

**T.R.**  
**GEBZE TECHNICAL UNIVERSITY**  
**GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE**

**CONTROLLING CIRCUITRY FOR DC-DC CONVERTERS -  
SURVEY**

**MUHAMMED BAYRAM**  
**A THESIS SUBMITTED FOR THE DEGREE OF**  
**MASTER OF SCIENCE**  
**DEPARTMENT OF ELECTRONIC ENGINEERING**

**GEBZE**  
**2019**

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**FEN BİLİMLERİ ENSTİTÜSÜ**

**DC-DC ÇEVİRİCİLER İÇİN KONTROL**  
**DEVRELERİ- ARAŞTIRMA**

**MUHAMMED BAYRAM**  
**YÜKSEK LİSANS TEZİ**  
**ELEKTRONİK MÜHENDİSLİĞİ ANABİLİM DALI**

**DANIŞMANI**  
**DR. ÖĞR. ÜYESİ ÖNDER ŞUVAK**

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## SUMMARY

In this work, open and closed loop control methods with PWM had been applied to some of DC-DC converters that isolated and non-insulated. Their theoretical calculations and applications have been made. The relation between the circuits examined with accuracy, efficiency, power consumption and the relation with the duty cycle were investigated. In this thesis, the boost (10V-24V) converter which is uninsulated, is designed with two different methods as open loop control. Firstly, it is designed with a timer and secondly with a microcontroller. These two different boost circuits were designed and operated at the same power circuit's elements. In the second stage, the boost converter designed in the first stage had been transformed into closed loop controlled boost converter (10V-24V) and simulated. The fly-back (325V-6.2V) converter, which is also an isolated DC-DC converter, was designed and operated as closed-loop control. Result of these studies, The theoretical calculations and application circuits of insulated and uninsulated DC-DC converters were observed to be consistent.

**Key Words:** DC-DC Converter (DDCC), Pulse Width Modulation (PWM), Open Loop Controlled Converter (OLCC), Closed Loop Controlled Converter (CLCC).

## ÖZET

Bu tez çalışması kapsamında, farklı topolojilere sahip izoleli ve izolesiz DC-DC dönüştürücülerin bazılarına, PWM ile açık çevrim ve kapalı çevrim kontrol metotları uygulanarak teorik hesaplamaları ve uygulamaları yapılmıştır. Yapılan çalışmalar ile incelenen devreler doğruluk, verimlilik ve güç kaybı olarak karşılaştırılması ayrıca görev döngüsü (Duty Cycle) ile olan ilişkisi araştırılmıştır. Bu tezde, birinci aşamada izolesiz olan boost (10V-24V) dönüştürücüsü açık çevrim kontrollü olarak iki farklı yöntem ile dizayn edilmiştir. İlk olarak bir zamanlayıcı entegresi ile, ikinci olarak bir mikro denetleyici ile tasarlanmıştır. Aynı güç devreleri ile tasarlanan bu iki farklı yöntemli boost devreleri kurulup çalıştırılmıştır. İkinci aşamada birinci aşamada tasarlanan boost dönüştürücüsü, kapalı çevrim kontrollü boost dönüştürücüye(10V-24V) dönüştürülüp simülasyonu yapılmıştır. Ayrıca izoleli DC-DC dönüştürücü olan fly-back (325V-6.2V) dönüştürücüsü kapalı çevrim kontrollü olarak dizayn edilip çalıştırılmıştır. Yapılan bu çalışmalar sonucunda izoleli ve izolesiz DC-DC dönüştürücülerinin teorik olarak yapılan hesaplamaları ile, yapılan uygulama devrelerinin tutarlılığı gözlemlenmiştir.

**Anahtar Kelimeler: DC/DC Dönüştürücü (DC/DCD), PWM (PWM), Açık Çevrim Kontrollü Dönüştürücü (AÇKD), Kapalı Çevrim Kontrollü Dönüştürücü (KÇKD).**

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## LIST of ABBREVIATIONS and ACRONYMS

| <b><u>Abbreviations</u></b><br><b><u>and Acronyms</u></b> | <b><u>Explanations</u></b>      |
|-----------------------------------------------------------|---------------------------------|
| DC                                                        | : Direct Current                |
| PWM                                                       | : Pulse Width Modulation        |
| D                                                         | : Duty Cycle                    |
| CCM                                                       | : Continuous Conduction Mode    |
| Hz                                                        | : Hertz                         |
| DCM                                                       | : Discontinuous Conduction Mode |
| BCM                                                       | : Boundary Conduction Mode      |
| T <sub>s</sub>                                            | : Period                        |
| V                                                         | : Volt                          |
| A                                                         | : Ampere                        |
| W                                                         | : Watt                          |
| F                                                         | : Farad                         |
| μ                                                         | : Micro                         |
| Ω                                                         | : Ohm                           |
| μH                                                        | : Micro Henry                   |
| f                                                         | : Frequency                     |
| K Ω                                                       | : Kilo Ohms                     |
| pF                                                        | : Pico Farad                    |
| μs                                                        | : Micro Second                  |
| C                                                         | : Coulomb                       |
| IC                                                        | : Integrated Circuit            |
| P                                                         | : Power                         |
| GTU                                                       | : Gebze Technical University    |
| T.R                                                       | : Republic of Turkey            |
| T.C                                                       | : Türkiye Cumhuriyeti           |

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# 1. INTRODUCTION

Purpose of the thesis, open and closed loop control methods with PWM had been applied to some of DC-DC converters that isolated and non-insulated. Their theoretical calculations and applications have been made. The relation between the circuits examined with accuracy, efficiency, power consumption and the relation with the duty cycle were investigated.

Content and contribution of the thesis, in chapter 2, dc/dc converters and 555 timer IC were examined. The boost (10V-24V) converter, which is uninsulated, is designed with two different methods as open loop control. These two different boost circuits were designed and operated at the same power circuit's components in section 3.1 and section 3.2. The closed loop controlled boost converter designed (10V-24V) and simulated in section 3.3. The fly-back (325V-6V) converter, which is also an isolated DC-DC converter, was designed and operated as closed-loop control in section 3.4. In chapter 3, the simulation results of the circuits designed in chapter 3 are included. In chapter 4, the experiment results of the circuits simulation in chapter 3 are included. Contribution of the thesis is that observing the accuracy of experiments with theoretical calculations.

## **2. DC/DC POWER CONVERTERS & 555TIMER IC**

### **2.1. Introduction of DC-DC Converter**

A dc dc converters are used to change dc input voltage level. Their dc output voltage can increase or decrease according to their dc input voltage level. Although SMPS circuits are smaller than linear transformers, they are more efficient than linear transformers. There are hundred types of SMPS regulators. Significant portion of dc-dc conversion designs in the power industry utilizes eight main converter topologies. SMPS converters are collected in two main title as isolated and non-insulated converters.

Non-isolated converters:

- Boost converter,
- Buck converter,
- Buck/Boost converter

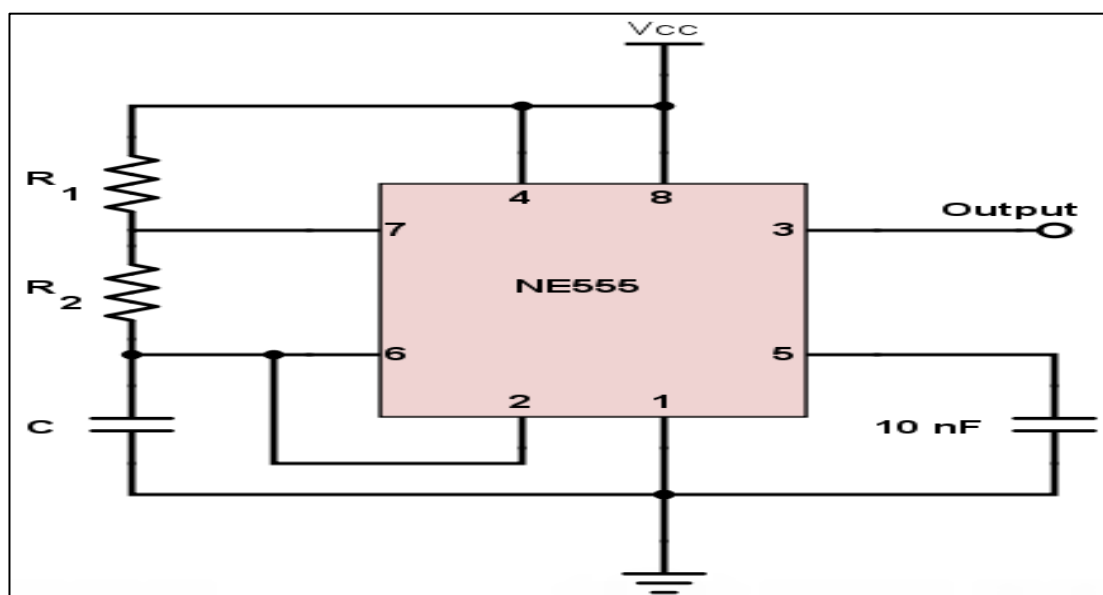
Isolated converters:

- Forward converter,
- Fly-back converter,
- Half-bridge converter,
- Full-bridge converter ,
- Push-pull converter

### **2.2. Introduction and Basic Operation of 555Timer IC**

The 555timer IC, usually used in monostable and astable mode. It occurs with two comparators, voltage divider circuits, SR flip-flop and discharge transistor as shown in figure 2.1. The timer has eight pins out. In thesis application, 555timer will be used as square wave generator as shown in figure 2.2. The  $V_{th}$ , low and  $V_{th}$ , high voltages are obtained by the voltage divider in the integrated circuit. The two comparators, which are filled via the R1 and R2 resistors and are discharged via R2,

555Timer integrated circuit can be used in many applications, for example pulse width modulation, pulse position modulation, flashers, schmitt trigger, missing pulse detector, alarm buzzer. The 555 integrated circuit is preferred for use in many applications with simple circuit element additions. The cheapness of the integration is one of the reasons of choice.



3

The 555Timer, in figure 2.2, is working in astable mode. The circuit running in astable mode generates periodic square wave signal. This signal produced with alternating between the supply voltage and ground. The frequency is the number of oscillations of a signal within one second. It is calculated as follows.

$$f = \frac{1.44}{(R_1 + 2R_2)C} \quad (2.1)$$

Period is the time taken for one complete cycle in continues wave signal. Period is inversely proportional to frequency.

$$T = \frac{1}{f} = 0.694(R_1 + 2R_2)C \quad (2.2)$$

$T_1$  and  $T_0$  show that high time and low time respectively. They were calculated as show below equations. Period (T) is the sum of the  $T_1$  and  $T_0$ .

$$T_1 = 0.694(R_1 + R_2)C \quad (2.3)$$

$$T_0 = 0.694R_2C \quad (2.4)$$

The duty cycle is:

$$Duty\ Cycle = \frac{T_1}{T} \times 100 \quad (2.5)$$

## 2.3. Basic Operation of Boost Converter

Boost converter that increase the input voltage to make a higher output voltage. The advantages of SMPS circuits are high efficiency, small size and cheaper than a linear transformer. Boost converter mainly has four elements as shown in figure 2.3. Below figure shows the basic boost converter circuit.

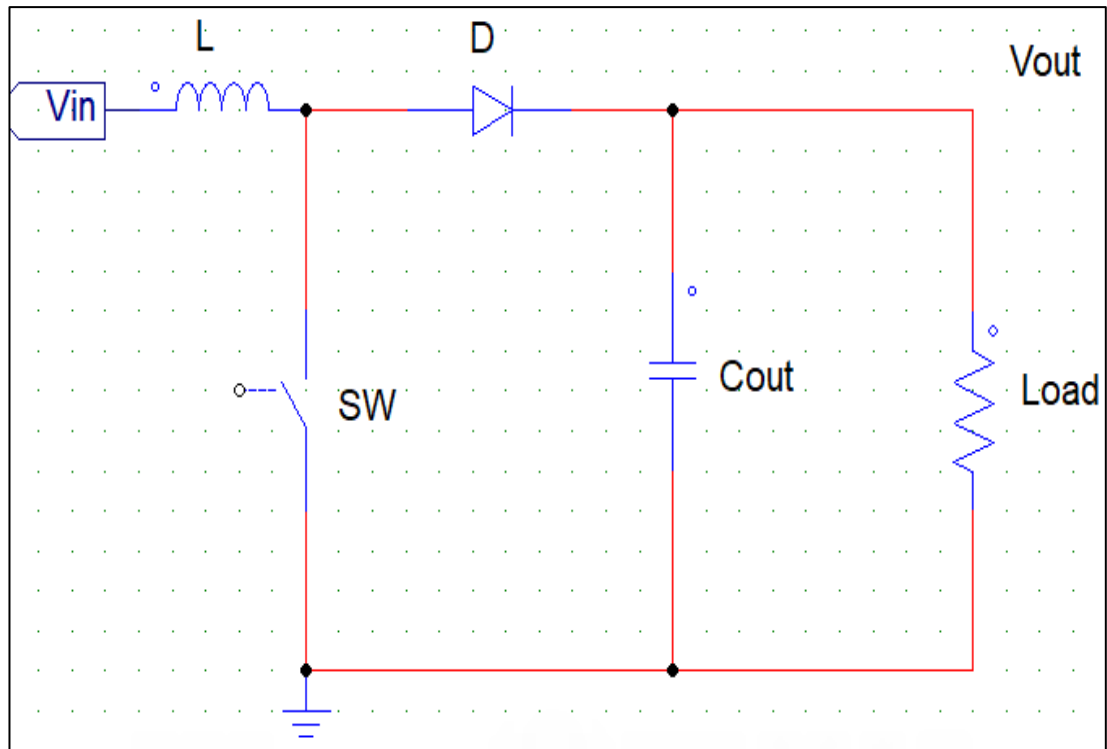


Figure 2.3: The Basic Boost Converter Circuit.

When the switch is on as shown in figure 2.4.a, voltage across the inductor positive and equal to  $V_{in}$ . For the average inductor voltage to be zero in PSS, the voltage across the inductor has to be negative during off time as shown in figure 2.4.b. Therefore,  $V_{out}$  has to be higher than the input.

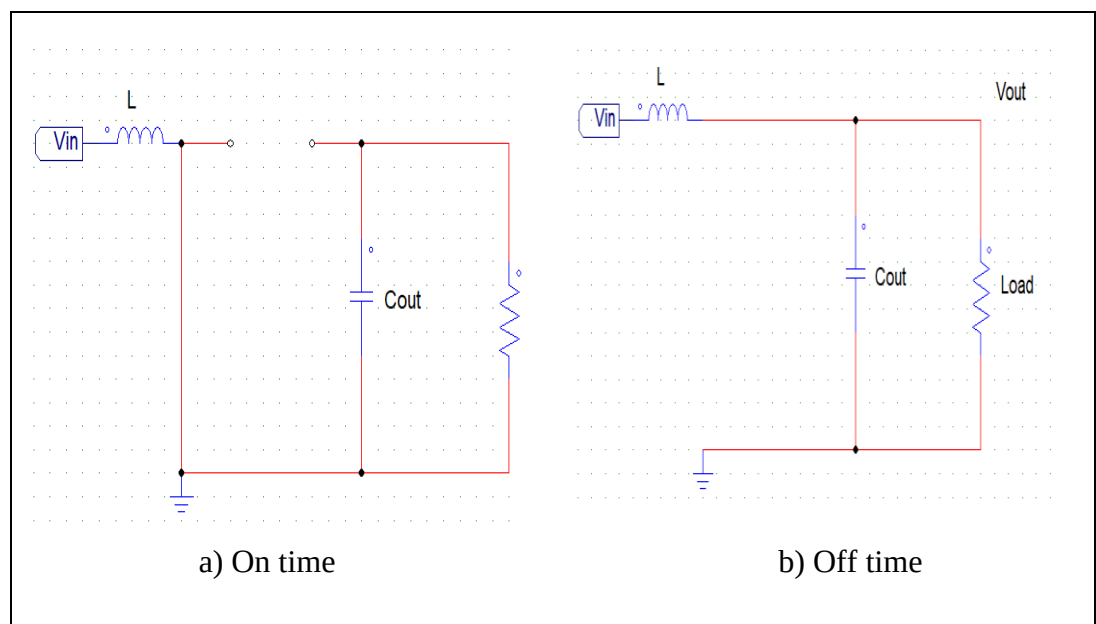


Figure 2.4: Two State of Boost Converter.

The current waveform of the inductor determines the conduction modes of the converter. Continuous Conduction Mode (CCM): Steady-state waveforms, Inductor current flows continuously (It is always positive in the switching cycle in CCM). Discontinuous Conduction Mode (DCM): Current of inductor touches zero while the cycle and it stays there until next switching. Boundary Conduction Mode (BCM): Out of the current is equal to half of the inductor peak current in the boundary conduction mode.

The input and output voltage relationship in steady state can find by writing volt-second balance across the inductor in CCM. [1]

Assume :

$$V_{out,ripple} \ll V_{inout} \quad (2.6)$$

$$T_s = T_{on} + T_{off} \quad (2.7)$$

$$D = \frac{T_{on}}{T_s} \quad (2.8)$$

During on-time ( $T_{on}$ ) inductor across voltage:

$$V_{L,on} = V_{in} \quad (2.9)$$

During off-time ( $T_{off}$ ) inductor across voltage:

$$V_{L,off} = V_{in} - V_{out} \quad (2.10)$$

Inductor volt-second during ( $T_{on}$ ):

$$V_{L,on} T_{on} = V_{in} D T_s \quad (2.11)$$

Inductor volt-second during ( $t_{off}$ ):

$$V_{L,off} T_{off} = (V_{in} - V_{out})(1 - D)T_s \quad (2.12)$$

In one switching cycle in PSS, inductor volt-second adds to zero:

$$V_{in} DT_s + (V_{in} - V_{out})(1 - D)T_s = 0 \quad (2.13)$$

Hence:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 - D} \quad (2.14)$$

As understood from the transfer function in equation 2.14, the output voltage depends on the input voltage and the duty cycle.

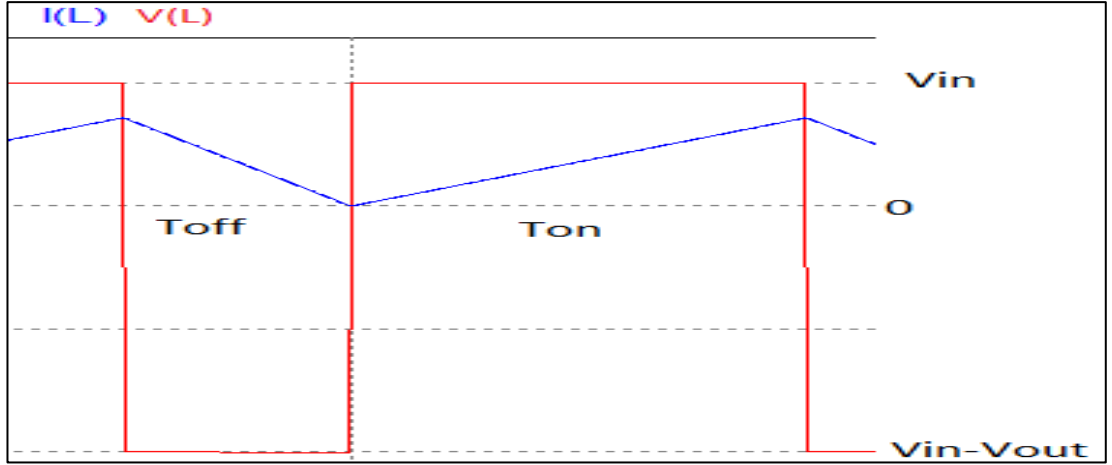


Figure 2.5: Volt-Second Graphic of Boost Converter in BCM.

$$\langle iL \rangle = \frac{1}{T_s} \left( iL_{peak} \cdot \frac{T_s}{2} \right) = \frac{iL_{peak}}{2} \quad (2.15)$$

In BCM,  $\langle iL \rangle$  doesn't depend on  $T_{on}$  or  $T_{off}$ . It is always half of the peak inductor current.

$$iL_{peak} = \Delta iL = \frac{V_{L,on} \cdot t_{on}}{L} = \frac{V_{L,on} \cdot t_{off}}{L} \quad (2.16)$$

$$\langle iL_{boundary} \rangle = \frac{iL_{peak}}{2} = \frac{DT_s}{2L} V_{in} \quad (2.17)$$

Replace that  $D=(1-D) \cdot V_{out}$  then,

$$\langle i_{L,boundary} \rangle = \frac{T_s V_{out}}{2L} D(1-D) \quad (2.18)$$

The input current is equal to the average inductor current. Neglecting losses with the topology, output power of converter assumed to be equal to the input power of converter. So,

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} = \frac{I_{in}}{I_{out}} \quad (2.19)$$

$$I_{in} = \frac{I_{out}}{1-D} \quad (2.20)$$

$$\langle i_{L,boundary} \rangle = \frac{T_s V_{out}}{2L} D(1-D) = \frac{I_{out}}{1-D} \quad (2.21)$$

Withdrawing L from this expression yields the following equation:

$$L_{critical} = \frac{T_s}{2} D(1-D)^2 \quad (2.22)$$

If L is smaller than this value, the converter is in DCM.

The dc component of the diode current flows to the load resistor and its ac component flows through the output capacitor. The capacitor current has to average to zero in one cycle in PSS. So, the ac component of the diode current (with zero average value) flows through the capacitor.

To calculate output voltage ripple in CCM:

$$\Delta V_{out} = \frac{DT_s I_{out}}{C} \quad (2.23)$$

## 2.4. Basic Operation of Fly-back Converter

The fly-back converter as shown in figure 2.6 is an isolated dc-dc converter. Fly-back converters provide insulation and voltage transformation by fly-back transformer. Fly-back converters are cost-effective and high efficiency. the converter can be designed up to 130 watts.

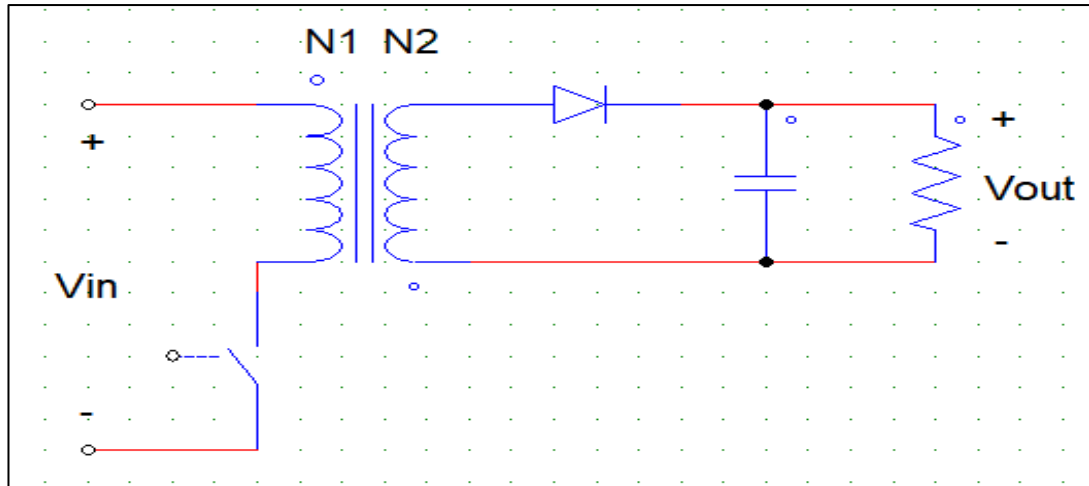


Figure 2.6: Fly-Back Converter Circuit.

While the switch at the primary side turned on, current starts to flow from the primary side, producing accumulating of electrical energy. Hence, the diode behaves as open circuit as shown figure 2.7

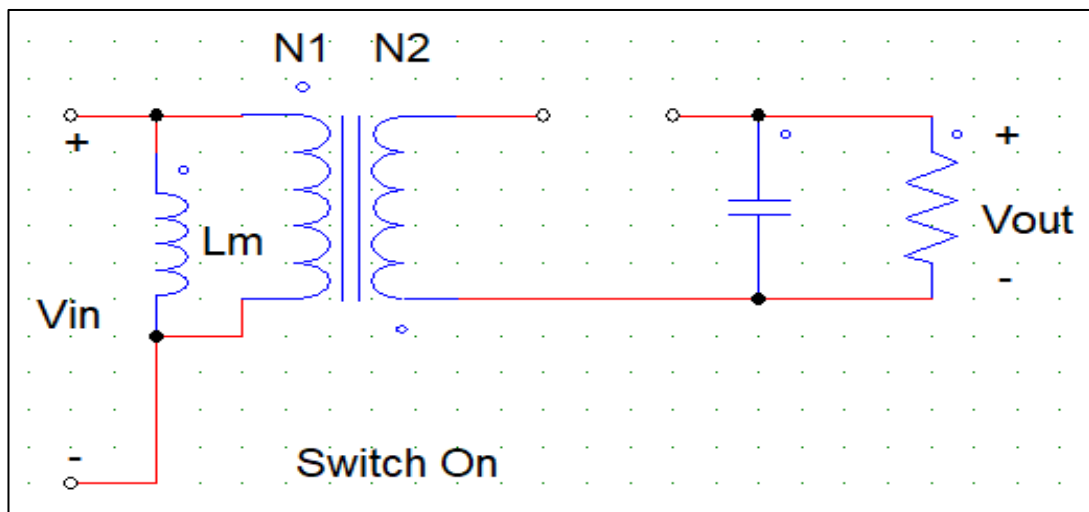


Figure 2.7: Fly-Back Circuit State of Switch On.

While the switch at the primary side turned off, the diode enters the transmission to generate the output voltage as shown figure 2.7.

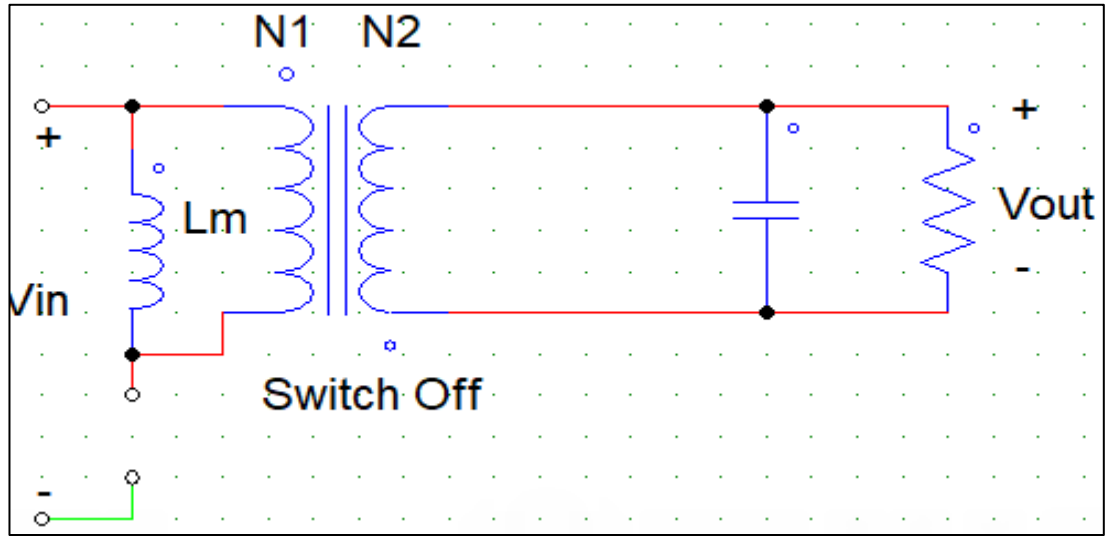


Figure 2.8: Fly-Back Circuit State of Switch Off.

Deriving the dc transfer function from input voltage to output voltage ( $V_{in}/V_{out}$ ), It needs to write the volt-second balance across the primary magnetizing inductance of the transformer in CCM. [1]

$$V_{in}DT_s + (-V_{out})\frac{N_2}{N_1}(1-D)T_s = 0 \quad (2.24)$$

Hence:

$$\frac{V_{out}}{V_{in}} = \frac{N_2}{N_1} \frac{D}{1-D} \quad (2.25)$$

Since the polarity is inverted by the transformer windings, the output doesn't have to have a polarity opposite of that of input.

To calculate output voltage ripple in CCM:

$$\Delta V_{out} = \frac{DT_s I_{out}}{C} \quad (2.26)$$

### 3. PRACTICAL CIRCUIT DESIGN AND SIMULATION

In section 3, the design values of the circuits specified according to headings will be determined and designed circuits will simulate.

#### 3.1. Open Loop Controlled Boost Converter with 555Timer and Micro-controller

Calculating L (boost inductance) and C<sub>out</sub> (output capacitance) of boost converter's values as shown figure 2.3 with the following requirements:

- V<sub>in</sub> = 10V, V<sub>out</sub> = 24V, Operating in CCM,
- I<sub>out, rated</sub> = 2A, f<sub>s</sub> = 75 kHz,
- ΔV<sub>out</sub> = 3 % of the output voltage,
- ΔI<sub>L</sub> = 30 % of the input current

Solution:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \rightarrow \frac{24V}{10V} = \frac{1}{1-D} \quad (3.1)$$

$$D = \frac{24V - 10V}{24V} \rightarrow D = 0.58 \quad (3.2)$$

$$T_s = \frac{1}{f_s} \rightarrow T_s = \frac{1}{75.000} = 13.33\mu s \quad (3.3)$$

In calculating the inductance value, need to calculate the input current and set the peak-to-peak inductor current to 30% of the input current. Assuming 100% efficiency, P<sub>in</sub>=P<sub>out</sub>. So,

$$I_{in} = \frac{V_o \cdot I_o}{V_{in}} \rightarrow I_{in} = \frac{24V \times 2A}{10V} = 4.8A \quad (3.4)$$

Writing the inductor ripple current during on-time,

$$\Delta I_L = I_{L,p-p} = 4.8 \times 0.3 = 1.44A \quad (3.5)$$

$$\Delta I_L = \frac{V_{in} \cdot D \cdot T_s}{L} \rightarrow L = \frac{V_{in} \cdot D \cdot T_s}{\Delta I_L} \quad (3.6)$$

$$L = \frac{10V \times 0.58 \times 13.33\mu s}{1.44A} = 53,69\mu H \quad (3.7)$$

Calculating output capacitor value:

$$\Delta V_{out} = 24V \times 0.03 = 0.72V \quad (3.8)$$

$$\Delta V_{out} = \frac{DT_s I_{out}}{C} \rightarrow C = \frac{D \cdot T_s \cdot I_{out}}{\Delta V_{out}} \quad (3.9)$$

$$C = \frac{0.58 \times 13.33\mu s \times 2A}{0.72V} = 21.48\mu F \quad (3.10)$$

At what load resistance does the converter operate in BCM ?

$$I_{in} = \frac{\Delta I_{L,p-p}}{2} \rightarrow I_{in} = \frac{1.44A}{2} = 0.72A \quad (3.11)$$

$$I_{out} = \frac{V_{in} \cdot I_{in}}{V_{out}} \rightarrow I_{out} = \frac{10V \times 0.72A}{24V} = 0.3A \quad (3.12)$$

$$I_{load,BCM} = \frac{V_{out}}{I_{out}} = \frac{24V}{0,3A} = 80 \Omega \quad (3.13)$$

Hence:

$$L=53.69\mu H, C=21.48\mu F, R_{load, BCM}=80 \Omega$$

Calculating  $R_1$ ,  $R_2$ , and  $C$  of 555Timer values for a-stable multivibrator as shown figure 2.2 with the following requirements:

- $f_s = 75 \text{ kHz}$ ,
- $D=0.58$

Solution:

$$T_s = \frac{1}{f} \rightarrow T_s = \frac{1}{75 \text{ kHz}} = 13.33 \mu s \quad (3.14)$$

$$T_s = T_1 + T_0 \quad (3.15)$$

$$D = \frac{T_1}{T_s} \rightarrow 0.58 = \frac{T_1}{T_1 + T_0} \rightarrow T_0 = 0.72 T_1 \quad (3.16)$$

$$T_s = T_1 + 0.72 T_1 \rightarrow 13.33 \mu s = 1.72 T_1 \quad (3.17)$$

$$T_1 = 7.75 \mu s, T_0 = 5.58 \mu s \quad (3.18)$$

Assume that  $C=220 \text{ pF}$ ,

$$T_0 = 0.694 R_2 C \rightarrow R_2 = \frac{5.58 \mu s}{0.694 \times 220 \text{ pF}} = 36.54 \text{ K } \Omega \quad (3.19)$$

$$T_s = 0.694(R_1 + 2R_2)C \rightarrow R_1 = \frac{13.33 \mu s}{0.694 \times 220 \text{ pF}} - 2 \times 36.54 \text{ K } \Omega \quad (3.20)$$

Hence:

$$R_1 = 14.27 \text{ K } \Omega, R_2 = 36.54 \text{ K } \Omega, C = 220 \text{ pF}$$

The circuit designed according to the calculated values above is shown in figure 3.1. Square wave generator was made with 555Timer to have a square wave signal 75

kHz and 58% duty cycle to drive the power circuit. The power converter circuit designed for 10V-24V was connected to 80  $\Omega$  load to operate in BCM mode as the calculated equation (3.13).

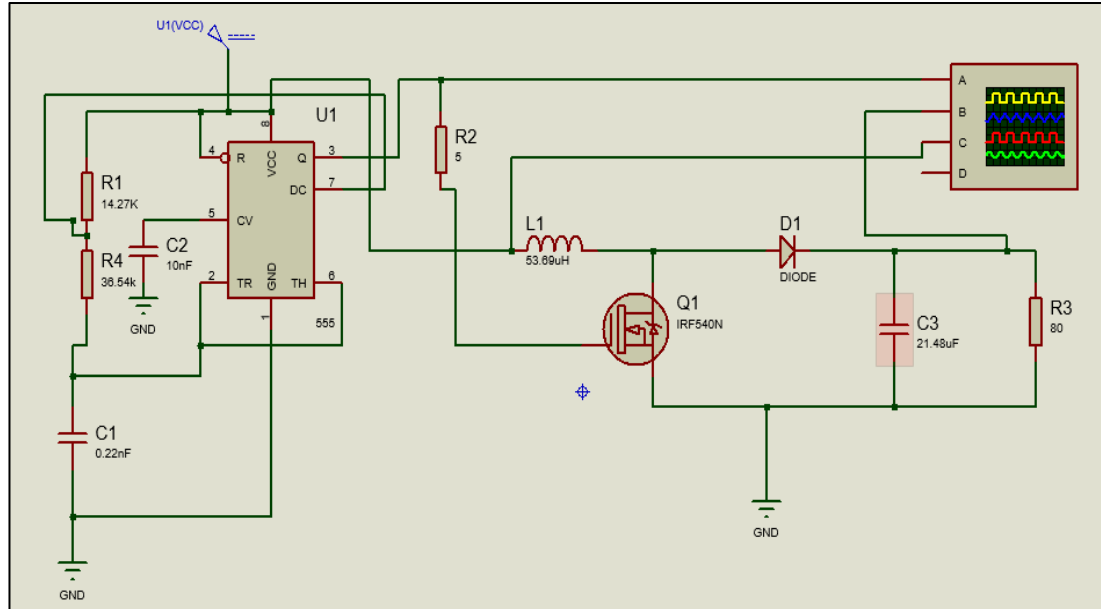


Figure 3.1: Boost Converter (10V-24V) with 555Timer.

The simulation results obtained when the figure 3.1 circuit diagram is simulated in Proteus. The simulation result is shown at figure 3.2.

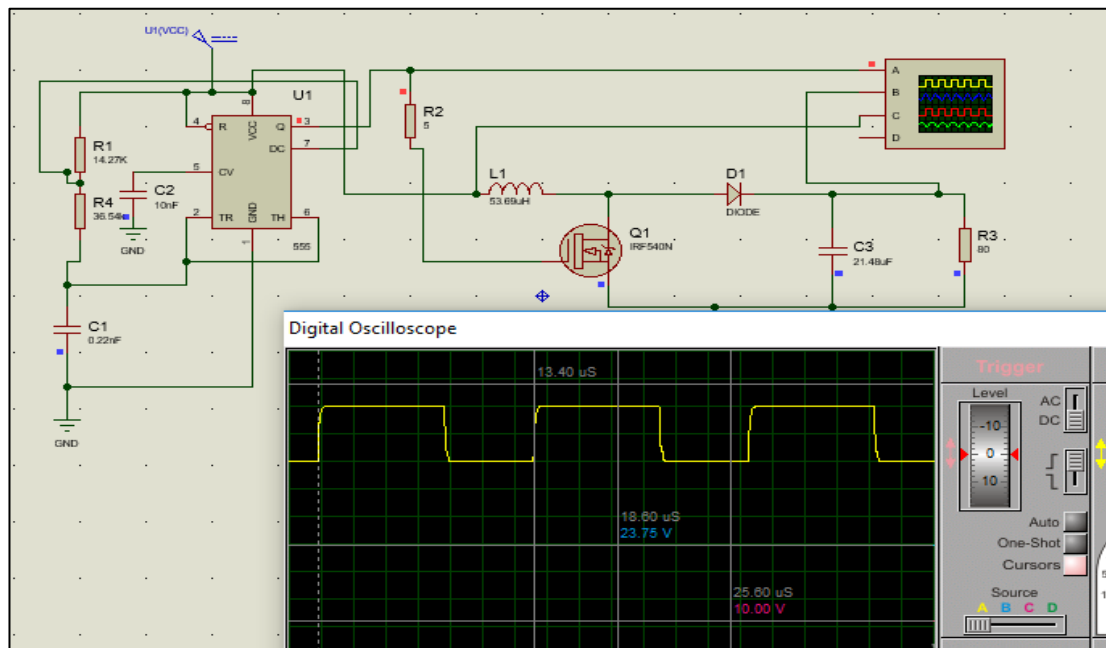


Figure 3.2: Input and Output - Second Figure 3.1.

Simulation results were taken as calculated in equation (3.5) and (3.12), figure 3.3, the boost converter has been driven in BCM mode.

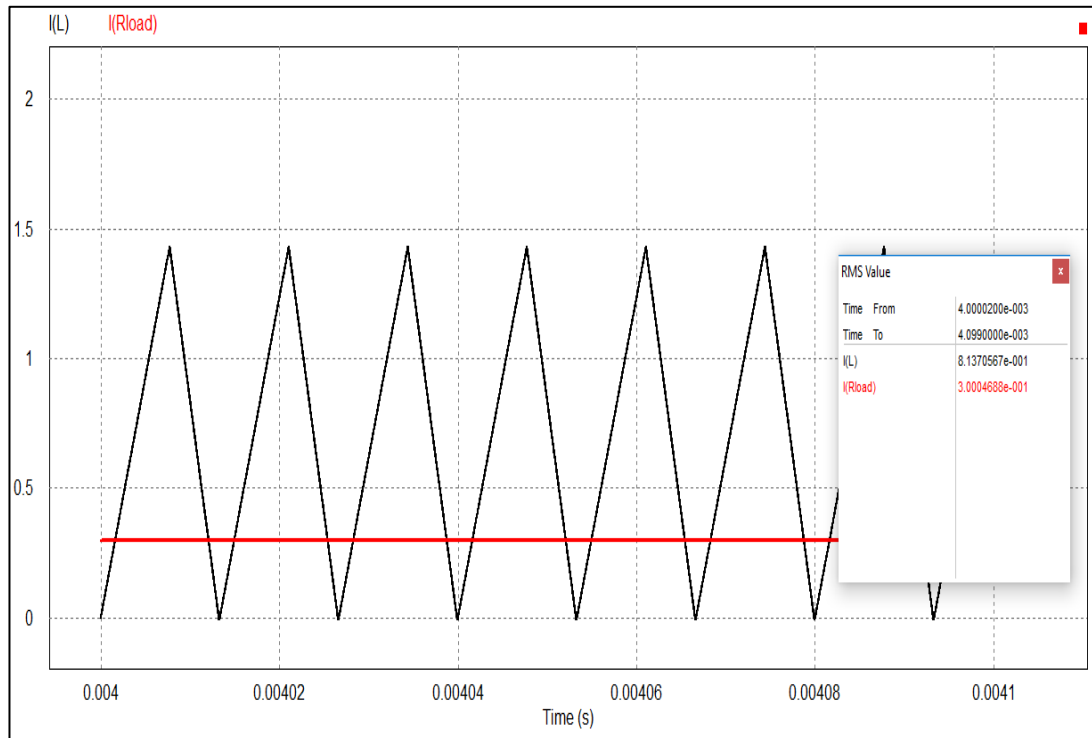


Figure 3.3:  $I_{L,p-p}$  and  $I_{out}$  – Second Figure 3.1.

### 3.2. Open Loop Controlled Boost Converter with Micro-controller

In this section, the values of the boost converter circuit elements are kept the same as the values (L and C) calculated in section 3.1. The square signal generator will be provided by a microcontroller. The following code was written to get, 77 kHz and %58 duty cycle, square wave signal from the microcontroller.

Table 3.1: Square wave generator source codes for PIC16F877.

```
#include <16f877.h>

#fuses

#use delay (clock=4000000) // Setting Delay function's oscillation frequency

#use fast_io(c) // Port forwarding commands apply to C port
```

Table 3.1: Continued of table.

```

int i;

void main ( )
{
    setup_psp(PSP_DISABLED);    // Parallel Slave Port Disable

    setup_timer_1(T1_DISABLED); // T1 Timer Disable

    set_tris_c(0x00); // Set C Port as Outputs

    setup_ccp2(CCP_PWM); // Set CCP2 as PWM output

    setup_timer_2(T2_DIV_BY_1,26,1); /* Setting Timer2 for 75-77 kHz

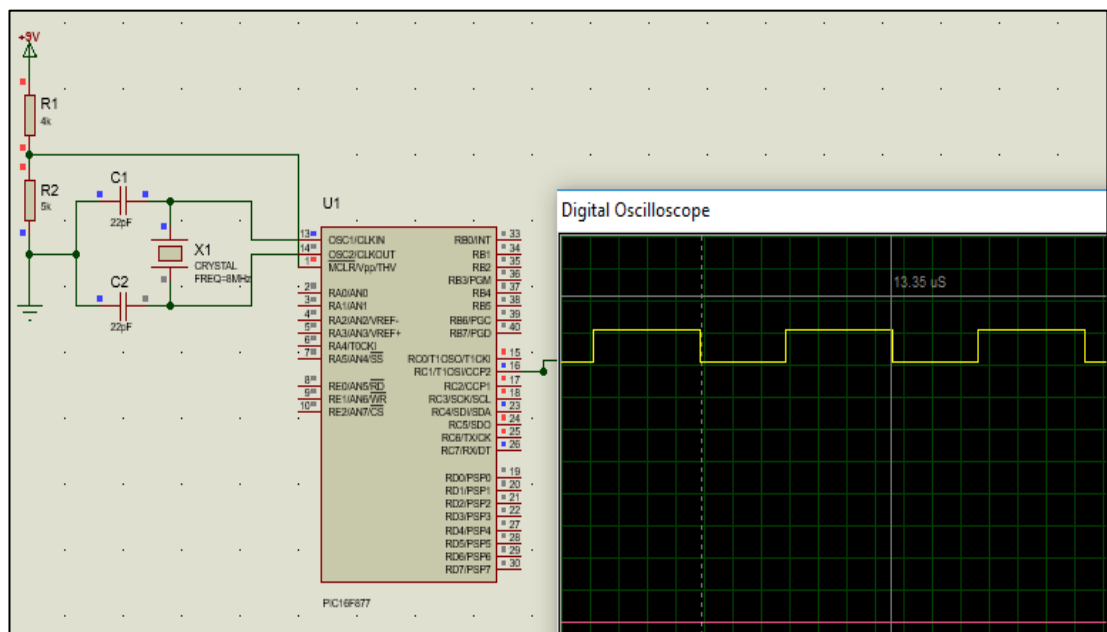
The period is (1/clock)*4*t2div*(period+1),

Period = (1/8000000)*4*1*26 = 13 uS or 76.9 kHz. */

    while(1)
    {
        set_pwm2_duty(15); // Setting Duty Cycle for % 55-60
    }
}

```

The desired square signal shape from the microcontroller was obtained as shown in figure 3.4.



The circuit designed according to the calculated values (L and C) in section 3.1 is shown in figure 3.5. Square wave generator was made with the microcontroller. The same power converter circuit designed for 10V-24V was connected to 80  $\Omega$  load to operate in BCM mode as the calculated equation (3.13).

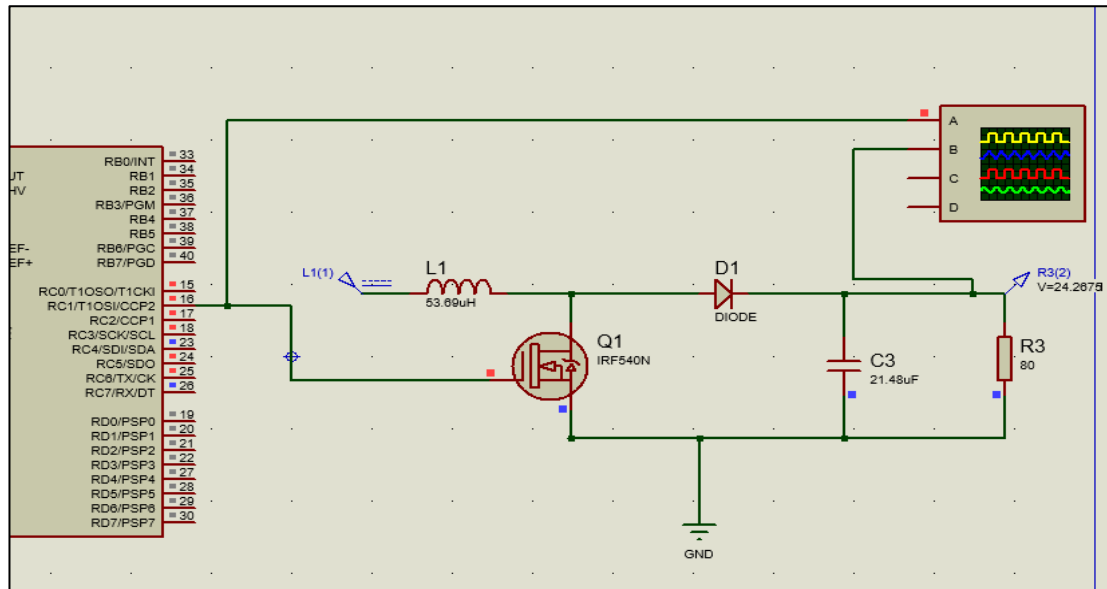


Figure 3.5: Boost Converter (10V-24V) with Microcontroller.

The simulation results obtained when the figure 3.5 circuit diagram is simulated in Proteus. The simulation result is shown at below.

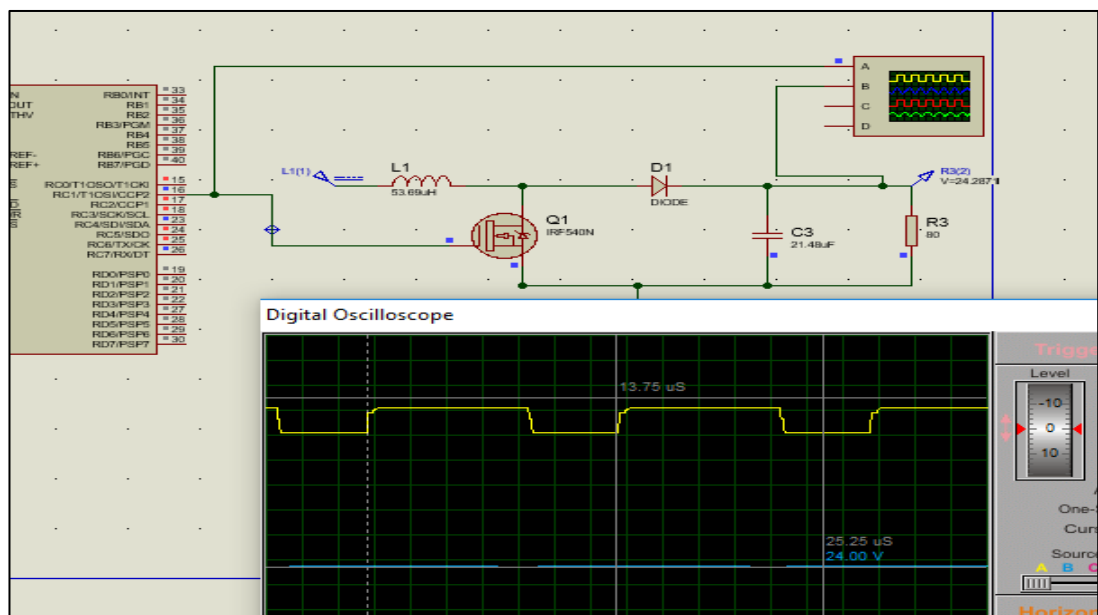


Figure 3.6: Waveform of Switching and Output Voltage in BCM Mode.

### 3.3. Closed Loop Controlled Boost Converter

Closed loop control does not need to any MOSFET driver circuit like open loop control. It generates its own switching signal by pulse width modulation (PWM). Hysteretic controlled boost converter without compensator is shown in figure 3.7.

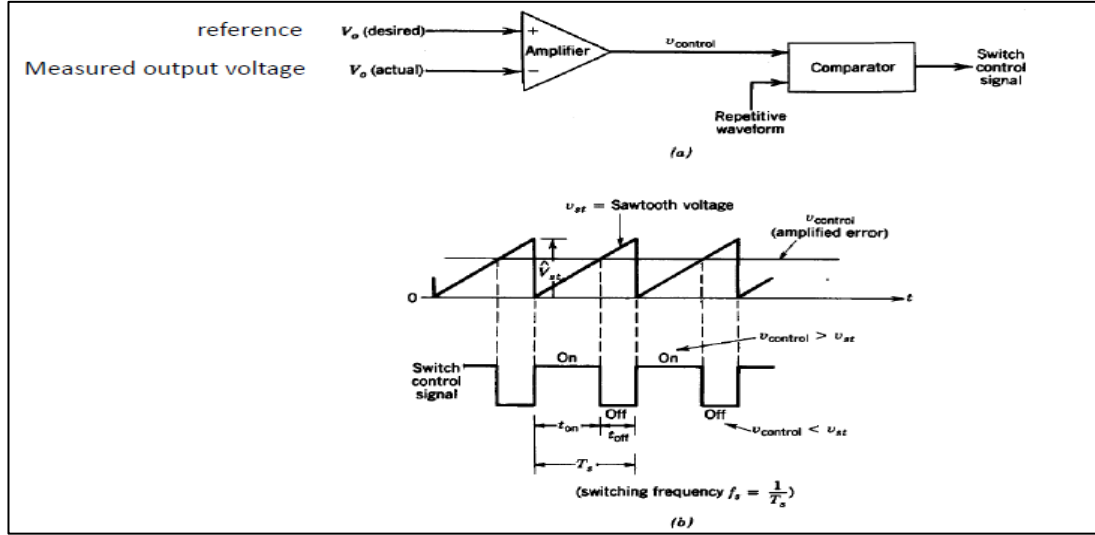


Figure 3.7: PWM a) Control Diagram b) PWM Signals.

In this section, the values of the boost converter (10V-24V) circuit elements are kept the same as the values (L and C) calculated in section 3.1 and 3.2. Figure 3.8 circuit working principle is as follows. Measurement is taken from the circuit output by voltage divider. This measurement compares with the desired voltage value to obtain control signal. If the repetitive signal is above control signal, the comparator will be low. If the repetitive signal is below control signal, the comparator will be high.

Voltage divider  $R_1$  and  $R_2$  values were chosen respectively 8.6K  $\Omega$  and 1K  $\Omega$  according to the following requirements:

- $V_{in} = 10V$ ,  $V_{out} = 24V$ ,
- $f_s = 75 \text{ kHz}$ ,  $V_{ref} = 2.5V$

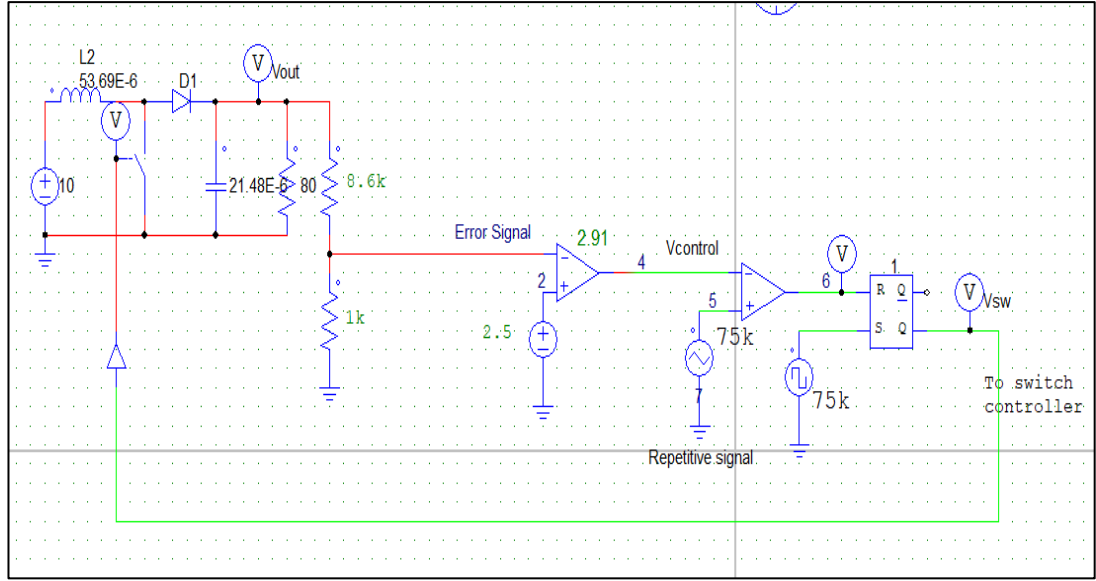


Figure 3.8: Closed Loop Controlled Boost Converter.

When the figure 3.8 simulation is done in the PSIM program, the following results were taken.

$$\eta_{efficiency} = \frac{V_{out} \times I_{out}}{V_{in} \times I_{in}} = \frac{24.1V \times 0.3A}{10V \times 1.134} = \%64 \quad (3.21)$$

$$P_{in} = P_{out} + P_{power\ loss} \quad (3.22)$$

$$P_{power\ loss} = P_{in} - P_{out} = 11.34W - 7.23W = 4.11W \quad (3.23)$$

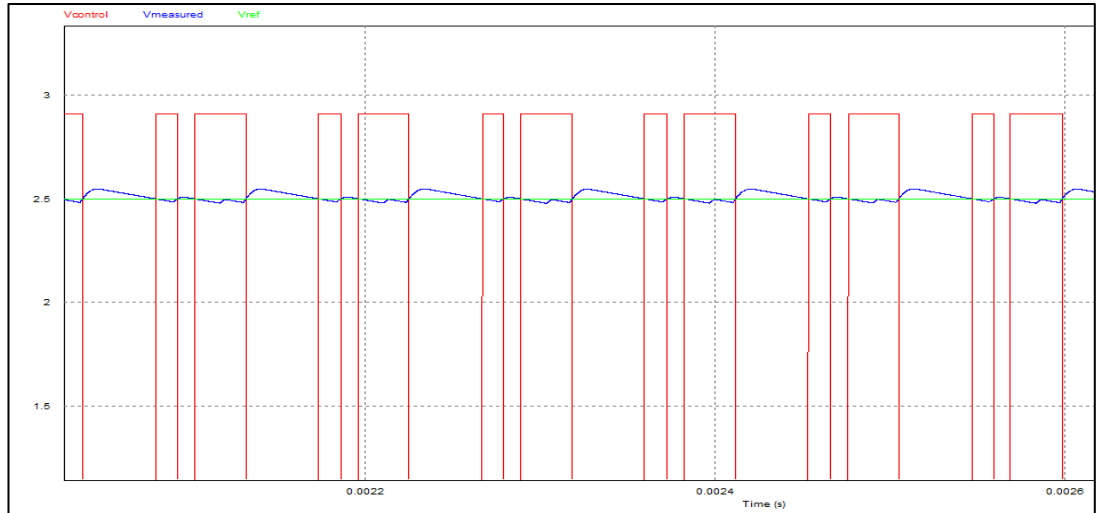


Figure 3.9: Waveforms of  $V_{control}$ ,  $V_{measured}$ ,  $V_{reference}$ .

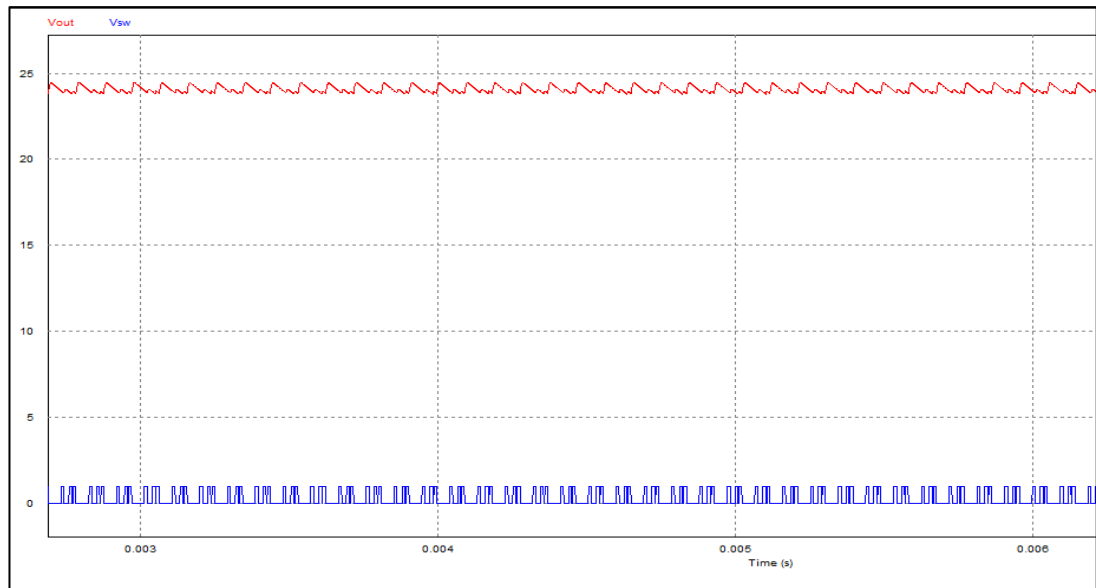


Figure 3.10: Graphic of PWM signal and  $V_{out}$ .

### 3.4. Closed Loop Controlled Fly-back Converter

Fly-back topology was implemented in this section, Fly-back converter is suitable for a low power, it provides isolation for safety. Viper12a was used in this circuit as a current mode PWM controller. The converter conduction mode depends on input and output voltage. Viper12a has fixed 60 kHz switching frequency. When it is using in a feedback circuit as in figure 3.11.

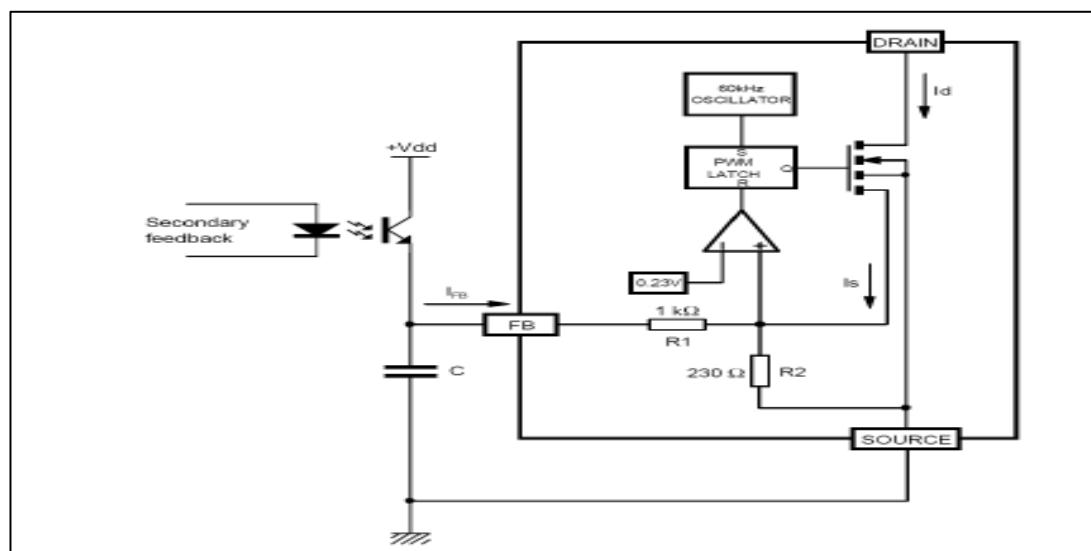


Figure 3.11: Internal Current Control Structure Viper12a.

It works as: The sum of the  $I_S$  and  $I_F$  currents is directed from the plus leg of the comparator inside the IC unit to obtain the comparison voltage. This voltage value is compared with 0.23 to generate the switching signal.

$$R_2 \cdot (I_S + I_{FB}) = 0.23V \quad (3.24)$$

The circuit in figure 3.12 is a standard fly-back converter with secondary voltage regulation driving the VIPer12A feedback pin through an optocoupler.

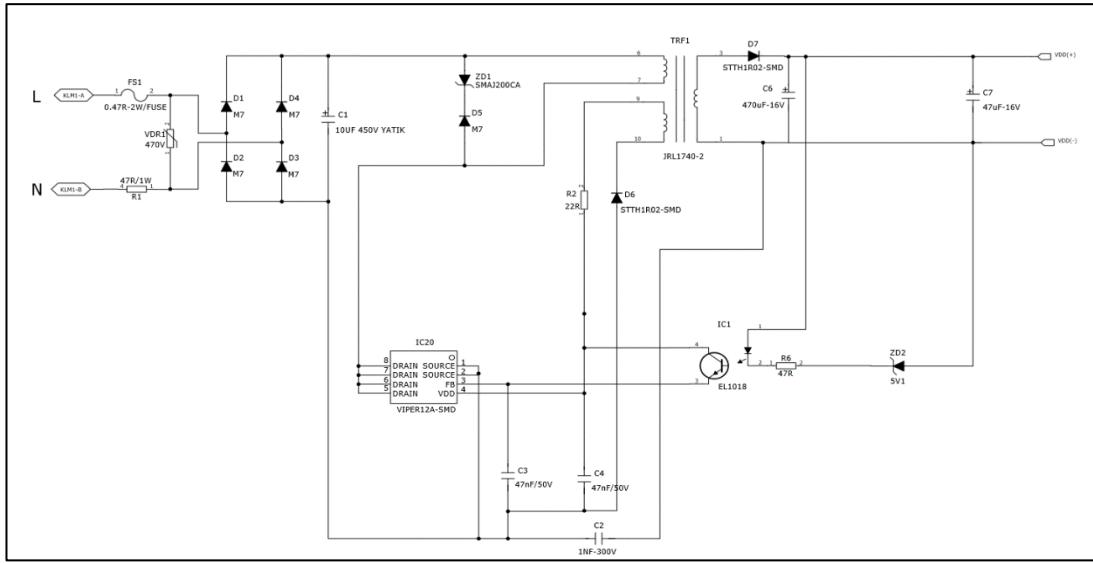


Figure 3.12: Fly-Back Converter Driving with Viper12a.

Calculating D with the following requirements:

- $V_{in} = 325V$ ,  $V_{out} = 6.2V$ ,
- $N_1=180$ ,  $N_2=25$

Solution:

$$\frac{V_{out}}{V_{in}} = \frac{N_2}{N_1} \frac{D}{1 - D} \quad (3.25)$$

$$\frac{6.2}{325} = \frac{25}{180} \frac{D}{1 - D} \rightarrow D = 0.12 \quad (3.26)$$

## 4. EXPERIMENT RESULTS

In this section, circuits are operated by reference to the values calculated in sections 3.1, 3.2 and 3.4. Experimental images and results are presented in the following sections.

### 4.1. Experiment Result of Open Loop Controlled Boost Converter with 555Timer

The circuit 555Timer was set with  $R1 = 14.16 \text{ K } \Omega$ ,  $R2 = 36.5 \text{ K } \Omega$ ,  $C=220\text{pF}$  for generate square wave signal (75kHz, %58 duty cycle) and The boost converter was set with  $L=50\mu\text{H}$ ,  $C=22\mu\text{F}$ ,  $R_{\text{LOAD}}= 82 \text{ } \Omega$  for 10V-24V dc/dc converter in figure 4.1.

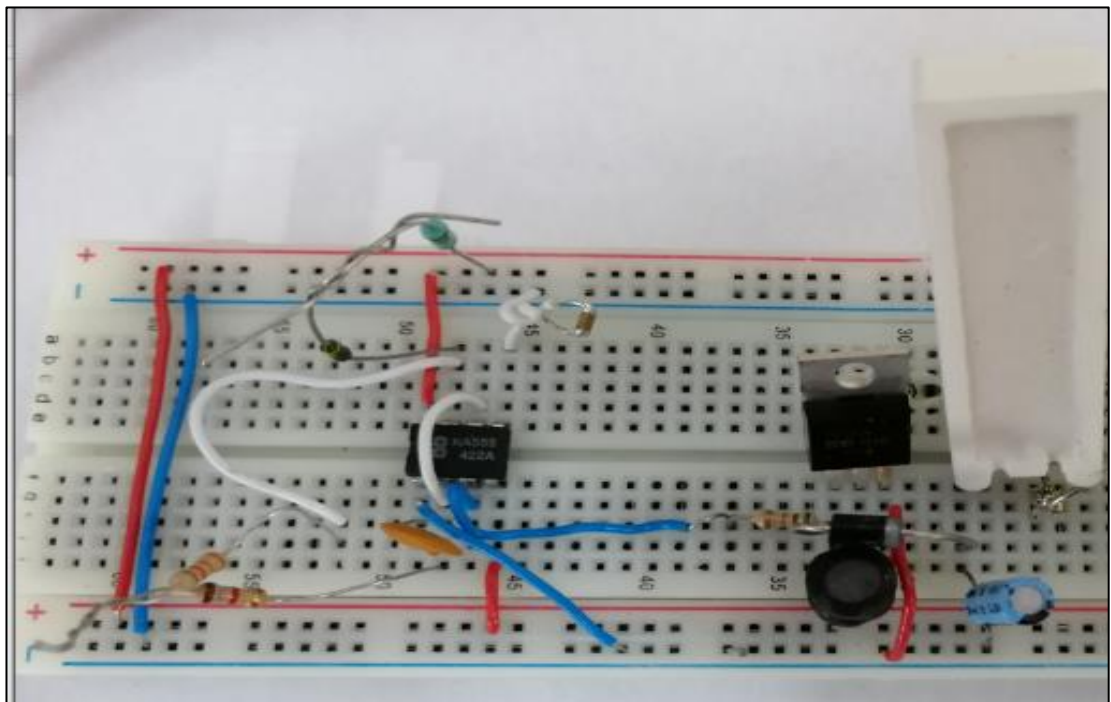


Figure 4.1: Boost Converter with 555Timer Experiment Circuit.

As shown in figure 4.2, 75.11 kHz and 56% duty cycle signal were generated. At the time of this signal generation, the 555IC was supplied with 10 volts. The square wave generator circuit was observed to have 0.07W power consumption during operation. The output voltage, on high duration, of this signal is 10 volts. This value is enough to switch MOSFET(IRF540). It is not necessary to use external MOSFET driver.

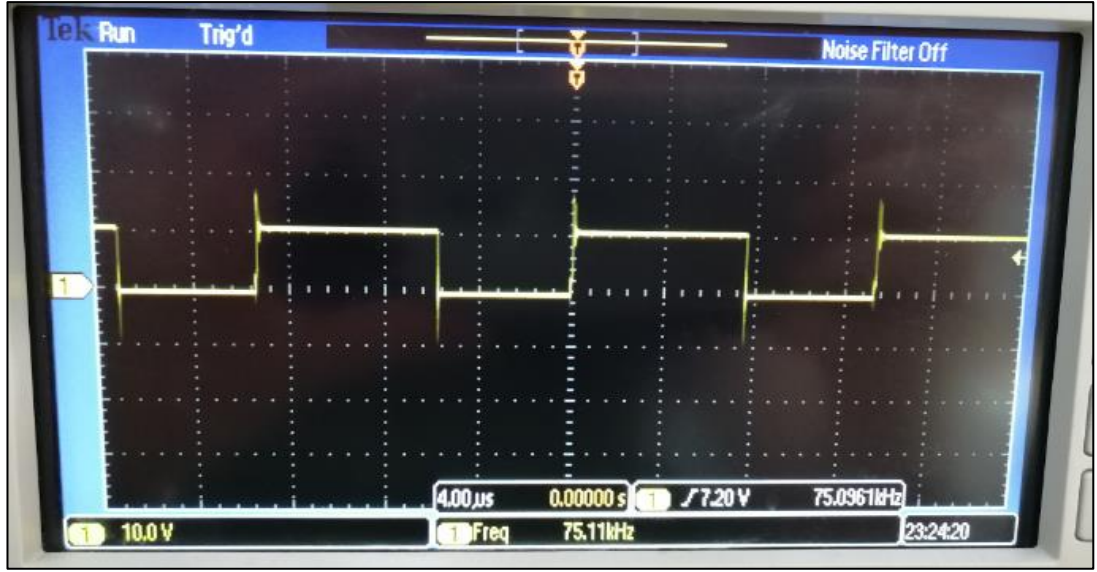


Figure 4.2: 555Timer Circuit Square Wave Signal Output.

When the figure 4.1 circuit was operated. The following results were observed.

- $V_{in} = 10V$ ,  $I_{in} = 1A$ ,  $R_{load} = 80 \Omega$ ,  $V_{out} = 22.5V$

$$I_{out} = \frac{V_{out}}{R_{load}} = \frac{22.5V}{80\Omega} = 0.28A \quad (4.1)$$

$$\eta_{efficiency} = \frac{V_{out} \times I_{out}}{V_{in} \times I_{in}} = \frac{22.5V \times 0.28A}{10V \times 1.02A} = \%61 \quad (4.2)$$

$$P_{in} = P_{out} + P_{loss} \quad (4.3)$$

$$P_{power\ loss} = P_{in} - P_{out} = 10.2W - 6.3W = 3.9W \quad (4.4)$$

$$P_{power\ loss} = P_{coil} + P_{diode} + P_{MOSFET} + P_{heat} \quad (4.5)$$

$$P_{heat} = 3.9W - 0.5V \times 1.02A + 1V \times 0.28A + 1.6V \times 1.02 = 1.5W \quad (4.6)$$

As observed in the experiment, efficiency was obtained % 61. Desired output voltage was 24V but observed that 22.5V as seen in figure 4.3 because 1V on the diode used in the circuit and the remaining 0.5V fall on the used coil.

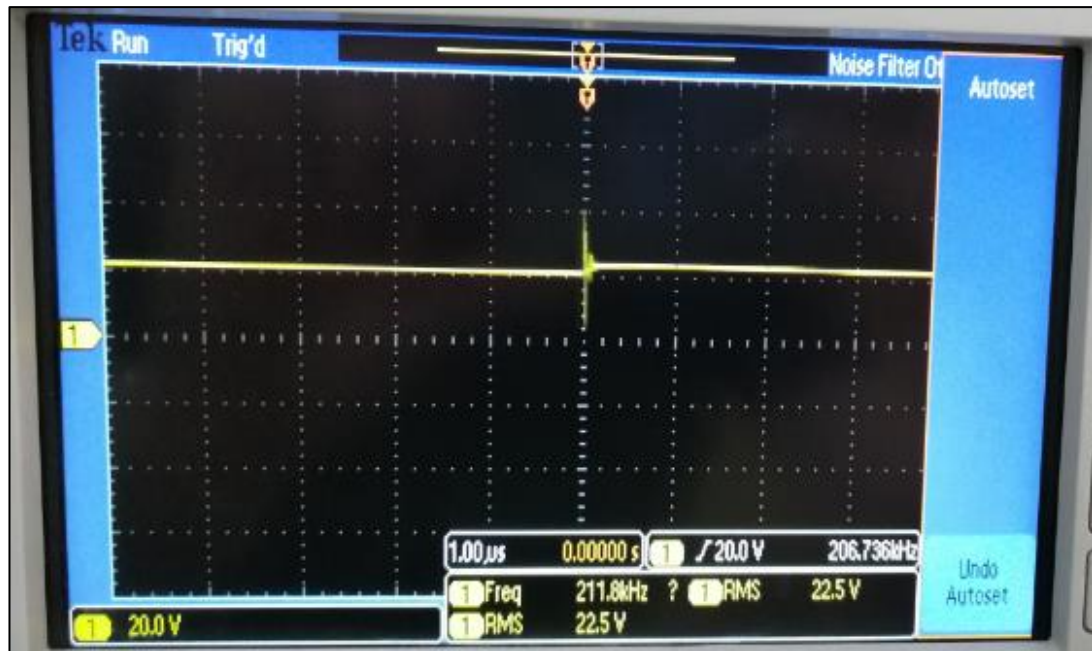


Figure 4.3: Boost Converter Output with 555Timer.

## 4.2. Experiment Result of Open Loop Controlled Boost Converter with Microcontroller

The microcontroller (STM32F0 Discover board) was set for generate square wave signal (75kHz, %58 duty cycle) and the boost converter was set with  $L=50\mu\text{H}$ ,  $C=22\mu\text{F}$ ,  $R_{\text{LOAD}}= 82 \Omega$  for 10V-24V dc/dc converter in figure 4.4.

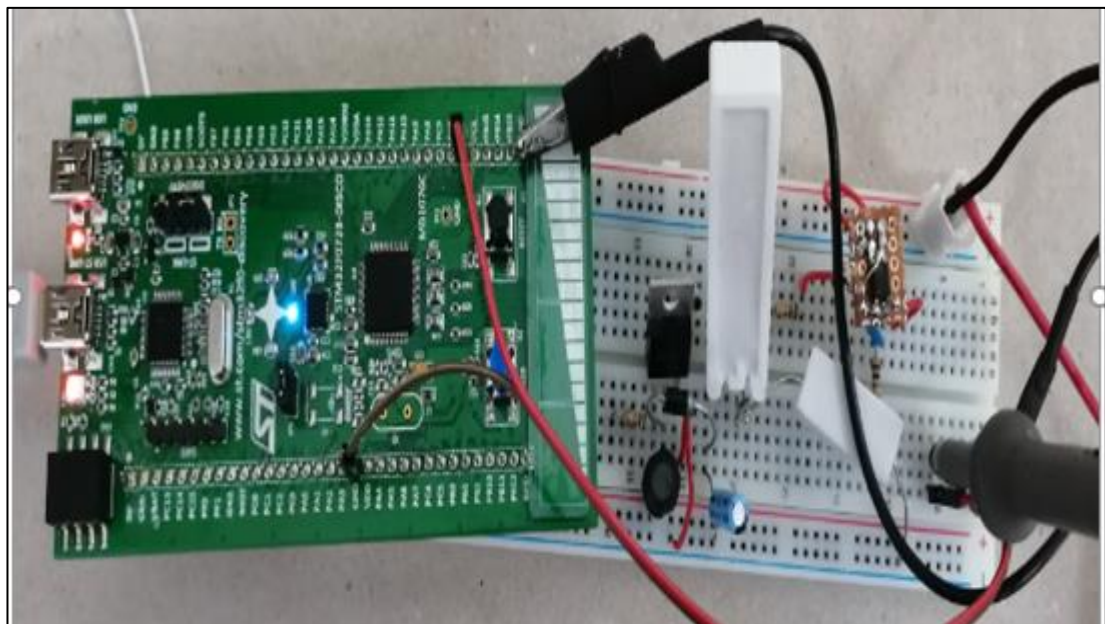


Figure 4.4: Boost Converter with Microcontroller Experiment Circuit.

As shown in figure 4.5, 75.76 kHz and 54% duty cycle signal were generated with below codes.

Table 4.1: Square Wave Generator Source Codes for STM32F072RB.

```
#include "stm32f0xx_hal.h"
#include "pwm_driver.h"
#define __CHECK_FLAG(__HANDLE__, __FLAG__) \
(((__HANDLE__) & (__FLAG__)) == (__FLAG__))
void pwm_init(void)
{
    GPIO_InitTypeDef GPIO_InitStructure;
    __HAL_RCC_TIM3_CLK_ENABLE();
    __HAL_RCC_GPIOB_CLK_ENABLE();
    __HAL_RCC_GPIOC_CLK_ENABLE();
    GPIO_InitStructure.Pin = GPIO_PIN_7;
    GPIO_InitStructure.Alternate = GPIO_AF0_TIM3;
    HAL_GPIO_Init(GPIOC, &GPIO_InitStructure);
    TIM3->PSC = 48;
    TIM3->ARR = 12;
    TIM3->CCR2 = 12;
    // CH-2 PWM MODE
    TIM3->CCMR1 |= TIM_CCMR1_OC2M_2;
    TIM3->CCMR1 |= TIM_CCMR1_OC2M_1;
    TIM3->CCMR1 |= TIM_CCMR1_OC2PE;
    // Enable OC1REF and OC2REF OUTPUT
    TIM3->CCER |= TIM_CCER_CC2E;
    // Enable Timer
    TIM3->CR1 |= TIM_CR1_CEN;
}
void pwm_enable(void)
{

```

Table 4.1: Continued of table.

```
TIM3->EGR |= TIM_EGR_UG;
}
void pwm_disable(void)
{
    TIM3->CR1 &= ~(TIM_CR1_CEN);
}
void pwm_set_duty_cycle(uint32_t duty, uint32_t channel)
{
    TIM3->CCR2 = duty;
}
#include "stm32f0xx_hal.h"
#include "pwm_driver.h"
static void SystemClock_Config(void);
static void Error_Handler(void);

int main(void)
{
    HAL_Init();
    /* Configure the system clock to have a system clock = 48 Mhz */
    SystemClock_Config();
    UART_Init();
    pwm_init();
    /* Infinite loop */
    while (1)
    {
        pwm_set_duty_cycle(7,2);
    }
}
```

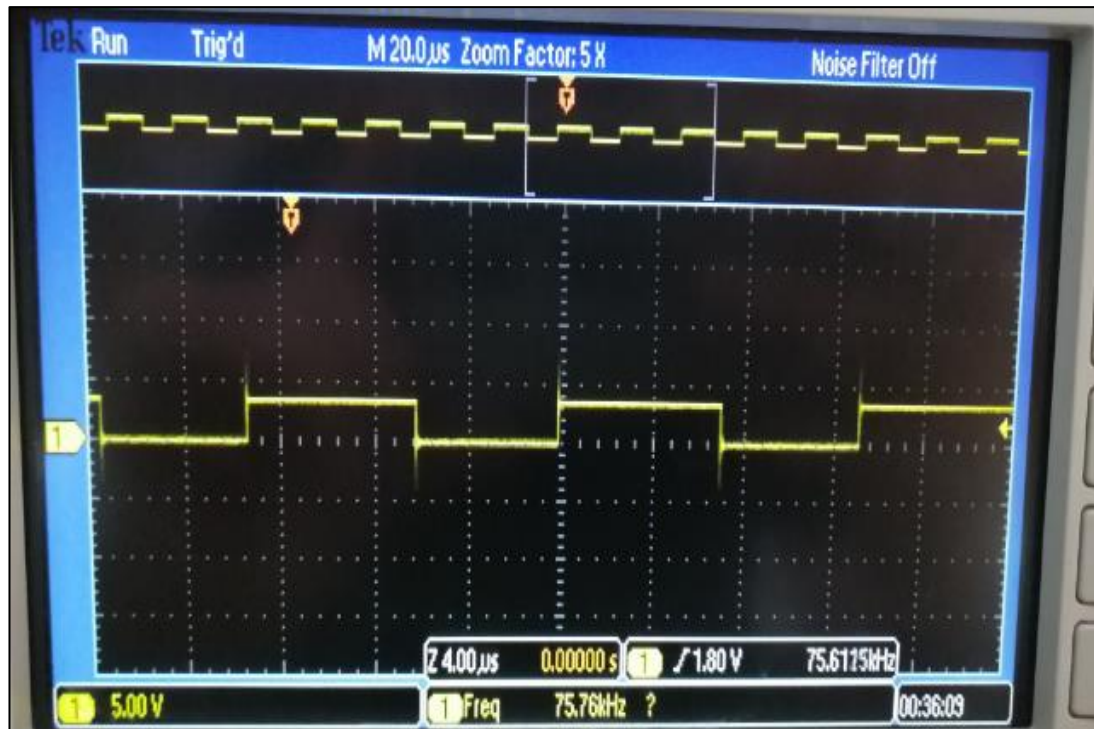


Figure 4.5: Square Wave Output of Microcontroller.

The output voltage, on high duration, of this signal is 3.3 volts as seen in figure 4.5. This value is not enough to switch MOSFET(IRF540). It is necessary to use external MOSFET driver. In figure 4.6 shows MOSFET driver that TLP152 IC equivalent circuit.

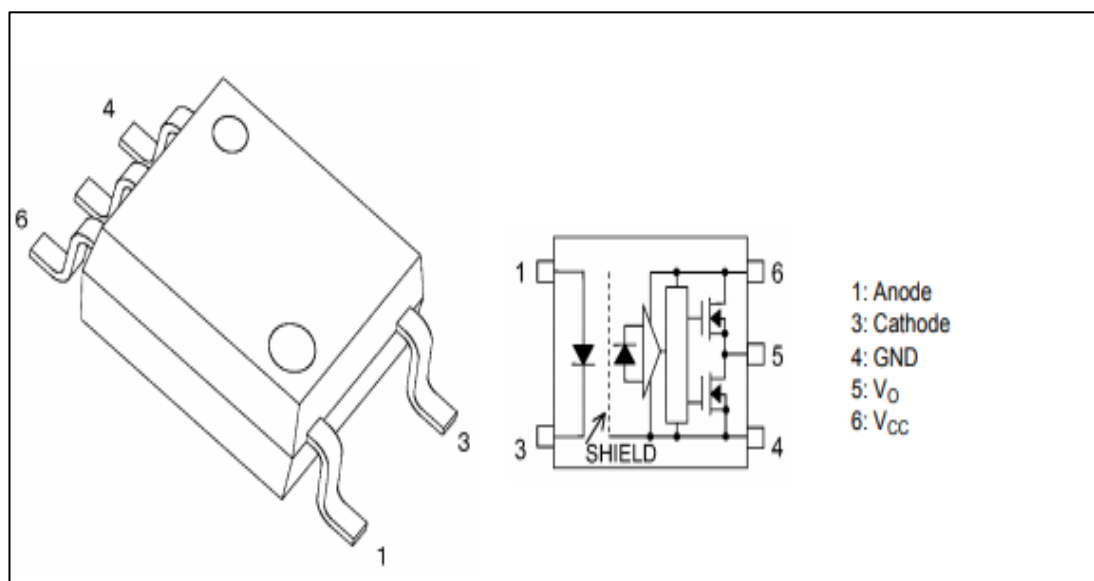


Figure 4.6: TLP152 IC Equivalent Circuit.

Square wave signal which produced from microcontroller was applied to pin 1. 10V supply voltage was applied to pin 6 then the square wave signal produced in figure 4.7 has occurred. The output signal is enough to switch MOSFET.

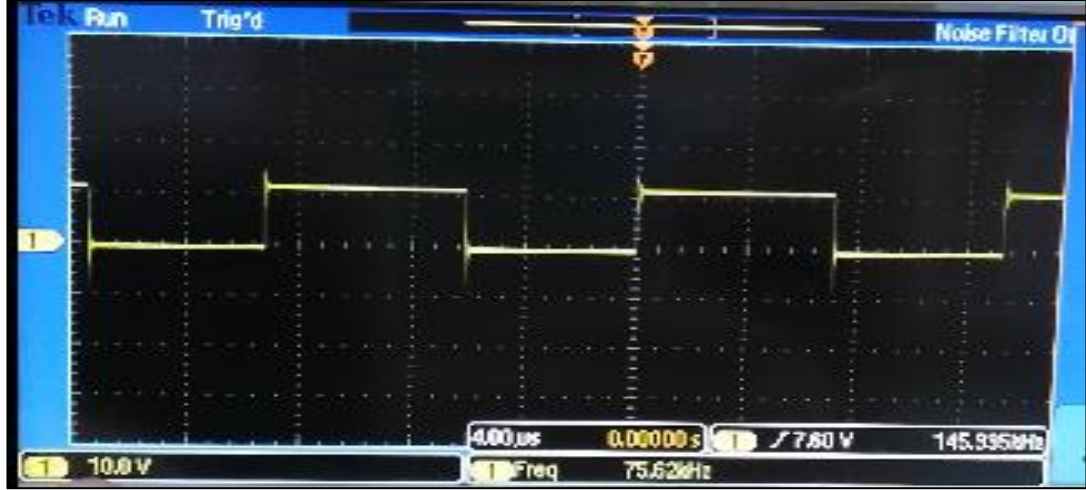


Figure 4.7: Square Wave Output of Microcontroller with TLP152.

When the figure 4.4 circuit was operated. The following results were observed.

- $V_{in} = 10V$ ,  $I_{in} = 1A$ ,  $R_{load} = 80 \Omega$ ,  $V_{out} = 22.5V$

$$I_{out} = \frac{V_{out}}{R_{load}} = \frac{22.7V}{80\Omega} = 0.28A \quad (4.7)$$

$$\eta_{efficiency} = \frac{V_{out} \times I_{out}}{V_{in} \times I_{in}} = \frac{22.5V \times 0.28A}{10V \times 0.98A} = \%64 \quad (4.8)$$

$$P_{in} = P_{out} + P_{power\ loss} \quad (4.9)$$

$$P_{power\ loss} = P_{in} - P_{out} = 9.8W - 6.3W = 3.5W \quad (4.10)$$

$$P_{power\ loss} = P_{coil} + P_{diode} + P_{MOSFET} + P_{heat} \quad (4.11)$$

$$P_{heat} = 3.5W - 0.5V \times 0.98A + 1V \times 0.28A + 1.6V \times 0.98 = 1.17W \quad (4.12)$$

Observed in the experiment, efficiency was obtained % 64. Desired output voltage was 24V but observed that 22.7V as seen in figure 4.8 because 1V on the diode used in the circuit and the remaining 0.5V fall on the used coil.

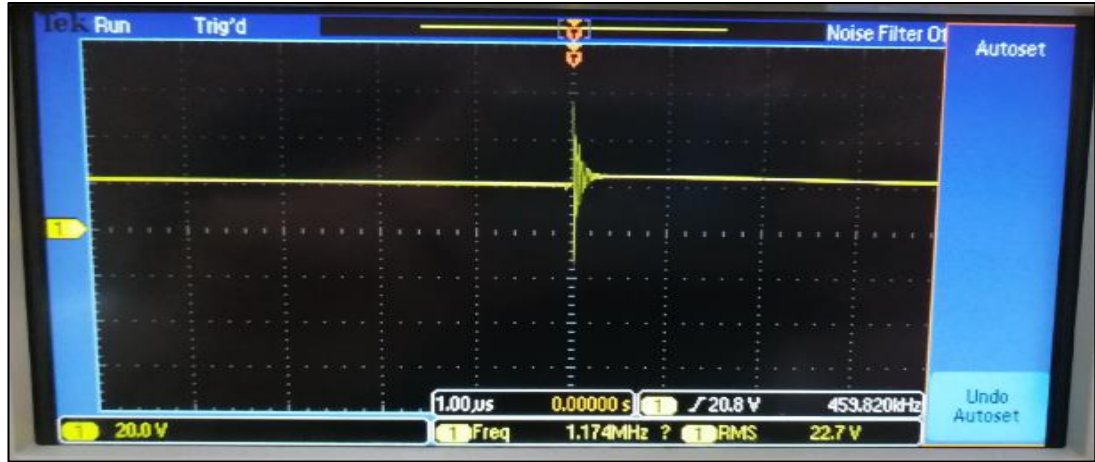


Figure 4.8: Boost Converter Output with Microcontroller.

### 4.3. Experiment Result of Closed Loop Controlled Fly-back Converter with Viper12a

The Viper12a was used to generate square wave signal in current mode controlled for 325V-6V dc/dc fly-back converter in figure 4.9. Supply voltage of Viper12a is provided by the auxiliary winding on the primary side. Viper12a has a wide supply voltage range (9 V to 38 V).

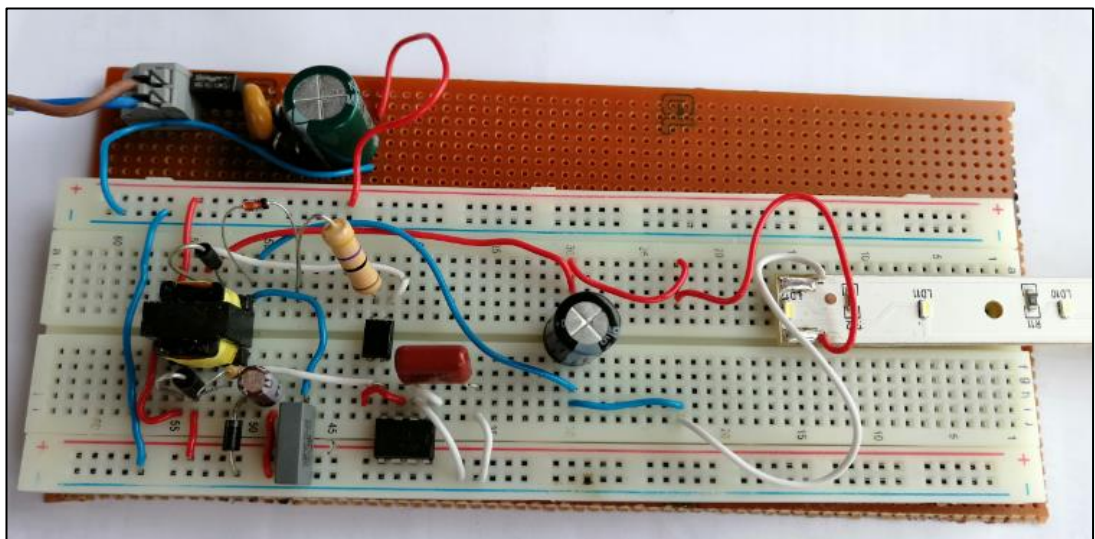


Figure 4.9: Closed Loop Controlled Fly-Back Converter Experiment Circuit.

The fly-back converter with secondary voltage regulation driving the Viper12A feedback pin through an optocoupler with Zener diode,  $V_Z = 5.1\text{ V}$ , for obtain 6.2V output voltage. When the output voltage exceeds the zener voltage, the optocoupler will active and send feedback to Viper12a for switch off.

Calculating  $D_{base}$  with the following requirements and figure 3.12 components values:

- $V_{in} = 325\text{V}$ ,  $V_{out} = 6.2\text{V}$ ,
- $N_1=180$ ,  $N_2=25$

Solution:

$$\frac{V_{out}}{V_{in}} = \frac{N_2}{N_1} \frac{D}{1-D} \quad (4.13)$$

$$\frac{6.2}{325} = \frac{25}{180} \frac{D}{1-D} \rightarrow D = 0.12 \quad (4.14)$$



Figure 4.10: Drain-Source Switching Wave Form.

$$D_{\text{drain-source}} + D_{\text{base}} = 1 \rightarrow D_{\text{base}} = 0.1 \quad (4.15)$$

$D_{\text{base}}$  was calculated 0.12 but in practice, it was observed 0.1 as seen in figure 4.10. The output voltage was desired 6.2V but in practice, it was observed 6.32V in figure 4.11. These differences are related to the working tolerances of the materials used.

$$\eta_{\text{efficiency}} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{1.93W}{2.91W} = \%66 \quad (4.16)$$

$$P_{\text{in}} = P_{\text{out}} + P_{\text{power loss}} \quad (4.17)$$

$$P_{\text{power loss}} = P_{\text{in}} - P_{\text{out}} = 2.91W - 1.93W = 0.98W \quad (4.18)$$

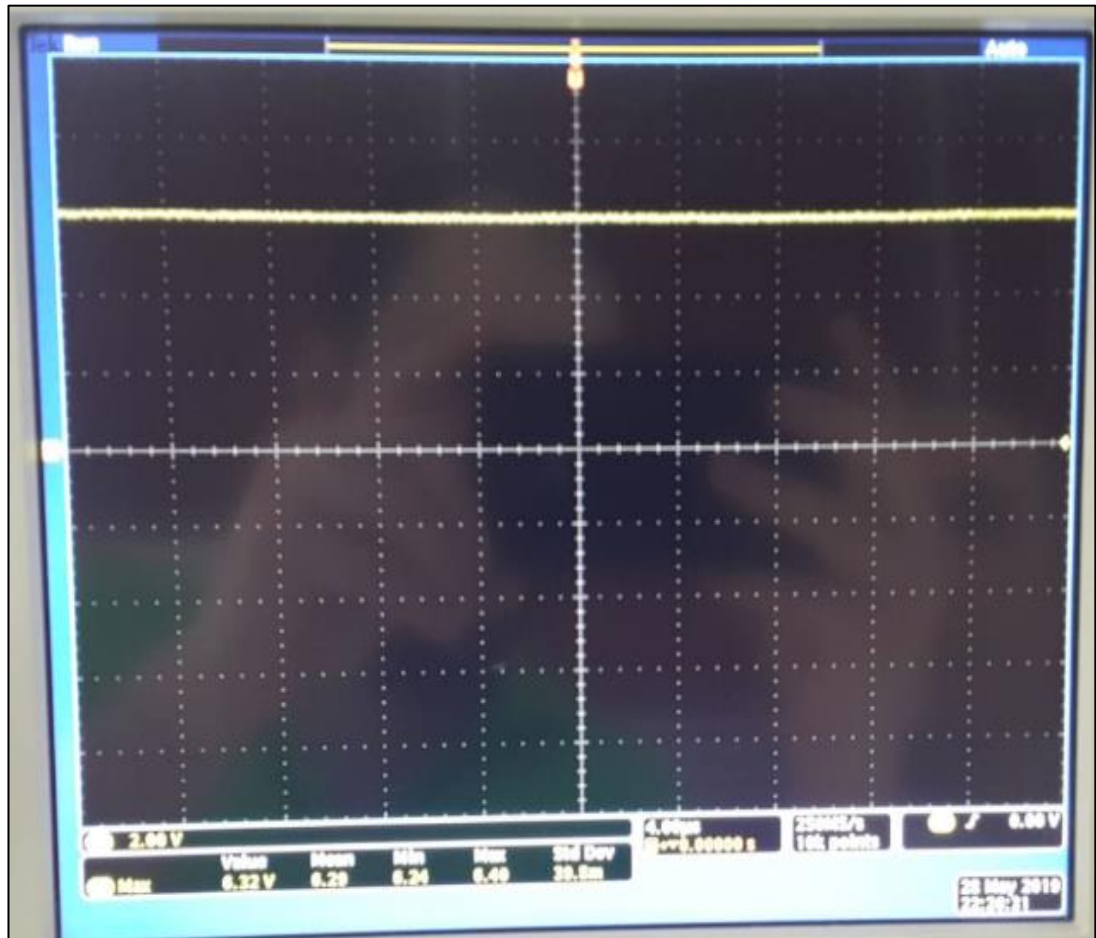


Figure 4.11: Closed Loop Controlled Fly-Back Converter Output.

## 5. CONCLUSION AND FUTURE WORK

### 5.1. Conclusions

Open loop controlled 10V-24V boost converters were operated in two different ways in section 4.1, section 4.2. Closed loop controlled 10V-24V boost converter was operated in section 3.3 and closed loop controlled fly-back converter in section 4.3. The following table is obtained as a result of these four studies respectively.

Table 5.1: 10V-24V Boost Converter and 325V-6V Fly-Back Converter.

| 10V-24V Boost Converter and 325V-6V Fly-Back Converter |      |       |            |           |            |
|--------------------------------------------------------|------|-------|------------|-----------|------------|
| Method                                                 | Vin  | Vout  | Efficiency | Accuracy  | Power loss |
| 555Timer                                               | 10V  | 22.5V | %61        | Good      | 3.9W       |
| Microcontroller                                        | 10V  | 22.7V | %64        | Good      | 3.5W       |
| Closed loop boost                                      | 10V  | 24.1V | %64        | Excellent | 4.11W      |
| Closed loop fly-back                                   | 325V | 6.2V  | %66        | Excellent | 0.98W      |

To change the PWM signal in the open loop controlled boost converter with 555Timer, it is necessary to determine correct resistors and capacitance values in order to obtain proper frequency and duty cycle. In open loop controlled boost converter with microcontroller, it can only be obtained in the program by replacing the corresponding block with the software. 555Timer circuit runs without the need for an external MOSFET driver, but because the processor has a 5V output, microcontroller needs an external MOSFET driver for boost. Microcontroller method provides to monitoring about system. Isolated closed loop DC-DC fly-back converter does not have a dc path between its input and output but boost converters have a dc path therefore isolated converter is safer than non-isolated converter for users. Isolation provides that voltage transients on the input are not transferred to the output in fly-back converter.

Open loop control systems are basic in construction and design. It is more economical than closed loop control systems and easy to maintain. It is less reliable than closed loop control systems as it cannot react to changes in output load due to

lack of feedback. Close loop control systems are less affected to the external noise sources with their feedback mechanism and reducing the errors. They are costlier than open loop system because of its complexity. The feedback in the closed loop system may have oscillatory response. Stability is a big problem for closed loop system. Closed loop system design should be done more carefully to solve the stability problem.

## **5.2. Future Works**

As it is understood from this thesis, there is more than one square wave generator method which can generate PWM signal to switching. The Open loop controlled boost converters in section 4.1 can be operated by driving with square generator circuits with op-amps or transistors. Simple feedback boost converter which are examined in section 3.3 can be supported by compensation circuits to work more stable and load-free. The written code that examined in section 4.2 can be improved to make open loop controlled boost converter to closed loop boost converter with feedback system also or developing code written in section 4.2, products such as remote control lighting products or engine speed controller can be made.

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## **BIOGRAPHY**

Muhammed BAYRAM was born in İzmit in 1991. In 2015, he successfully completed Department of Electronics Engineering of Faculty of Engineering at Gaziantep University. In 2016, he started his graduate study in the Department of Electronic Engineering at the Institute of Science and Technology of Gebze Technical University. Since 2015, he has been working as a production manager in Beş-a electronic company which produces electronic emergency lighting systems

## **APPENDICES**

### **Appendix A: Publications within the Scope of Thesis**

Bayram M., Şuvak Ö., (2019), “Controlling circuitry for dc/dc converters - survey”, Gebze Technical University Institute of Natural and Applied Sciences, Graduate Studies Symposium & Presentation Days, 17-18 June 2019.