İbrahim Yaman 2576288
Esma Duman 2604932
Muhammed Raşid Gökcen 2443091

EE463 Term Project Proposal Report

This project aims to design and implement a controlled rectifier to drive a DC motor according to the design specifications shared on the GitHub repository of the hardware project. We are going to use a variac as the main power supply. The field winding of the DC motor is going to be excited separately.

Topology Selection

We investigated various topologies that can be used in this project, considering feasibility, simplicity, and cost. In this section, the advantages and disadvantages of the different topologies are going to be discussed. Tables 1 & 2 below show the advantages and disadvantages of the different topologies we investigated.

Table 1: Advantages & Disadvantages of 3-Phase Thyristor Rectifier Topology.

3-Phase Thyristor Rectifier	
Advantages	**Disadvantages**
Suitable for high-power applications.	High current ripple.
Simple controller.	Poor grid power factor.
Low cost.	Pulsating torque on the DC motor.

Table 2: Advantages & Disadvantages of 3-Phase Diode Rectifier & Buck Converter Topology.

3-Phase Diode Rectifier & Buck Converter	
Advantages	**Disadvantages**
Suitable for medium to high power applications.	Complex drive.
Precise control with PWM.	Moderate cost.
Small motor current ripple.	
Good grid power factor. (DPF =1)	
Smooth DC motor torque.	
Low output voltage ripple.	

Table 3: Advantages & Disadvantages of 1-Phase Diode Rectifier & Buck Converter Topology.

1-Phase Diode Rectifier & Buck Converter	
Advantages	**Disadvantages**
Suitable for low to medium power applications.	Complex drive. (Simpler than 3-phase)
Precise control with PWM.	Poor grid power factor. (low PF)
Small motor current ripple.	
Smooth DC motor torque.	
Low output voltage ripple.	
Low cost.	

We chose the 1-phase diode rectifier & buck converter topology because of its suitable power range for the aimed application, low torque pulsating and output voltage ripple, and low cost. It is simpler than the 3-phase diode rectifier & buck converter topology because the DCM operation is harder to reach in this case.

Our approach to this project is to divide the project into 3 sub-modules, which are the 1-phase diode rectifier, the buck converter, and the buck controller. Then, we can discuss the sub-modules separately and lastly comment on the overall result.

1- Phase Diode Rectifier

We will be implementing a simple single-phase rectifier which will take one phase of the grid through the variac as its input and will give a rectified output voltage waveform. Our main simulation for this part of the circuit can be seen in Figure 1 below.

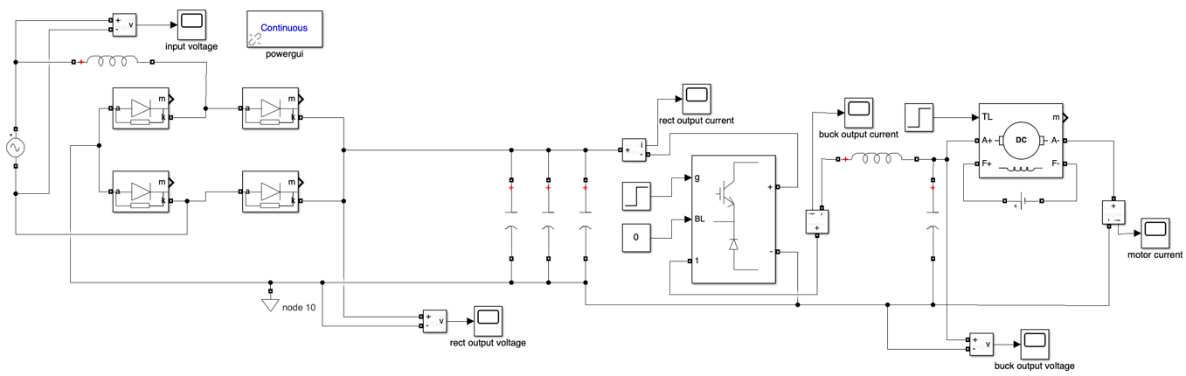

Figure 1: Rectifier Circuitry Simulation

As displayed in Figure 1, the left part of the circuit including the 3 parallel capacitors is the rectifier portion, with the rest modeling the load. A placeholder buck converter was placed in this simulation along with a DC motor to be able to model the expected demand from the load more realistically. The details of the actual buck converter topology will be discussed in the next section.

The first element after the input voltage is an inductor that is merely placed to model line inductance and is not a part of the design. Following this unideality, we have 4 power diodes to form a full wave rectifier. For this part, we are planning to use a readily available diode bridge rectifier unit. We chose the product KBPC3510W which can be shipped from within Türkiye hence ensuring ease of procurement. This device has a current rating of 35 A and a voltage rating of 1000 V, which both satisfy our needs even after the addition of a safety margin.

Just to the right of the diode bridge can be seen our output capacitors, 2 of which are placed to reduce the output ripple and the last, to reduce the ESR (equivalent series resistance). We determined both ripple capacitor values as 470 μF and found applicable capacitors having an acceptable voltage rating of 450 V on direnc.net, with a stock code of DSTK2922. The remaining one will be a smaller, 10 nF capacitor, and the only other limitations it has are having a small ESR and a voltage rating of at least 450 V, both of which are easily satisfied for such capacitance values. Hence although our choice for such a product does not have to be final and may be adjusted according to component availability or shipping alongside other products etc., we determined one of many suitable options as the product with a stock number of 19424 on direnc.net.

With these capacitance values, our rectifier output voltage ripple peak-to-peak value of around 75 V, from ~260 to ~335 V for an input connected to the grid, as can be observed from Figure 2 below.

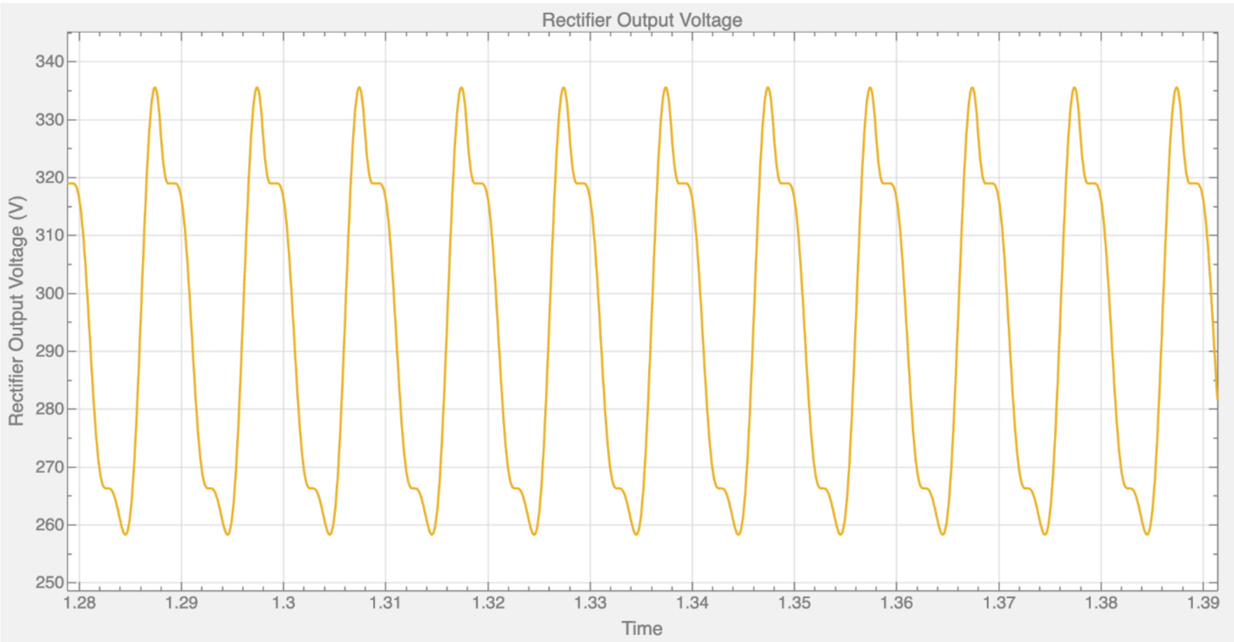

Figure 2: Rectifier Output Voltage Ripple

This ripple is effective enough for our needs, as the following elements of our design are not highly sensitive.

2- Buck Converter

Circuit Configuration and Operation Parameters

This section details the design and simulation of the DC-DC Buck Converter stage, which interfaces the unregulated DC output of the single-phase rectifier with the DC motor load. The converter is designed to step down the DC bus voltage (approx. 325 V) to a controllable output range of 0-180 V, enabling precise speed regulation of the motor.

The switching frequency is set to fsw = 30 kHz. This specific frequency was selected to strictly satisfy the project requirement of a current ripple frequency greater than 1 kHz while keeping switching losses within manageable limits. The design ensures operation in Continuous Conduction Mode (CCM) under nominal load conditions (23.4 A), providing a smooth armature current and minimizing torque ripple. The detailed simulation schematic of the designed Buck Converter is illustrated in Figure 3.

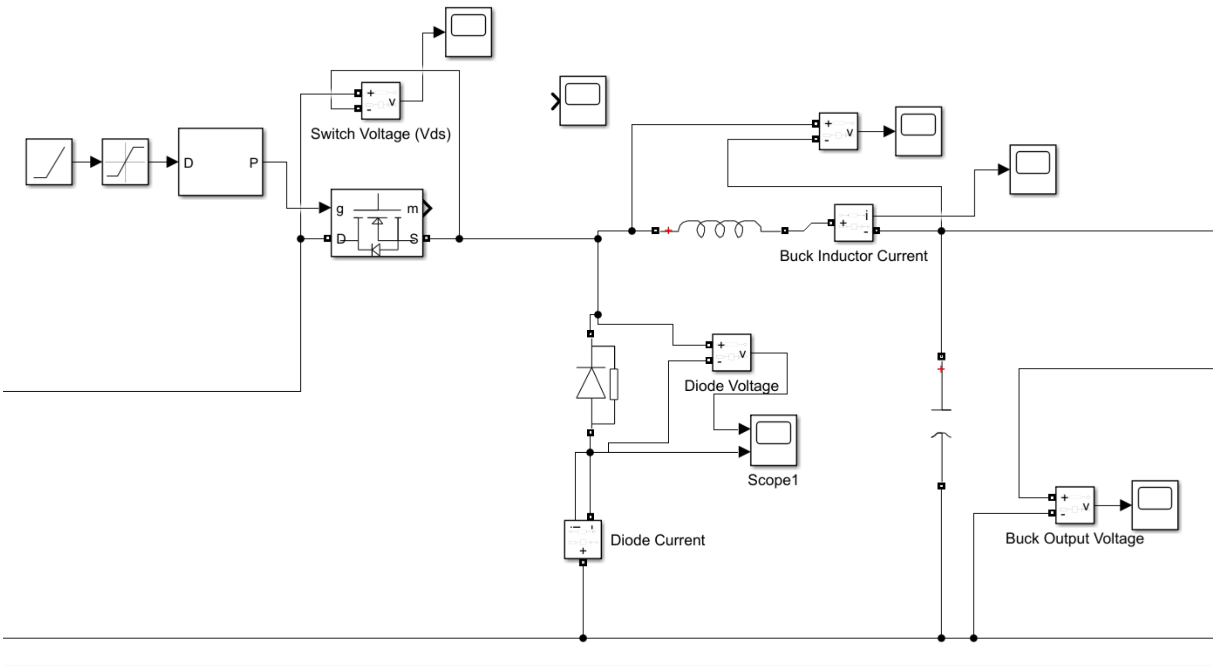

Figure 3: Buck Conver Schematic

Buck Converter Output Voltage

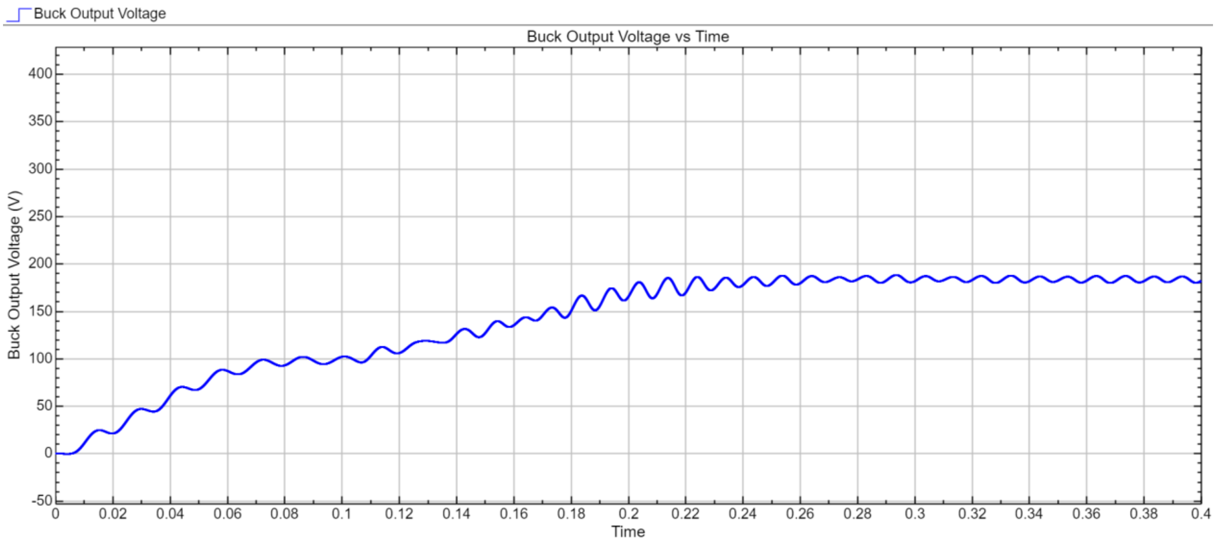

Figure 4: Buck Output Voltage Waveform

As seen in Figure 4, we analyzed the time-domain response of the Buck converter's output voltage with the soft-start algorithm enabled. Unlike the open-loop step response, we did not observe any harmful voltage overshoot or high-frequency oscillations during the startup phase. Instead, thanks to the gradual increase of the duty cycle, we observed a smooth and monotonic voltage rise from 0 V to the target level.

The system reached the desired operating point of 180 V in approximately 0.2 seconds without stressing the components. Following this controlled startup, the output voltage stabilized firmly at 180 V. We also examined the steady-state region and observed that the peak-to-peak voltage ripple remained well below the 5% limit. This confirms that our chosen switching frequency of 30 kHz and the 1500 F capacitor bank are working correctly to filter the switching noise while the soft-start mechanism effectively eliminates startup transients.

Buck Converter Inductor Current

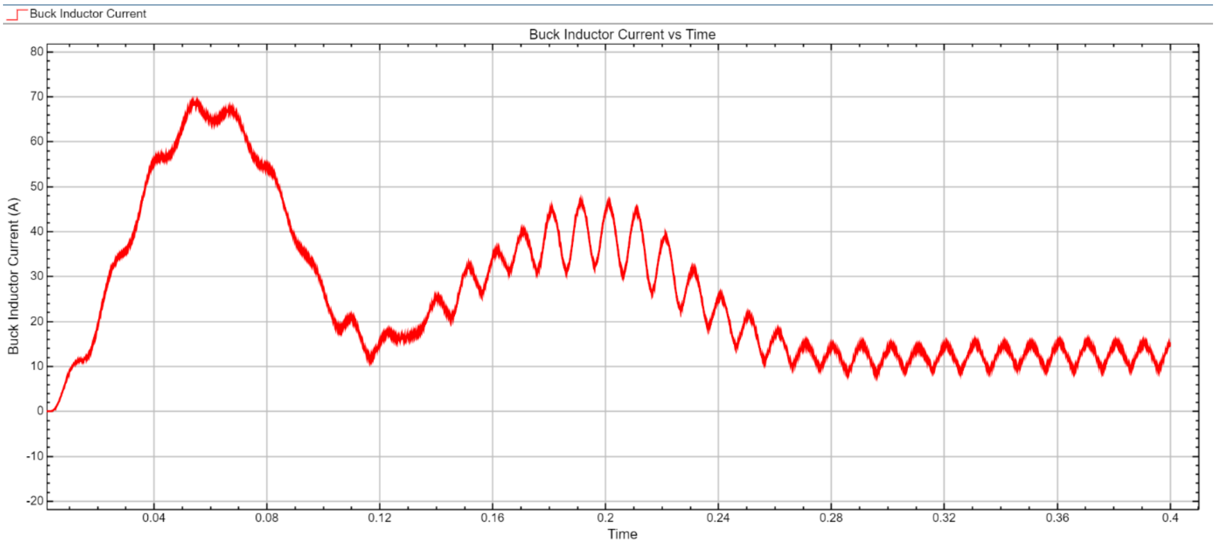

Figure 5: Inductor Current Waveform

As shown in Figure 5, we analyzed the inductor current waveform to verify both the startup safety and the steady-state operating mode. Initially, the implemented soft-start ramp limited the inrush current peak to approximately 70 A, which is well within the 141 A pulsed current rating of our selected SPW47N60C3 MOSFET, confirming the safety of the power stage. Following this transient phase, the current stabilized, fluctuating between approximately 9.5 A and 15.5 A. Crucially, the current never drops to zero, confirming that our design operates in Continuous Conduction Mode (CCM). We also observed a 100 Hz fluctuation caused by the single-phase rectifier's DC bus ripple; however, the minimal switching ripple at 30 kHz validates that our selected 3 mH inductor provides sufficient filtering performance.

Buck Converter Switch Voltage (Vds)

As seen in Figure 6, we examined the voltage stress across the MOSFET during startup. In the first 50 ms, we observed a large voltage spike reaching approximately 560 V. This overshoot happens because we used a "Hard-Start" in this open-loop simulation, applying the full duty cycle instantly. This caused a resonance between the parasitic inductances and the output filter. However, even under this worst-case stress, our chosen SPW47N60C3 MOSFET survived without failure because it has a high breakdown rating of 650 V.

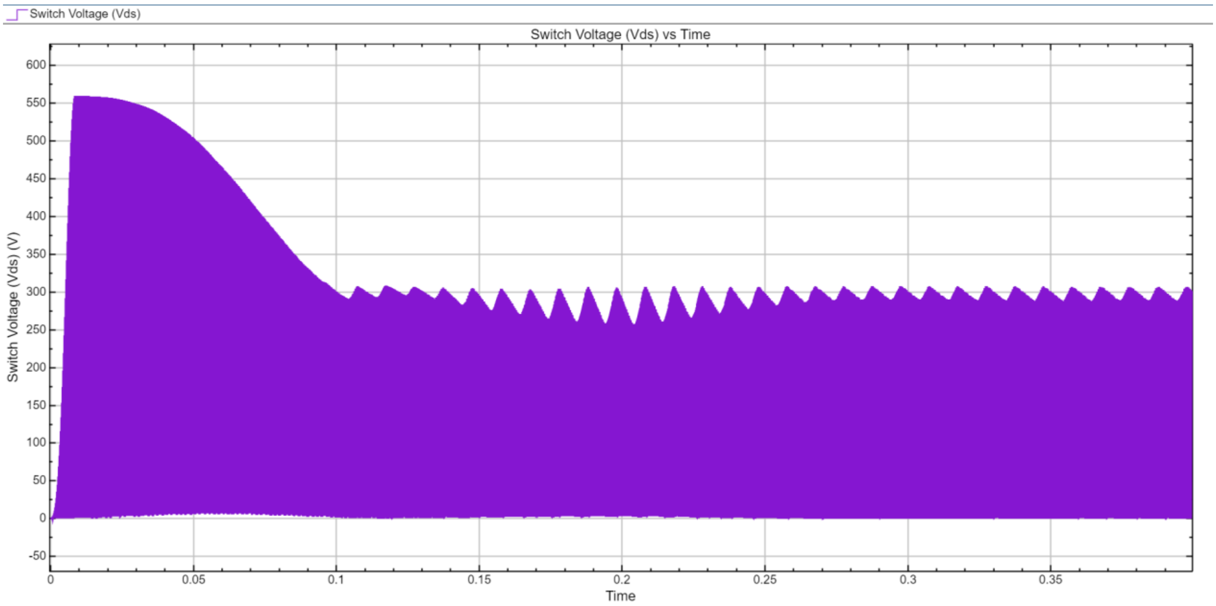

Figure 6: Switch Voltage (Vds) Waveform

In the actual physical implementation, this high-voltage spike will be eliminated. As mentioned in the controller design section, our digital controller (Arduino) uses a Soft-Start algorithm. This will ramp up the duty cycle gradually, preventing the sudden inrush of energy and keeping the switch voltage safely around the normal DC bus level (325 V). Moreover, unlike the fixed ramp used in the simulation, our real controller uses closed-loop feedback, meaning it will actively monitor the system during startup and adjust the ramp speed to ensure smooth and safe operation.

Buck Converter Diode Current

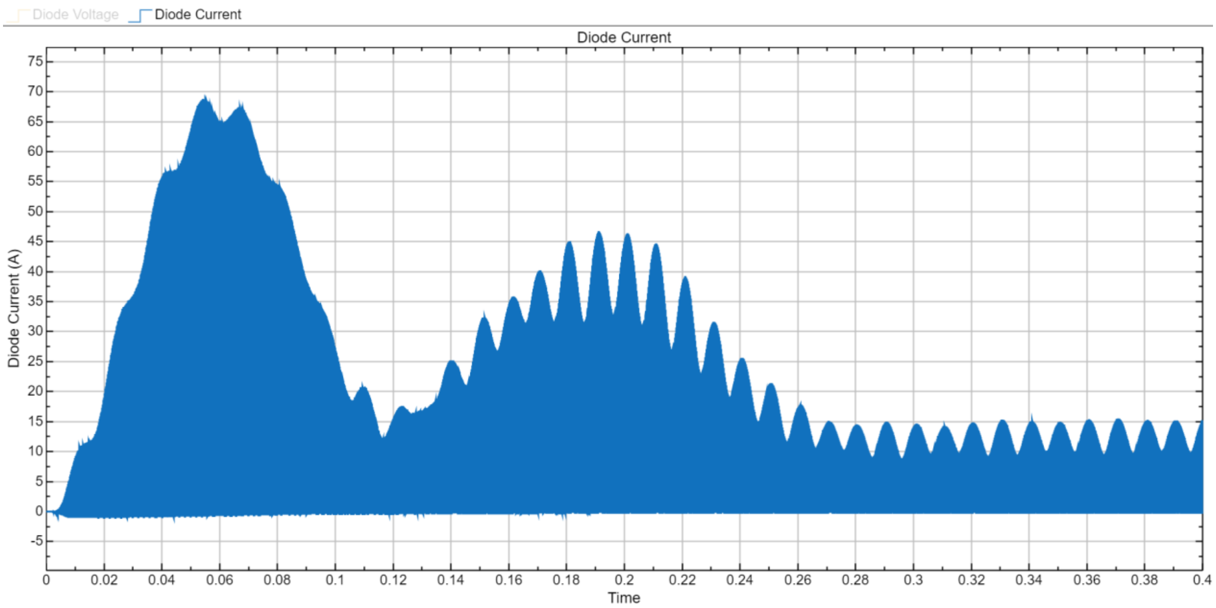

Figure 7: Free-Wheeling Diode Current Waveform

As shown in Figure 7, the current waveform through the free-wheeling diode confirms the correct operation of the Buck Converter. The diode conducts current only when the MOSFET is OFF, maintaining the continuity of the inductor current.

The waveform follows the same envelope as the inductor current, exhibiting an initial transient peak during startup and then settling into a periodic pattern. In the steady-state region, the diode carries the inductor current for approximately (1-D) of the switching period. The observed peak currents are well within the 30 A continuous rating and 150 A surge rating of the selected MUR3060 diode, confirming that the component is operating safely.

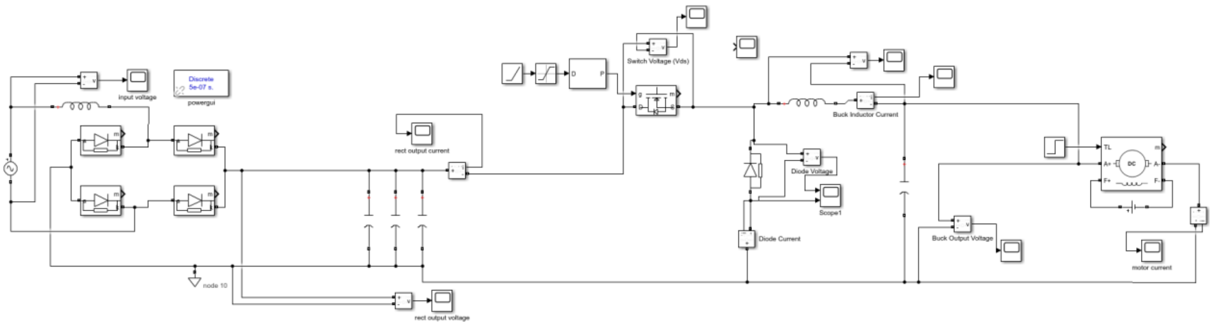

Figure 8: Overall Circuit Schematic

Component Selection

Buck Converter MOSFET Selection

Figure 9: 47N60C3 MOSFET

The switching element is the most critical component of the buck converter, requiring high voltage and current endurance to drive the load reliably. Based on our simulation results, the steady-state DC bus voltage is approximately 325 V, but we observed significant transient voltage spikes during the open-loop startup. To ensure reliability against these spikes and provide a sufficient safety margin, we determined that a breakdown voltage of at least 600 V was necessary. Regarding current handling, although the nominal motor current is 23.4 A, we aimed for a higher rating to safely manage potential startup inrush currents and thermal stresses. Consequently, we selected the SPW47N60C3 CoolMOS power transistor, as seen in Figure 9. With its 650 V breakdown voltage and 47 A continuous drain current rating, it comfortably meets our safety requirements, while its extremely low on-resistance of 0.07 Ohm ensures high efficiency and simplifies thermal management.

Buck Converter Diode Selection

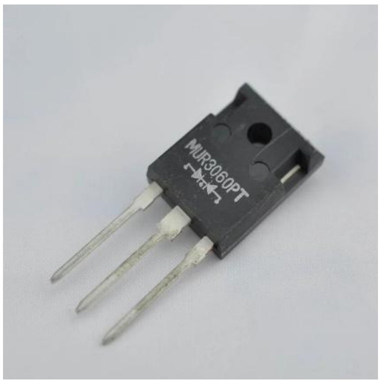

Figure 10:MUR3060 Diode

For the free-wheeling diode, a standard rectifier diode is unsuitable due to the high switching frequency of 30 kHz, which would lead to significant switching losses and potential failure caused by reverse recovery issues. Therefore, we required a diode with fast recovery characteristics to minimize losses and protect the main switch during turn-on transitions. In terms of ratings, the diode must withstand the full DC bus voltage of 325 V and carry the load current when the MOSFET is off. Based on these requirements, we selected the MUR3060 Ultrafast Recovery Diode, as shown in Figure 10. With a reverse voltage rating of 600 V and a forward current capacity of 30 A, it provides the necessary safety margins. Furthermore, its ultrafast recovery time of approximately 60 ns ensures efficient operation and minimizes the reverse recovery current spikes that stress the MOSFET.

Passive Elements (Inductor and Capacitor)

Buck Inductor Selection We determined that a 3 mH inductor is necessary to satisfy ripple requirements. Given the limited availability of standard components with high saturation currents (>30 A), we will select the most suitable off-the-shelf component based on market availability, prioritizing saturation characteristics and thermal limits.

Output Capacitor Selection To maintain consistency with the rectifier stage, we selected the same 470 uF / 450 V Aluminum Electrolytic Capacitors. By connecting three units in parallel, we achieved the target 1500 uF capacitance, which simplifies procurement and reduces total ESR for improved voltage stability.

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3- Buck Converter Controller

We are going to implement a digital control for our buck converter. We are going to use Arduino Uno for this purpose. The controller will have negative feedback from the output voltage and will have a speed control feature. The overall block diagram of the controller can be seen in Figure 11.

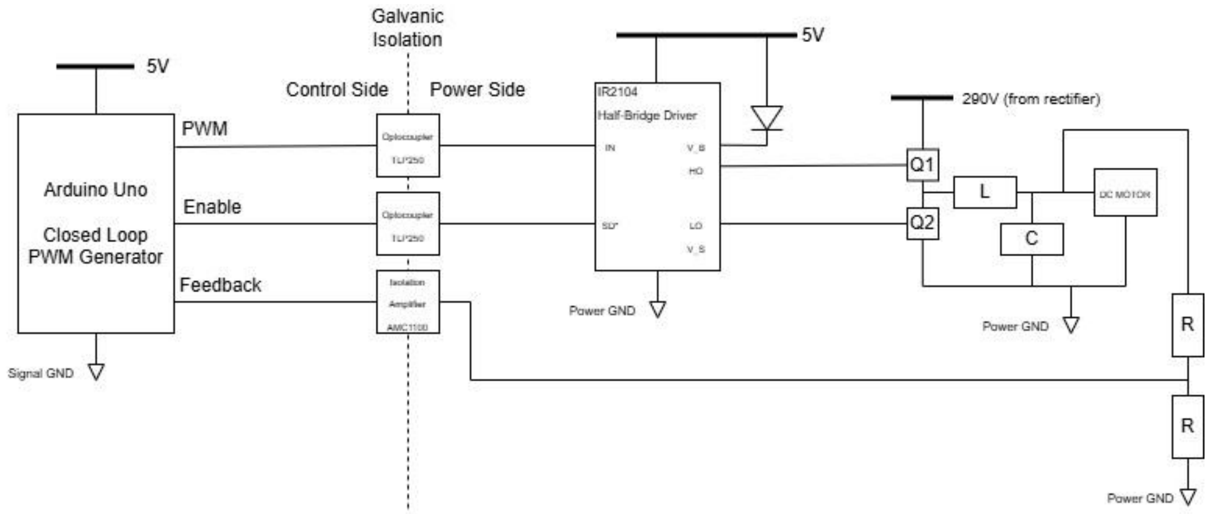

Figure 11: Buck Driver & Controller Block Diagram.

The PWM signal created by the digital controller is going to the IR2104 half-bridge driver with the optocoupler. Also, a feedback signal is going back to the controller after a resistor divider. The digital controller has an enabled pin, which is going to be used to shut down the system in any emergency case.

The most important part of the controller is the electrical isolation between the power side and the control side. To prevent high voltage or current that can damage the sensitive equipment on the control side, a noisy environment on the precise signals (such as PWM), and a danger to the safety of humans & equipment, we apply galvanic isolation between the driver and converter.

The reason we use an extra half-bridge driver on the power side is the high voltage requirement of the high voltage and power MOSFET that we will use in this project. The $V_{GS(on)}$ of the MOSFET is going to be larger than 3.3V or 5V on the control side. We must apply a larger voltage to get through the gate charge.

We are going to use the TLP250 optocoupler and the AMC1100 isolation amplifier for isolation purposes. The reason that we do not use an optoocoupler to transmit the feedback signal is that the continuous non-zero signal on the feedback channel can be disturbed as the optocoupler gets hot, so we are going to use an isolation amplifier for this purpose.

The control algorithm sets a target for V_o, hence a target for D. Then evaluates a new D value by comparing the target and feedback. Also, it has a PI controller and a soft-start feature. The test result of the control algorithm can be seen in Figure 12. The target V_o is yellow, the feedback voltage is orange, and the duty cycle is the purple lines.

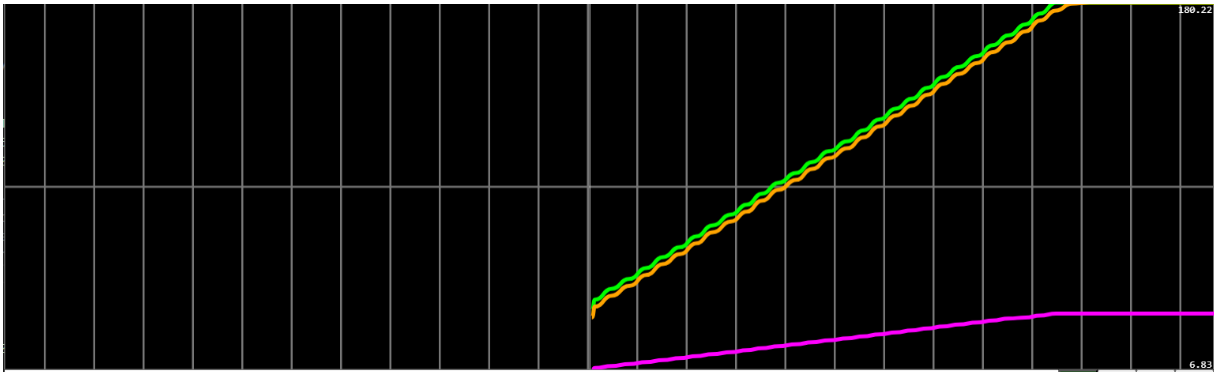

Figure 12: Test Result of the Buck Converter Control Algorithm.

Conclusion

In this report, we discussed how we are planning to implement a motor driver circuit, including the reasons for our topology selection and other design choices. We analyzed each part of our circuit separately, presented our simulation results and the components we are planning to use in our design. This plan will be our roadmap for implementing this project.

References

[1] 47N60 C3 MOSFET – SEE Institute Delhi. (n.d.). https://seeinstitutedelhi.com/product/47n60-c3-mosfet/

[2] MUR3060 Power Diode at Rs 25/piece | Power Diodes in Mumbai | ID: 27153208312. (n.d.). Indiamart.com. https://www.indiamart.com/proddetail/mur3060-27153208312.html