Middle East Technical University

Department of Electrical & Electronics Engineering

EE 463

STATIC POWER CONVERSION-I

HARDWARE PROJECT

DC MOTOR DRIVER BY USING THREE PHASE AC VOLTAGE

TEAM: KARAŞİMŞEKLER

Students: Deniz Boran KARACA 2093987

Nurettin ÇAVUŞ 2094878

CONTENTS

INTRODUCTION ……………………………………………………………………[3]

TOPOLOGY SELECTION …………………………………………………………….[3]

SIMULATION RESULTS …………………………………………………………….[4]

Three Phase Full Wave Diode Rectifier Simulations…………[4]

Buck Converter Simulations …………………………………………[5]

Overall System Simulations with RL Load ………………………[7]

Overall System Simulations with DC Motor ……………………[9]

COMPONENT SELECTION ……………………………………………………[12]

Three Phase Diode Rectifier…………………………………………[12]

Duty Cycle Generator ……………………………………………[13]

Optocoupler ……………………………………………………[14]

IGBT ……………………………………………………………[14]

Diode ……………………………………………………………[15]

Heat Sinks ……………………………………………………[16]

DC Link Capacitor ……………………………………………[16]

TEST RESULTS ……………………………………………………………[17]

R Load …………………………………………………………[17]

RL Load …………………………………………………………[19]

Motor Load ……………………………………………………[23]

THERMAL CHARACTERISTICS ………………………………………[25]

CONCLUSION ……………………………………………………………[26]

REFERENCES ……………………………………………………………[27]

1. INTRODUCTION:

In that project, a DC motor driver which can adjust the speed is designed. There are some design criterions. Motor's speed cannot be adjusted by the variac directly. In other words, variac is fixed to some value and output power is changed with the help of designed circuit to get a speed control mechanism. Moreover, nearly 180 V output voltage has to be obtained. Apart from these necessities, there are some bonuses such as obtaining 1.6 kW output power during five minutes to boil the water, providing four quadrant operation or, implementing the circuit on a PCB or pertinaks and enclosing it with a box.

Firstly, topologies which may be used are investigated and the best topology is chosen for this purpose by considering the all design restrictions and bonuses. Secondly, simulations with the chosen topology and a representative motor schematic are made. Thirdly, according to simulation results, proper components are selected. Fourthly, components are implemented to the chosen topology and some real life tests are done in the laboratory. Finally, motor is driven with the designed circuit.

The report starts with the topology selection part including an explanation of the pros and cons of some useful topologies and the chosen one. It is continued with the simulation results of the chosen topology and selected components for the proper operation. Then, R and RL load test results of the designed circuit are shown. Lastly, the demonstration results of the DC motor are stated. In short, this report includes all of the necessary points of the hardware project steps.

2. TOPOLOGY SELECTION:

Before deciding topology, advantages and disadvantages of the some topologies are investigated to find optimal solution. Firstly, 3 phase and single phase rectification are compared and it is obvious that 3 phase rectification is more advantageous due to:

- Lower voltage ripple which provides a more DC output
- Higher output voltage and power
- Lower AC component of the output current

Then, a comparison between controlled and uncontrolled rectifiers is made. Controlled rectifiers solve the two main problems of a DC motor driving directly. It provides AC to DC conversion, and firing angles determine the ON and OFF times of the thyristors which provide controllable output power to drive the motor with different speeds. On the other hand, uncontrolled rectifiers or diode rectifiers just convert AC to DC, they need a supportive topology called buck rectifier to control the speed of the motor. Therefore, controlled rectifiers are cheaper. However, implementation of a three phase controlled rectifier is harder since thyristors have to be fired synchronously and change with a mechanism to obtain an adjustable output power.

By considering all of these pros and cons of topologies, a three phase uncontrolled rectifier with a buck converter is chosen to drive the DC motor. Note that this topology is remodeled a bit to obtain a better outcome. Firstly, since a buck converter is simply a DC-DC converter, a DC link capacitor is connected at the output of the three phase diode rectifier in order to get a more DC output. Secondly, there is no need to use an extra inductor since the own inductor of the DC motor is pretty high. In other words, the usage of an inductor in a buck converter is quite meaningless if the load is highly inductive. Lastly, since desirable output power and average output voltage can be provided without a capacitor, no capacitor is used in buck converter to decrease the cost and increase the simplicity of the design. The main disadvantage of the absence of a buck converter capacitor is that higher input voltages have to be supplied in order to obtain the same output power and voltage due to increase in voltage ripple. The output voltage ripple of a step down converter is shown in Equation 1. Voltage ripple may increase the stresses on the components, and so it may cause the usage of bigger components.

$$\Delta V_O = \frac{T_S}{8C}\frac{V_O}{L}(1-D)T_S \quad \textbf{(1)}$$

Overall design is shown in Figure 1.

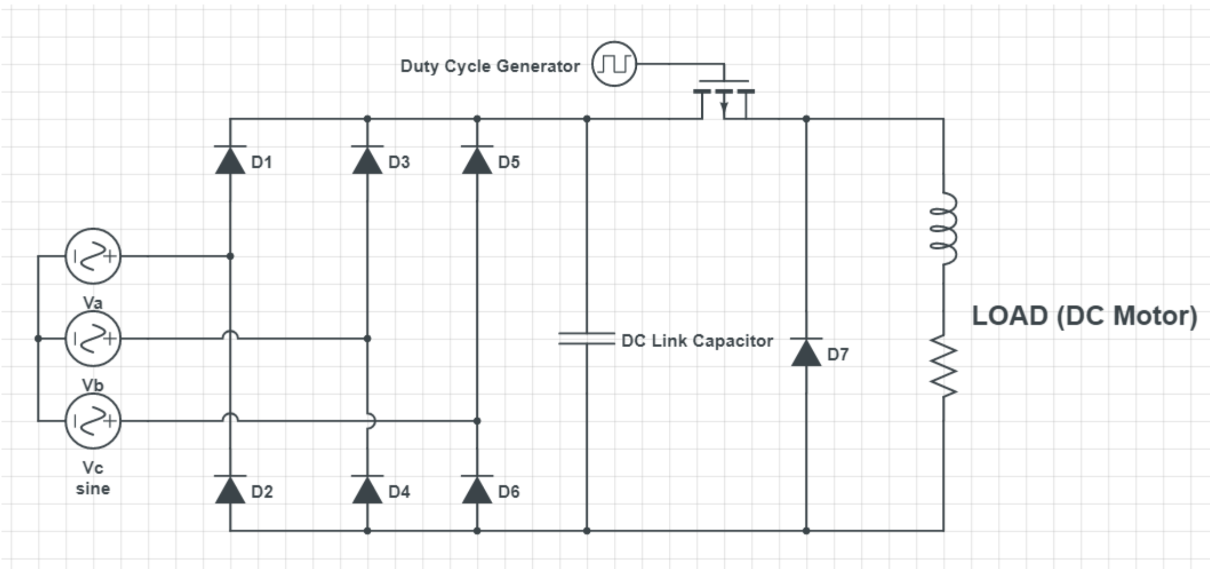

Figure 1: Overall Topology

3. Simulation Results:

Before we start to build our hardware project, we have done some simulations by using Simulink to find the size of the required components. Simulations help us to build better DC motor driver. At rectifier side we used 3 phase full wave diode rectifier so first we simulate the rectifier side and we choose a DC link capacitor for that rectifier. Secondly, we applied a DC voltage and simulate the buck converter design. After that we combined these two simulations and obtained DC motor driver which can be adjusted by duty cycle. To obtain a more realistic results, we added the DC motor simulations to the system. This was so important for us because IGBT and DIODE ratings were found from simulation results. Finally, for bonus part we show that our design can supply 1.6 kW power.

3.1. Three Phase Full Wave Diode Rectifier Simulations:

Simulations of the three-phase full wave diode rectifier is given in this part.

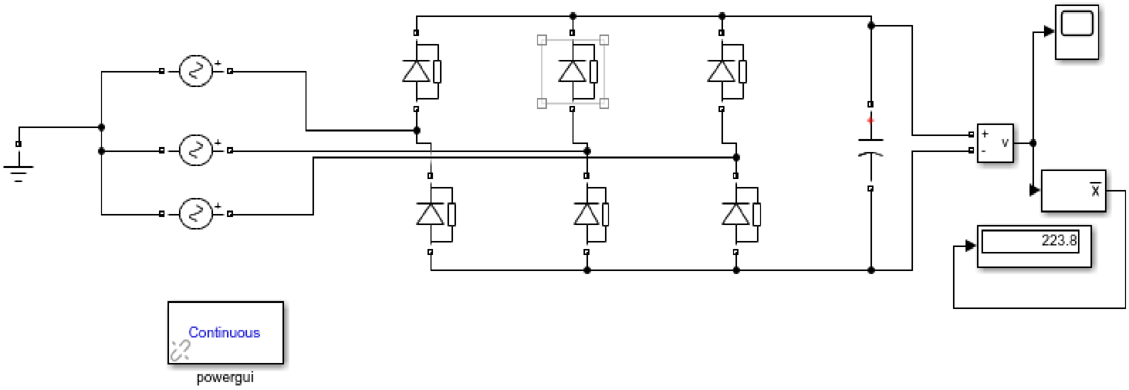

Figure 2: Schematic of the three-phase full wave diode rectifier.

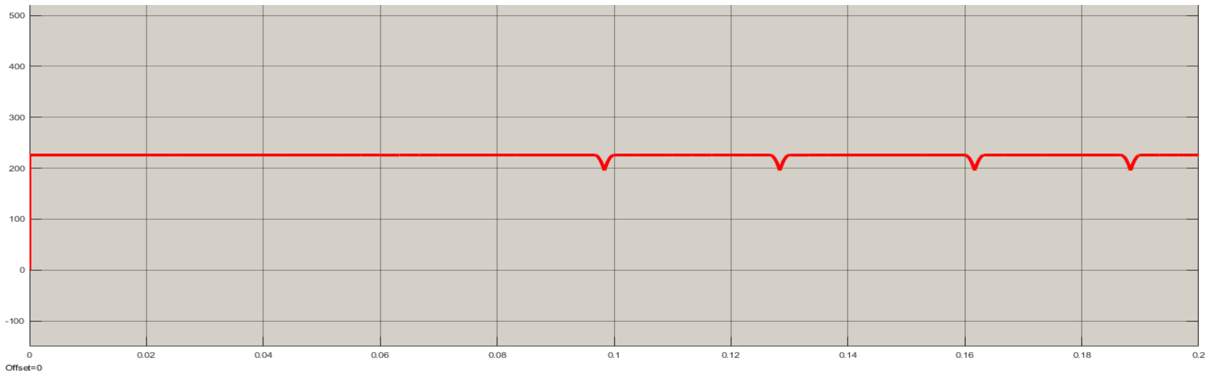

Figure 3 : Output voltage waveform of three-phase full wave diode rectifier with 1mF DC link capacitor.

3.2. Buck Converter Simulations:

Output voltage of the three-phase rectifier is higher than 180 V but in this project we should adjust the speed of the dc motor so we need to adjust the output voltage between 0 to 180 V by using buck converter. Simulation results of the buck converters are given here.

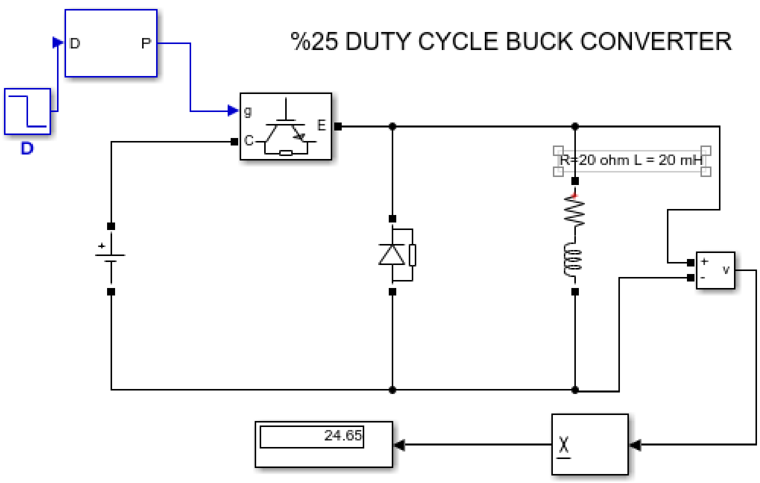

Figure 4: Buck converter simulation design for duty cycle = 0.25 and Vin = 100 V

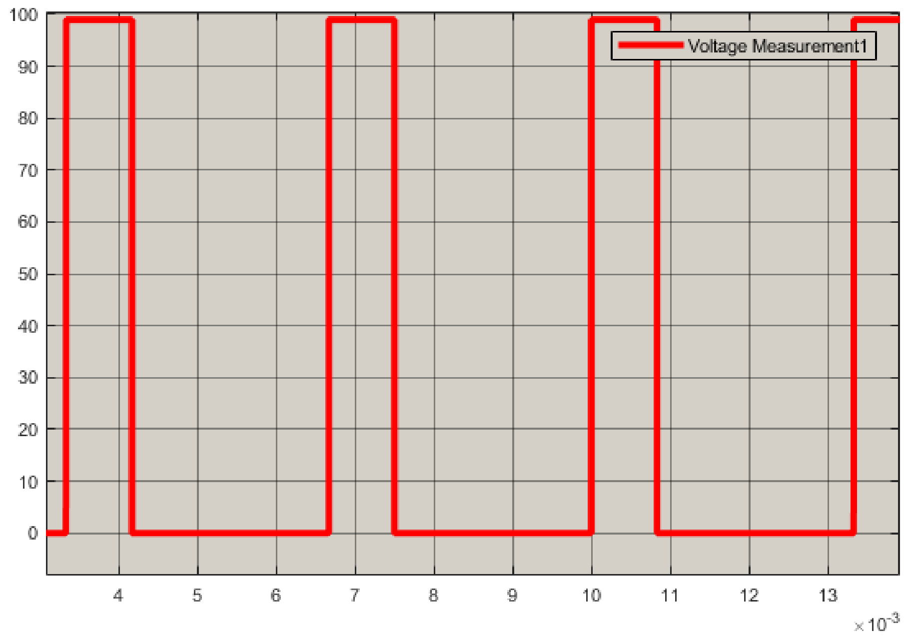

Figure 5 : Output waveform of the buck converter for 0.25 duty cycle.

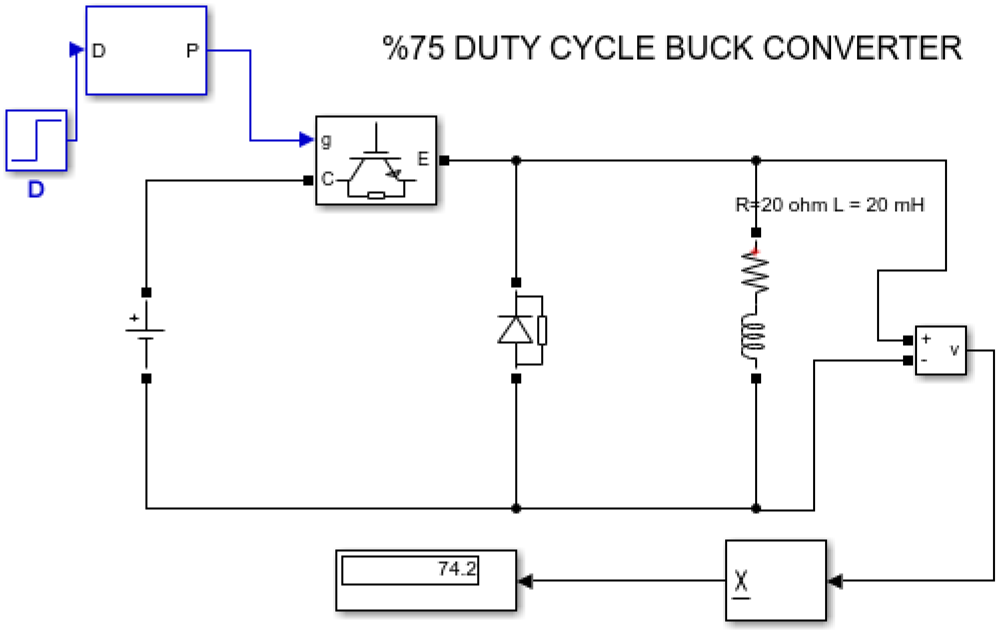

Figure 6: Buck converter simulation design for duty cycle = 0.75 and Vin = 100 V

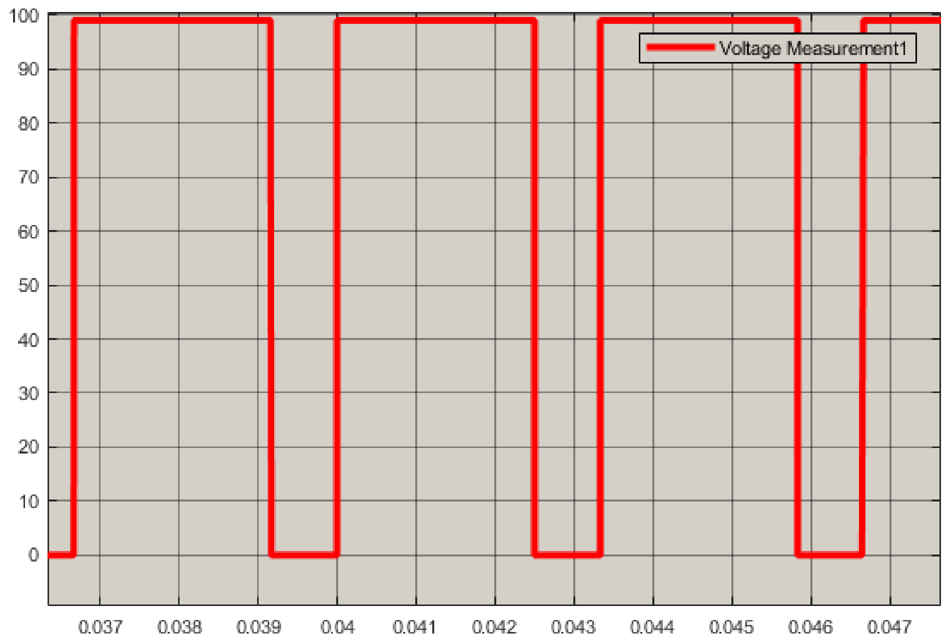

Figure 7: Output waveform of the buck converter for 0.75 duty cycle.

3.3. Overall System Simulations with RL Load:

In this part buck converter and rectifier design was combined to get overall system simulation results.

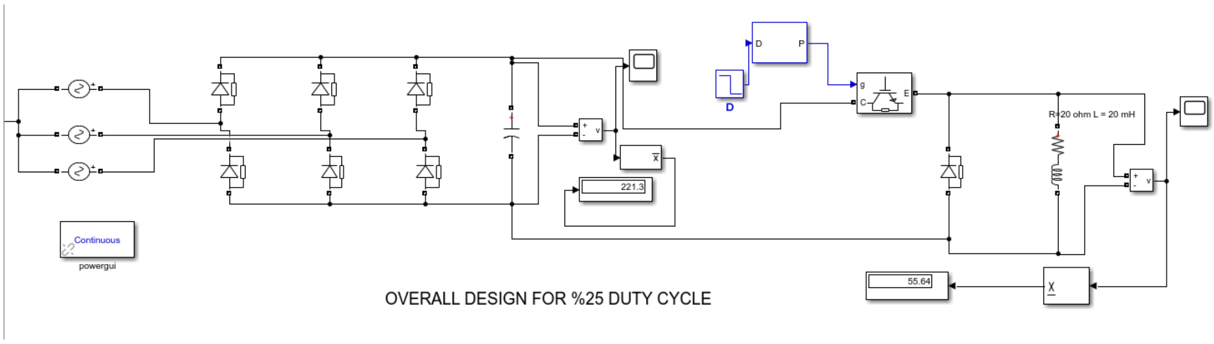

Figure 8 : Overall system design when the duty cycle is 0.25. (Switching frequency is 300 Hz)

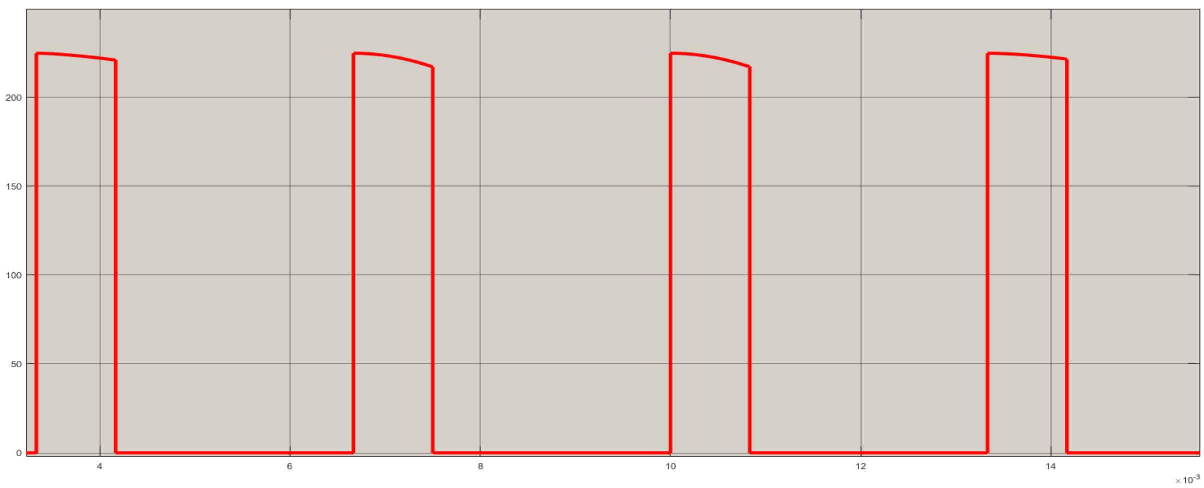

Figure 9: Output waveform of the overall system (0.25 duty cycle)

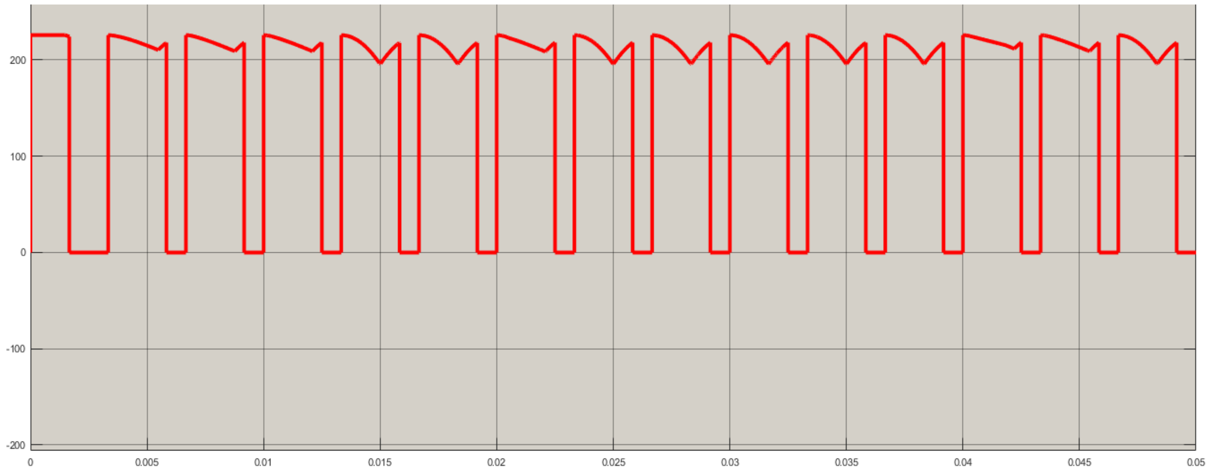

Figure 10: Output waveform of the overall system. (0.75 duty cycle)

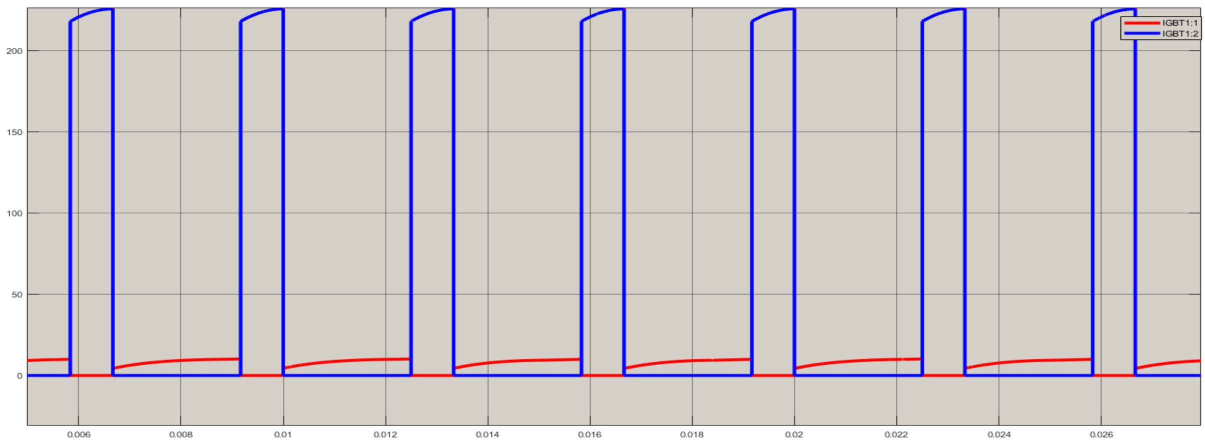

Figure 11: Voltage and Current waveform of IGBT for given RL load. (Red= Current Blue= Voltage)

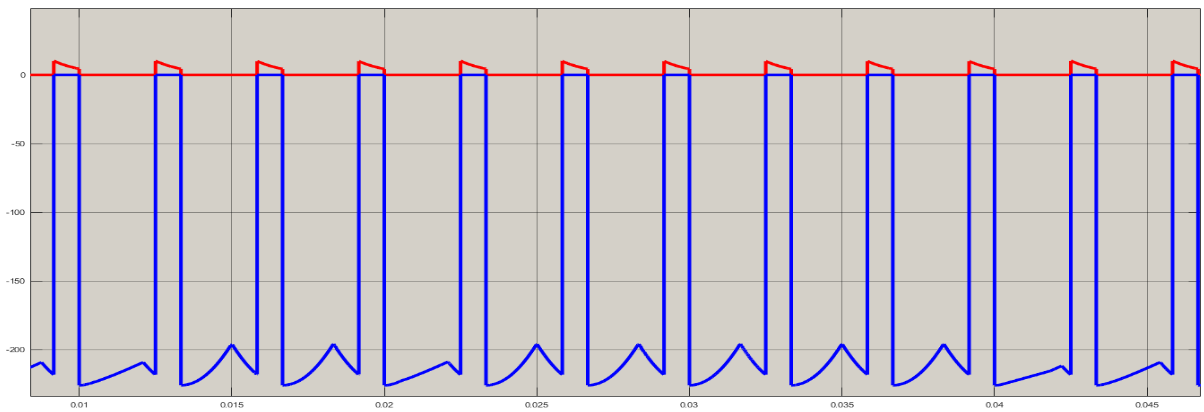

Figure 12: Voltage and Current waveform of IGBT for given RL load. (Red= Current Blue= Voltage)

3.4. Overall System Simulation with DC Motor:

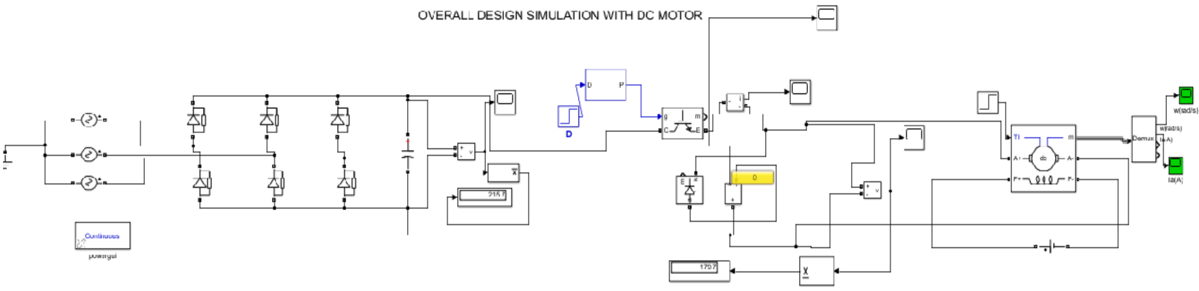

Figure 13: Schematic of the overall system with DC motor.(Output voltage of the buck converter adjusted the 180 V)

According to overall design with DC motor, diode and IGBT current and voltage waveforms are given here. This is important for our hardware design because, diode and IGBT was chosen by using this current and voltage ratings. Also, armature current and speed of the motor was calculated by using Simulink.

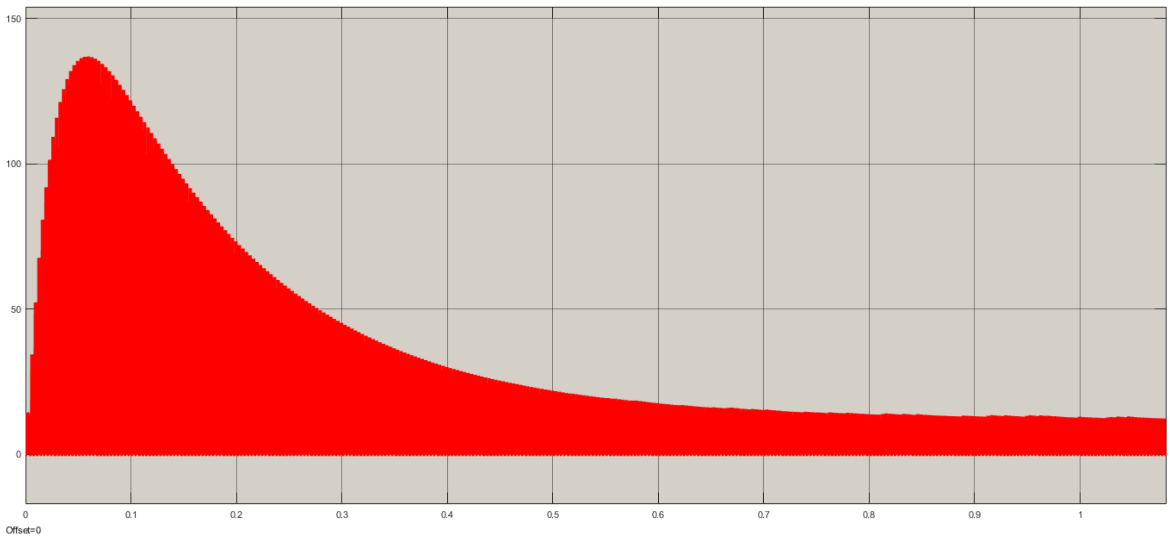

Figure 14: Diode current waveform with DC motor

In Figure 14 diode current was very high at the beginning, we applied directly 180 V DC to the motor that's why the current is not stable at the beginning, so we were considered the stabilized current waveforms to obtain required ratings for diode. Stabilized current waveform is given below.

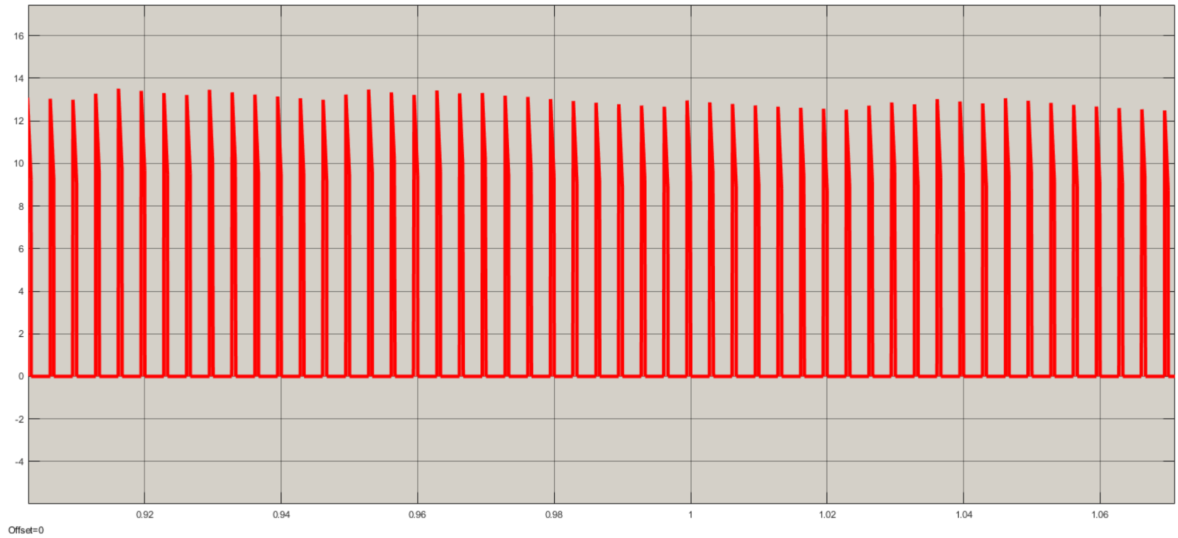

Figure 15: Stabilized diode current waveform with DC motor.

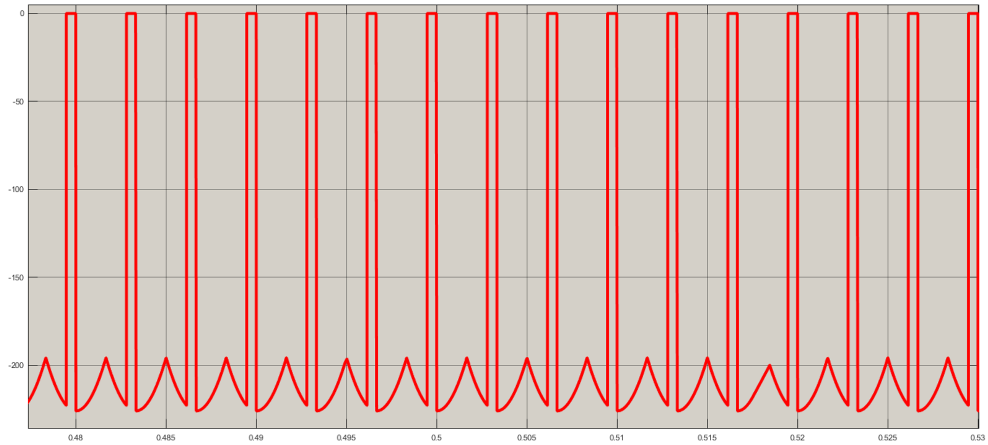

Figure 16 : Voltage waveform of diode

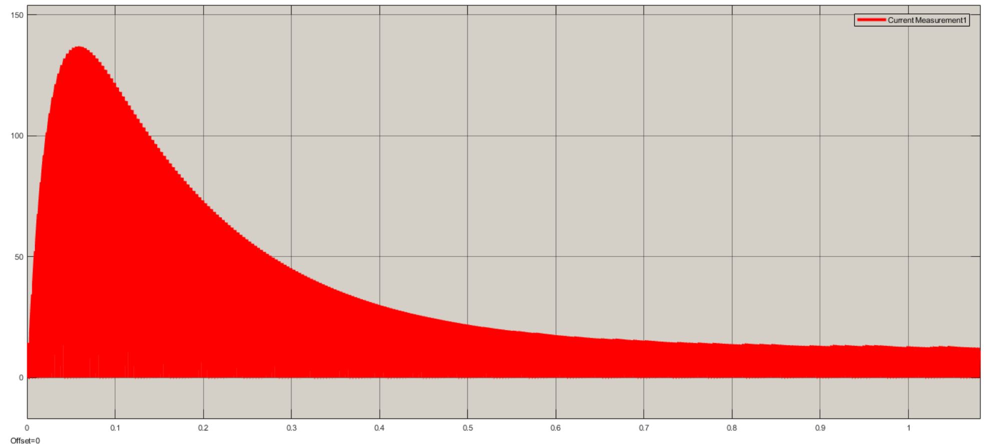

Figure 17: IGBT current waveform with DC motor.

As we mentioned for diode, current waveform is not stable at the beginning so the stabilized current waveform to obtain IGBT ratings are given below.

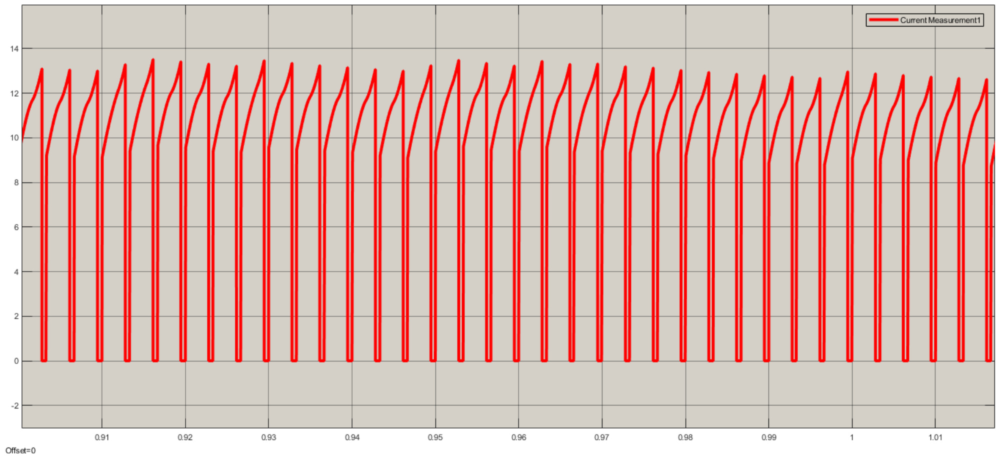

Figure 18: Stabilized IGBT current waveform with DC motor.

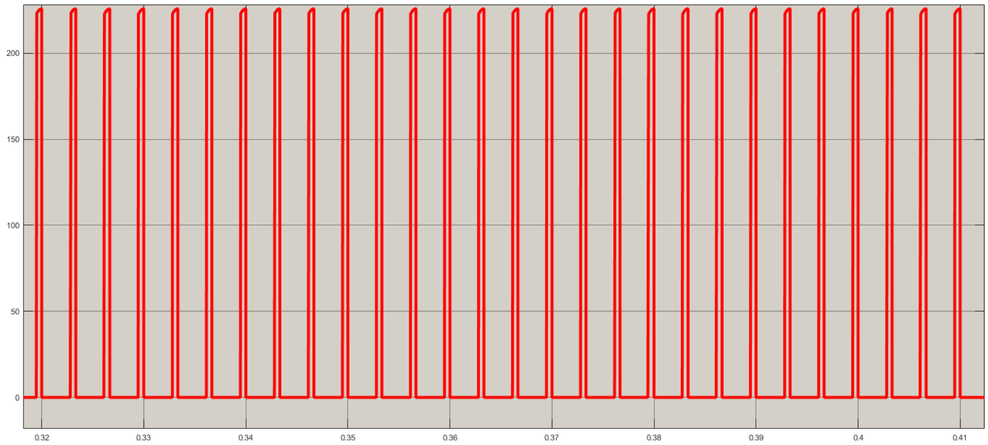

Figure 19: Voltage waveform of IGBT

Motor speed and armature current waveforms are given below.

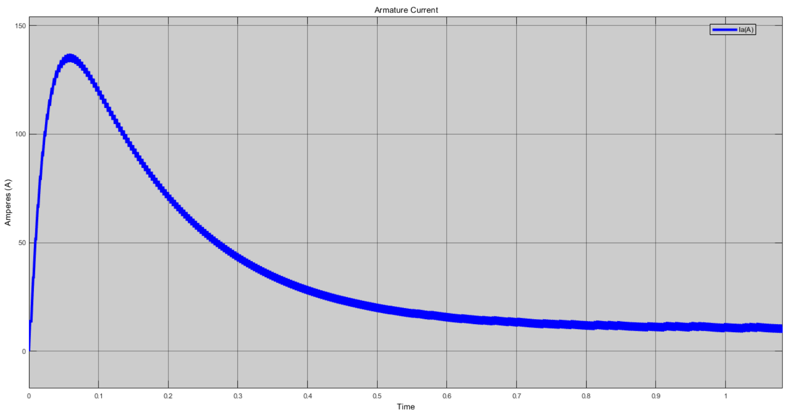

Figure 20: Armature current waveform.

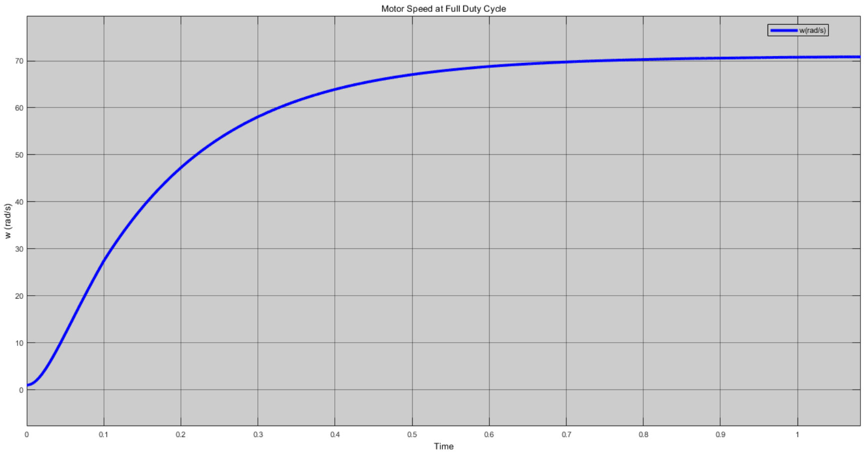

Figure 21: Speed of the motor.

4. Component Selection:

4.1. Three Phase Diode Rectifier:

For that purpose, a 1600 V 35 A diode rectifier package [1] shown in Figure 22 is used. Note that there is no need to design a diode rectifier with 6 diodes. There are already useful constructed ones.

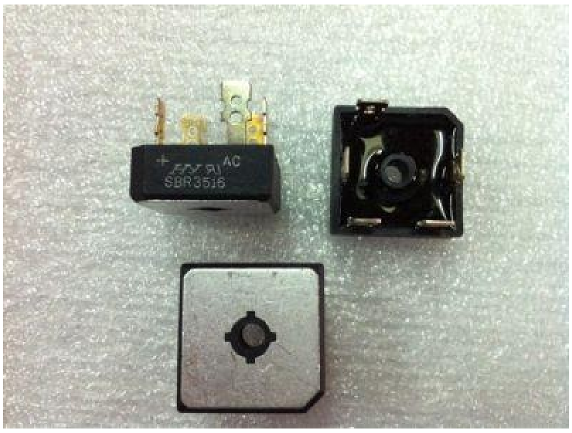

Figure 22: SBR3516 Full Wave Diode Rectifier

It has three inputs which are simply three phases and two outputs. Even if it is never exposed to such 1600 V and 35 A values, using larger rating values are safer due to over voltage and over current spikes which may result from the absence of soft start mechanism. In other words, duty cycle is adjusted manually by hand and that situation may form such mistakes that cause over voltages and currents.

4.2. Duty Cycle Generator:

An analog duty cycle is generated to control the speed of the motor. Since it is decided that closed loop operation is not implemented, there is no need to use a microcontroller.

Figure 23: NE555 Timer

A NE555 timer chip [2] which is shown in Figure 24 is used with a circuit design shown in Figure 24.

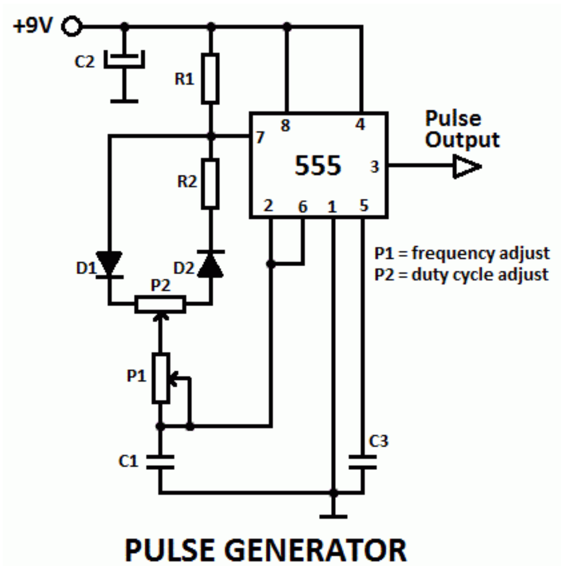

Figure 24: Duty Cycle Generator Timer Circuit

Some small changes are made in that design. C2 and P1 disconnected. Since constant frequency duty cycle is wanted to produce, there is no need to use P1. The characteristics of duty cycle and frequency are shown in Equation 2 and 3.

$$n = 1 - \frac{P_2}{P_1} \quad \textbf{(2)}$$

$$f = \frac{0.69}{((2P_1 + P_2 + R_1) * C_1)} \quad \textbf{(3)}$$

There is a tradeoff between frequency and duty cycle. As P2 increases, both frequency and duty cycle decreases. In other words, using a small P2 increases the switching frequency but duty cycle bottom limit may be quite high to stop the motor. Using a large P2 may decrease the duty cycle to very low values but it may decrease the switching frequency too much. It is tested that switching frequency decreases to 20 Hz with a 1M potentiometer P2. After testing different potentiometer values, the parameters are decided as:

- R1=R2=1kΩ
- P2=47kΩ
- C1=0.1uF
- C3=0.01uF
- V_{CC}=12V not 9V

4.3. Optocoupler:

One of the most important issues of the project is isolation between high voltage and low voltage side. In order to get the isolation, a TLP250 [3] shown in Figure 25 is used.

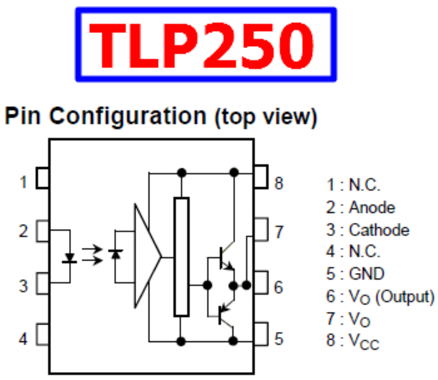

Figure 25: Pin Configuration of the TLP250

One of the most crucial advantages of the TLP250 is that it has its own double emitter follower gate driver. Therefore, there is no need to use extra gate driver circuit to open the MOSFET. To decrease the low voltage side current and prevent TLP250 from burning, a small 470 Ω resistor is connected. Moreover, to get a better square wave from the output of the TLP250, a small 330 Ω resistor is connected to output pin and a small capacitor is connected between V_{CC} and ground pin. Note that it is crucial to connect TLP250 to an isolated DC voltage source to have an isolation between high and low voltage sides, and the ground of the TLP250 is connected to positive terminal of the output in order to get a reference to open the MOSFET.

4.4. IGBT:

In that project, an insulated gate bipolar transistor (IGBT) is used instead of a MOSFET due to:

- Higher voltage and current ratings than power MOSFET and BJT.
- Low ON-resistance which provides lower ON state loss.
- Easy to drive.

In Table 1 [4], some comparisons are shown.

Device Characteristic	Power Bipolar	Power MOSFET	IGBT
Voltage Rating	High <1kV	High <1kV	Very High >1kV
Current Rating	High <500A	Low <200A	High >500A
Input Drive	Current, h_{FE} 20-200	Voltage, V_{GS} 3-10V	Voltage, V_{GE} 4-8V
Input Impedance	Low	High	High
Output Impedance	Low	Medium	Low
Switching Speed	Slow (uS)	Fast (nS)	Medium
Cost	Low	Medium	High

Table 1: Comparisons Among BJT MOSFET and IGBT

Note that the most important characteristic of an IGBT in that project is high voltage and current ratings. This provides designed circuit to supply larger amount of power to the output. Therefore, with an IGBT a loaded DC motor can be driven.

As seen from Figure 18 and 19: at the simulation results part the rated voltage of the IGBT must be higher than 400 volt and current rate of the IGBT must be higher than 15 Ampere but in reality there will be a lot of non ideality so the voltage and current rate of the IGBT were chosen much higher than simulation results. So IXYS - IXGH40N120C3D1 IGBT was chosen. Voltage and current ratings of the IGBT are, 1200 V , 40A. [5]

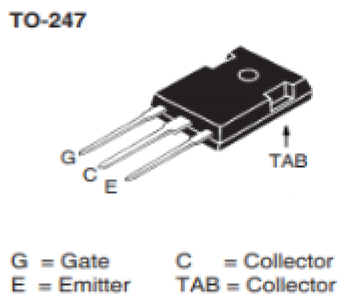

Figure 26: Pin configuration of chosen IGBT.[6]

4.5. Diode:

In the buck converter, there is required diode to create a path when the IGBT is closed. Current flows through diode when the IGBT is closed so diodes are important for the converters.

This diode should be fast recovery diode. Fast recovery diodes are optimized to accept high dynamic stress. Fast transition from conducting to blocking state that is why they are named fast recovery diodes. This type of diodes are useful for converters, because in the converters there is an

IGBT which is fast component. Diode must work synchronously with the IGBT, so it must be fast recovery diode too. Fast diodes are offered for the fast switch applications.

So there is required fast diode but the ratings of the diode is obtained from simulation results. As we have done for IGBT, diode was chosen which have higher voltage and current ratings. IXYS DSEI30-06A [7] was chosen as a fast diode. Voltage and current ratings of the chosen diode is, 600 V , 37 A. This ratings are useable for our design.

Figure 27: IXYS DSEI30-06A diode.

4.6. Heat Sinks:

In our dc motor driver design, there will be one IGBT and one diode where can be occured some heat problems. If the temperature of the components are higher than the maximum value, components will not work properly anymore, so we must keep temperature lower than maximum value. To keep temperature at lower values, heat sinks were used. Heat sinks help to increase the surface area of the components, so the temperature of the component getting higher slowly. Especially when the load was connected to the DC motor, water was boiled thanks to the heat sinks, because temperature of the IGBT were really high at that moment. We also used for the bridge rectifier to have a more thermal resistive design.

4.7. DC Link Capacitor:

A DC link capacitor is connected at the output of the three phase rectifier to obtain more DC voltage. The bigger capacitor means lower voltage ripple and higher cost. Moreover, since maximum output voltage of the system is nearly 180 V, obtaining 250 V at the output of the diode rectifier is enough with a duty cycle 0.72 (0.72*250=180). Therefore, a capacitor whose rating is above 250 V is proper for that operation. Nevertheless, a 1 mF 600 V capacitor is chosen to overcome voltage and current spikes.

5. Test Results:

Before driving the motor, some tests under R and RL load are done with the test setup shown in Figure 28.

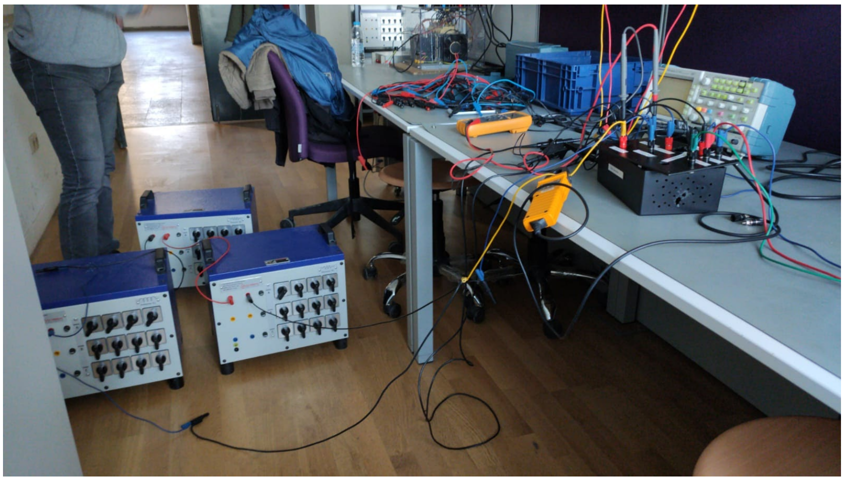

Figure 28: Test Setup

5.1. R Load:

Firstly, a test is performed with 48 Ω load for 25%, 50% and the one which supplies the rated 180 V output voltage. Test result for 25% duty cycle is shown in Figure 29. Channel 1 is the voltage after rectification, channel 3 is the output voltage and channel 4 is the output current.

Variac is adjusted to %40 which is nearly $400 * \frac{40}{100} = 160 V_{ll}$. Voltage after three phase rectification is $1.35 * V_{ll} = 216\ V$ theoretically without a capacitor. However, since a 1mF capacitor is used, voltage ripple decreased and average voltage increased. The voltage difference between experimental and theoretical results is caused by the DC link capacitor.

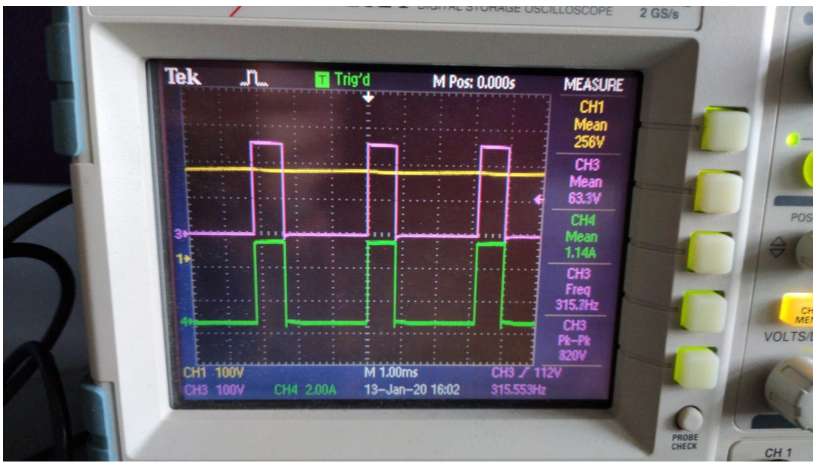

Figure 29: R Load Test Result for 25% Duty Cycle

It is obvious that the shape of output current and voltage waveforms are almost same since there is no inductor or capacitor at the output. Moreover, switching frequency of the IGBT is shown as 315 Hz.

Test result with 48 Ω and 50% duty cycle is shown in Figure 30. Since output voltage is nearly half of the input voltage. Output current increased from 1.14 A to 2.51 A since output voltage increases.

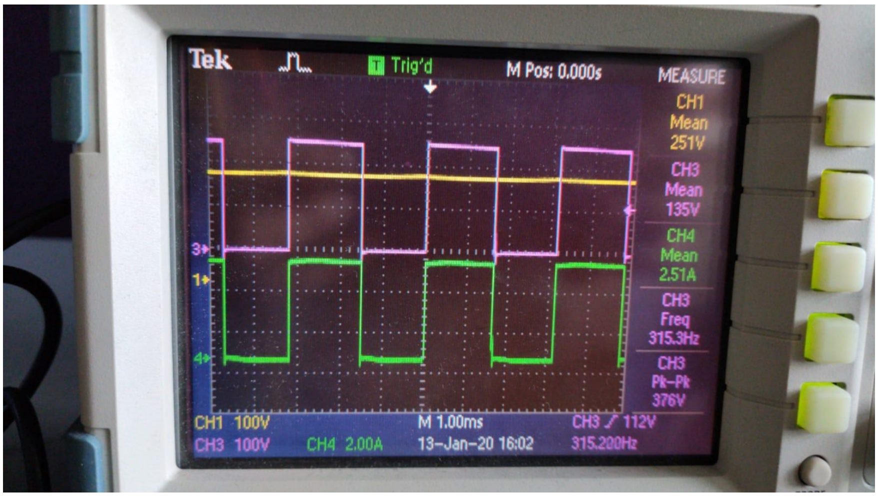

Figure 30: R Load Test Result for 50% Duty Cycle

Test result with 48 Ω and the duty cycle supplies the rated 180 V output voltage is shown in Figure 31. Rated voltage supplied with almost 75% duty cycle with $160V_{ll}$ input voltage. Output current increased from 2.51 A to 3.46 A since output average voltage increases. Switching frequency is 315 Hz for 3 cases which provides that the frequency of the duty cycle is almost same even if duty cycle changes. Moreover, it is obvious that there is a big voltage ripple at the output since capacitors or inductors are not used in order to filter the output waveforms. Nevertheless, rated output average voltage can be supplied with that voltage ripple.

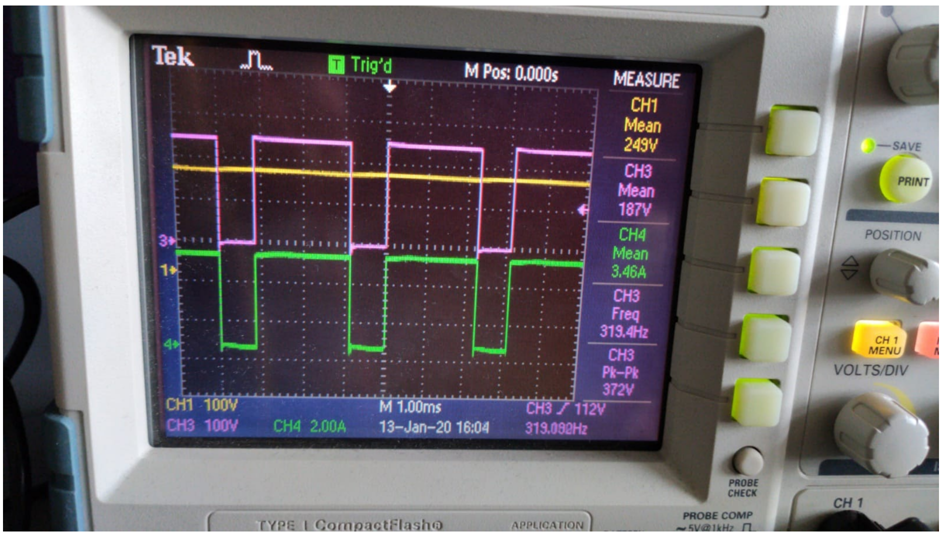

Figure 31: R Load Test Result for 75% Duty Cycle

5.2. RL Load:

After R load tests, the behaviour of the system under RL load is observed. RL load tests are separated into two parts. Firstly, the test is made under 48 Ω and nearly 0.15 H with 25%, 50% and 75% duty cycle which supplies the average rated 180V output voltage is observed. Secondly, R load is increased from 48 Ω to 256 Ω in order to observe both DCM and CCM operation of the system since the system operates in CCM at all times with 48 Ω load. Note that input voltage is $160V_{ll}$ again in both cases. The test result with 48 Ω 0.15 H load for 25% duty cycle is shown in Figure 32.

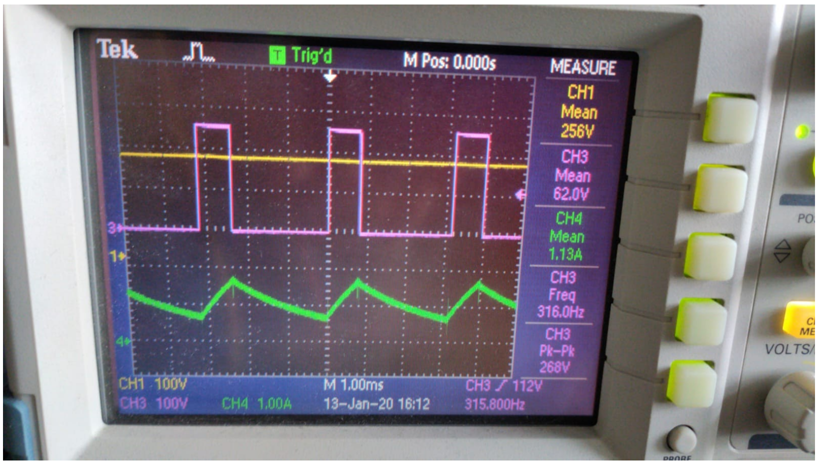

Figure 32: 48 Ω 0.15 H Load Test Result for 25% Duty Cycle

It is obvious that the output current shape changes due to inductance. In other words, the output current waveform is filtered with that inductance. However, since there is no capacitor, output voltage waveform is not filtered, it is almost a square wave. Decreasing current ripple decreases the stresses on the components.

Test result with 48 Ω 0.15 H load for 50% duty cycle is shown in Figure 33. It is obvious that average output voltage and current is nearly doubled since duty cycle doubles.

Figure 33: 48 Ω 0.15 H Load Test Result for 50% Duty Cycle

Test result with 48 Ω 0.15 H load for 75% duty cycle is shown in Figure 34. Rated output voltage is supplied with 75% duty cycle. Note that system is operated at CCM in three cases. Moreover, switching frequency is nearly 320 Hz in three cases which means frequency of the timer circuit is independent of the duty cycle.

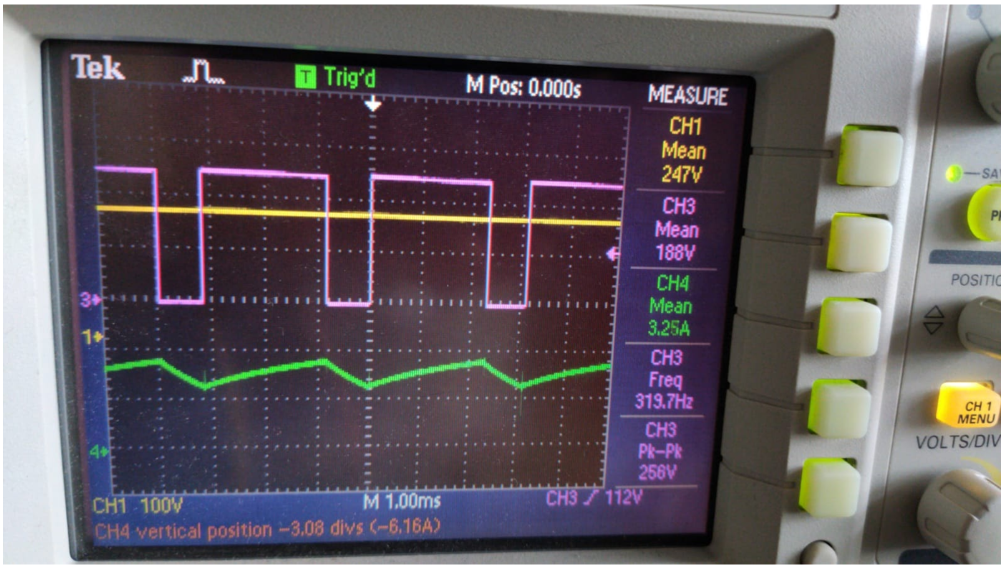

Figure 34: 48 Ω 0.15 H Load Test Result for 75% Duty Cycle

Test result with 256 Ω 0.15 H load for nearly 5% duty cycle is shown in Figure 35. As mentioned before, load is increased in order to observe both CCM and DCM operation by decreasing the average output current. It is obvious that system is operated in DCM for 5% duty cycle.

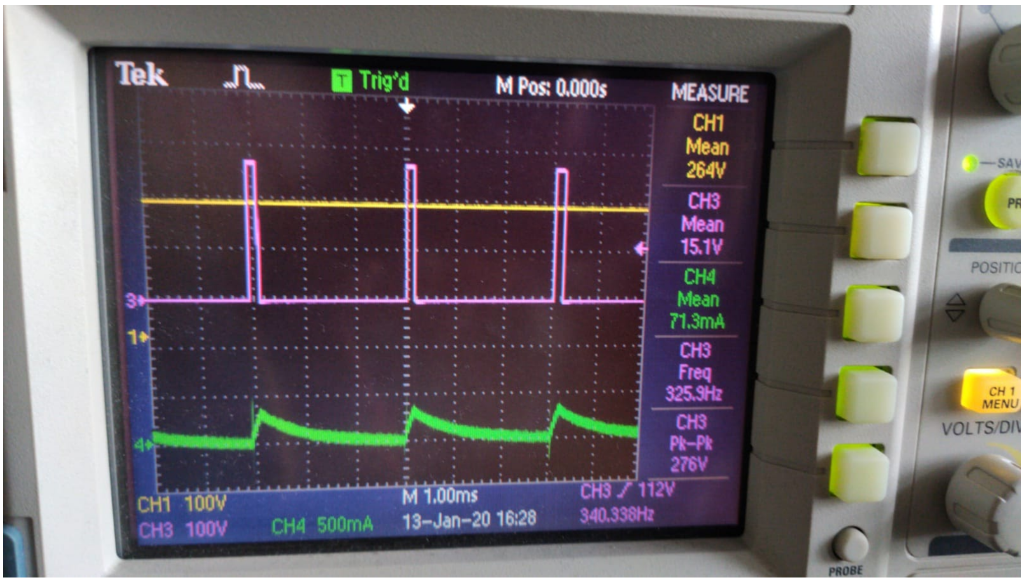

Figure 35: 256 Ω 0.15 H Load Test Result for 5% Duty Cycle

Test result with 256 Ω 0.15 H load at the boundary between DCM and CCM is shown in Figure 36. Duty cycle is nearly 13% at the boundary. To find the boundary condition theoretically:

$I_{oB} = \frac{DT_S}{2L} * (V_d - V_o) = \frac{0.13*0.003}{2*0.1525} * 225.8 = 288mA$ which means that output current values below 288 mA makes the system DCM. There is a small 66 mA difference between experimental and theoretical results due to stray inductances and non idealities.

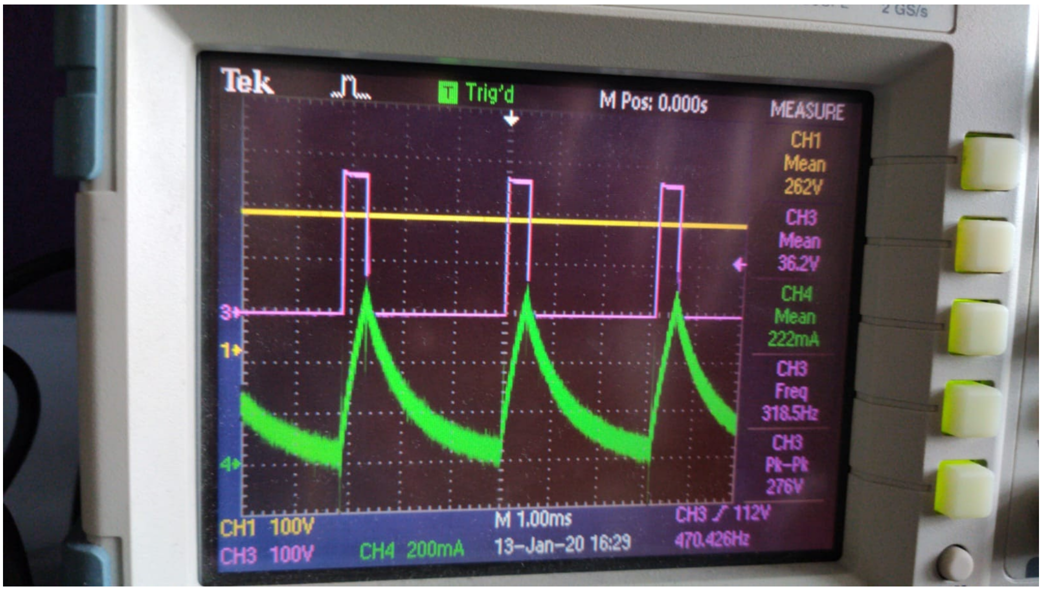

Figure 36: 256 Ω 0.15 H Load Test Result at Boundary Between CCM and DCM

Test result with 256 Ω 0.15 H load for 25% duty cycle is shown in Figure 37. It is shown that system operates in CCM, but it is close to boundary.

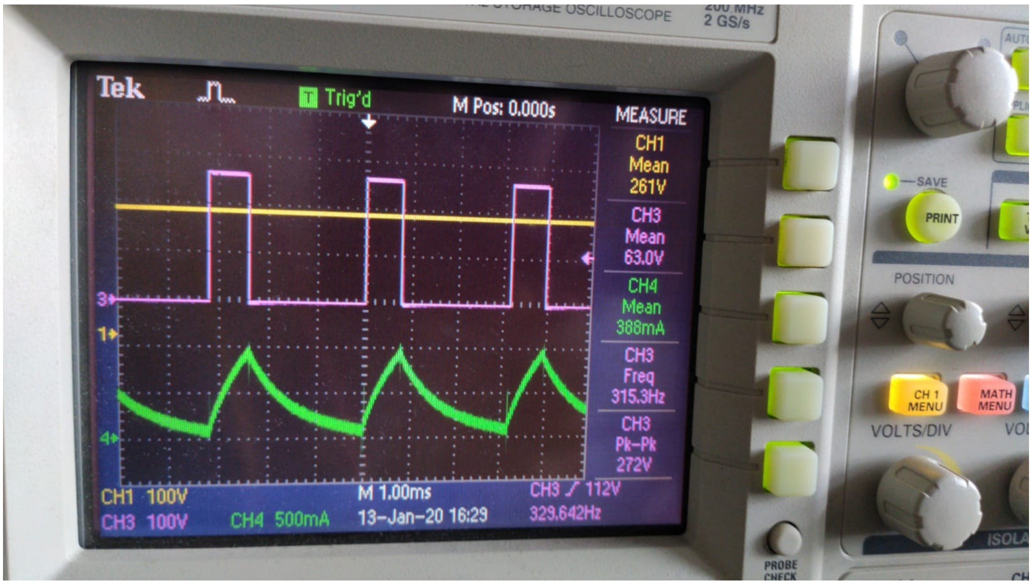

Figure 37:256 Ω 0.15 H Load Test Result for 25% Duty Cycle

Test result with 256 Ω 0.15 H load for 50% duty cycle is shown in Figure 38. The system starts to move away from the boundary. Output voltage and current waveform doubles since duty cycle doubles.

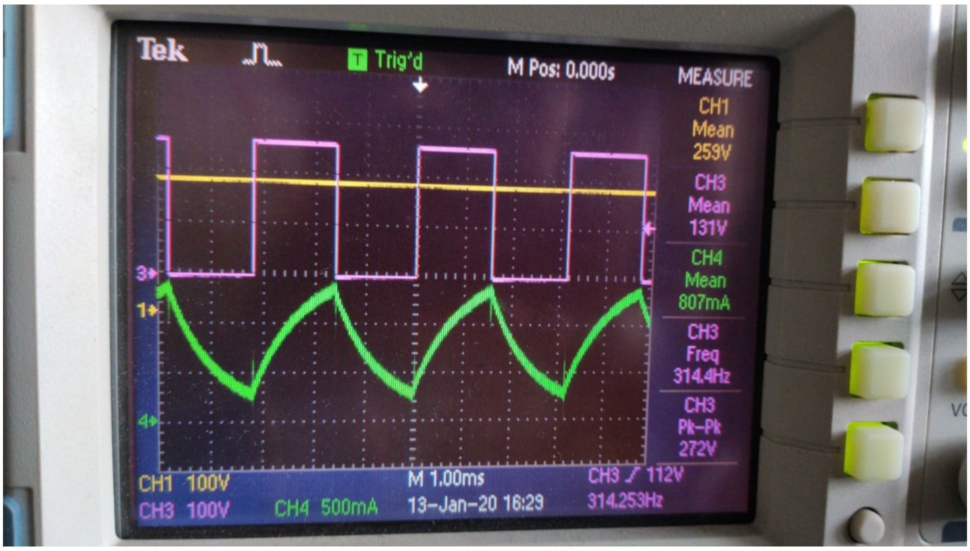

Figure 38: 256 Ω 0.15 H Load Test Result for 50% Duty Cycle

Test result with 256 Ω 0.15 H load for 75% duty cycle providing rated output voltage is shown in Figure 39. Again, it is obvious that usage of additional inductor is not needed. Moreover, rated output voltage can be supplied without a capacitor.

Figure 39: 256 Ω 0.15 H Load Test Result for 75% Duty Cycle

Note that the switching frequency is a little small for such motor drivers. However, there is no need to use snubbers due to small switching frequency, and that switching frequency is enough for that application.

5.3. Motor Load:

After these tests, actual motor shown in Figure 40 is driven. Field winding is feeded with $320\ V_{ll}$ and motor is connected as parallel. Firstly, it is driven with no load which makes the system operating at DCM. Secondly, a generator is connected and nearly 1.6 kW is supplied along 5 minutes. It means that design is durable enough for high load operations.

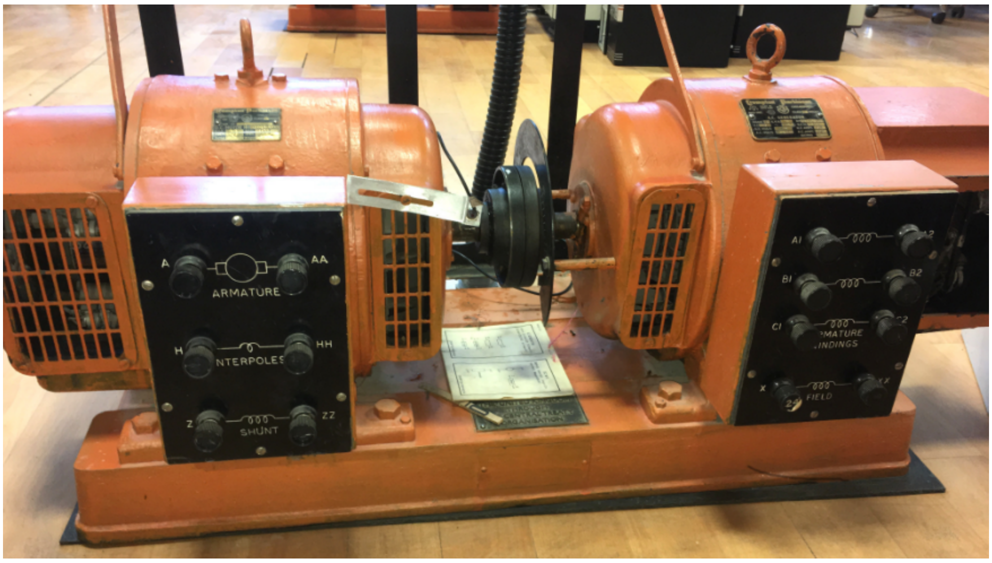

Figure 40: DC Motor in the Project

Test result with no load operation at rated output voltage is shown in Figure 41. Channel 1 is output voltage and channel 2 is the output current. It is obvious that even if output voltage is at its rated value, system operates in DCM since output current is nearly 230 mA which is smaller than the boundary condition 288 mA found before theoretically. Note that DCM operation may be understood with the output voltage characteristics. The shape of the output voltage differs from the square wave as shown in Figure 41.

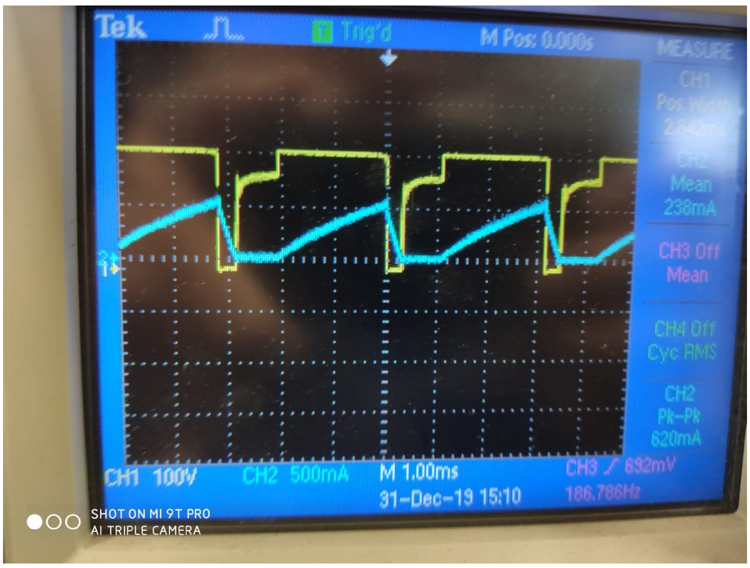

Figure 41: Motor Test Result with No Load at Rated Output Voltage

Test result with the generator at rated output voltage is shown in Figure 42. It is obvious that system operates in CCM since output current is higher than the boundary value.

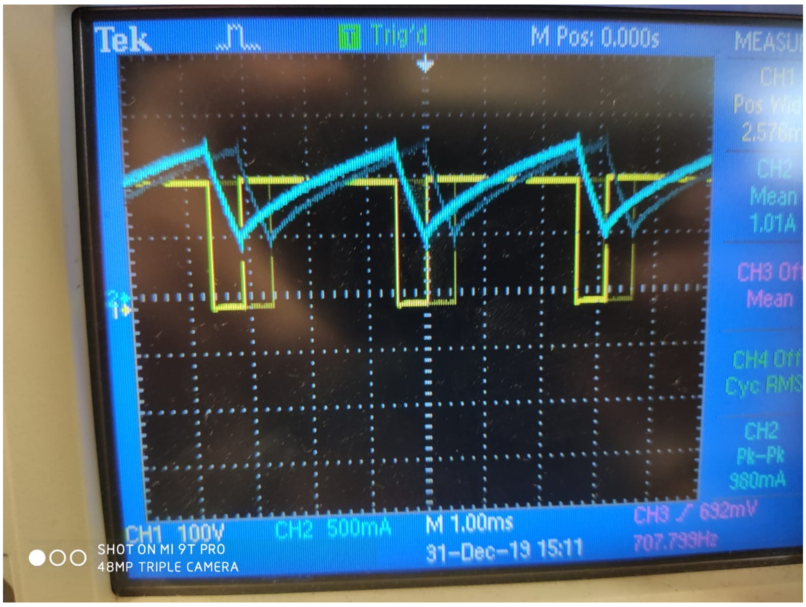

Figure 42: Motor Test Result with Generator at Rated Output Voltage

Output voltage and current characteristics are shown in Figure 43 directly. 1.561 kW is supplied to the load along five minutes which boils the water into kettle.

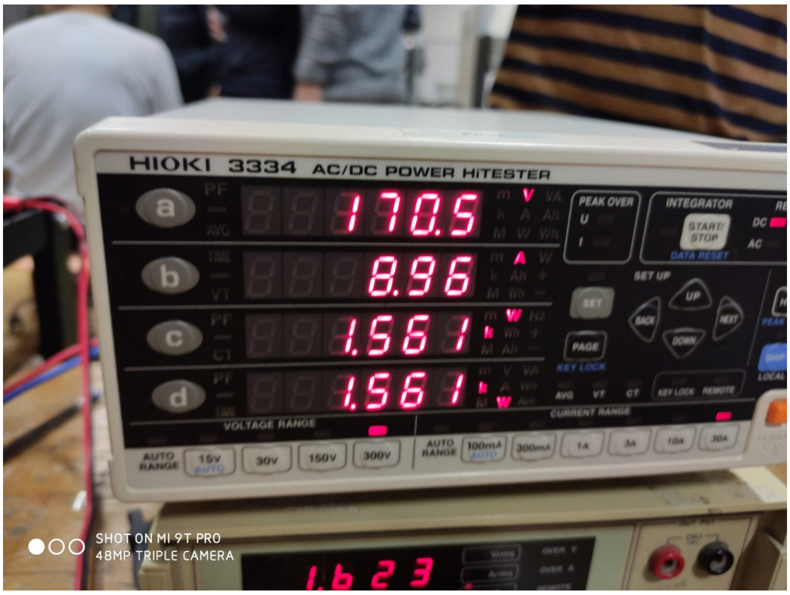

Figure 43: Output Voltage, Current, and Power Characteristics with Generator at Rated Voltage

After that five minutes, thermal characteristics of the system is recorded and shown in Figure 44. The hottest component in the system is IGBT which is 90 C. That value is quite high. In other words, temperature can be a problem if the time rises. However, air flow can be provided with a fan and temperature can be balanced. It was aimed but it cannot be applied since the fan is broken during circuit implementation.

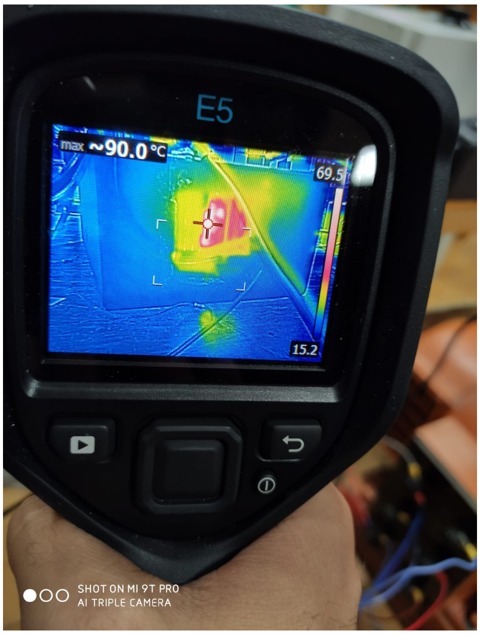

Figure 44: Thermal Characteristics of the System After Generating 1.5 kW Along Five Minutes,

6. Thermal Characteristics:

The IGBT temperature is nearly saturated at 90 C. A theoretical thermal behaviour analize can be done as follows:

From the datasheet of the IGBT, $V_{CE} = 2.7V \ \ and \ E_{Tot} = 2.35mJ$

Conduction loss of IGBT: $V_{CE} * I_O * D = 2.7 * 8.96 * 0.75 = 18.144W$

Switching loss of IGBT: $E_{Tot} * f_{sw} = 2.35 * 350 = 0.822W$

Total loss of IGBT: $P_{sw} + P_{con} = 19W$

Assuming ambient temperature is 23 C, the circuit shown in Figure 45 is obtained. Heatsink to ambient resistance is not known since a random heatsink is used.

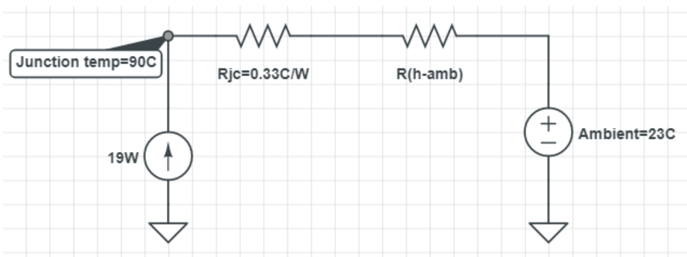

Figure 45: Thermal Circuit of the IGBT

To find the heatsink to ambient resistance following equation is used:

$19 * (0.33 + R(h - amb)) + 23 = 90$

$R(h - amb) = 3.17\ C/W$

Thermal resistance of the heatsink is found. Note that junction to case resistance is found from the datasheet, and diode loss of the IGBT is neglected.

Then, to find the junction temperature of the fast recovery diode by assuming the identical heatsinks are used for IGBT and diode separately, following operations are done:

From the datasheet of the diode, $V_{on} = 1.01V$, since it is a fast recovery diode, switching loss can be neglected.

Total loss of the diode: $P_{tot} = P_{con} = V_{on} * I_O * (1 - D) = 1.01 * 8.96 * 0.25 = 2.26W$

Therefore, thermal circuit of the diode shown in Figure 46 is obtained.

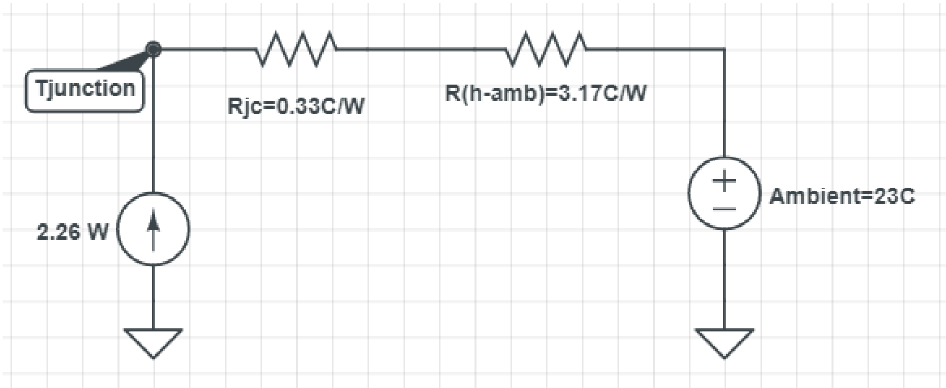

Figure 46: Thermal Circuit of Diode

To find the junction temperature of the diode following equation is used:

$$2.26 * (0.33 + 3.17) + 23 = T_{junction} = 30.91C$$

Since duty cycle is 0.75 at rated output voltage, diode loss is quite low. Therefore, diode's temperature is not as problematic as the IGBT's.

Note that these thermal calculations are based on two issues. Firstly, junction temperature of the IGBT is known, and thermal resistance of the heatsink is found by using that value. Secondly, it is assumed that identical heatsinks are used, and junction temperature of the diode is found with the thermal resistance of the heatsink learned in the first part.

7. Conclusion

In this project, DC motor driver was designed which is working by using AC voltage as a source. Firstly we need an rectifier to obtain DC voltage from AC voltage then to control the speed of the DC motor, buck converter was built. To drive a DC motor we should get more like DC voltage from rectifier so we used a DC link capacitor to reduce voltage differences. After rectification, buck converter side was built. Buck converter side have only one diode and one IGBT, but to open and close the gate of the IGBT we need an IGBT driver circuit which was made by using NE555. IGBT driver circuit is a duty cycle generator. Ratio of the duty cycle can be adjusted by the potentiometer.

Sampling frequency of the our IGBT driver is about 300 Hz. After duty cycle was generated, there is required isolation circuit between high voltage and low voltage side of the system. NE555 IGBT driver circuit is low voltage side which was fed by 12 V DC voltage supply. To isolate we set up optocoupler circuit by using TLP250 which is digital optocoupler. We used another 12V DC supply to feed TLP250, because the isolation must be perfect between high voltage and low voltage side. After TLP250 circuit reflected to duty cycle to the gate of the IGBT, our buck converter started to work. 12V DC voltage is high enough to open IGBT. According to duty cycle output voltage of the buck converter which is also output voltage of the overall system, can be adjusted to expected values which is between 0-180 V DC. Output voltage was directly connected to the DC motor's armature points. Some connections was done considering the line inductances. The distances between diode and IGBT was very short because we did not want to create a high line inductance. Cables were done as short as possible for high voltage side. We do not want high line inductances, because unwanted line inductances can create unexpecting peaks on the voltage and current. These peaks are dangerous because IGBT and diode have maximum rated current and voltage values. These peaks can exceed the limits of the IGBT and diode.

Most important thing, what we learned in this project, is not giving up when we were failed. We set up 4 different pcb and pertinaks for DC motor driver we have faced with some problems but we have not given up at the end we could set up a DC motor driver and finalized this project successfully.

8. References:

[1]= **SBR25/35A SERIES Diode Rectifier Datasheet**

https://www.datasheets360.com/pdf/-5504576933865586968

[2]= **LM555 TIMER Datasheet**

http://www.ti.com/lit/ds/symlink/lm555.pdf

[3]= **TLP250 Optocoupler Datasheet**

https://pdf1.alldatasheet.com/datasheet-pdf/view/32418/TOSHIBA/TLP250.html

[4]=**Insulated Gate Bipolar Transistor**

https://www.electronics-tutorials.ws/power/insulated-gate-bipolar-transistor.html

[5]= **IXYS All Components Datasheet**

http://www.ixys.com/Documents/IXYS_Shortform2013.pdf

[6]= **IXYS IXGH40N120C3D1 Datasheet**

https://datasheet.octopart.com/IXGH40N120C3D1-IXYS-datasheet-15913579.pdf

[7]=**IXYS DSEI30-06A Datasheet**

http://ixapps.ixys.com/DataSheet/DSEI30-06A.pdf