MIDDLE EAST TECHNICAL UNIVERSITY

EE463 STATIC POWER CONVERSION - I

Hardware Project Report

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INTRODUCTION

In this project, we are expected to design and implement a controlled rectifier topology in order to be used as a DC-motor driver which is a complicated job and hence has many steps. This report presents these steps that are taken while designing and implementing the required topology. In order to organize the report better, we divided and named our focuses for each part. These parts include the following:

- Project Definition: The requirements of the project are going to be stated.
- Design Alternatives: Each possible topology is going to be evaluated with respect to its advantages and disadvantages. Also, in this part, the chosen topology is going to be mentioned.
- Solution Approach: Design plans according to the chosen topology are going to be elaborated in detail.
- Computer Simulations: The chosen topology is going to be tested with the intended components by considering possible non-idealities.
- Components' Selection: Each chosen component –according to mathematical calculations- is going to be given with their specs by supplying their product codes. Also, their compatibility for desired operation is going to be discussed.
- Test Results: The results of a R-Load test is going to be supplied. In addition, some important characteristics are going to be presented which are obtained while managing the actual DC-motor operation belonging to the demonstration day.
- Software: The operation principle of the relevant Arduino code is going to be explained
- Discrepancies: If there are inconsistencies between theoretical and practical applications, in this part they are going to be discussed.
- Expenditures: Total cost is going to be supplied.
- Conclusion: Difficulties, some critical points and benefits of the project are going to be evaluated.
- Appendices: Data sheet links of the crucial components are going to be provided.
- References: Utilized websites, lecture notes and other sources are going to be given.

PROJECT DEFINITION

As mentioned beforehand, we are going to implement a DC-motor drive topology to be used on an industrial DC motor. While designing it, a few criteria have to be obeyed namely:

- Power input is going to be either 3-phase or 1-phase AC Grid which is going to be adjusted by Variac. However, any other adjustments by using Variac –except the initial one- are forbidden. Hence, we cannot use Variac for speed control purposes.

- Output is expected to be adjustable and DC which should be a minimum of 180 V (rms) in order to operate our motor appropriately.

- The topology choice (among the alternatives of; 3-phase thyristor rectifier, 1-phase thyristor rectifier, diode rectifier+ buck converter) is up to us.

Field winding of the motor is going to be fed separately.

Specifications of the DC motor windings:

- Armature Winding: 0.8 Ω, 12.5 mH
- Shunt Winding: 210 Ω, 23 H
- Interpoles Winding: 0.27 Ω, 12 mH
- Inertia: TBA

DESIGN ALTERNATIVES

As alternatives to be implemented, we are free to choose one alternative among three which are all capable of driving the motor by fulfilling the design limitations. These alternatives are evaluated below with respect to their advantages and disadvantages.

3-Phase Thyristor Rectifier:

This topology is composed of 6 separate thyristors to be opened and closed by applying proper gate signals to them. So we need a total of 6 gate driver circuitries and a main controller unit that are also going to be utilized while controlling the speed of the motor by changing the value of output voltage with proper firing angles which is actually the main advantage of this alternative. In addition, we need a DC-link capacitor at the output of the rectifier to smooth out the waveform which is going to be supplied to the DC-motor. Although it gives a low rippled output voltage without using any DC-DC converter circuitries and hence it may seem to be simple to design, we have to deal with synchronizing delays between the firing angles of six different thyristors which is indeed challenging.

1-Phase Thyristor Rectifier

This topology is composed of 4 separate thyristors which actually leads us to use fewest components. Although the control part is easier than the previous alternative, we still need to deal with arranging firing angles. Moreover, the ripples at the output voltage would be more than the previous one which is not a limitation for this project but yet important for a safe and pure operation.

Diode Rectifier + Buck Converter (Chosen)

This topology is composed of an integrated 3-phase diode bridge rectifier to take a DC kind of output while supplying 3-phase AC input to them, a DC-link capacitor to decrease the ripple at the output of the rectifier and a buck converter topology -to be used to decrease the voltage value at the output of the rectifier- which includes a single switching device (MOSFET or IGBT), a freewheeling diode, an inductor and a capacitor. Also note that it is vital to isolate our circuitry from Arduino (where we control our switching device by generating a gate signal) and hence we need to use an isolation component such as an optocoupler. So, clearly this alternative has more components than other two.

Nevertheless, it has various advantages such as:

- ✓ No need to deal with firing signals.
- ✓ Easy speed control with a single switching device with a simple code.
- ✓ Controllable switching frequency to decrease output voltage ripples.
- ✓ Full control on L and C values in buck converter which can also be used to decrease the ripples.

But also, it has a number of disadvantages and operational risks namely:

- ➢ This topology consists of many components and hence calibration may take greater effort and it may be costly while installation. If a problem occurs for example in the DC-DC converter part, all of the components in this part may burn out which is not desired for the sake of the design and in terms of cost considerations.
- ➢ If L value –in the buck converter- and/or switching frequency are chosen to be too large to decrease ripples, it gets easier to go into discontinuous conduction mode where output voltage increases out of our control hence may be hazardous to both our components and DC motor itself.

Note that all three topologies have their own advantages and disadvantages. However, we as M.A.N. Power have chosen the alternative of using diode rectifier + buck converter thanks to its advantages and easiness of control.

Solution Approach

With the chosen alternative (3-ph diode bridge rectifier + buck converter) in minds, we have three main sub-blocks in our design namely; a 3-phase diode bridge rectifier, a DC-link capacitor and a buck converter with its diode's gate signal is supplied by utilizing Arduino Uno.

To elaborate in more detail;

- As an ultimate goal, we need to obtain a DC kind of an output (a DC waveform having small ripples) from AC (to be supplied from 3-phase Variac) to be used in our DC-motor terminals. Hence, firstly we plan to utilize a 3-phase bridge rectifier and supply it with 3-phase AC of Variac. By doing this, we actually get a DC-like output with a scaling ratio of 1.35 for line-to-line voltage.

- But also note that, obtained waveform at the output of the rectifier still has bigger ripples [$(1-\sqrt{3}/2)$*V_{ll}] than we aim to supply the motor with. For this purpose, we find it appropriate to use a DC-link capacitor which can bear with high voltages (in the range of [180V, 200V]) at the output terminals of bridge rectifier. Keep in mind that this capacitor should be discharged for our safety after the operation ends which we plan to manage by using an external resistor.

- In order to control the speed of our motor, we need a buck converter topology to be connected at the output of the DC-link capacitor. In this topology we plan to utilize an IGBT to bear with high voltages and currents whose gate signal is to be given in the form of PWM (duty percentage is arranged by a potentiometer) by using Arduino with a switching frequency of 1 kHz to be beneficial for both decreasing ripples and not to experience big switching losses. This Arduino should be isolated from the main circuit, but it can also deliver gate signals. In this manner, utilizing an opto-coupler circuitry is what we need. We also need a RC snubber circuitry to be connected between collector and emitter terminals of IGBT for the purposes of:

  - ✓ Limiting high voltage transients and dv/dt protection.
  - ✓ Preventing accidental turn-ons.
  - ✓ Reducing switching losses and EMI problems.

In addition, a fast recovery diode (again bearing with high voltages and currents*) is needed to operate our system with non-stop. Lastly an LC filter can be utilized but it may not be so critical for our purposes since LC-filter's duty is to decrease the voltage ripples which are not our first priority (the DC motor is an industrial one, so its operation does not get affected harshly by small ripples). Yet we plan to utilize this LC combination to obtain smoother turns.

- Since IGBT and diode are the crucial components in terms of heat concerns, we are going to couple them with heatsinks.

(*) high voltages and currents: At full duty we are going to have approximately 200 V applied on our components. And for the currents we expect to have 3A for the unloaded case and 5A for the loaded case which is a bonus that we aim to manage.

SIMULATION RESULTS

Although we decided on topology and the main components, we needed to make simulations in various conditions so that we can be sure that topology is working. Moreover, simulations are important when selecting specific components. We used Simulink for simulations and the schematic of our design is shown in Figure 1.

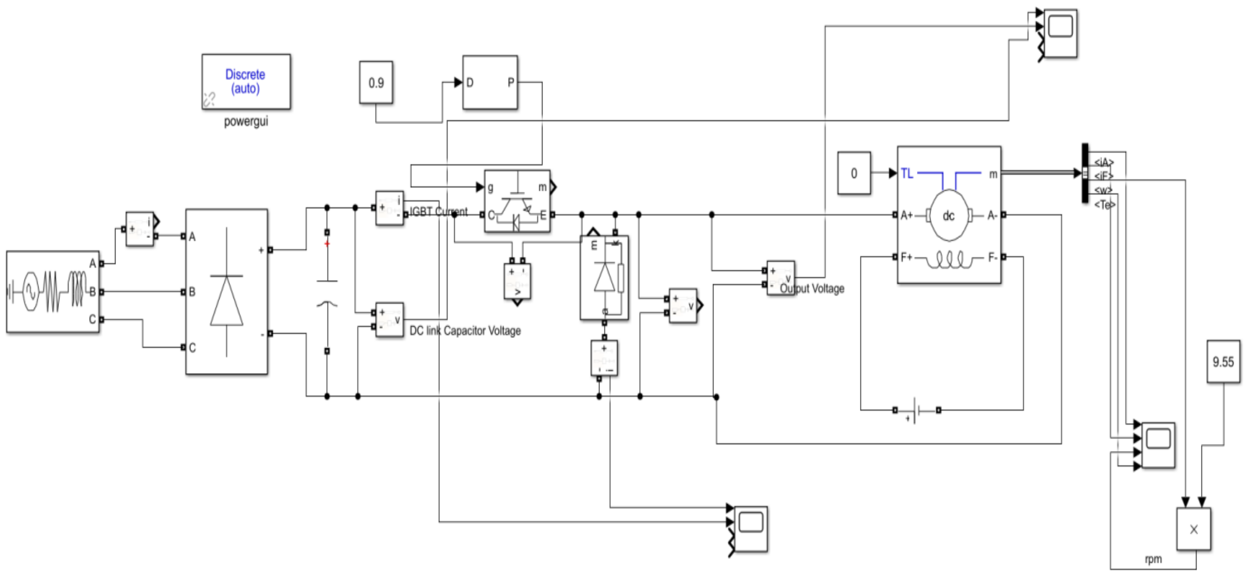

Figure 1: Controlled rectifier design simulation schematic

We simulate our circuit in %5, %50 and %90 duty cycles. Reasons for selecting these duty cycles are explained in next sections.

% 5 Duty Cycle Results

Since we will be exposed to high starting currents, we needed know peak currents and voltages for each component. Hence, we think it would be suitable to run the simulation at %5 duty cycle.

Peak voltages of IGBT and diode of the buck converter is indicated in Figure 2.

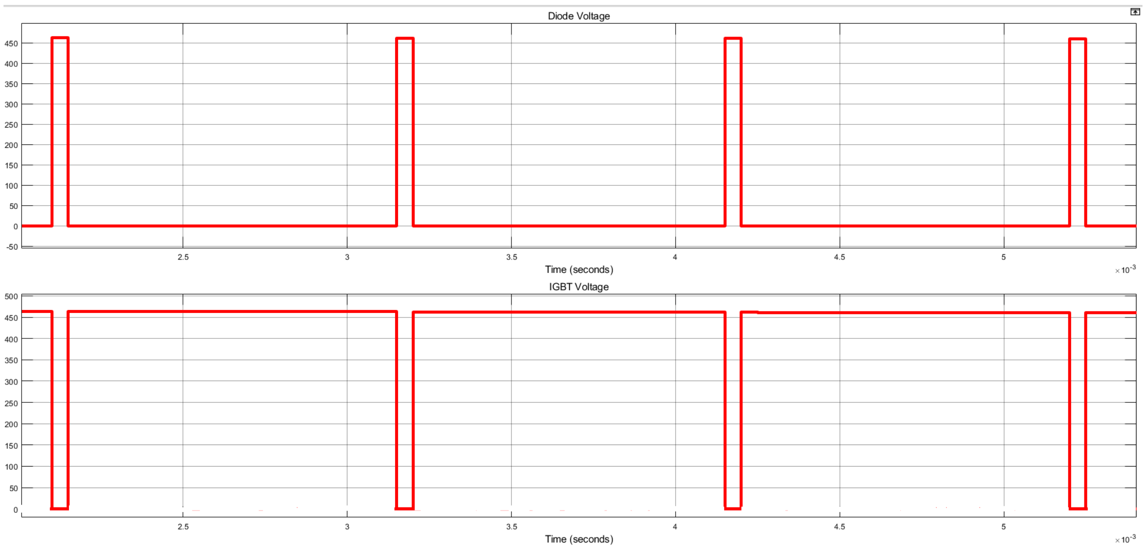

Figure 2: Voltage vs. time graphs of diode (top) and IGBT (bottom) for %5 duty cycle

As seen in the Figure 2 both diode and IGBT has 465 V peak voltages. Peak currents of these components are shown in Figure 3.

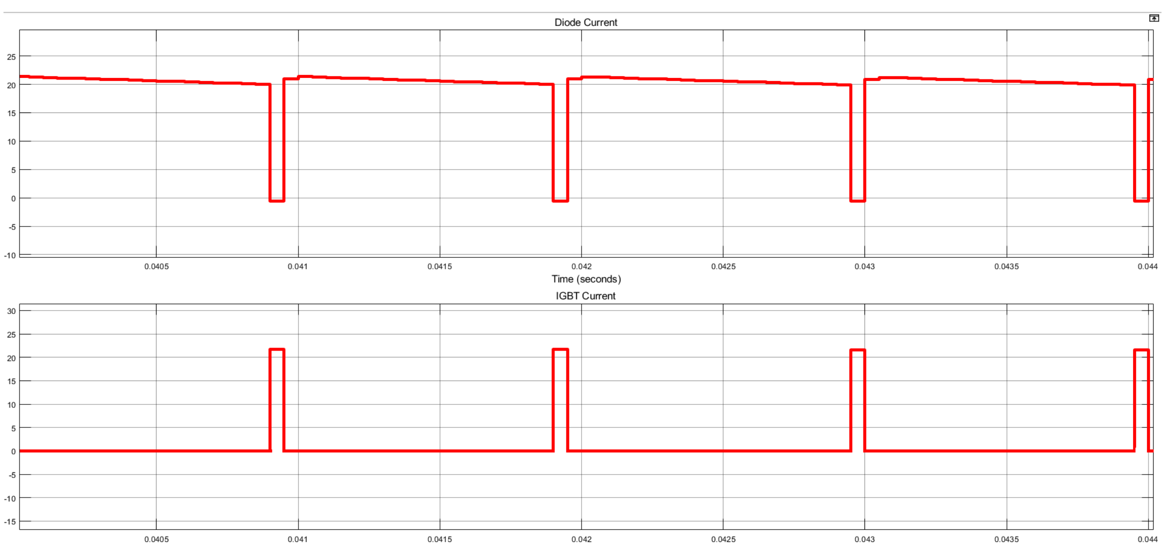

Figure 3: Current vs. time graphs of diode (top) and IGBT (bottom) for %5 duty cycle

Approximately 21 A current is passing through diode and IGBT for 0.5 sec. Output voltage and DC link capacitor voltage is also shown in Figure 4.

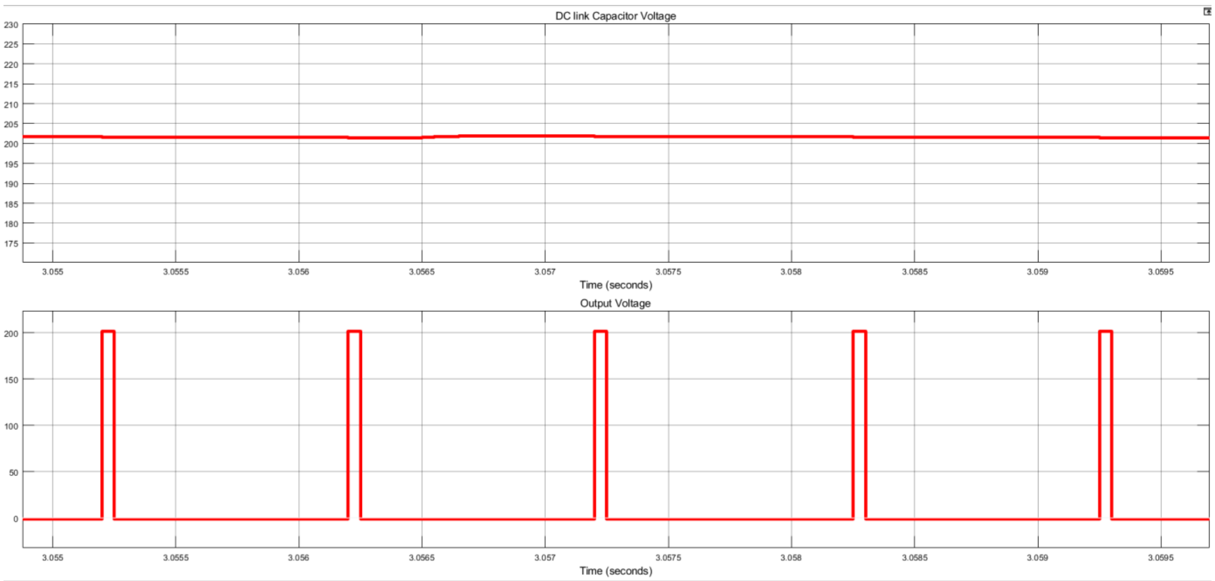

Figure 4: DC link Capacitor (top) and Output voltage (bottom) vs. time graph for %5 duty cycle

Lastly, for %5 duty cycle DC motor parameters indicated in Figure 5.

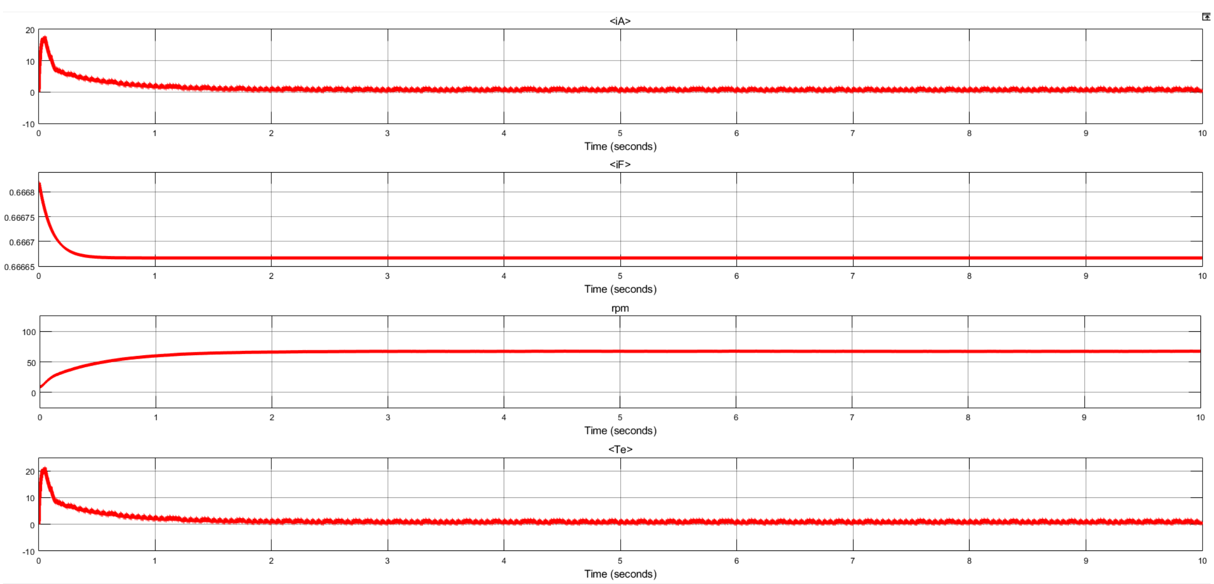

Figure 5: Armature current (1st), field current (2nd) , rpm (3rd) torque (4th) vs time graphs for %5 duty cycle

% 50 Duty Cycle Results

In order to be sure from chosen topology we simulate our circuit also in % 50. In the Figure 6 below DC link capacitor voltage and output voltage are shown.

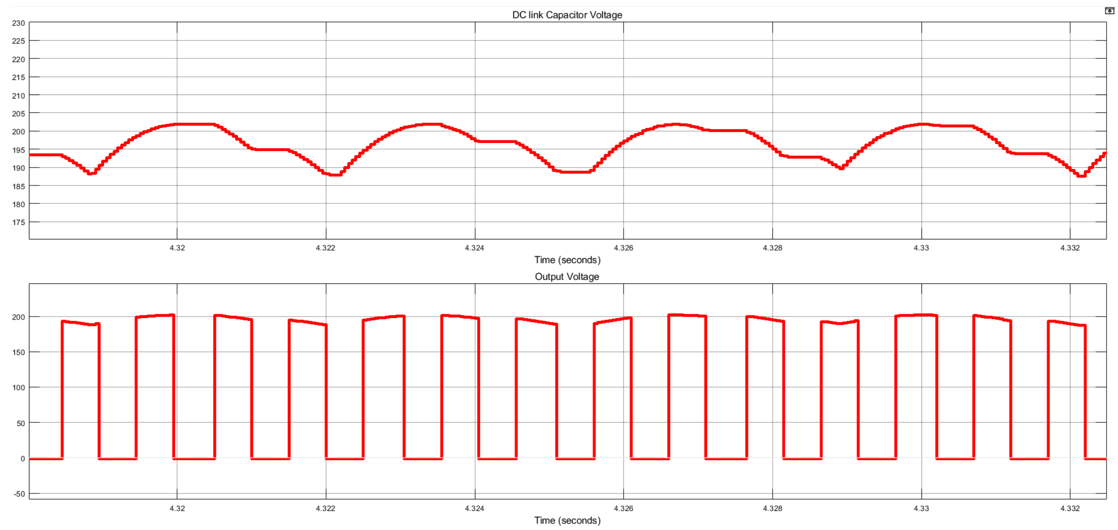

Figure 6: DC link Capacitor (top) and Output voltage (bottom) vs. time graphs for %50 duty cycle

DC motor parameters for this duty cycle are also shown in Figure 7. Note that high armature current at the starting pf the motor is not important, since we will not start the motor from %50 duty cycle.

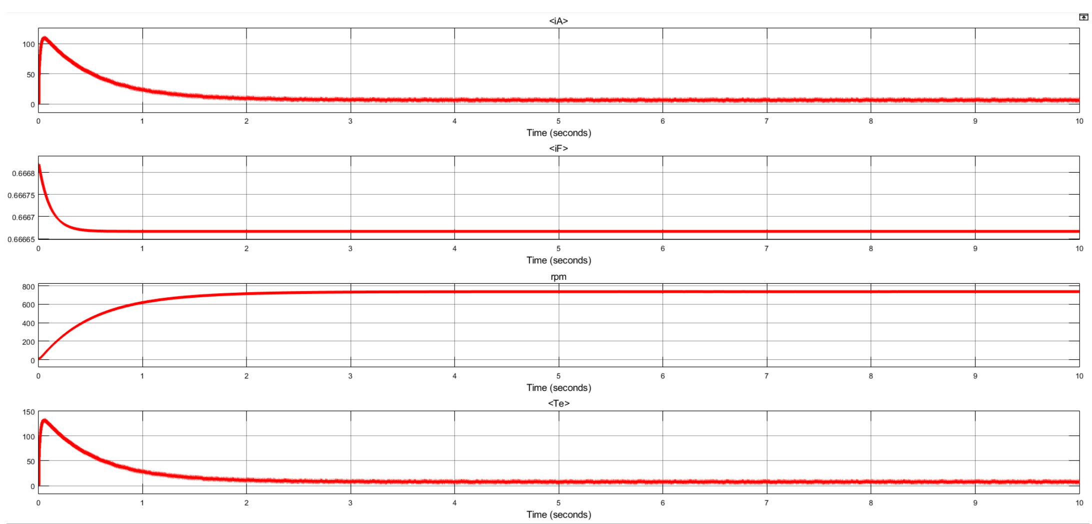

Figure 7: Armature current (1st), field current (2nd) , rpm (3rd) torque (4th) vs. time graphs for %5 duty cycle

% 90 Duty Cycle Results

Since continuous operation of the motor will be done around full duty cycle, we also added results of this simulation. Note that all the simulations before done at no load conditions, however for robust design bonus we have done this duty cycle simulation under load. First, we looked at continuous current values at steady state for diode and IGBT results are indicated in Figure 8.

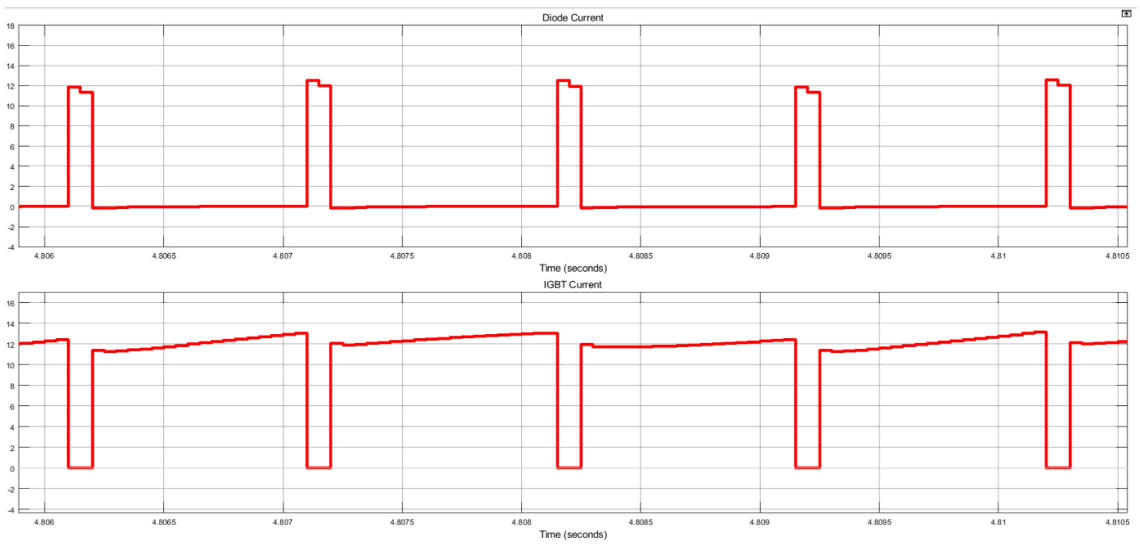

Figure 8: Steady state diode current (top) and IGBT current (bottom) vs. time graphs at %90 duty cycle

DC link capacitor and output voltages for this duty cycle added in Figure 9.

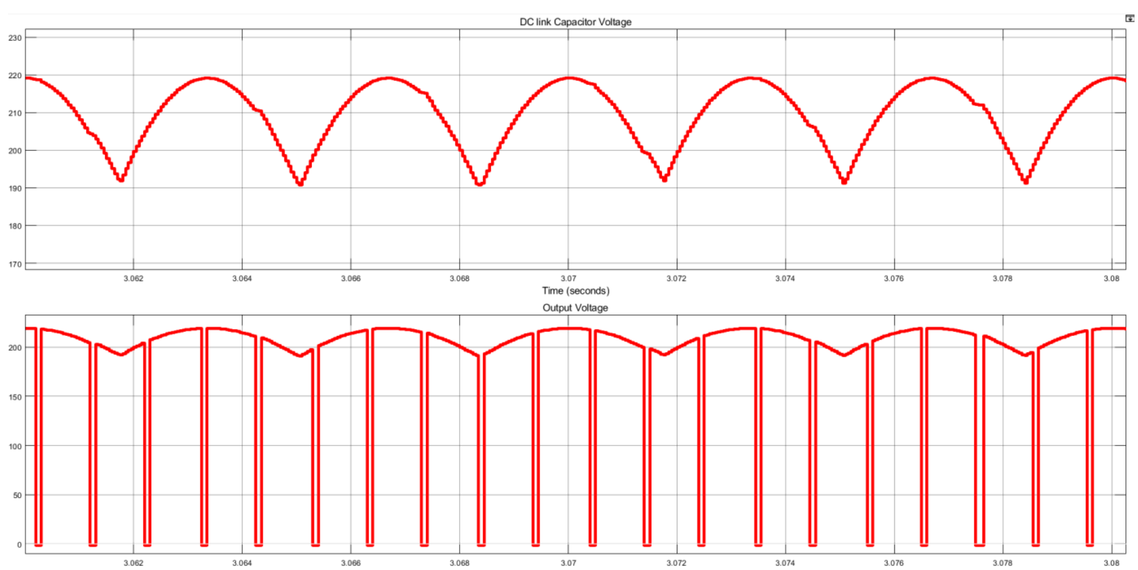

Figure 9: DC link Capacitor (top) and Output voltage (bottom) vs. time graphs for %90 duty cycle

Lastly graphs of motor parameters indicated in Figure 10.

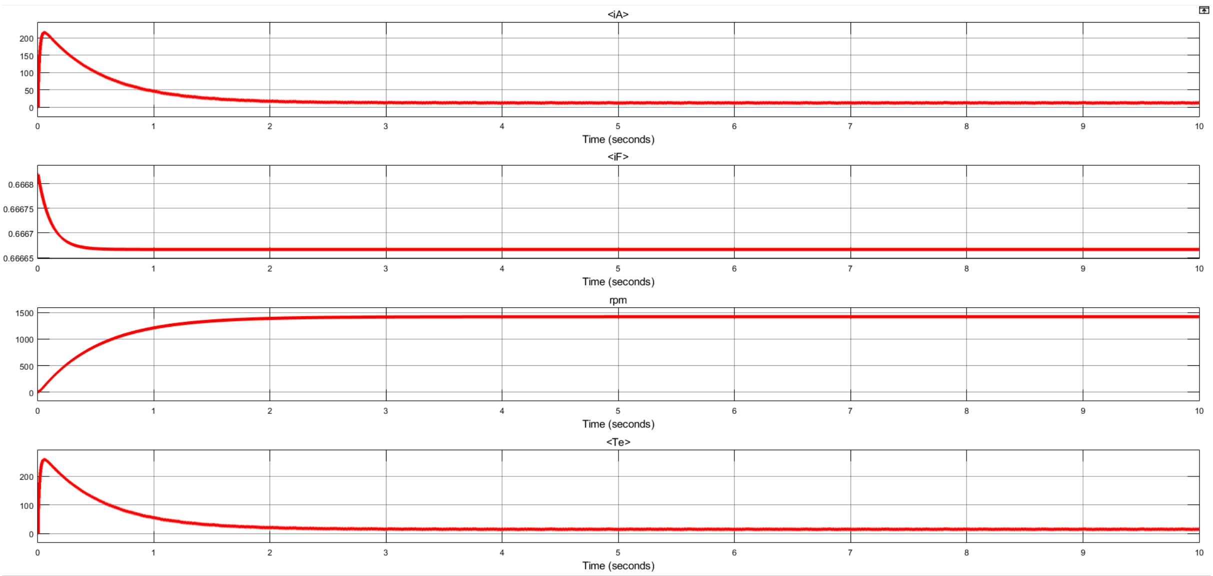

Figure 10: Armature current (1st), field current (2nd), rpm (3rd) torque (4th) vs. time graphs for %90 duty cycle

To conclude each of these simulations are important when selecting right component. Voltage and current values are observed in these simulations used in the component selection section. We tried to include non-idealities to our simulations in order to get more realistic results, however it will not be like real application.

COMPONENT SELECTION

After completing simulations next step is deciding components. We explained why we select 3-phase diode rectifier + buck converter topology but in this section, we try to explain why we select the specific components.

3-Phase Bridge Rectifier

First component of our topology is 3-phase full wave bridge rectifier. We select 3-phase instead of single phase since ripple at the output voltage is smaller as a result 3-phase rectifier require smaller capacitor. Selected component and its important parameter listed in Table 1.

Table 1: 3-phase full wave bridge rectifier parameters

Model Name	MDA 1505-2 7346
Peak Reverse Voltage	1200 V
DC output voltage	570 V
DC output current	8 A @ 55^0C
Peak full wave one cycle surge current	200 A
Peak full wave recurrent forward current	45 A

Also note that we decided to use this component and not use 6 separate diodes, since using 6 diodes will cause increase in size and connection which might be problematic.

DC-Link Capacitor

Although we have 3- phase rectifier we still require a capacitor to have more DC like input for buck converter. To achieve this, we used a capacitor that we decided on simulations. Our capacitor is 470 µF and voltage rating is up to 630 V.

IGBT

As explained in the solution approach section we chose IGBT over MOSFET. There are also MOSFETs available for our application, however we chose IGBT since it can withstand higher voltages. Chosen IGBT model and its technical specifications indicated in Table 2.

Table 2: IGBT model and its technical data

Collector-Emitter Voltage	1200 V
Gate-Emitter Voltage	+- 20 V
Collector Current	50 A @ 25^0C
Pulsed Collector Current	75 A
Diode Continuous Forward Current	25 A @ 100^0C
Diode Maximum Forward Current	150 A
Diode Maximum Forward Current	-55^0C to + 150^0C

Thermal characteristics of the IGBT are written in the thermal design section. Since we do not need to have high switching frequencies, our IGBT will have 980 Hz switching frequency. This value is Arduino's own value.

Diode

To complete buck converter design we need to have a diode. Other than its voltage and current restrictions we need to have diode that has fast recovery time. Considering these factors, we choose a diode, chosen diode and technical data of it shown in Table 3.

Table 3: Buck converter diode and its specifications

Peak Repetitive Reverse Voltage	1200 V
Average Rectified Forward Current	30 A
Repetitive Peak Surge Current	60 A
Nonrepetitive Peak Surge Current	300 A
Forward Voltage	2.6 V
Reverse Current	250 μA
Reverse recovery time	85 ns

RC Snubber

We used RC snubber and its purpose was explained in solution approach section. W used a calculator for R and C values. This basic calculator takes peak current, rise time, peak voltage, switching frequency of the IGBT and gives a result. Our snubber is consisting of 33 ohm and 2-watt resistor and 3.3 nF 630 V capacitor.

THERMAL DESIGN

In order select proper heatsink we made thermal design calculations. Thermal and switching characteristic of the IGBT indicated in Table 4.

Table 4: Thermal and switching characteristic of IGBT

Thermal Resistance, Junction-to-Case for IGBT	0.4 °C/W
Thermal Resistance, Junction-to-Case for Diode	2 °C/W
Thermal Resistance, Junction-to-Ambient	40 °C/W
Turn-On Switching Loss	4.1 mJ
Turn-Off Switching Loss	0.96 mJ

Using these values first we calculate conduction switching losses.

$$P_{\text{total loss}} = 12.475\ \text{W}$$

After finding this value we choose suitable maximum junction temperature. As a result, we find that we need maximum heatsink thermal resistance is 8.6 °C/W. Our heatsink package is TO-247 and datasheet of the selected heatsink indicated in appendices section. Moreover, since IGBT warm-up more we used same heatsink for diode as well. Lastly, we decided to use a DC fan for forced cooling, since we will put the PCB into a box.

TEST RESULTS

The following test results include R-load tests for different duty cycles applied. For RL-load tests, we prefer to give directly the demonstration results since DC motor itself is an actual RL load hence sufficient.

R-Load Tests

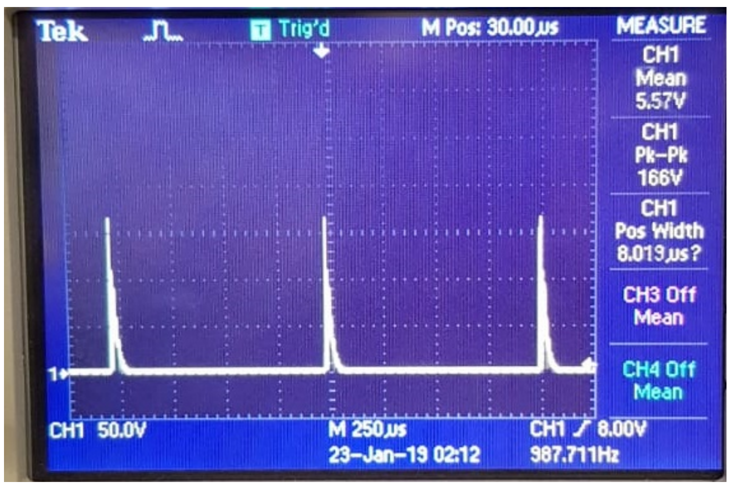

Figure 11: R load test results for nearly zero duty cycle. Vavg(o/p) =5.57 V

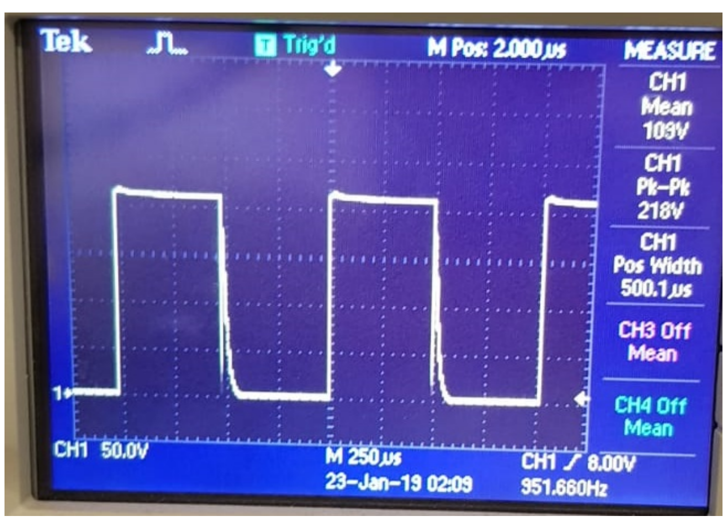

Figure 12: R load test results for 50% duty cycle. Vavg(o/p) =109 V

Figure 13: R load test results for 90% duty cycle. Vavg(o/p) =195 V

As can be seen from the figures above, our system performs like expected for R-load case i.e. it satisfies the requirement of $V_o=V_{in}*D$ which is totally okay for our purposes. Note that these are the values when LC-filter is taken out from the system which is our final decision.

DEMONSTRATION RESULTS

The following six figures illustrate the armature voltage, armature current and thermal values (for IGBT which is the component that really gets affected from temperature rises. Note that diode performance is also critical in this manner, but its temperature did not go further from 35 degrees thanks to the heatsink coupled to it) for the unloaded and loaded cases respectively. Noting that the armature voltage is desired to be 200 V for unloaded operation, Figure 14 shows that this requirement is satisfied. Meanwhile, 0.5 A current (Figure 15) is drawn in armature terminals which is indeed safe because of choosing our equipment with larger ratings (i.e. bearing up to 25 A). In Figure 16 thermal readings of IGBT is shown to be 53.1°C. Keeping in mind that our IGBT can bear up to 150°C, the measured value does not constitute any danger to our system. Figure 17, 18 and 18belong to the loaded case which is a bonus part that we were able to manage. As can be seen from Figure 17, armature voltage (170 V) has deviated from 200V a little because of loading and hence normal. Meanwhile, armature current has increased up to 3.5 A (Figure 18) again due to the loading. Nevertheless, this increase in the armature current and related heat increase (shown as 71.8°C in Figure 19) did not harm any of our components thanks to our thermal design.

- Note that all of the measurements shown below (figures 14, 15, 16, 17, 18 and 19) are taken when 100% duty cycle applied which is the most difficult case to come over because of enormous temperature rise.

Unloaded Case (100% duty)

Figure 14: Armature voltage for unloaded case, 200 V in rms

Figure 15: Armature current for unloaded case, 0.6 A in rms

Figure 16: Thermal readings for IGBT (unloaded case), 53.1°C

Loaded Case: (100% duty)

Figure 17: Armature voltage for loaded case, 170 V in rms

Figure 18: Armature current for loaded case, 3.5 A in rms

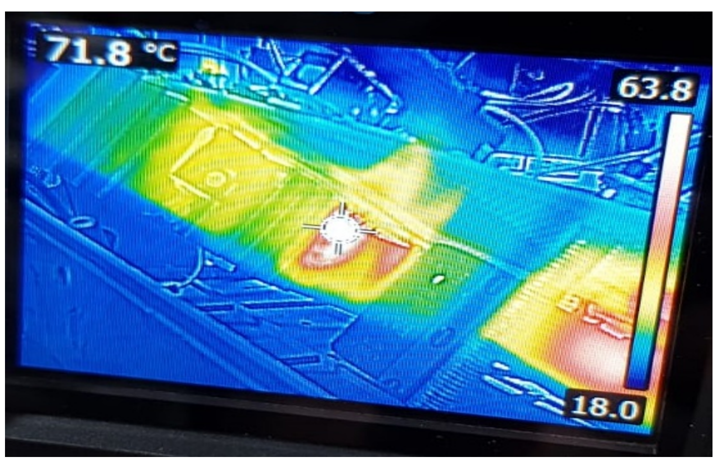

Figure 19: Thermal readings for IGBT (loaded case), 71.8°C

Oscilloscope Readings from Demo

<u>Note that in Figures 20 and 21:</u>

- Yellow: Output Voltage
- Blue: Output Current
- Purple: Output Power

Figure 20: Output voltage, current and power readings for unloaded case

Figure 21: Output voltage, current and power readings for unloaded case

As can be seen from figures 10 and 11, the voltage and current values are consistent with what we have stated (voltage decreases and current increases with loading) at the beginning of this section. Looking from above figures, two things worth to point out here:

1. Our output current does not go into discontinuous conduction mode.
2. Power drawn from motor increases with loading.

SWITCH CONTROL SOFTWARE

In order to make use of the IGBT which is used as a switching component in the circuit, a software which controls the switching characteristics of the IGBT was needed. For this purpose, as mentioned, Arduino Uno was used to read all the analog values from a potentiometer which determines the duty cycle of the circuit and gives digital 5 Volt output according to the desired frequency and output. This output signal of the Arduino is feeding the input pin of the Optocoupler IC which is TLP250 in our case. The codes of the Arduino (with the explanations of each line) which controls the switching frequency and digital output is given below:

```
// Analog input pin is defined that the potentiometer is connected to.
const int analogInPin = A1;
// Analog output pin defined that the TLP250 is connected.
const int analogOutPin = 11;

// The values of the pot is defined.
int POTValue = 0;

// value output to the PWM.
int DutyCycle = 0;

void setup()
{

  // initialize serial communications at 9600 bps:
  Serial.begin(9600);

  // Sets frequency.
  TCCR2B = TCCR2B & 0b11111000 | 0x03;

}

void loop()
{

  // Reads the analog in value:
  POTValue = analogRead(analogInPin);

  // Maps it to the range of the analog out:
  DutyCycle = map(POTValue, 0, 1023, 0, 205);

  // Changes the analog output value:
  analogWrite(analogOutPin, DutyCycle);

  // Print the results to the Serial Monitor:
  // This is used on computer to see the output.

  Serial.print("POTValue = ");
  Serial.print(POTValue);
  Serial.print("\t DutyCycle = ");
  Serial.println(DutyCycle/2.55);

  delay(2);

}
```

The optocoupler is used in order to isolate the control circuit from the main power flowing circuit. Besides this Arduino gives 0-5V output, however IGBT needs 12-17V voltage difference between its terminals to make the switching operation. The other advantage/use of the optocoupler is driving the IGBT. The datasheet of TLP250 is given below:

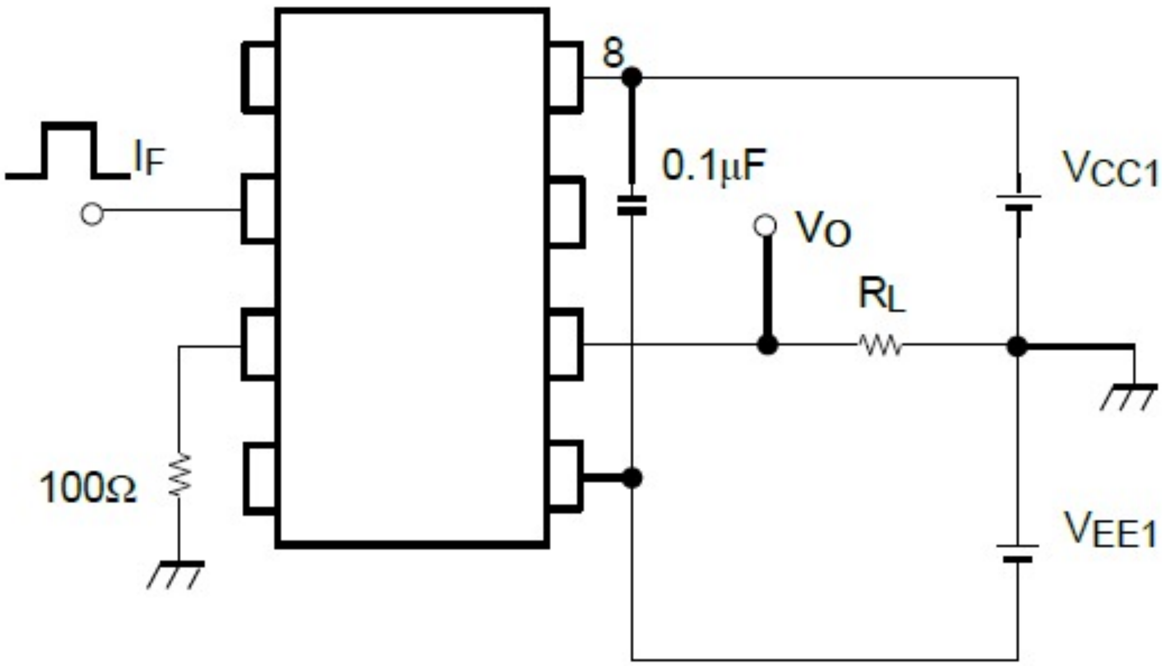

Figure 22: The Connection diagram of TLP250

EXPENDITURES

Table 5: Cost Table

Item Name	Quantity	Cost
3-Ph Bridge Rectifier	1	25 TL
DC-Link Capacitor (470 uF)	1	30 TL
Buck Converter Capacitor (270 uF)	1	20 TL
IGBT	4 (burn-outs included)	40 TL
Diode	1	12 TL
Pot (10K)	1	1.5 TL
Inductor Core	1	47 TL
Inductor Copper Wire	10 meters	15 TL
Snubber (R+C)	1	1 TL
Optocoupler	1	9.5 TL
Heatsink	2	16 TL
PCB	1	15 TL
Cables	3 meters	15 TL
Casing Box	1	50 TL
Others	-	10 TL
Overall Cost		**307 TL**

As can be seen from the table above, we spent approximately 300 TL to build this project which may seem to be more than enough but note that we picked our equipment among the ones that have higher threshold values for the sake of our design and hence their costs are a little higher than the others. Apart from burning out 3 of our IGBTs, we did not give any harm to any other component in our design. So, it was not a bad idea to choose our components a little more expensive in order to have larger rated values and hence a safer operation. Also note that we decided not to use our LC filter just before demonstration. So, it actually diminishes our cost by 70 TL.

CONCLUSION & DISCREPANCIES

In this year's hardware project, we aimed to make a controllable (PWM) DC motor drive circuitry for an industrial type f DC motor by utilizing a 3-phase diode rectifier bridge and a buck converter topology. In this manner we took a few steps that have feedback loops i.e. there are return backs such as:

- Setting up simulations.
- Equipment selection according to simulations (safety margins applied).
- Implementation on the physical environment.
- Calibration of each component to the main circuitry and also to other components.
- Tests on R-load.
- Tests on DC motor which is the real application.

Apart from the general procedure we had the chance to get experienced in many respects relating the power electronics' practical applications that actually introduced us some real-life problems and possible discrepancies between simulation results and real applications while dealing with such kind of a project which can be listed as:

- While deciding the ratings of the components, only looking at the steady state values are not sufficient. Actually, the decisive thing while choosing them is the surge values for both voltage and current. If these values are not taken into account, we may burn our equipment.

- In power electronics area, thermal design for the critical components (IGBT and diode for our case) is very critical because the drawn currents are not in the level of milliamperes. Instead they are a few amperes which may cause our equipment to heat up excessively then breakdown. In this manner we coupled heatsinks to IGBT and diode. But also note that the heatsinks cannot prevent our devices from burning due to excessive heat, instead they just slow down the procedure.

- While mounting the components in PCB, their orientation constitutes great importance in terms of dealing with less non-idealities such as parasitic effects originating from the lengths of cables and/or unintended inductance loops due to some of the components being non-planar with respect to each other. In fact, we used an external breadboard in our design which may have caused those parasitic effects to increase due to being placed as non-planar with the PCB. However, this situation luckily did not distort the operation of our design.

- Isolating the high voltage side of the circuitry from the signal generating side is vital for the long-lasting of the utilized controller like Arduino in our case. For this purpose, isolator circuitries may be used like TLP250 which can deliver signals by using light hence is able to make isolation.

- Using equipment/s (LC filter in our case) whose selection is done according to rough calculations is nonsense since it may not help the circuitry to perform better. On the contrary, it is highly probable for that equipment to corrupt the desired operation.

- In power electronic project, we may need to use a number of protective components such as snubbers, fuses, opto-couplers that are crucial for a safe operation.

- Trusting only the simulation results and choosing the components by just taking them into account may destroy the aimed system since there are many non-ideal effects in real life applications such as parasitic effects, time needed for charge and discharge capacitors, losses on the cables, unintended inductive loops, speed of the operation and resulting switching losses in addition to the conduction losses. Thus, adding as much as non-idealities to the simulations and choosing components with reasonable safety margins diminish the effect of Murphy's laws.

- We also learnt that rate of changing the duty cycle with potentiometer a little rapidly can cause our IGBT to burn out. There is no remedy for this situation like using trim pots having more turns instead of potentiometer having fewer turns. In fact, trim pots performed not as good as potentiometer. The critical thing here is to appreciate that output voltage does not change as linearly as expected with the PWM arranged. Hence, it is vitally important to arrange PWM as slowly as possible in order not to be affected from the inertia of the motor which can cause IGBT to burn out.

- Apart from all of these above, we now are more experienced in managing time and stress in a 3 people project which we hope to be beneficial for our professional lives.

APPENDICES

This part includes mainly the datasheets of the chosen components that are elaborated in the previous sections and also the YouTube link for the trailer video:

3-ph diode bridge rectifier:
[1]
https://www.datasheet.live/index.php?title=Special:PdfViewer&url=https%3A%2F%2Fpdf.datasheet.live%2F35576c26%2Ffreescale.com%2FMDA942-1.pdf

DC-link capacitor:
[2] https://www.mouser.com.tr/datasheet/2/427/259phmsi-1289014.pdf

IGBT:
[3] http://pdf1.alldatasheet.com/datasheet-pdf/view/104921/FAIRCHILD/FGA25N120ANTD.html

Diode:
[4] http://pdf1.alldatasheet.com/datasheet-pdf/view/54448/FAIRCHILD/RHRG30120.html

Opto-coupler:
[5] http://pdf1.alldatasheet.com/datasheet-pdf/view/32418/TOSHIBA/TLP250.html

Toroid for inductor:
[6] https://www.mag-inc.com/Media/Magnetics/Datasheets/ZW46113TC.pdf

Capacitor for LC-filter:
[7] https://www.mouser.com.tr/datasheet/2/293/LGM_e-953550.pdf

Heatsinks:
[8] https://eu.mouser.com/datasheet/2/303/sink_r2-1265503.pdf

YouTube link for trailer video:
[9] https://youtu.be/HsMJPRiH0SY

REFERENCES

[1] https://www.digikey.com/products/en

[2] https://www.mouser.com.tr/Electronic-Components/

[3] http://uni-site.ir/khuelec/wp-content/uploads/Mohan-Power-Electronics.pdf

[4] http://keysan.me/ee463/

[5] http://what-when-how.com/motors-and-drives/dc-drives-motors-and-drives/

[6] https://www.researchgate.net/publication/249993508_AC-DC_DC-DC_Converters_for_DC_Motor_Drives_Review_of_basic_topologies

[7]ftp://doc.nit.ac.ir/cee/power/sheykholeslami.abdorreza/power%20electronic%20book/Power%20Electronics%20Handbook,%20The/7336_pdf_c09.pdf

[8] https://www.daycounter.com/Calculators/Snubbers/Snubber-Design-Calculator.phtml