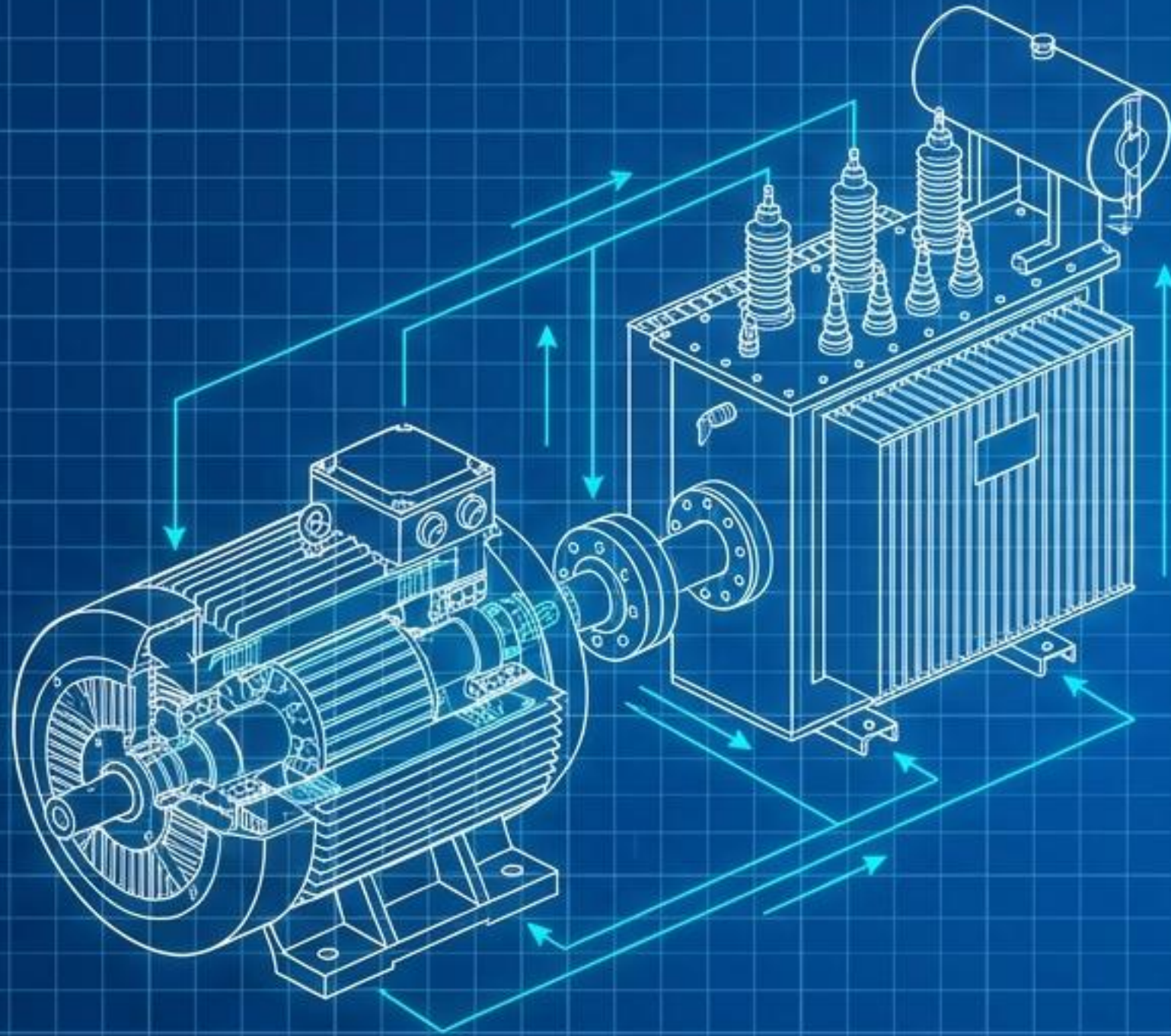




Energy Efficiency in Electrical Systems

Energy Conservation Techniques and Efficient Operation

Module	Module-2
Course	Energy Conservation and Audit (Course Code: BEE755B)
Instructor	Dr. Sathish K. R. Assistant Professor
Department	Electrical and Electronics Engineering (EEE)
Institution	ATME College of Engineering

Diagnostic Baseline: Industrial Utility Billing

COST BREAKDOWN



DAILY LOAD PATTERN & TARIFF ZONES



TARIFF STRUCTURES

Two-part tariffs mandate paying for maximum capacity required (**Demand**) plus actual consumption (**Energy**).

PENALTIES & INCENTIVES

Utility grids enforce **ToD tariffs** and **power factor penalties** to stabilize grid loads.

COST REDUCTION STRATEGY

Shift non-critical loads (e.g., pumping, heating) to **off-peak hours** to avoid **peak demand multipliers**.

$$\text{Total Bill} = (\text{Max Demand} \times \text{Demand Rate}) + (\text{Energy Consumed} \times \text{Energy Rate}) \pm \text{Power Factor Penalty}$$

Taming the Peak: Load Management & Demand Control



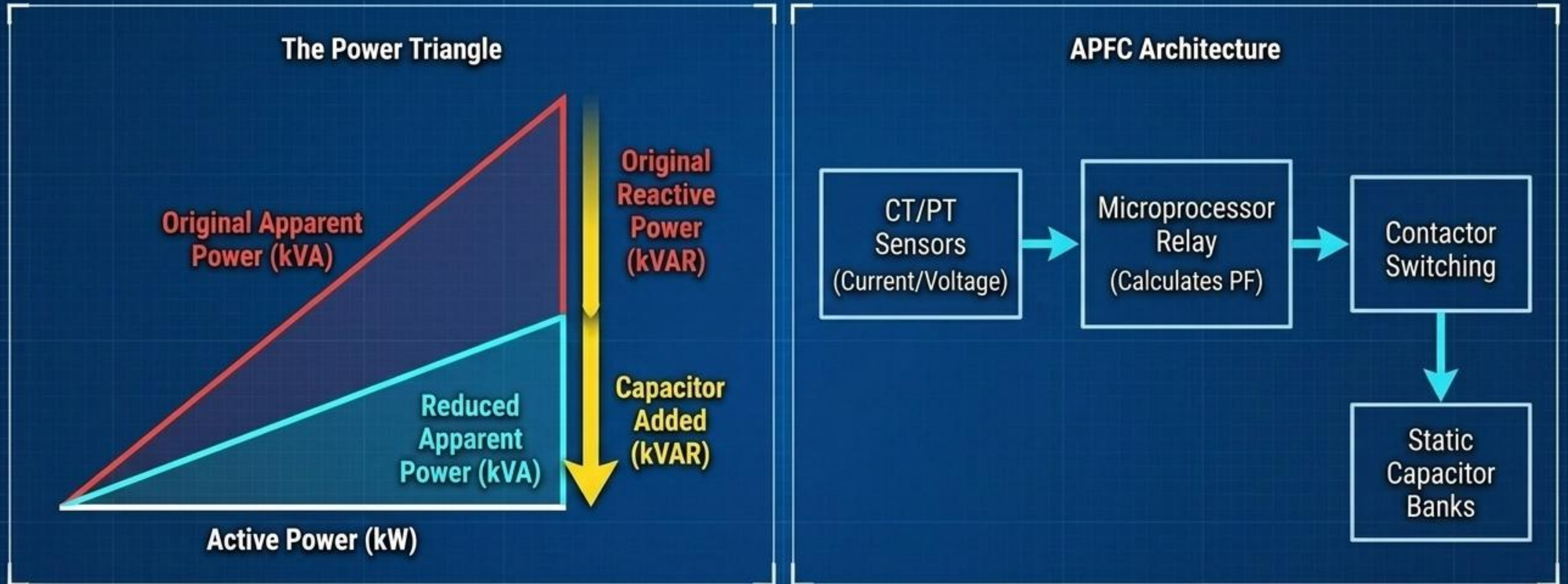
Maximum Demand (MD): Highest average load over a specific 15-30 min interval.

Load Factor: Ratio of average load to maximum demand. Higher indicates better asset utilization.

Demand Control: Proactive shedding of non-critical loads to prevent tariff penalties.

$$\text{Load Factor} = \frac{\text{Average Load}}{\text{Maximum Demand}}$$

Reactive Power Mitigation: Power Factor & APFC

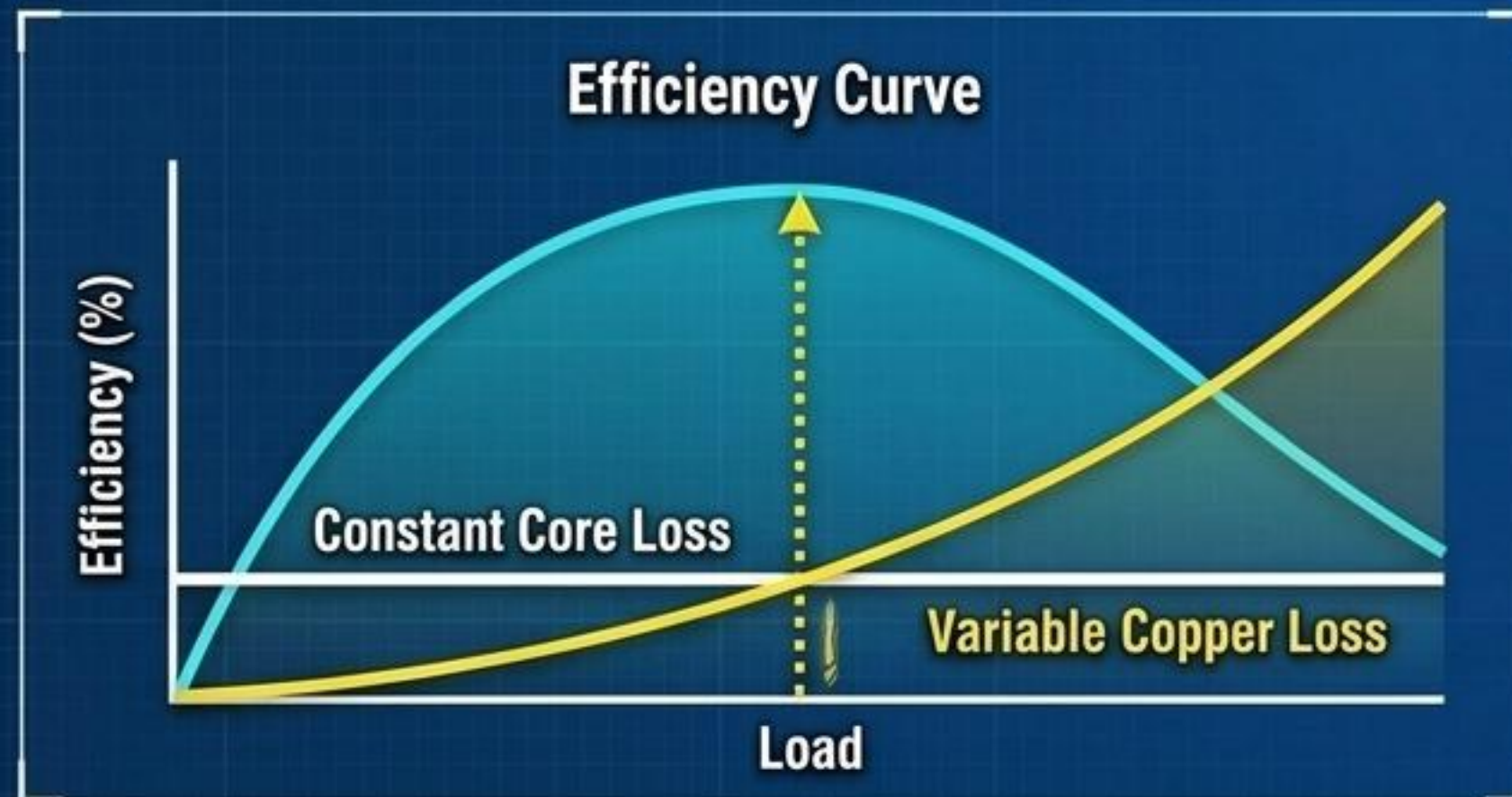


The PF Dilemma: Low PF (inductive loads) increases kVA demand, causing utility penalties and high I^2R distribution losses.

APFC Operation: Microprocessor continuously senses reactive power and automatically switches capacitor banks to maintain unity PF.

$$\text{Required kVAR} = \text{kW} \times (\tan \theta_1 - \tan \theta_2)$$

Core Infrastructure: Transformer Efficiency



No-Load Losses (Core): Hysteresis and eddy currents. Constant 24/7 regardless of the load.

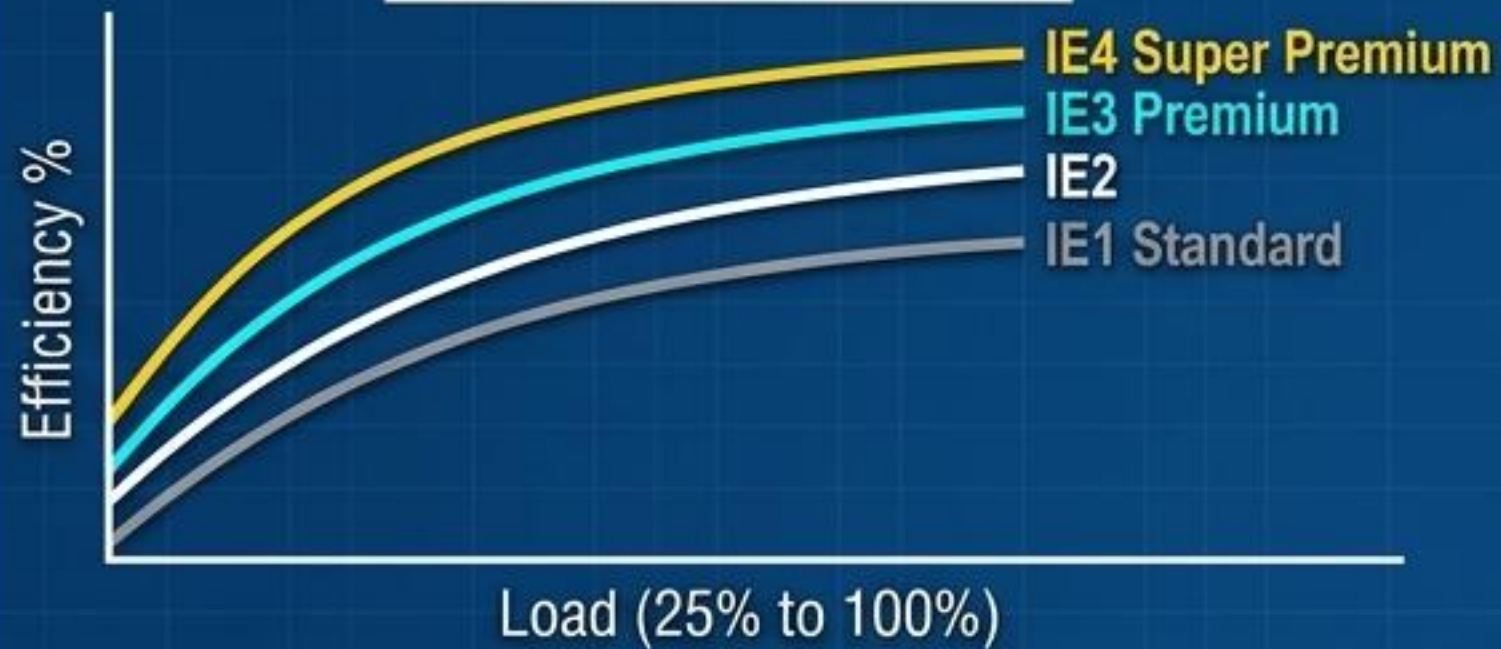
Load Losses (Copper): I^2R losses. Vary quadratically with load fluctuations.

Amorphous Core Tech: Replaces standard steel with ultra-thin magnetic ribbons, reducing no-load core losses by up to 70%.

Max Efficiency Condition: Constant Loss (P_i) = Variable Loss (I^2R)

Rotational Power: High-Efficiency Motors & Soft Starters

IE Efficiency Classes



Motor Loss Breakdown

Stator/rotor I^2R , iron losses, friction/windage, and stray load losses.

High-Efficiency Design

Thinner laminations, larger copper cross-sections, and optimized air gaps to drastically reduce continuous operational losses.

Starting Current Dynamics

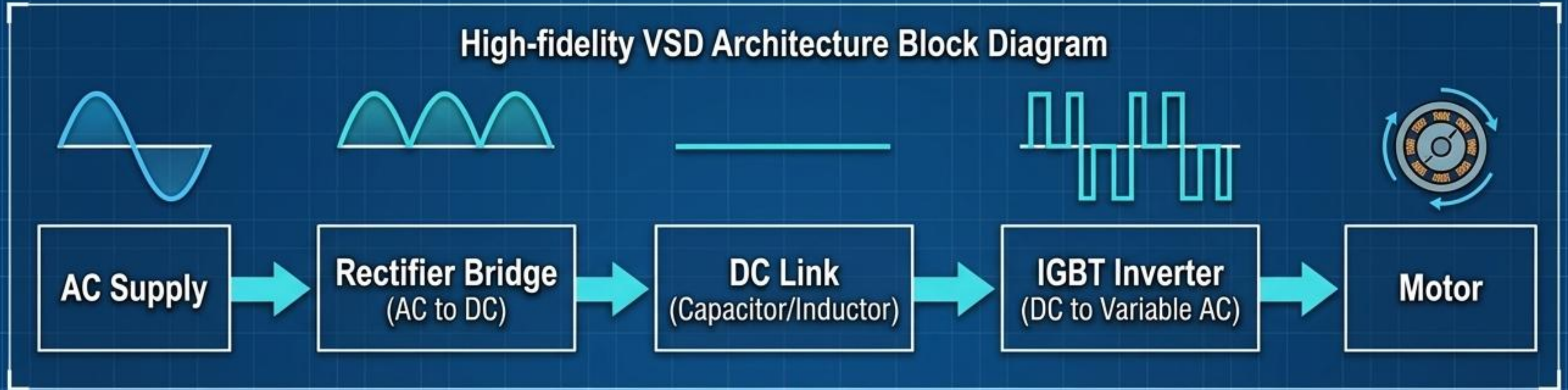


Soft Starters

Thyristor-based voltage control restricts massive inrush currents during motor ignition, preventing grid voltage dips and severe mechanical shock to drivetrains.

Dynamic Control: Variable Speed Drives (VSDs)

High-fidelity VSD Architecture Block Diagram



The Throttling Problem

Running motors at 100% full speed and using mechanical dampers/valves to throttle the output is highly inefficient and wastes **massive energy**.

VSD Principle

Converts incoming grid AC power to DC, then inverts it back to AC at a **customized frequency** to precisely match process load requirements.

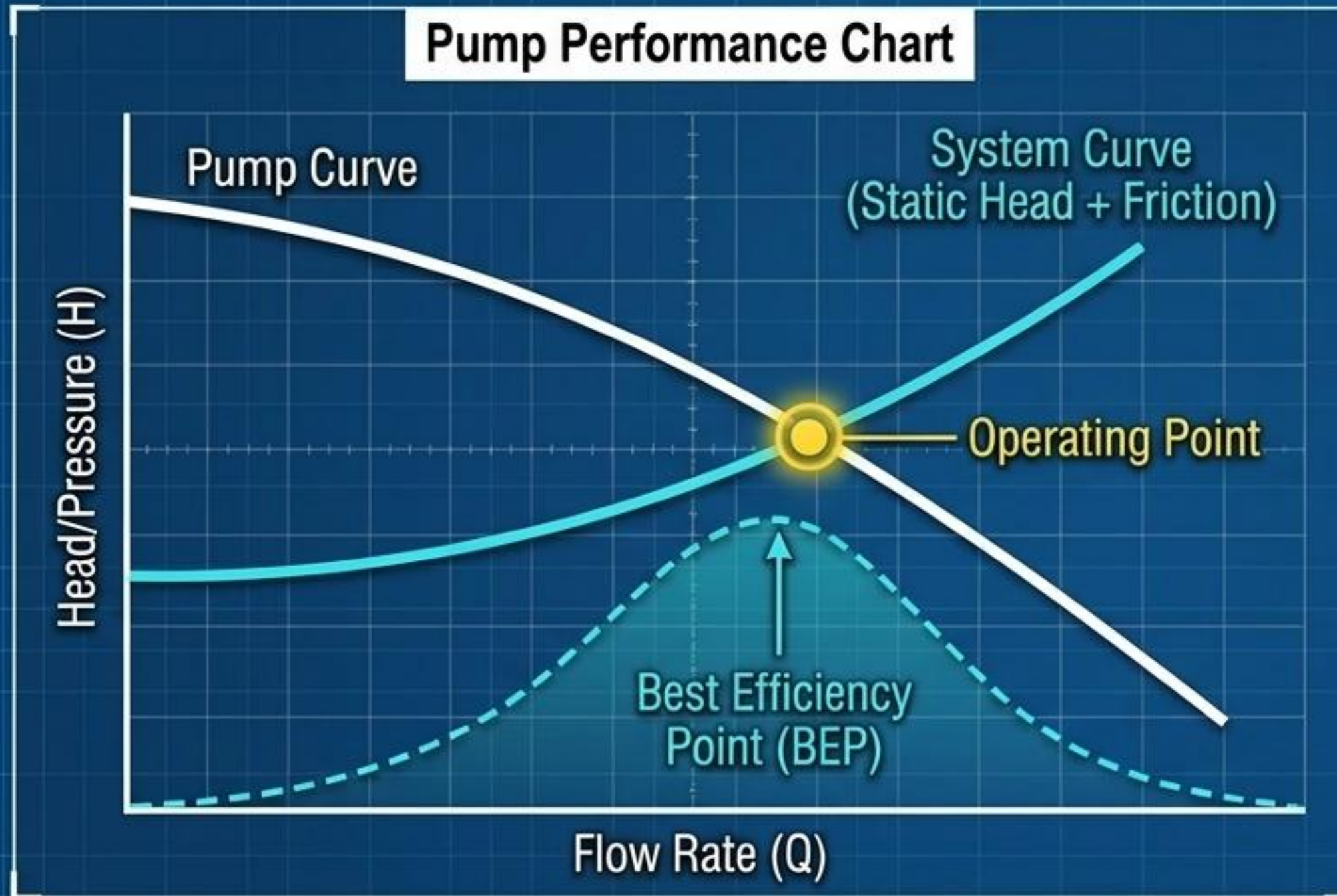
Speed Equations

$$\text{Synchronous Speed } (N_s) = \frac{120f}{P}$$

$$\text{Motor Slip } (s) = \frac{(N_s - N_r)}{N_s}$$

Speed is directly proportional to frequency ($N \propto f$).

Fluid Dynamics Baseline: Fan & Pump Evaluation



System Resistance

Represents the absolute friction and static elevation head of the piping or ducting network.

Operating Point

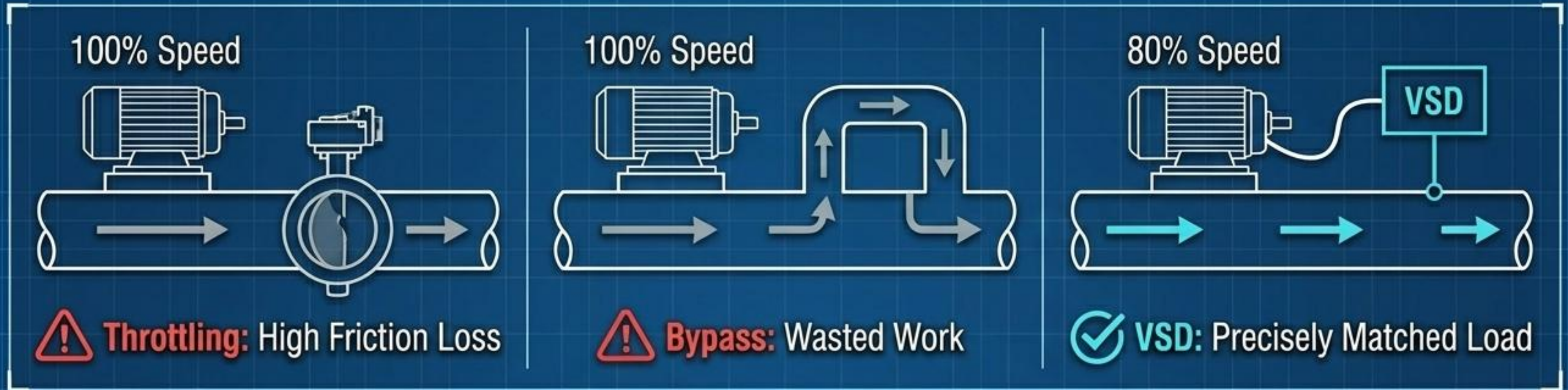
The exact intersection equilibrium where the pump/fan mechanical output perfectly matches the system resistance.

Audit Methodology

Measure actual flow rate, differential pressure, fluid density, and electrical power input to verify deviation from BEP.

$$\text{Pump Efficiency } (\eta) = \text{Hydraulic Power Output } (Q \times H \times \rho \times g) / \text{Shaft Power Input}$$

The Affinity Laws: Exponential Energy Savings



Centrifugal Affinity Laws

1. Flow is directly proportional to Speed ($Q \propto N$).
2. Head is proportional to Speed Squared ($H \propto N^2$).
3. Power is proportional to Speed Cubed ($P \propto N^3$).

$$\text{Power Ratio: } P_2 = P_1 \times \left(\frac{N_2}{N_1} \right)^3$$

Example: $(0.8)^3 = 0.512$
(48.8% Energy Savings)

The Cube Law Magic

Because power drops with the cube of the speed, lowering motor speed by just 20% slashes total power consumption by nearly 50%.

Illumination Technology: Ballasts & Solid-State Lighting

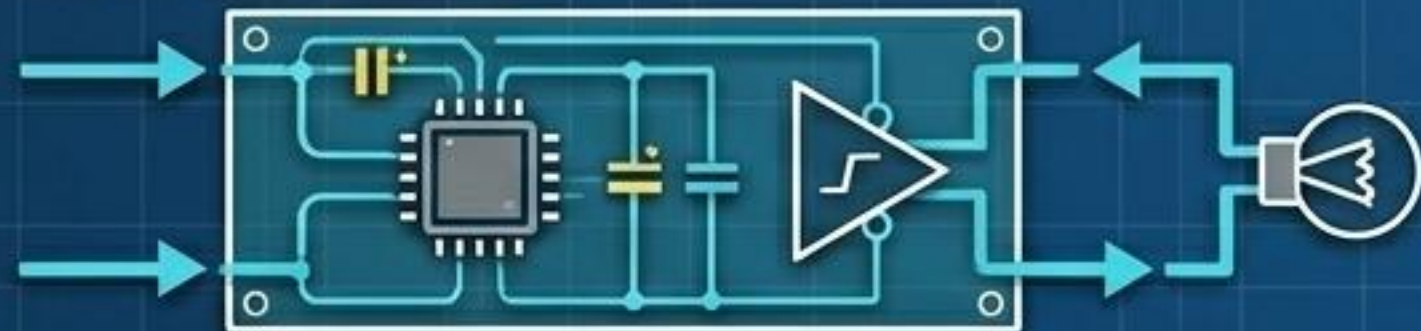
Ballast Circuits

Electromagnetic Ballast



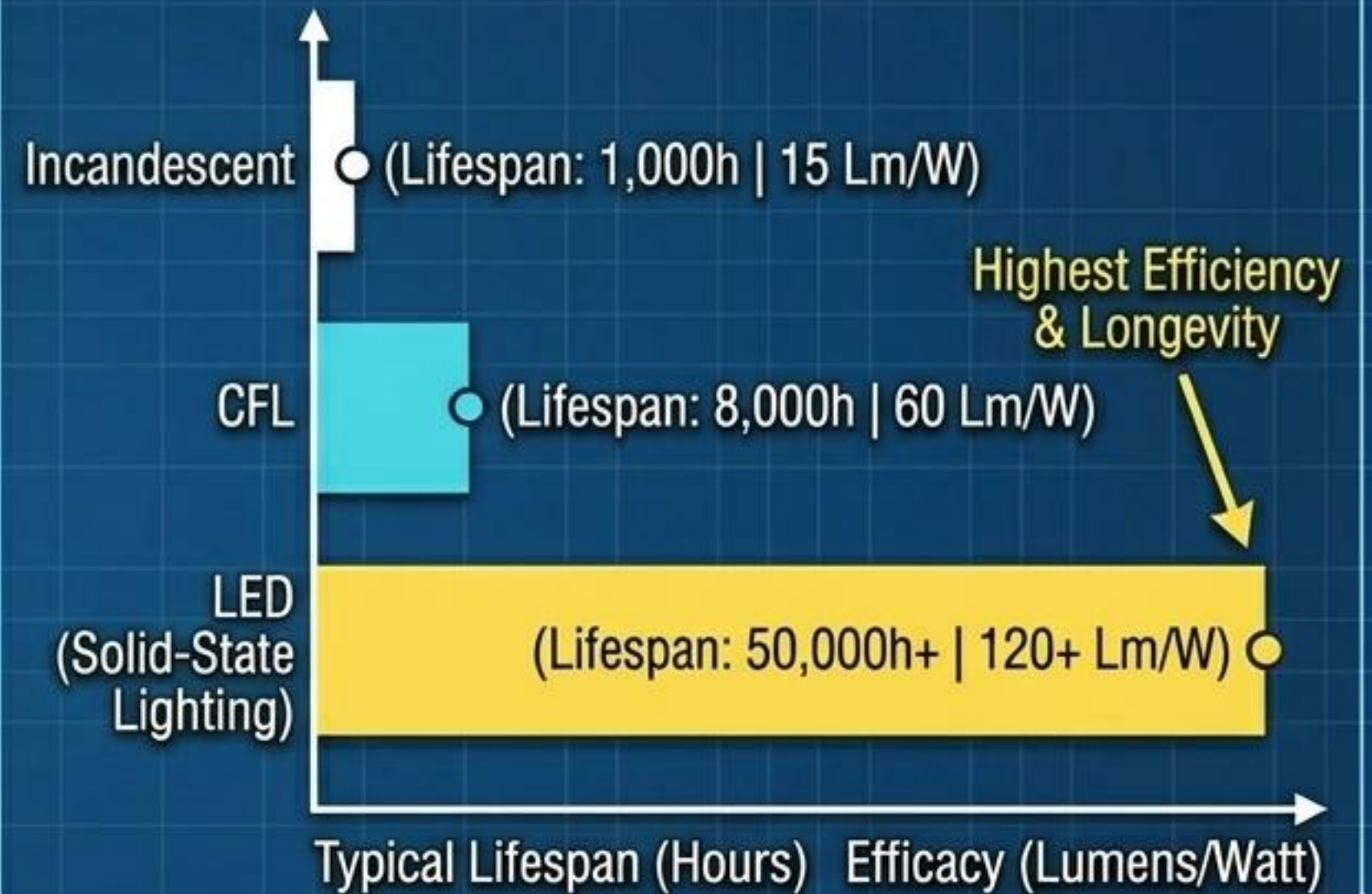
Inductive, heavy, extremely low power factor, and causes stroboscopic flicker.

Electronic Ballast



Operates at high frequency (20-30 kHz), extremely low loss (<2W), improves power factor, and absolutely no flicker.

Lamp Comparison



LED Technology: Solid-State Lighting (SSL) offers the highest luminous efficacy, highly directional output (eliminating fixture loss), and contains no toxic mercury.

The Lighting Audit: Metrics & Smart Controls

Diagnostic Table

Area Type	Target Lux	Measured Lux	Installed LPD	Action
Corridor	100	250	12 W/m ²	De-lamp 50%
Office Desk	500	300	8 W/m ²	Upgrade to LED
Warehouse	200	210	4 W/m ²	Optimal

Key Metrics: Luminous Efficacy (Lumens/Watt), Lux Levels (Lumens/m²), and Lighting Power Density (LPD in Watts/m²).

Daylight Harvesting Sensor:
Photosensors dynamically dim artificial lights based on available ambient sunlight.

PIR Occupancy Sensor:
PIR & Ultrasonic sensors automatically de-energize circuits in vacant zones.



$$\text{Room Index Calculation} = \frac{(L \times W)}{H_m \times (L + W)}$$

Synthesis Matrix: Conventional vs. Efficient Technologies

Domain	Conventional Tech	Efficient Alternative	Primary Engineering Benefit
Motors	IE1 Standard Motor	IE3 / IE4 Premium	Lower slip, optimized core, reduced I^2R loss.
Starters	Direct-On-Line (DOL)	Soft Starter / VSD	Eliminates mechanical shock, curbs inrush current, dynamic speed control.
Ballasts	Electromagnetic	Electronic	High-frequency operation, high PF, minimal thermal loss.
Lamps	Fluorescent / Gas Discharge	Solid-State LED	High luminous efficacy, highly directional output, extended lifecycle.

Recurring Engineering Theme: Modern energy efficiency relies almost entirely on solid-state electronics replacing legacy mechanical, thermal, or inductive components.

The Audit in Action: Case Studies & Economics

Case 1: Motor Retrofit



Upgrading **50kW IE1 to IE3**. Continuous 24/7 operation justified the higher capital cost within **14 months**.

Case 2: VSD Integration



Installed VSD on a cooling tower pump to match variable seasonal loads, yielding an immediate **35% energy reduction**.

Case 3: APFC Panel



Mitigated a massive **₹50,000/month** utility PF penalty; achieved complete payback in under **8 months**.

Payback Timeline

Initial Capital Expense

Ongoing Savings

Net Profit (Ongoing Energy Savings)

Break-Even Point

Simple Payback Period (SPP)

$$\text{Simple Payback Period (SPP)} = \frac{\text{Capital Investment}}{\text{Annual Net Savings}}$$

Return on Investment (ROI)

$$\text{Return on Investment (ROI)} = \frac{\text{Annual Net Savings}}{\text{Capital Investment}} \times 100$$

Engineering Toolkit: Critical Calculations

Power Factor Correction

P → (kW)

kVAR → (Reactive Power unit)

$$\text{Required kVAR} = P \times (\tan \theta_1 - \tan \theta_2)$$

$\tan \theta_1, \tan \theta_2$ (dimensionless factors)

Motor Slip Calculation

dimensionless slip →

$$s = \frac{N_s - N_r}{N_s}$$

N_s → (Synchronous Speed in RPM)

N_r → (Rotor Speed in RPM)

Transformer Max Efficiency Point

(Apparent Power unit) →

$$\text{Output kVA} = \text{Full Load kVA} \times$$

$$\sqrt{\frac{\text{Iron Loss}}{\text{Full Load Copper Loss}}}$$

Iron Loss → (W)

Full Load Copper Loss → (W)

Affinity Law (Power)

(Power in kW) →

$$P_2 = P_1 \times \left(\frac{N_2}{N_1} \right)^3$$

(Power in kW)

(Power in kW) →

(Speed in RPM)

Pump Hydraulic Power

Result in kW →

$$P_h = \frac{\rho \times g \times Q \times H}{1000}$$

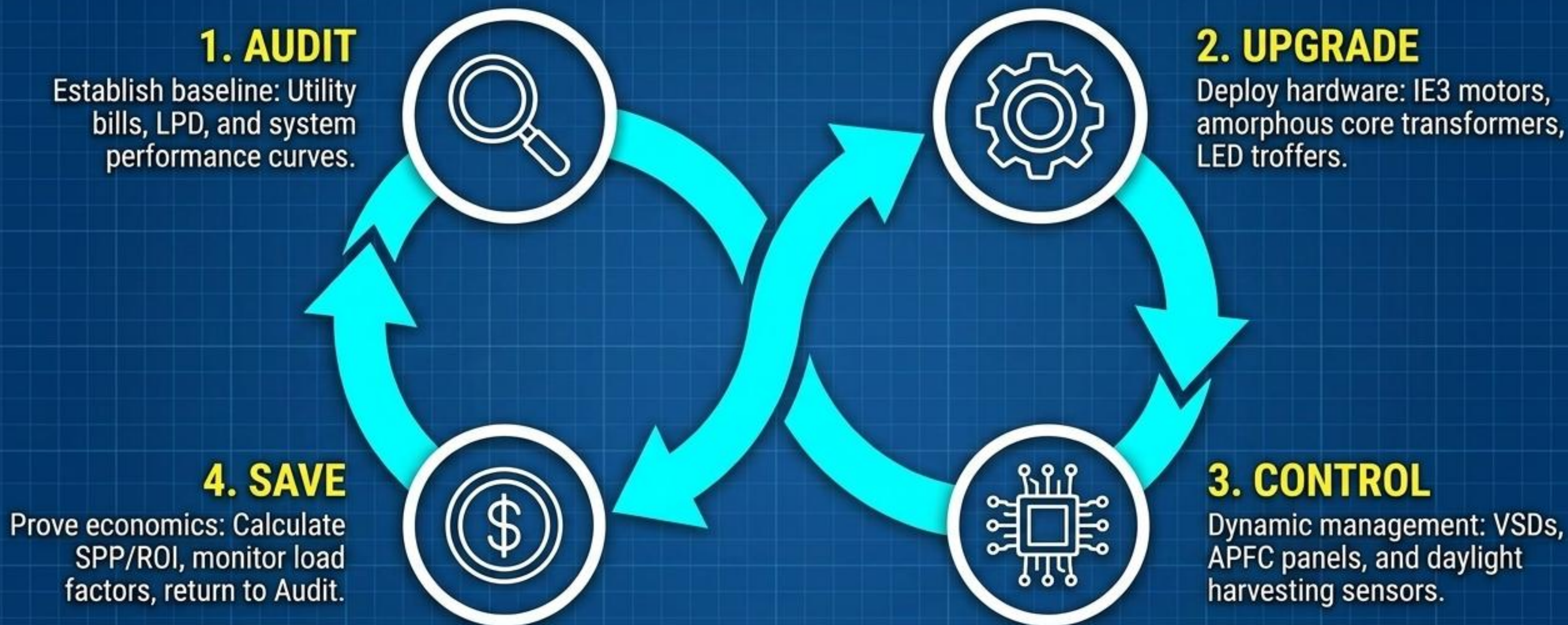
ρ → (kg/m³)

g → (9.81 m/s²)

Q → (m³/s)

H → (meters)

Module Synthesis: The Lifecycle Cost Cycle



Continuous Optimization: Energy management is never a one-time project. It is a permanent operational standard. By bridging technical engineering solutions with rigorous financial analysis, facilities transform energy from a fixed overhead cost into a controllable asset.