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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ADJUSTING STARTER GENERATOR TOPOLOGY TO UNMANNED AERIAL VEHICLES

M.Sc. Thesis by

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ANKARA

ADJUSTING STARTER GENERATOR TOPOLOGY TO UNMANNED AERIAL VEHICLES

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **‘‘ADJUSTING STARTER GENERATOR TOPOLOGY TO UNMANNED AERIAL VEHICLES’’** completed by **ATEŞ BATUHAN İLHAN** under supervision of **Assoc. Prof. Dr. SİNAN KIVRAK** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ADJUSTING STARTER GENERATOR TOPOLOGY TO UNMANNED AERIAL VEHICLES

ABSTRACT

Recently unmanned aerial vehicles are used widely for many purposes. From daily needs to military services their specific usages exist. The more usage of UAV, the more requirements occurs. Some of these requirements are endurance and starting problem. This study propose a solution for starting and generating energy of these using relatively cheaper components. A hybrid system are presented in this document to handle both endurance and starting problem using easy but effective methods. It is presented to combination of combustion engine and DC motor to start the system and generate energy. The proposed system is to use the mechanical energy as much efficient as possible. Combustion engine's heat energy which is turned to mechanical energy also benefits to generate energy. It also starts the system via DC-DC converter and battery. So every turn of mechanical shaft coupled with a dc motor generates energy with the help of the buck boost converter. A dc motor connected to a battery starts the system by taking first energy from the battery. With this study, it is expected that mini UAVs working with combustion engine won't have starting problem in the air. In case of stopping engines, which is a kind of problem that is faced during flight, mini UAV's engine can be started and it can keep flying. This study analyzes how it can be achieved with a DC motor and a buck boost converter with a mechanical test setup.

Keywords: Hybrid, Starter generator, Unmanned aerial vehicles, Efficiency, Dc-dc converter

MARŞ JENERATÖR TOPOLOJİSİNİN İNSANSIZ HAVA ARAÇLARINA UYARLANMASI

ÖZ

Son zamanlarda insansız hava araçları birçok amaç için yaygın olarak kullanılmaktadır. Günlük ihtiyaçlardan savunma amaçlı hizmetlere kadar bir çok kullanımı mevcuttur. İHA kullanımı arttıkça, daha fazla gereksinim ortaya çıkar. Bu gereksinimlerden bazıları daha uzun havada kalabilme ve motorun çalıştırılması problemidir. Bu tez, nispeten daha ucuz bileşenler kullanarak sistemi çalıştırmak ve çalışan sistem üzerinde enerji üretmek için bir çözüm önermektedir. Önerilen sistem mekanik enerjiyi mümkün olduğu kadar verimli kullanmaktır. Yanmalı motorun yakıtla sağladığı ısı enerjisinden ürettiği mekanik enerjiyi, kullanılan sistem sayesinde elektrik enerjisine dönüştürüp pil şarj edilebiliyor. Bu sistem aynı zamanda kullanılan pil sayesinde röle üzerinden enerjinin yönünü ayarlayarak sistemi de çalıştırmaya yarıyor. Böylece, bir DC motorla birleştirilmiş yanmalı motorun her dönüşü, pili şarj etmeye yarıyor. Kullandığımız çevirici sayesinde motorun hızına bağlı olarak üretilen voltajın seviyesi sabit tutularak pil şarj edilebiliyor. Sistem her gerekli olduğunda çalıştırılabiliyor ve bu enerjisini sürekli şarj olan pilden alıyor. Bu çalışmayla birlikte yanmalı motorla çalışan mini İHA'ların çalıştırılma probleminin olmaması beklenmektedir. Uçuş sırasında karşılaşılan bir problem olan motorların durması durumunda yeniden çalıştırma ile uçuş devam ettirilebilir. Bu çalışma sistemin nasıl başarılı olduğunu alçaltıcı yükseltici çevirici ve DC motor ile beraber mekanik test düzeneğinde analiz etmektedir. Bu sistemle ilgili ayrıntılı anlatım tezin devamında sunulmaktadır.

Anahtar Kelimeler: Hibrit, Marş jeneratör, İnsansız hava aracı, Verimlilik, Dc-dc çevirici

CONTENTS

NOMENCLATURE

Acronyms

A	Ampere
ADC	Analog Digital Converter
AC	Alternating Current
BMS	Battery Management System
BLDC	Brushless DC Motor
DC	Direct Current
EMI	Electromagnetic Interference
IC	Integrated Circuit
KHz	Kilohertz
kW	Kilowatt
Li-Ion	Lithium-Ion
Li-Po	Lithium Polymer
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
Opamp	Operational Amplifier
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RMS	Read Mean Square
RPM	Revolutions Per Minute
UART	Universal Asynchronous Receiver Transmitter
UAV	Unmanned Aerial Vehicle
V	Voltage
W	Watt

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General Information

Unmanned aerial vehicles (UAVs) usage are increasing fast in many areas. Rapidly increasing UAV fleet poses new challenges to its designers with the expanding scope of its applications. They are used especially in military applications (from surveillance to eradicating enemy's bases with payload). Because of its autonomous control, it is preferred to handle issues without losses. However their future potential civil applications are enormous (e.g., border patrol, forest fire monitoring and firefighting; nonmilitary security work such as surveillance of industrial sites, road/rail infrastructure, mineral exploration, coastal surveillance, pipeline surveillance, spraying of fertilizers, insecticides, aerial photography, land mapping, environmental monitoring, transportation, and gathering scientific data)[1]. Today's UAV manufacturers, considered as air robots, attach great importance to technologies such as imaging, communication, electro-optical sensor systems, sensor fusion, technologies that provide the operator with reliable visual information that allows the pilot of an airplane to make decisions about future flight paths. These debates are widely conferred in many papers. These papers related to UAV controlling is not a new topic in terms of control theory of autonomous drones. However, many studies on this topic about duty distribution, targeting vs. the issues that operator interferes to UAV manually is tried to be minimized. Everything related to this autonomous system is tried to be minimum operator interfered. Because payloads on autonomous UAVs like bombs or missiles are controlled with complicated systems. Although it is almost completely autonomous, it has still risks. The talent to detect and prevent both ingenuous and human-made obstacles and reconstruct the flight path is an important feature that UAVs must possess, and the relevant algorithms should be embedded in guidance and control systems. In many situations, UAVs are defined only one air vehicle (with concerning surveillance systems) or a UAV combination, which is generally constituted with more than one air vehicles with their control mechanisms (ground control). To ensure its stable working and operator interference, artificial intelligence is embedded to the systems. Because bombs or any other tools to destroy enemys , artificial intelligence directed their rotation and those tools hit that enemys.

Recent developments are based on complicated sensor systems, communication systems etc. with more payload and longer endurance. For UAVs to perform long endurance applications, their power sources need to be developed to ensure the long endurance functionality of the propulsion system and onboard equipment [2]. These researches are developed after complicated control mechanism of mini UAVs are developed and their usage become comprehensive. It is becoming more comprehensive in the light of fast technological developments. Operators are simulated by computer programs as if they are operators. It is already expected when we look the recent developments. Especially artificial intelligence enters to our daily life. Moreover, since the unmanned lethal capability problem requires the knowledge of parameters different from what would be used in the mentioned computational programs, it is logical to try to create UAV guidance laws that use the same parameters as missiles, which, we want to underline again, are also unmanned aerial vehicles [3].

These are some examples of UAVs using in various application but as we discussed above, they are used mostly in military applications.

Figure 1.1 TerraHawk CW-30 Hybrid Drone [4]

Figure 1.2 Hybrid Quadrotor Technology [5]

There is another topic to discuss which is converters. It is an essential part of this system. It is used a non-inverting buck boost converter in this study. There is a lot of converters used in the market that works on step up and step down applications like buck boost converter, cuk converter etc. Traditional converters use polarities but it is changed in this application. The non-inverting converter uses only one inductor and one capacitor to perform step up and step down processes and output voltage stays in the same polarity with input voltage. With these advantages, the non-inverting buck-boost converter has been favored for many industrial applications in both high and low power level such as power factor correction applications, fuel-cell power systems, battery supplied power systems, etc. [6].

To adjust charging system of the battery, the converter operates in buck mode if the generated voltage is higher than battery's voltage and the converter operates in boost mode if vice versa. However, in real application it is hard to control the converter. There is a dead zone when the input and output voltages have approximate values which is between 22V and 26V in this case. Because of this, duty cycle of the system should be around 5% or 95% and it is hard to switch the switching components at these duty cycle values. For smooth transition between buck and boost mode, it is used an additional loop inside the software.

There is used an engine of motor scythe and a DC motor to test this study. Why DC motor used in this study is to see whether it works or not starter generator topology. There would be used a BLDC motor but it wouldn't be easy to drive. BLDC motor have also a complicated structure compared to DC motor. One of the purpose of this study is to show whether energy can be generated from this system and to supply that energy, it would be used additional AC-DC converter.

For starting process on mini UAVs, there is commonly used an engine starter. This is an additional system and in case of stopping of engines, there is nothing to do when mini UAVs fly in the air. An example of the engine starter is in the figure below.

Figure 1.3 An Engine Starter [13]

Figure 1.4 A Mini UAV Started With Engine Starter [13]

The other purpose of this study is to start this combustion engine whenever it is needed. With an engine starter, it is impossible to interfere to the system on operation. However, with the system studied on this thesis, it can be solved starting problem of mini UAVs.

1.1.1 Scope of This Study

The content of this study is specified below:

- General definitions of UAV
- General approach to buck boost converter
- Explanations about used components on this study
- Starter generator processes and their detailed explanations.
- Supporting results with real time datas

1.2 Outline of the Thesis

The content of this study is specified below:

In Chapter 1, General definitions and information about studied system

In Chapter 2, Technical details and definitions about this hybrid system in terms of used components and general specifications

In Chapter 3, Detailed explanation of used circuit, experimental setups, simulations and results

In Chapter 4, General conclusion about the system

CHAPTER 2

TECHNICAL DETAILS AND DEFINITIONS

2.1 Combustion Engine Definitions, Specifications and Operations

Internal combustion engines are engines that burn the appropriate fuel and convert it into power to use the chemical energy contained in the fuel. Unlike steam engines, an internal combustion engine is based on the principle of producing energy by burning or oxidizing this fuel in the combustion chamber inside the engine. The most common fuel of these engines is gasoline, also called gasoline or diesel engine. Methane, hydrogen and propane can also be used as fuel in such engines.

2.1.1 Ideal Gas law

All of the internal combustion engines work according to the ideal gas law. It is simply related to the fact that heated gas increases the pressure of gas and it tends to expand.

In other words, the gases that have zero gravitational forces between molecules are called ideal gases. All gases approach the ideal state at low pressure and high pressure. There is no ideal gas but in equations and calculations we derive from hydrogen, nitrogen, air, oxygen, carbon dioxide and so on. We can think of gases as ideal gas.

In actual engine operation, combustion takes place in the engine cylinder. The heat energy released after combustion is converted into mechanical energy. Suction, compression, work and exhaust times occur during engine operation. In the theoretical otto cycle, there is an intermediate fluid which provides heat transfer in the cylinder. This medium is the air that is considered to be the ideal fluid gas. The air inside the cylinder is heated by an external heat source. The theoretical otto cycle consists of two fixed volumes and two isentropic (adiabatic) processes.

2.1.2 Pistons and Turbines

Gas turbines, which are a kind of internal combustion engine, compress the gas (air) and expand it by adding heat to it (as a result of the combustion of fuel) and convert it to rotational movement. it makes a difference. There is no need for the crankshaft required to achieve the rotational movement of gasoline and diesel engines. However, the most important drawback is that it has a lower efficiency compared to other internal combustion engines. The reason for this is that the blades of the turbine are constantly exposed to high temperatures and consequently the permissible material stresses are low. In addition, the piston and cylinder are cooled with the air taken in each circuit. This results in lower yields. It is widely used in power motors as application areas. Furthermore, it has an important place in obtaining electricity and in conveying gases through pipes.

It is the name given to the part produced so that it can enter into the cylinders of the engine. After combustion occurs in the cylinder, the piston generally moves backwards and has a linear motion.

Piston engine is extremely responsive, in comparison to a turbine, as well as more fuel-efficient at low outputs. This makes them ideal for use in vehicles, as they also start up more quickly [7].

2.1.3 Two Stroke Engine

Two-stroke engines may be unheard of for some of us, but two-stroke engines have a wide range of uses in our daily lives. Generally speaking, we can think of four-stroke engines in our cars, but two-stroke engines have an important place in our lives. For example, it is a type of engine used from lawn mowers to jet-skis and even model aircraft. Let's take a brief look at what a two-stroke engine is and how the two-stroke engine works.

In these engines, as the name suggests, they complete a cycle with up and down movement of the piston twice. At the end of the crank would have made a full round. Unlike a four-stroke engine, the two-stroke engine finishes in two, not four.

As is known, in four-stroke engines, the suction, compression, combustion and exhaust times are separate times, which are the four mentioned times. In two-stroke engines, suction and compression occur at the same time, with combustion and exhaust at the same time. In other words, suction and compression occur together at a time, followed by combustion and exhaust times together.

2.1.3.1 Two Strokes Ignition(Petrol) Engine Working Principle

The principle of two stroke ignition engine is shown in the figure. Its two strokes are as follow:

- Upward Stroke
- Downward Stroke

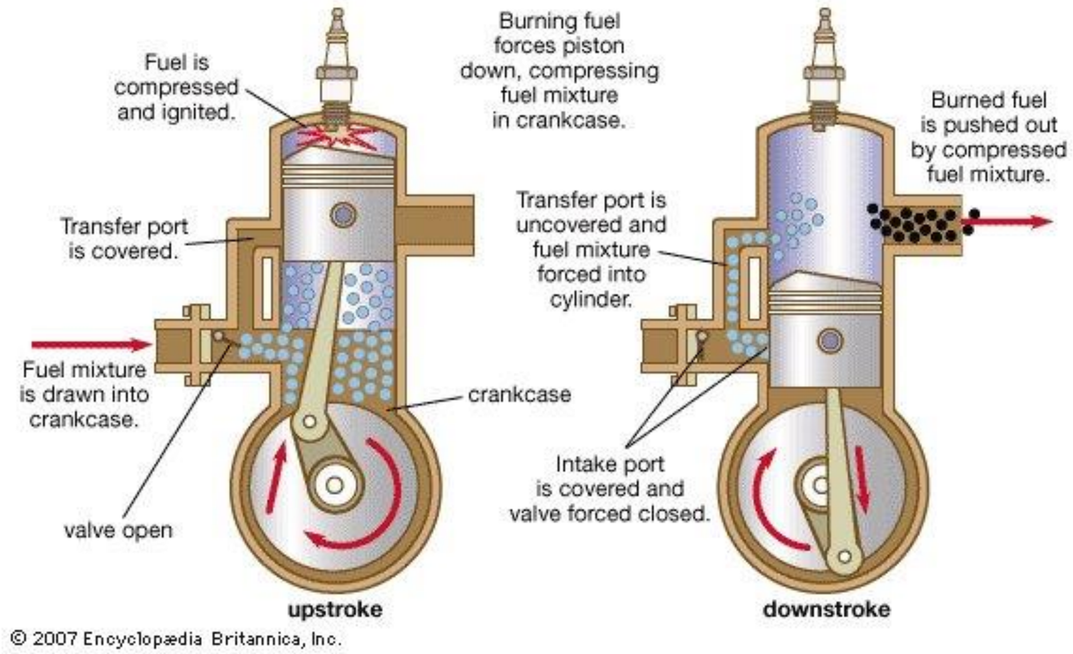

Figure 2.1 Two-Stroke Cycle [8]

2.1.3.1.1 Upward Stroke

As the piston moves upwards, it starts compressing the mixture on the cylinder. By means of the upward movement of the piston and the rotation of the crank, the fuel mixture is now filled into the crank section by means of the negative pressure formed inside. This mixture is a mixture of fuel, air and oil. In these engines, as in the case of four-stroke engines, the crank is not separately contained in the oil, so lubrication occurs in this way. With oil mixed with gasoline, the elements are lubricated.

2.1.3.1.2 Downward Stroke

The trapped mixture is ignited by the spark plug and combustion occurs. The piston moves down due to the pressure generated in the combustion event. As the piston moves down, the suction port closes and the exhaust port opens. As the piston moves down, the exhaust process continues and the exhaust gases are exhausted. At the same time, the piston makes it possible to fill the filled mixture into the piston by means of the carrying pocket by its downward movement. This means that the same events happen again and the timesgo back to back.

2.1.3.2 Engine Of Motor Scythe

Engine of motor scythe is one of the two-stroke gasoline engines. Its working principle is defined above. In this study Kaan brand engine of motor scythe is used as illustrated below

Figure 2.2 Kaan Professional Engine of Motor Scythe [9]

It is relatively easy to find to use for such an application and it is relatively cheaper according to the motors with similar features. For example an 50cc UAV engine costs approximately 400 dollars in Turkey whilst an engine of motor scythe costs approximately 50 dollars. The motors used for UAV applications in the market has external ignition system. Hence they are also known for using special purposes, they are relatively expensive. Their characteristic features and technical specifications is similar with the engine of motor scythe. For example, it is needed high rpm values to takeoff and this motor has max. 10500 rpm values. It is needed enough power to supply enough torque and it is needed engine of motor scythe to make the mini UAV move flexibly. What is expected from this engine is to take off the drone and lift payload with overall load. When it is combined all these together, this engine meets the expectations for this study. It is a two stroke combustion motor featured with 62cc 3,1hp 10500 rpm values. These specifications meet the requirements to takeoff a mini UAV. For the scope of this study, it is adequately enough features.

In the scope of the project for a master of science lecture, it is studied on a kamikaze drone using this engine before. Required components is chosen suitable for that system. From its mechanical design to used components, everything is implemented from the beginning. Finally, the project is accomplished and the UAV project for that lecture is flied. Its appearance is figured as below

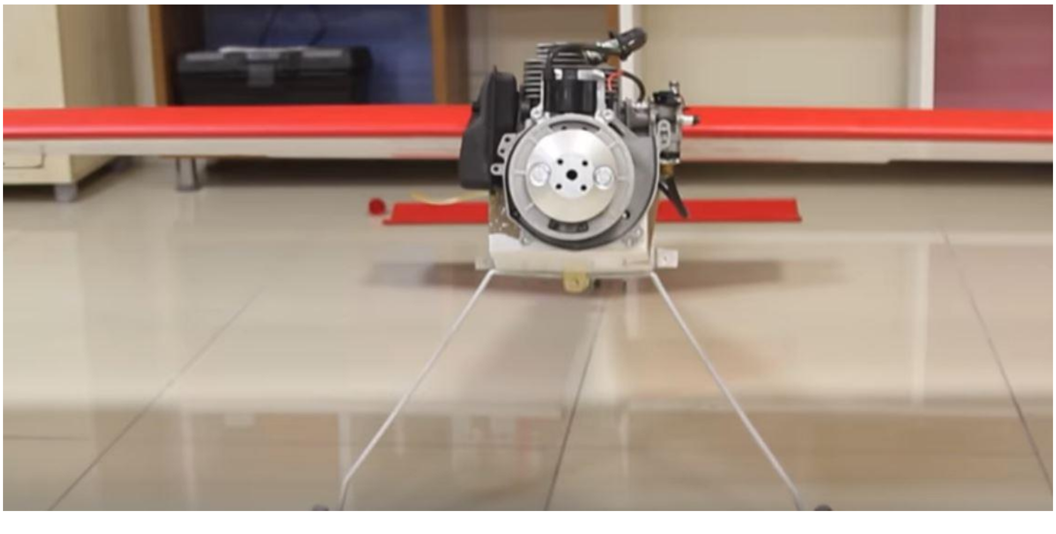

Figure 2.3 The UAV Project Designed In A Lecture Scope

This system starts manually. It is had to be pulled its trigger to ignite fuel inside it. This thesis is aimed to start the engine of motor scythe without manually triggered and adjust to a UAV like this and also charge its power source under variable voltage values generated by this engine. This is the purpose of this study.

2.2 Buck Boost Converter

DC-DC converters are bi-directional converters. The basic logic of buck / boost converters is based on switching power supplies, as with other converters. There is a fully controlled switching element on the circuit and the value of the voltage at the output of the circuit is controlled according to the duty cycle value of this element. The basic structure of buck boost converters is given in the following figure.

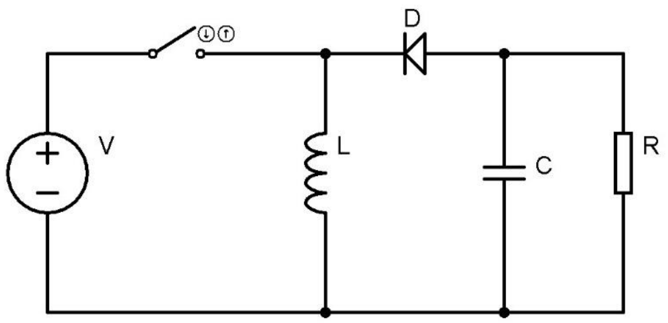

Figure 2.4 General Buck Boost Converter Schematics

The circuit consists of a voltage source, a switching element, a coil, a diode, a capacitor and a parallel load at the input. Buck / boost inverters are inverting DC-DC converters, which translate the input voltage's alternance to reverse polarity. As seen in the figure above, the polarity of the voltage has changed by passing the positive end at the input while the upper end is at the top. The switching element in the circuit is switchable by means of a simple driver circuit. The control diagram of the circuit is the same as the down converter and amplifier converter. The difference between the voltage value obtained from the output and the desired voltage value is found with a difference amplifier and this difference is compared with the triangular or sawtooth wave and the transmission / cut state of the switching element is checked if the triangular signal is not big or small according to the difference signal.

2.2.1 Buck Boost Converter Working

The controlled switch is turned on and off by using Pulse Width Modulation (PWM). PWM can be time based or frequency based. Frequency based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation. [10]

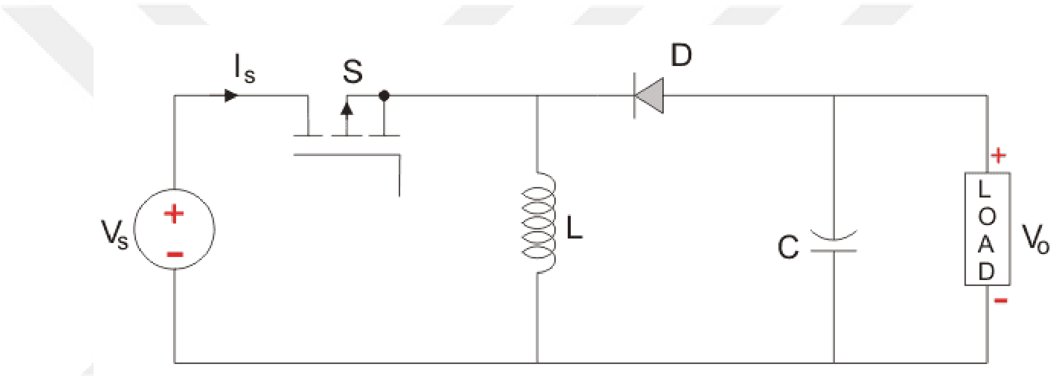

Figure 2.5 A Typical Buck Boost Converter [10]

Advantages of Buck Boost Converter

- Higher output voltages
- Low voltage on MOSFET
- Low operating duty cycle

2.2.2 Non-inverting Buck Boost Converter

On the system used in the scope of this study, the aim is to start the engine and generate energy from it. To achieve this, it is used non-inverting buck boost converter whose figure is below

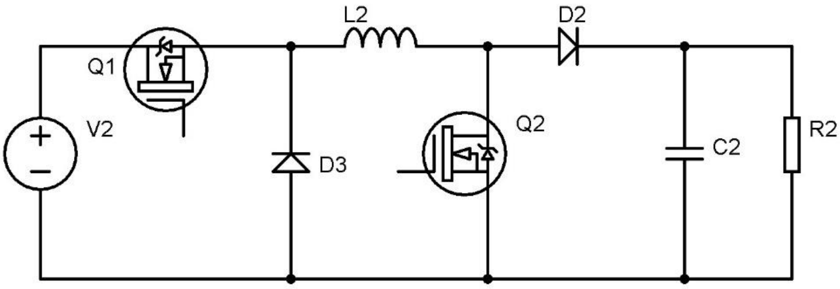

Figure 2.6 Non-inverting Buck Boost Converter

A non-inverting buck boost converter is essentially a cascaded combination of a buck converter followed by boost converter, where a single inductor capacitor is sued for both. As the name implies, this converter does not invert the polarities of the output voltage in relation to the polarities of the input. This converter requires the use of two active switches and is designed by combining buck converter and boost converter design in the same topology. Due to this design this converter can work buck-only, boost-only or buck boost converter.

When this converter is needed to work in buck mode, Q1 buck MOSFET is switched with proper PWM value adjusted by a microcontroller. During this operation, boost MOSFET Q2 is grounded. Because it isn’t wanted the current to flow on it. When Q1 is on state, the inductor and capacitor is charged. When Q1 is off state, the charged current on inductor and capacitor becomes in reverse polarity and starts to discharged. So the voltage value is descended.

When this converter is needed to work in boost mode, Q1 buck MOSFET is always on state and Q2 boost MOSFET is switched. Charged capacitor increases voltage value of load so the voltage value is ascended.

The input voltage is connected in parallel with diode D2, MOSFET Q2, load capacitor, C2 as indicated in the figure. MOSFET Q1 is connected between the input voltage source and diode D3. The inductor is connected between D3 and Q2 while D2 is connected between Q2 and the output or load capacitor.

$$D=\frac{V_{out}+V_D}{V_{out}+V_D+V_{in}} \quad \textbf{(3.1)}$$

$$L=\frac{V_{in}*D}{f*\Delta I} \quad \textbf{(3.2)}$$

$$C=\frac{I_{out}*D}{f*\Delta V} \quad \textbf{(3.3)}$$

These equations is used to find the values of inductor, capacitor and duty cycle in order to obtain optimum values to operate the circuit efficiently.

2.3 Li-Po Battery Overview

Li-Po batteries (Lithium Polymer) is a lithium ion battery that uses polymer electrolyte instead of liquid electrolyte and is rechargeable for reuse. Li-Po batteries are a type of battery that is now used in many consumer electronic devices. When not in use, it provides a great advantage because of the slow energy losses and high power during operation.

True Li-Po batteries use dry electrolyte polymers. These polymers which are coated on a thin plastic film form a layer stacked on top of each other.

In the structure of Li-Po batteries; there is a microporous porous separator that allows only ions to pass from one side to the other, not electrode particles, to prevent direct contact of the electrodes.

2.3.1 General Terminology About Li-Po Battery

2.3.1.1 Discharge C Rating

The rate at which a battery is charged is measured without damaging the battery, called the discharge rate. The discharge rate alone does not make sense. The capacity value must also be known to be calculated.

This value is the maximum and continuous load we can load on our battery. Setting a value higher than this will cause the battery to fail at a faster speed than normal and can cause damage to life. Therefore, a maximum load of 250A can be processed on the sample battery.

2.3.1.2 Battery Capacity

The capacity of a battery is a measure of how much power the battery can hold. The unit of measurement is milliamp hours (mAh). Returns the amount of time it takes for the battery to discharge within one hour. The larger the capacity, the longer the operating time.

2.3.1.3 Cell Number/Voltage

LiPo batteries consist of cells. Each cell should have an empty state of 3V and a full state of 4.2V. Cells of LiPo batteries; can be connected in series (S) and parallel (P). LiPo batteries are named according to their connection type. For example; If 5 cells in LiPo battery are connected in series, they are called '5S', if 2 cells are connected in parallel, P 2P , 4 cells are connected in series and if there are 2 cells connected in parallel, they are called' 4S2P '. The higher the 'S' value, the higher the voltage value of the battery and the higher the 'P' value. A battery's capacity is basically a measure of how much power the battery can hold. The higher the number, the longer the operating time. However, the greater the capacity, the greater the physical size and weight of the battery, the greater the capacity for the electronic device to be used.

2.3.1.4 Li-Po Battery Used In This System

In this system, a Li-Po battery is used to start the scythe motor. Why it is chosen Li-Po battery is that it can gives instant high current. This is what is needed for this system. Because first inertia is very important to start the scythe motor. It is needed high torque to turn the shaft to ignite the system. It is needed much more current than it is normally driven.

It is started to motor as expected with a Li-Po battery in the figure below

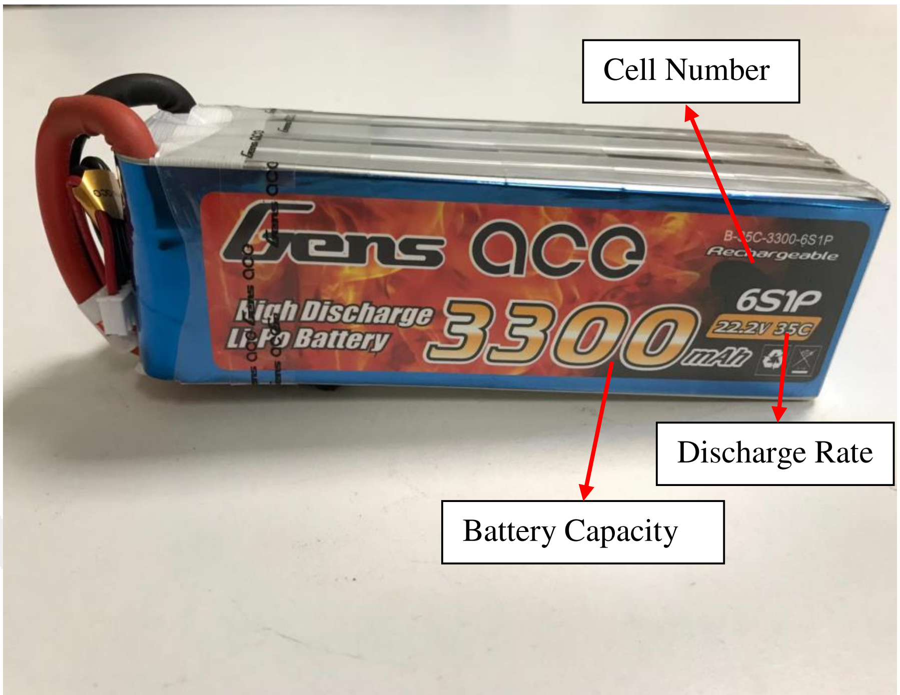

Figure 2.7 Li-Po Battery Used In This System

2.3.2 Battery Management System (BMS)

The battery management system (BMS) is a system that controls and manages battery packs of one or more cells during charging and discharging. Battery, current, voltage, temperature and so on. These are the structures that interfere with the system by measuring the important values and going out of the optimum values.

A system that consists of more than one cell is called a battery or a battery pack. Battery packs consist of cells connected in series or in parallel. In battery packs, serial connections determine the voltage, parallel connections determine the current and capacity that can be drawn. Battery management systems are used to ensure coordination between these serial and parallel connected systems. BMS (Battery Management System) are electronic systems that control and control rechargeable batteries. It acts as a protector in the battery systems, examining the current operating status of the batteries and ensuring that they remain within the optimum operating value range.

2.3.2.1 BMS Functions

2.3.2.1.1 BMS Data Acquisition

Total voltage of battery pack, voltage level of one cell, minimum and maximum voltage levels of one cell is traced in terms of voltage. Average temperature, temperature of each cell, cooling output temperature is traced in terms of temperature. Input output currents of cells, state of charge and durability of battery is also traced.

2.3.2.1.2 BMS Security

Overcharge, over discharge, high voltage during charging, low voltage during discharging, high temperature, low temperature cases are the subjects of security of BMS.

2.3.2.1.3 Measurement And Calculations

During charging and discharging operations, it should be calculated some values. Maximum charge and discharge currents, maximum and minimum voltage values of battery packs, dissipated energy and operating time from the first time battery is used, life cycle of battery should be calculated by BMS.

2.3.2.1.4 BMS Optimization

The BMS ensures that the voltage values of each cell forming the battery pack are balanced to maximize the capacity of the batteries and to prevent overcharging while charging. In case of overvoltage or undervoltage in any cell and voltage balance is disturbed, it intervenes in the system and enters the system. When necessary, it takes the energy from the most full cell and transfers it to the least charged cell and makes them balanced. In this way, the BMS establishes a continuous control over the system and intervenes against the damages that may occur in the event of a malfunction in the system or takes the system to the cut.

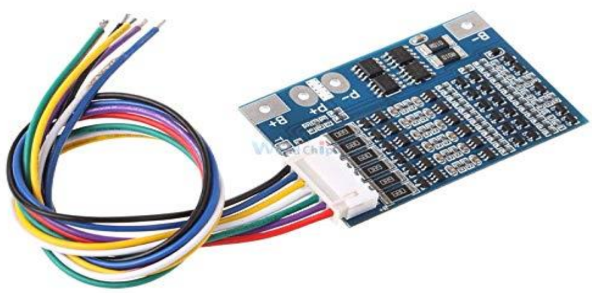

Figure 2.8 Li-Po BMS Circuit [14]

2.4 Brushed DC Motor Definition And Specifications

The magnetic field in the moving parts of DC motors can be generated by the effect of electric current. In this movable motor section, the current cannot be supplied via a fixed conductor wire (because this conductive wire is wound on the motor shaft by rotation). With a special device called brush and collector, current can be transferred to this moving part of the motor.

Brush and collector used motors are called brushed dc motor. Brushed dc motors are divided into “Permanent Magnet Motor” and “Electro Magnet Motor göre according to the source of the magnetic field used in their bodies. However, in all engine types, the components that make up the engines are almost identical. Now let's examine these pieces.

2.4.1 Rotor

Rotor; DC dynamo is the rotating part of DC motor and AC series motor. This element is composed of windings placed on the grooves and opened on the cylindrical body made of 0.3-0.7 mm thick steel sheets. The ends of the armature windings are connected to the part (collector) made of copper slices on which the brushes come into contact. The entire structure rotating with the spindle is shown as armature.

2.4.2 Stator

In DC or AC machines, the part where the windings made to form N-S poles is placed is called inductor. Inductors of small machines are made of natural magnets; The high-power machine inductors are fitted into the housing, ie inside the stator. It can be either a natural magnet or an electromagnet inside the stator.

2.4.3 Brushes And Its Components

DC and AC-powered collector machines, the parts of the collector that adheres to the electrical current is called brush (coal) is called. Brushes are produced with different properties (hard, medium hard, soft carbon, carbon-copper alloy etc.) according to the current and voltage value of the machine. Pressure springs are used to ensure that the brushes press the collector properly. Brushes are wearable and will eventually run out. This can be understood from the sound of the machine, excessive sparking in the collector. This spark generates ozone gas from time to time.

Figure 2.9 Rotor and Stator of a DC Motor[11]

In this study, it is used a DC motor with high torque. It is powerful enough to turn the shaft and break the resistance of combustion engine and start it. It is also easy to drive. It doesn't require any other complicated driver circuit as a BLDC motor needs. The only drawback of brushed DC motor for this study is warming problem. Because when it starts the combustion engine, it draws much current to break the resistance. When it is used as generator, high rpm value of scythe motor forces the DC motor to warm. Beside this drawback, it meets the expectations.

A DC motor as an example is shown in the figure below. The motor in the figure is tried to be mounted to the system in this study. It started the engine of motor scythe but after a couple of test, its mile was broken. After that, it is used more powerful DC motor is used in the scope of this study whose pictures is in the next chapter.

Figure 2.10 12V 3000 Rpm Bicycle Motor[12]

CHAPTER 3

GENERAL SETUP, SIMULATIONS AND EXPERIMENTAL RESULTS

3.1 General Overview Of The System

After the literature review and general definitions, this chapter contains detailed explanations of working of the system. As it is discussed before, it is expected from this system to start and generate energy. To achieve this, a Li-Po battery is used to take the first energy for starting. The overall system is figured as below

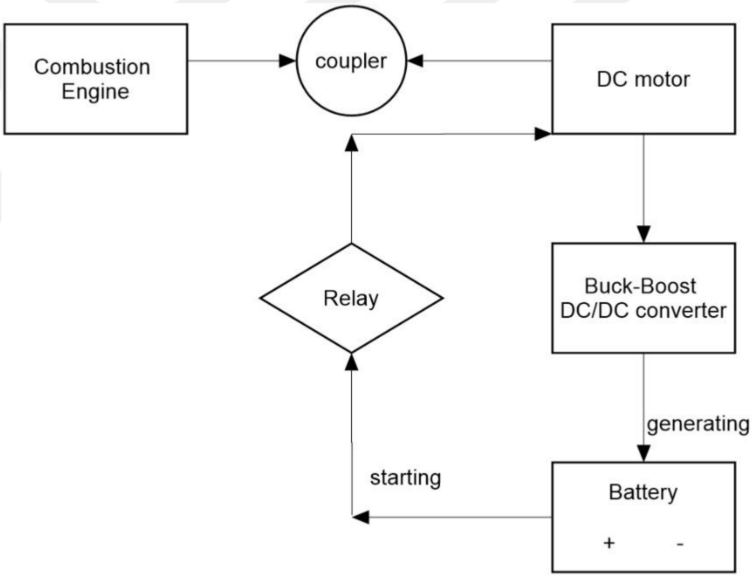

Figure 3.1 Overall System Flowchart

The system is united like that: DC motor is coupled with scythe motor with two pieces of metal shaft coupled by a coupler. These two critical components coupling is very sensitive because if their axes wasn't absolutely straight, the system wouldn't work properly. When the scythe motor's rpm value increased, there would be remarkable amount of power loss. Moreover, the coupling components would be broken. Additionally, to ensure this system's stability, it is supported by a sigma profile. It is an effective way to ensure the system’s rigidity for this study. The overall system with all its connections is looks as in the figure below:

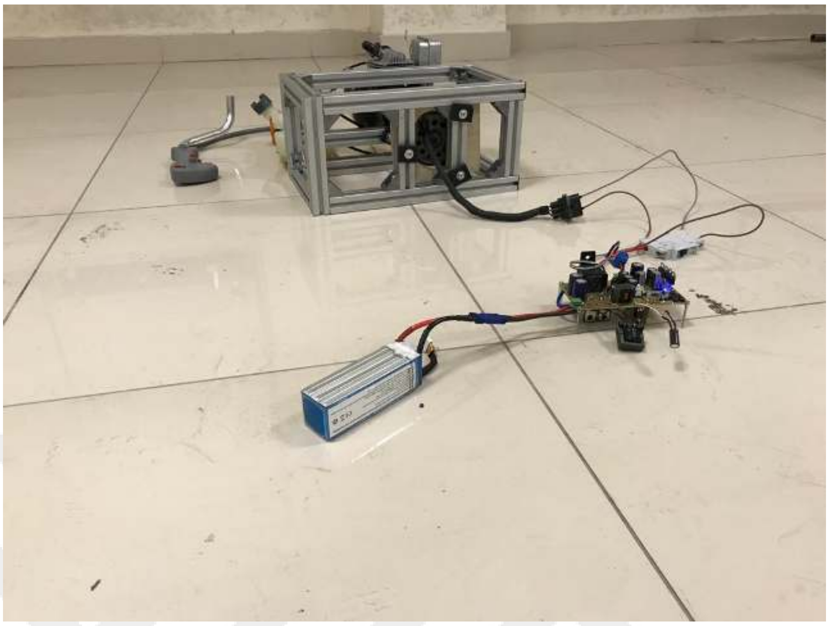

Figure 3.2 Overall System With Connections

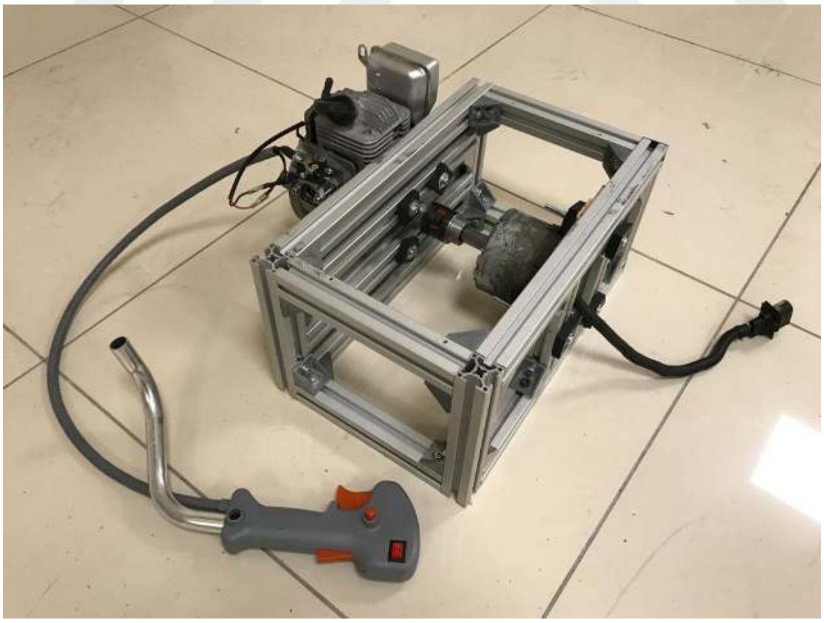

Figure 3.3 Mechanical Test Setup

The circuit board contains not only buck boost converter but also the power bus to start the DC motor and relay. With some additional corrections on circuit board and its PCB appearance, they look as in the figures below.

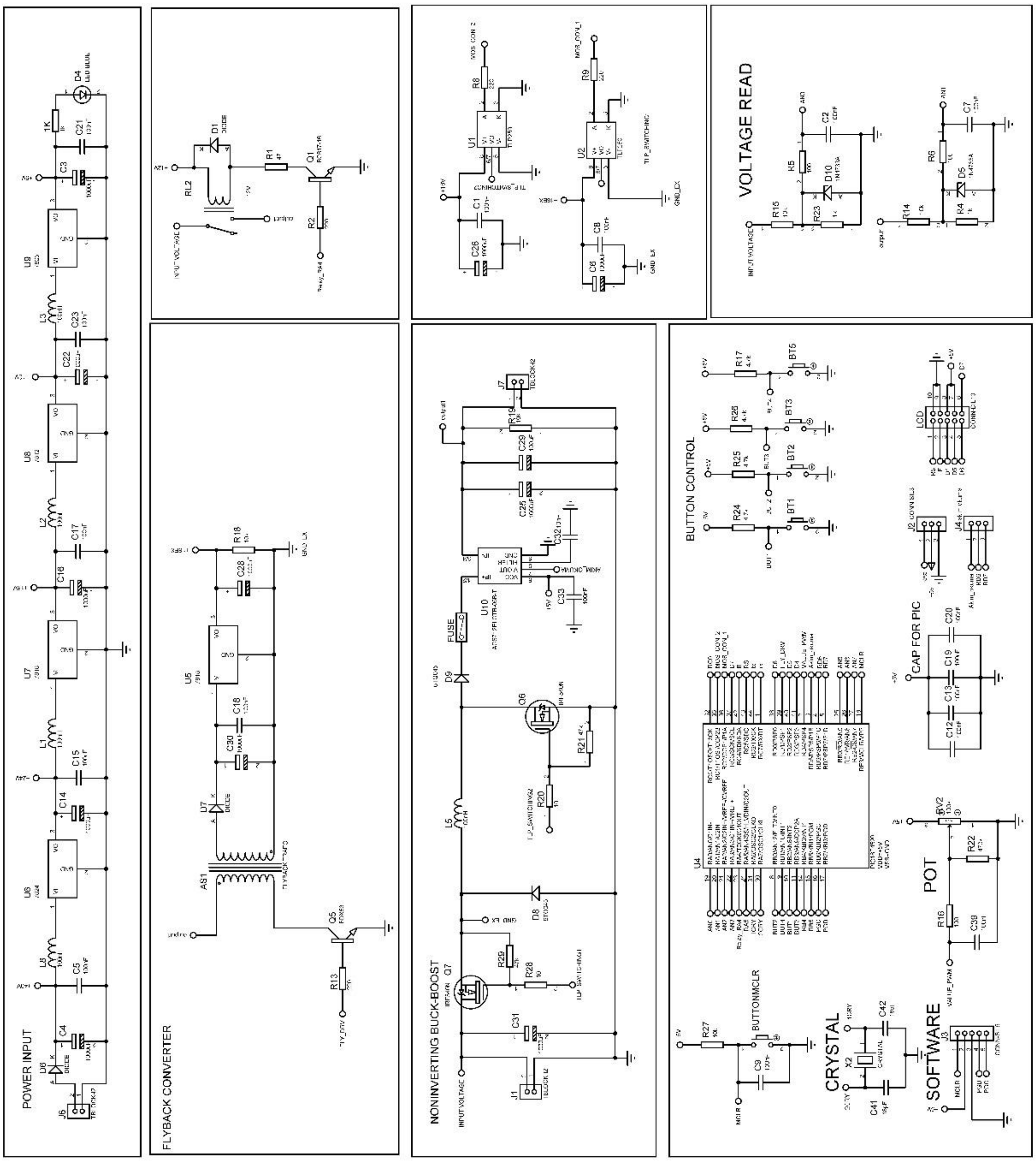

Figure 3.4 Overall System Schematics

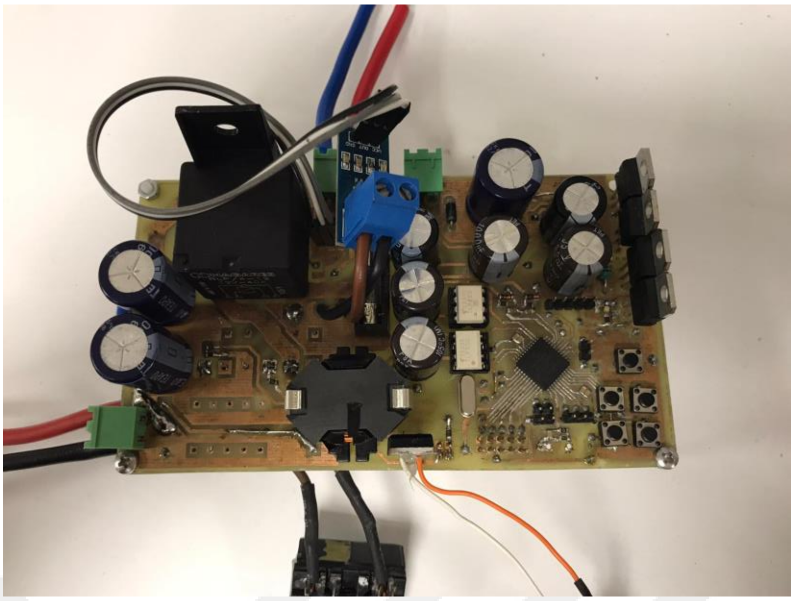

Figure 3.5 Prototype Circuit Board

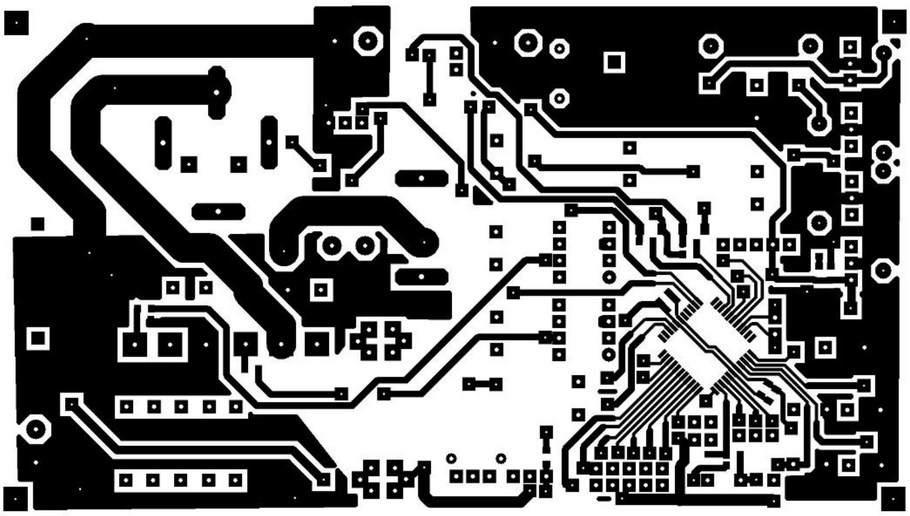

Figure 3.6 PCB Top Copper Appearance

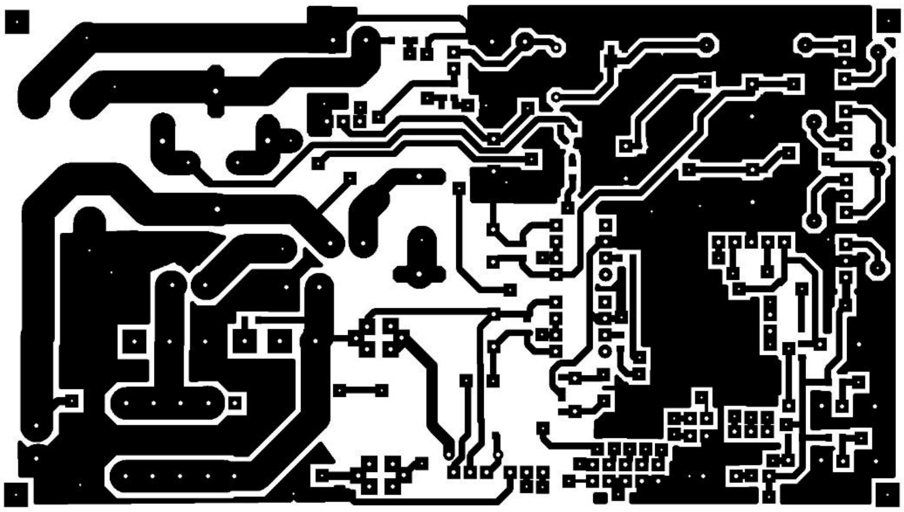

Figure 3.7 PCB Bottom Copper Appearance

3.2 Working Of The System

The buck boost converter is connected between DC motor and battery. There is a relay mounted on buck boost converter circuit. It works as a switch between starting and generating mode of the system. To control relay without damaging circuit components because of the high current flow especially on starting process, it is set button controlled which is connected to the microprocessor. There is a transistor which is also used as a switch connected to relay to drive it. When the button is pressed once, the transistor drives the relay. The driven relay opens and starts to flow currents required to start the combustion engine.

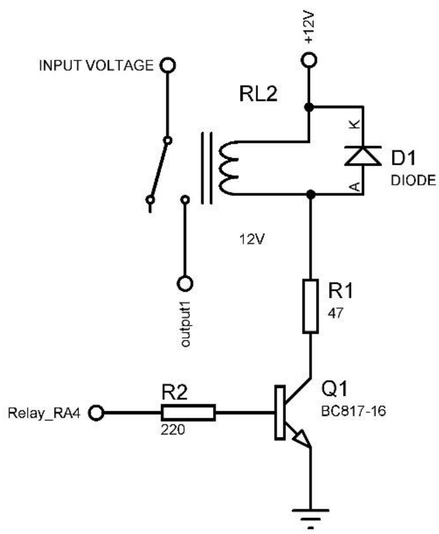

Figure 3.8 Switching Relay

The system working principle is simple enough. Firstly 22,2V (3,7V x 6) battery (with fully charged it is 4,2 x 6 = 25,2V) gives the energy to the system. When it is pressed the relay control button, the relay opens and DC motor is energized so the system starts to operate. After the combustion engine works itself with gasoline, the relay control button is pressed again not to draw current from Li-Po battery. There is another button to activate buck boost converter. When the buck boost button is pressed, the DC motor coupled to combustion engine starts to generate energy.

In starting position, when it is pressed the relay control button, the system worked but the power busses on the PCB circuit are crashed. Especially when combustion engine is started, the DC motor draws relatively huge amount of current to break the resistance of scythe motor. To overcome this problem, some part of the PCB is thickened by soldering. In addition, the input and output voltage values were transmitted with the help of PCB terminal blocks. However, in case of adverse situation, it is strengthen with thick cables.

In generating mode, buck boost converter works phase by phase. From driving MOSFETs to obtain energy generation, it is a cascaded system. The generated voltage is regulated gradually to 18V, 12V and 5V. 5V voltage runs the microcontroller and buttons. The transistor which drives the relay requires 12V to operate. 18V is needed to drive boost MOSFET.

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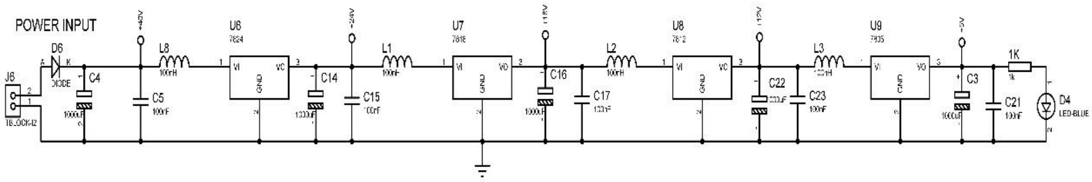

Figure 3.9 Voltage Regulation Schematics

These MOSFETs are driven by a proper PWM values depending on generating voltage values. Hence the Li-Po battery is 24V, the output of the buck boost converter is also 24V. Fixing it to 24V is the aim of the buck boost converter but depending on the changing generated voltage values, PWM values also changes. It is controlled by microcontroller.

The boost MOSFET and buck MOSFET takes its 18V voltage values separately. One of the 18V source is obtained from generated voltage from DC motor. The other 18V source is obtained from battery. There is a flyback circuit to switch the DC voltage obtained from battery. That circuit is figured as below.

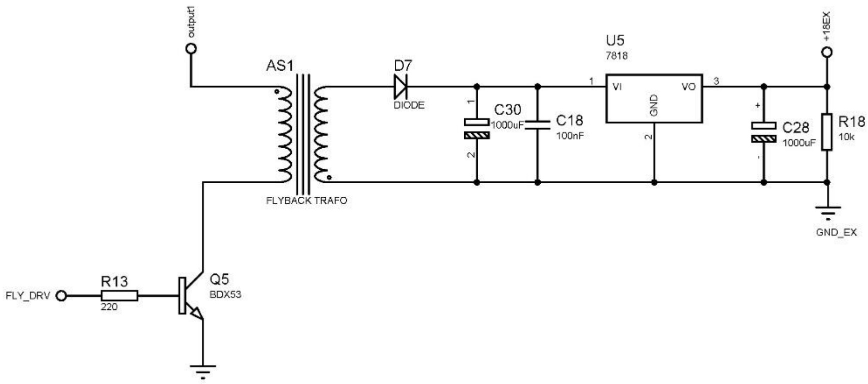

Figure 3.10 Small Flyback Circuit

This flyback circuit is deactivated before starting process. Because it is in parallel with DC motor and battery. In starting process, when the relay opens and current flows onto it, the flowing current tries to complete circuit on this flyback circuit because of its low impedance value. So if we didn't deactivate the flyback circuit in starting process, it would burn.

There is another situation that flyback circuit can burn. The PWM value of buck MOSFET is adjusted with the help of flyback circuit energized from battery. If PWM values wasn't adjusted gradually with the help of the software of the microprocessor, the switching transistor would burn because of instant PWM changes and instant voltage change.

Back to the driving MOSFETs, it is driven by TLP250 ICs. That ICs takes its Vo voltage separately as explained above. Those ICs schematic is shown in figure below

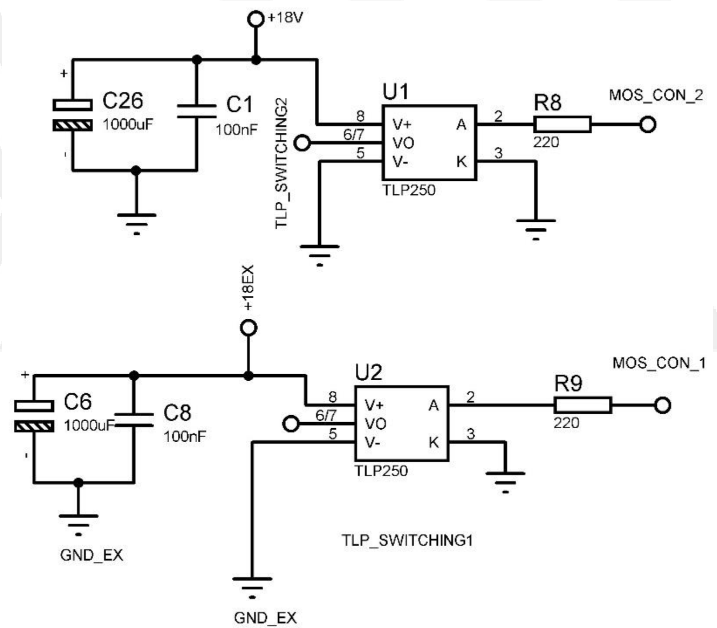

Figure 3.11 TLP250 Mosfet Driver

The main part of this circuit is buck boost converter. In the scope of this study, it is used a non-inverting buck boost converter topology. It can be used as only buck converter, only boost converter or buck boost converter. It is figured as below

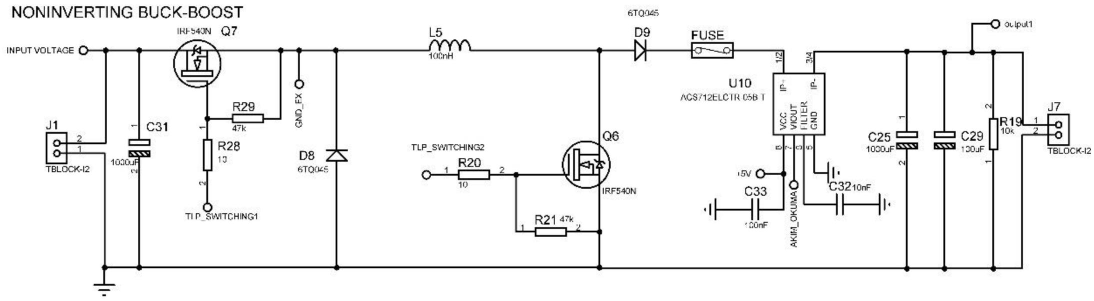

Figure 3.12 Non-inverting Buck Boost Converter Schematics

This converter works properly with the proper switching and software. The only problem solved with software is to switch this converter around 24V voltage value. Because when input and output voltage has close values, the microcontroller doesn't switch the MOSFETs properly. That problem is solved with proper software. In the interval between 22V and 26V, additional switching loops added to software

3.3 Simulation Results

This converter is designed to have input voltage between 15V and 40V and gives output voltage 24V to charge the Li-Po battery. It is driven in 25 kHz frequency from microcontroller. This converter's setup is prepared in LTSpice program and its results are below.

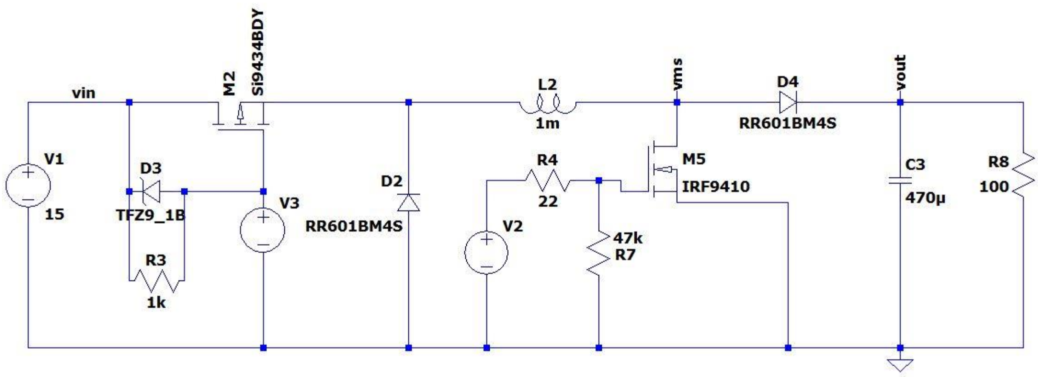

Figure 3.13 LTSpice Test Setup

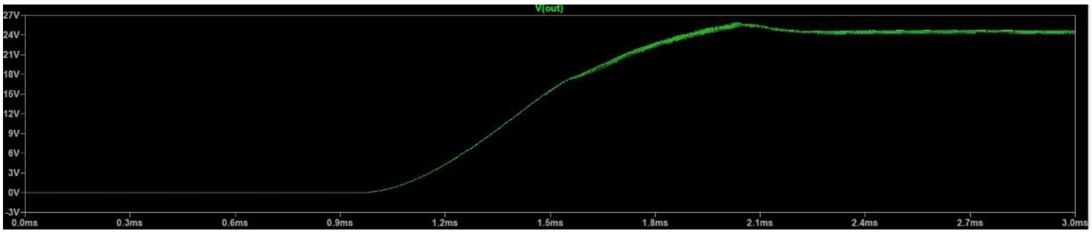

Figure 3.14 Output Voltage When Input is 15V

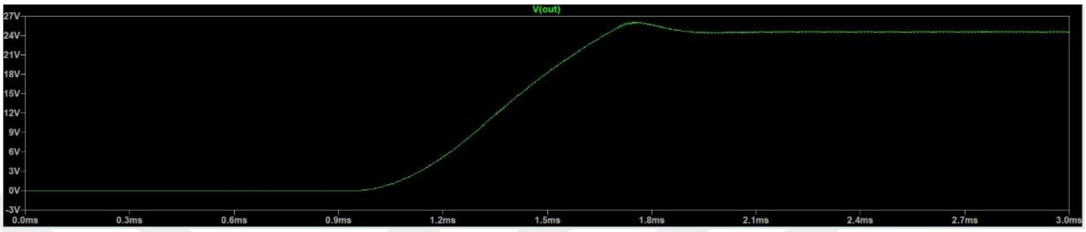

Figure 3.15 Output Voltage When Input is 30V

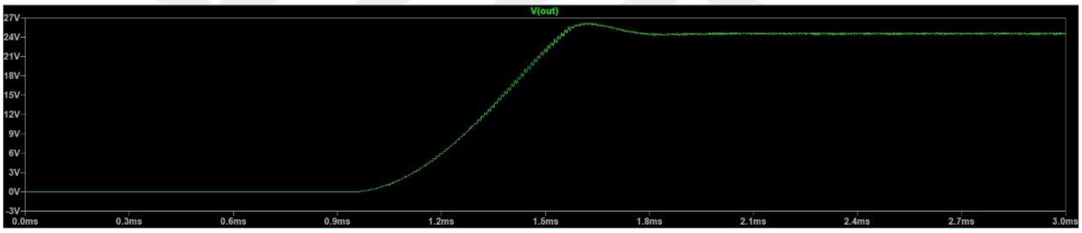

Figure 3.16 Output Voltage When Input is 40V

3.4 Experimental Results

When this system operates in generating mode, its switching results and behavior of components are examined. These are real time operating measurements.

First of all, the flyback circuit gives its PWM values as shown in the figure below. This is taken from flyback transistor's base. It switches the voltage comes from battery to switch buck MOSFET. This base is directly connected to microcontroller as it is discussed in previous section.

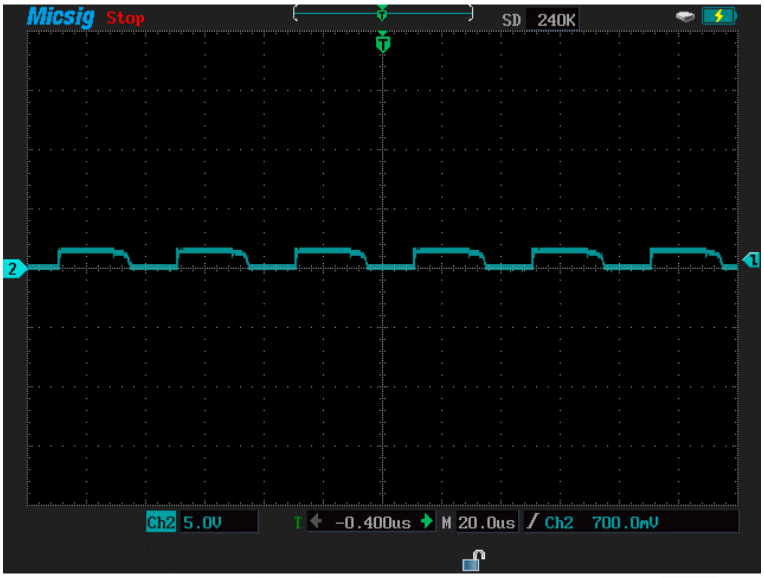

Figure 3.17 Base Signal of Flyback

The voltage values and PWM values are ready in generating mode. Now it can be examine in two part of MOSFETs.

When it is in buck mode, in this case when the input voltage generated from combustion engine is higher than 24V, the experimental results are shown in below. The buck MOSFET is switched and its PWM shape can be distinguished as seen in figure 3.18. It is driven 18V but with some losses it looks 14,8V but it is still close to the voltage value outputted from TLP250 ICs. In this mode, boost MOSFET gate voltage is zero to make it in off state as it is seen in the figure 3.17. The output voltage is 24V as expected as seen in the figure 3.19.

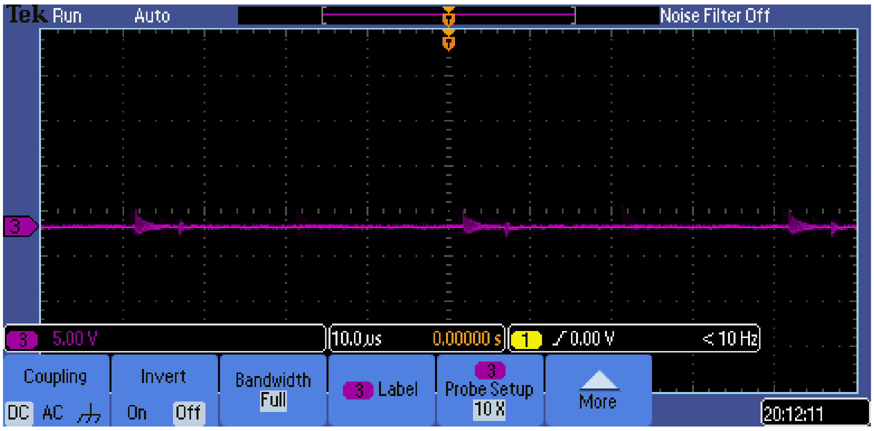

Figure 3.18 Gate Signal of Boost Mosfet in Buck Operation

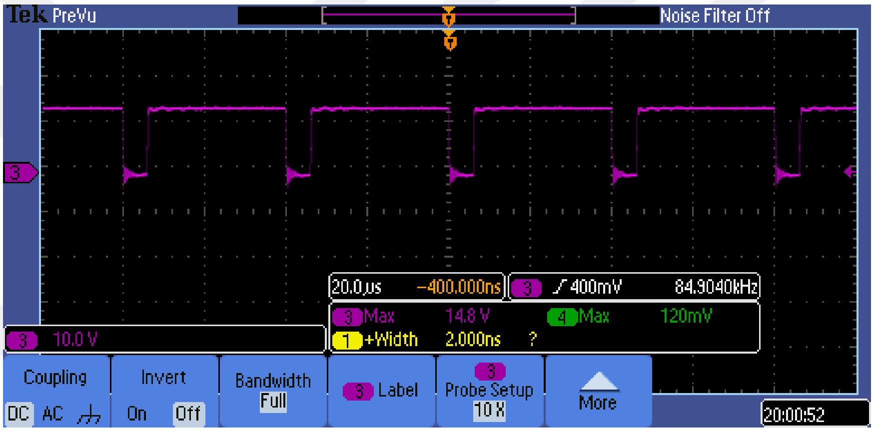

Figure 3.19 Gate Signal of Buck Mosfet in Buck Operation

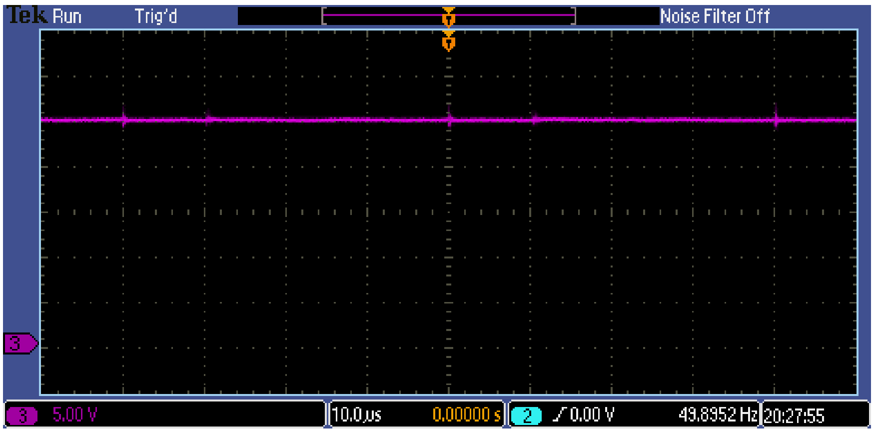

Figure 3.20 Output Voltage in Buck Operation

When it is in boost mode, in this case when the input voltage generated from combustion engine is lower than 24V, the experimental results are shown in below. The boost MOSFET is switched and its PWM shape with its voltage value is shown in the figure 3.21. The buck MOSFET is always on state to flow the current through on it. So the gate voltage of buck MOSFET is kept stable on around 15V seen in the figure 3.20. The output voltage is 24V as seen in the figure 3.22.

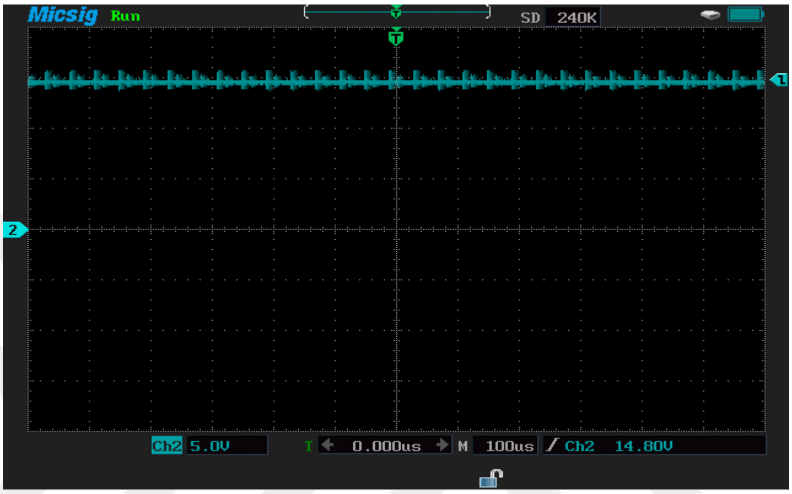

Figure 3.21 Gate Signal of Buck Mosfet in Boost Operation

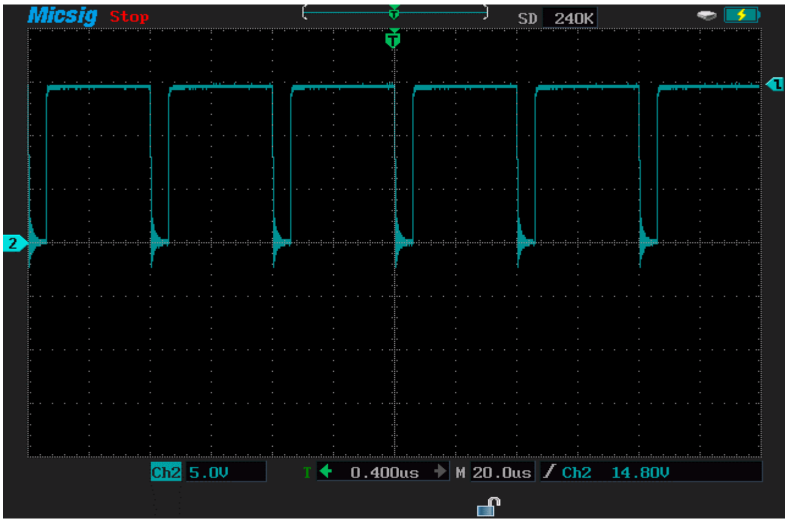

Figure 3.22 Gate Signal of Boost Mosfet in Boost Operation

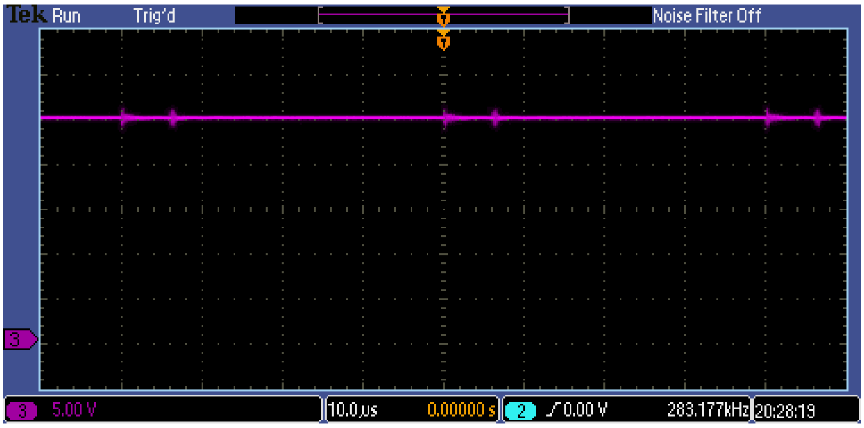

Figure 3.23 Output Voltage in Boost Operation

CHAPTER 4

CONCLUSION

UAVs are used for many purposes. From most complicated and expensive ones to cheaper ones, all of their common feature is takeoff and landing. It is studied in the scope of a master of science lecture on a kamikaze drone to have longer endurance and to lift as many payloads as possible. It is still needed to be developed but it is reached its goal. It doesn't matter whether it has more function or not. This study on this thesis is make that study one step forward. Manually started scythe motor is now started with a DC motor. On the other hand, it also generates energy.

When in testing stage of the system, there were some problems to overcome.

As this system requires high current on some stages, some of the busses which carry high current are crashed. Especially when the system is in starting mode, the DC motor draws high amount of current instantly to turn the shaft. So those busses are strengthen by soldering. Additionally, the input and output voltage transmission which is provided with terminal blocks in the first design is provided with cables in the last working circuit which can carry high amount of current to handle this system's requirements.

Another problem is that the transistor used in flyback circuit is burnt many times. Instant voltage changes and high amount of current make it burnt. Instead of sudden PWM changes, it is adjusted gradually. It also burnt when the flyback is active when the system is in starting state.

To obtain generated voltage value, scythe motor and DC motor has to work stably. It is faced many mechanical problems before testing the buck boost converter. Some of the DC motors didn't start the scythe motor because they weren't powerful enough. The shaft which turns with DC motor and scythe motor is broken because of the pressure on it. The connection points on the shaft is harmed before it is made durable enough. There was vibration on the system and it made the screws loosen. All of those problems are overcome in the last mechanic system.

In terms of electronics engineering, it is a challenging study to combine both mechanical process with electronic process. However, that basic but state-of-the-art principle which is achieved on this experimental setup can be used in every area where hybrid system is needed. This study is also inspirational for the developers to enhance the functionality of systems like that.

As a summary, what is seen on this study is starting a combustion engine with a DC motor as a starter and using mechanical energy as efficient as possible by using electronic circuits. So the starting problem of mini UAVs can be solved with this system. They are manually started before takeoff. However, especially when they are in the air their starting problem can be solved so they can keep working and they don't need to land or they don't have an emergency problem because of stopping their engines.

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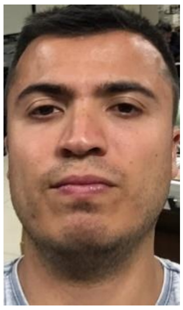
CURRICULUM VITAE



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