MIDDLE EAST TECHNICAL UNIVERSITY
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

EE 463- Hardware Project – 2023 Fall

Simulation Report

Wind Turbine Battery Charger

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Table of Contents

INTRODUCTION

In this project, we are making a Wind Turine Battery Charger. We will implement a design for the given varying voltage input (15-25 V_{ll}) and output of 10 A current with the 20 percent of ripple. The design specificiations are given in the Github repository of the hardware project.

We investigated the possible topologies that we might implement. We decided based on our calculations and other parameters like feasibility, easy to implement and cost. Throughout this report, we will investigate the toplogy selection in this report and analysis of the simulations. Based on the analysis, we will select our components. We will try to focus on some Bonus Parts as well.

TOPOLOGY SELECTION

3 Phase Thyristor Rectifier

For the 3 Phase Thyristor Rectifier, we researched for this project. The advantages for this topology are;

- High power usage availabilty
- There is no need to have a DC/DC converter, since its output is controllable.

However, for this topology the disadvantages are more dominant;

- It cannot be used with high frequency, which will result in a high volume.
- Its turn-on circuitry is not easy to implement.
- Low switching speed, which will increase losses.

Centre-Tap Rectifier + Buck Converter

For the 3 Phase Thyristor Rectifier, we researched for this project. The advantages for this topolpgy are;

- Good voltage regulation
- Less ripple
- High efficiency

However, for this topology the disadvantages are more dominant.

- Cost
- Complexity
- High switching losses

3 Phase Full Bridge Diode Rectifier + Buck Converter

For this project we decided to choose this topology since it provides a simple solution and cheaper compared to other topologies.

Here are advantages of the selection of this topology;

- Compact Design
- Cost Effectiveness
- Open to more applications
- Reliability

However, we should consider the disadvantages and the major disadvantage we should consider is the efficiency. Buck converter is not efficient due to the components of the circuit. By selection of cicuit components, we will try to be as efficient as possible.

SIMULATION

1) Simulation of Full Bridge Three Phase Diode Rectifier with Ideal Diodes

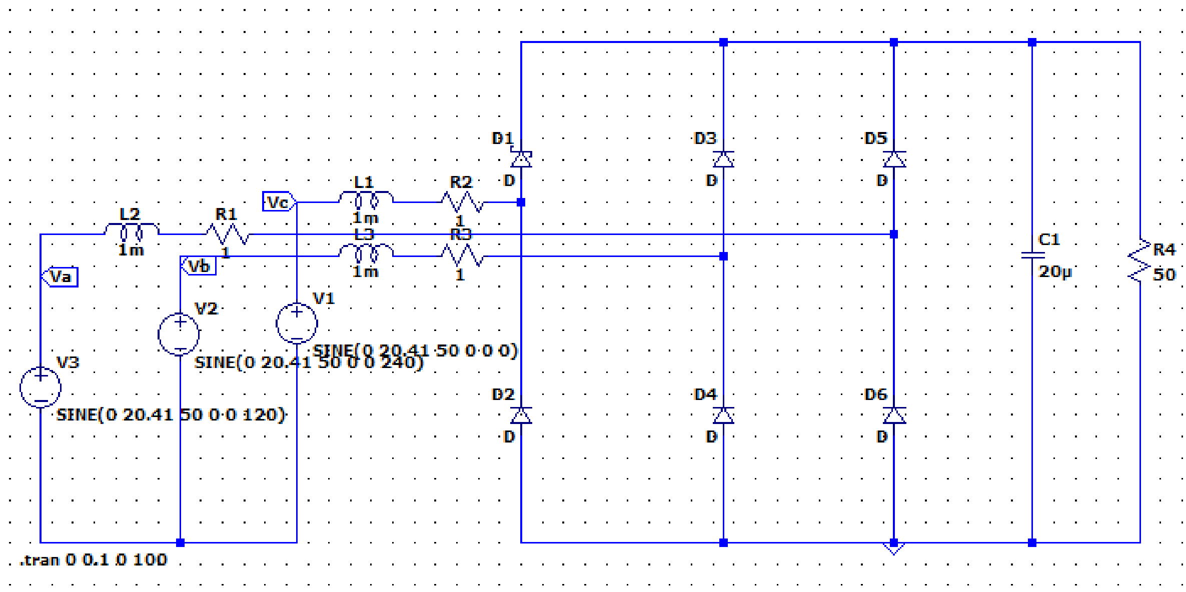

Figure 1. Full Bridge Three Phase Diode Rectifier Topology

First, we use LTSpice program for simulations. For detecting maximum voltage values and current values, ideal diodes are used.

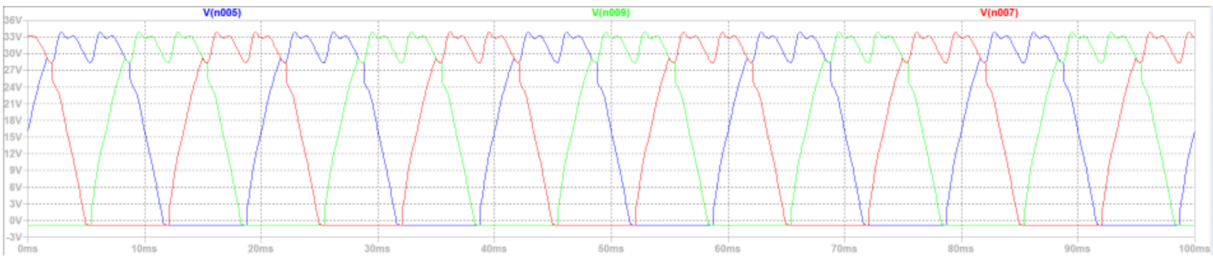

Figure 2. Diode Voltage Waveforms

For this detection, maximum value of input value is used, 25 V_{ll}. From the formula $V_{ll} = \frac{\sqrt{2}*V_s}{\sqrt{3}}$, amplitude of minimum input voltage for one phase is 20.41 V. Line inductances are selected as 1 mH and output capacitor is selected as 20 µC. As seen in Figure 2, maximum diode voltage is around 34 V. It is the first critical specification of diodes.

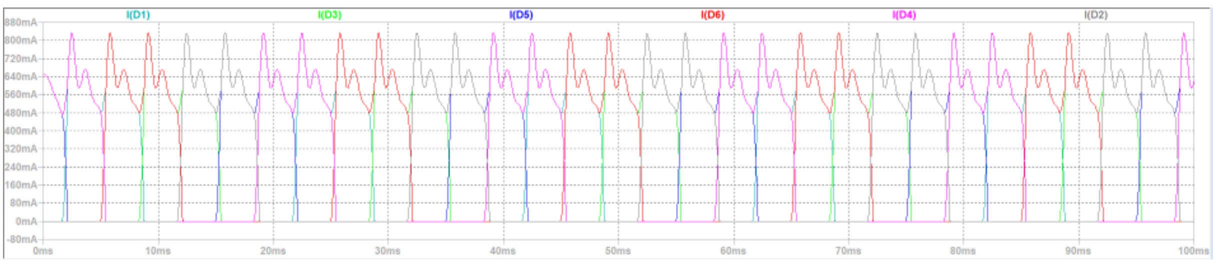

Figure 3. Diode Current Waveforms

As seen in the Figure 3, maximum current value on the diodes is around 1 A. It will be the second critical specification of diode for selection. Of course, these values are measured for minimum input voltage value.

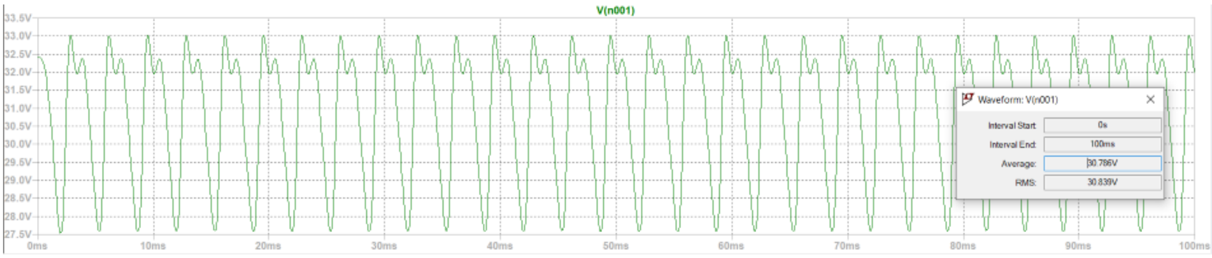

Figure 4. Output Voltage Waveform

As seen in Figure 4, average voltage of output voltage, it is 30.78 V. These simulations give us an idea for minimum input voltage case.

Second, the same tests are implemented for maximum input voltage. From the formula $V_{ll} = \frac{\sqrt{2}*V_S}{\sqrt{3}}$, maximum input voltage amplitude is 12.25 V.

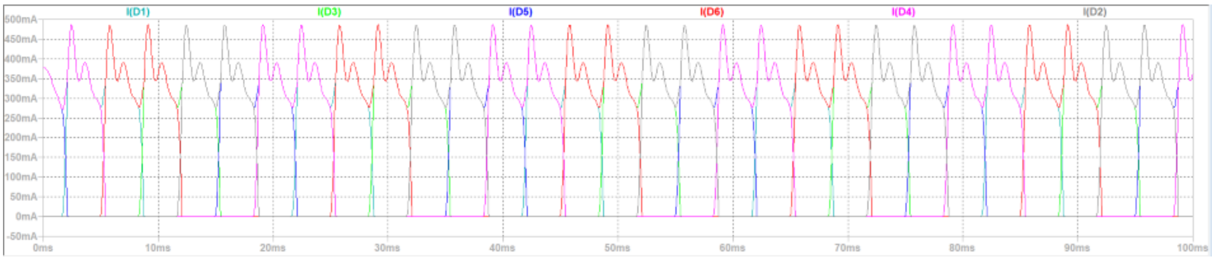

Figure 5. Diode Current Waveforms (Maximum Input Voltage)

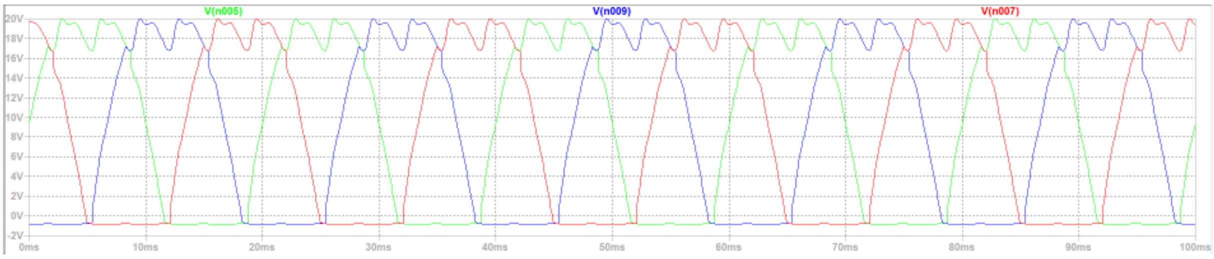

Figure 6. Diode Voltage Waveforms (Maximum Input Voltage)

Figure 7. Output Voltage Waveforms (Maximum Input Voltage)

From the waveforms, some critical specifications are detected. Maximum diode current is around 0.5 A, voltage is 20 V and average output voltage is around 19.2 V. Peak value of voltage waveform is around 20 V. They are very critical for component selection. With safety margin, rating values of components will be determined, and component will be selected according to these determinations.

2) Simulations of Buck Converter

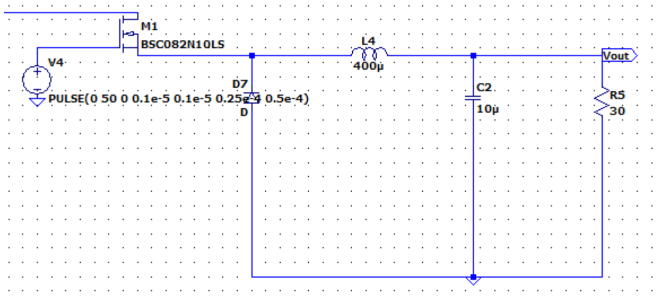

Figure 8. Topology of Buck Converter

First, we detect the frequency of switching. We used 20 kHz switching frequency and gate voltage amplitude 50V for PWM. In Figure 9, voltage waveform of gate signal can be seen.

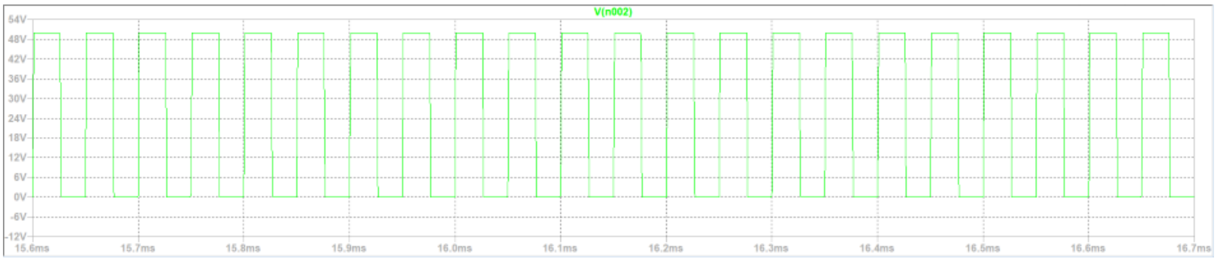

Figure 9. Voltage Waveform of Gate Signal

Then, BSC082N10LS Mosfet and ideal diode is used for buck converter design. MOSFET selection is just a reference because ideal MOSFET in LTSpice has different characteristic, and it is not suitable for topology. Lastly 400 µH inductor and 10 µF capacitor is used. These variables can be change according to MOSFET and diode selections. We must adjust a ripple at output 20%. In Figure 10, output voltage waveform can be seen.

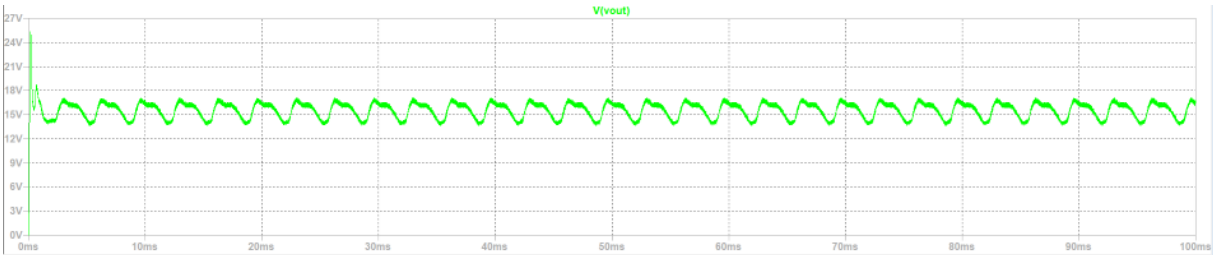

Figure 10. Output Voltage Waveform of Buck Converter

Here, we get our input voltage from output of rectifier. This design, at the output, we have 24% ripple. It will be adjusted to 20 with selection of components.

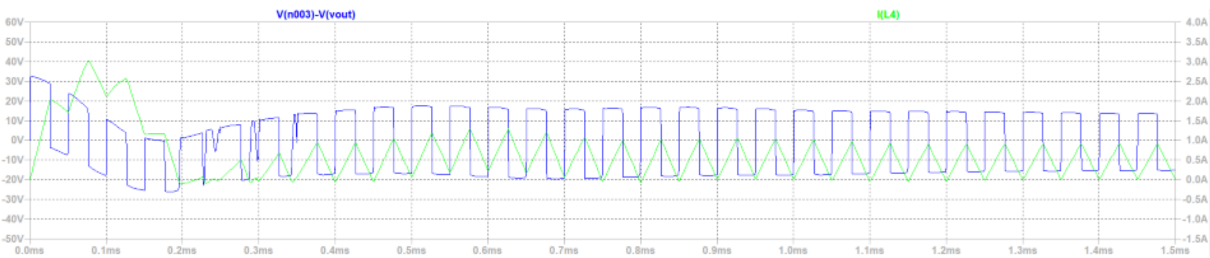

Figure 11. Voltage and Current Waveform of Inductor

As seen in the Figure 11, inductor's current and voltage waveform can be seen. Inductor voltage varies between -15 V and 15 V, current varies between 0.1 and 1 A. They are critical for selection of inductor. Moreover, before the steady state, voltage can go up to 40 V and current can go up to 2.6 A. These values should be considered for inductor selection with safety margin.

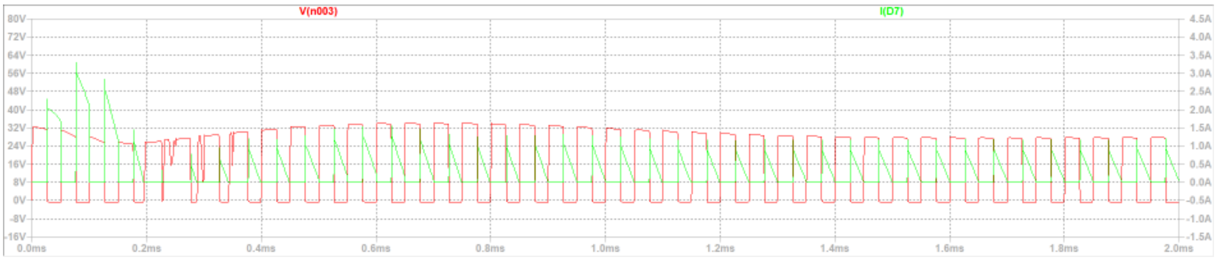

Figure 12. Voltage and Current Waveform of Diode

As seen in the Figure 12, diode's current and voltage waveform can be seen. Diode voltage varies between -0.8 and 32 V, and current varies between 0 and 1 A. However, before the steady state, current can go up to 3.3 A. It is critical specification for selection of diode.

In summary, MOSFET and diode selection will be critical for system. Duty cycle can be adjusted with PWM. With modulation of PWM, output voltage can be adjusted. As our input voltage can vary, adjusting duty cycle will be critical for charger.

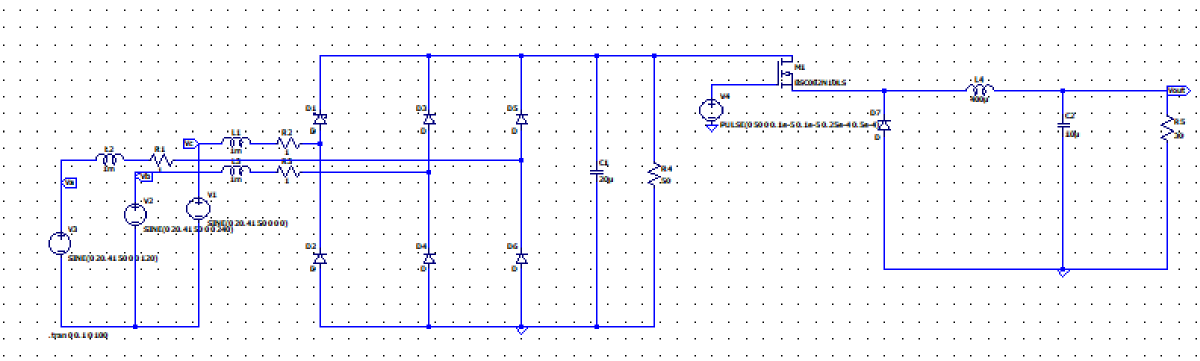

Figure 13. Overall Circuit Schematic for Battery Charger

COMPONENT SELECTION

Buck Converter MOSFET Selection

From the critical compenent selection parameters, as seen in the github repository, we calculated the rating current value. Is>Iomax * Dmax = 10*0.68 = 6.8 A. We will charge our battery with 10 A in control current situation. So, it will be maximum current value for our charger. From the simulations output, we saw the maximum voltage which drops on the MOSFET. It is 33 V. From these informations, we should choose our MOSFET with safety margins. We put the diode with rating voltage is around 40 V and current rating is around 8 A. Our selection is SQ2318AES. Its Vds value is 40 V and Rds(on) is around 32 mΩ. Of course, it is a n-channel MOSFET. Moreover, stock situation and price is critical parameters for us.

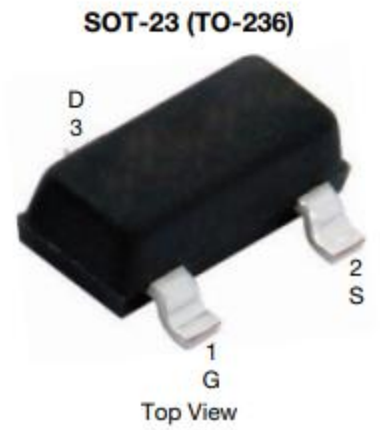

Figure 14. SQ2318AES MOSFET

Also, we propose a possiblity of selection these MOSFET's in case of emergency. We will use a component in the list that fits well to our design **IRF540 N** Kanal Power Mosfet TO-220. It has a current rating of 30A which is little high if we think that our steady state current is 10A. However, if we think the thermal issues and transient, our MOSFET will be only sufficient to carry such current at high temperatures. We can also use a different MOSFET by looking at other parameters such as heating affect and heat sink. **SQJ942EP** this MOSFET has a 15A continous drain current, which seems okey and has a good resilient to temperature.

IRF540 N SQJ942EP

Figure 15. IRF540 N and SQJ942EP MOSFETs

Buck Converter Diode Selection

From the critical component selection parameters, as seen in the github repository, we calculated the rating current value. If>Iomax * (1-Dmin) = 10*0.61 = 6.1 A. We will charge our battery with 10 A in control current situation. So, it will be maximum current value for our charger. From the simulations output, we saw the maximum voltage which drops on the diode. It is 33 V. From these informations, we should choose our diode with safety margins. We put the diode with DC reverse voltage is around 40 V and current rating is around 8 A. Our selection is SD2114S040S8R0. Its Vrr-max value is 40 V and Vf is around 0.5 V. It is a schottky diode.

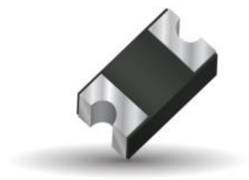

Figure 16. SD2114S040S8R0 Diode

Diode

We thinked that we can use a **Schottky Diode** since we are working on low voltage and we can increase efficiency bu using this diode. We can reduce the effect of V_f by using a Schottky Diode. This is the one that is on the components list in the Github repository. We will build our full bridge rectifier by these diodes.

Figure 17. 1N5822-HT Diode

Another component possibility is a full-bridge rectifier. If we select a full-bridge rectifier, our efficiency will be low but we can use this if we can not achieve good results with schottky diodes.

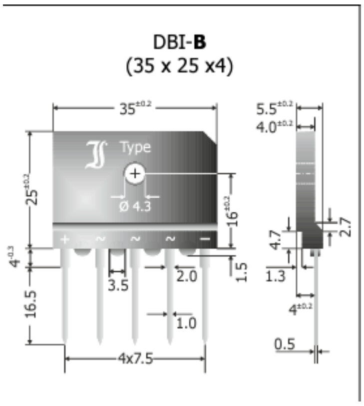

Figure 18. DBI20-08B Diotec Semiconductor

Passive Elements

For inductors, we will use different sizes and capacitys for the circuits necessiy. So, we will use a variety to achieve a solution considering different parameters like filtering and heating. We will try to select a inductor by looking its design of circuitry and its capability to high current values.

For capacitors, we will use different sizes according to our design. We will try to select our capacitors based on peak voltage values in order to work in a safe limit. Another limit for the capacitor selection is the ripple value. We should consider the ripple while selecting a capacitor.

PWM Generator

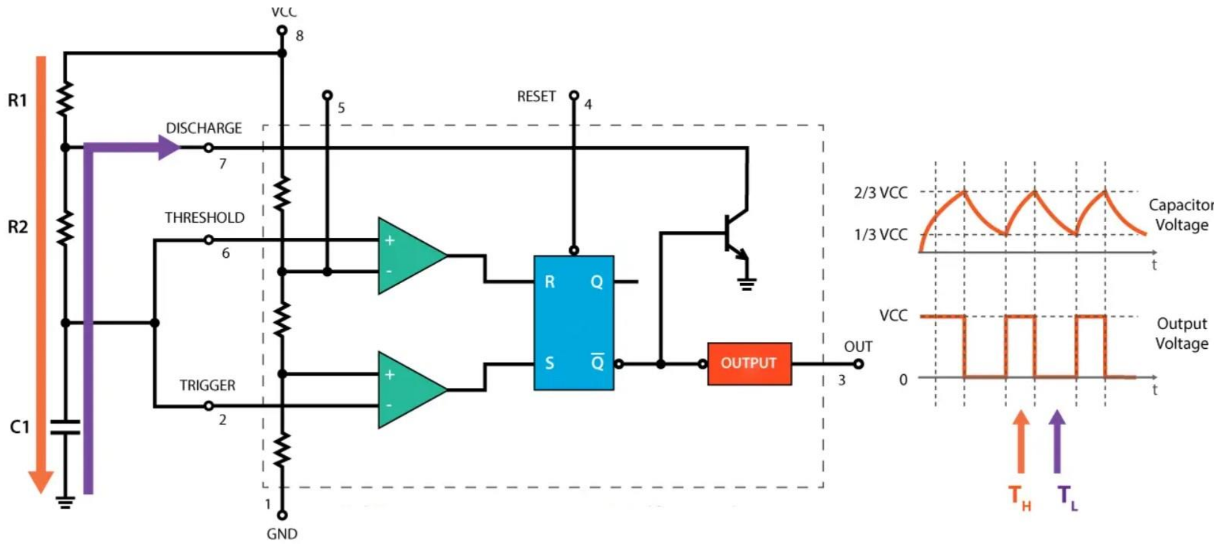

Figure 19. PWM Generator Circuit

$$TH = 0.693 * C1 * (R1 + R2)$$
$$TL = 0.693 * C1 * (R2)$$
$$T = TH + TL$$
$$f = 1.44 /(R1 + 2R2) * C1$$
$$D = (R1 + R2)/(R1 + 2R2)$$

A digital signal is used in the pulse width modulation (PWM) technique to precisely control analog devices. A signal with pulse width modulation is made up of electronic pulses that replicate an analog voltage change. An astable oscillator using a 555 timer is demonstrated in the circuit above.

When capacitor C1 charges through resistors R1 and R2, the output is HIGH. On the other hand, if capacitor C1 only discharges through resistor R2, the IC's output is LOW. The square wave output signal's duty cycles and ON/OFF times can be altered by varying the values of any one of these three components. Adding two diodes to the circuit and substituting a potentiometer for the R2 resistor is a quick and simple way to achieve this. Under this setup, resistor R1, the potentiometer's left side, capacitor C1, and the potentiometer's right side will determine the On time and the Off time, respectively. Because the total resistance won't change during charging or discharging, the frequency and cycle period in this configuration will always be the same.

We will use LM555 for our timer which can be found in the component list because its supply voltage limits are between 4.5V-16V. It is adequate because we just use this component as the pulse for switching.

BONUS PARTS

PCB BONUS

We will try to build our circuitry on PCB by using a building software. The main idea of the PCB is becoming more compact and neat. While building PCB, we should take consideration of the paths where too much current flows and seperate thoso as much as possible. Also, thermal considerations will be discussed according to our design and heat sink selection.

COMPACTNESS BONUS

Since we will try to build a PCB, we will try to put our design in a compact and small way. We will try to build our design with a small inductor and capacitor. Our switching frequency becomes important in this manner and we will try to optimize by selecting a high switching frequency to avoid losses. While selecting a high frequency, we should take our PCB design into consideration so that EMI effects do not affect too much.

Protection

After we will focus on the first two bonuses, we will try to build a protection for over-voltage and over-current problem which can cause damage to the battery.

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