MIDDLE EAST TECHNICAL UNIVERSITY
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

EE 463- Hardware Project – 2025 Fall

Simulation Report

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INTRODUCTION

In this project, we design and implement a controlled power electronic driver to drive a DC motor to meet the critical technical constraint of a ripple frequency (f_ripple) greater than 1 kHz in the armature current. The system must provide the maximum adjustable DC output voltage of 180 V required by the motor, powered by the existing 3-phase AC mains.

Throughout this report, we will first present the topology selection and analyze it based on parameters such as feasibility, ease of implementation, and cost. Simulation analyses will verify circuit performance, and component selections will be made based on this. Possible bonus features will also be discussed.

TOPOLOGY SELECTION

Single Phase Rectifier Full Bridge Diode Rectifier + Buck Converter

In this topology, the input AC voltage is converted to DC by a four-diode full-bridge rectifier and filtered by a DC-link capacitor. A buck converter (high-frequency switch) then takes this DC voltage and generates the adjustable DC voltage required by the motor. The buck stage meets the critical requirement of f_ripple > 1 kHz.

Pros:

- Simple design.

Cons:

- High Vripple.
- Low fripple.

Centre-Tap Rectifier + Buck Converter

This topology uses a dedicated transformer with a center-tapped winding and only two diodes to convert AC voltage to DC. The voltage from the pre-stage is taken by the buck converter, providing the high ripple frequency (f_ripple > 1 kHz) and adjustable DC voltage required by the motor.

Pros:

- Requires a minimum component.

Cons:

- Cost.
- Complexity.

3 Phase Thyristor Rectifier

This topology allows direct control of the output voltage when converting AC to DC. By using a thyristor (SCR) instead of diodes, the average DC output voltage (V_out) is controlled by adjusting the firing angle (alpha).

Pros:

- Single block control.
- High power capacity.

Cons:

- Does not meet the f_ripple > 1 kHz requirement.
- Complexity.

3 Phase Full Bridge Diode Rectifier + Buck Converter

In this configuration, the three-phase diode rectifier takes a 380 V AC input and creates a stable, high DC voltage (~520 V). This voltage is then taken by the buck converter, providing the adjustable DC output required by the motor. The buck converter's high-frequency switching ensures a ripple frequency of f_ripple > 1 kHz, a critical requirement for the project.

Pros:

- Provides a highly reliable, stable, and high DC voltage.
- Control is simple.
- Easily meets the f_ripple > 1 kHz requirement.
- Cost-effectiveness.

Cons:

- Efficiency could be a problem.

3 Phase Full Bridge Diode Rectifier + Buck Converter topology easily meets switching frequency requirements. It also generates a much more stable and higher DC bus voltage than other single-phase alternatives by utilizing the existing three-phase supply. For these reasons, it was chosen as a reliable and cost-effective solution that best balances high performance requirements with low control complexity.

SIMULATION

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

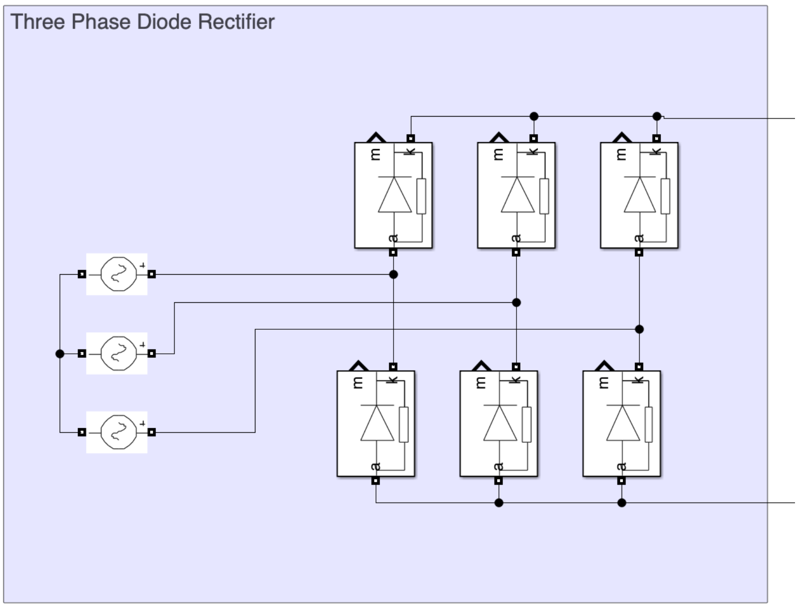


Figure 1. Full Bridge Three Phase Diode Rectifier Topology

We used MATLAB Simulink for simulations. For detecting maximum voltage values and current values, ideal diodes are used.

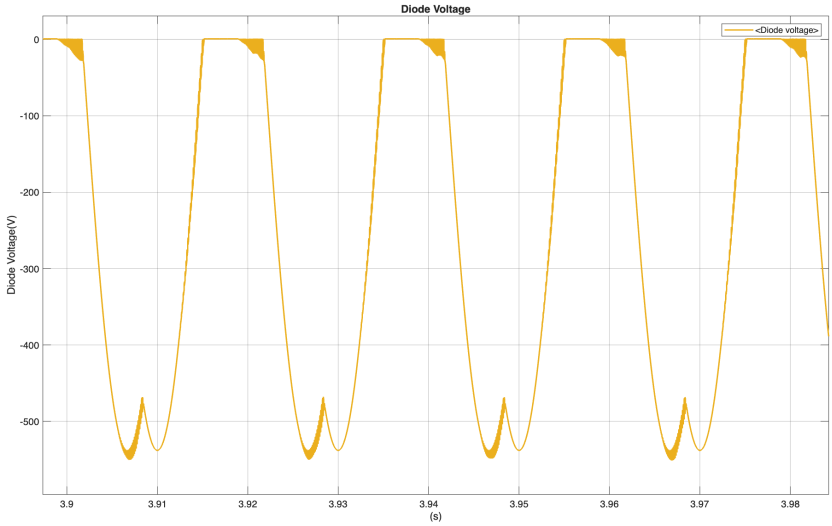


Figure 2. Diode Voltage Waveform

We used the input source as three phase 220 Vrms. Thus our line to line voltage become 380 V_{ll} from the equation $V_{ll} = \frac{\sqrt{2}*V_s}{\sqrt{3}}$, and in diode we need to see its peak value which is 380 times square root 2, 540 V. This value is critical for the diode selection.

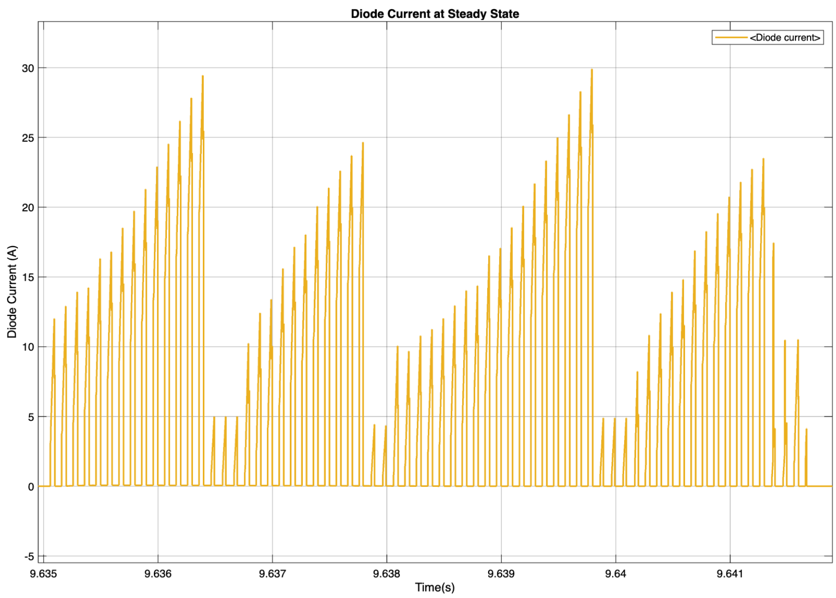


Figure 3. Diode Current at Steady State Waveform

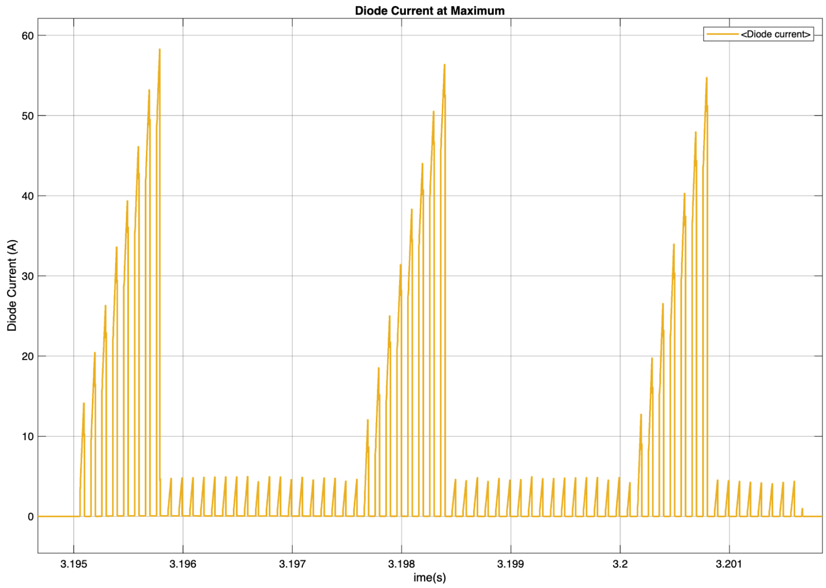


Figure 4. Diode Current at Maximum Waveform

As seen in Figure 4, the maximum current value on the diodes is less than 60 A. It will be the second critical specification for the 3-phase diode rectifier selection. Therefore, current ratings of the diode rectifier must be higher than 60 A.

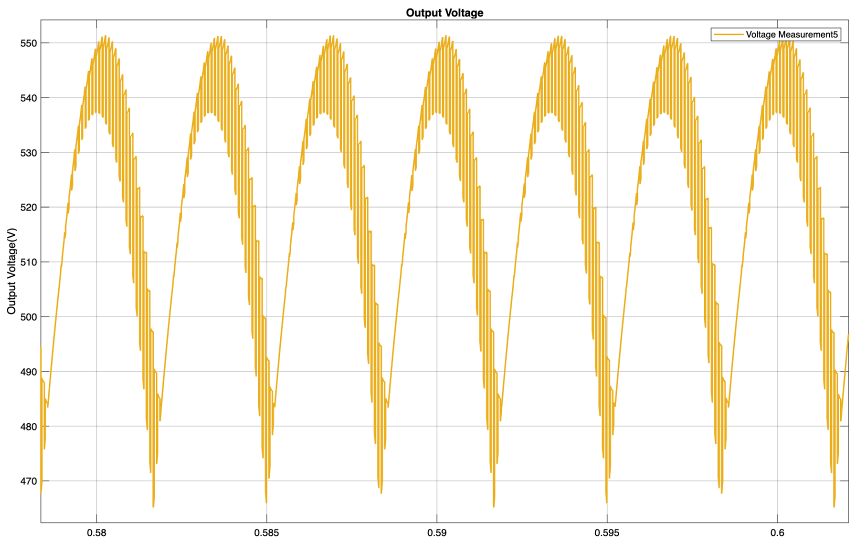


Figure 5. Output Voltage Waveform

As seen in Figure 5, average output voltage is about 530 V. These simulations give us an idea for the maximum voltage case for the 3-phase diode rectifier selection.

$$Voltage\ Ripple\ = \left(1 - \frac{\sqrt{3}}{2}\right)\sqrt{2}V_{L-L} = 75.8V$$

2) Simulations of Buck Converter

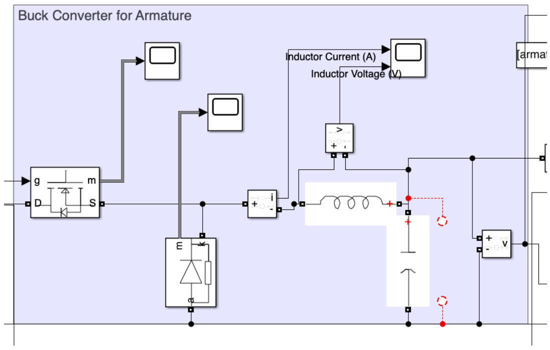


Figure 6. Topology of Buck Converter

We used 10 kHz switching frequency In Figure 7, voltage waveform of MOSFET voltage and current can be seen.

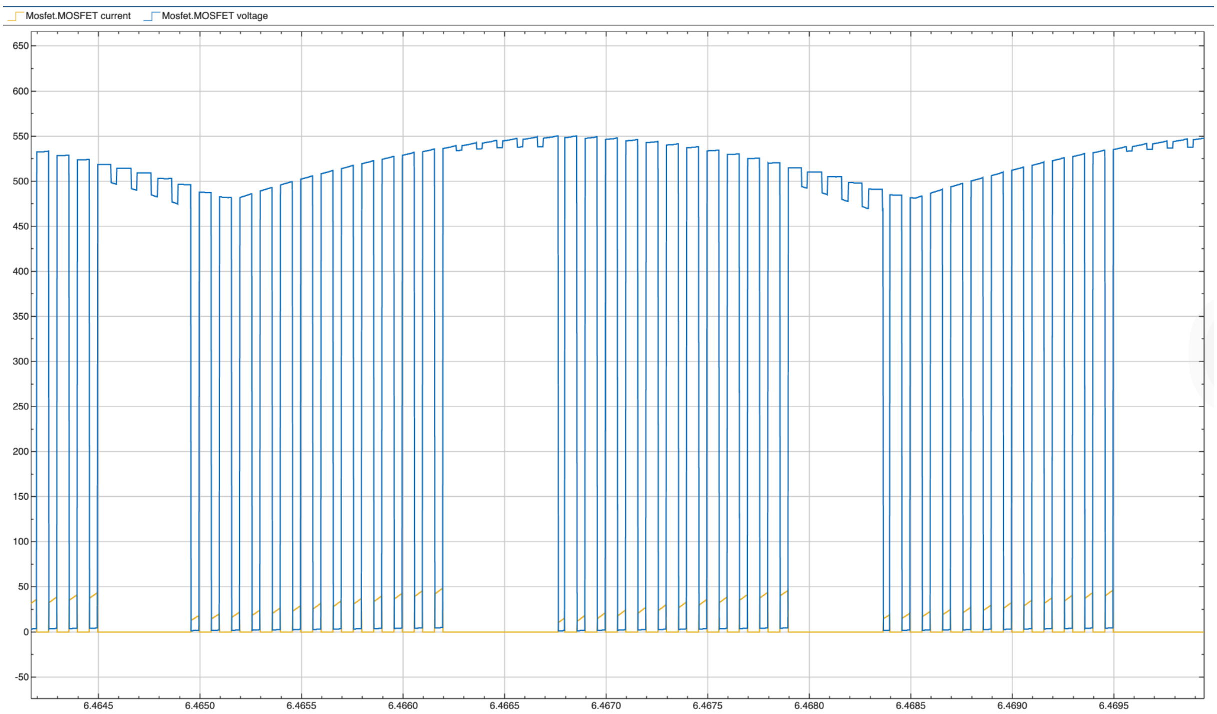


Figure 7. Voltage Waveform of Gate Signal

We used 2.2 mH inductor and 470 µF capacitor is used. These variables can be change according to MOSFET and diode selections. In Figure 8, output voltage waveform can be seen.

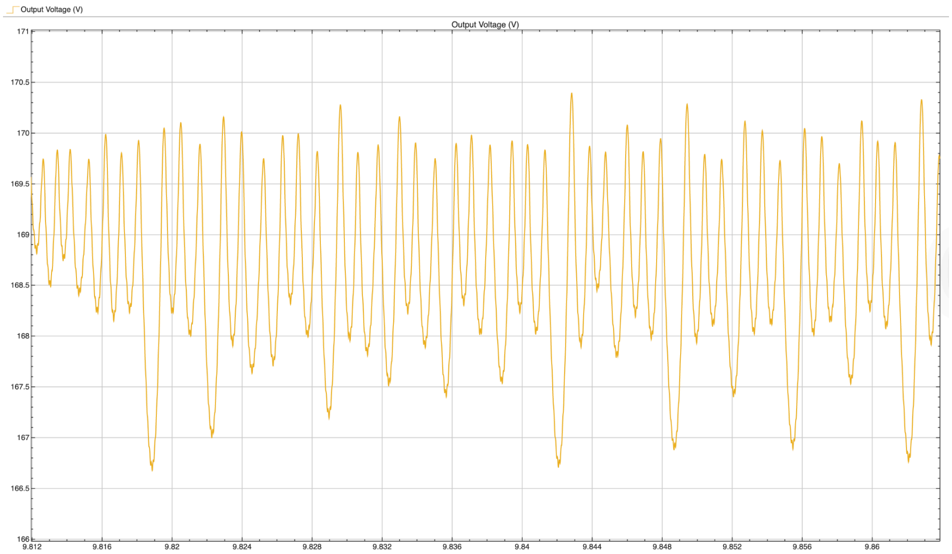


Figure 8. Output Voltage Waveform of Buck Converter

Here, we get our input voltage from output of rectifier. We have 1% ripple.

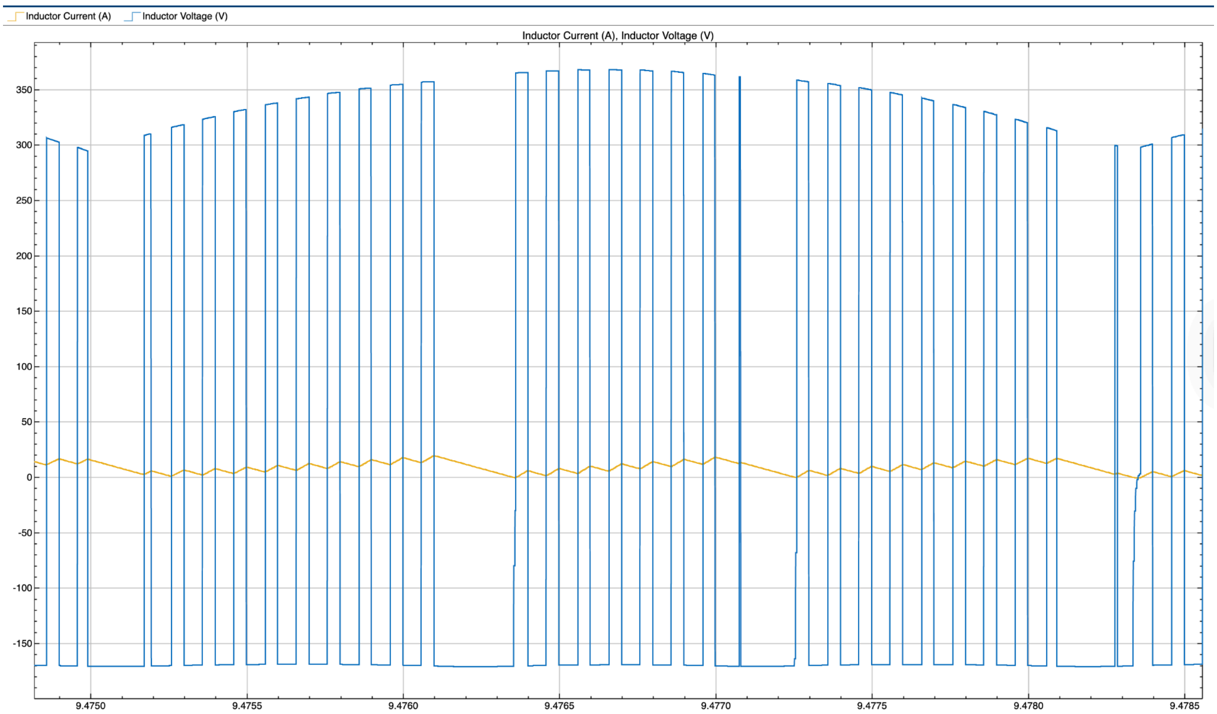


Figure 9. Voltage and Current Waveform of Inductor

As seen in the Figure 9, inductor's current and voltage waveform can be seen. Inductor voltage varies between -170 V and 370 V, current varies between 0 and 20 A.

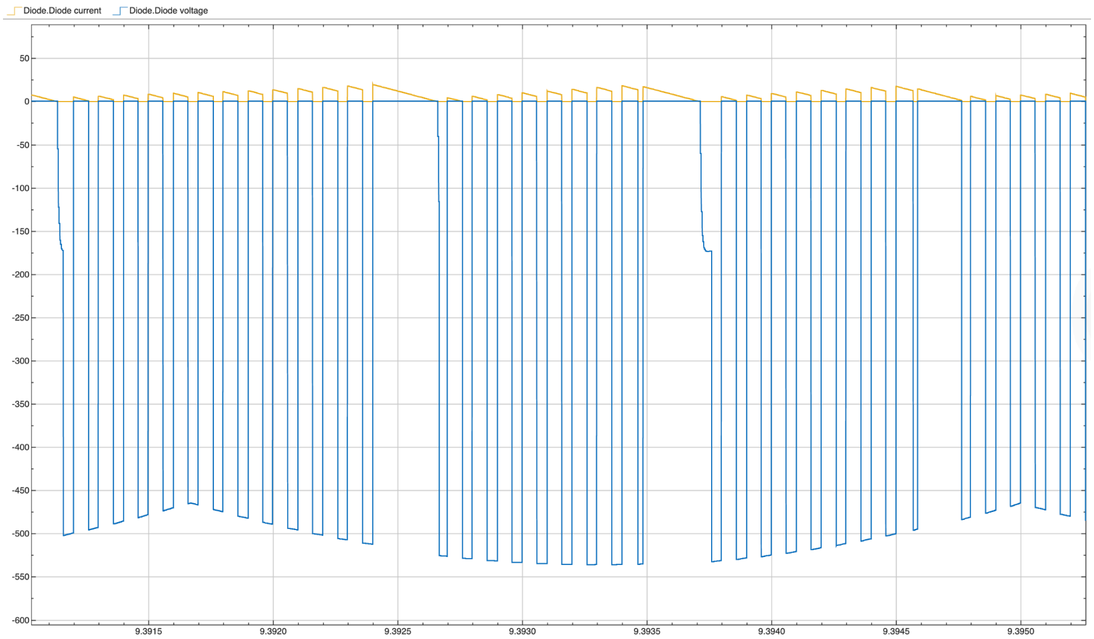


Figure 10. Voltage and Current Waveform of Diode

As seen in the Figure 10, diode’s current and voltage waveform can be seen. Diode voltage varies between -540 and 0 V, and current varies between 0 and 20 A.

3) Overall Structure

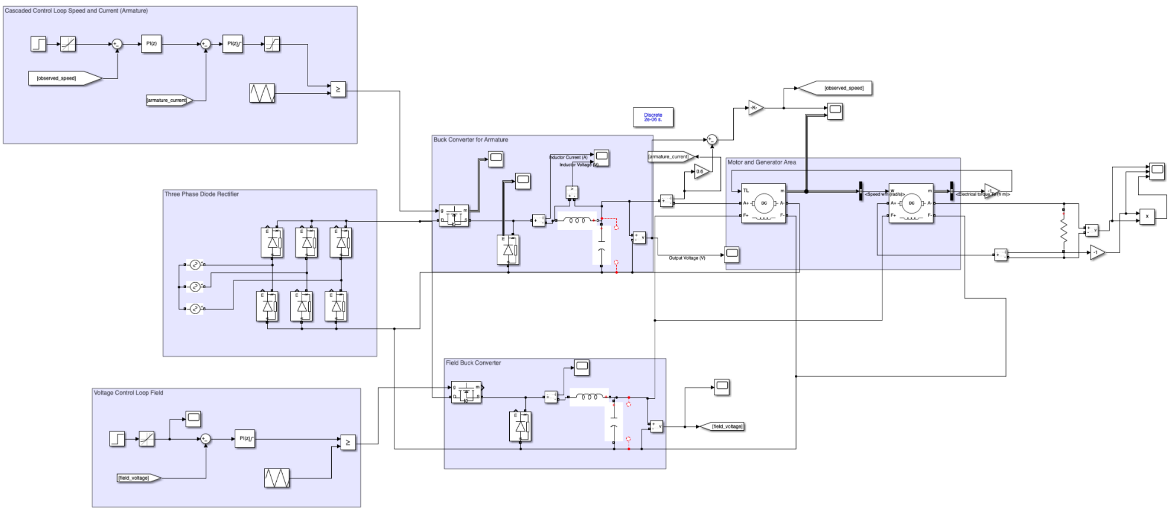


Figure 11. Overall Circuit Schematic for Motor Control

In this simulation we start with creating a motor-generator combination which will simulate the actual system. To do that we connect one motor's speed output to the other motors, which will act as a generator, speed input. Then we connect the generator's torque output to the motor's torque input as a reverse value. Then we connect generator field voltage to our 180 V buck generated field voltage and connect 17 ohm resistive load to the armature of it. We can see this structure in Figure 12.

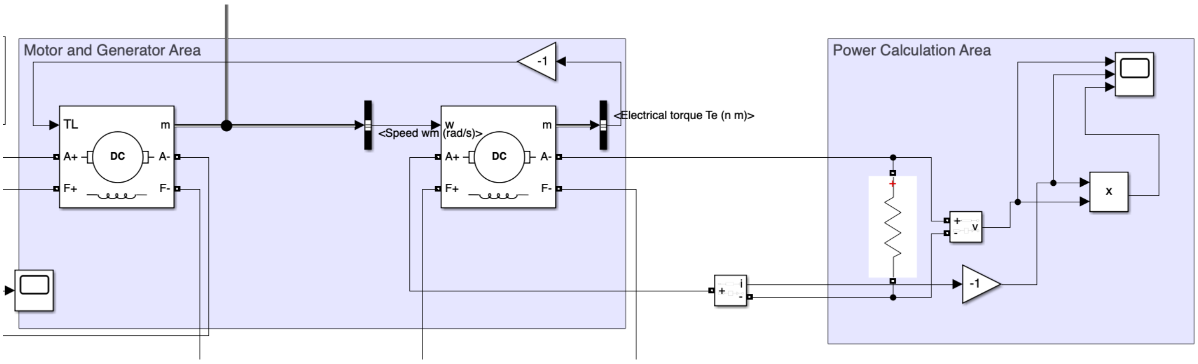


Figure 12. Motor and Generator Area

Then we connect this structure to the previously explained topologies:

- Buck Converter
- Three Phase Diode Rectifier

We connect field of motor and generator to the same buck converter with 180 V controlled output. We set its output to 180 V using the PI control loop. We measure the output voltage and by subtracting it from 180 we give it to the PI loop as an error term. We can see the field control loop in Figure 13.

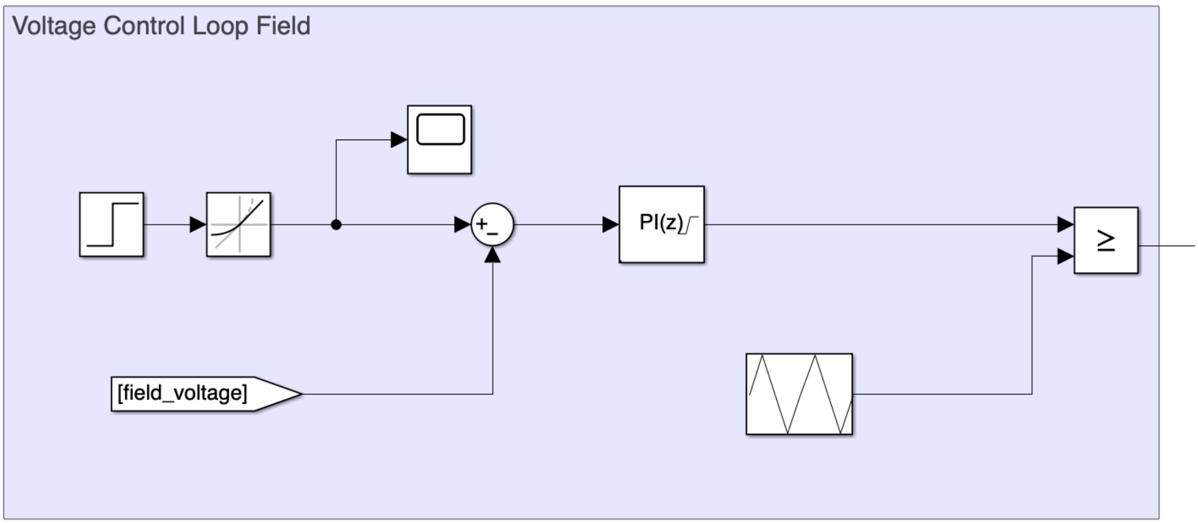


Figure 13. Field Control Loop

To control speed of the motor we control the armature current by using cascaded PI loop which consists of first speed loop and then current loop. We give a difference between reference speed and the observed speed to the outer PI loop then by subtracting output of it from the armature current we create the error term for the inner PI loop. After that we use this output as a duty in our PWM generation. We can see this control loop in Figure 14.

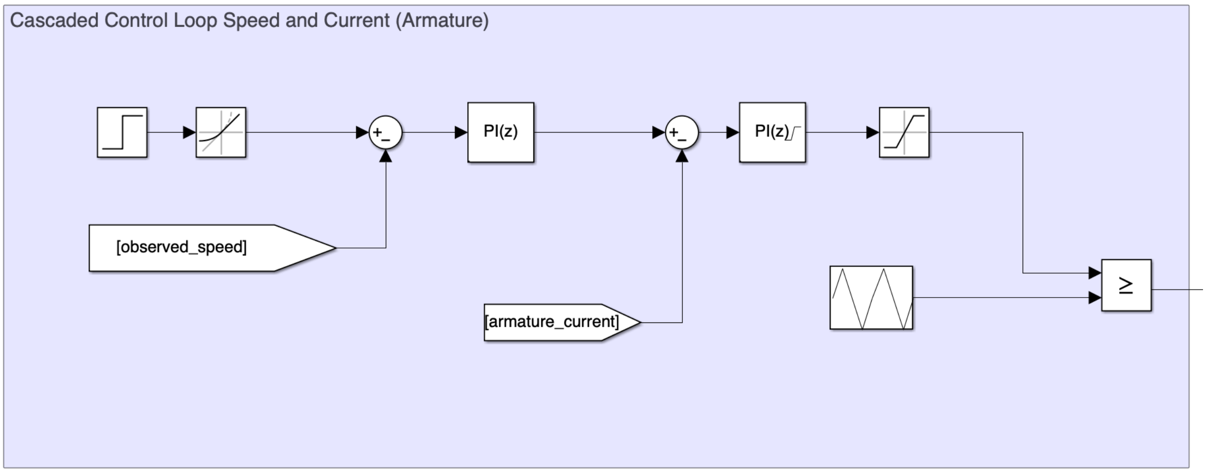


Figure 14. Armature Control Loop

To avoid sudden current jumps we first start with the increasing field voltage to the 180 V by giving its reference as a ramp. Then we start to control armature current again giving its speed reference as a ramp. We can see the measurements of the motor in Figure 15.

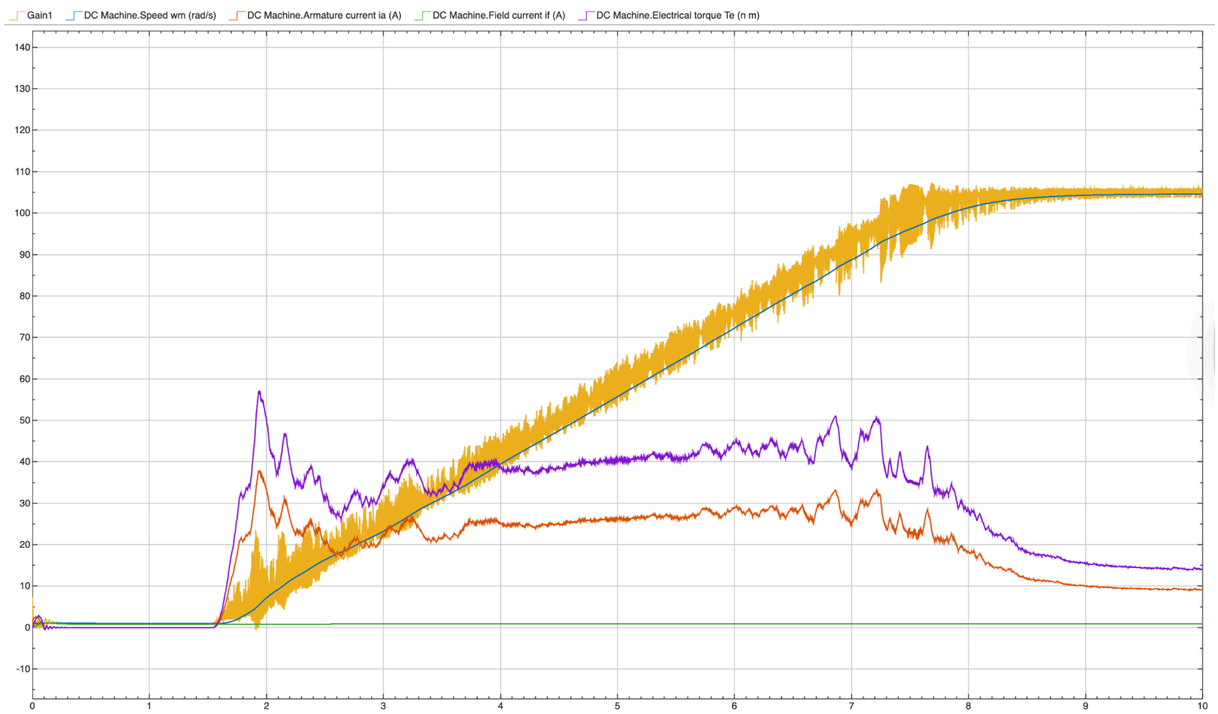


Figure 15. Motor Measurements

In this figure we can see that after speed get its steady state armature current and torque decrease. Also we can see that our observed speed track the actual speed well.

Finally if we look at the generators output voltage, current and, power at steady state we achieve 1.4kW. By optimizing some parameters we are planning to achieve 1.6kW power generation. We can see it in Figure 16.

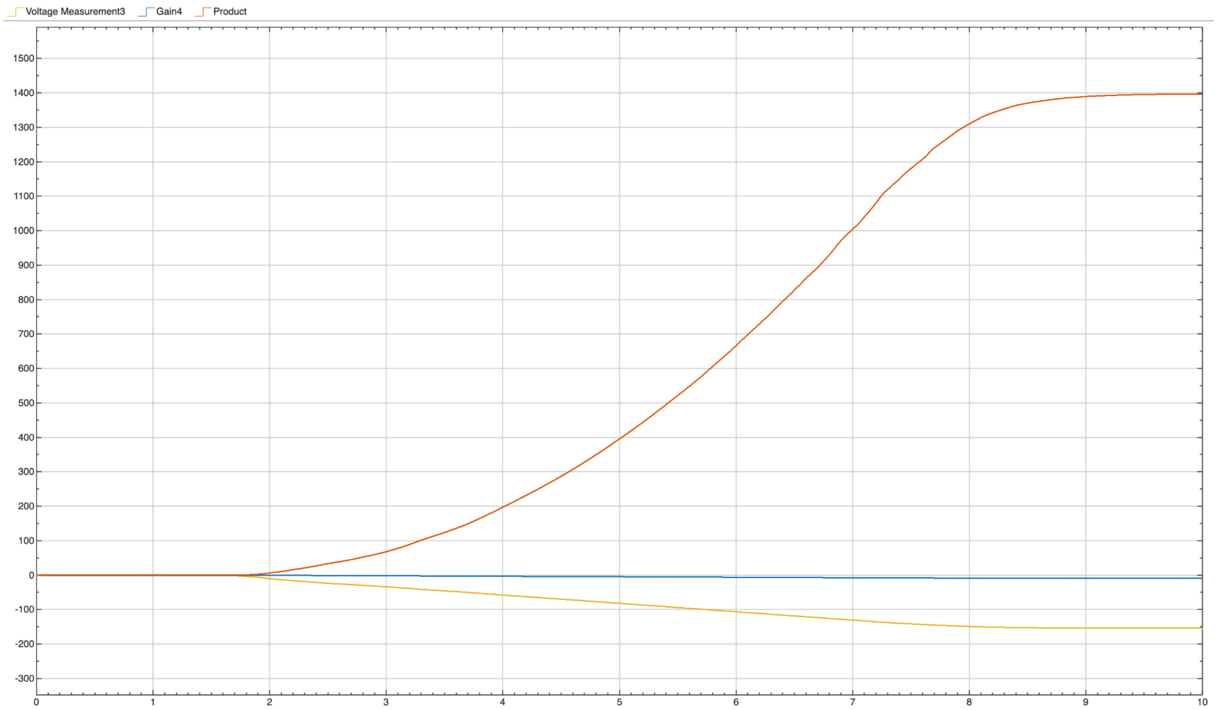


Figure 16. Figure For Generator Measurements (Red: Power, Blue: Current, Yellow: Voltage)

COMPONENT SELECTION

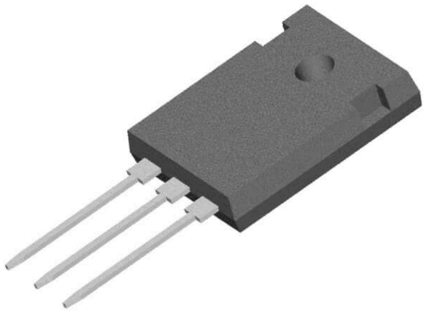
3-Phase Full Bridge Diode Rectifier Selection

We selected the VUO98-16NO7 3-phase bridge rectifier module to handle the rectification of the 380 V line-to-line AC input. Since the rectified DC voltage can reach approximately 515 V, the module's 1600 V voltage rating provides a significant safety margin. Additionally, its 105 A current rating comfortably supports our calculated nominal load current of 12 A. Also 105 A current rating is enough for our project for inrush motor current since we use soft start.

VUO98-16NO7 3-phase full bridge rectifier

Buck Converter MOSFET Selection

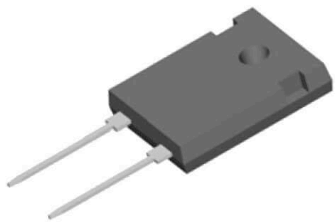
We selected the IXYS IXFH80N65X2 Power MOSFET as the primary switching element to ensure robust operation under high-voltage conditions. Since our rectified DC voltage will reach approximately 520 V, the MOSFET’s 650 V drain-source breakdown voltage provides a critical safety margin of over 100 V against inductive voltage spikes during switching events. Furthermore, its continuous drain current rating of 80 A is significantly higher than our motor’s peak inrush current of 30 A and nominal load of 12 A. This substantial current over-rating, combined with its ultra-low on-resistance, drastically minimizes conduction losses, thereby maximizing the drive's efficiency and reducing the thermal stress on the cooling system.



IXFH80N65X2 N-Channel Power MOSFET

Buck Converter Diode Selection

Since the variac acts only as a supply and not a controller, the controller regulates the DC output voltage by adjusting the duty cycle of the PWM signal. To supply the rated 1.6 kW output power at 180 V, the required load current (Iout) is 8.9 A. The worst-case average current stress on the diode is calculated as IF(avg)=Iomax×(1−Dmin)=8.9×0.649≈5.78A. Based on these requirements, the DSEI30-06A was selected as the freewheeling diode. Its ultra-fast recovery characteristics are critical for minimizing switching losses in our high-frequency Buck converter. With a 30 A average current rating, it accommodates the calculated current stress with a significant safety margin. Furthermore, its 600 V reverse repetitive voltage rating ensures robust protection against breakdown from the DC bus voltage during the reverse-bias phase.



DSEI30-06A freewheeling diode

Inductor Selection

For the inductor, the primary goal was to keep the current ripple within a reasonable range (around 20-30%). We decided to select a standard **1 mH** power inductor since it is a widely available component for this power range, and easier to find. Furthermore, since the DC motor has a significant armature inductance of its own, it naturally contributes to the filtering process, making the standard 1 mH choice both practical and effective.should consider the ripple while selecting a capacitor.

Capacitor Selection

For the output capacitor, we aimed to keep the voltage ripple below 1%. In practical applications, the Equivalent Series Resistance (ESR) often affects the ripple more than the capacitance value itself. Therefore, rather than sticking to a minimum theoretical limit, we chose a 470 µF capacitor. This value is standard in the market and provides a strong safety margin against voltage spikes and ESR-related ripple, ensuring a stable output for the motor.

PWM Generation

The generation of the PWM signal required for our driver circuit and the execution of the control algorithms will be done by the Texas Instruments LAUNCHXL-F28379D MCU.

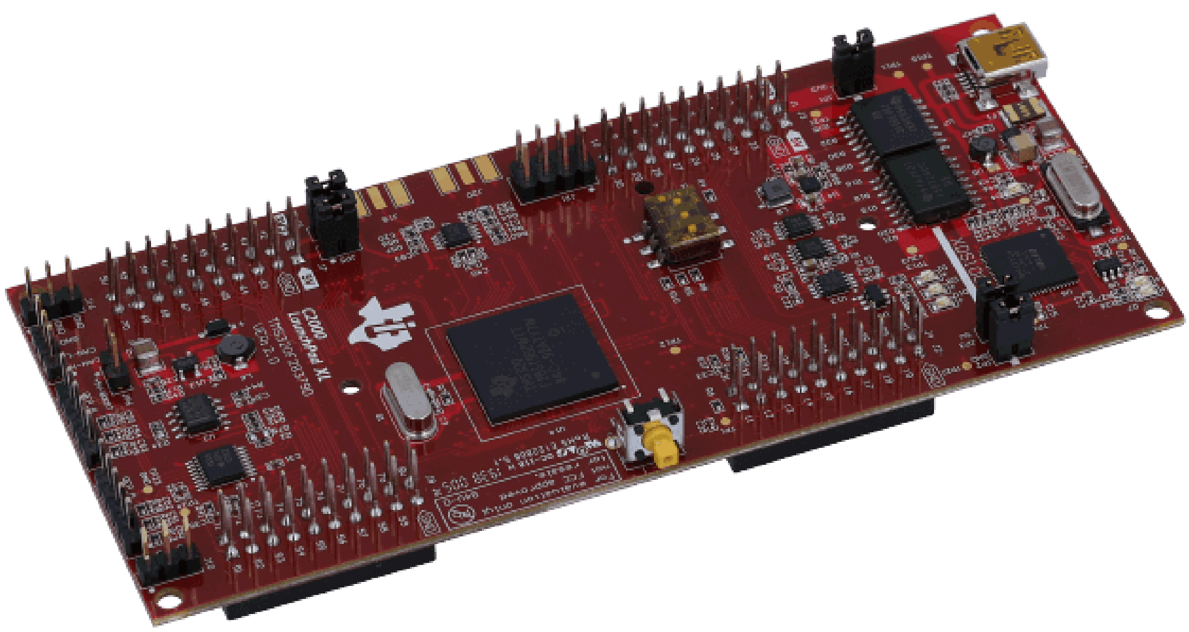


Figure 17. Texas Instruments LAUNCHXL-F28379D MCU

1. Armature Voltage (V_a) Measurement:

This measurement aims to scale the high voltage safely and isolated by a ratio of 1:56. A voltage divider circuit is used to make the voltage measurable by the MCU. The voltage divider reduces the voltage from V_a,max = 180 V to the input of the MCU, V_ADC,max = 3.3 V. Resistance Values: Practically selected resistors are used: R_1 = 550 kΩ and R_2 = 10 kΩ. This reduces the 180 V voltage to 3.21 V while providing a safe measurement range of up to 184.8 V. The scaled voltage is passed through an Isolation Amplifier (TI AMC1200) to prevent electrical contact that could damage the control board. The amplifier's output is connected directly to the ADC pin of the F28379D.

2. Armature Current (I_a) Measurement:

Current measurement is achieved with the Hall Effect Current Sensor(ACS758lcb), which guarantees natural electrical isolation.

3. PI Loop Control:

Using the measured V_a and I_a values calculate the Back EMF (E_a) and hence the speed (w):

$$w_{estimated} = (V_a - I_a . R_a)/K$$

The calculated speed enters the outer loop (Speed Control), and the Speed PI Controller determines the reference armature current I_a,ref by taking the difference between w_ref and w_estimated. I_a,ref then enters the inner loop (Current Control), where the Current PI Controller minimizes the difference between I_a,ref and the measured I_a, and produces the reference armature voltage V_a,ref. Finally, V_a,ref is converted to a duty cycle D by proportioning it to the DC-link voltage. This value is written to the ePWM module switching at 10 kHz, which drives the Buck IGBT/MOSFET via the Isolated Gate Driver.

BONUS PARTS

Our design addresses several bonus goals. We selected components to handle the 1.6 kW load, which meets the requirements for the Tea Bonus. We also designed the system to use a single input source, aiming for the Single Supply Bonus. Although our hardware supports these features, we will decide on the final implementation after receiving advice in the upcoming Feedback Session.

CONCLUSION

We selected the 3-Phase Full Bridge Diode Rectifier with a Buck Converter topology since it supplies a stable DC output and meets the critical 1 kHz ripple frequency requirement. Simulation results confirmed a voltage ripple under 1% and validated the cascaded PI control loops, currently achieving 1.4 kW power generation with optimizations planned to reach 1.6 kW.
Key components, including the VUO98-16NO7 rectifier and IXFH80N65X2 MOSFET, were selected for their high safety margins, while the TI LAUNCHXL-F28379D was chosen to handle the control algorithms. Finally, our design aims to support both the Tea Bonus and Single Supply Bonus, pending final decisions after the upcoming Feedback Session.