MIDDLE EAST TECHNICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

E463 – Hardware Project

“DC motor Drive’’

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INTRODUCTION

In this project, we are required to make a controlled rectifier that will be used to drive a DC Motor. As a power input, 3 phase or 1 phase AC Grid which is adjustable with variac are used and output must be adjustable DC output which is higher than 180 V_{dc}. Because variac should not be used to control the voltage while the motor is running, some topologies are used in order to control the speed of DC Motor. These topologies are 3-Phase Thyristor Rectifier, 1-Phase Thyristor Rectifier or Diode Rectifier with Buck Converter.

In this report, firstly, by comparing rectifier topologies we will explain which topology we chose. After selection of rectifier, simulation results on SIMULINK are presented. According to simulation and theoretical results, required components (MOSFET, diode etc.) which have proper current ratings, voltage rating, temperature limit etc. are listed. Finally, test results of demonstration day and test results using different loads are provided.

TOPOLOGY SELECTION

The AC/DC converter can be implemented in many ways. For the motor drive application, the DC output of the converter should be controllable somehow. However, in any case, the input AC voltage will be rectified. There are many rectifier topologies utilizing diodes and thyristors. It should be noted that the output of the diode rectifiers is constant whereas the output of the thyristor rectifiers is adjustable. As discussed before, to be able change the speed of the rotor, a controllable DC voltage is required. This means, if the selected rectifier is a thyristor-based rectifier, then there is no need for supplementary circuitry to adjust the output DC voltage, since it is already adjustable by changing the firing angle of the thyristors. However, if the selected rectifier is a diode rectifier another circuitry must be implemented in order to adjust the output DC voltage. This circuitry is called DC/DC converter in general. In our application, a buck (step-down) converter should be utilized since the load will be a DC machine.

There are two types of rectifiers in terms of how they utilize the input voltage. Full bridge and half bridge. In general, half bridge rectifiers are not used since they give almost the half of the full bridge rectifier DC output voltage. Therefore, we will use full bridge variations.

Another important decision is the number of phases fed into the rectifier. We are given access to three phases. This means, we can choose to supply our rectifier either with a single-phase input or with a three-phase input. A single-phase full bridge rectifier has ripples of two times the frequency of the supplied input whereas a three-phase full bridge rectifier has ripples of six times the frequency of the supplied input. Therefore, if the chosen topology is fed with a single-phase input, in order to reduce the DC output ripple factor a large DC link capacitor is needed at the output of the rectifier. The tradeoff here is the number of rectifying components used. Evidently, for a single-phase rectifier fewer rectifying components are needed. Basically, a single-phase full bridge rectifier requires 4 diodes or thyristors and a three-phase full bridge rectifier requires 6. Also, it should be noted that the three-phase variation will output a much higher DC value. However, this is not a crucial consideration for our application because; firstly, the rated voltage of the DC machine is already low and secondly, we have access to a variac so that we can adjust the AC input of the rectifier so that we have a desired output DC voltage level at the beginning. Therefore, we can conclude that we will make use of three phases.

The last decision is the choice between diode and thyristor rectifier. As explained already diode rectifier outputs an uncontrollable DC voltage and hence a buck converter is needed. Buck converter is a very simple circuitry. It requires a switching device such as a MOSFET and filtering components such as a capacitor and an inductor. Also, a PWM signal which can be easily created is required for the switching device. Thyristor rectifier outputs a variable DC voltage by changing the firing angles of each thyristors. We have chosen that the rectifier will be a three-phase rectifier which means there will be 6 individual thyristors. At each firing instance two thyristors will be fired. Then after 60 degrees another set of thyristors will be fired. Generating these gate signals is a much harder procedure than designing a buck converter. Therefore, the topology we are going to implement is a three-phase full bridge diode rectifier followed by a buck converter.

At the end, we ended up with a chopper topology instead of a buck converter. We have taken out the low pass filter that way we had better experimental results.

SIMULATION RESULTS

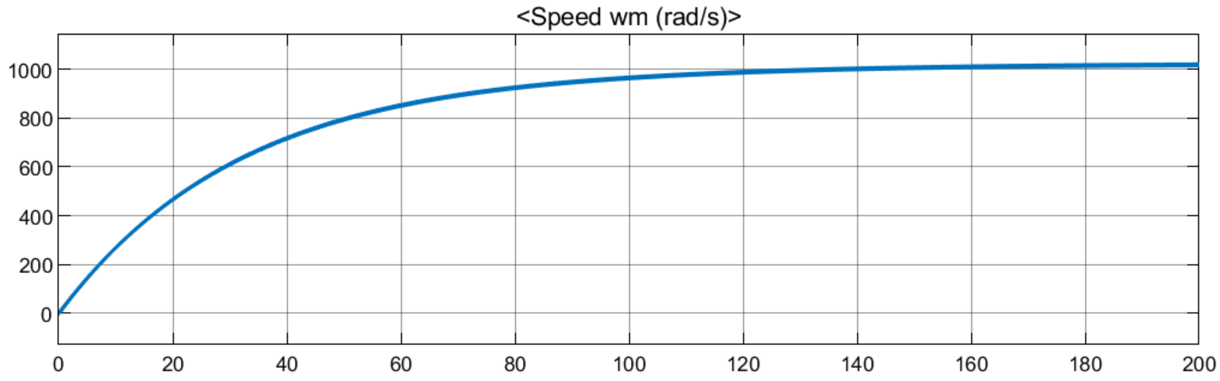


Figure: Speed with duty cycle 0.95, input voltage 220 V, armature voltage 205 V

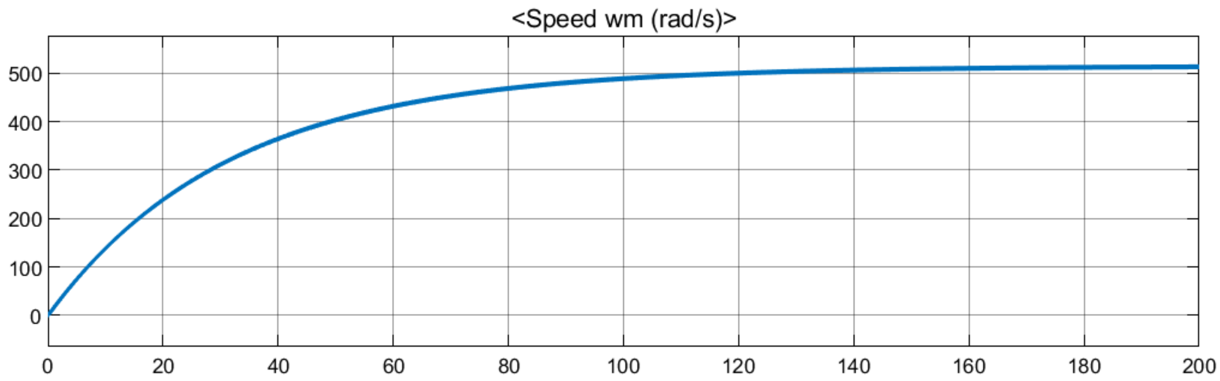


Figure: Speed with duty cycle 0.5, input voltage 220 V, armature voltage 110 V

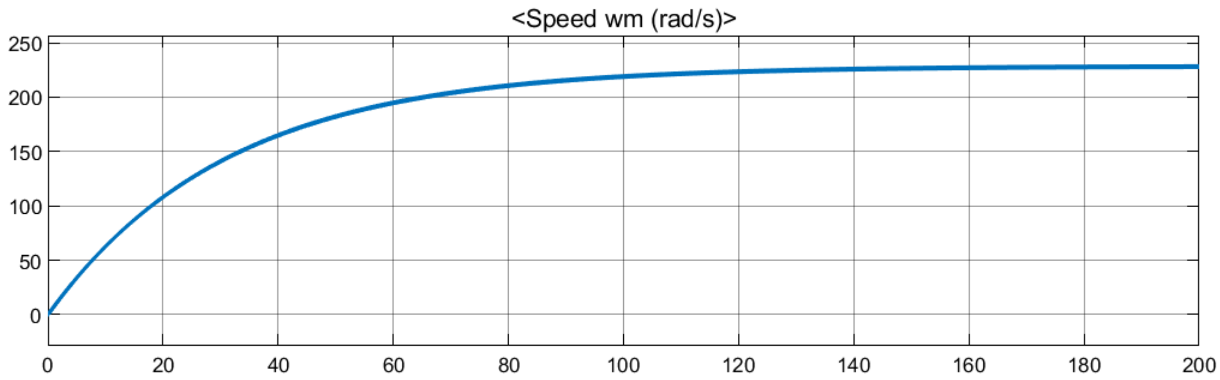


Figure: Speed with duty cycle 0.25, input voltage 220 V, armature voltage 55 V

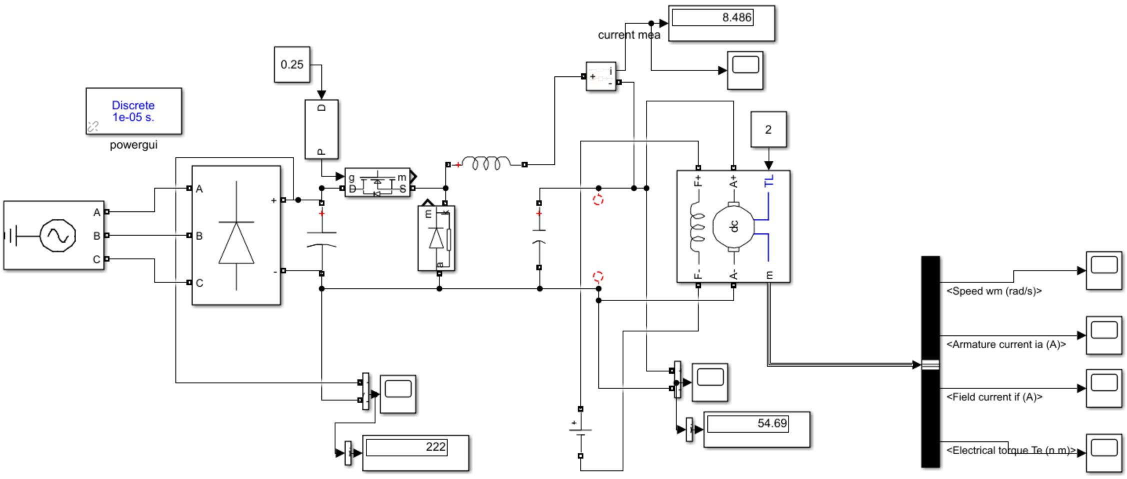


Figure: Simulink diagram

COMPONENT SELECTION

While deciding which component to use, we considered rated voltage and current values. Since the rated voltage 200 V and we were required to supply a power of 2 kW, we chose 400 V and above 15 A for the rated voltage and rated current.

- MOSFET: IRFP460

Drain to Source Voltage	500 V
Drain to Source ON Resistance	0.27 Ω
Continuous Drain current at room temperature	20 A

- 3-phase diode rectifier: SKBPC3504

VRRM	400 V
Forward rectified current	35 A

- Freewheeling diode: BY229-600

VRRM	600 V
Forward rectified current at 100 °C	8 A
Reverse Recovery Time	145 ns

- DC Link Capacitor: 470 uF,400V, Electrolytic.

- **Filter Capacitor:** 47uF,400 V, Electrolytic.

- **Optocoupler:** TLP250

- **Arduino Uno**

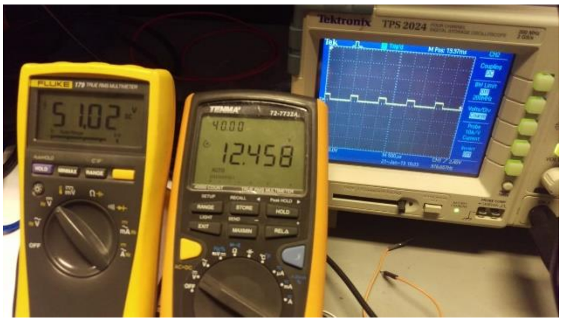
While selecting proper components, some features are considered because circuit is exposed to high voltage and current values. For nearly all components, voltage and current ratings are important. For 3-phase diode Rectifier, requirement is the maximum voltage on diode is 250 Volt. Components which we chose have ratings very above the limits of the requirements because during implementation some problems may occur due to high voltage or current and to prevent this component which have higher ratings can be selected. As a switching element, we chose MOSFET. Apart from current rating, we looked at Drain to Source Voltage of MOSFET which is appropriate for our requirement. Also, to obtain fast switching, MOSFET should have lower gate capacitance and Rds(on). This results in lower conduction and switching losses. For freewheeling diode, we pay attention to current rating and reverse breakdown voltage. Moreover, lower forward voltage of diode causes lower conduction losses.

TEST AND DEMONSTRATION RESULTS

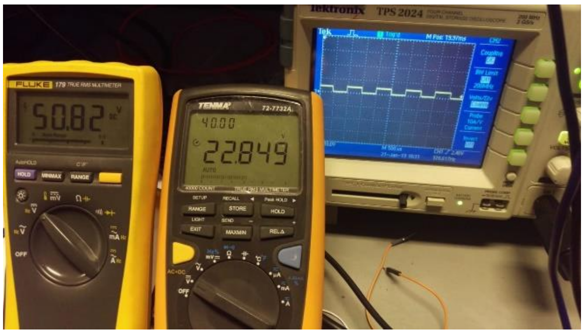
We first designed the buck converter with an LC filter at the output and tried with different loads and different duty cycle values. The switching frequency was 7.8 kHz. After trying the converter with the actual DC motor, the Mosfet burned out. We first lower the switching frequency and remove the LC filter at the output. We made the same tests and tried with the DC motor. We would be able to drive the motor without no load and a load of 2kW (kettle) for 5 minutes this time. The difference was that we just drove the DC motor with a square wave whose average value dependent on the duty cycle rather than a pure DC voltage.

The reason for reducing the switching frequency was that switching loss increases with increasing switching frequency due to the increase in the number of switching per second, thus leading to lower efficiency and higher heat dissipation in the switch. Therefore, we removed the LC filter since the motor has its own inductance value, 12.5mH which is much greater than 2.4mH for the LC filter. Since we cannot remove the inductance in the filter not to short DC link and filter capacitance when the Mosfet is ON, we removed both LC components. Also, lower duty cycle values may not be achievable at much higher switching frequencies resulting in a minimum output voltage which is larger than zero. The voltage would jump from zero to this minimum value instantly at the armature terminal due to mentioned reason above. All in all, there are tradeoffs to design high-frequency switching converters. The main disadvantage is a reduction of efficiency and increased heat dissipation.

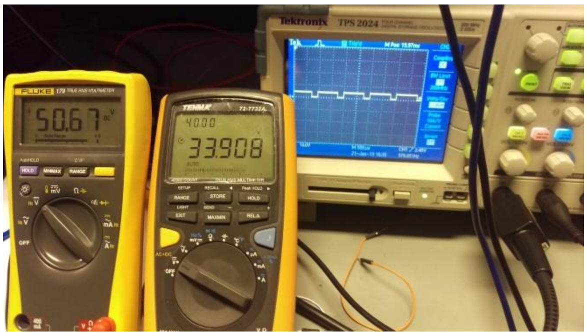
a) Test Results

<table>
<tr><td colspan="2">Duty cycle tests with low input voltages</td></tr>
<tr><td>
</td><td>Left multimeter: Input to the Buck converter

Right Multimeter: Output with R load

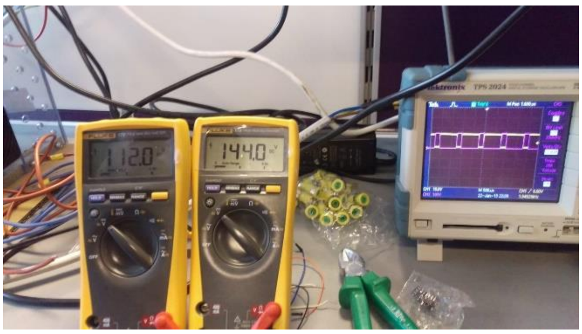
Scope: Duty cycle =0.25</td></tr>
<tr><td>
</td><td>Left multimeter: Input to the Buck converter

Right Multimeter: Output with R load

Scope: Duty cycle =0.5</td></tr>
<tr><td>
</td><td>Left multimeter: Input to the Buck converter

Right Multimeter: Output with R load

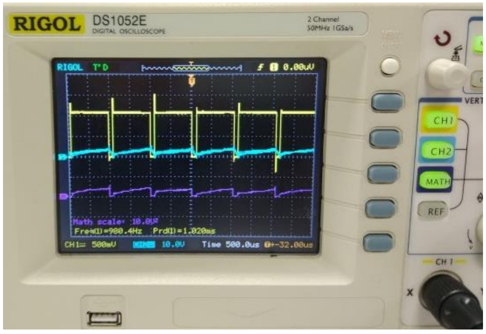
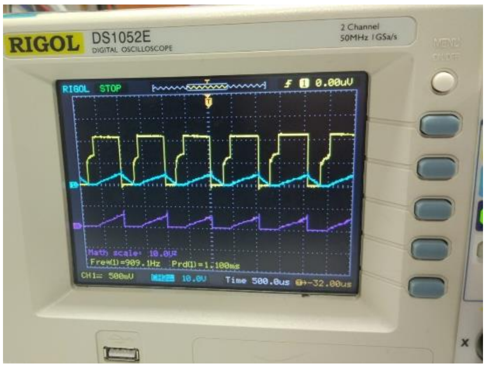
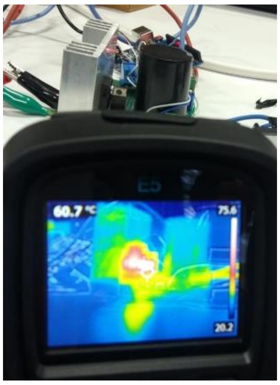
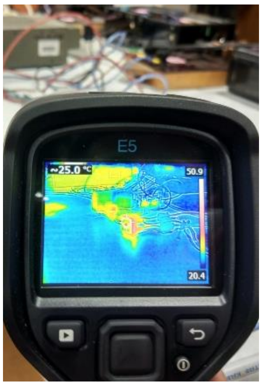
Scope: Duty cycle =0.75</td></tr>
</table>

<table>
<tr><td colspan="2">Duty cycle tests with higher input voltage</td></tr>
<tr><td>
</td><td>Left multimeter: Output voltage with R load, 112 V

Right Multimeter: Input to the Buck converter, 144 V

Scope: Duty cycle = 0.75 (yellow)
: Drain to Source Voltage (purple)</td></tr>
</table>

b) Demonstration Results

	On the scope, the duty cycle
	Discontinuous conduction mode, the back emf (yellow) can be seen when the armature current (blue) is zero
 	The temperatures of the components can be seen, temperature of the freewheeling diode(left) and 3 phase diode(right). With the load, at the end of 5-minute duration the Mosfet temperature rose up to 130 ^{o}C.

Overall Cost

Component names	Pcs	Cost,TL
3 phase diode block	1	35
DC link Capacitor 470 uF	1	22
Mosfet	2	7
Freewheeling diode	1	12
Cored inductor coil	1	12
Filter Capacitor	2	25

Connectors,cables etc.	-	15
Arduino, optocoupler, resistances	-	30
Total		158 TL

CONCLUSION

The aim of this project is to design and implement a controllable DC Motor driver. For topology, 3-Phase Diode Rectifier with Buck Converter is selected. However, in our design buck converter does not have LC filter because while we are trying to our design with LC filter, our design didn't work, but when LC filter is excluded, our design works properly. In the buck converter part switching element (MOSFET) is important in order to obtain proper results. Gate driving of switching element is one of the critical issues for DC-DC applications. Any discrepancies on the gate driver can cause problem on the switching element. Optocoupler should be used for isolation. When choosing components, voltage and current rating should be considered because motor has high startup current. Also, due to differences between simulation experimental results, components which have higher rating value should be selected. On the other hand, during hardware implementation, some issues are important. Temperature is the one of the crucial issues. While circuit is working, temperature of components rises up. At high level temperature, without proper cooling system some components can be burnt. Therefore, heat sink or fan should be used for cooling. Also, thermal paste can be required. Another issue is the stray inductance. Stray inductances affect operation of circuit significantly. The closer switching element (MOSFET), freewheeling diode and the gate driver circuit are, the lower the stray inductance.

As a result, thanks to this project, we had the chance to practice what we learned in EE463. This project showed us how we can make project planning in business life and what difficulties we will face.

Video: https://www.youtube.com/watch?v=V_7s3zLAC80&feature=youtu.be