier Device

A project report submitted in partial fulfillment of
the requirements for the degree of

Bachelor of Engineering

by

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October 23, 2017

This work is dedicated to my family.

I am very thankful for their motivation and support.

Internal Approval Sheet

CERTIFICATE

This is to certify that the project entitled **"Portable Refrigerator Using Peltier Device"** is a bonafide work of **Mamaniya Karan Rajesh(7319), Nagar Vaibhav(7330), Mathew Sen Rajan(7322)** submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of **Bachelor of Engineering** in **Electronics**

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Approval Sheet

Project Report Approval

This project report entitled by **Portable Refrigerator Using Peltier Device** by **Mamaniya Karan Rajesh, Nagar Vaibhav, Mathew Sen Rajan** is approved for the degree of Bachelor of Engineering

Examiners

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Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Date: October 23, 2017

Abstract

The global increasing demand for refrigeration in field of refrigeration air-conditioning, food preservation, vaccine storage, medical services, and cooling of electronic devices, led to production of more electricity and consequently more release of CO_2 , Chlorofluorocarbons (CFC) and Hydrochlorofluorocarbons ($HCFC$) all over the world which it is contributing factor of global warming on climate change. Thermoelectric refrigeration is new alternative, to conventional compressor type refrigerator. Therefore, thermoelectric refrigeration is greatly needed, because of long life and low maintenance are needed. The objective of this project is to design and develops a working thermoelectric refrigerator that utilizes the Peltier effect to refrigerate and maintain a selected temperature from 5 °C to 25 °C. The design requirements are to make a refrigerator with a small and powerful power supply unit for system to meet the requirements of the system. The power supply unit contains a transformer less switched mode power supply design, making the unit small and portable. The supply unit has an input rating as 230V, 50Hz and output rating as 12V, 6A. The portability nature of the refrigerator will lead to easy installation in automobiles and aircrafts. Thereby carrying the achieving low temperatures instantly for sensitive applications like organ transport would be achieved on contrary to the slow cooling by compressor refrigerators.

Acknowledgments

We have great pleasure in presenting the report on **"Portable Refrigerator Using Peltier Device"**. I take this opportunity to express my sincere thanks towards the guide Prof. Shilpa Patil, C.R.C.E, Bandra (W), Mumbai, for providing the technical guidelines, and the suggestions regarding the line of this work. We enjoyed discussing the work progress with him during our visits to department.

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Chapter 1

Introduction

Refrigeration is the process of heat-removal from a space in order to bring it to a lower temperature than surrounding temperature. In this context, my seminar topic, "Peltier cooling module" which works on thermoelectric refrigeration, aims to provide cooling by using thermoelectric effects rather than the more prevalent conventional methods like 'vapour compression cycle' or the 'vapour absorption cycle'.
There are three types of thermoelectric effect: The Seebeck effect, the Peltier effect, the Thomson effect. From these three effects, Peltier cooler works on the Peltier effect; which states that when voltage is applied across two junctions of dissimilar electrical conductors, heat is absorbed from one junction and heat is rejected at another junction. Peltier coolers are basically used as a cooling element in laser diodes, CCD cameras (charge coupled device), blood analyzers, portable picnic coolers laser diodes, microprocessors, blood analyzers and portable picnic coolers.
Thus designing a portable refrigeration unit using this device has many benefits. The overview of the system is as follow:

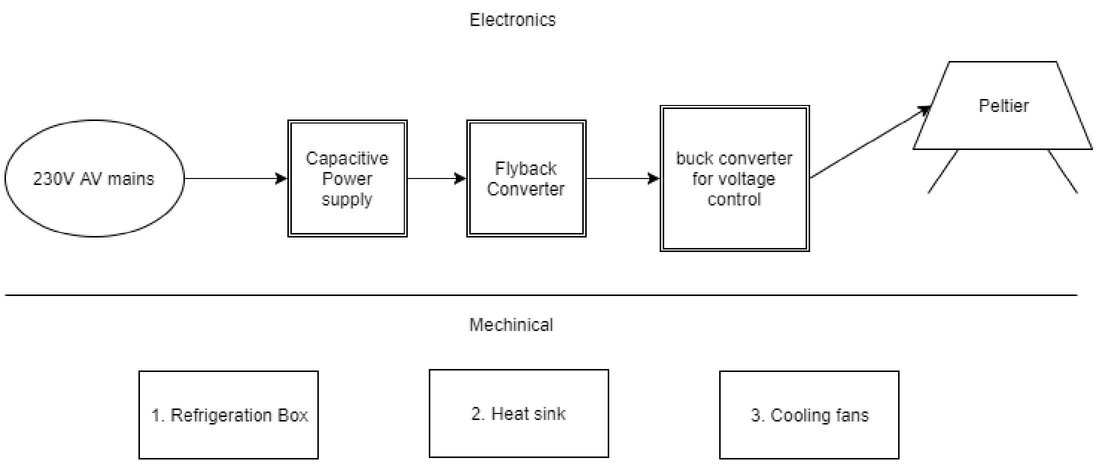

Figure 1.1: Basic Block diagram of the System

1. 230V/50Hz AC mains input.
2. Capaciter power supply.
3. SMPS power supply to obtain 12V/6A power.
4. Buck converter to control voltage thereby cooling.

1.1 Motivation

In recent years, with the increase awareness towards environmental degradation due to the production, use and discharge of ChloroFluoroCarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) as heat carrier fluids in conventional refrigeration systems has become a subject of great concern and resulted in extensive research into development of refrigeration technologies. Thermoelectric operated cooler provides a best alternative in refrigeration technology due to their distinct advantages. While using thermoelectric effect in system the COP of the system also increases. And also in thermoelectric refrigeration system all mechanical part are eliminated and it replaced by thermoelectric module, thus making them light, compact and portable. Also, instead of mechanical parts electrical parts are being used, the life cycle of the system increases. The cooling can be controlled by the varying the input current/voltage, thus provides a range of temperatures, which is not seen in mechanical refrigerators.

1.2 Objectives

The problem statement of our project is âĂIJPortable Refrigerator unit using Peltier devicesâĂİ. To give a compact, light and portability feature to the system, the power supply unit is designed on basis of transformer less- switch mode power supply designed. Cooling is provided by the thermoelectric coolers like peltier device (TEC1-12706) which are more efficient as compared to other traditional methods. Since no mechanical parts are used in the system for cooling instead electronics are used thus making it lightweight and portable.

Chapter 2

Literature Review

2.1 Working of Peltier

2.1.1 The Peltier effect

Peltier found there was an opposite phenomenon to the Seebeck Effect, whereby thermal energy could be absorbed at one dissimilar metal junction and discharged at the other junction when an electric current flowed within the closed circuit.

In Figure 2, the circuit is modified to obtain a different configuration that illustrates the Peltier Effect, a phenomenon opposite that of the Seebeck Effect. If a voltage (Ein) is applied to terminals T1 and T2, an electrical current (I) will flow in the circuit. As a result of the current flow, a slight cooling effect (QC) will occur at thermocouple junction A (where heat is absorbed), and a heating effect (QH) will occur at junction B (where heat is expelled). Note that this effect may be reversed whereby a change in the direction of electric current flow will reverse the direction of heat flow.

Joule heating, having a magnitude of I2 x R (where R is the electrical resistance), also occurs in the conductors as a result of current flow. This Joule heating effect acts in opposition to the Peltier Effect and causes a net reduction of the available cooling. The Peltier effect can be expressed mathematically as

$$Q_C \, or \, Q_H = \beta \times I = (\alpha T) \times I \tag{2.1}$$

Where,

β is the differential Peltier coefficient between the two materials A and B in volts.

I is the electric current flow in amperes.

QC and QH are the rates of cooling and heating, respectively, in watts.

[2]The application of a current at an interface between two dissimilar materials results in the absorption/release of heat. At the subatomic level, this is a result of the different energy levels of materials, particularly n and p type materials.
As electrons move from p type material to n type material, electrons jump to a higher energy state absorbing energy, in this case heat, from the surrounding area.
The reverse is also true. As electrons move from n type material to p type material, electrons fall to a lower energy state releasing energy to the surrounding area.
The relationship between the amount of current and heat absorbed/released at the junction of the two dissimilar semiconductors is given by the Peltier coefficient equation 2.2

$$\pi_{ab}(T) = \frac{\Delta Q_{ab}}{I} \tag{2.2}$$

2.2 Capacitive power supply

[1]In most non-battery applications, the power to the microcontroller is normally supplied using a wall mounted transformer, which is then rectified, filtered and regulated. In most applications, this method of generating the regulated voltage is cost effective and can be justified. However, there are applications where the PIC12/16/17 is the main controller and low voltage is not required by other components except the PIC12/16/17. In these instances, the cost of the transformer becomes the sizable cost factor in the system. Transformerless power supplies, thus, have a distinct advantage in cost as well as in size. The disadvantages of using a transformerless power supply are:

1. Low current supply
2. No isolation from the AC line voltage

. The drawback of low current will be overcomed by a DC - DC voltage to current converter such as SMPS or a buck converter which will be explained later and the electric isolation will be provided with the use of small, high frequency transformer in the SMPS design.
When a capacitor and resistor are connected in series to an AC source, as in figure 2.1, a constant current can be maintained through the resistor, so long as the reactance of the capacitors is much greater than the resistance. The current flow is dependent upon the value of the capacitor and assuming that V_1 is much greater than V_2, the value of the

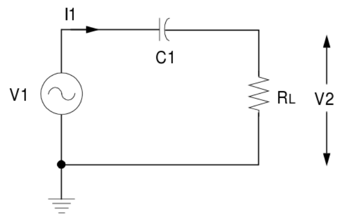

Figure 2.1: Constant current obtained due to transformerless supply

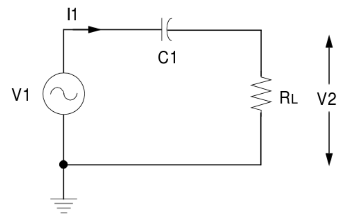

Figure 2.2: Rectifier and filter model after transformerless design

current can be assumed to be

$$I_{RMS} = V_1/X_C \tag{2.3}$$

where X_C is the reactance of the capacitor.
Assuming a line voltage of V1 = 230V and line frequency = 50 Hz,

$$I_{RMS} = 115 \times (2\pi \times 50 \times C) = 4300C \, or \, I_{RMS} \approx 40 \, mA/\mu F. \tag{2.4}$$

In order to get a DC voltage using this system, a pair of rectifiers and filter caps can be added as shown in figure 2.2. This would give us a capability of driving one half of the current through the positive part and the other half through the negative part. The max current on each side would be approximately equal to $20mA/\mu F$

2.3 SMPS

[3]A switched-mode power supply (SMPS) is an electronic circuit that converts power using switching devices that are turned on and off at high frequencies, and storage components such as inductors or capacitors to supply power when the switching device is in its non-conduction state.
Switching power supplies have high efficiency and are widely used in a variety of electronic equipment, including computers and other sensitive equipment requiring stable and efficient power supply. Switched-mode power supplies are classified according to the type of input and output voltages. The four major categories are:

- AC to DC
- DC to AC
- DC to DC
- AC to AC

A basic isolated AC to DC switched-mode power supply consists of:

1. Input rectifier and filter

2. Inverter consisting of switching devices such as MOSFETs

3. Transformer

4. Output rectifier and filter Feedback and control circuit

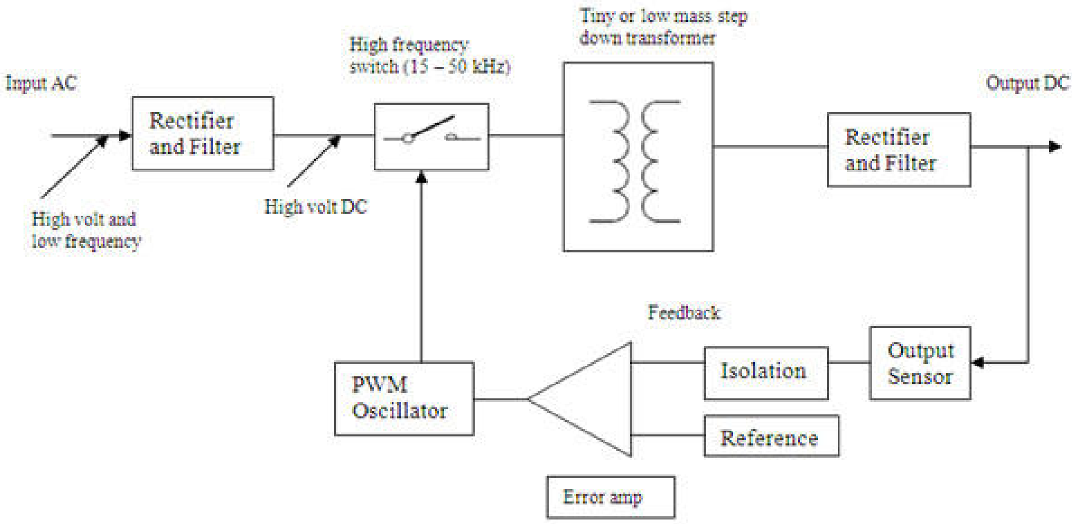

Figure 2.3: Basic Block diagram of SMPS

The input DC supply from a rectifier or battery is fed to the inverter where it is turned on and off at high frequencies of between 20 KHz and 200 KHz by the switching MOSFET or power transistors. The high-frequency voltage pulses from the inverter are fed to the transformer primary winding, and the secondary AC output is rectified and smoothed to produce the required DC voltages. A feedback circuit monitors the output voltage and instructs the control circuit to adjust the duty cycle to maintain the output at the desired level.

There are different circuit configurations known as topologies, each having unique characteristics, advantages and modes of operation, which determines how the input power is transferred to the output. Most of the commonly used topologies such as flyback, push-pull, half bridge and full bridge, consist of a transformer to provide isolation, voltage scaling, and multiple output voltages. The non-isolated configurations do not have a transformer and the power conversion is provided by the inductive energy transfer.

Advantages of switched-mode power supplies:

1. Higher efficiency of 68% to 90%

2. Regulated and reliable outputs regardless of variations in input supply voltage

3. Small size and lighter

4. Flexible technology

5. High power density

2.4 Refrigeration Unit

[4]The mechanical refrigeration unit is a major part of our system. It can be divided into the following components

2.4.1 Heat Transfer Methods

There are several methods which can be employed to facilitate the transfer of heat from the surface of the thermoelectric to the surrounding. These methods are described in the following three sections. Natural convection, Liquid cooled, Forced convection when the co-efficient of thermal transfer (K) was investigated, the K for natural convection was approximately 25 W/mK. This value compared to 100W/mK for forced convection. Clearly the size of the heat sink for a natural convection apparatus would need to be 4 times that for a forced convection set-up.

2.4.2 Geometry

Two main geometries were considered for the device the first was a rectangle. The advantage of rectangle is its simplicity to build and insulate. A door can easily be attached to one of the sides. Finally any insulation, thermoelectric modules or heat sinks are easily fastened to the sides. The second choice for cooler geometry was a cylinder. The advantage found with this shape is that it has the largest volume to surface area ratio of the two designs considered. This is a good property when the objective is to minimize heat loss. But considering the simplicity to build and insulate rectangle box is considered.

2.4.3 Material

We explored three different materials for the construction of the outer casing and frame of the device. These were aluminum, stainless steel and Hips. High impact polystyrene is desirable as it has a low thermal conductivity. Building the device out of would make it very light, portable while maintaining rigidity is readily available and reasonably priced, is easy to cut and drill. The outer casing and container would be made by first making a positive mold and applying a cloth coated with resin.

2.4.4 Heat Sink Design

In order to visualize the energy flow in the entire system, a thermal circuit is constructed, which is schematically shown in Figure 2. Rc and Rh and are the overall thermal resistances for the internal heat sink and external heat sink, respectively. The components of the air cooler are an internal heat sink, a thermoelectric module, and an external heat sink as shown in Figure 2 is the amount of heat transported at the internal heat sink, which is actually the design requirement (33 Watts).

Chapter 3

Report on present investigations:

3.1 [1]Capacitive supply design

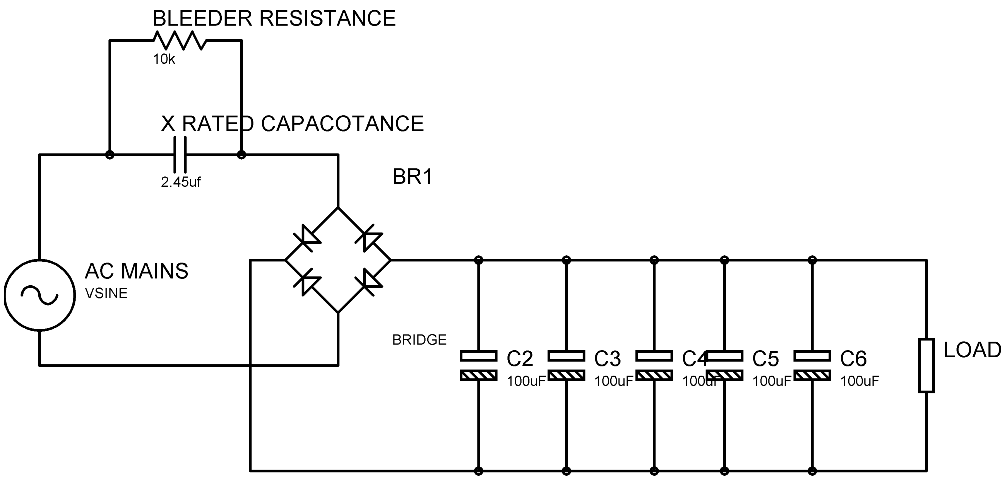

Figure 3.1: Capacitive supply circuit

If a non-polarised capacitor and a resistor are put in series with the AC power line, constant current can be maintained through the resistor, provided that the reactance of the capacitor is greater than the resistance of the series resistor used. The current flowing through resistor R depends on the value of capacitor C. That is, a higher-value capacitor delivers more current to the circuit. Current flow through dropping capacitor C depends on its reactance, and the value of the current passing through the capacitor is represented as:

$$I_{RMS} = V_{IN}/X \tag{3.1}$$

where X is the reactance of the capacitor and V_{IN} is the line voltage (230V).
Before selecting the capacitor, it is necessary to understand how a dropping capacitor behaves when it passes current. The capacitor designed to operate in AC voltage belongs to the 'X' category with operating voltage ranging from 250 volts to 600 volts. If the mains frequency is 50 Hz, the reactance (X) of the capacitor is:

$$X = \frac{1}{2\pi f C} \tag{3.2}$$

Taking peak voltage as $325V$, forvard voltages of diodes as $0.7V$ thus for a maximum current of $250mA$, the 'X-rated' capacitor is

$$X_C = \frac{V_{MAX}}{I_{MAX}} \tag{3.3}$$

Thus, from equations 3.2 & 3.3, we get the value of 'X- rated' capacitor to be $2.4\mu F$
[5]Now, the value of capacitor C2 needed to filter the the DC pulses at the rectifier output is to be determined by thr formula

$$C = 0.7 \times I/(\Delta V \times F) \tag{3.4}$$

3.2 Buck converter

3.2.1 Calculate the Maximum Switch Current

The first step to calculate the switch current is to determine the duty cycle, D, for the maximum input voltage. The maximum input voltage is used because this leads to the maximum switch current. The Maximum Duty Cycle is

$$D = \frac{V_{out}}{V_{IN(max)} \times \eta} \tag{3.5}$$

Where,
$V_{IN(max)}$ = maximum input voltage
V_{OUT} = output voltage
η = efficiency of the converter, e.g., estimated 90%

3.2.2 Inductor Selection

Data sheets often give a range of recommended inductor values. If this is the case, choose an inductor from this range. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current.
In general, the lower the inductor value, the smaller is the solution size. Note that the inductor must always have a higher current rating than the maximum current given is

$Isw = \Delta I_l/2 + I_{OUT(max)}$; this is because the current increases with decreasing inductance. For parts where no inductor range is given, the following equation is a good estimation for the right.

$$L = \frac{Vout \times (Vin - Vout)}{\Delta I_L \times fs \times vin} \tag{3.6}$$

Where,

V_{IN} = typical input voltage

V_{OUT} = desired output voltage

f_S = minimum switching frequency of the converter

ΔI_L = estimated inductor ripple current

ΔI_L = estimated inductor ripple current

$I_{OUT(max)}$ = maximum output current necessary in the application

3.2.3 Rectifier Diode Selection

To reduce losses, use Schottky diodes. The forward current rating needed is equal to the maximum output current:

$$I_F = I_{OUT(max)} \times (1 - D) \tag{3.7}$$

Where,

I_F = average forward current of the rectifier diode

$I_{OUT(max)}$ = maximum output current necessary in the application

Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current in the system is not a problem. The other parameter that has to be checked is the power dissipation of the diode. It has to handle:

$$P_D = V_F \times I_F \tag{3.8}$$

Where,

I_F = average forward current of the receiver diode

V_F = forward voltage of the rectified diode

D = duty cycle calculated in Equation 3.5

3.2.4 Input Capacitor Selection

The minimum value for the input capacitor is normally given in the data sheet. This minimum value is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply. The best practice is to use low-equivalent series resistance (ESR) ceramic capacitors. The dielectric material must be X5R or better. Otherwise, the capacitor loses much of its capacitance due to dc bias or temperature.

The value can be increased if the input voltage is noisy.

3.2.5 Output Capacitor Selection

The best practice is to use low-ESR capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice if the dielectric material is X5R or better. If the converter has external compensation, any capacitor value above the recommended minimum in the data sheet can be used, but the compensation has to be adjusted for the used output capacitance. With internally compensated converters, the recommended inductor and capacitor values must be used, or the recommendations in the data sheet for adjusting the output capacitors to the application in the data sheet must be followed for the ratio of L × C.

With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple:

$$C_{OUT} = \frac{\Delta I_L}{8 \times fs \times \Delta V_{OUT}} \tag{3.9}$$

Where,

$C_{OUT(min)}$ = minimum output capacitance

ΔI_L = estimated inductor ripple current

f_S = minimum switching frequency of the converter

ΔV_{OUT} = desired output voltage ripple

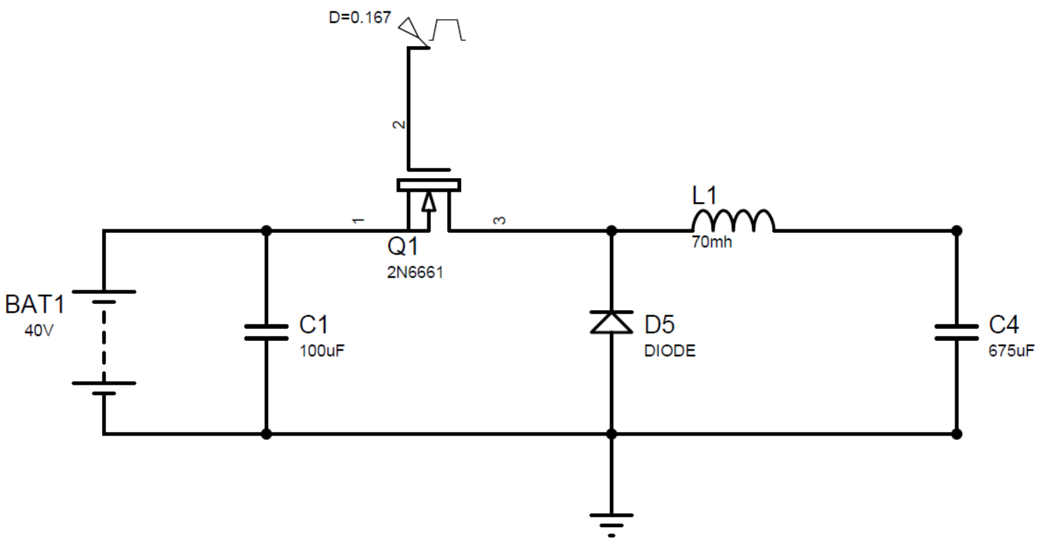

Figure 3.2: Buck converter circuit

For the above Current Booster design;

$V_{OUT} = 12V$ $V_{IN(MAX)} = 40V_{DC}$ $\eta = 90\%$

Therefore by using above mentioned formulas we get;

$D = 0.67$

$L = 70mH$

$C_{OUT} = 675\mu F$

3.3 Simulation

3.3.1 Power Supply Unit of the Peltier TEC1-12706

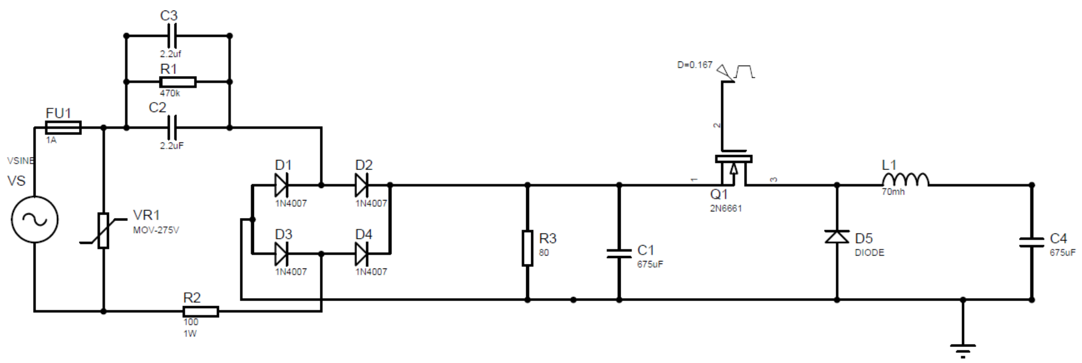

Figure 3.3: Simulation circuit

The circuit in figure 3.3 constitute of a Capacitive Power supply followed by a Current Booster.

The capacitive power supply block converts the $230V_{AC}/50Hz$ to regulated $40V_{DC}$.

The regulated DC supply is boosted with the current booster block to 12v-6Amps, which is the supply requirement for the Peltier TEC1-12706. The X Rated Capacitor C1 is the core part of this power supply as it will drop the excess mains voltage across it. The excess energy will not dissipated as heat as we are using capacitor dropper instead of resistor.

The resistor R1 is the bleeder resistor for capacitor C1 which will discharge the capacitor when the supply is switch off, so it will prevent any shocks due to capacitor charge. Resistor R2 is provided to prevent excess transient current that can flow when the power supply is switch on.The 275V MOV (Metal Oxide Varistor) will protect from power supply spikes or surges.

X-rated $2.2\mu F$ capacitors are used in this capacitive power supply. A bleeder resistor of $470k\Omega$ is connected parallel to the X-rated capacitors. Therefore the maximum current obtained from this capacitive power supply is

$$I = (Vs - Vd)/Z$$

$$I = (325 - 0.7)/X_C$$

$$\therefore I \approx 250mA$$

3.4 SMPS (flyback converters design)

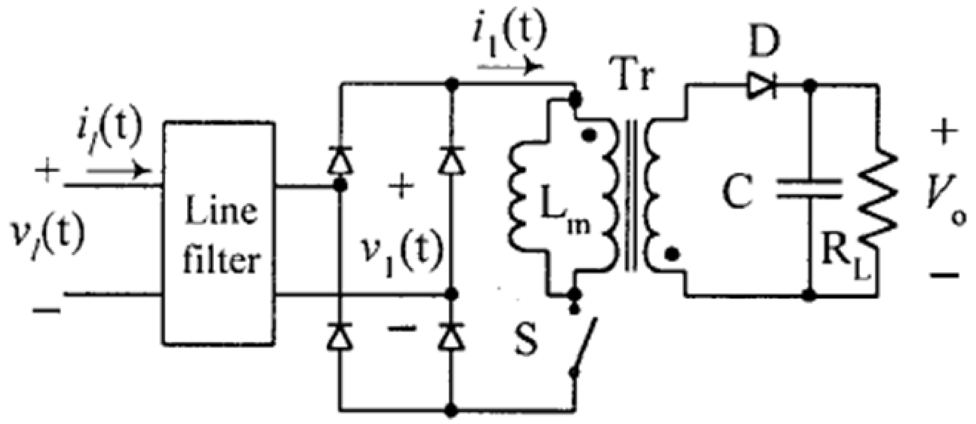

Figure 3.4: Flyback converter

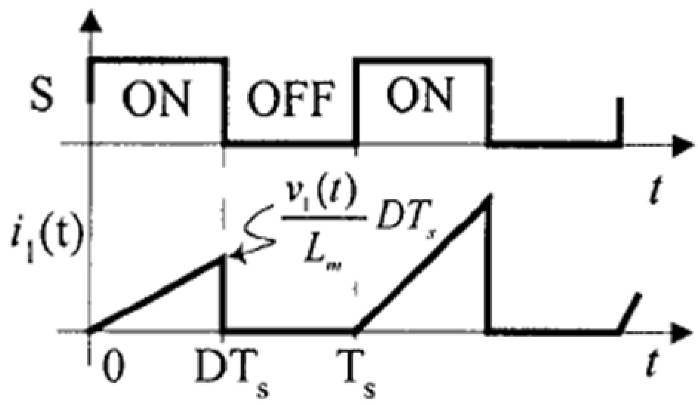

Figure 3.5: Input current waveform

[3]Flyback converter is an isolation converter. Its topology is shown in figure 3.4. Figure 3.5 shows its input current waveform. The input voltage-input current relationship is similar to that of buck-boost.

The current equation is

$$i_{1,avg}(t) = \frac{D^2 T_s}{2L_m} v_1(t) \tag{3.10}$$

Where,

L_m is the magnetizing inductance of the output transformer.

It is been seen that the output current waveform for buck converter has many ripples which cannot be ignored as this may affect the performance of peltier module. This may also lead to overheating of power supply unit thus buck converter is not used.

Comparing with buck-boost converter, flyback converter has all the advantages of the buck-boost converter without any limitation and has advantages over buck converter. More it has input-output isolation can be provide by flyback converter. These advantages make flyback converter most preferable in our project as part of power supply system.

Chapter 4

Results

4.1 Observations

In the simulation cirucit in figure 3.3, constant voltage and current cannot be achieved, thus leading to in appropriate control of cooling of refrigerator.
Since the concept of transformerless power supply design is implemented, the isolation between AC mains and DC output is not achieved in this circuit.
Considering the above note, the flyback converter design meets the necessary and sufficient requirements for proper and safe functioning of the system.
Flyback converter is one of the best smps topologies which provides a good isolation between AC mains and DC output, thus reducing the chances of short circuiting the live and neutral wire.
The current requirement of the peltier are not fulfuilled as 6A current is not observed at the output even after theoretical calcutions.

4.2 Drawback

In the mentioned circuit, constant voltage and current cannot be achieved, thus leading to in appropriate control of cooling of refrigerator and may even damag sensitive device like the peltier.
Since the concept of transformerless power supply design is implemented, the isolation between AC mains and DC output is not achieved in above circuit, this makes the circuit vulnerable to electric shock which may be fatal for the end user. Thus a major drawback in the buck converter designed is seen.

4.3 New approach

Flyback topology of Switch Mode Power Supply is being implemented. It provides the necessary stability of the output by appropriate selection of gate control IC for the switch in the SMPS.

Alongwith stability, flyback topology will also provide electrical isolation due to the use of transformer. Since we are focussing on making the system small and portable, flyback is a better approach because, it uses a high frequency transformer which reduces the size significantly.

Chapter 5

Conclusion

After reasearch, analysis, simulations and harware implementations, we were able to achieve the capacitive power supply design. Also we had to go back on the buck converter design due to the drawback discused earlier and the suitable alternative, which is the flyback converter has been chosen.

The circuit designing, values and components for the Flyback SMPS converter are yet to be determined, as simulations are in progress. Also, controller for the switch is to be finalized.

On completion of the final power supply design, testing with peltier module is scheduled for the next semester. Also, design of mechanical refrigeration unit and heat sinks is to be conducted in the next semester.

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