1 Topology Selection and Analysis

1.1 Design Requirements and Constraints

The primary objective of this project is to design a DC motor drive capable of providing a controllable output voltage (V_{out}) up to 180 V. The critical constraint defining the topology selection is the output current ripple frequency requirement:

$$f_{ripple} > 1 \text{ kHz} \tag{1}$$

Standard line-commutated converters (such as controlled thyristor bridges) produce ripple frequencies dependent on the grid frequency ($2f_{grid} = 100$ Hz for single-phase, $6f_{grid} = 300$ Hz for three-phase). To meet the > 1 kHz requirement, a Switch Mode Power Supply (SMPS) approach—specifically a DC-DC chopper—is required. Therefore, all topologies considered utilize a two-stage conversion process:

1. **AC-DC Rectification:** Uncontrolled diode rectification to create a DC bus.
2. **DC-DC Conversion:** High-frequency switching to control the motor voltage and satisfy the ripple frequency constraint.

1.2 Candidate Topologies

Three primary topologies were evaluated for this application.

1.2.1 Option A: Single-Phase Rectifier + Buck Converter

This topology utilizes a single-phase AC input rectified by a full-bridge diode rectifier, followed by a standard step-down (buck) converter.

- **Advantages:**
  - Simplest implementation and lowest component count.
  - Easier PCB/Stripboard layout due to fewer power traces.
- **Disadvantages:**
  - **High DC Link Ripple:** The rectified voltage drops to zero every half-cycle (without capacitance). To maintain a stable DC link voltage above the required motor voltage (180 V), a very large and physically bulky DC-link capacitor is required.
  - **High Current Stress:** The single-phase input diodes must handle the full power load, increasing thermal management requirements.

1.2.2 Option B: Three-Phase Rectifier + Buck Converter

This topology utilizes a three-phase AC input rectified by a 6-pulse diode bridge, creating a DC link that feeds the buck converter.

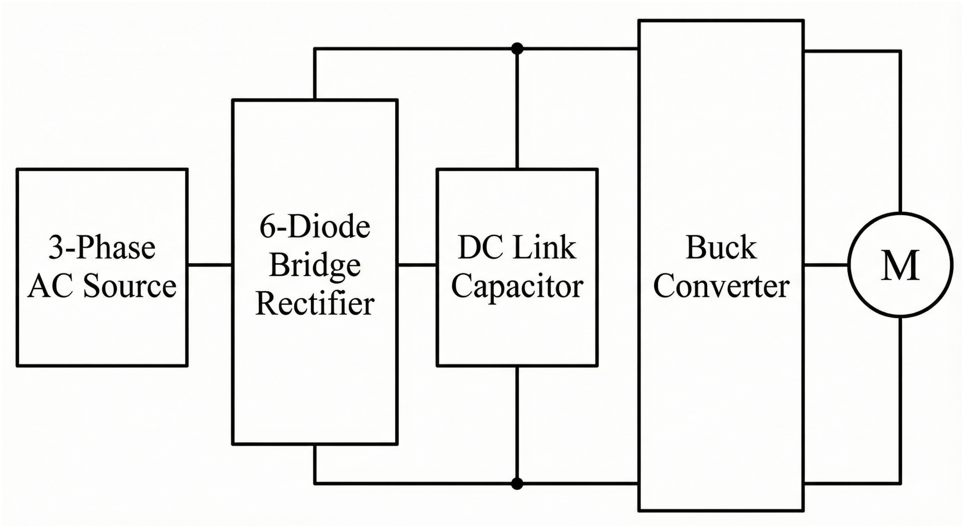

Figure 1: Proposed Topology: Three-Phase Diode Rectifier with Buck Converter

- **Advantages:**
  - **Superior DC Link Quality:** The voltage ripple of a 3-phase rectifier is significantly lower (approx. 4%) and the frequency is higher (300 Hz). The voltage never drops to zero (minimum $\approx 1.5 \times V_{line-peak}$).
  - **Reduced Capacitor Requirements:** Due to the smoother rectified voltage, the DC link capacitor can be smaller while still maintaining the "headroom" voltage required for the buck converter operation.
  - **Load Balancing:** Draws power symmetrically from the grid, which is standard industrial practice.
- **Disadvantages:**
  - Requires a 3-phase source (available per project specs) and 6 diodes.
  - Slightly more complex input wiring.

1.2.3 Option C: Synchronous Buck (Half-Bridge) Converter

This topology replaces the freewheeling diode of the standard Buck converter with a second MOSFET/IGBT.

- **Advantages:**
  - **Regenerative Braking:** Allows current to flow from the motor back to the DC link, enabling active braking.
  - **Efficiency:** Lower conduction losses in the low-side switch compared to a diode.
- **Disadvantages:**
  - **Shoot-Through Risk:** Requires precise "dead-time" control to prevent shorting the DC link.

- **Drive Complexity:** Requires a complex gate driver with bootstrap circuitry. Given the project timeline and the "Safe Stop" requirement (which can be achieved by coasting), this adds unnecessary risk.

1.3 Comparative Analysis Matrix

Table 1: Topology Comparison Matrix

Feature	1-Phase + Buck	3-Phase + Buck	Sync Buck
Complexity	Low	Low-Medium	High
DC Link Stability	Low	High	High
Capacitor Stress	High	Low	Low
Ripple Frequency	> 1 kHz	> 1 kHz	> 1 kHz
Risk Factor	Medium (Voltage Sag)	Low	High (Control Logic)

1.4 Final Selection and Justification

Based on the analysis above, the team has selected **Option B: Three-Phase Diode Rectifier + Buck Converter**.

Justification 1: Voltage Headroom The motor requires a maximum voltage ($V_{out,max}$) of 180 V. A buck converter can only step down voltage ($V_{out} = D \times V_{in}$). Therefore, the DC link voltage (V_{in}) must consistently remain above 180 V plus the voltage drops across switches and inductors.

$$V_{link,min} > \frac{V_{out,max}}{D_{max}} \approx \frac{180 \text{ V}}{0.95} \approx 190 \text{ V} \tag{2}$$

A 3-phase rectifier provides a stiff DC voltage averaging $1.35 \times V_{LL}$. Using the Variac to provide a line-to-line voltage of approx 150 V_{rms} will result in a DC link of $\approx$ 200 V, providing the necessary headroom with minimal capacitance. A single-phase rectifier would require excessive capacitance to prevent the DC link from dipping below 190 V in the valleys of the AC sine wave.

Justification 2: Reliability and Timeline The 3-phase diode bridge is extremely robust and minimizes stress on the DC link capacitor, which is a common failure point. The standard Buck topology (single switch) eliminates the risk of "shoot-through" associated with half-bridge topologies, simplifying the gate drive requirements to a single isolated driver. This aligns with the project goal of reaching a robust, working prototype by the demo deadline.

Justification 3: Ripple Requirement By selecting a switching frequency (f_{sw}) for the Buck converter in the range of 5 kHz $-$ 20 kHz, we inherently satisfy the project requirement of $f_{ripple} > 1$ kHz.