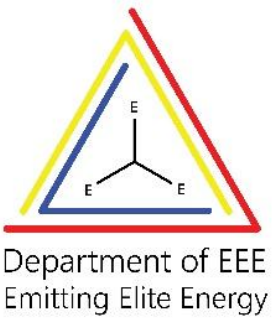




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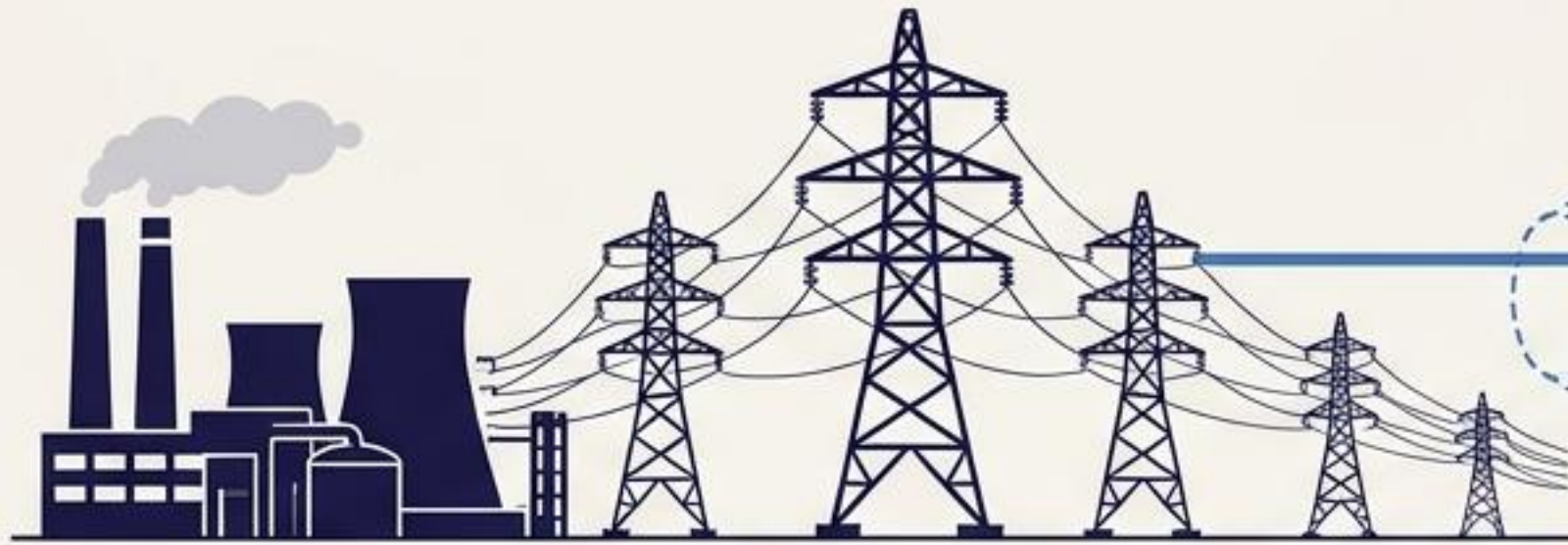


Foundations and Architectures of Modern Power Electronics

Module-1(a): Introduction to Solid-State Power Conversion

Presenter:	Dr. Sathish K. R.
Designation:	Assistant Professor
Department:	Electrical and Electronics Engineering (EEE)
Institution:	ATME College of Engineering

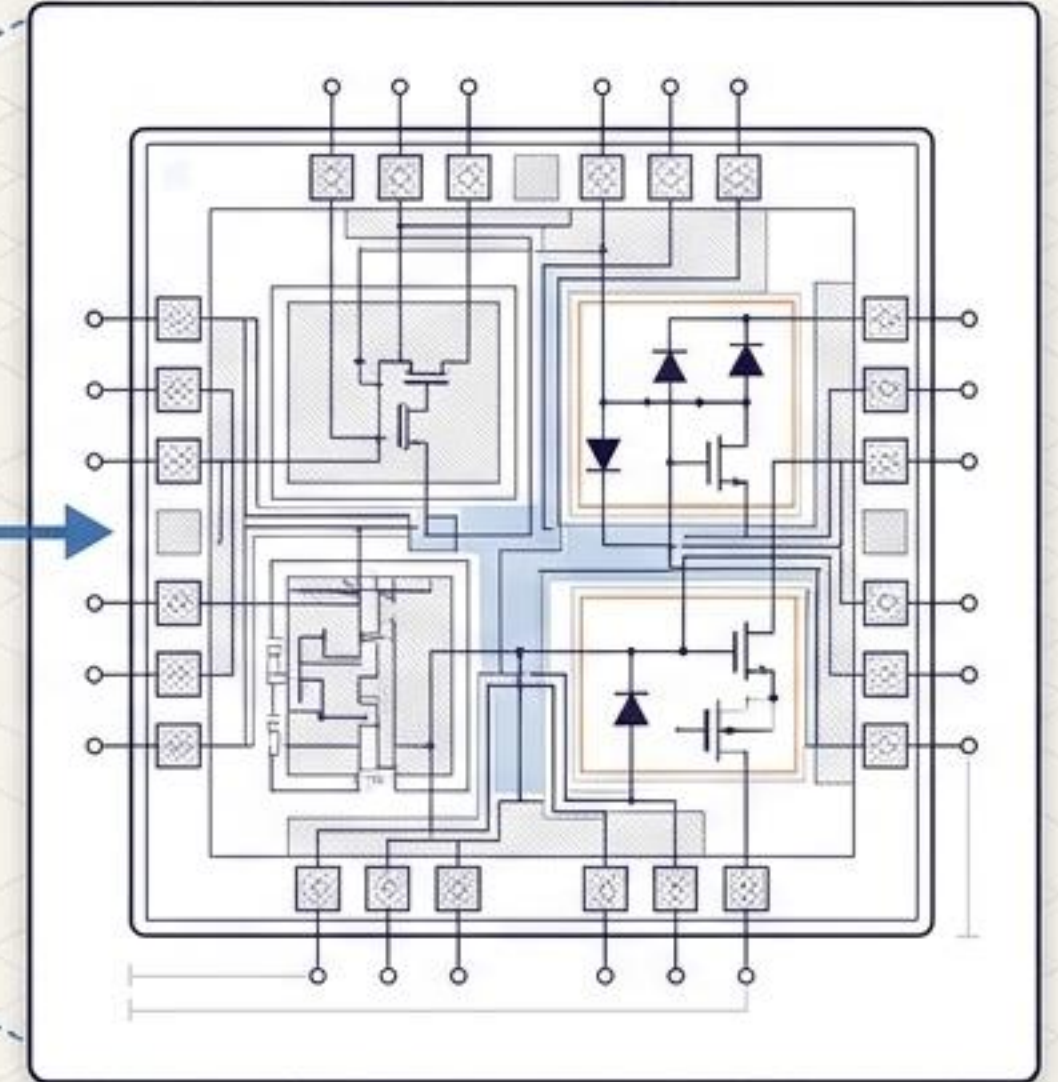
Controlling Electrical Power with Solid-State Precision



Power Electronics is the application of solid-state electronics to the control and conversion of electric power. It bridges the gap between raw power generation and specific load requirements.

Key Term Highlight: Solid-State Conversion

Significance: Maximizes system efficiency, reduces physical footprint, and enables complex dynamic control in modern grids.

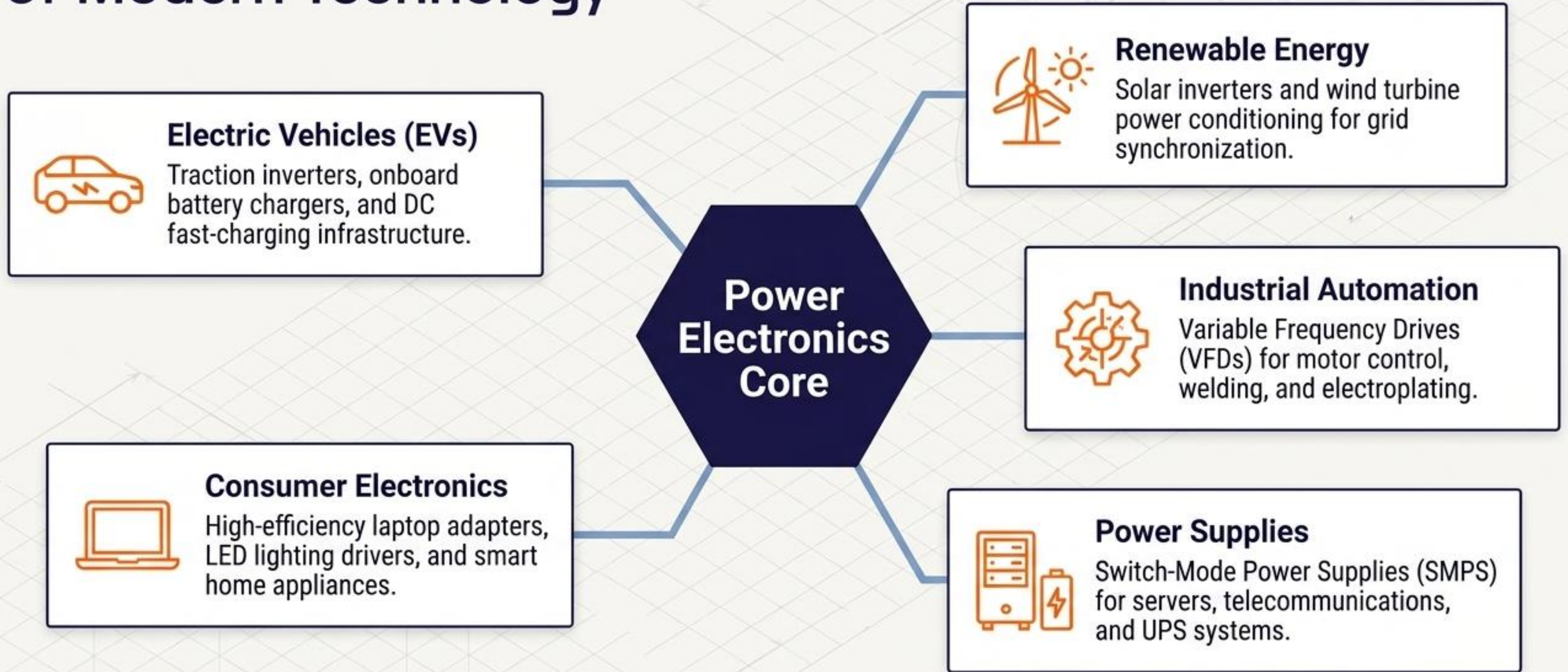


1950s: Thyristor invention
(The dawn of solid-state)

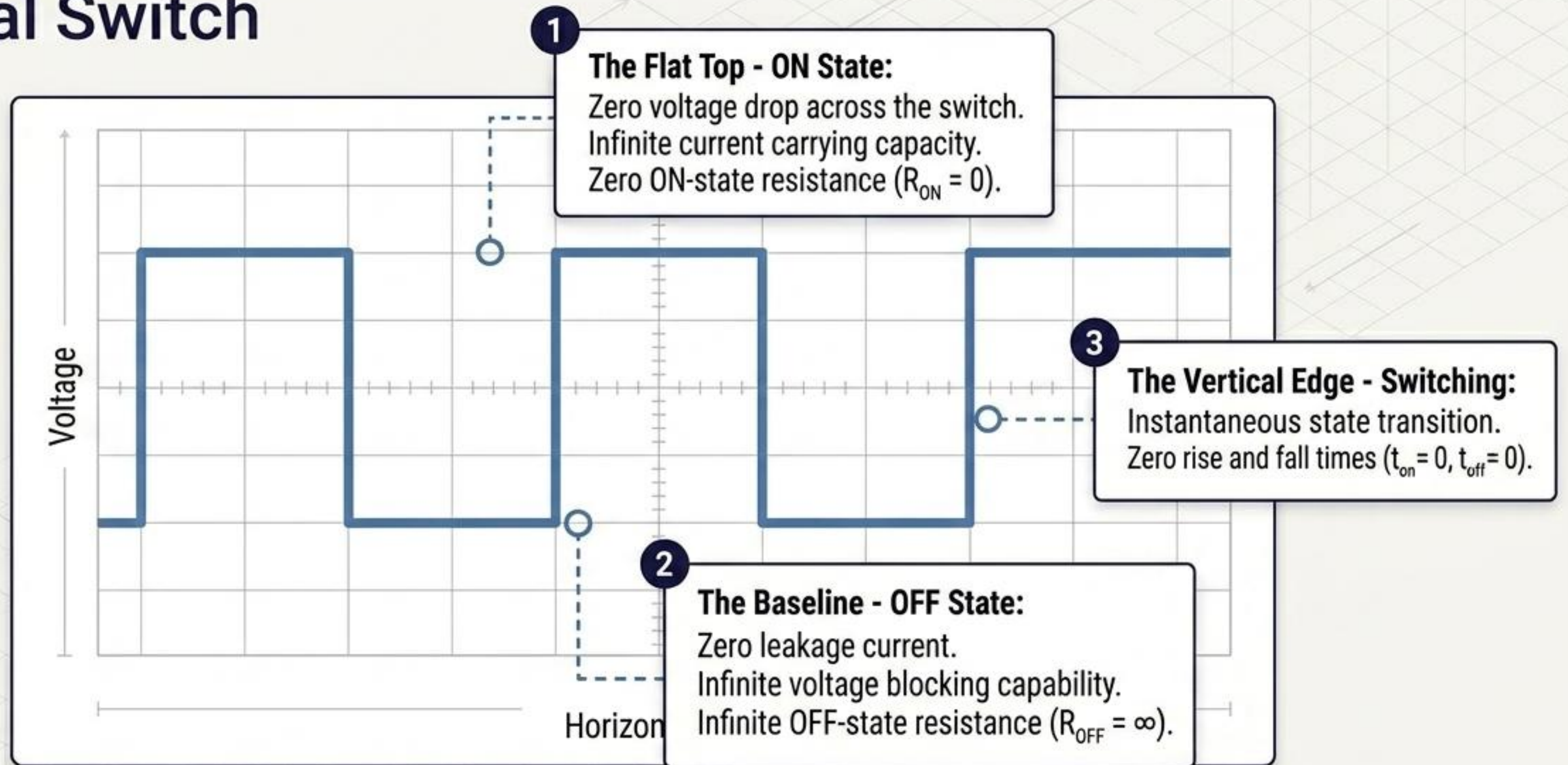
1980s: MOSFETs & IGBTs
(High-frequency revolution)

Today: Wide Bandgap [SiC/GaN] & Smart Modules
(Maximized efficiency and power density)

Driving the Infrastructure of Modern Technology

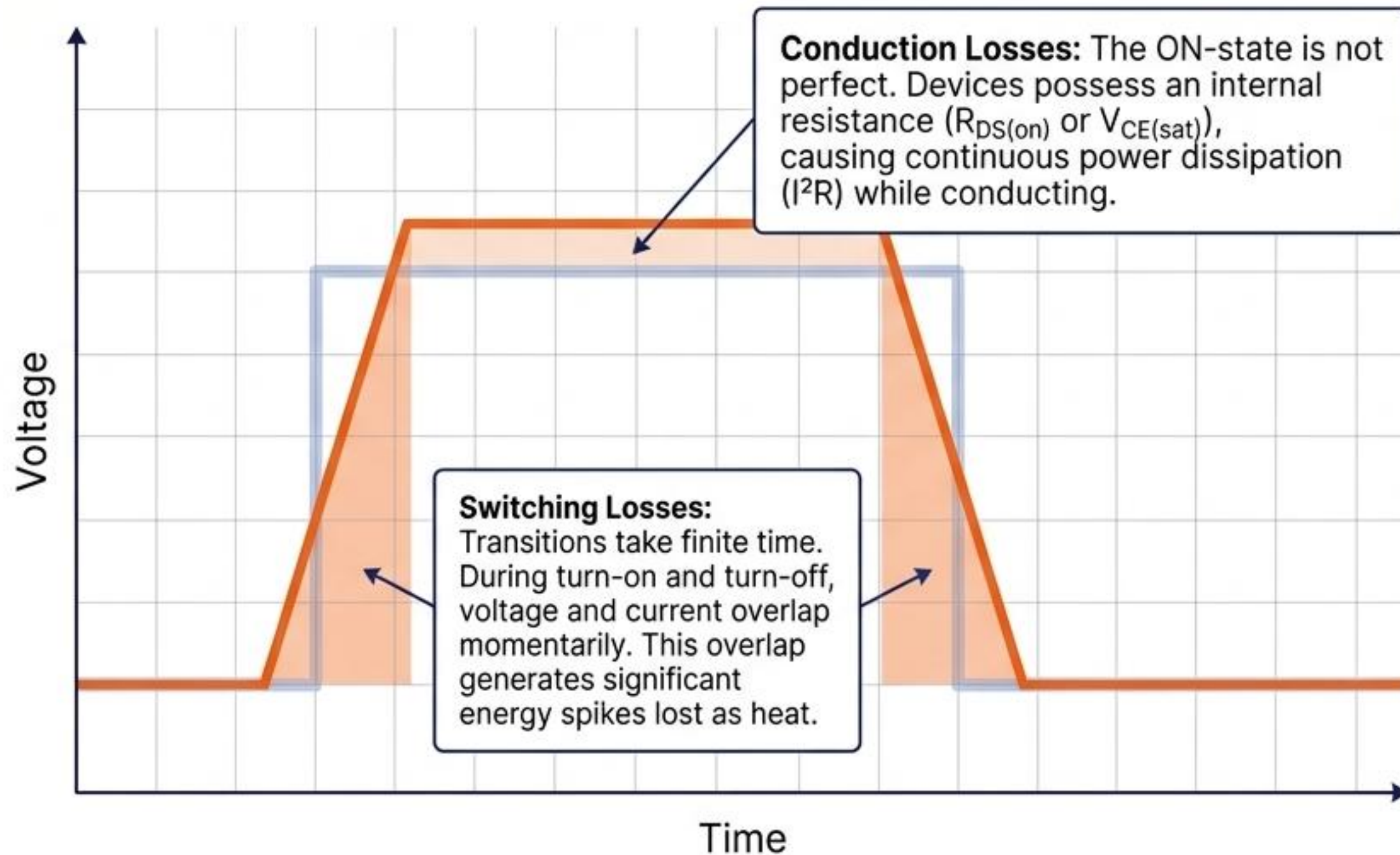


The Engineering Baseline: The Ideal Switch



Core Advantage: 100% efficiency. An ideal switch dissipates absolute zero power ($P = V \times I = 0$) during all operational phases.

Real-World Physics: Losses and Thermal Realities



Thermal Considerations: Because efficiency is $<100\%$, heat sinks and active cooling are mandatory to prevent catastrophic thermal runaway.

Reliability Factors: High temperatures degrade semiconductor junctions, shortening device lifespan and reliability.

Key Term Highlight:
Finite Switching Time.

Defining Operational Limits: Switch Specifications



600 V

Voltage Rating: Maximum blocking voltage before avalanche breakdown.



50 A

Current Rating: Continuous and peak pulse current handling limits.



100 kHz

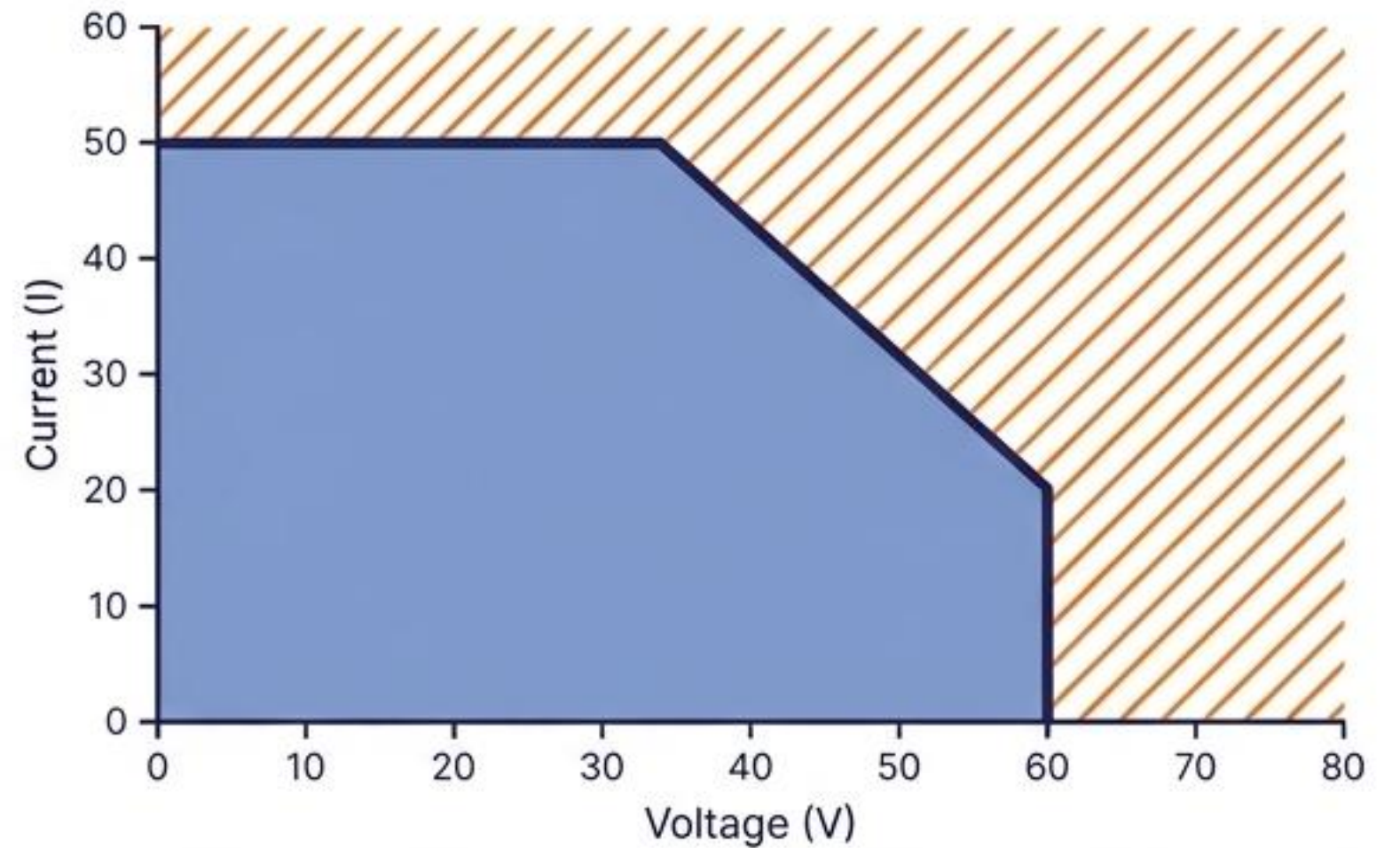
Switching Frequency: Maximum operations per second without excessive thermal loss.



150 °C

Thermal Rating: Maximum allowable junction temperature (T_j), typically 125°C to 175°C.

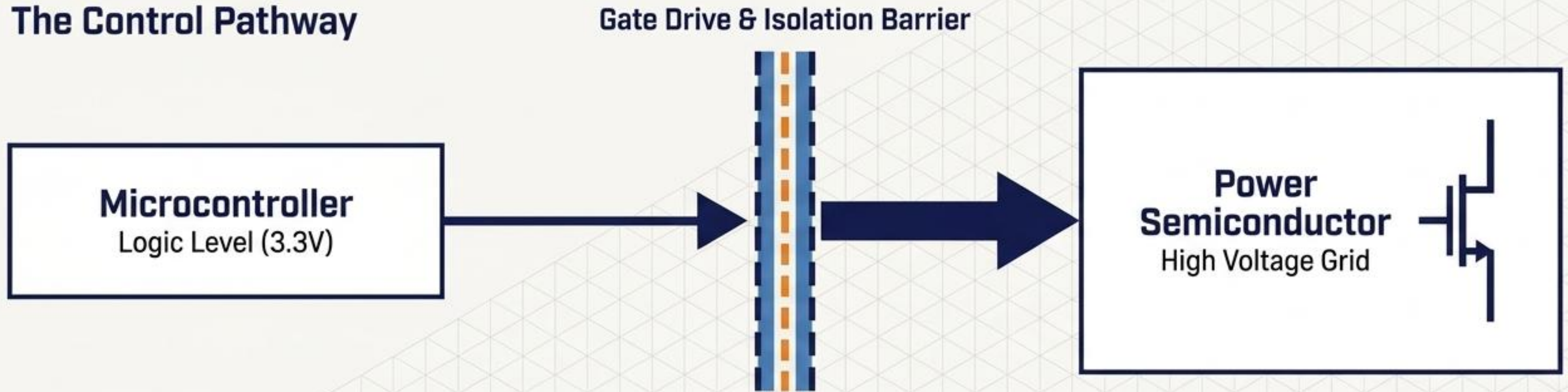
Safe Operating Area (SOA) Panel



The critical boundary defining the maximum simultaneous voltage and current a device can withstand. Operating outside the SOA guarantees component destruction.

Commanding the Switch: Control and Triggering

The Control Pathway



Device Control Types

Voltage-Controlled: MOSFETs, IGBTs. Require specific gate voltage to maintain ON-state. High input impedance, easier to drive.

Current-Controlled: BJTs, Thyristors. Require continuous base/gate current. Lower input impedance.

Triggering & Isolation

Gate Drive Requirements: The critical intermediary circuit that amplifies low-power microcontroller logic to the high-current pulses needed to rapidly charge semiconductor gate capacitance.

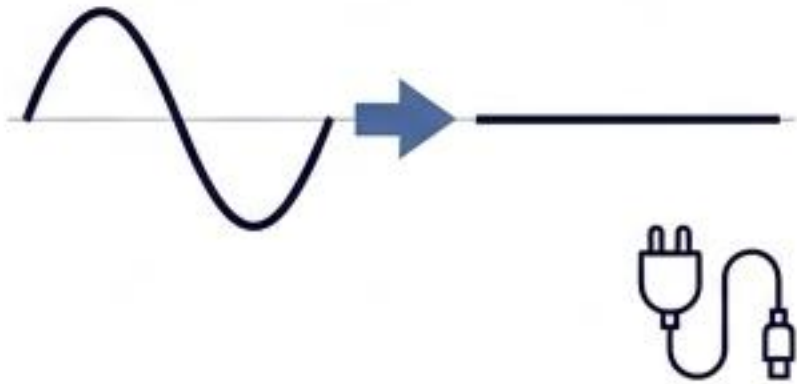
Isolation Techniques:

Optical (Optocouplers): Uses light to separate high-voltage noise from low-voltage logic.

Magnetic (Transformers): Uses magnetic coupling for robust, high-speed isolation.

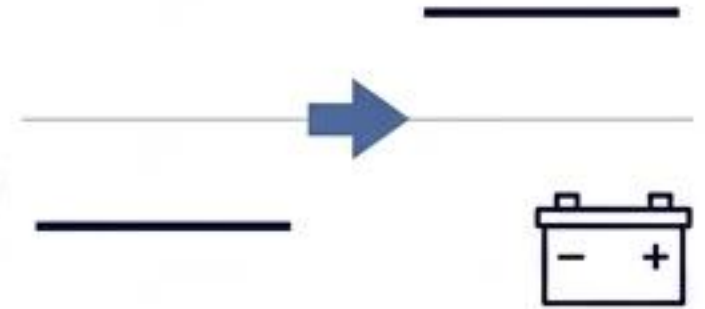
Foundational Architectures: The Four Conversion Topologies

Quadrant 1: AC to DC (Rectifiers)



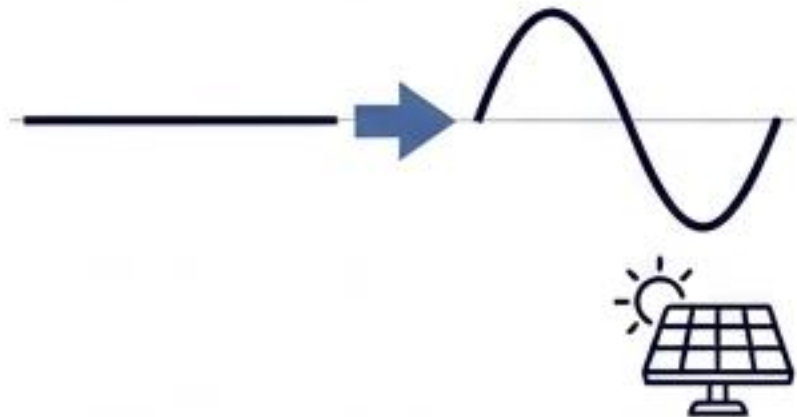
Transformation: Alternating current to unipolar direct current.
Application: Laptop chargers, electroplating, DC motor drives.

Quadrant 2: DC to DC (Choppers/Converters)



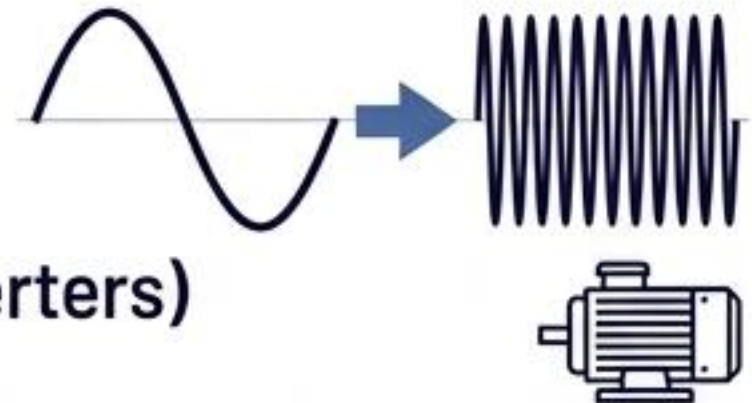
Transformation: Stepping up (Boost) or stepping down (Buck) constant DC voltage.
Application: EV battery management, solar panel MPPT, smartphone internals.

Quadrant 3: DC to AC (Inverters)



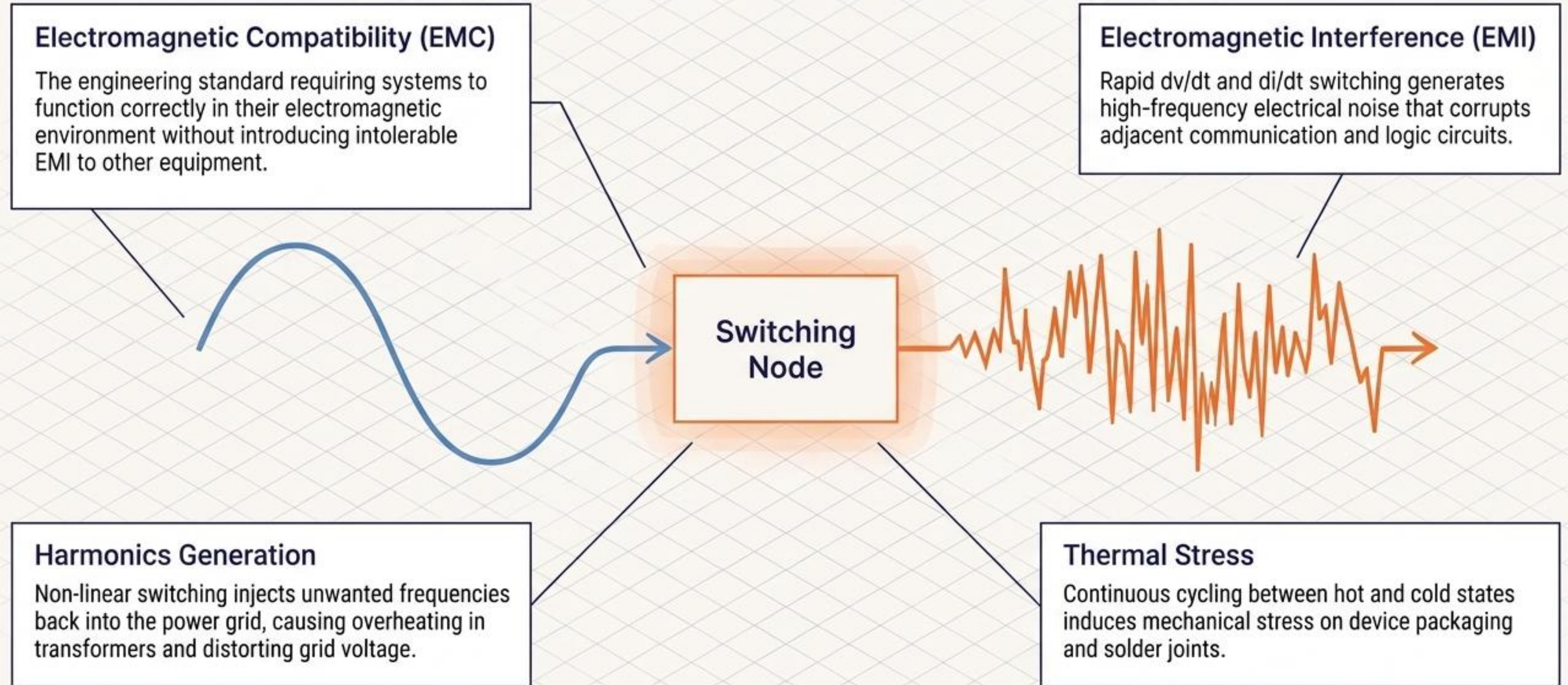
Transformation: Smooth DC into variable frequency/voltage AC.
Application: Solar grid tie-in, Tesla traction motors, UPS systems.

Quadrant 4: AC to AC (Voltage Controllers/Cycloconverters)

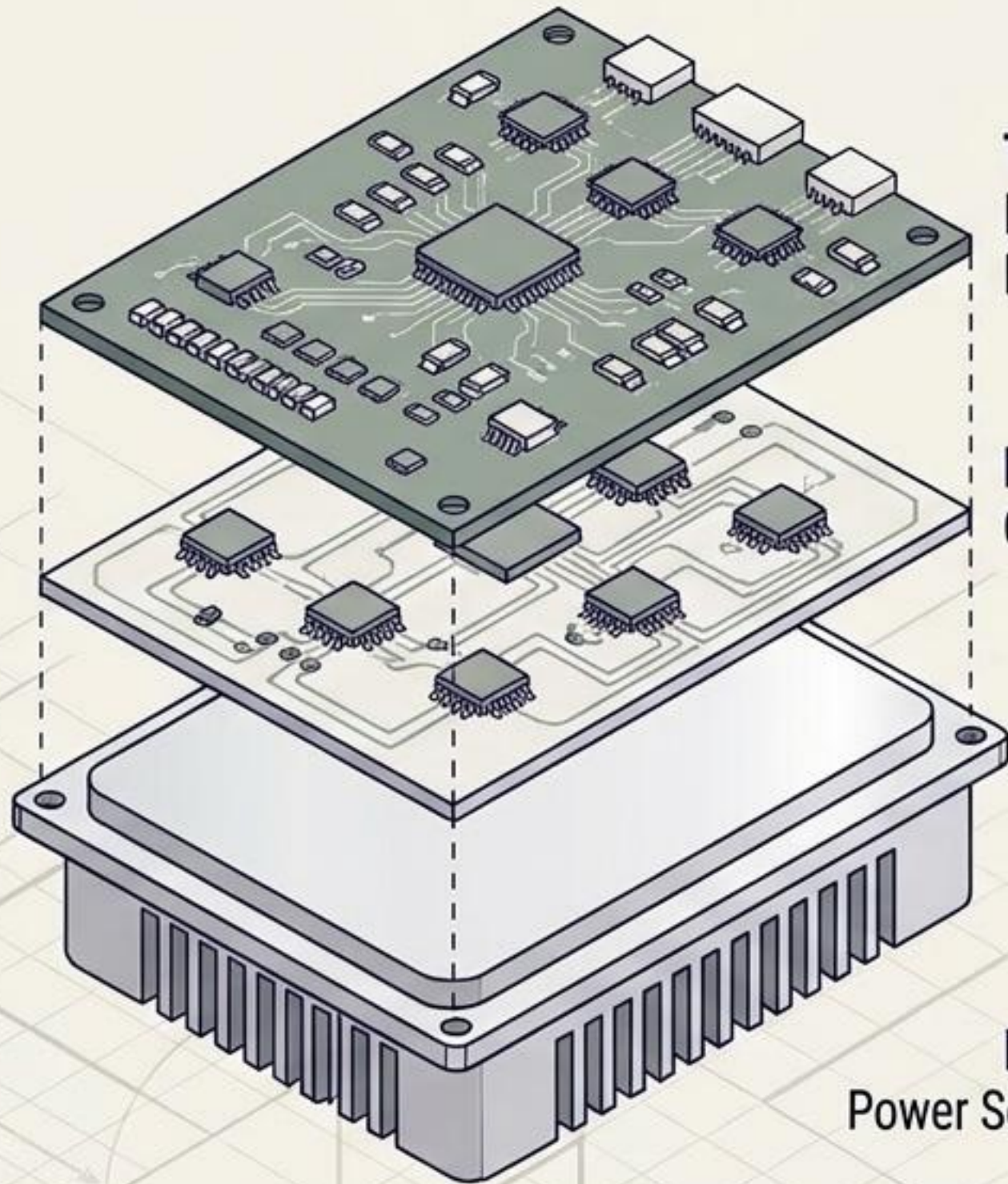


Transformation: Fixed AC to variable magnitude or variable frequency AC.
Application: Industrial heating, massive marine propulsion motors.

Peripheral Effects: Mitigating System Disturbances



The Modern Solution: Intelligent Power Modules (IPMs)



Top Layer:
Logic/Protection
PCB

Middle Layer:
Gate Drivers

Bottom Layer:
Power Semiconductors
& Heat Sink

Definition & Structure

Highly integrated, hybridized packages that combine high-power switching devices (IGBTs/MOSFETs) with their dedicated control, drive, and thermal sensors onto an isolated substrate within a single unified footprint.

Industrial Advantage: Drastically reduces PCB space, eliminates parasitic inductance from long traces, and guarantees reliability in harsh environments (e.g., EV drivetrains).

Active Protection Features

Over-Current / Short-Circuit: Instantaneous autonomous shutdown.

Under-Voltage Lockout (UVLO): Prevents weak switching that causes massive thermal spikes.

Over-Temperature: Direct die-level thermal sensing.

Diagnostic Summary: Components & Architectures

Panel 1: The Switch Reality Check

Parameter	Ideal Switch	Practical Switch
ON-Resistance	Zero	Finite ($R_{DS(on)} / V_{CE(sat)}$)
Transition Time	Instantaneous	Finite (Creates Switching Loss)
Leakage Current	Zero	Micro/Milli-amps
Thermal Output	Cold (0W loss)	Requires Heat Sink

Panel 2: Evolution of Packaging

Feature	Conventional Discrete Modules	Intelligent Power Modules (IPMs)
Integration	Separate Power, Drive, Logic	All-in-one unified housing
Protection	External (Slower response)	Internal (Microsecond shutdown)
Parasitic Noise	High (Due to PCB trace length)	Low (Optimized internal layout)

Module Synthesis: The Power Electronics Workflow

Block 1: Device Selection (Physics)

Evaluate practical limitations (Conduction/Switching losses) against the Safe Operating Area (SOA) requirements.

Block 2: Topology Design (Architecture)

Select the correct conversion matrix (Rectifier, Chopper, Inverter, AC Controller) based on source and load profiles.

Block 3: Control & Mitigation (Implementation)

Implement isolated gate drives and filter networks to command the switch while suppressing EMI and harmonic injection.

Block 4: Integration (Modern Execution)

Deploy Intelligent Power Modules (IPMs) to maximize power density, reliability, and automated fault protection in end-user applications.



The Future is Solid-State

Power Electronics is no longer just a subsystem; it is the fundamental enabler of the global transition to renewable energy and electrified transport.

Closing Insight: As engineers, our continuous objective is moving the practical switch ever closer to the ideal switch—pushing the boundaries of power density, thermal management, and absolute efficiency.

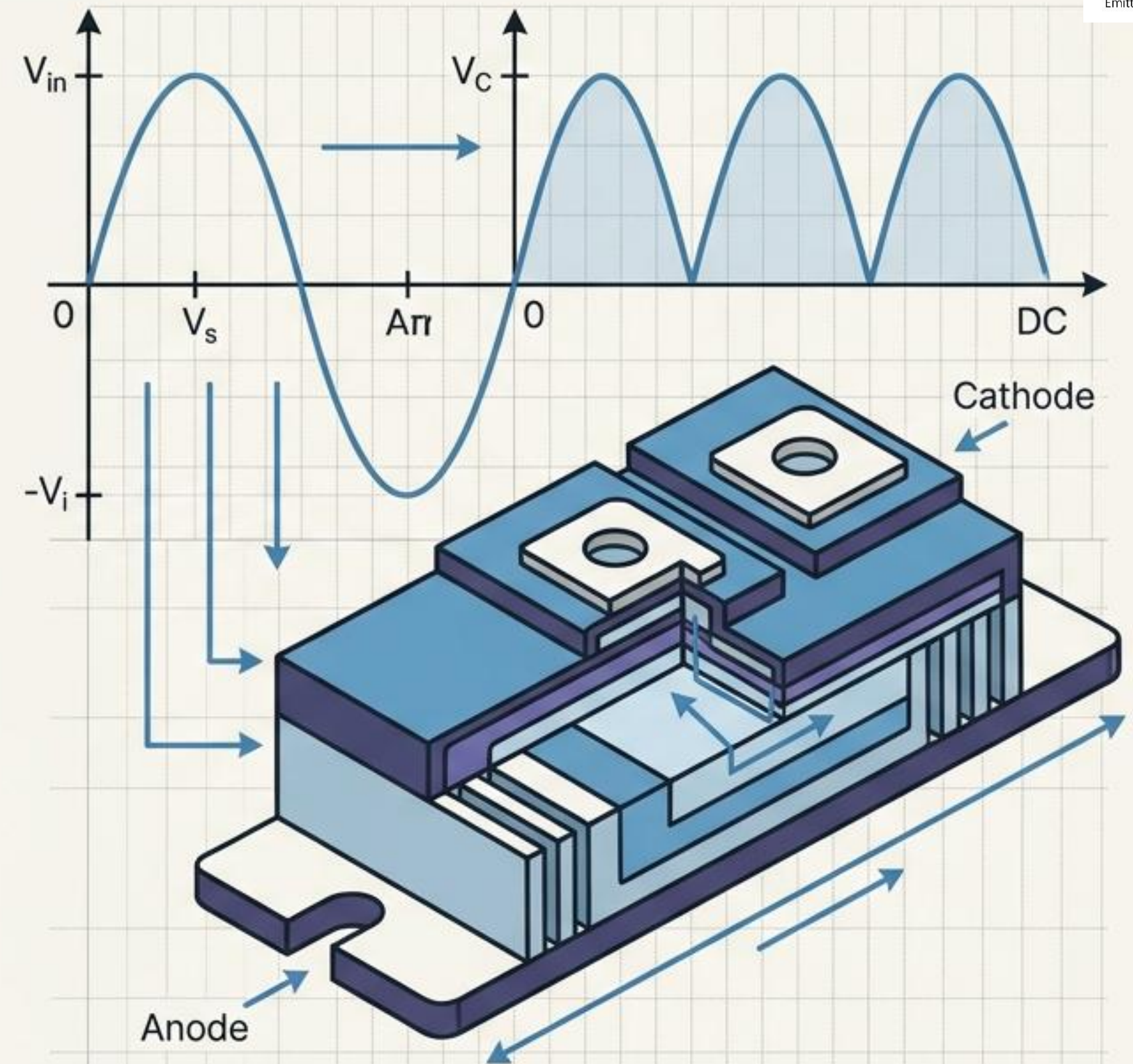
Power Diodes

The Backbone of Power Semiconductor Devices

Module-1(b) | Course: Power Electronics

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

Institution: Dept. of Electrical and Electronics Engineering (EEE), ATME College of Engineering



The Evolution of Power Semiconductors



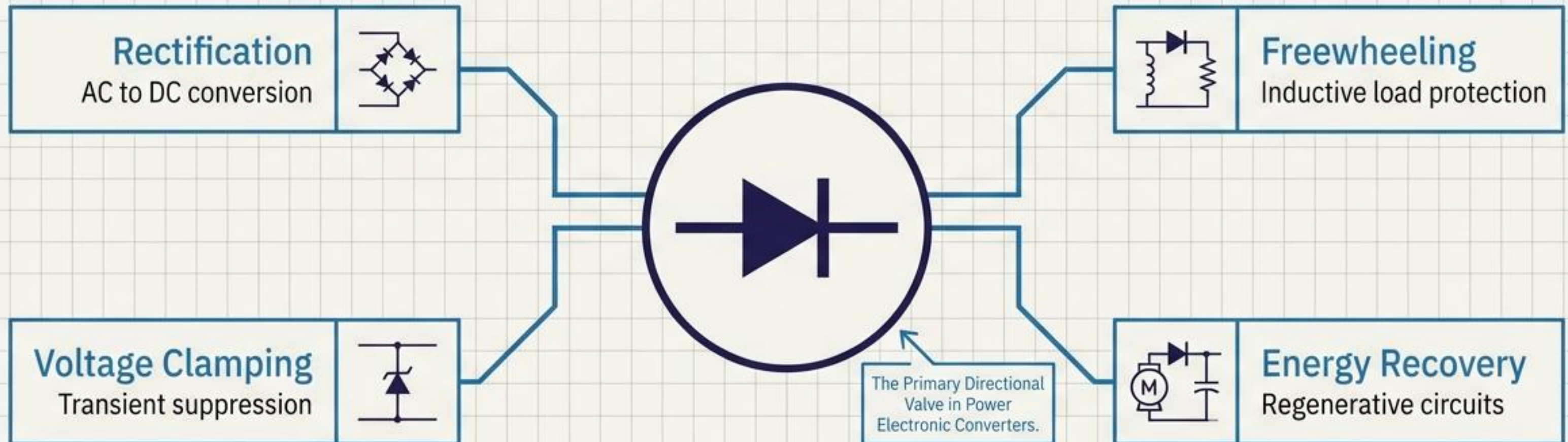
Vacuum Tubes



Solid State
Silicon

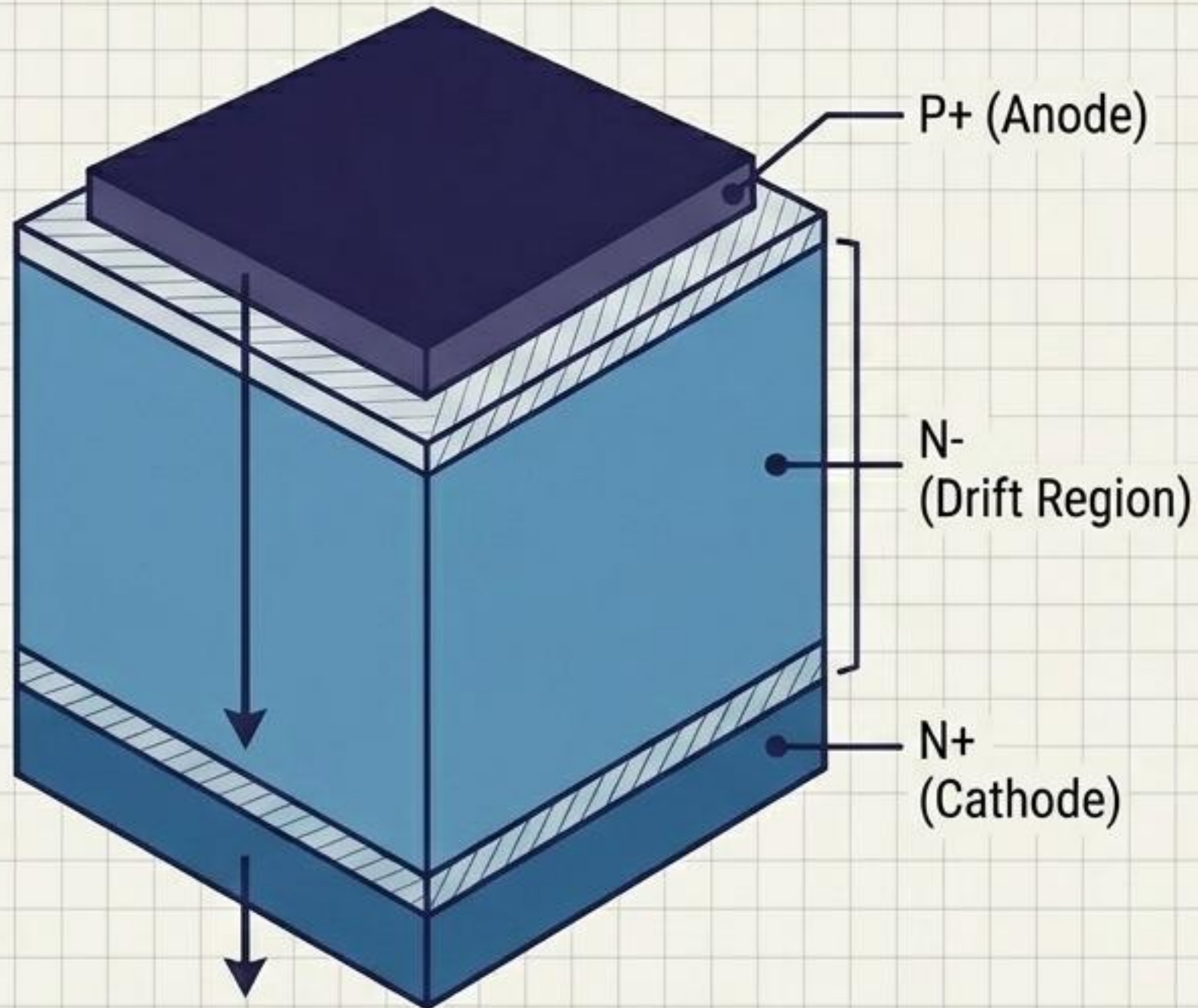


Wide Bandgap
(WBG)

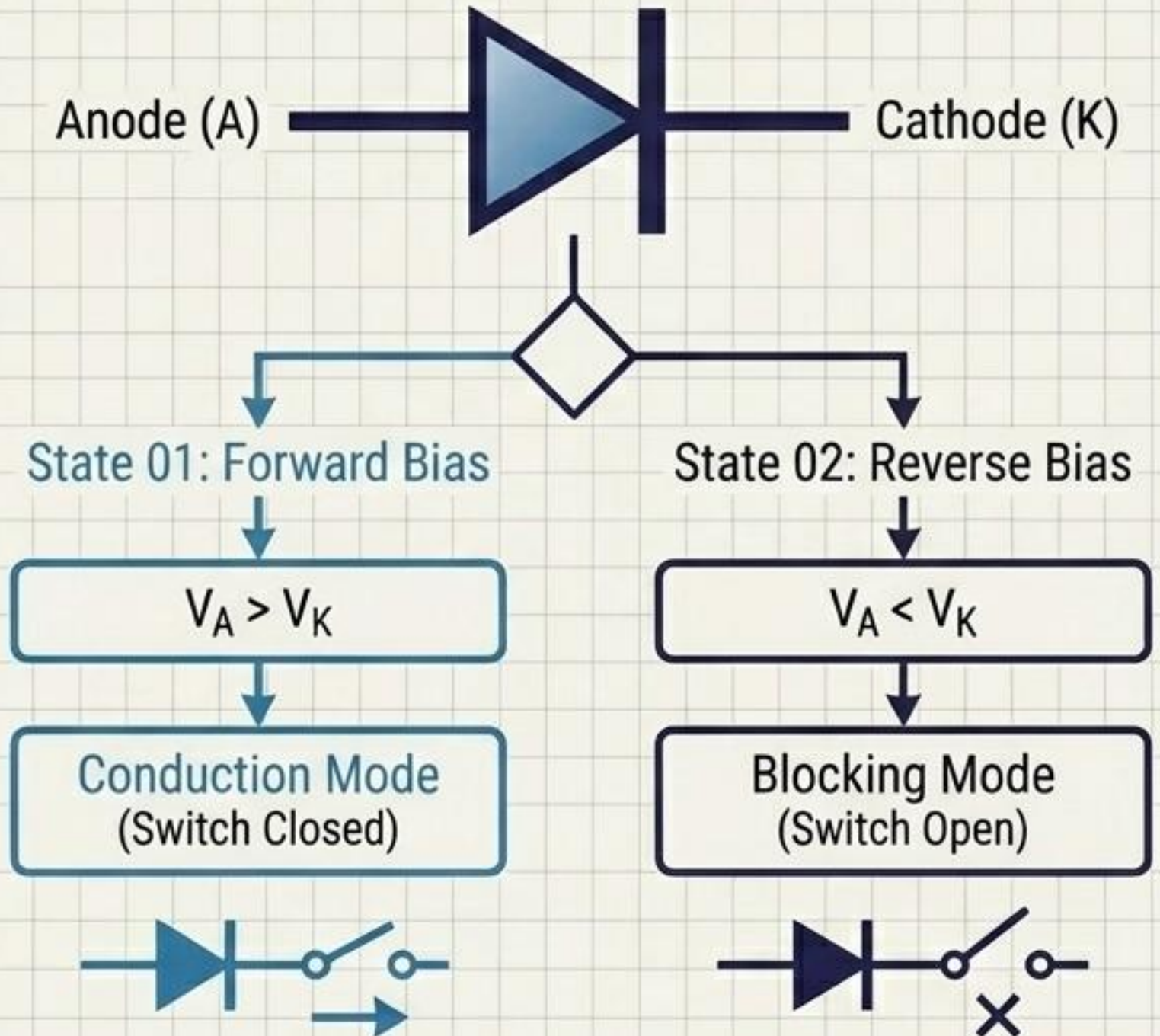


Anatomy & Conduction Mechanics

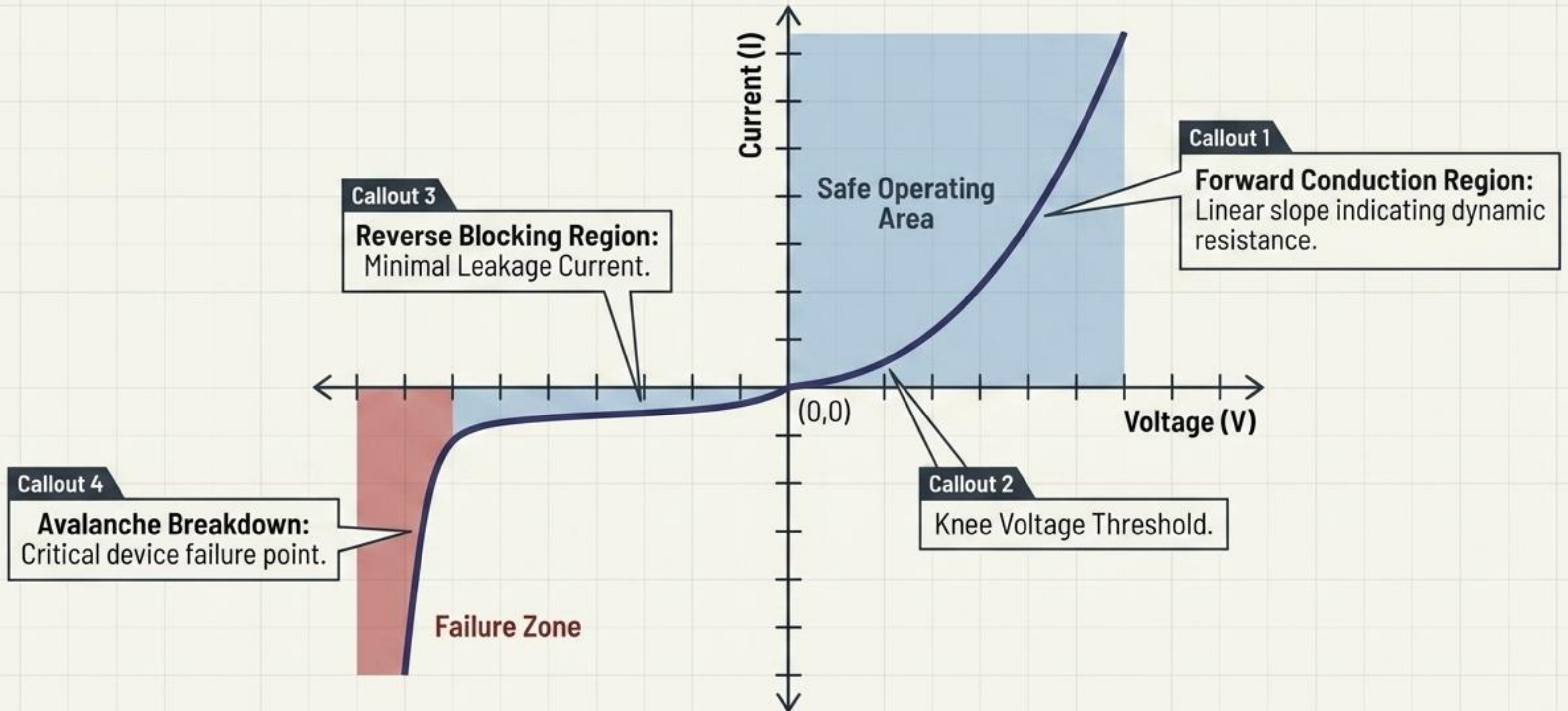
Physical Anatomy



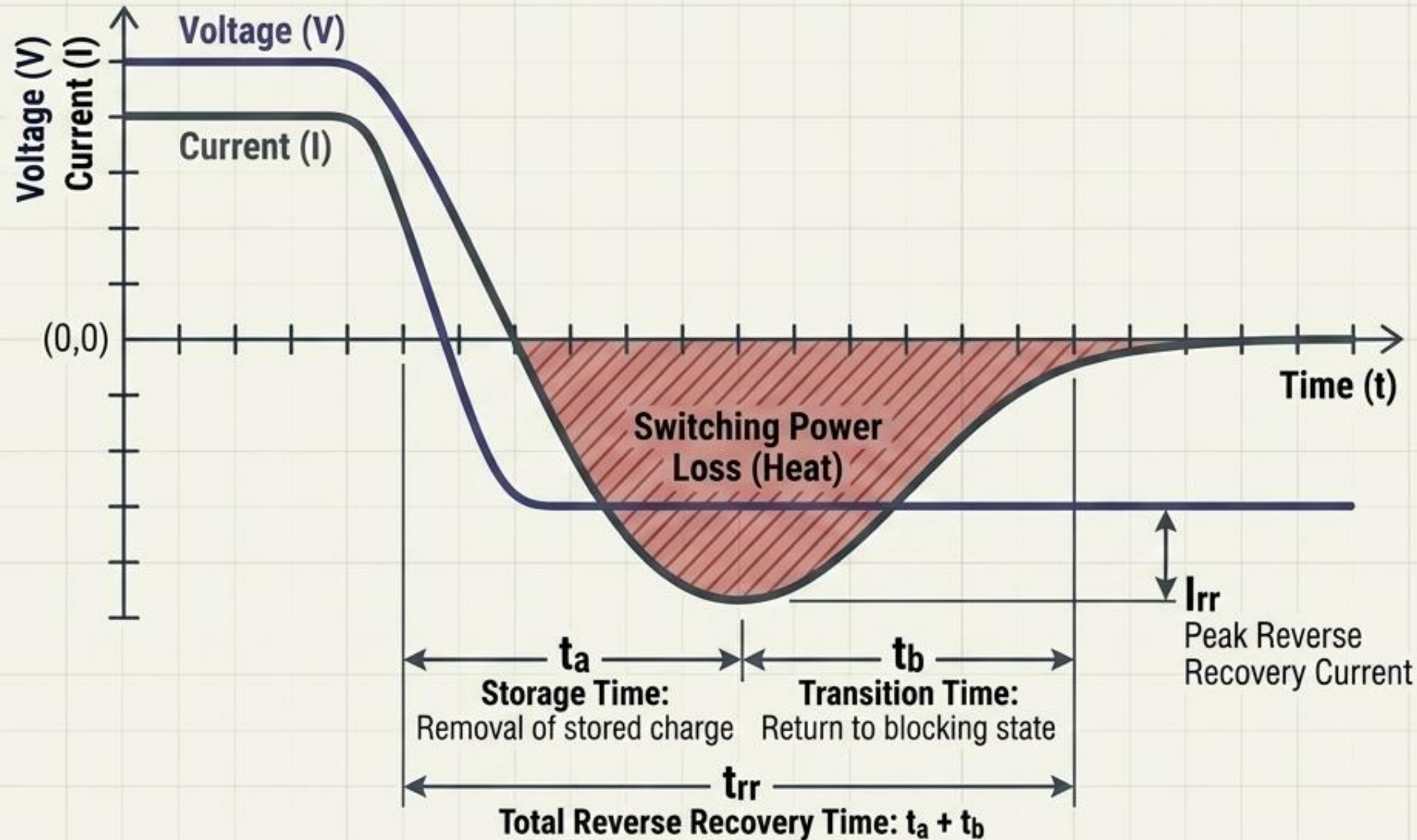
Schematic & Logic



V-I Characteristics: The Operating Map



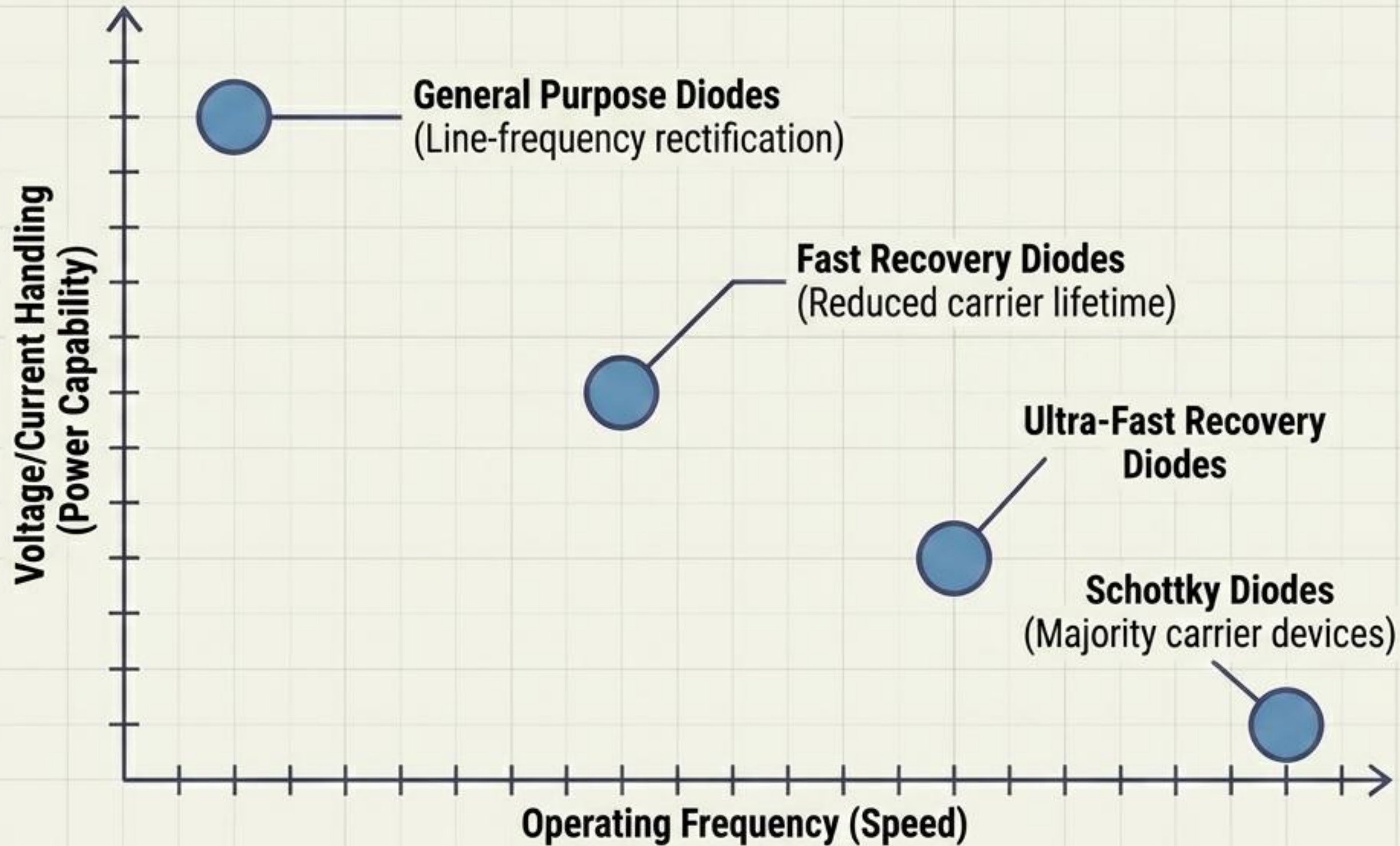
The Challenge of Reverse Recovery



Factors Affecting Recovery Performance:

- Forward current magnitude
- di/dt (Rate of current fall)
- Junction temperature

Power Diode Taxonomy & Selection



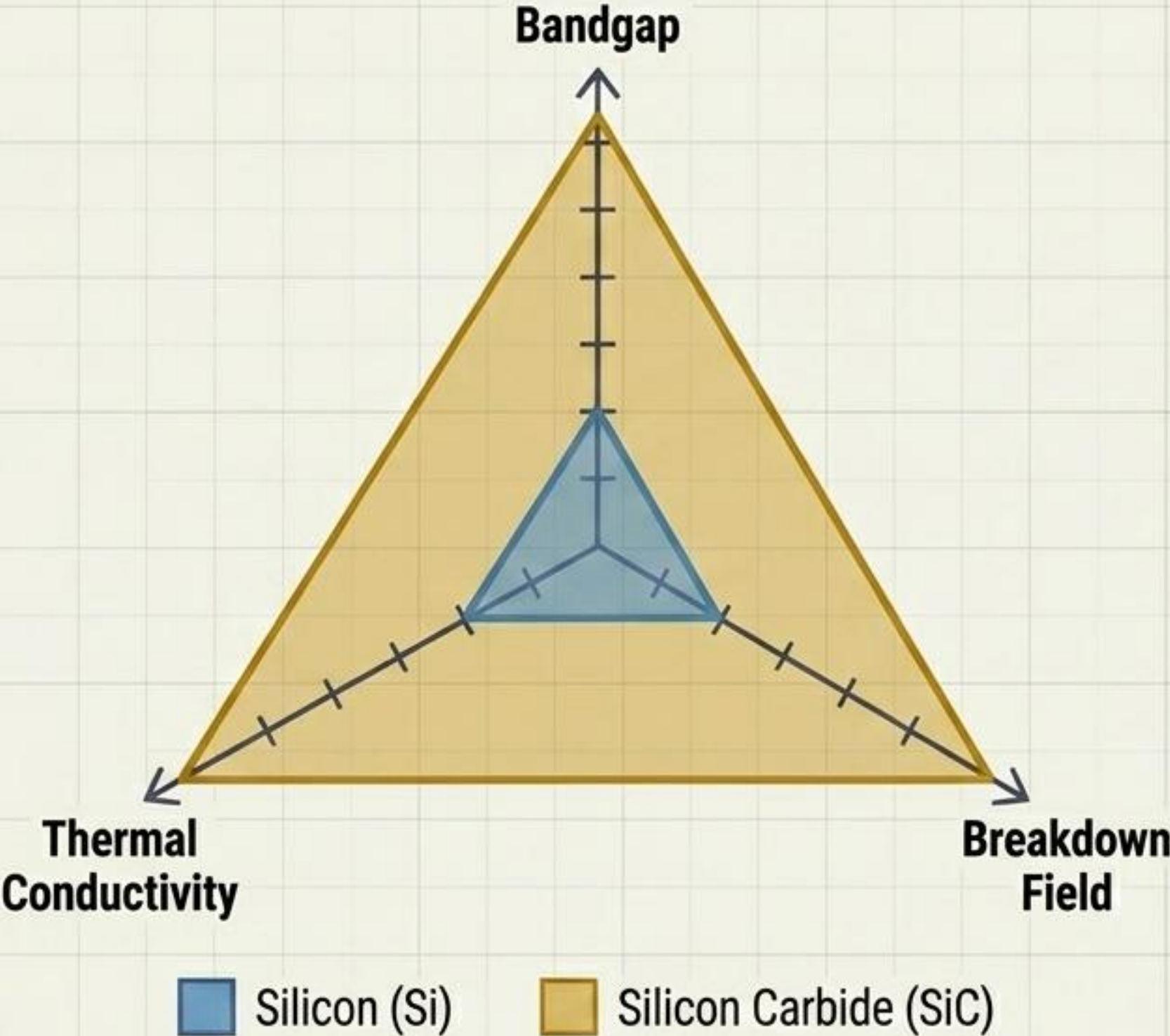
Selection Criteria Profile

Application Demands

Required
Switching Speed

Diode Architecture
Choice

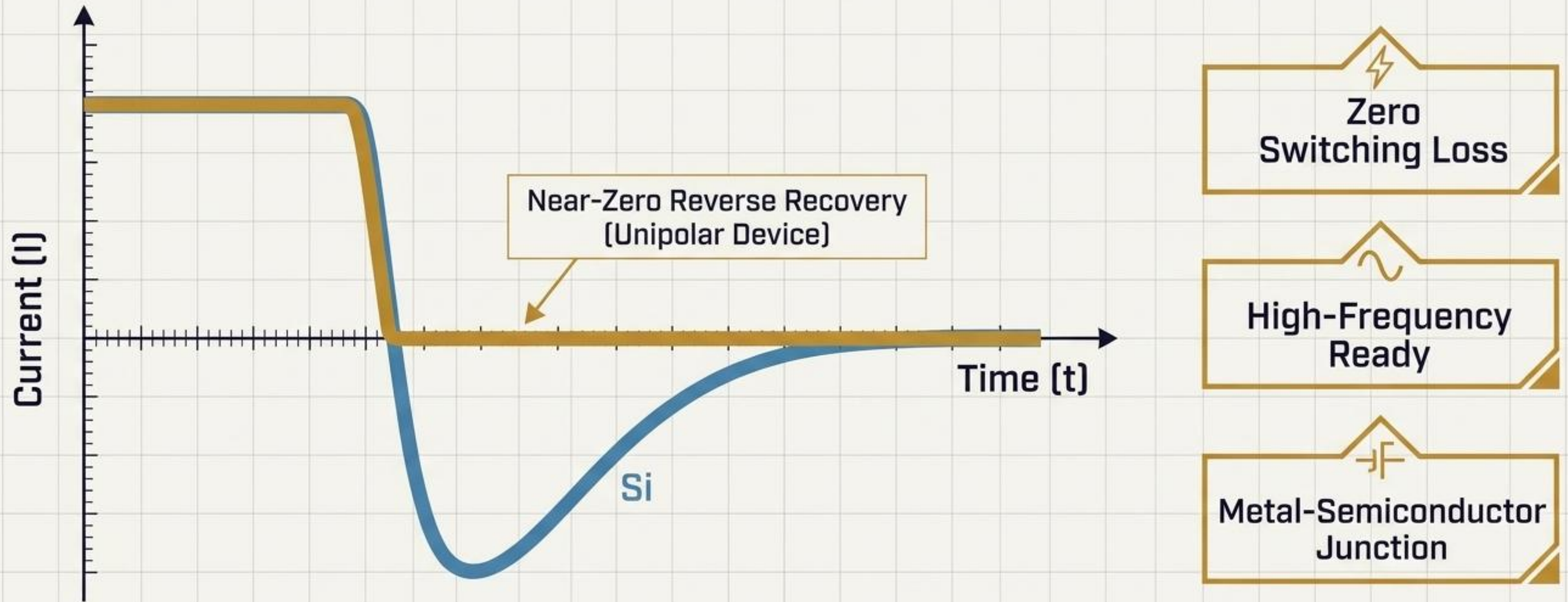
The Silicon Carbide (SiC) Revolution



Engineering Translation Block

Wider Bandgap	→	High-Temperature Operation (Reduced cooling requirements)
Higher Breakdown Field	→	High-Voltage Capability (Enables thinner drift layers)
High Thermal Conductivity	→	Superior Heat Dissipation (Allows for smaller heat sinks)

SiC Schottky Diodes: Near-Zero Recovery



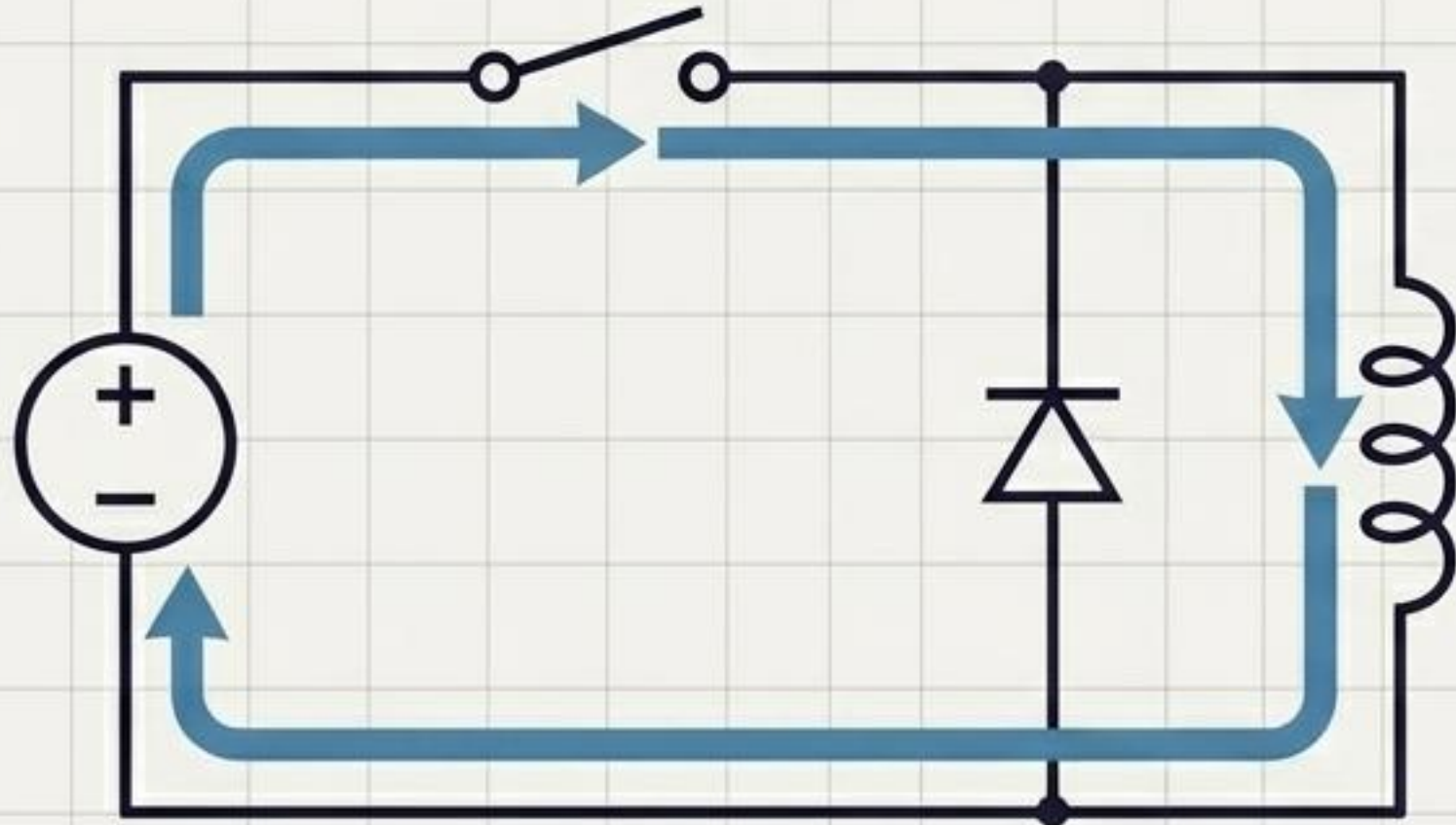
Target Applications:

EV Traction Inverters

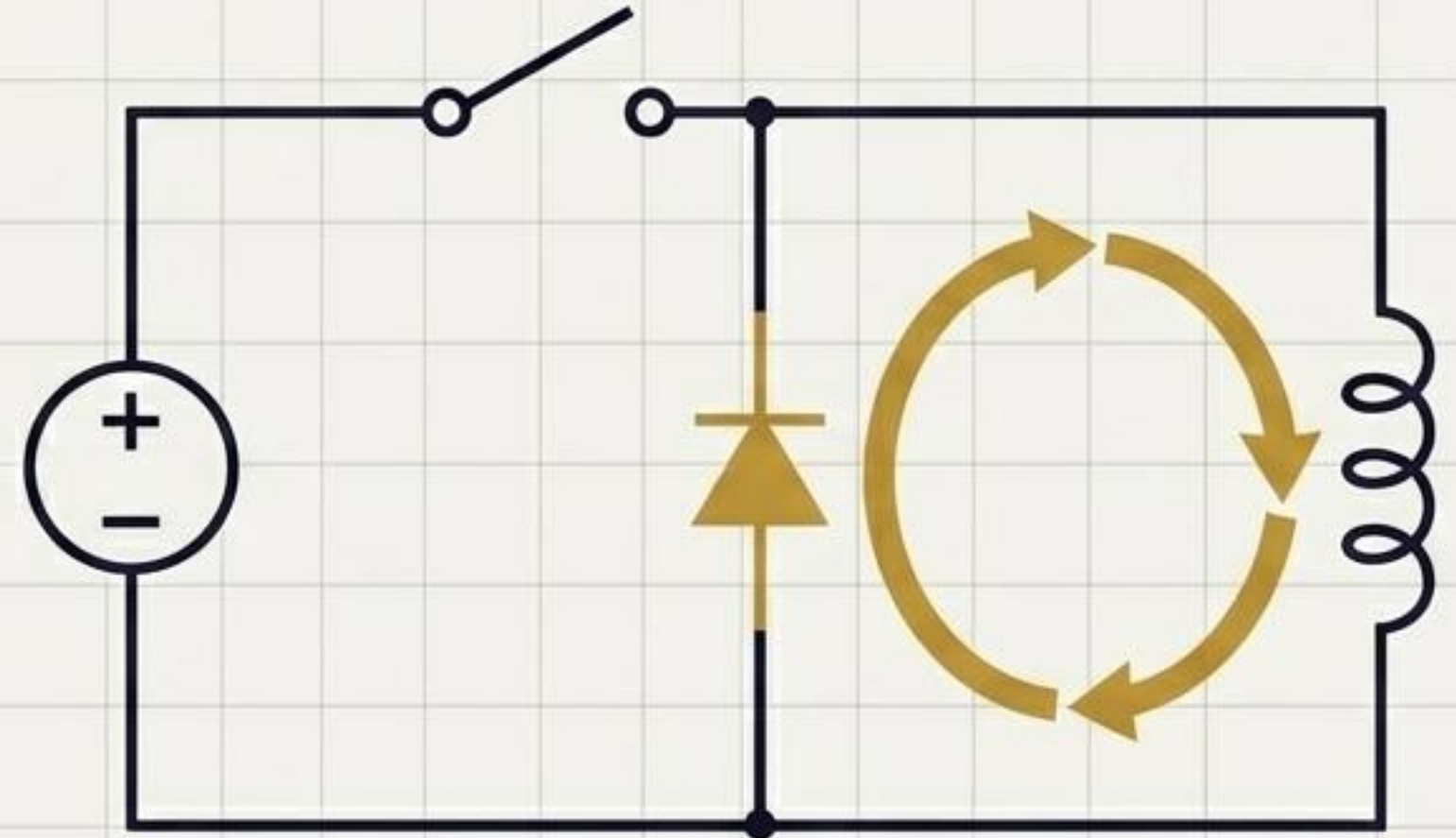
Renewable Solar Inverters

The Mechanics of Freewheeling Diodes

State 1: Switch ON



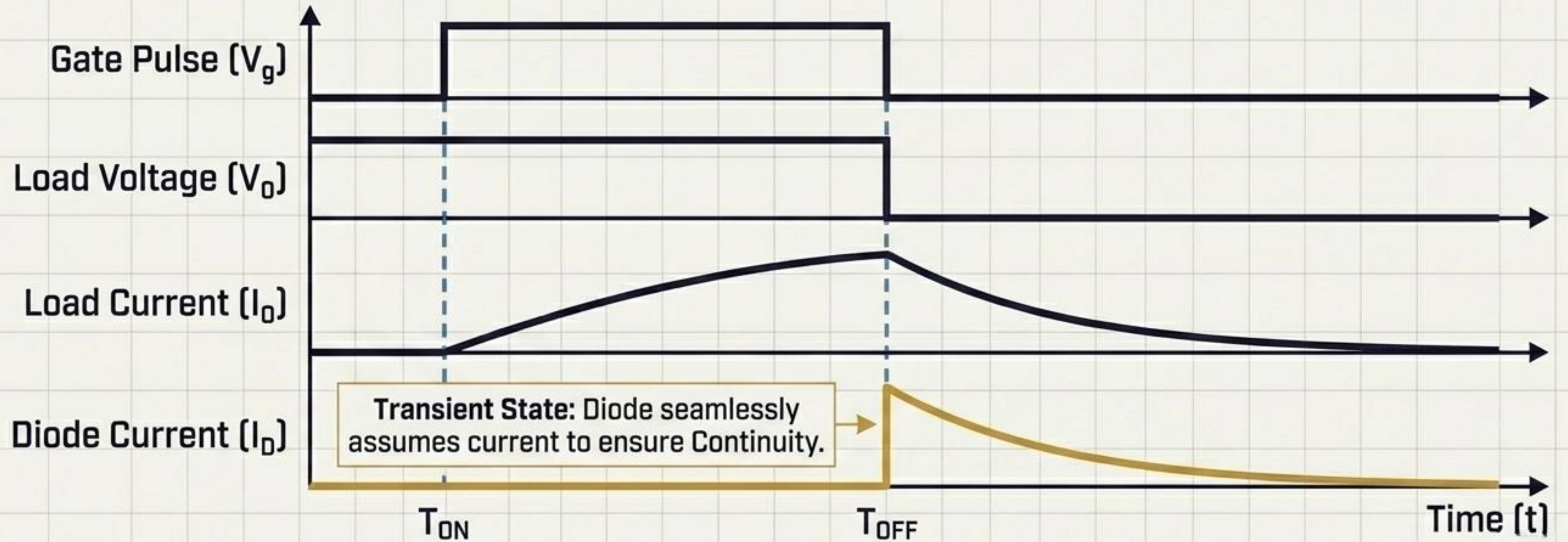
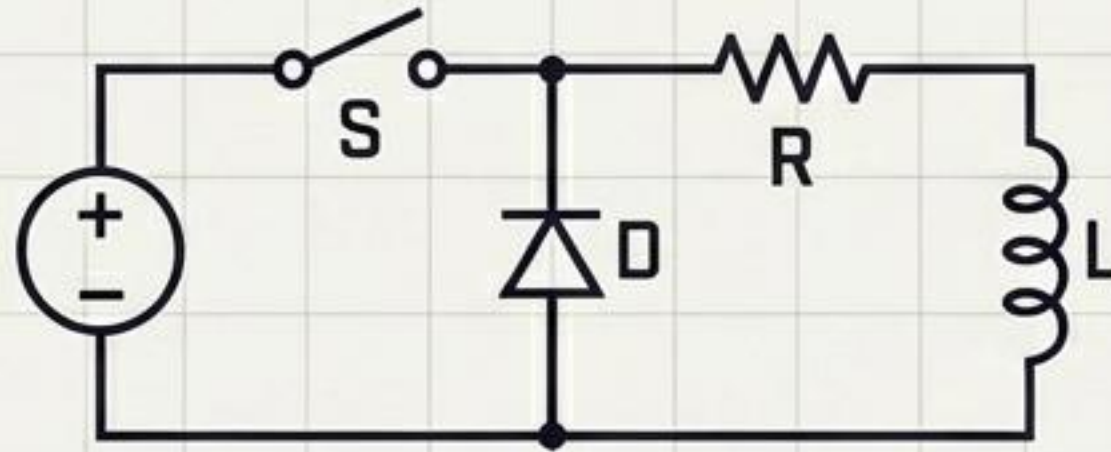
State 2: Switch OFF



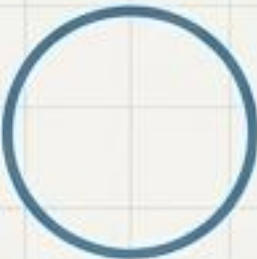
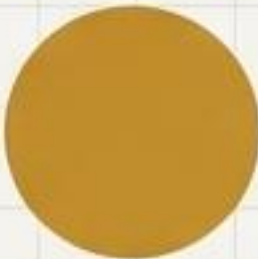
Purpose of the Freewheeling Diode:

- **Energy Circulation Mechanism:** Provides a continuous path for the release of magnetic energy.
- **Switch Protection:** Prevents high-voltage transient spikes (Inductive Kickback) from destroying the main switch.

Freewheeling Dynamics in RL Loads



Comparative Analysis: Performance Trade-offs

	Standard Silicon	Fast Recovery	Schottky	SiC Schottky
Switching Speed				
Voltage Rating				
Thermal Efficiency				
Cost Rating				
Best Use Case	General Rectification	Server UPS Systems	Low-Voltage Logic	High-Frequency EV Inverters

Industrial Ecosystem & Applications

SiC Schottky Diodes

Enables high efficiency and high-temperature operation in EV traction inverters.

Fast Recovery Diodes

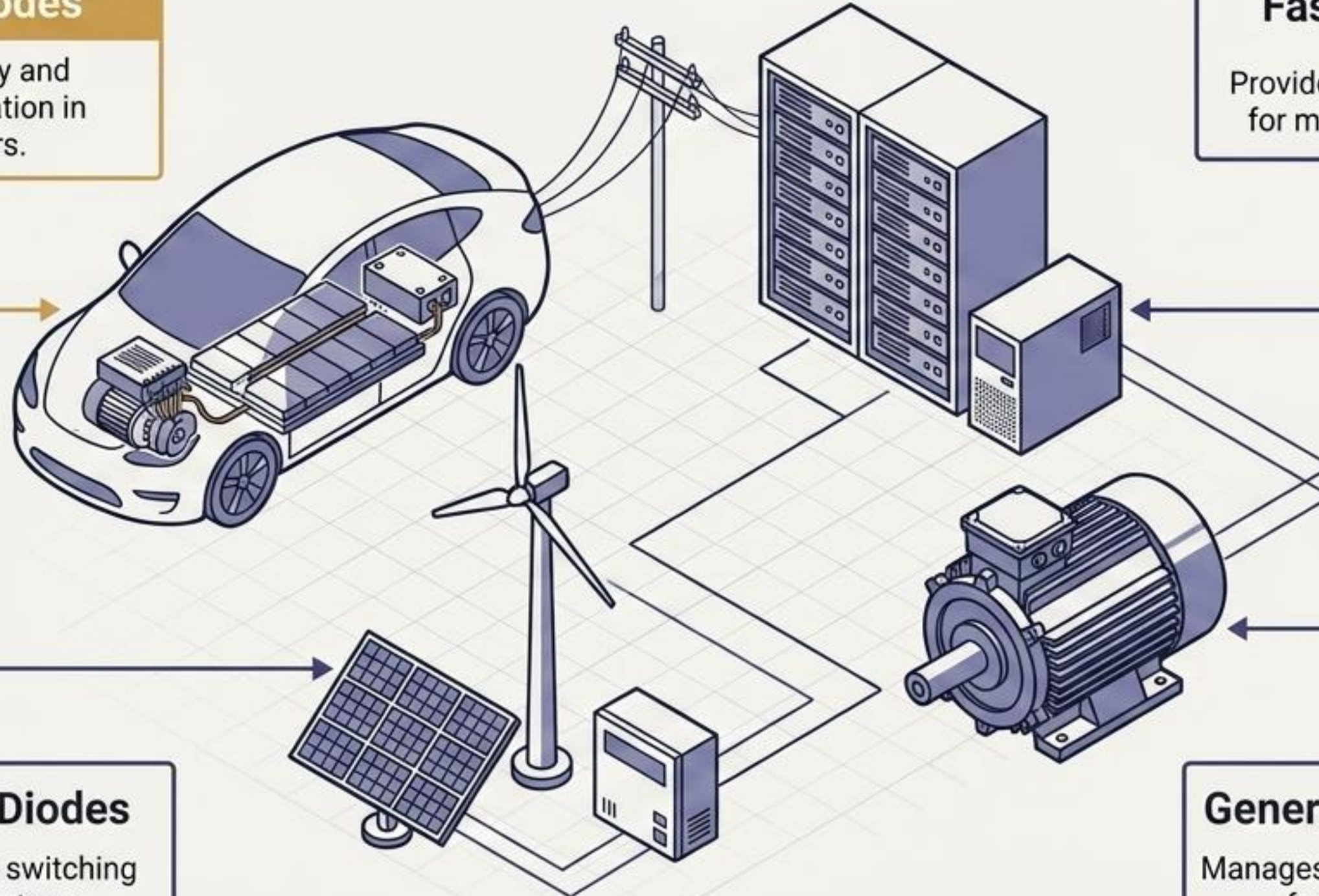
Provides reliable transient response for mission-critical UPS systems.

Ultra-Fast / WBG Diodes

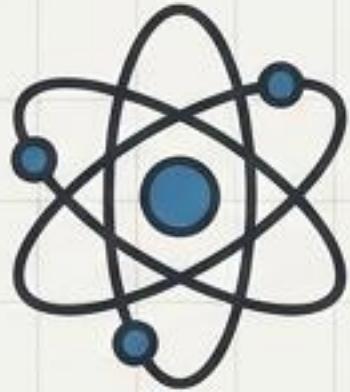
Crucial for high-frequency switching in renewable energy systems.

General Purpose Rectifiers

Manages massive line-frequency loads for industrial motor drives.



Module 1(b) Key Takeaways



The Physics [Core Concepts]

- **Drift Layer (N-):** The defining structural difference allowing high voltage handling.
- **Conduction Mechanics:** Forward vs. Reverse Bias states.
- **Wide Bandgap Superiority:** SiC material allows for extreme thermal and voltage limits.



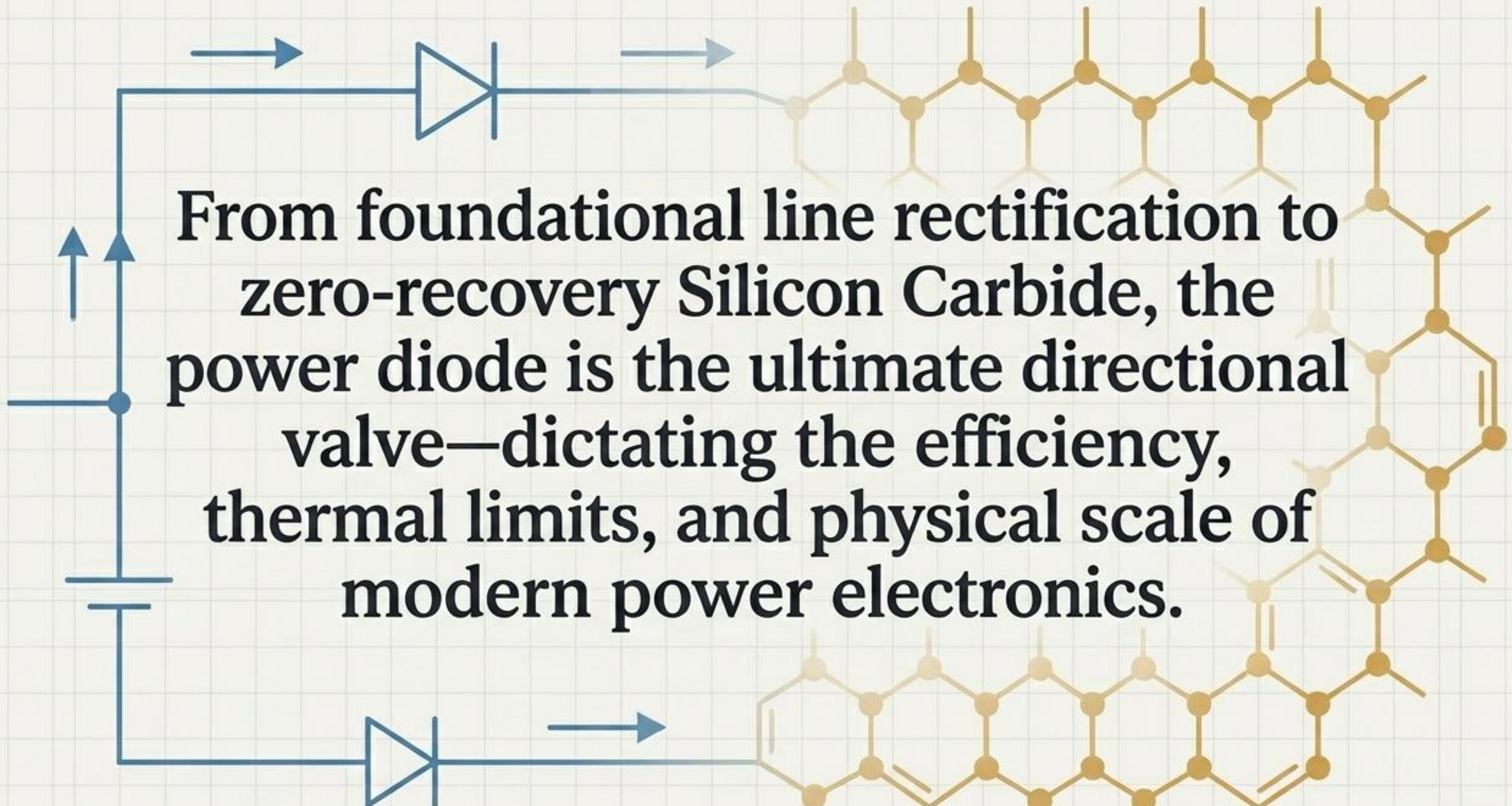
The Math & Curves [Exam Focus]

- **V-I Characteristics:** Master the Safe Operating Area vs. Avalanche Breakdown.
- **Reverse Recovery (t_{rr}):** Understand the graphical calculation of switching losses and trapped charge.



The Circuit [Industry Reality]

- **Inductive Kickback:** Understand the destructive nature of unmanaged RL loads.
- **Freewheeling Diodes:** Map the precise transient current paths ensuring Switch Protection.



From foundational line rectification to zero-recovery Silicon Carbide, the power diode is the ultimate directional valve—dictating the efficiency, thermal limits, and physical scale of modern power electronics.

Academic Inquiry & Discussion

Open for discussion regarding:

- The graphical calculation of t_{rr} parameters and switching losses.
- SiC material limitations and thermal considerations.
- Transient current continuity and switch protection in RL freewheeling loads.

Dr. Sathish K. R. | Assistant Professor
Dept. of Electrical and Electronics Engineering (EEE)
ATME College of Engineering

AC to DC Power Conversion using Diode Rectifier Circuits

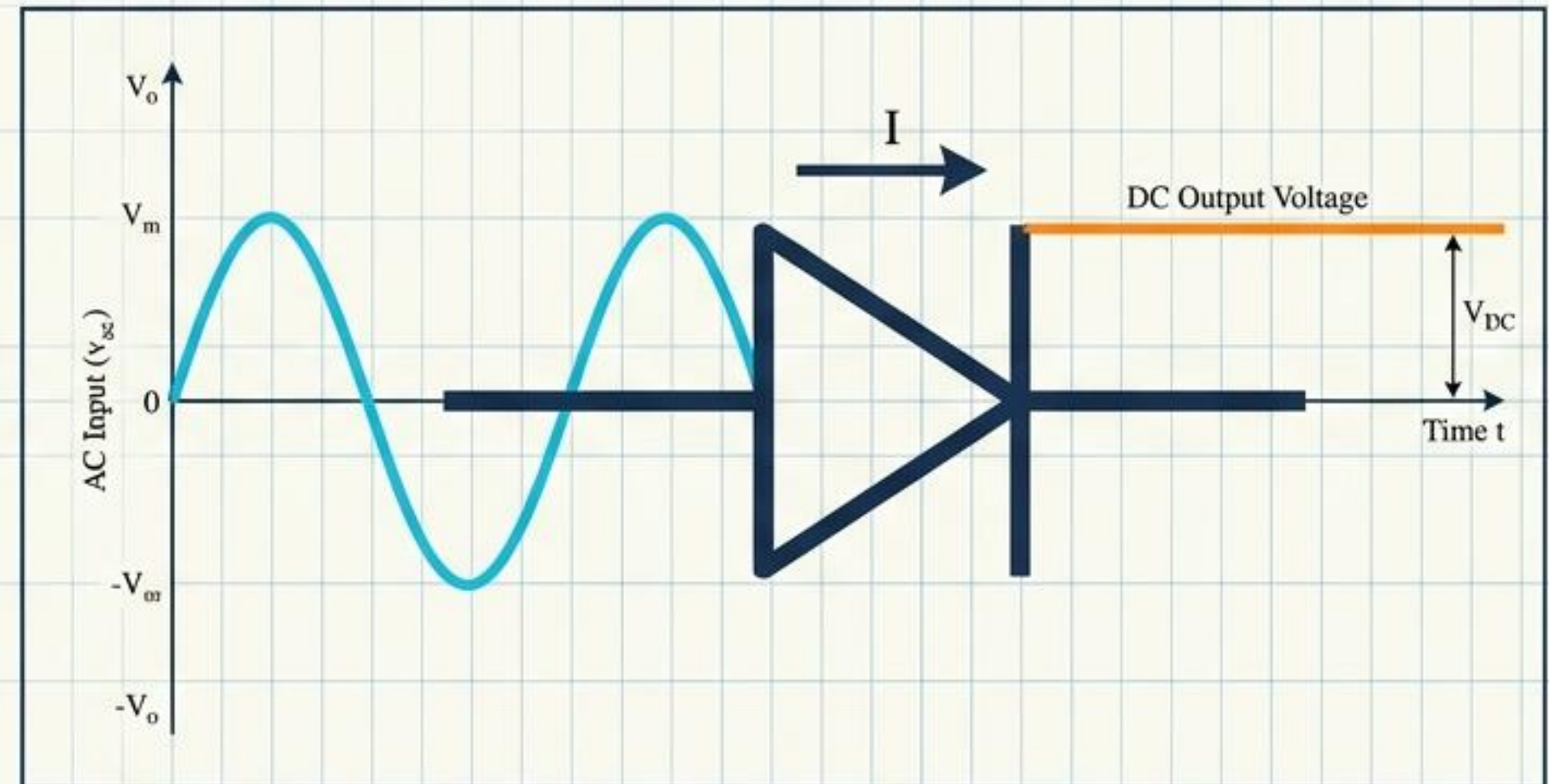
Power Electronics | Module-1(c)

Topic: Diode Rectifiers

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

Department of Electrical and
Electronics Engineering (EEE)

ATME College of Engineering



$$V_{DC} = \frac{V_m}{\pi} \text{ (Half-Wave)}$$

$$V_{DC} = \frac{2V_m}{\pi} \text{ (Full-Wave)}$$

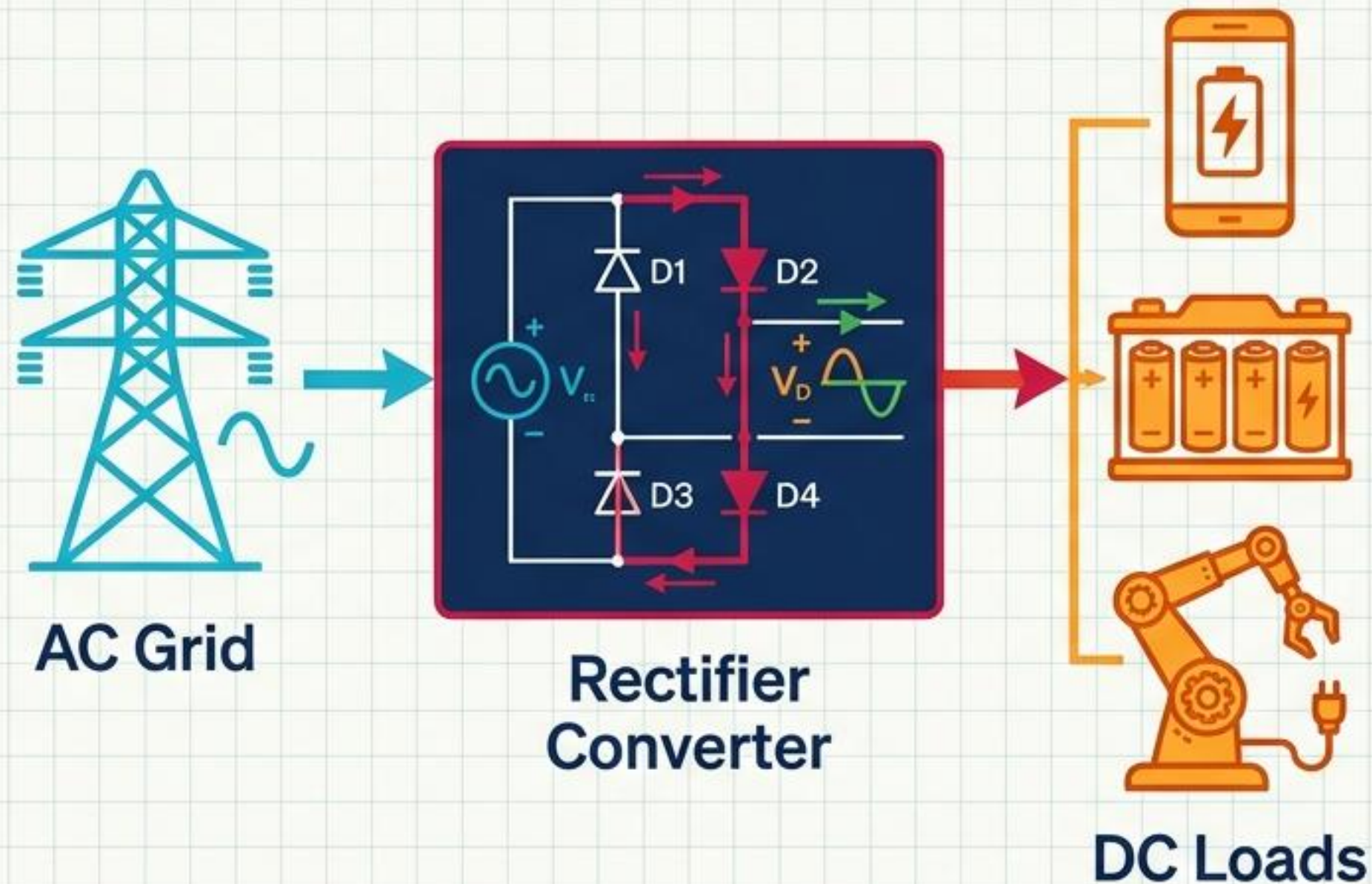
Bridging the Gap Between the AC Grid and DC Loads

The Problem:

Power is generated and transmitted as bidirectional Alternating Current (AC), but most modern electronics and energy storage systems require unidirectional Direct Current (DC).

$$P = V \times I$$

(AC/DC differences)



The Solution:

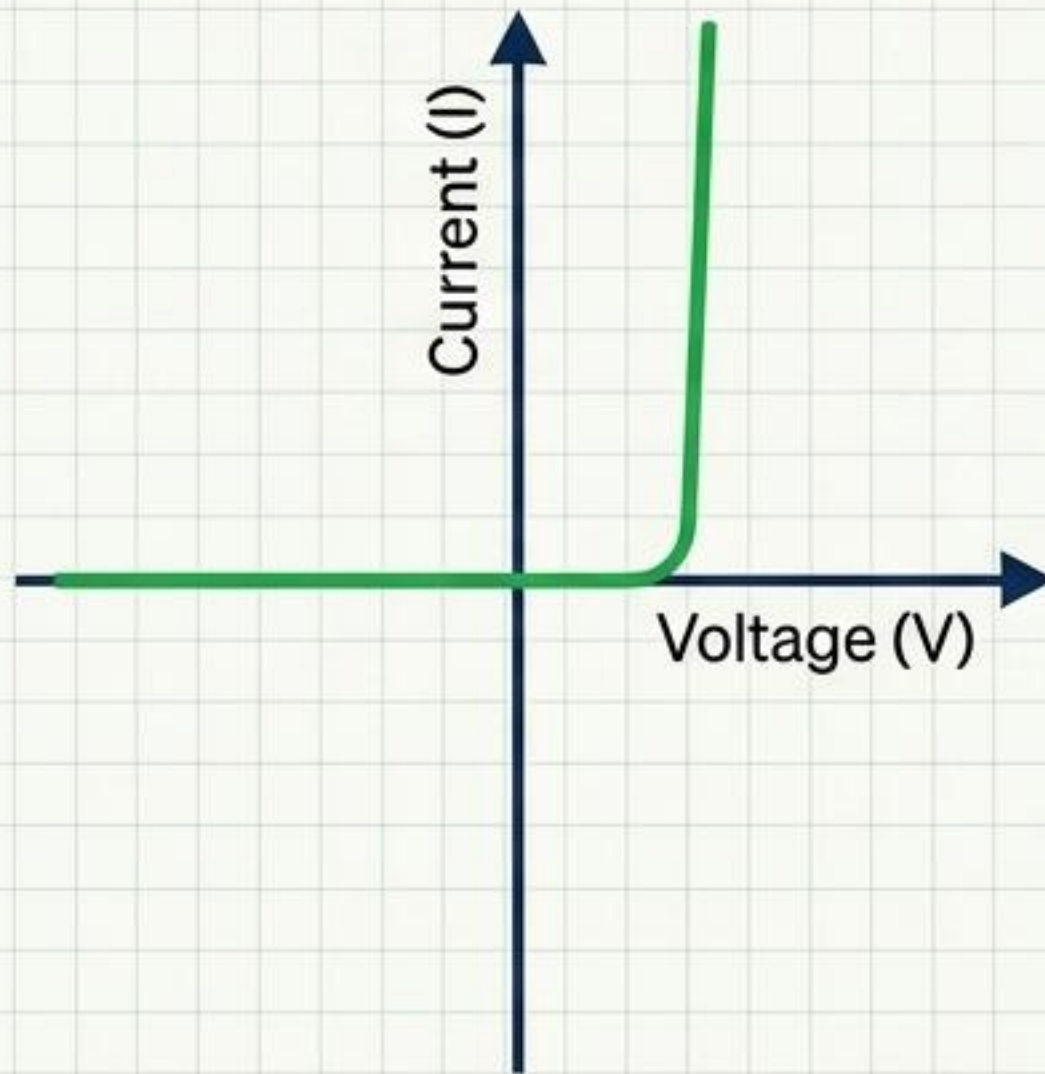
Rectification is the process of converting AC to DC, acting as the foundational front-end stage for power electronic systems.

Classification:

Rectifiers are categorized by phase (Single vs. Three-phase) and control (Uncontrolled diodes vs. Controlled thyristors).

$$\text{Rectifier Types} = [\text{Single/Three-Phase}] \times [\text{Uncontrolled/Controlled}]$$

The Diode as a Unidirectional Electrical Valve



Forward-Biased (Closed Switch)

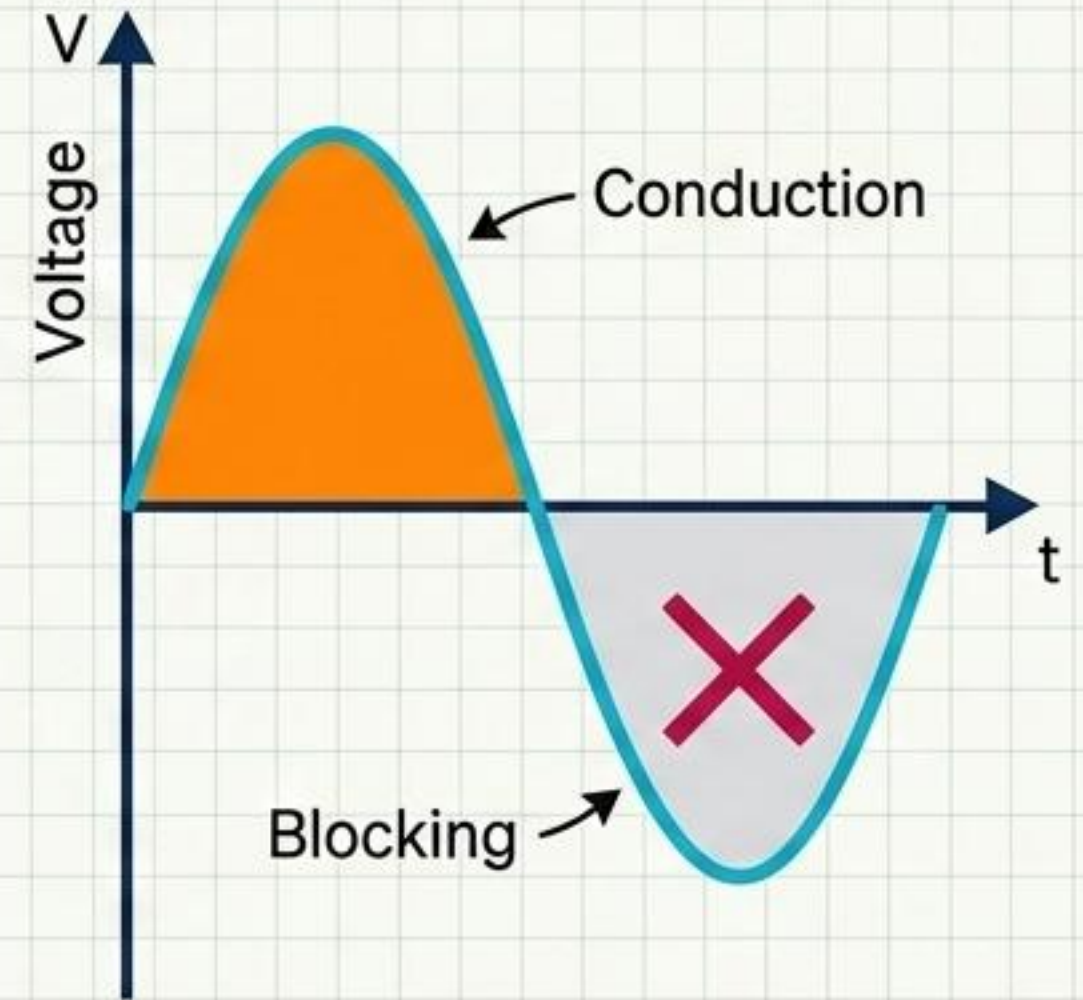
Anode voltage $>$ Cathode voltage.
The diode conducts, passing power to the load.

Reverse-Biased (Open Switch)

Anode voltage $<$ Cathode voltage.
The diode blocks, preventing reverse current flow.

The Rectification Process

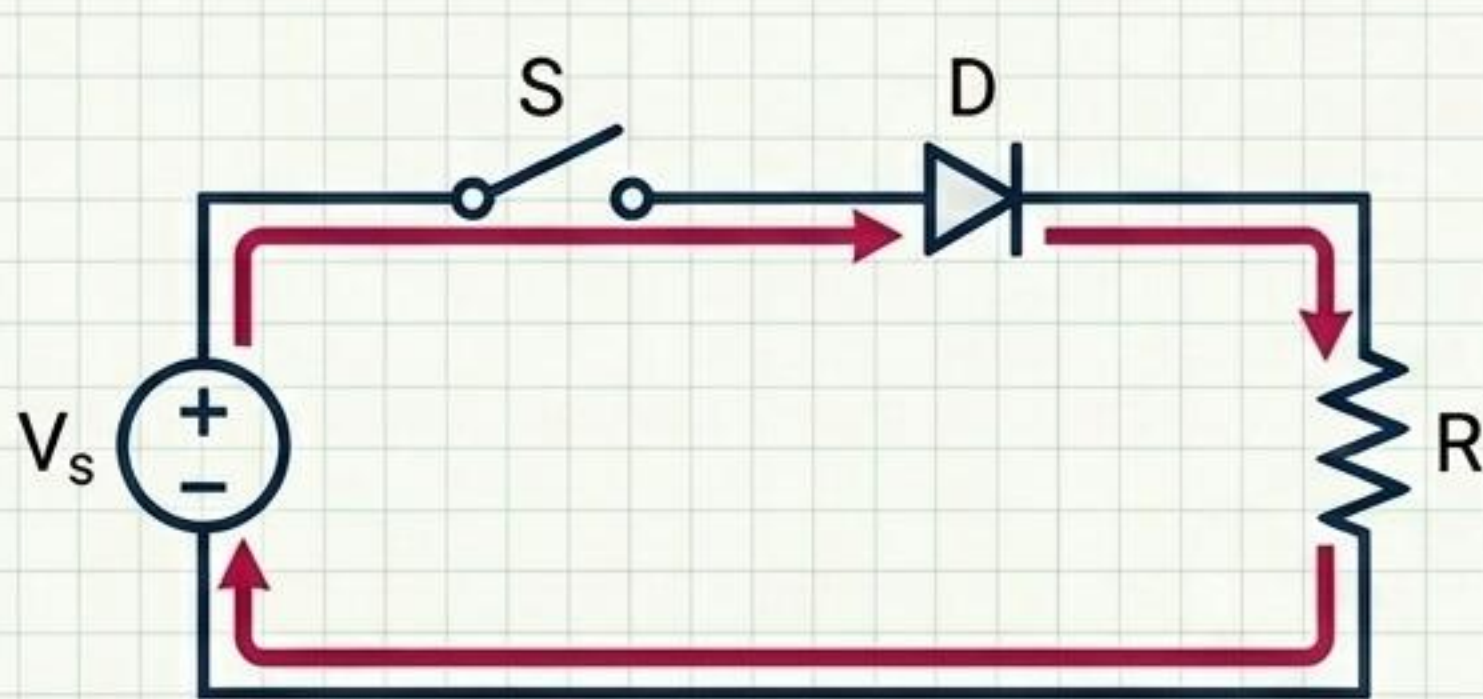
Mathematically clipping the negative half of a sinusoidal wave to create a non-zero average DC value (pulsating DC).



Baseline Steady-State Analysis: The Resistive (R) Load

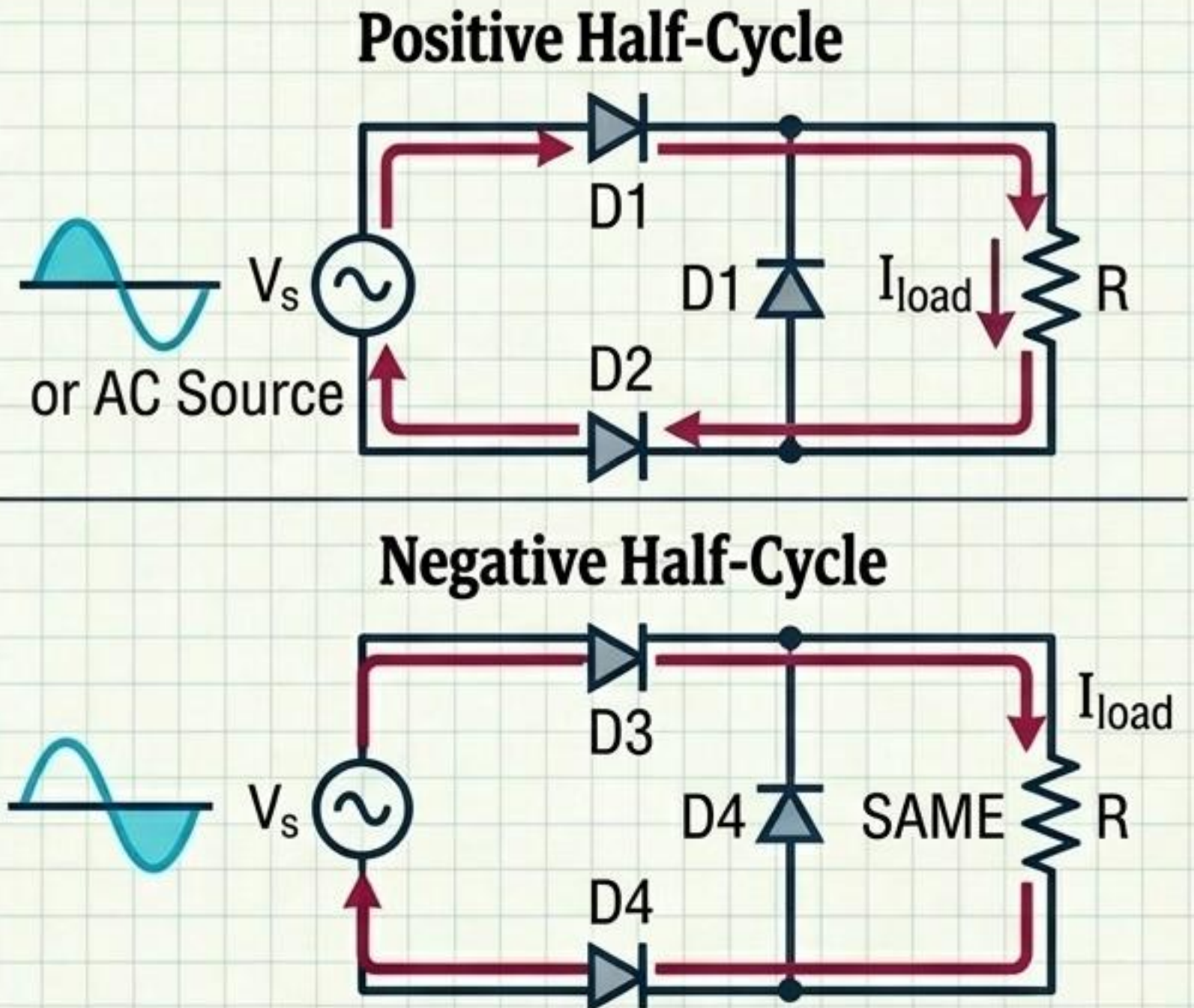
Configuration: Series circuit with a constant DC voltage source (V_s), diode (D), and resistor (R).

- **Instantaneous Response:** Current responds instantly to source changes.
- **Ohmic Relationship:** $I = \frac{V_s}{R}$ (assuming an ideal diode with zero forward voltage drop).
- **Energy Dynamics:** Voltage and current remain perfectly proportional and in-phase; no energy is stored in the system.



Full-Wave Bridge Rectification (Resistive Load)

- **Topology:** Utilizes four diodes (D1-D4) in a bridge configuration to capture the entire AC cycle.
- **Positive Half-Cycle (0 to π):** Diodes D1 and D2 are forward-biased.
- **Negative Half-Cycle (π to 2π):** Diodes D3 and D4 are forward-biased, routing current through the load in the same direction.
- **System Advantage:** Utilizes 100% of the input cycle, doubling the average output voltage and drastically reducing ripple compared to half-wave designs.



Mathematical Derivations for Full-Wave Analysis

Average Output Voltage (V_{dc})

The integrated usable DC output.

$$V_{dc} = \frac{2V_m}{\pi} \approx 0.636 V_m$$

Ripple Factor (γ)

AC content remaining in the DC output.

$$\gamma \approx \mathbf{48.2\%}$$

$$\frac{1}{\pi} \int_0^\pi V_m \sin(\omega t) d(\omega t)$$



$$V_{dc} = \frac{2V_m}{\pi}$$

RMS Output Voltage (V_{rms})

The effective heating value.

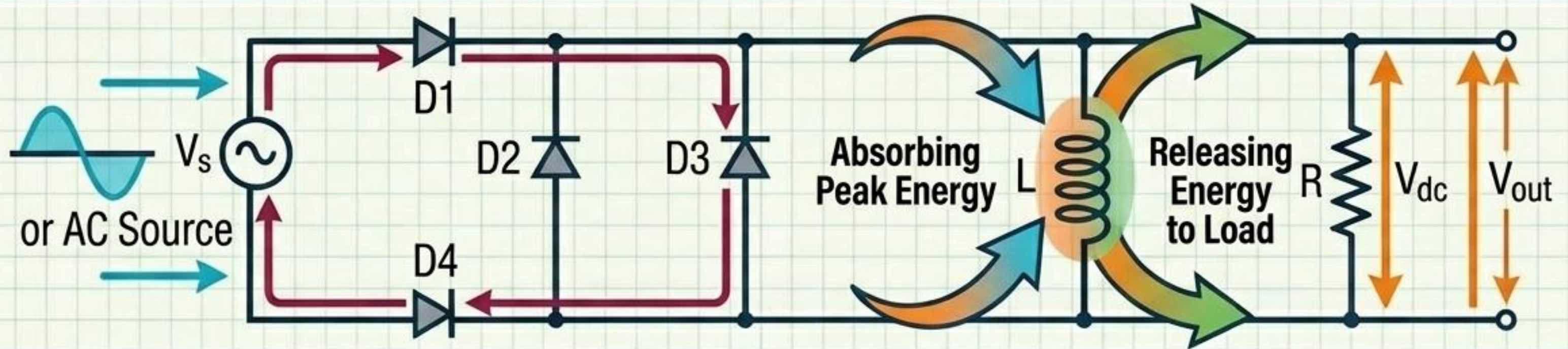
$$V_{rms} = \frac{V_m}{\sqrt{2}} \approx 0.707 V_m$$

Rectification Efficiency (η)

Conversion effectiveness.

Theoretical maximum $\approx \mathbf{81.2\%}$
(exactly double that of a half-wave rectifier).

Industrial Reality: Full-Wave Rectification with RL Loads



The Inductive Effect: The inductor attempts to keep load current constant, preventing it from dropping to zero at the AC zero-crossings.

Energy Transfer: Energy stored in L during peak voltage is discharged into the load when source voltage drops.

Continuous Conduction Mode (CCM): With sufficient inductance, load current never reaches zero (highly desirable for motor stability).

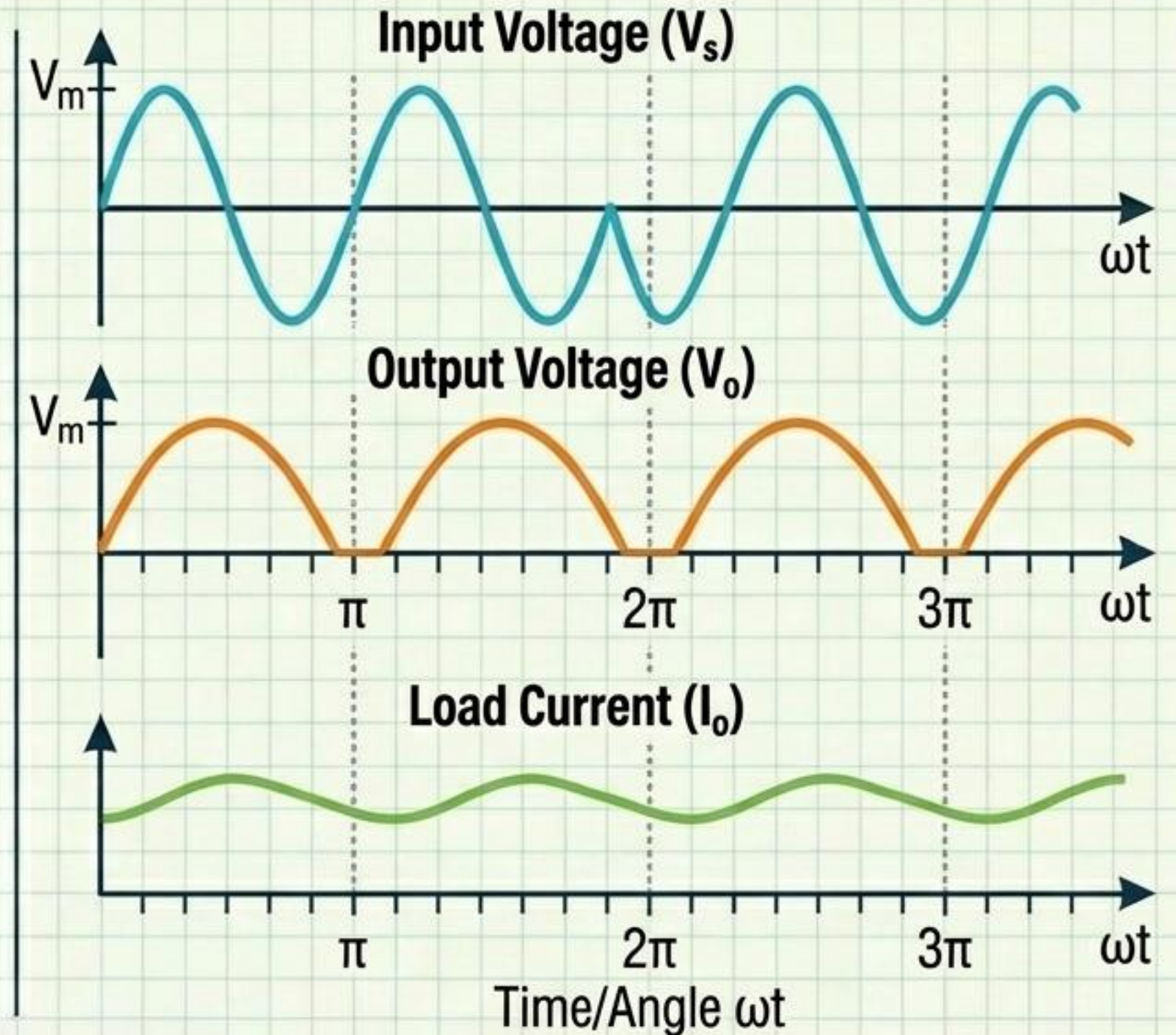
Discontinuous Conduction Mode (DCM): With low inductance, current reaches zero before the next half-cycle begins.

Synchronized Waveform Dynamics (RL Load)

- **Input Voltage (V_s):** Full sinusoidal wave.
- **Output Voltage (V_o):** Pulsating unidirectional wave (identical to R-load shape).
- **Load Current (I_o):** Smoothed current rippling around an average DC value; it never touches zero in Continuous Conduction Mode.

- **Commutation:** The exact moment at zero-crossings ($\pi, 2\pi$) where current hands off from D1/D2 to D3/D4.

- **Infinite Inductance Limit:** As $L \rightarrow \infty$, I_o approaches a perfectly flat DC line.



Diagnostic Matrix: R Load vs. RL Load Dynamics

Dimension	Resistive (R) Load	Inductive (RL) Load
Current Output	Pulsating, reaches zero	Smoothed, continuous (in CCM)
Voltage Output	Pulsating unidirectional	Pulsating unidirectional
Power Factor	Higher fundamental PF	Lower PF due to phase shifts
Ripple Behavior	High current ripple 	Low current ripple (Choke effect) 
Target Applications	Heaters, incandescent lighting	DC motor drives, relays, power supplies

Rectifier System Performance Dashboard

Ripple Factor (γ)

$$\gamma = \sqrt{FF^2 - 1} \text{ where } FF = \frac{V_{rms}}{V_{dc}}$$

Indicates necessary filter sizing.



Rectification Efficiency (η)

$$\eta = \frac{P_{dc}}{P_{ac}}$$

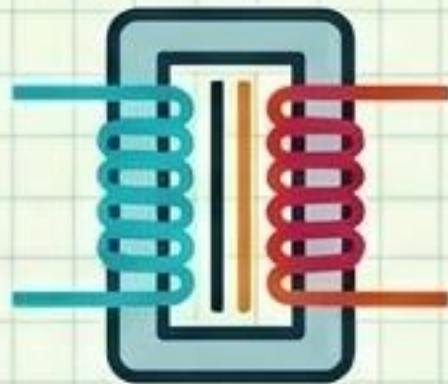
Dictates thermal losses.



Transformer Utilization Factor (TUF)

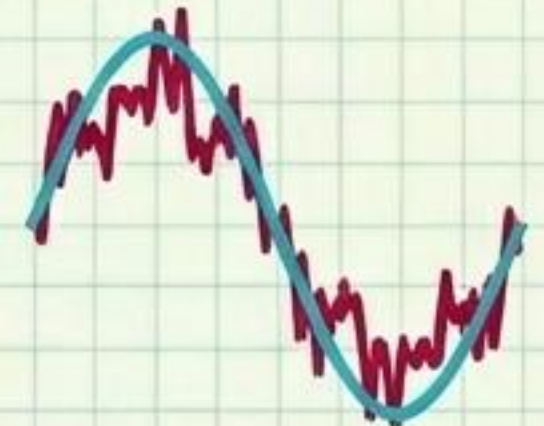
$$TUF = \frac{P_{dc}}{\text{Transformer VA rating}}$$

Critical for cost-effective transformer sizing.

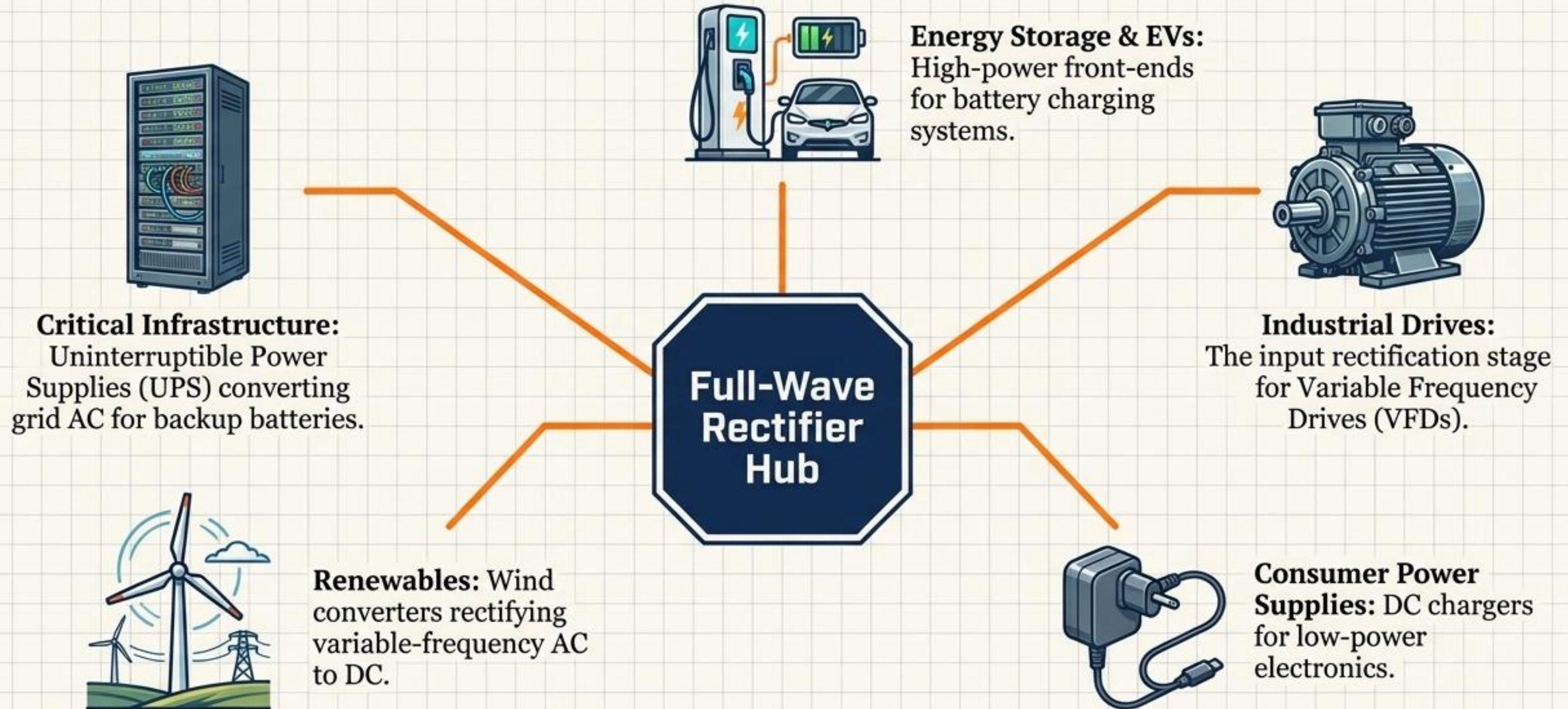


Total Harmonic Distortion (THD)

Measures grid pollution injected by non-sinusoidal current draw.



Real-World Applications of Rectifier Topologies



Practical Design Constraints and Limitations

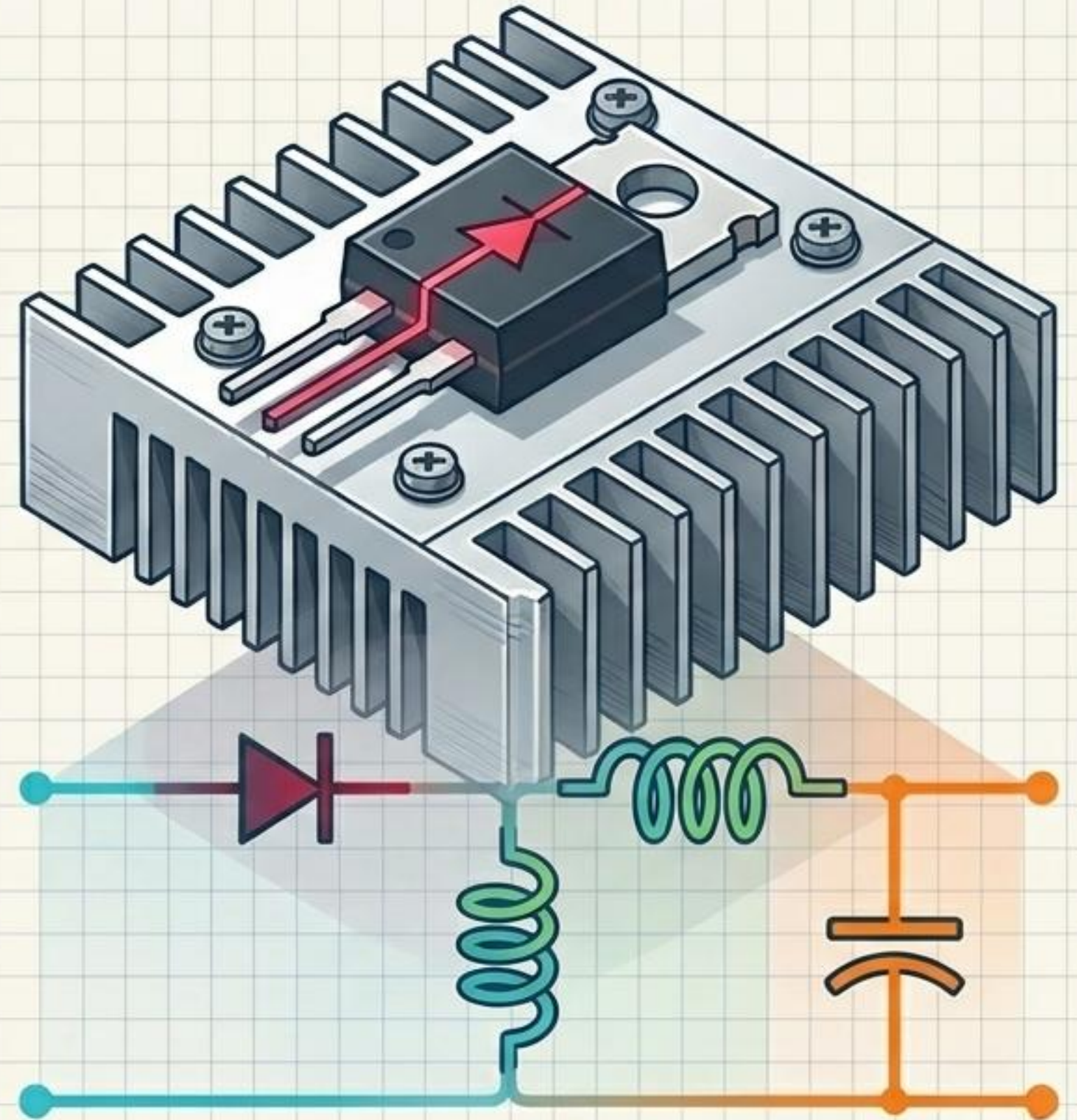
Peak Inverse Voltage (PIV): Diodes must withstand maximum reverse voltage without catastrophic avalanche breakdown.

Thermal Dissipation: Real diodes have a forward voltage drop ($V_f \approx 0.7V$). Power loss ($P = V_f \times I$) requires calculated heatsink integration.

Surge Currents: Component I^2t ratings must handle massive initial transient surges during turn-on.

Filtering Bulk: Capacitors (voltage) and inductors (current) required to achieve true flat DC add significant cost, weight, and PCB footprint.

Grid Harmonics: Pulsed current draws require active Power Factor Correction (PFC) stages to meet utility grid regulations.

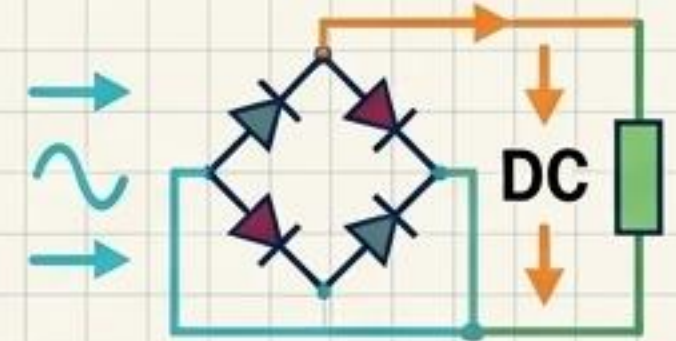


Module Synthesis: Core Concepts & Exam Preparation

Diode Rectification Mastery

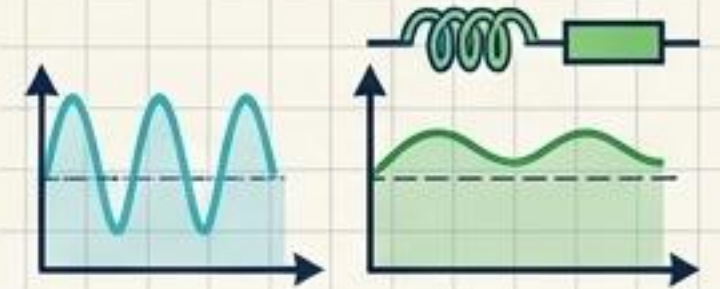
Topologies & Architecture

The Full-Wave Advantage: Yields double the efficiency (81.2%) and significantly lower ripple (48.2%) compared to half-wave architectures.



Load Dynamics

R loads yield pulsating current; RL loads introduce current continuity (CCM) and vital filtering.



Mathematical Foundations: Exam success requires fluid calculation of V_{dc} , V_{rms} , Ripple Factor, and Efficiency from standard sine inputs.

$$V_{dc} = \frac{2V_p}{\pi}$$

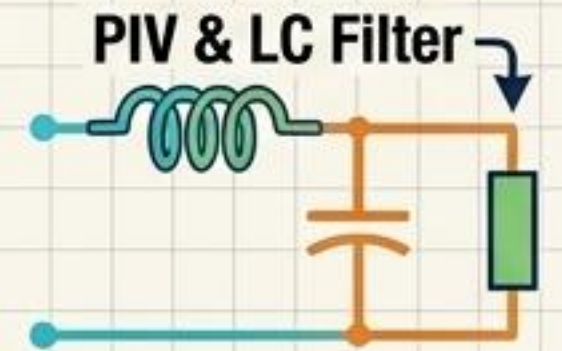
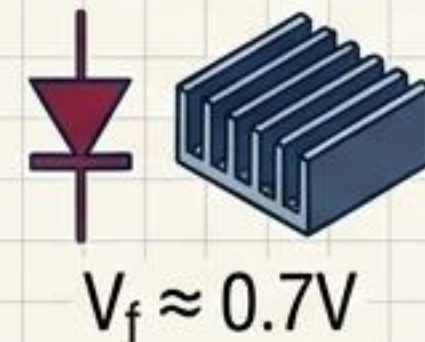
$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

$$\text{Ripple} = \frac{V_{r(rms)}}{V_{dc}}$$

$$\eta = \frac{P_{dc}}{P_{ac}}$$

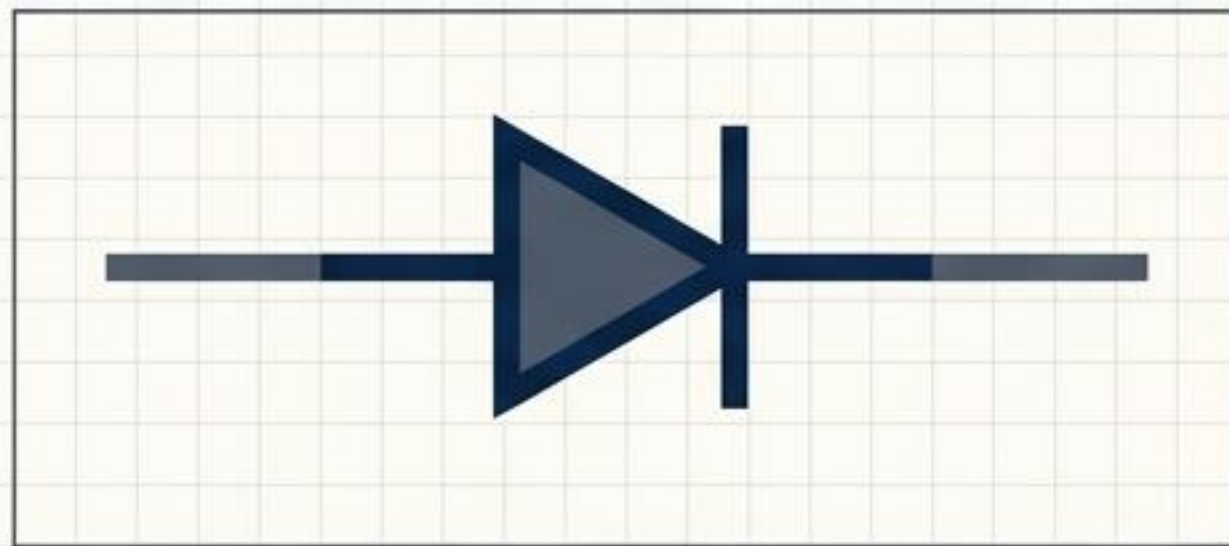
Engineering Reality

Ideal calculations must be adjusted for physical PIV limits, thermal losses, and bulky LC filtering requirements.

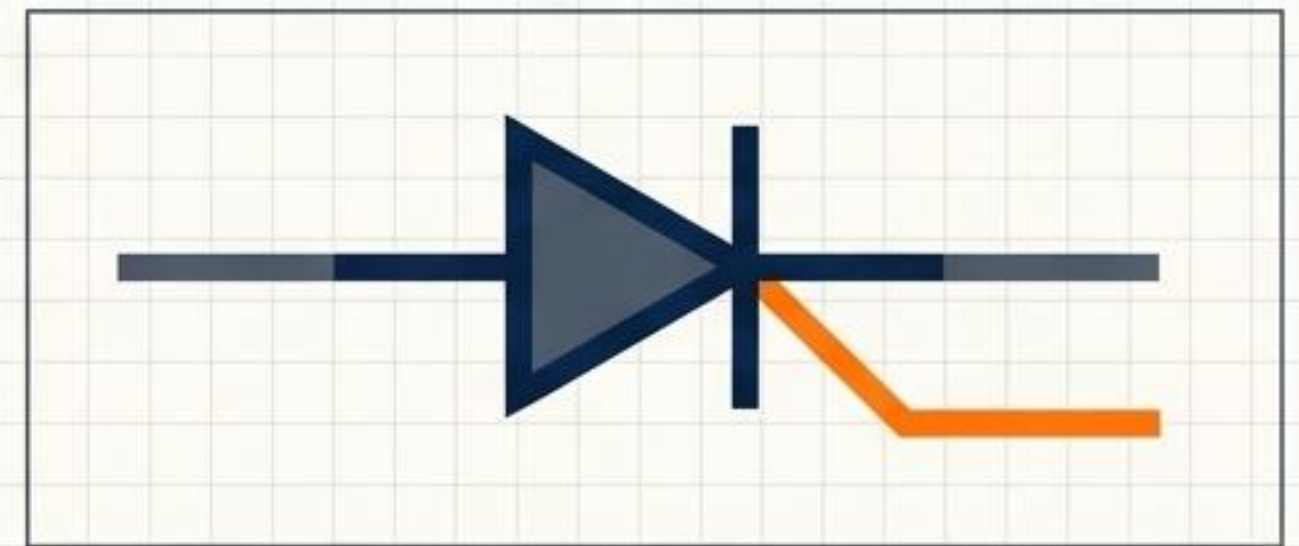
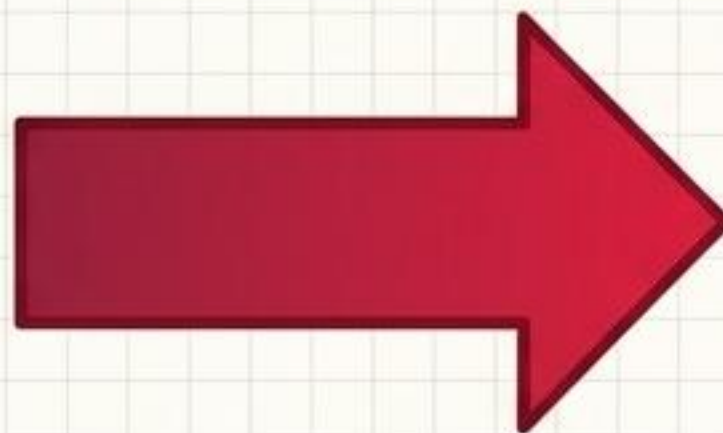


The Next Frontier: Controlled Rectification

- **The Limitation of Diodes:** Diode rectifiers are uncontrolled. The output DC voltage is strictly fixed by the input AC voltage amplitude.
- **The Industrial Requirement:** Complex industrial systems (like variable speed motor drives) require adjustable, dynamic DC voltage on demand.
- **Next Module Preview:** We will replace uncontrolled two-terminal diodes with three-terminal controllable thyristors (SCRs).
- **The Control Variable:** By delaying the firing angle (α) of the thyristor, we can precisely sculpt the output waveform and control the exact amount of power delivered.



Uncontrolled - Fixed Output



Controlled - Variable Output (Gate Firing)