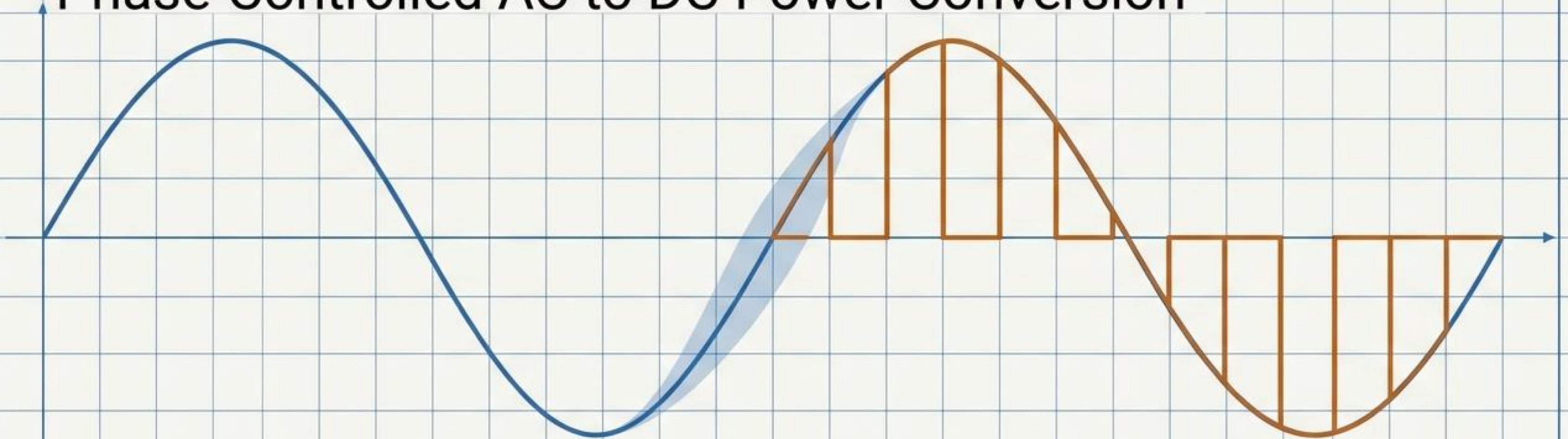


Controlled Rectifiers

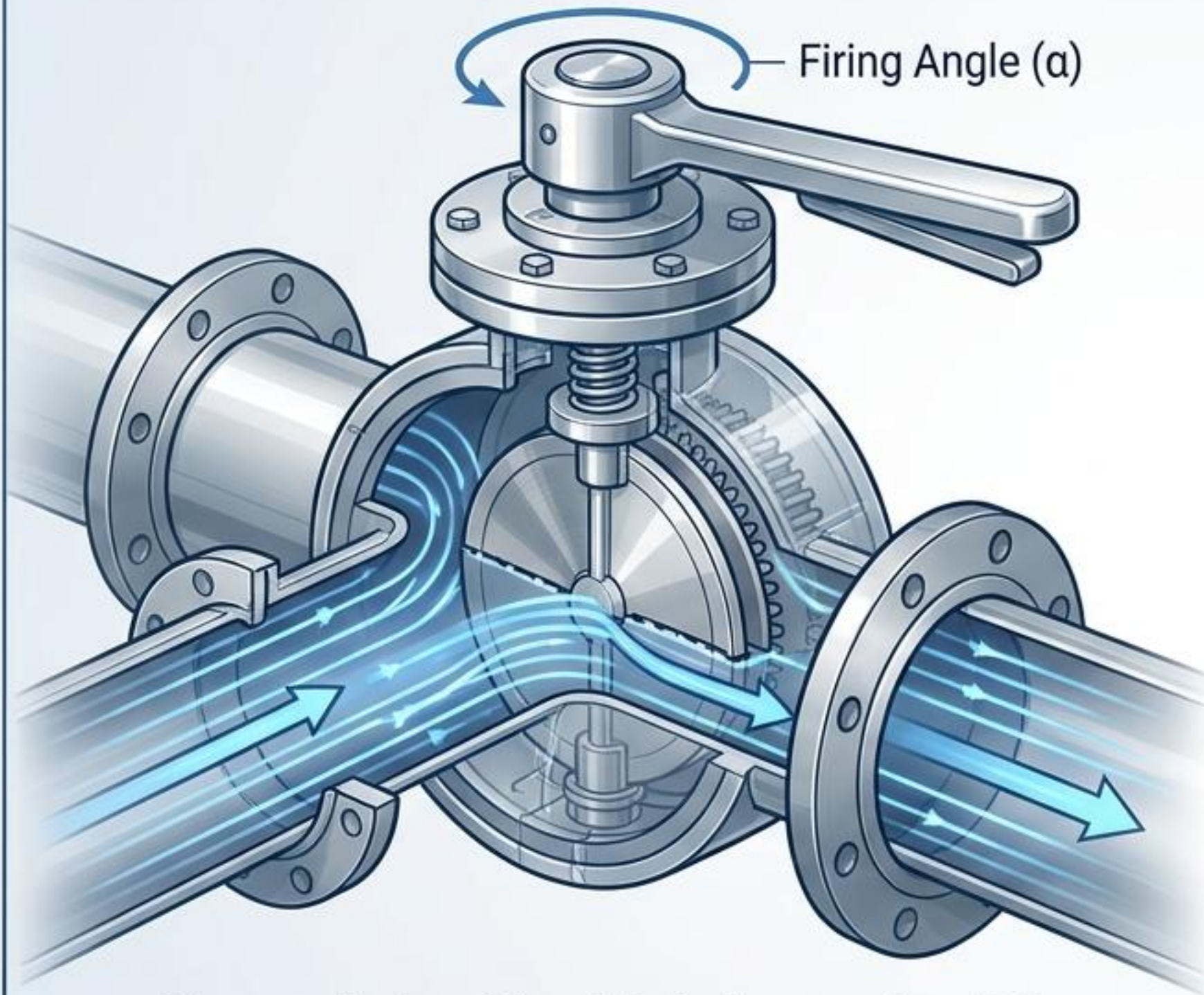
Phase-Controlled AC to DC Power Conversion



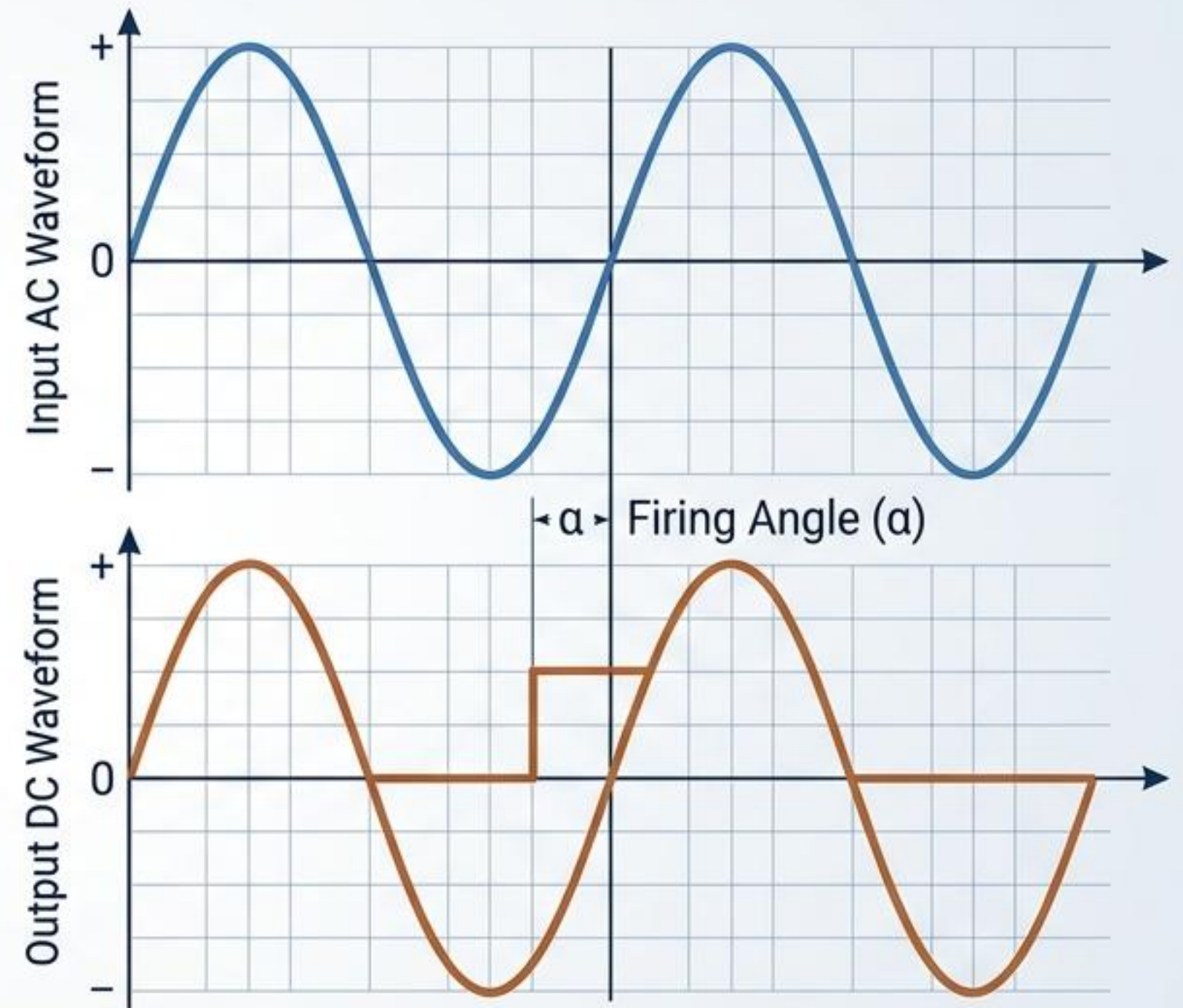
Module-4(a) | Power Electronics

Dr. Sathish K. R. | Assistant Professor | Dept. of EEE | ATME College of Engineering

The Firing Angle (α): Modulating Power Flow



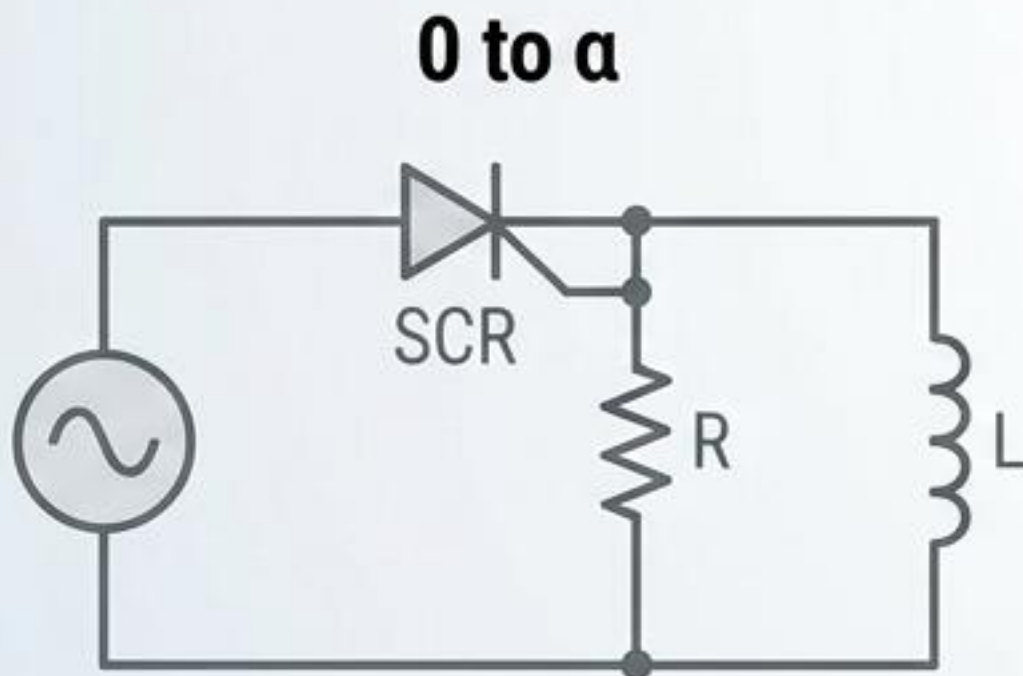
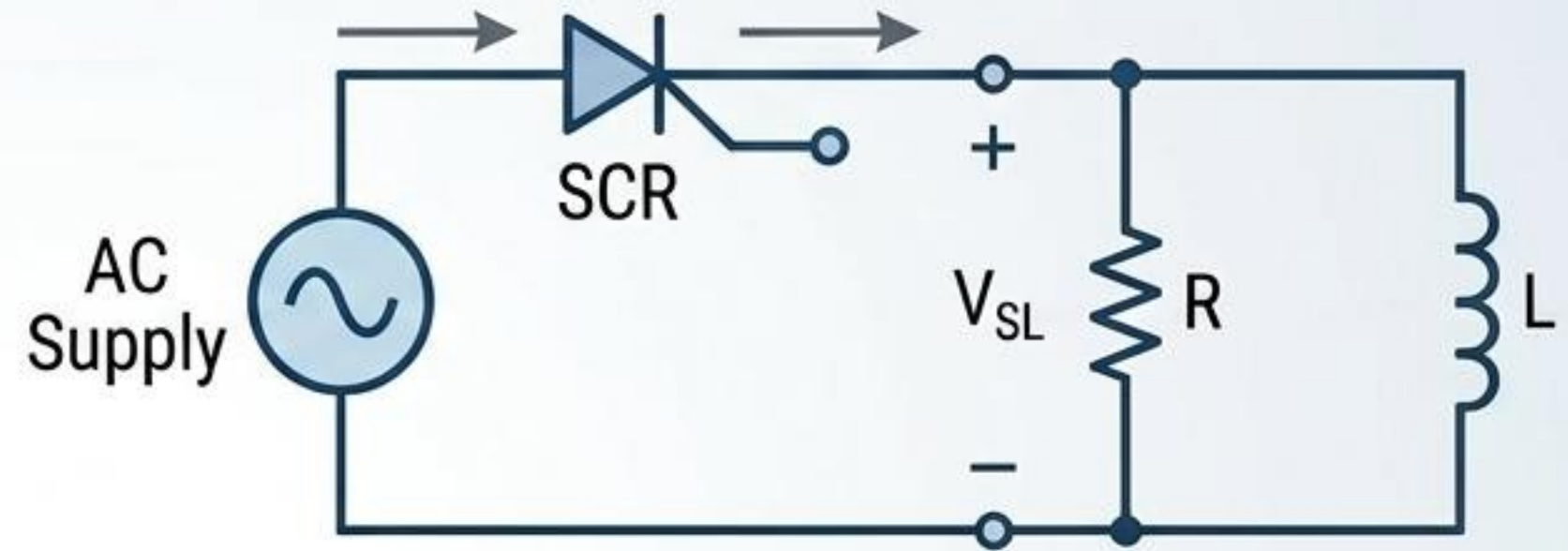
Uncontrolled rectifiers (diodes) output fixed DC.
Controlled rectifiers use SCRs, acting as electronic valves.



By delaying the trigger pulse (gate signal) to angle α , the SCR blocks the forward voltage until commanded, "chopping" the waveform to produce variable average DC output.

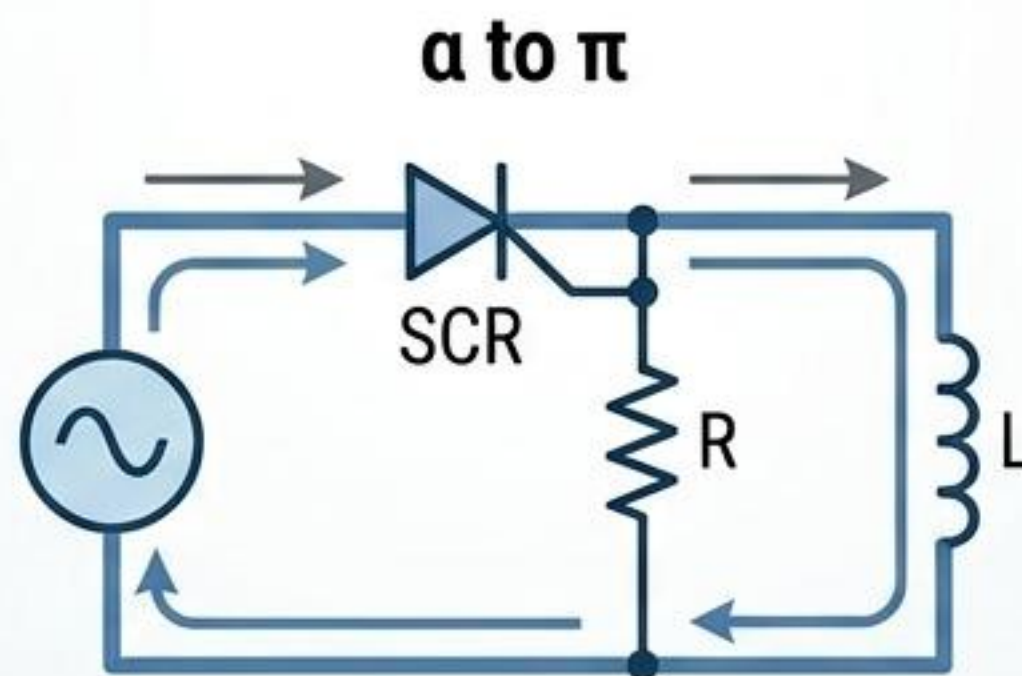
The Baseline: Half-Wave Rectification with an Inductive Load

Inductance changes everything. It forces the load current to continue flowing **even after** the source voltage crosses zero, dragging the system into **unexpected territory**.



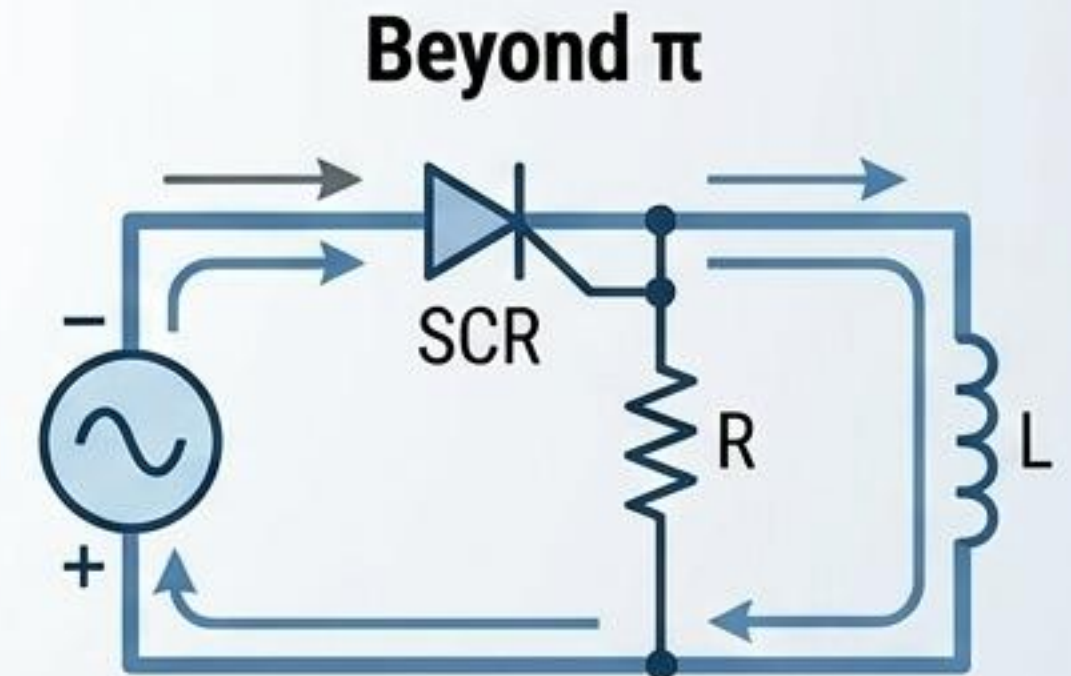
0 to α

Source positive, SCR off. No current.



α to π

SCR fires. Inductor stores energy.



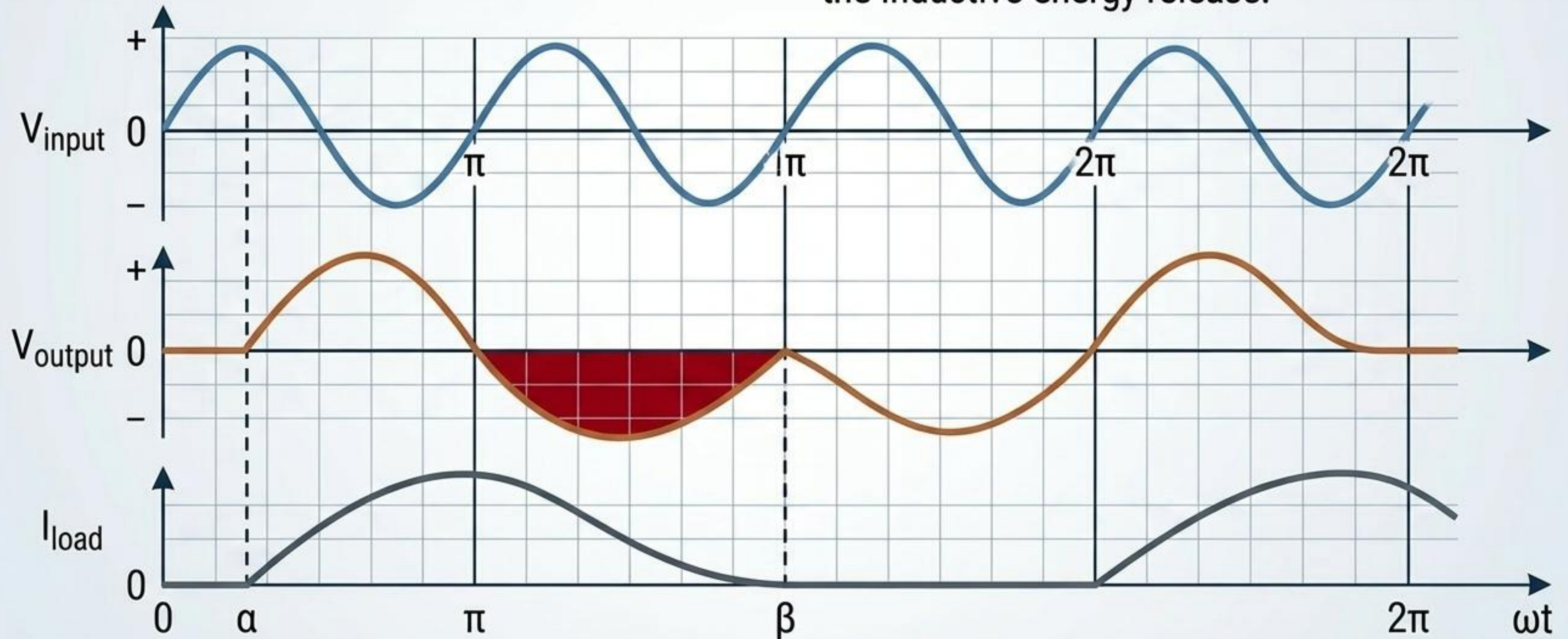
Beyond π

Source negative. Inductor releases energy, forcing SCR to stay forward-biased.

The Inductive Drag: Waveform Analysis of RL Loads

The shaded negative voltage area reduces the overall **average DC output voltage** (V_{avg}).

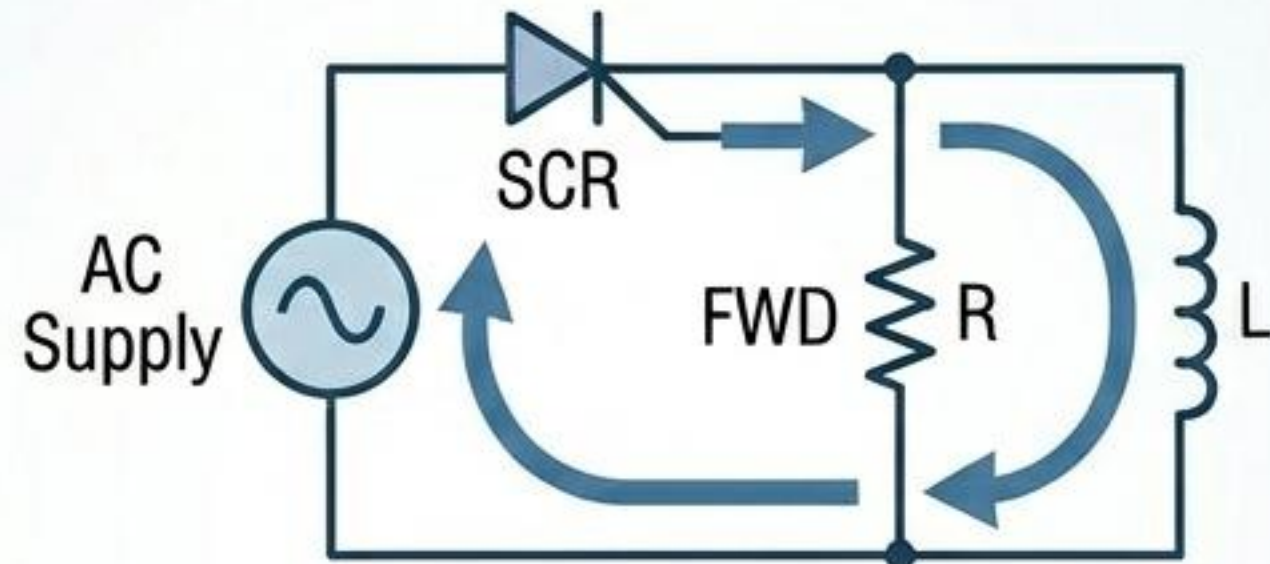
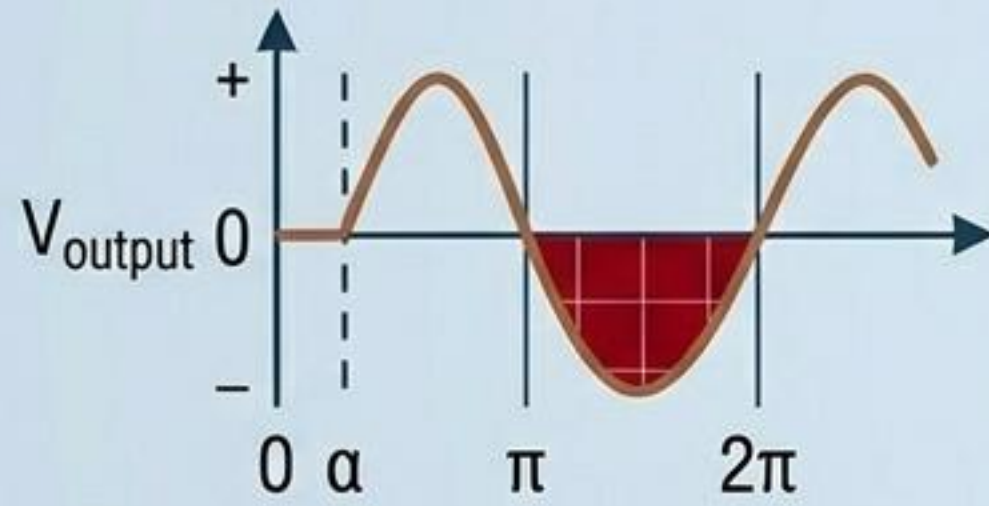
Conduction Interval: α to β . The SCR remains conducting in the negative half-cycle due to the inductive energy release.



The Fix: Isolating the Inductor with a Freewheeling Diode

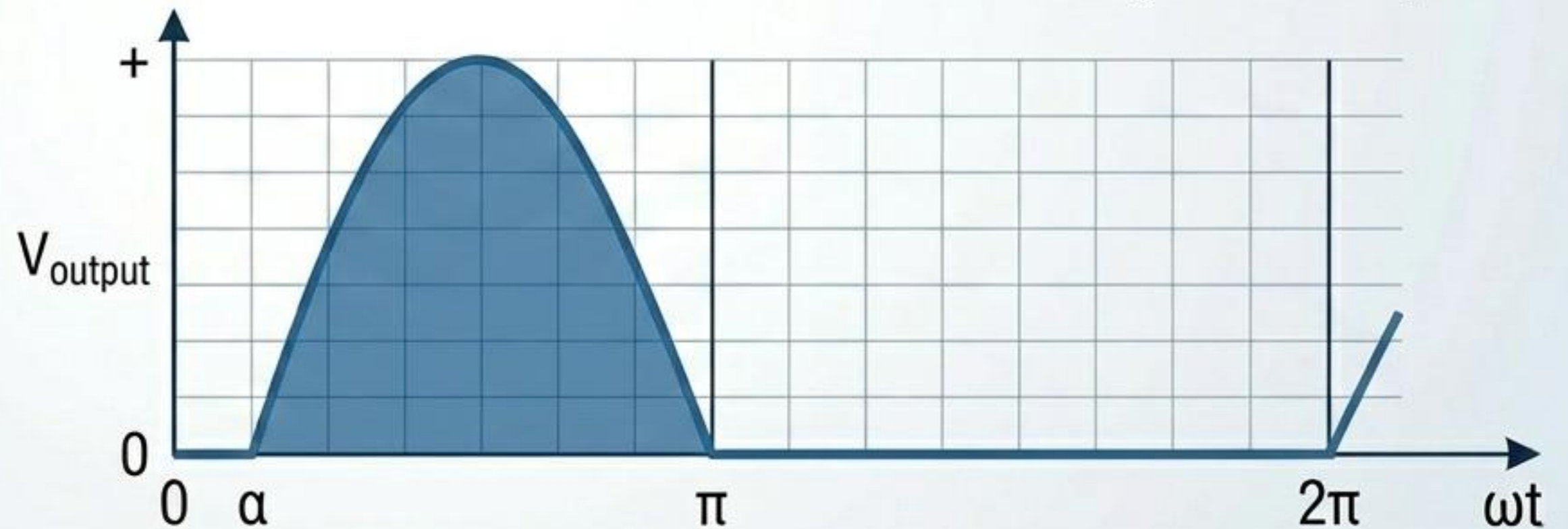
The FWD becomes forward-biased at $\omega t = \pi$, providing a zero-voltage short-circuit path for the inductor's energy.

Without FWD



Three Key Advantages:

1. Eliminates negative load voltage (increases V_{avg})
2. Improves input power factor
3. Protects switching devices from high inductive spikes



Half-Wave Topologies: Analyzing Load Dynamics

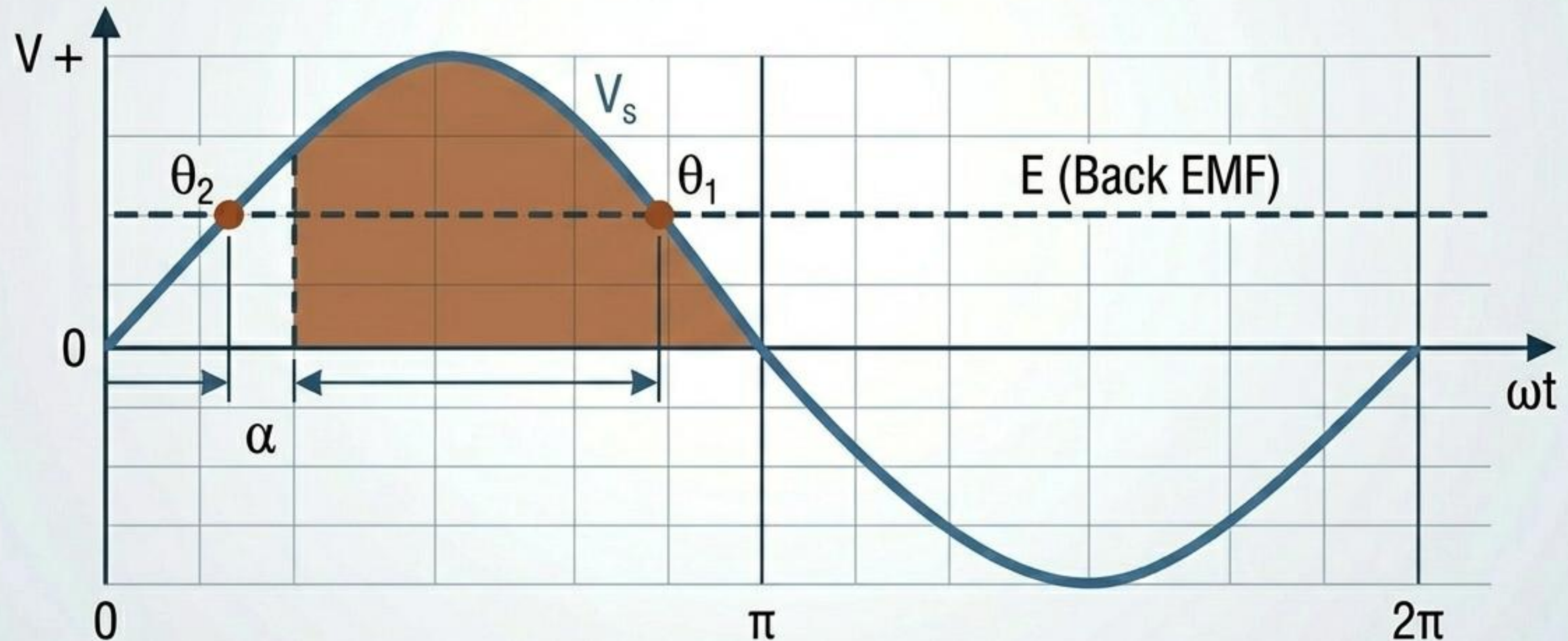
While FWD solves inductive drag, industrial applications involve active loads like DC motors, requiring RLE analysis.

	RL Load	RL + FWD Load	RLE Load
Circuit Diagram			
Output Voltage Profile			
Conduction Interval	α to β	α to π (SCR)/ π to β (FWD)	α to β (only when $V_s > E$)
Primary Characteristic	Negative voltage drag	Maximizes V_{avg}	Models practical DC motor dynamics

RLE Loads: The Impact of Motor Back EMF

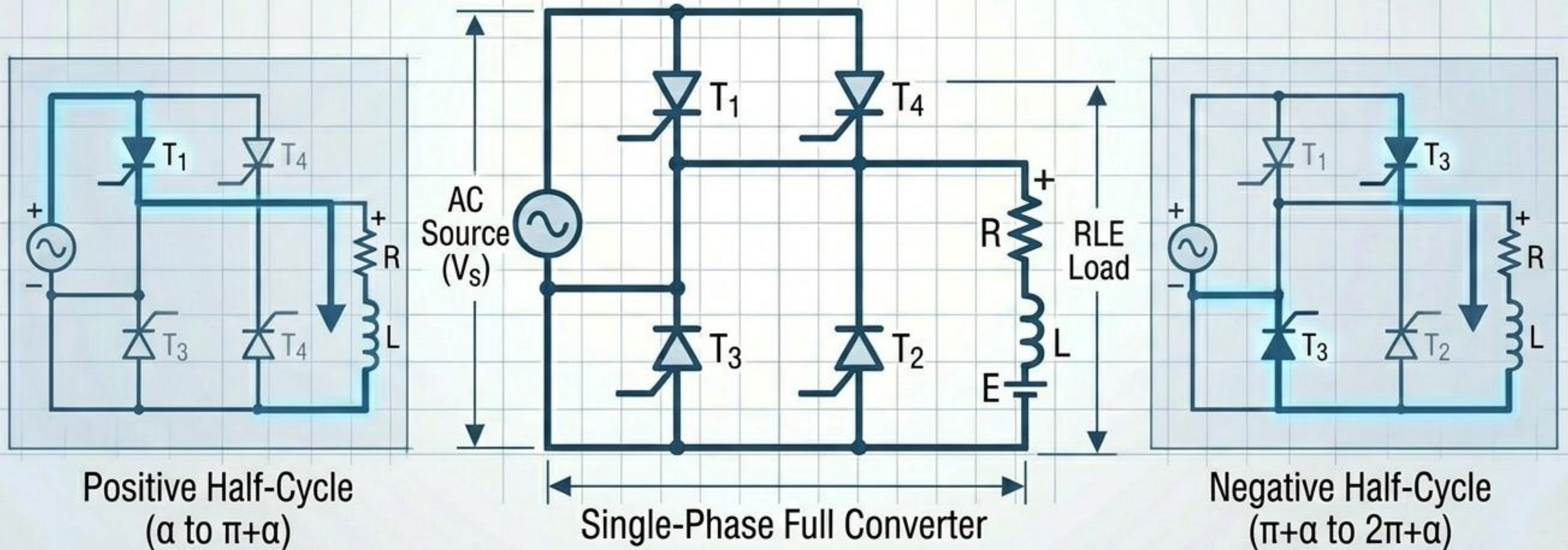
In a DC motor, the armature generates a counter-voltage (E). The SCR cannot become forward-biased—and therefore cannot fire—until the source voltage exceeds E .

Operating Window: Firing angle α must be greater than θ_1 , where $V_m \sin(\theta_1) = E$.



Scaling to Full Power: The Four-SCR Bridge

- Problem: Half-wave topologies waste the negative half-cycle of the AC source.
- Solution: The full converter utilizes paired SCRs to direct current through the load in the same direction during both halves of the AC cycle.

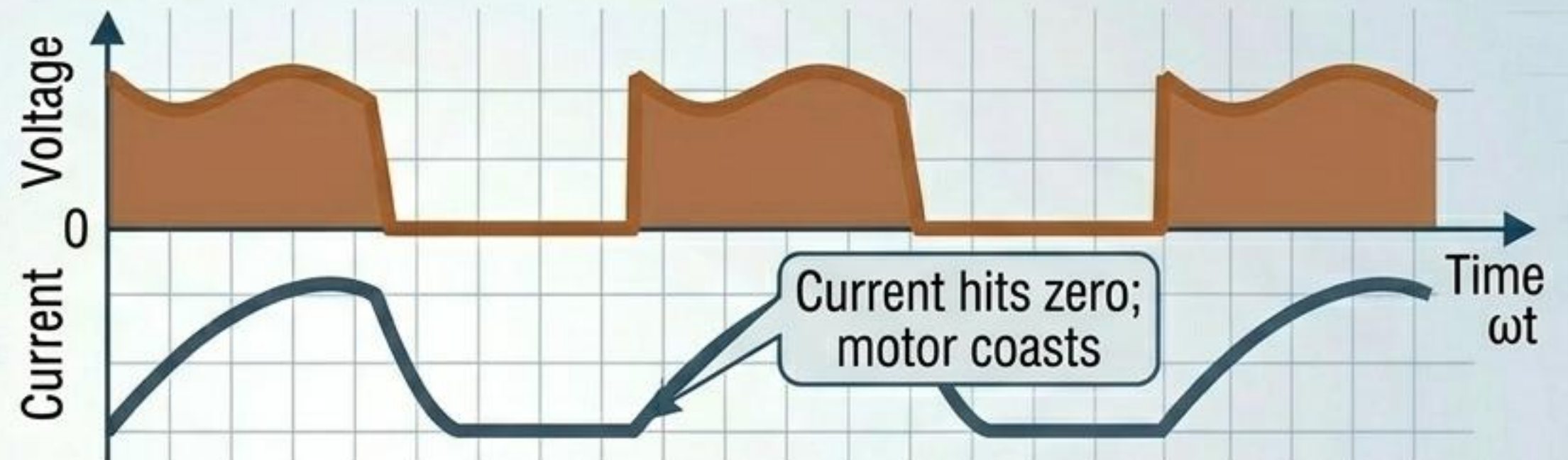


Conduction Modes: Discontinuous vs. Continuous

Discontinuous:

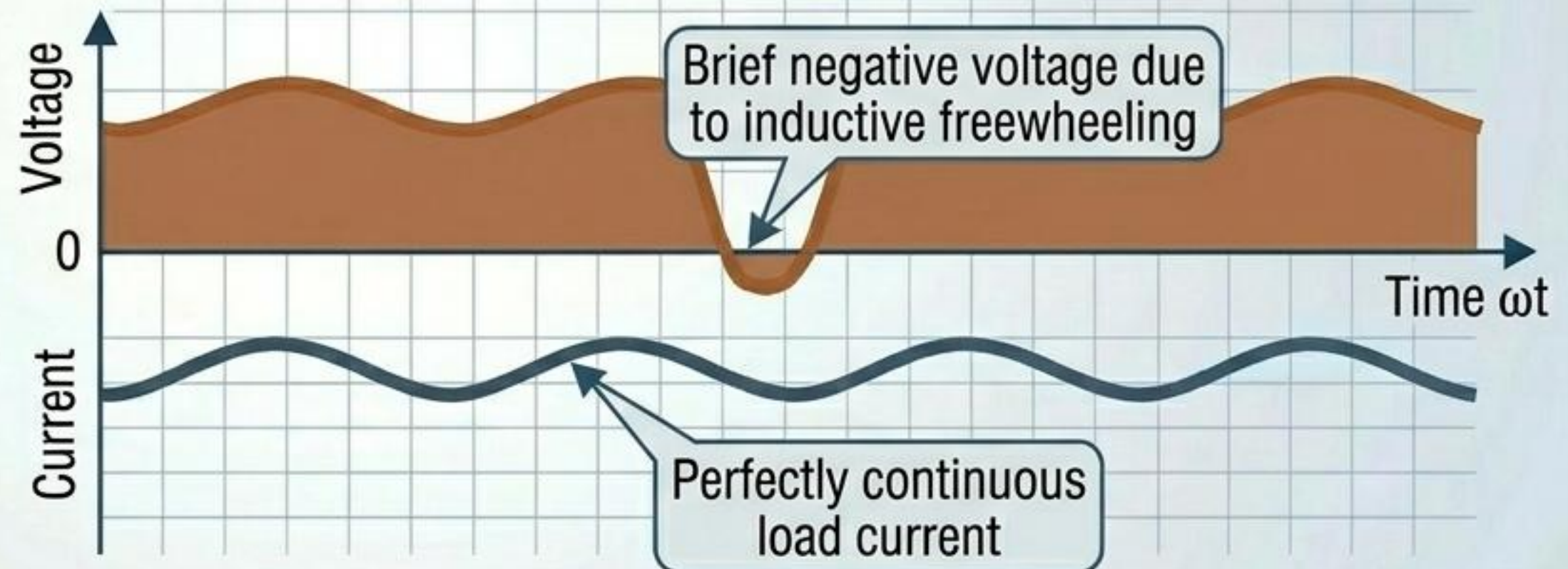
Low inductance. Current falls to zero before the next firing sequence.

Reduces motor efficiency.



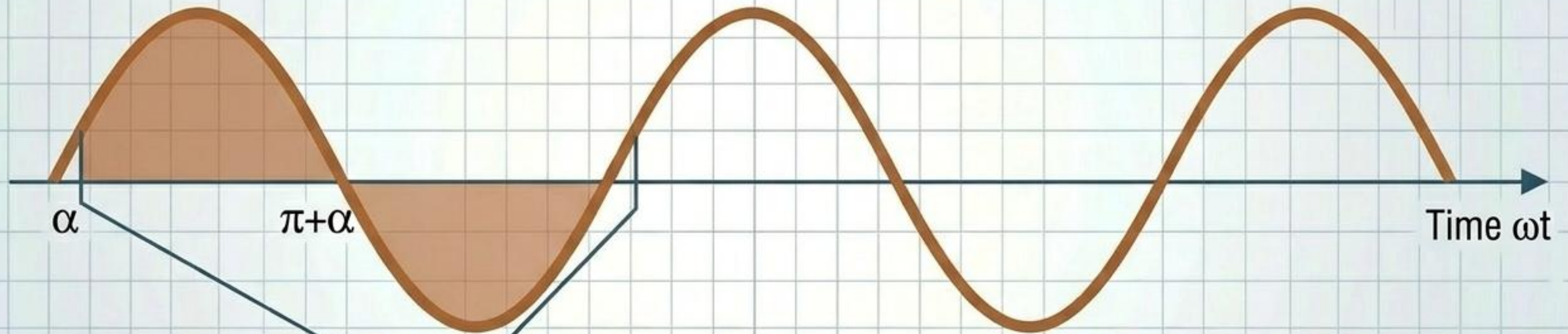
Continuous:

- High inductance maintains current flow at all times. T_1/T_2 conduct until T_3/T_4 are fired, a brief negative voltage region but perfectly continuous load current.



Performance Analytics: Determining Average Output

- For continuous conduction, V_{avg} is entirely dependent on the cosine of the firing angle.
- Exam Focus: If $\alpha < 90^\circ$, V_{avg} is positive (Rectification).
If $\alpha > 90^\circ$, V_{avg} is negative (Inversion).



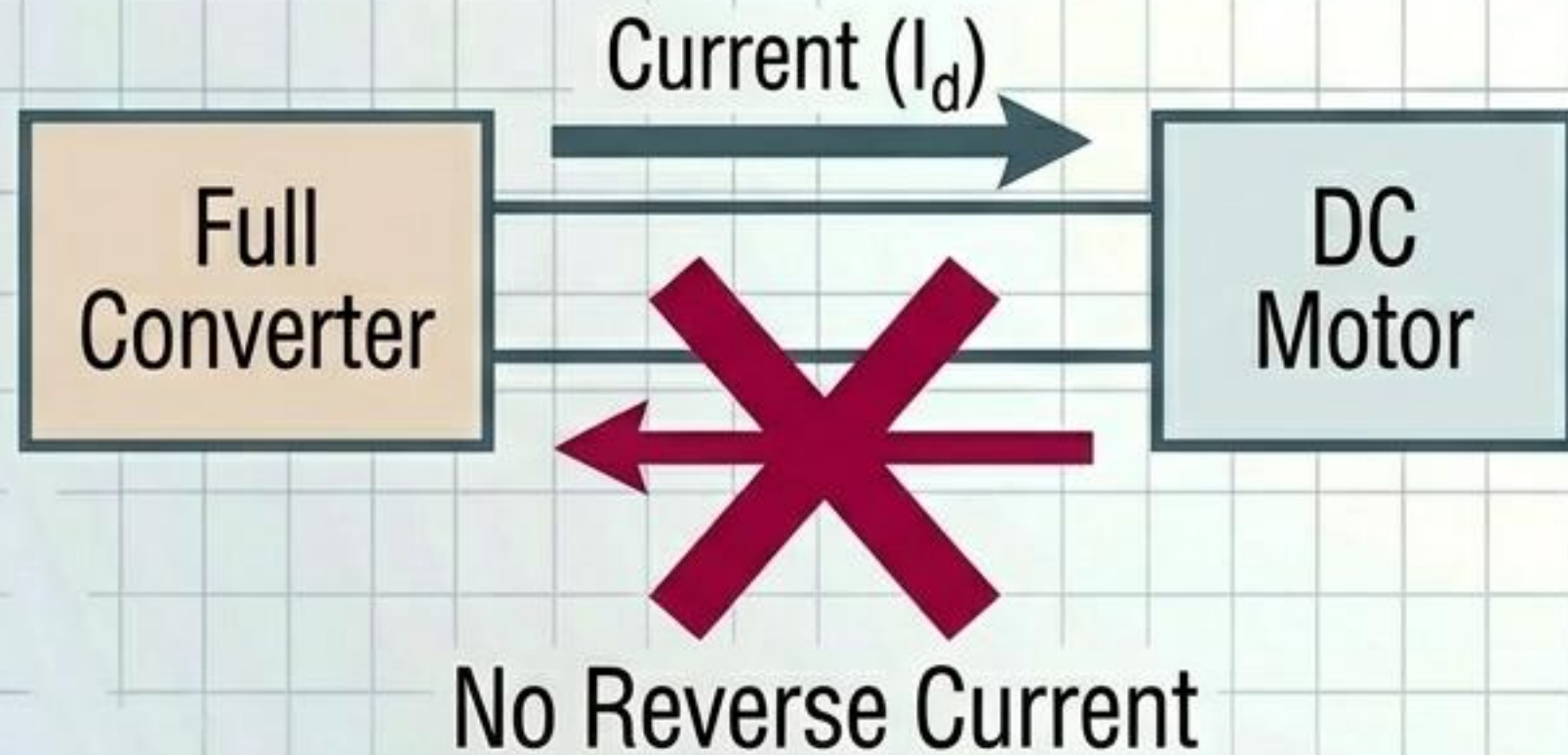
$$V_{avg} = \frac{1}{\pi} \int_0^1 V_m \sin(\omega t) d(\omega t) = \frac{2V_m}{\pi} \cos(\alpha)$$

The Directional Limit: Why We Need Dual Converters

The Barrier:

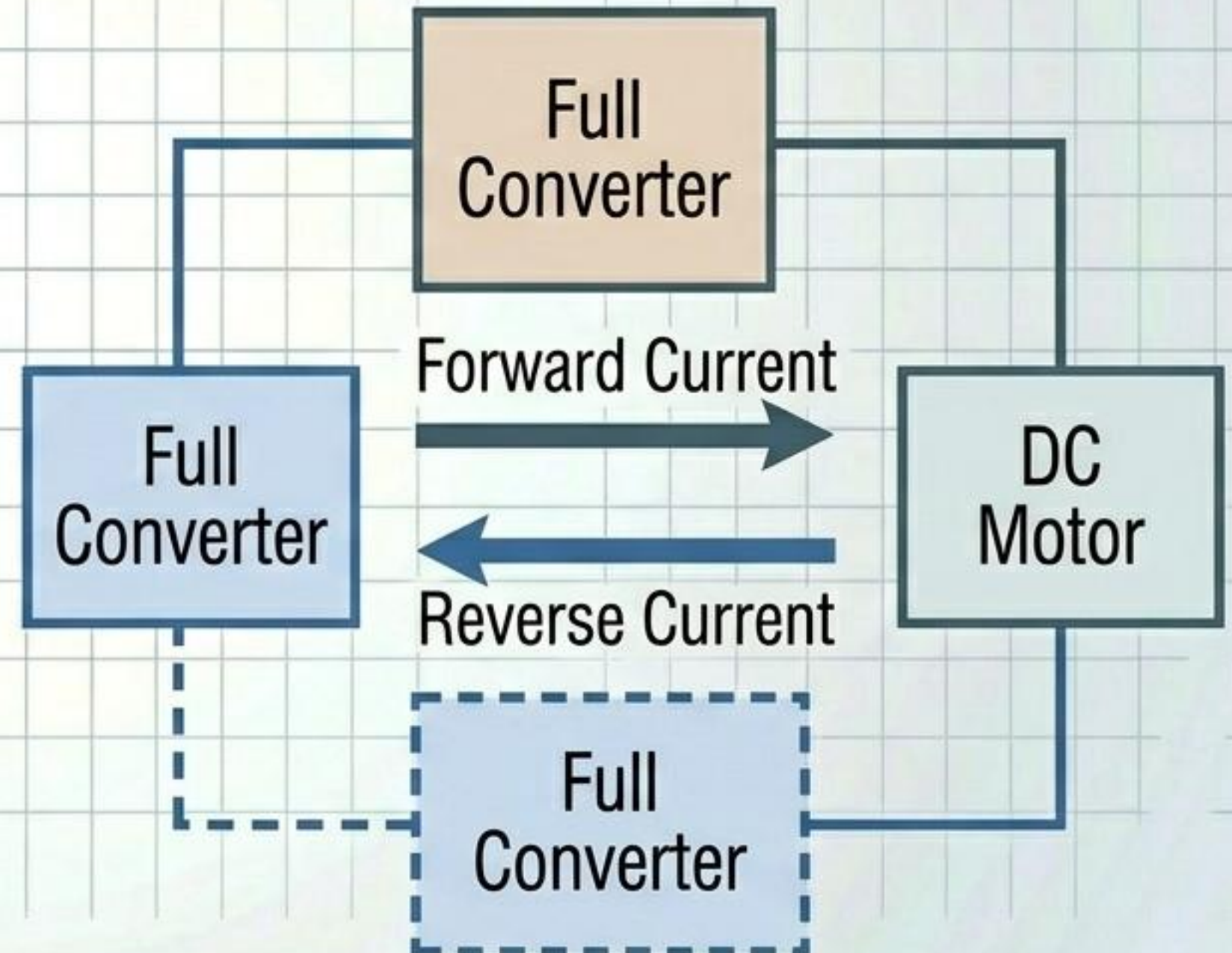
A single full converter can reverse voltage ($\alpha > 90^\circ$), but SCRs only conduct current in one direction.

It provides 2-quadrant operation (forward motoring, reverse regeneration).



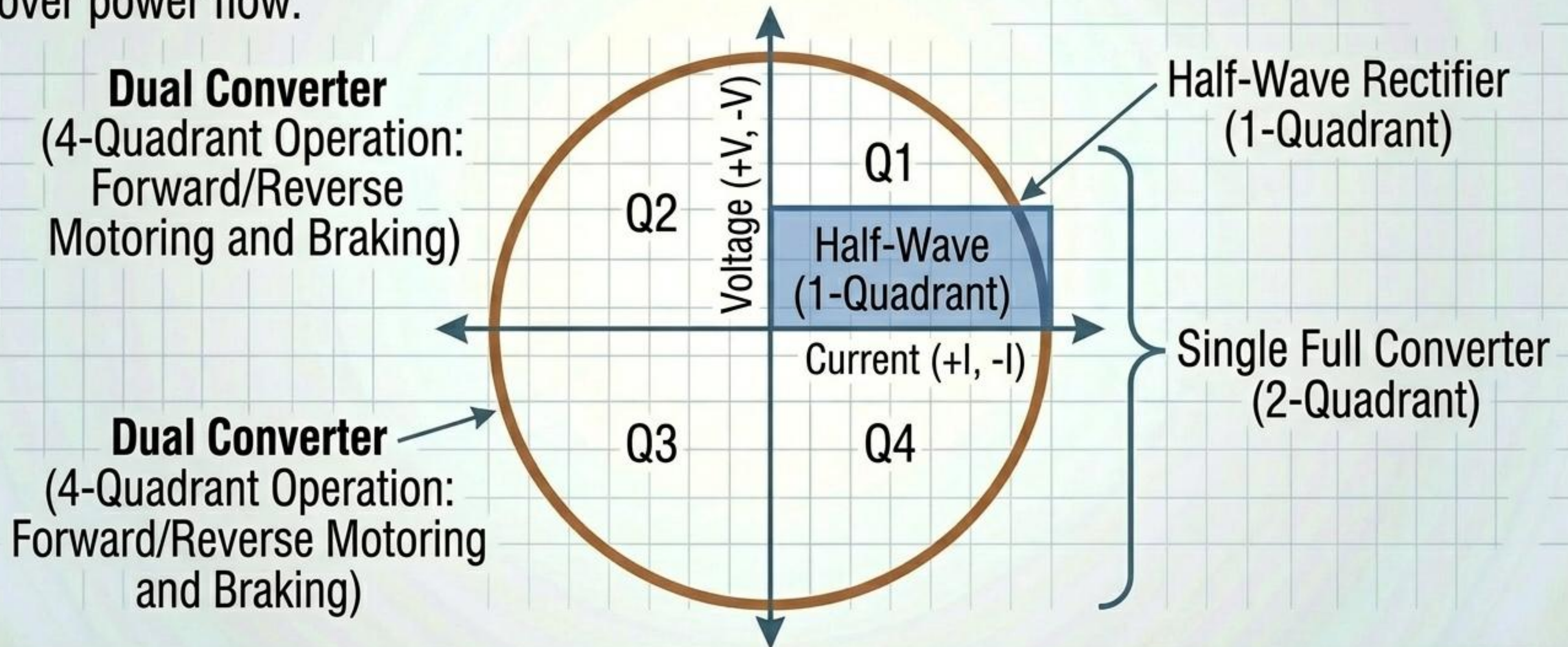
The Goal:

Reversible DC voltage AND reversible DC current for full 4-quadrant control.



The Synthesis: Unlocking Four-Quadrant Operation

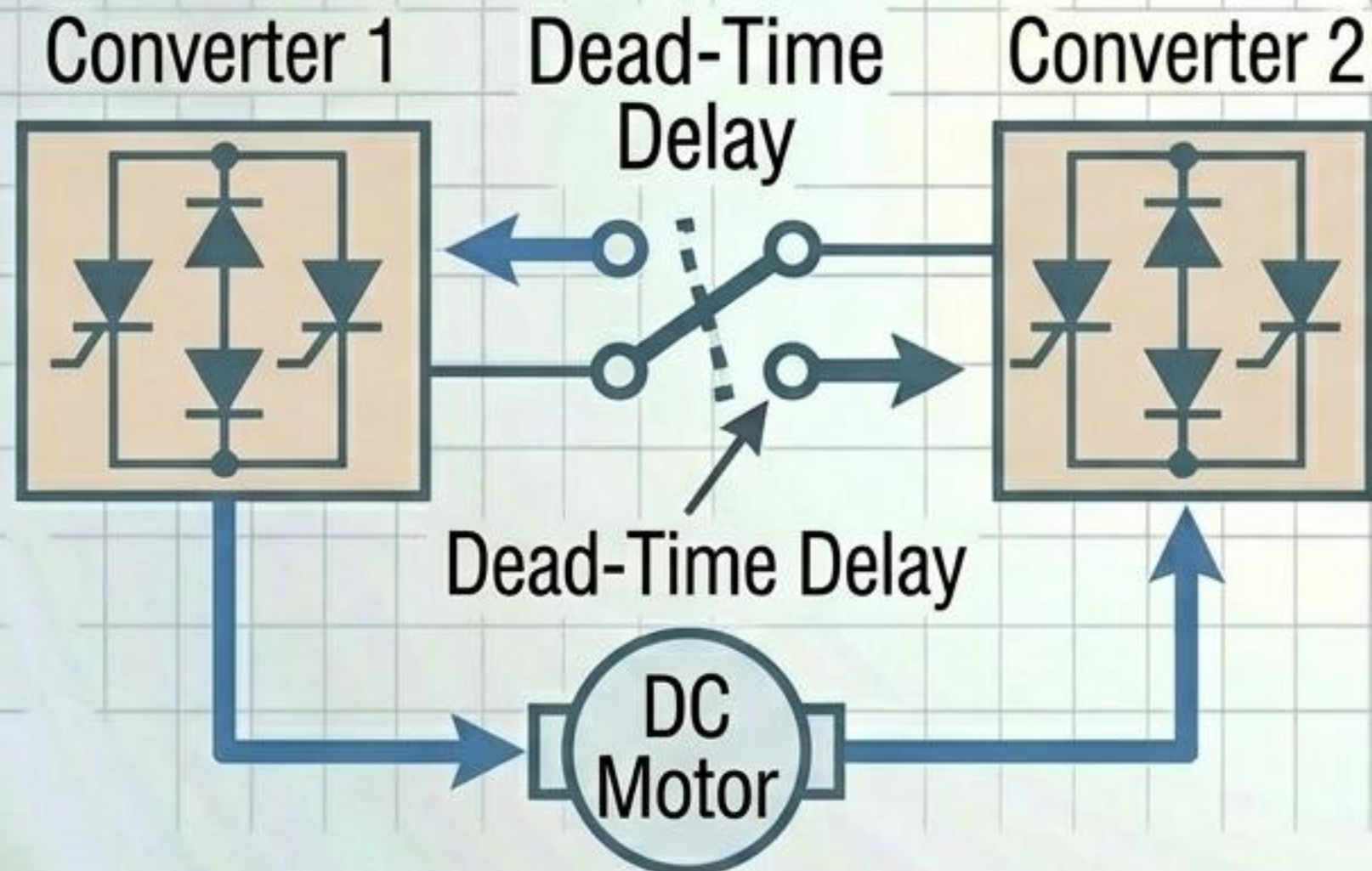
The evolution of controlled rectifiers is the geometric expansion of power control. Dual converters combine two full converters to achieve total bidirectional mastery over power flow.



Dual Converter Coordination: Managing the Conflict

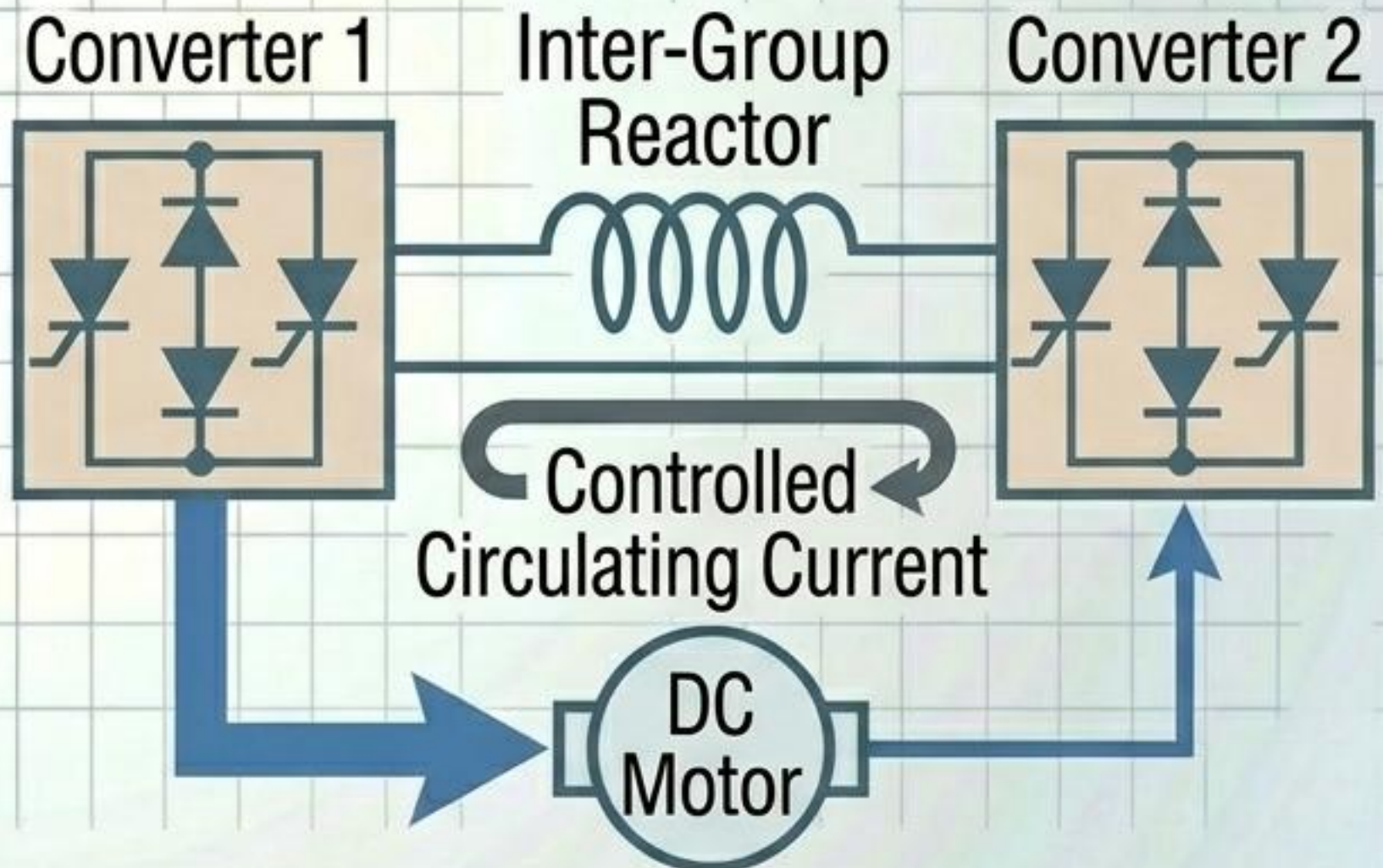
Non-Circulating Mode

Converters fire exclusively. Highly efficient, but requires complex dead-time logic to prevent short circuits during handover.



Circulating Mode

Both fire continuously. Reactor limits short-circuit current. Offers flawless, instantaneous reversal of power flow at the cost of reactor losses.



Industrial Scale: Three-Phase Dual Converters

Why Three-Phase? Single-phase converters produce high ripple requiring massive filters. Three-phase systems overlap pulses naturally, delivering near-flat DC output and handling bidirectional power flow for heavy industrial loads.

Single-Phase Full Converter

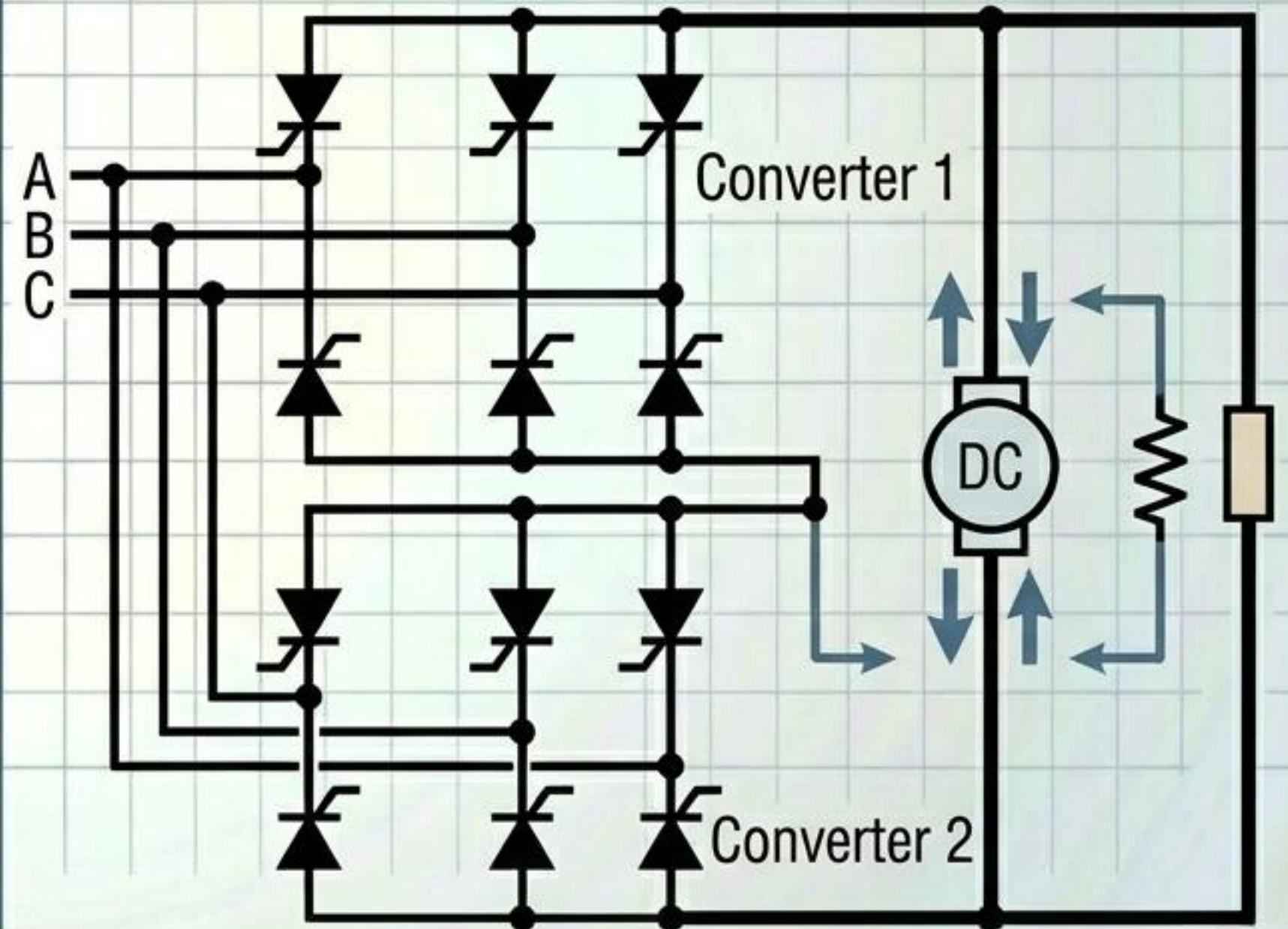
High ripple, 2-Quadrant, Low/Medium Power

Single-Phase Dual Converter

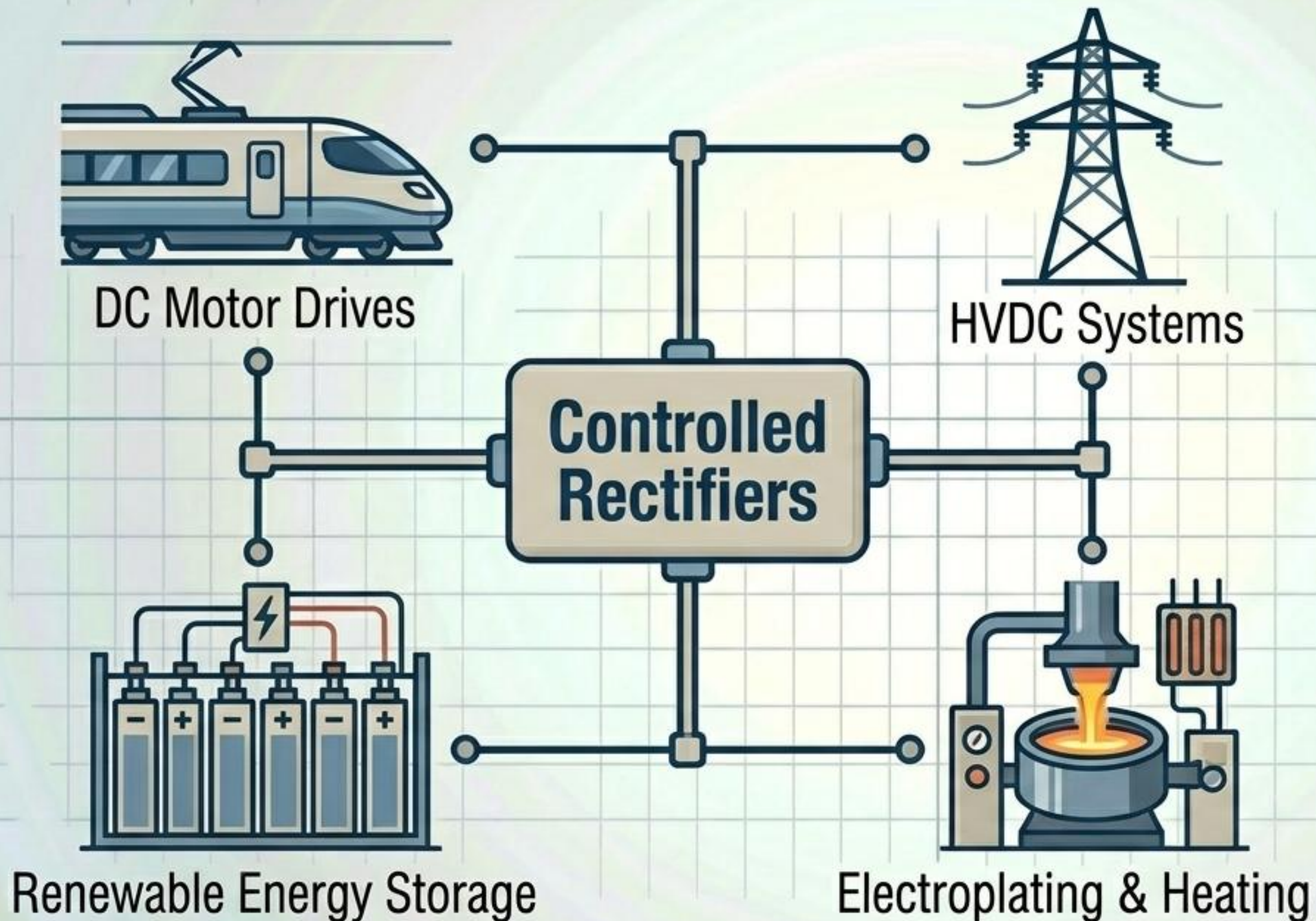
High ripple, 4-Quadrant, Medium Power

Three-Phase Dual Converter

Minimal ripple, 4-Quadrant, Megawatt Power



Engineering Reality: Applications & Key Takeaways



Exam & Design Imperatives

- Inductance sustains current ($>\pi$); Freewheeling diodes reclaim efficiency.
- Continuous conduction locks V_{avg} exclusively to firing angle α .
- Dual converters are required for true 4-quadrant power reversal.