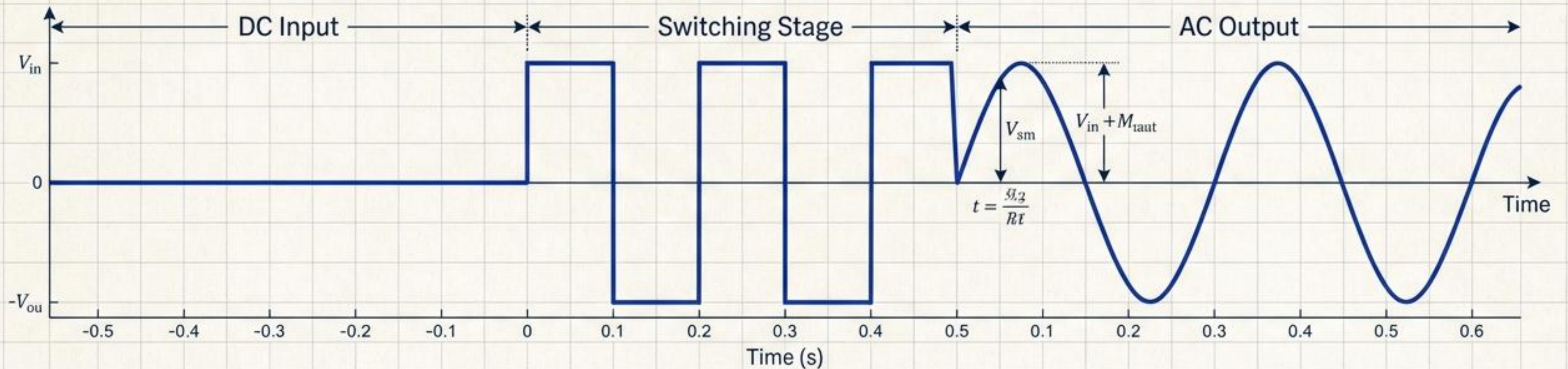


DC-DC and DC-AC Converters

Switching Converters for DC Voltage Control and AC Power Generation



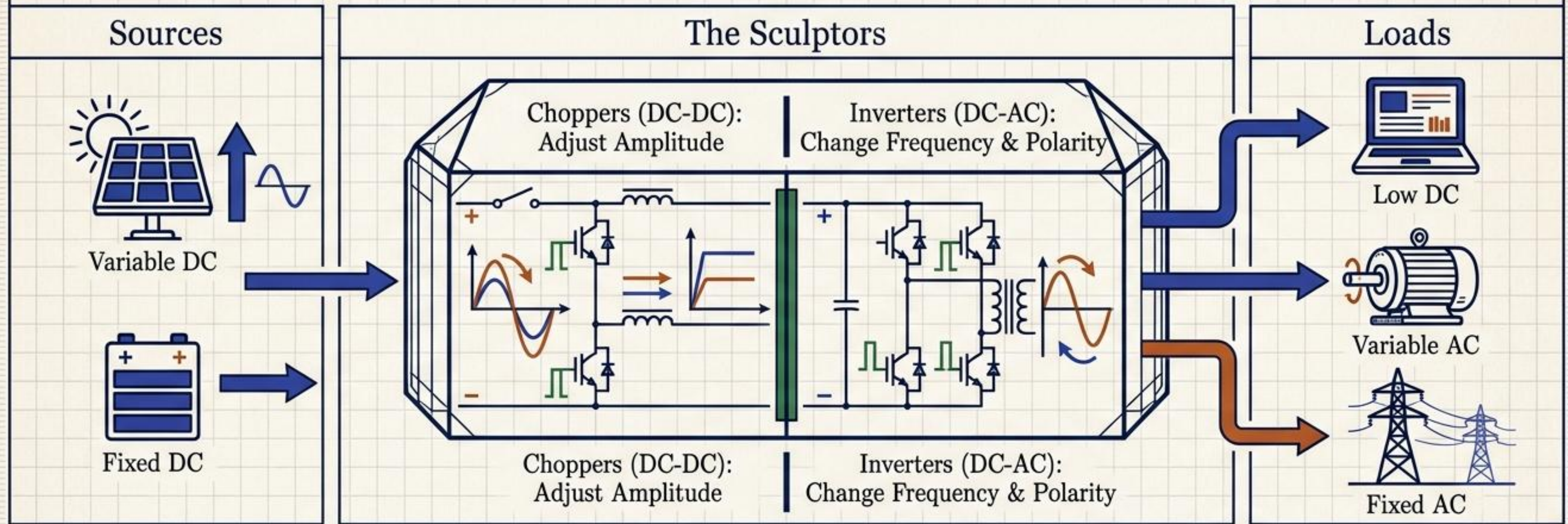
Module: Module-5 | Power Electronics

Presenter: Dr. Sathish K. R., Assistant Professor

Department: Electrical and Electronics Engineering (EEE)

Institution: ATME College of Engineering

The Power Translation Problem



The Challenge

Traditional linear regulators burn excess voltage as heat, causing massive energy loss.

The Solution

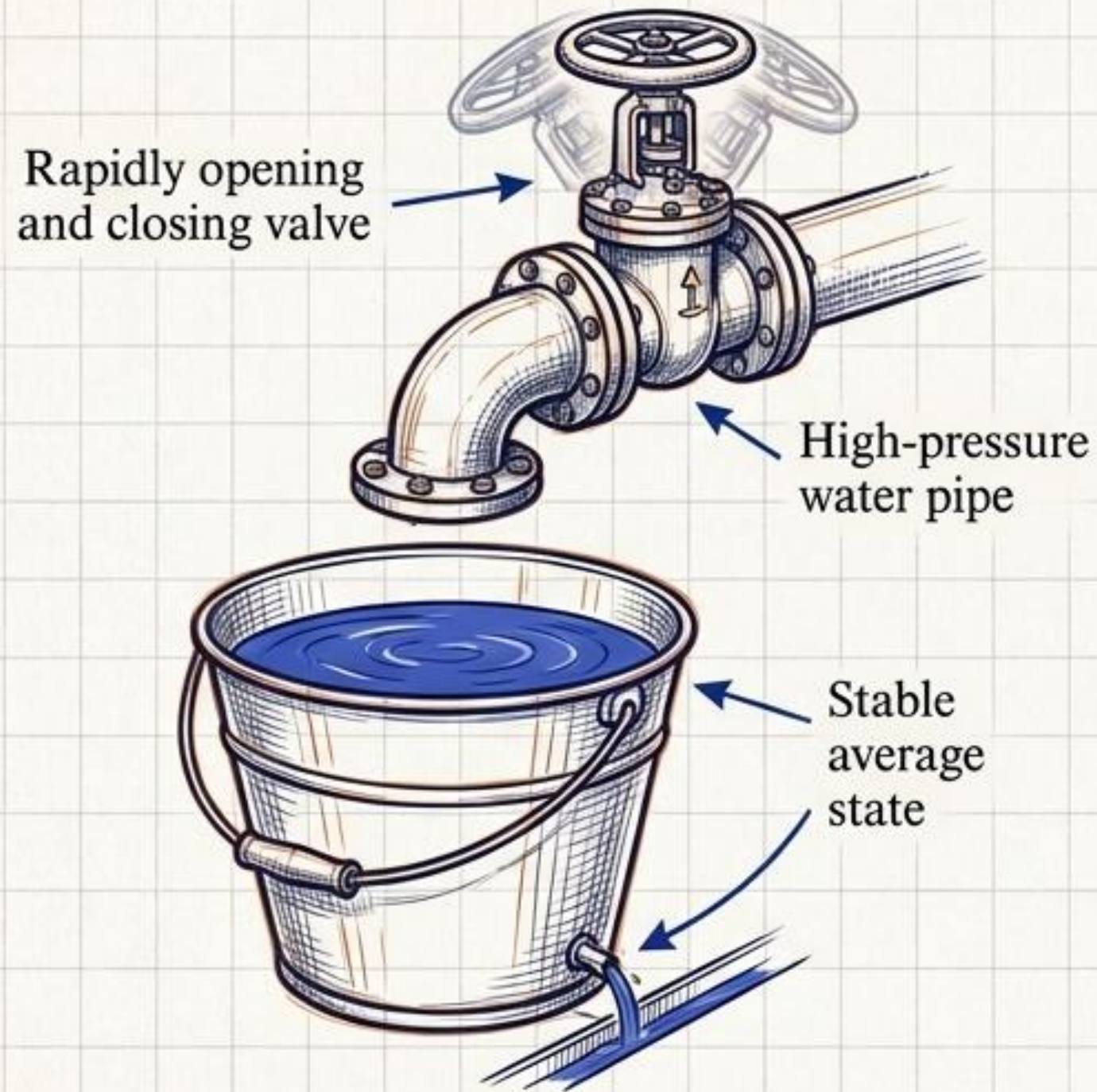
High-frequency solid-state switching achieves near-100% theoretical efficiency by rapidly transitioning between fully ON (zero voltage drop) and fully OFF (zero current).

Industrial Impact

The foundation of Electric Vehicles, Renewable Microgrids, Switch-Mode Power Supplies (SMPS), and HVDC transmission networks.

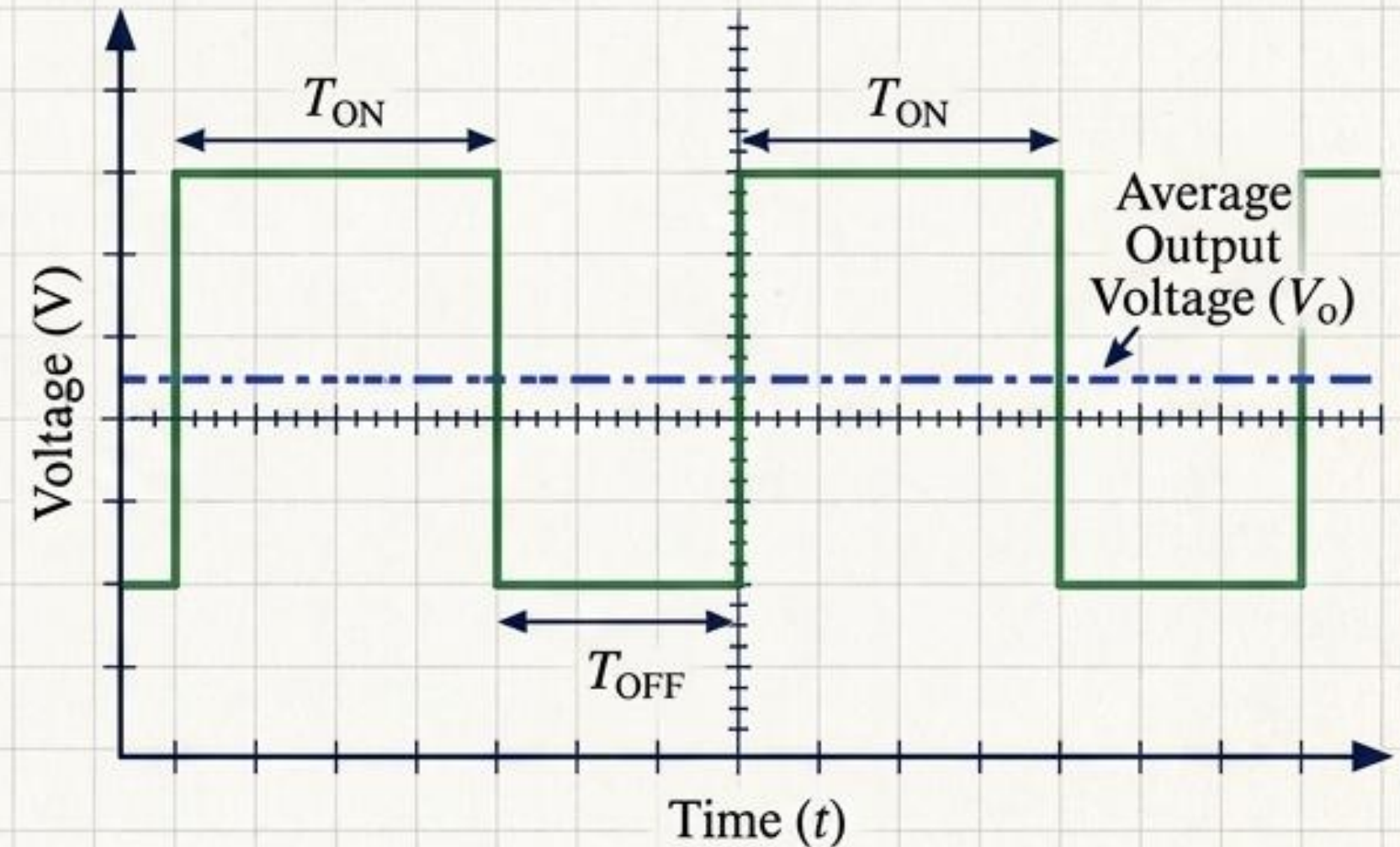
First Principles: The Physics of Duty Cycle

The Metaphor



The Bucket and Valve Analogy: If the valve is open 50% of the time, the bucket maintains a 50% fill level. Fast switching creates a stable average state from a pulsating source.

The Oscilloscope Trace



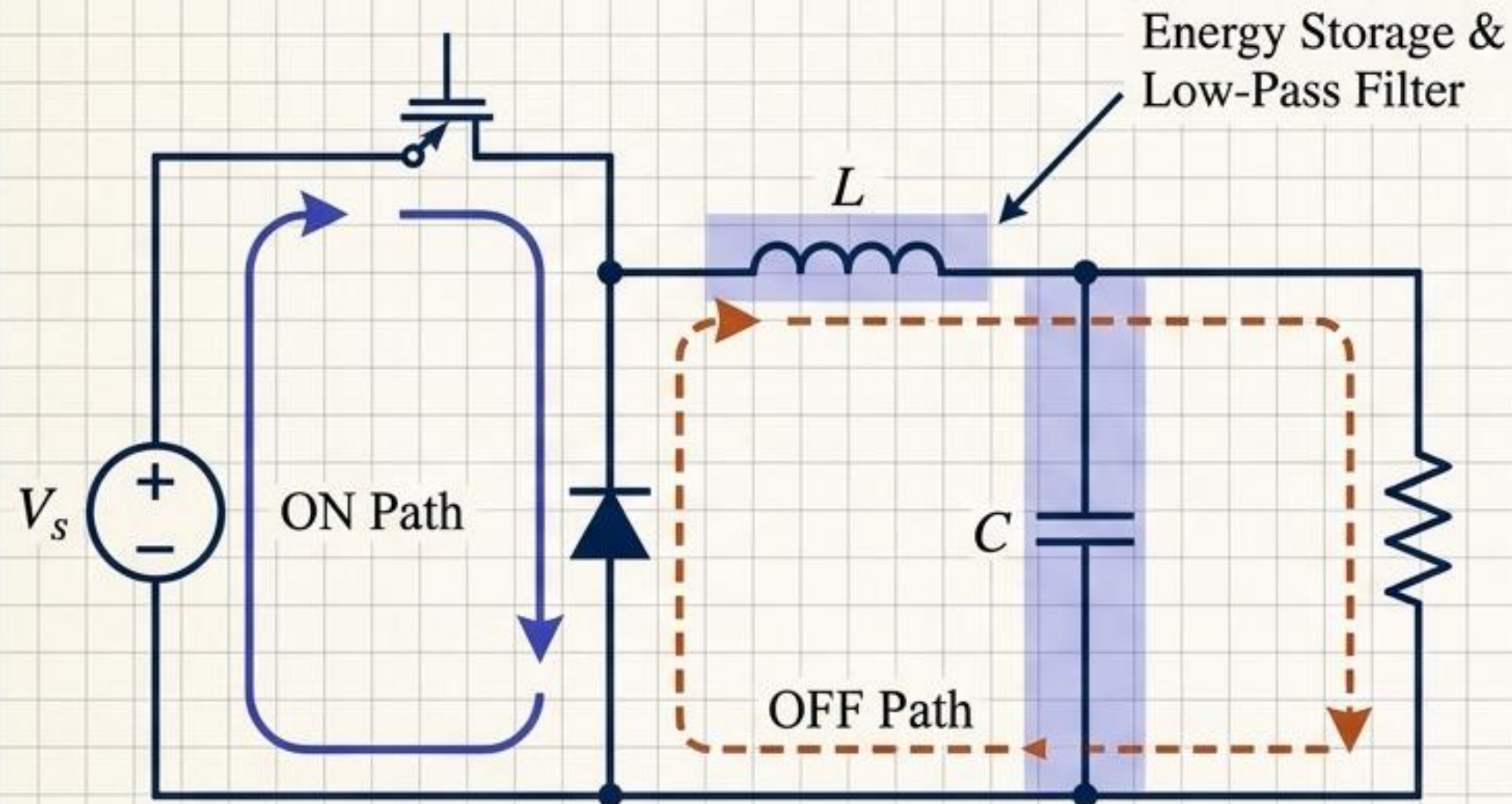
$$\text{Total Time } (T) = T_{ON} + T_{OFF}$$

$$\text{Duty Cycle } (D) = \frac{T_{ON}}{T}$$

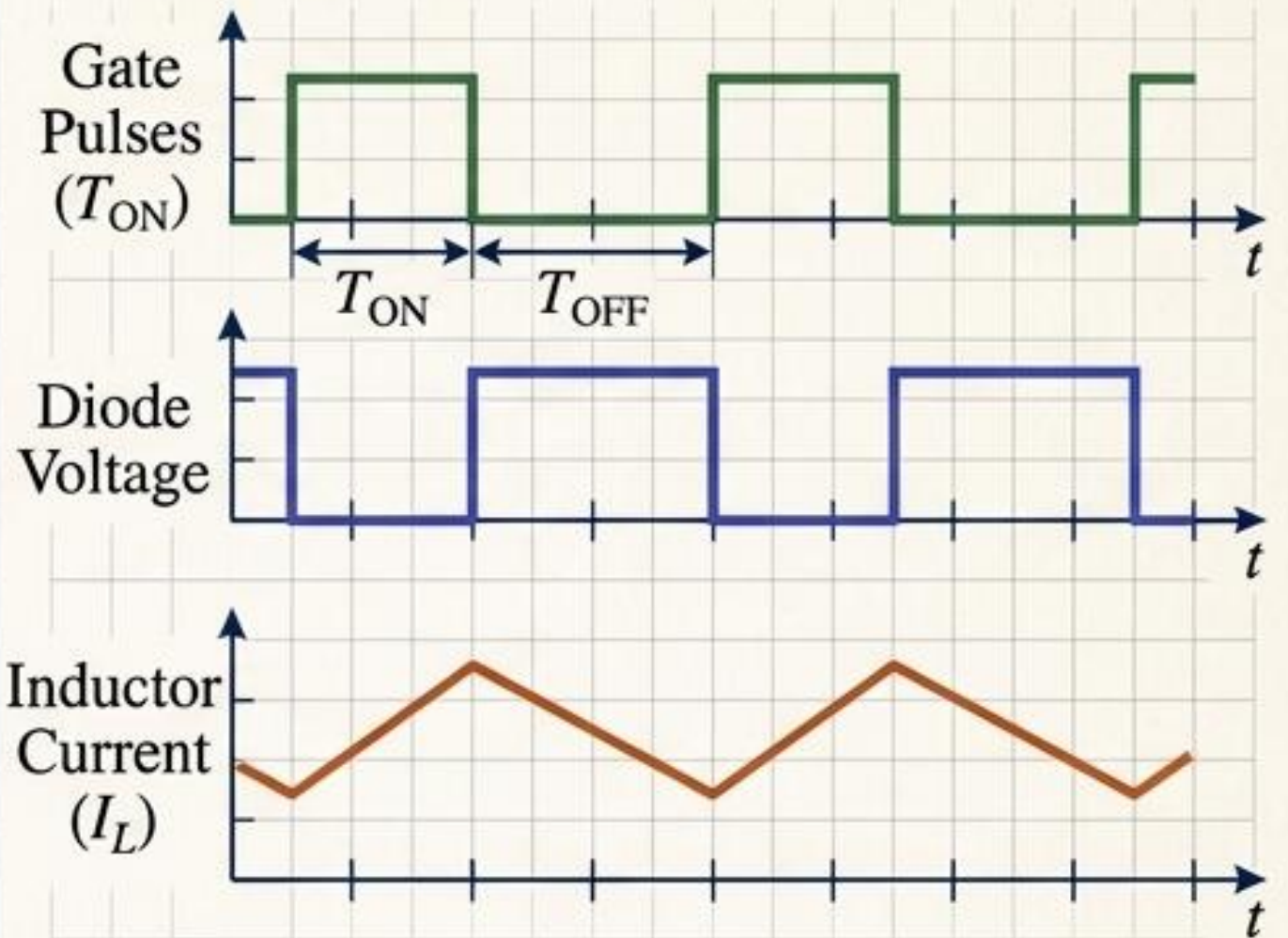
$$\text{Output Voltage: } V_o = D * V_s$$

Step-Down Chopper (Buck Converter)

Circuit Schematic



Waveforms



Mathematical Engine

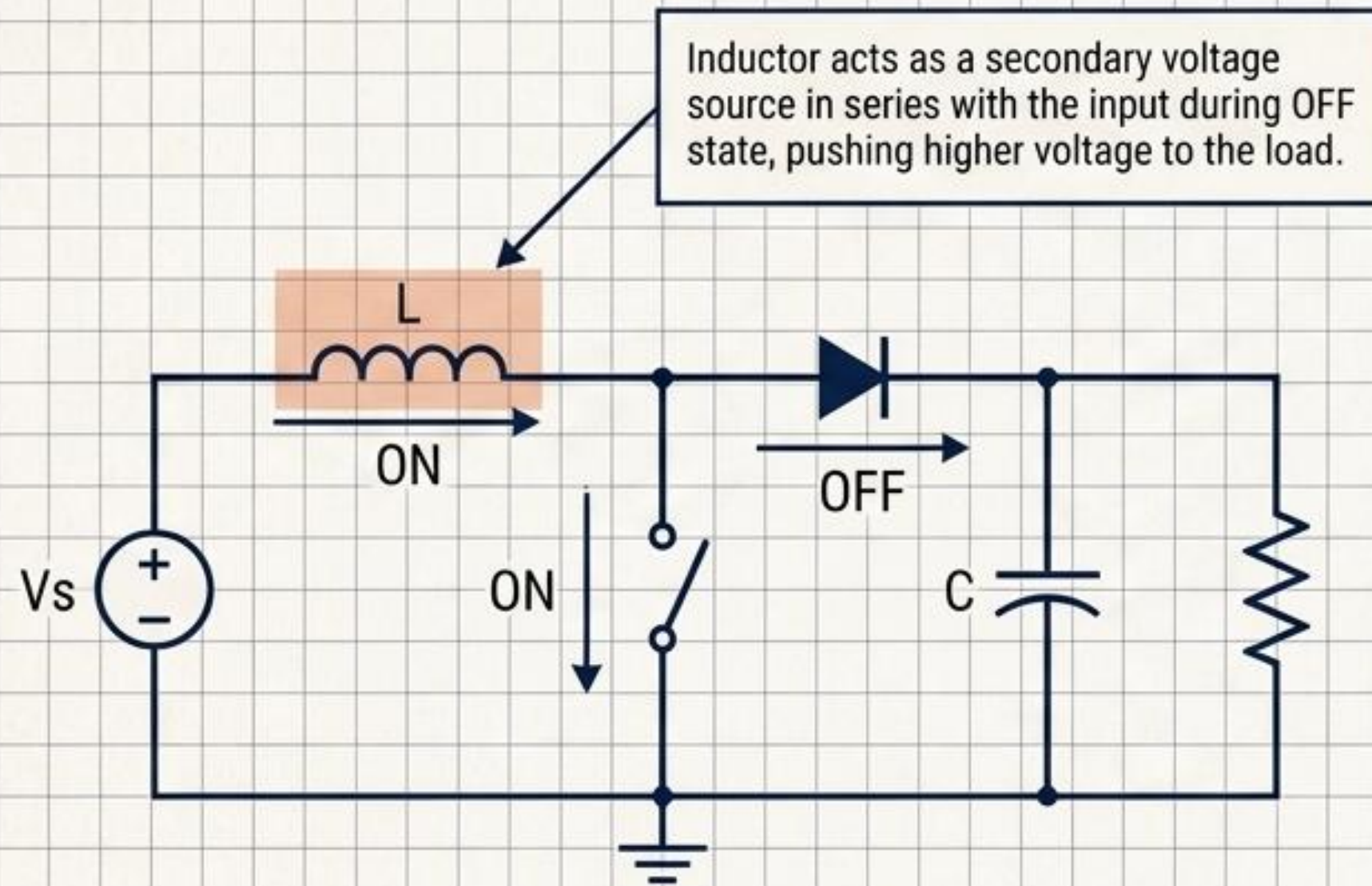
Voltage Gain: $V_o / V_s = D$

RMS Output Voltage: $V_{or} = V_s * \text{sqrt}(D)$

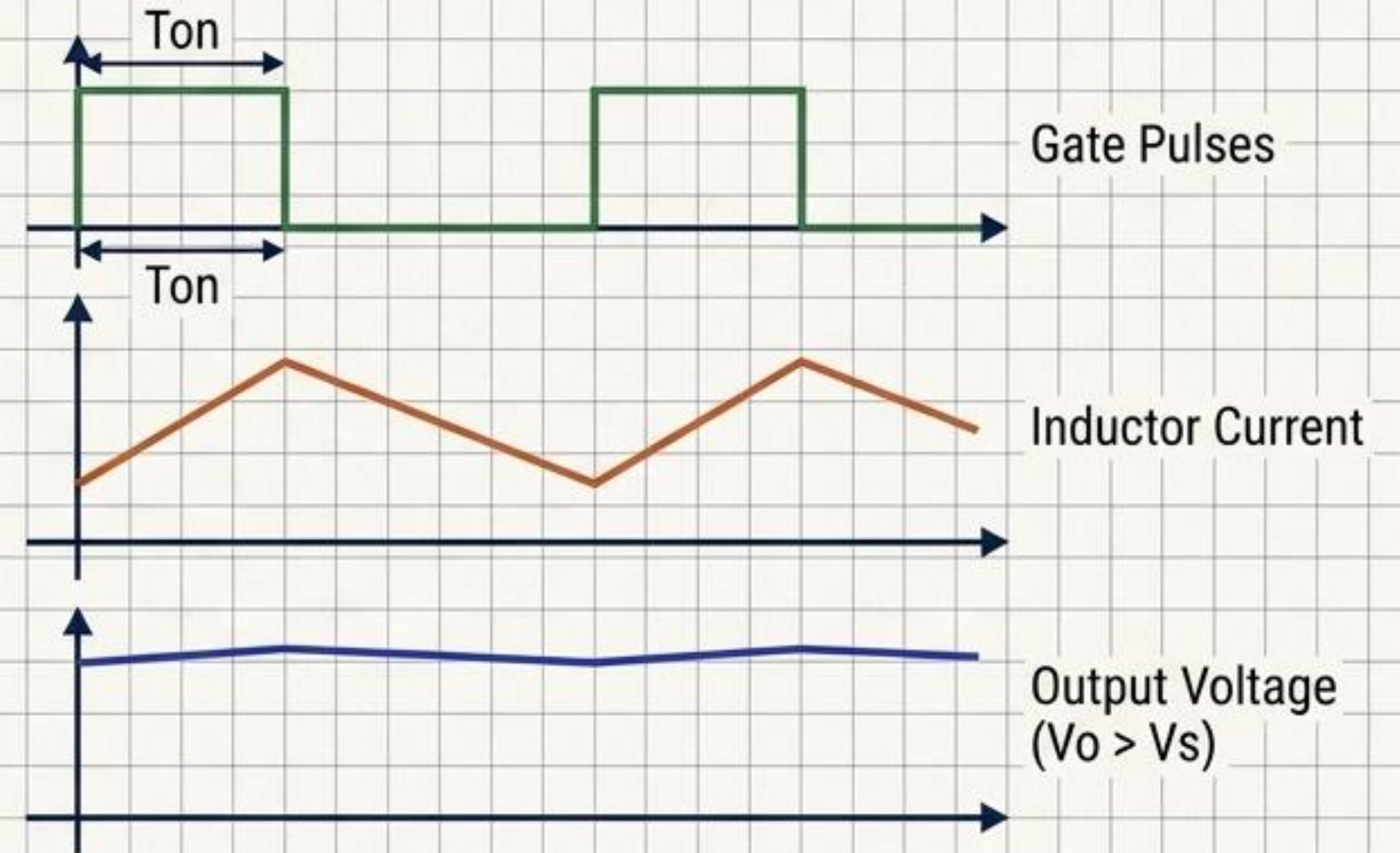
Takeaway: The LC filter smooths the chopped DC into a flat, steady lower-voltage DC line.

Step-Up Chopper (Boost Converter)

Circuit Schematic



Waveforms



Mathematical Engine

Energy Balance: Input Energy = Output Energy

Voltage Gain: $V_o = V_s / (1 - D)$

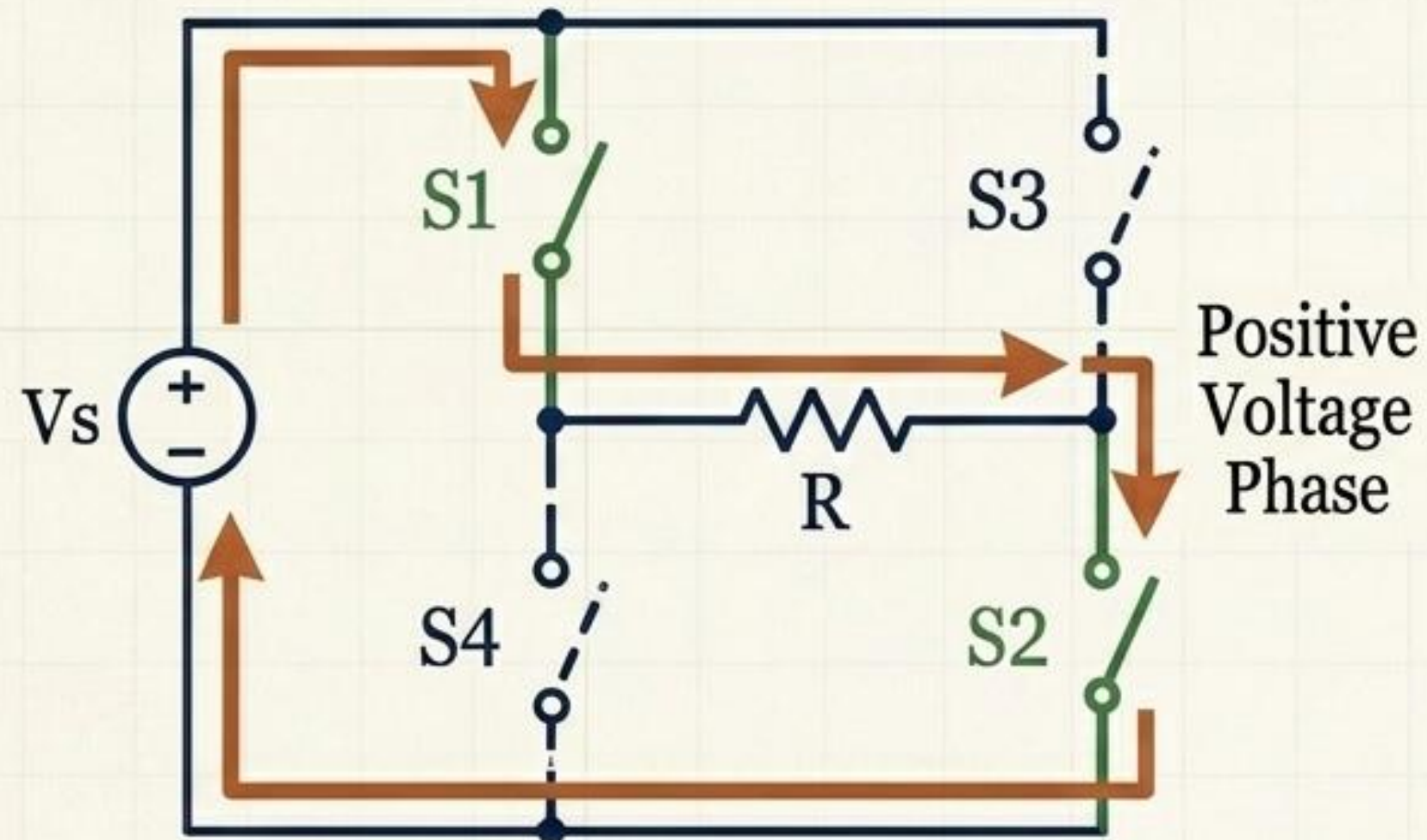
System Limit: As D approaches 1, V_o theoretically approaches infinity, but is limited by parasitic resistance.

The DC-DC Topologies Matrix

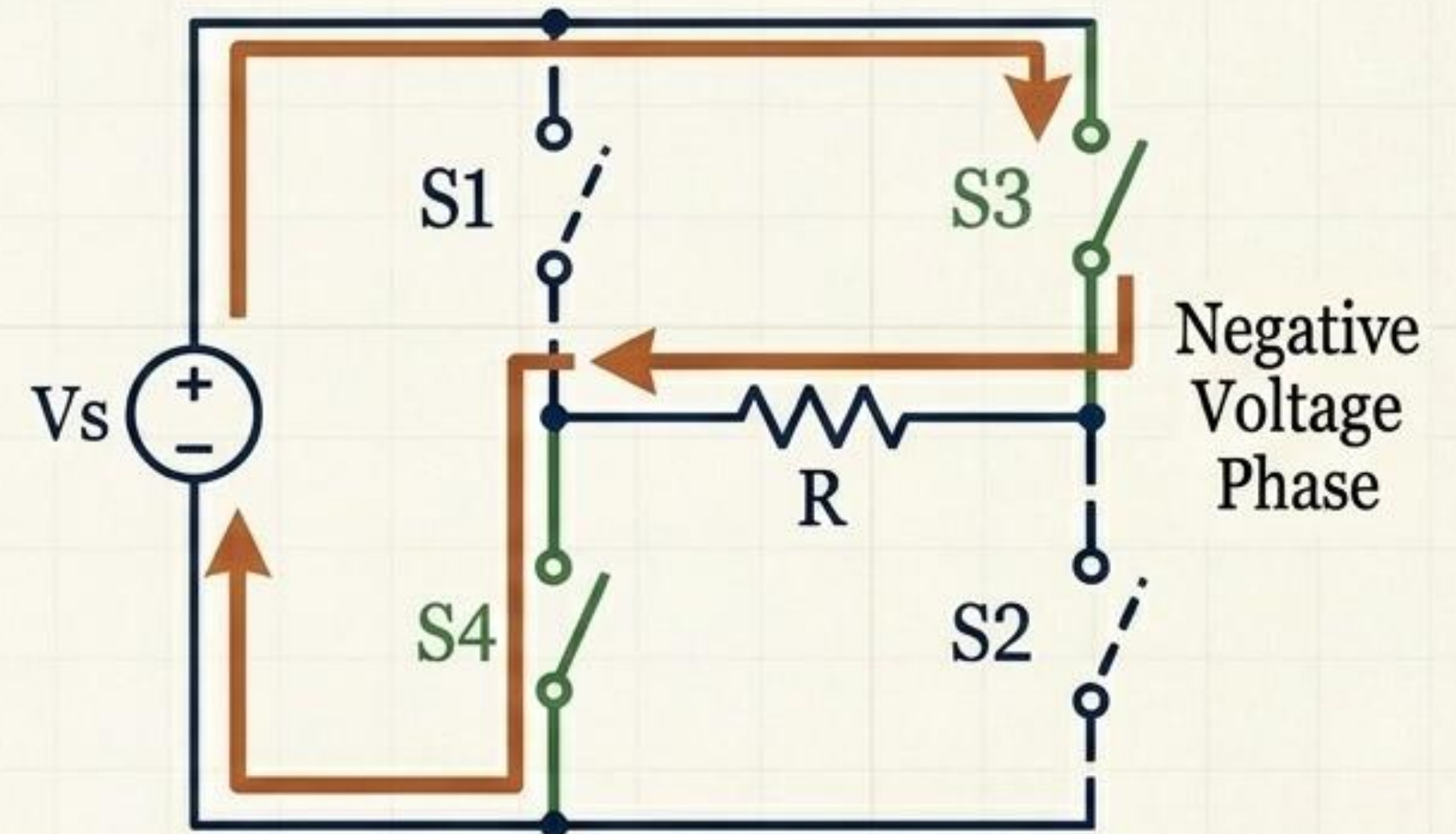
	Buck	Boost	Buck-Boost	Cuk
Voltage Gain V_o/V_s	D	$\frac{1}{1-D}$	$\frac{-D}{1-D}$	$\frac{-D}{1-D}$
Output Polarity	Positive	Positive	Inverted (Negative)	Inverted (Negative)
Current Profile	Pulsating Input, Smooth Output	Smooth Input, Pulsating Output	Pulsating Input & Output	Smooth Input & Output
Complexity & Stress	Low switch stress	High capacitor stress	High switch stress	Requires two inductors & capacitors
Primary Applications	SMPS, Battery chargers	Solar MPPT, EV Powertrains	Portable electronics	High-end low- ripple supplies

Inverter Fundamentals: The H-Bridge Concept

State A

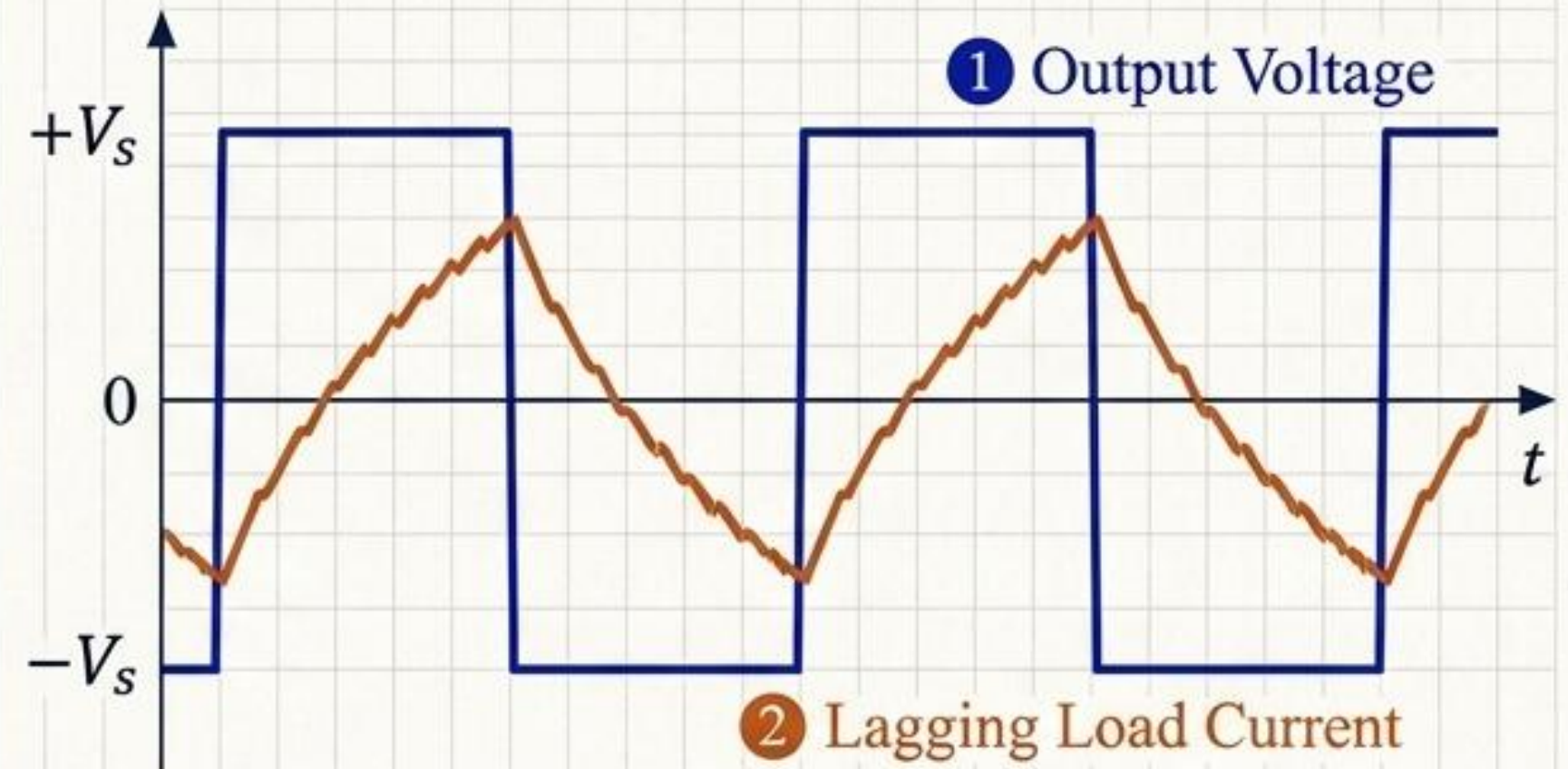
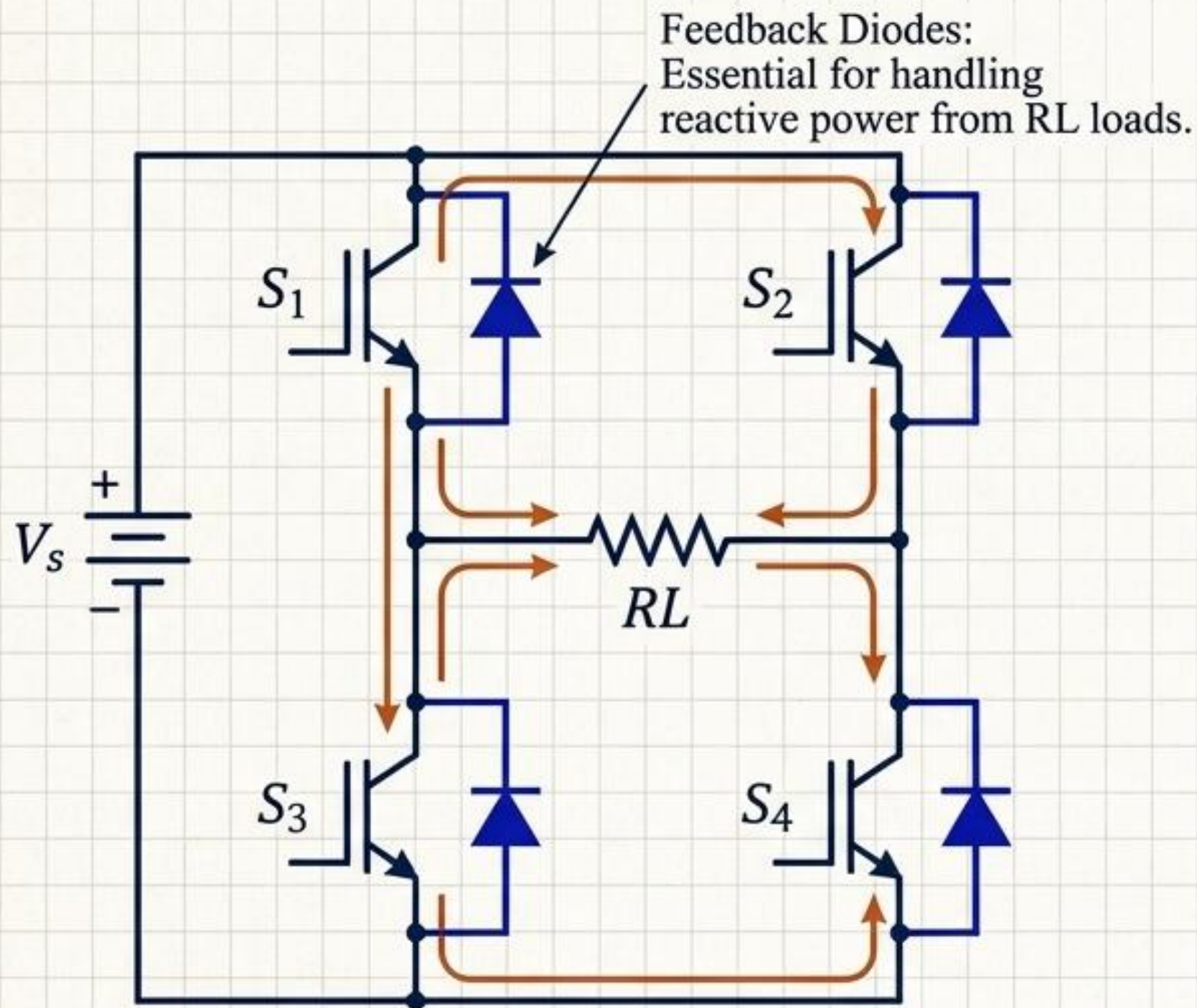


State B



By rapidly alternating between State A and State B, a unipolar DC source creates a bipolar alternating current across the load. Core Applications: Motor Drives, Solar PV grid integration, UPS systems, HVDC links.

Single-Phase Bridge Inverter (Square-Wave)



Mathematical Engine

Fundamental RMS Voltage:

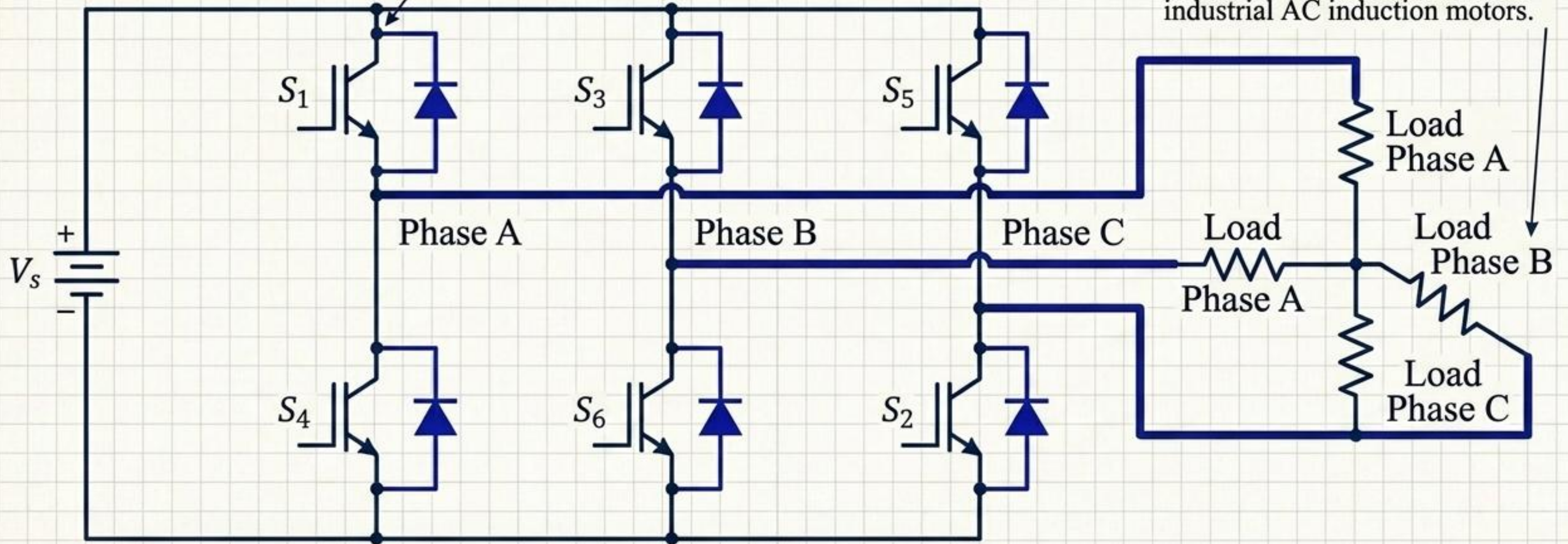
$$V_{o1} = \frac{4 * V_s}{\pi * \sqrt{2}} \approx 0.9 * V_s$$

Diagnostic Note: Square waves contain massive low-order harmonic distortion. The rigid switching creates heavy electromagnetic noise, making this raw output unsuitable for sensitive electronics.

Three-Phase Bridge Inverters: Architecture

Crucial Rule: Never turn on top and bottom switches in the same leg simultaneously. This creates a deadly short-circuit (shoot-through) across the DC source.

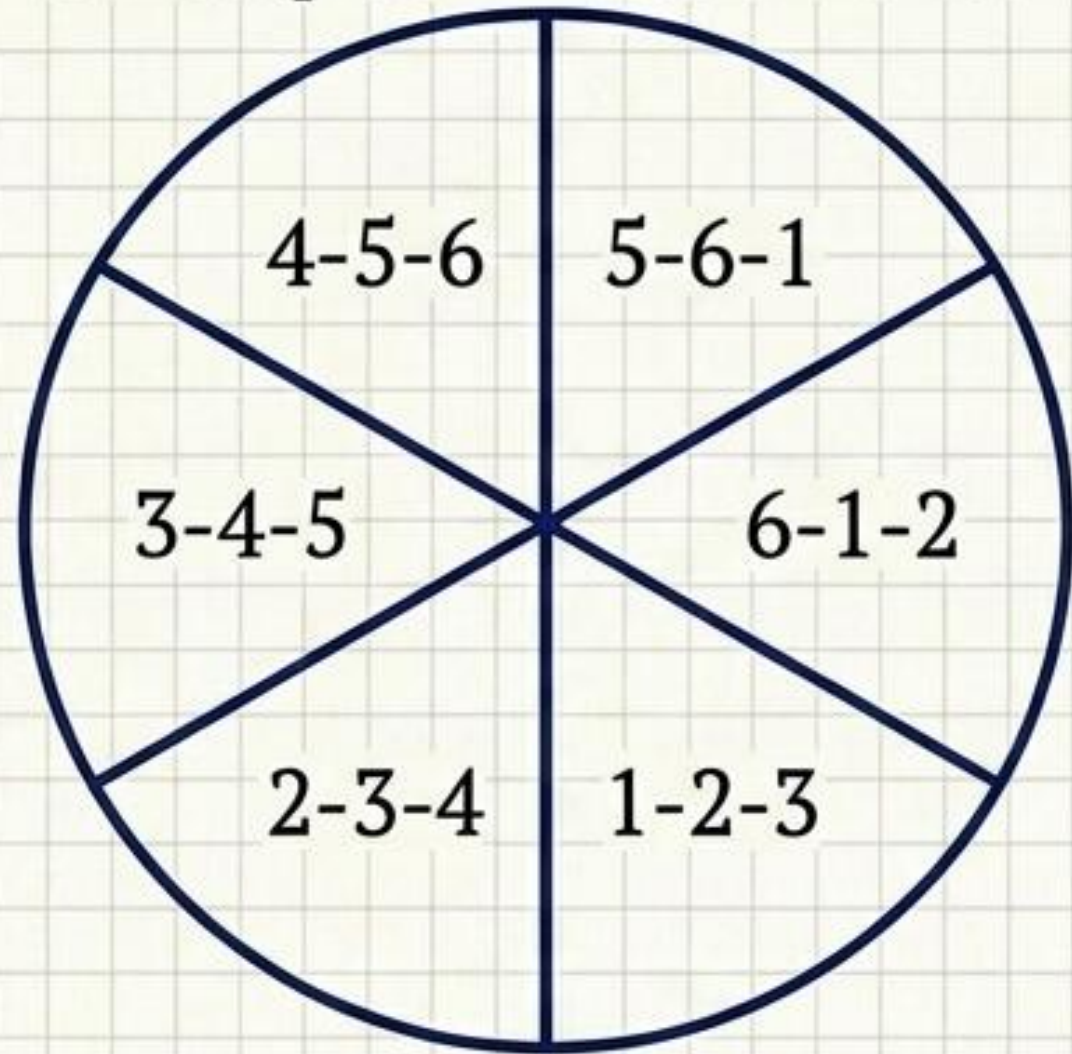
The staggered switching of these three legs synthesizes a rotating magnetic field, which is the foundational mechanism driving industrial AC induction motors.



Operational Frameworks: This architecture operates primarily in two distinct sequencing patterns: 180° Conduction Mode and 120° Conduction Mode.

Conduction Modes: 180° vs. 120° Sequencing

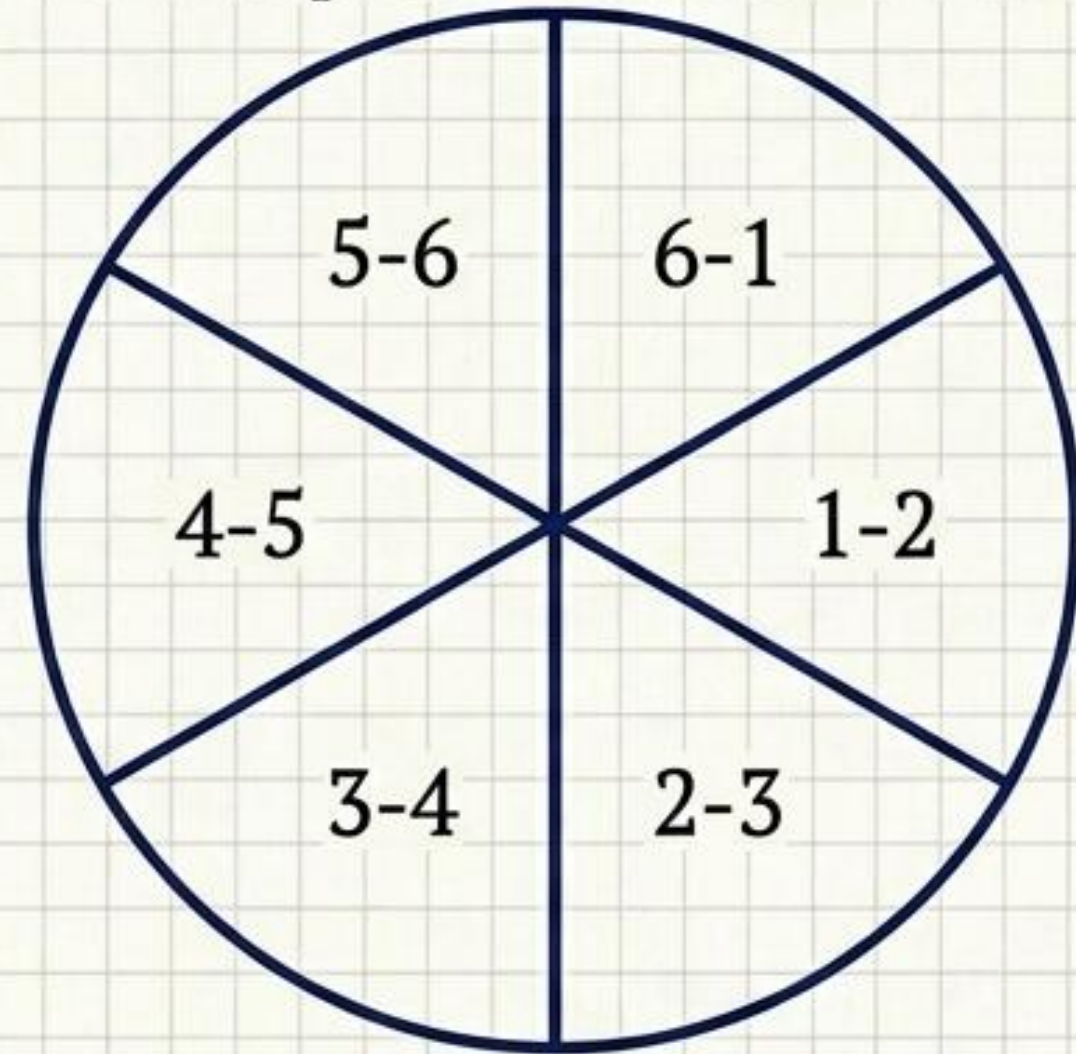
Six-Step Commutation Wheel



- Each switch conducts for a full 180°.
- Three switches are always ON simultaneously.
- Phase voltages form a distinct 6-step staircase waveform.
- Better utilization of the DC supply voltage.

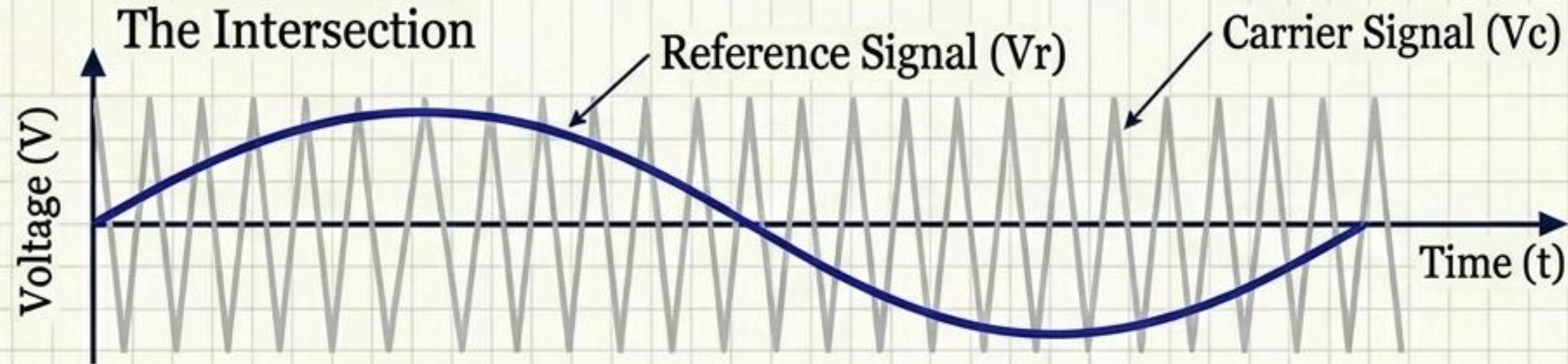
120° Conduction

Six-Step Commutation Wheel



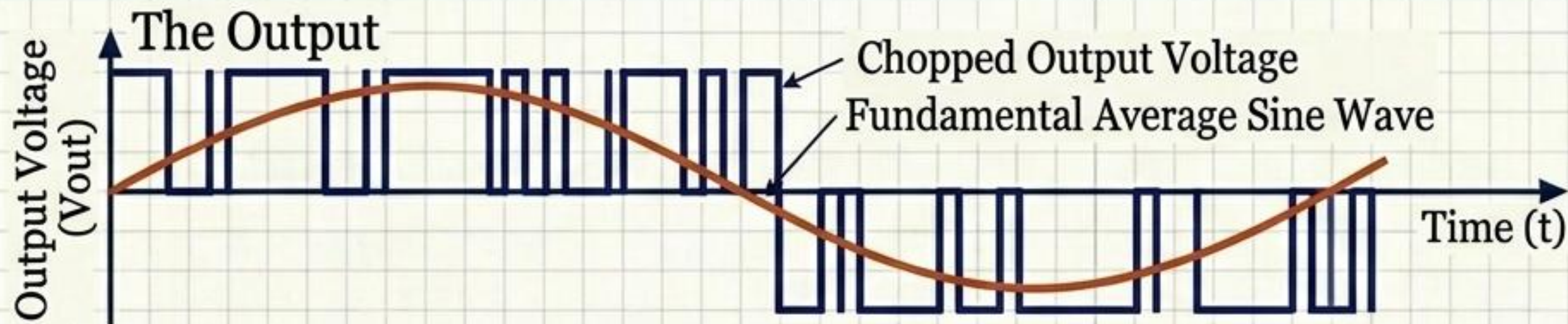
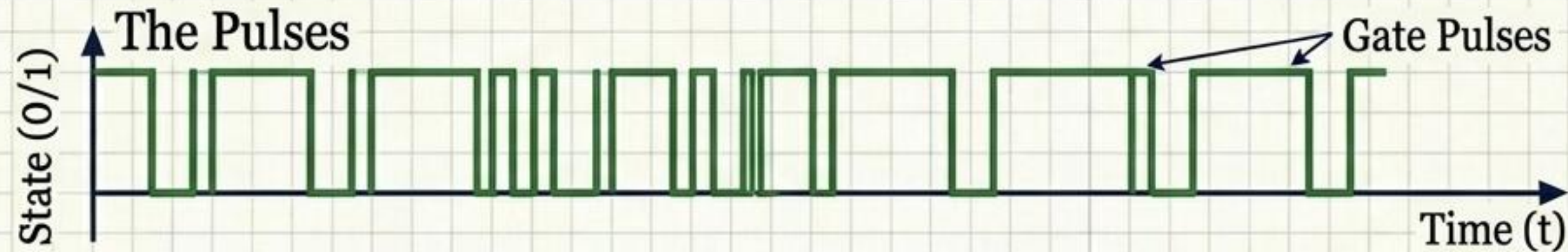
- Each switch conducts for 120°.
- A built-in 60° dead-band prevents leg short-circuits.
- Only two switches are ON simultaneously.
- Inherently avoids shoot-through faults, improving safety.

The Art of PWM: Sculpting the Sine Wave



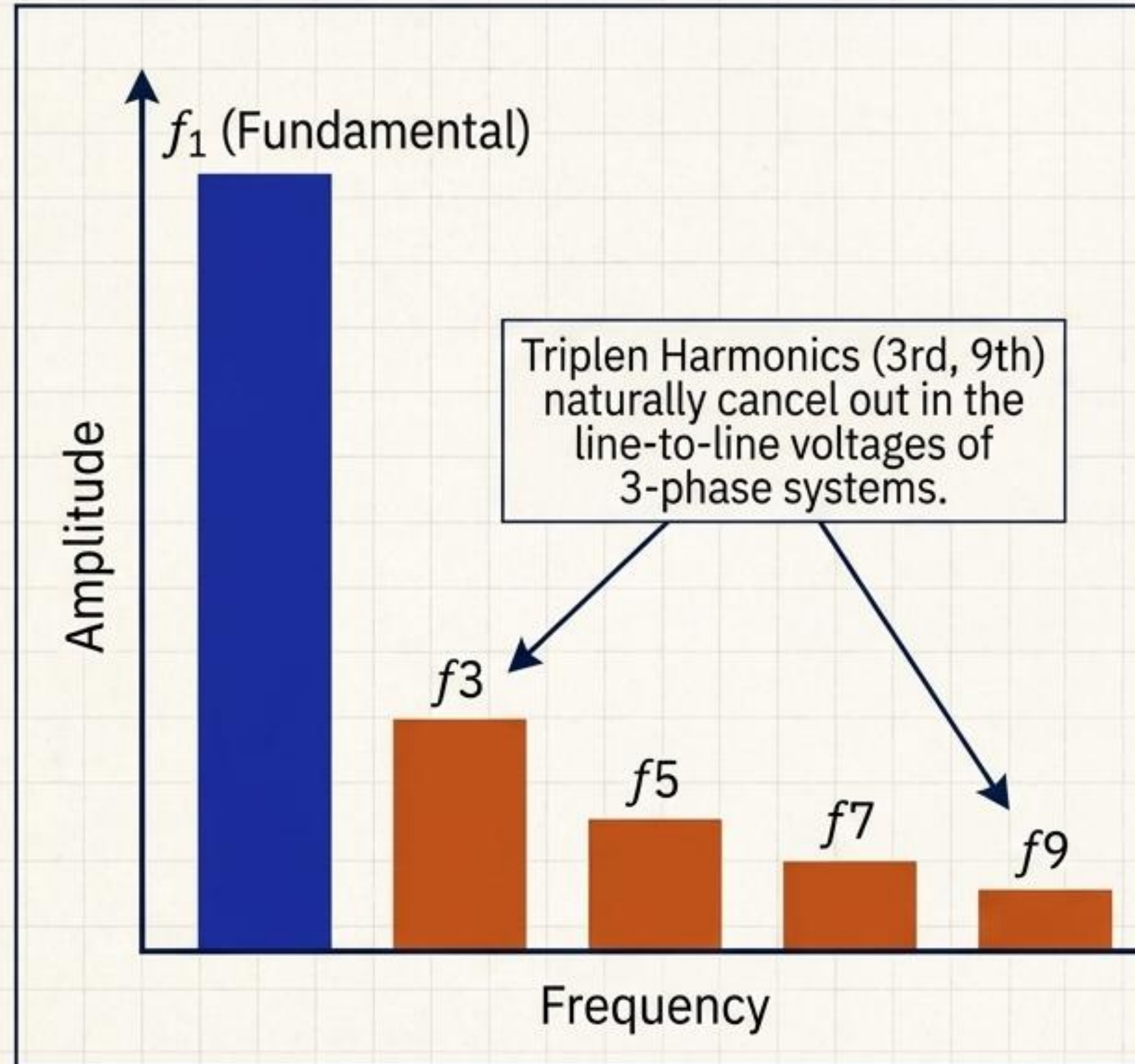
PWM eliminates low-order harmonics by shifting electrical noise to high frequencies, making it easily filtered.

Modulation Index ($M_a = V_r / V_c$) dictates the output voltage amplitude.



Harmonics & Power Quality

The Harmonic Spectrum



THD & Mitigation

Total Harmonic Distortion (THD)

$$THD = \left[\frac{\sqrt{\sum (V_n^2)}}{V_1} \right] * 100\%$$

(Note: V_n represents harmonic RMS voltages, V_1 is fundamental).

Effects of High THD

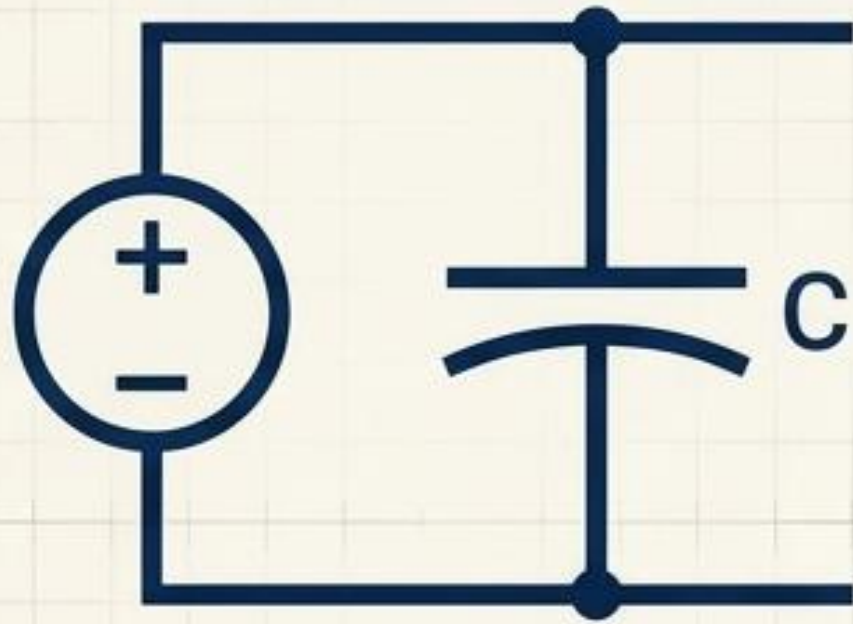
- Severe motor overheating.
- Mechanical torque pulsations and vibration.
- Interference with sensitive grid communications.

Reduction Techniques

1. Selective Harmonic Elimination (SHE)
2. Passive LC Low-Pass Filtering
3. Multilevel Inverter Topologies

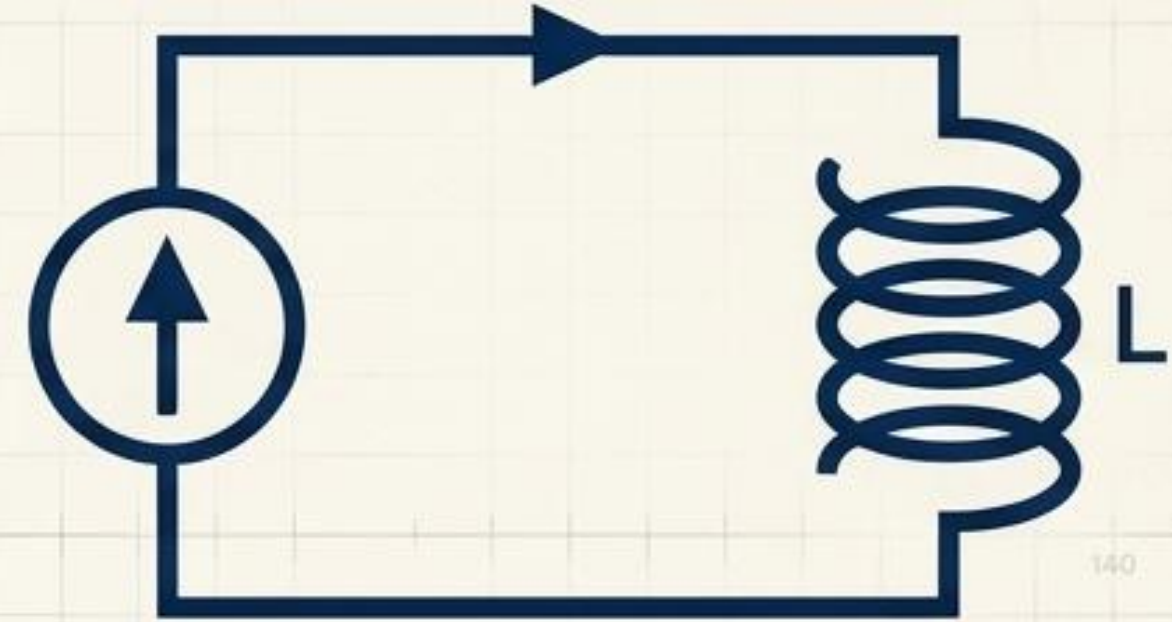
VSI vs. CSI: Source Inverter Diagnostic

Voltage Source Inverter (VSI)



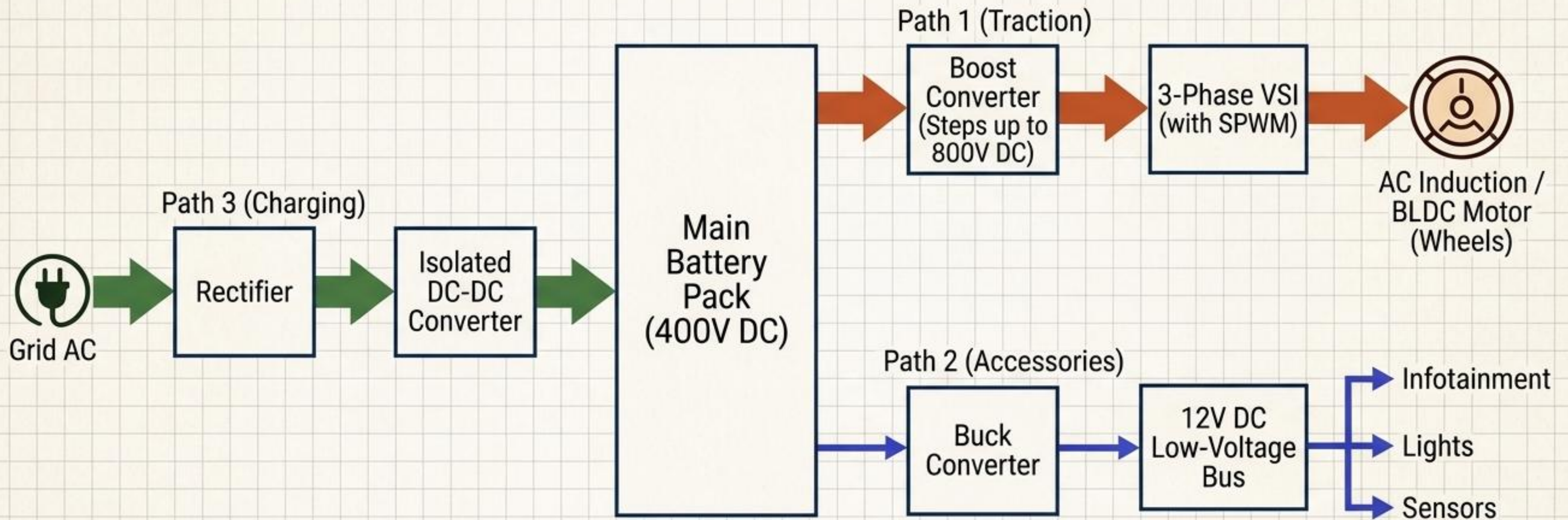
- Input: Stiff, constant DC voltage source.
- Output Waveforms: Voltage waveform is independent of the load. Current waveform depends entirely on load impedance.
- Component Needs: Requires freewheeling diodes to handle reactive power.
- Primary Applications: Uninterruptible Power Supplies (UPS), precise variable speed AC servo and EV drives.

Current Source Inverter (CSI)



- Input: Stiff, constant DC current source.
- Output Waveforms: Current waveform is independent of the load. Voltage waveform depends entirely on load impedance.
- Component Needs: Does NOT require freewheeling diodes because current cannot reverse direction.
- Primary Applications: High-power medium-voltage motor drives, rugged induction heating systems.

Real-World Synthesis: EV Powertrain Architecture



System Takeaway: A modern Electric Vehicle is a complex, integrated network of switching converters routing, sculpting, and managing continuous energy flow across multiple voltage and frequency domains.

The Engineer's Toolkit: Master Reference

Duty Cycle & Gain Equations

- Buck Converter:

$$V_o = D * V_s$$

- Boost Converter:

$$V_o = \frac{V_s}{1 - D}$$

- Buck-Boost Converter:

$$V_o = V_s * \left[\frac{D}{1 - D} \right]$$

Inverter RMS Outputs

- 1-Phase Square Wave:

$$V_{or} = V_s \text{ (Fundamental} = 0.9 * V_s)$$

- 3-Phase (180° Mode Line Voltage):

$$V_{L(rms)} = V_s \sqrt{\frac{2}{3}}$$

- 3-Phase (120° Mode Line Voltage):

$$V_{L(rms)} = V_s \sqrt{\frac{1}{2}}$$

System Design Guidelines

1. Use PWM to push harmonic distortion to higher frequencies where passive LC filters are physically smaller and cheaper.
2. Select CSI for rugged, high-power induction heating; select VSI for precise servo and EV motor control.
3. Always ensure adequate dead-time in VSI legs to prevent catastrophic shoot-through faults across the DC bus.