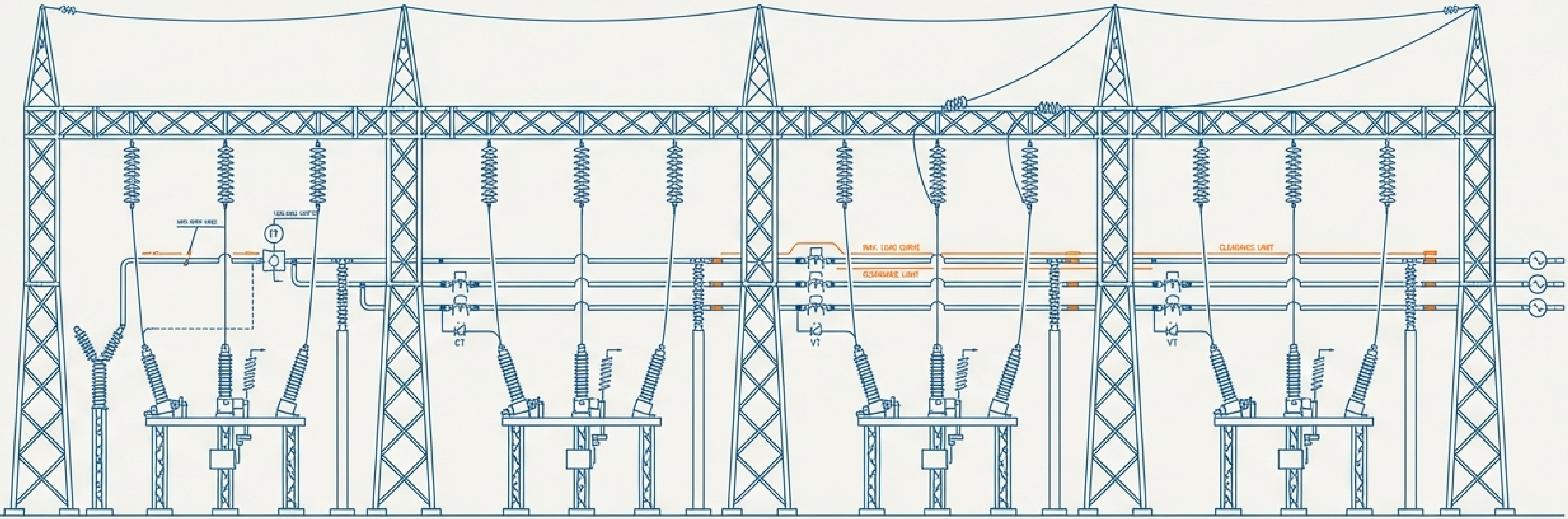
SUBSTATION DESIGN & ENGINEERING PRINCIPLES

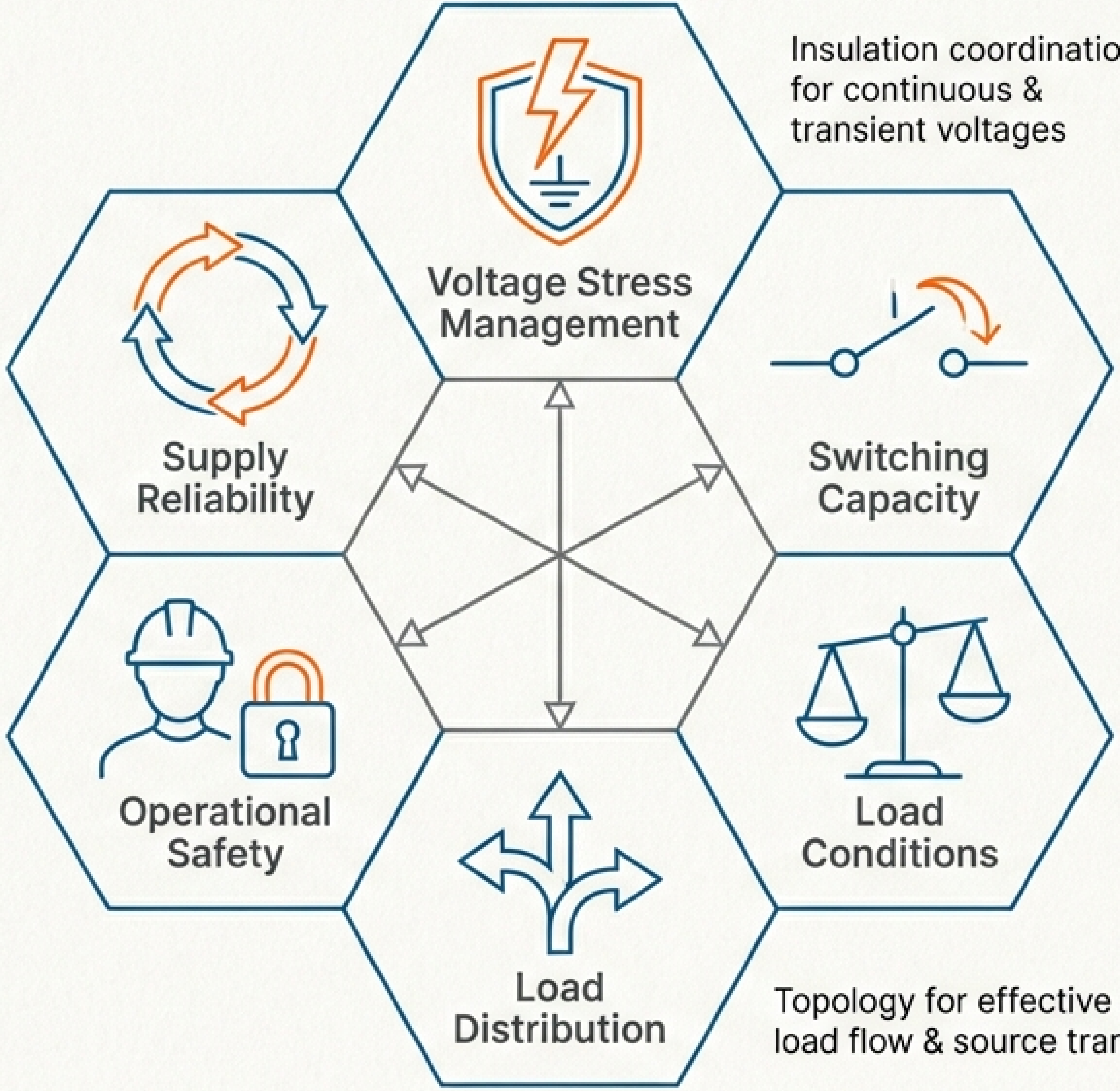
Feeder Connections, HV/MV Component Selection, and Critical Design Criteria

Designing a switchyard is not a simple assembly of parts. It is a simultaneous calculation of stress management, thermal endurance, and fault isolation to ensure grid stability.



Based on technical analysis by Hüseyin GÜZEL and Power System Engineering (Schlabbach & Rofalski)

THE SIX PILLARS OF DESIGN LOGIC



Insulation coordination for continuous & transient voltages

Redundancy, alternative paths, & rapid restoration

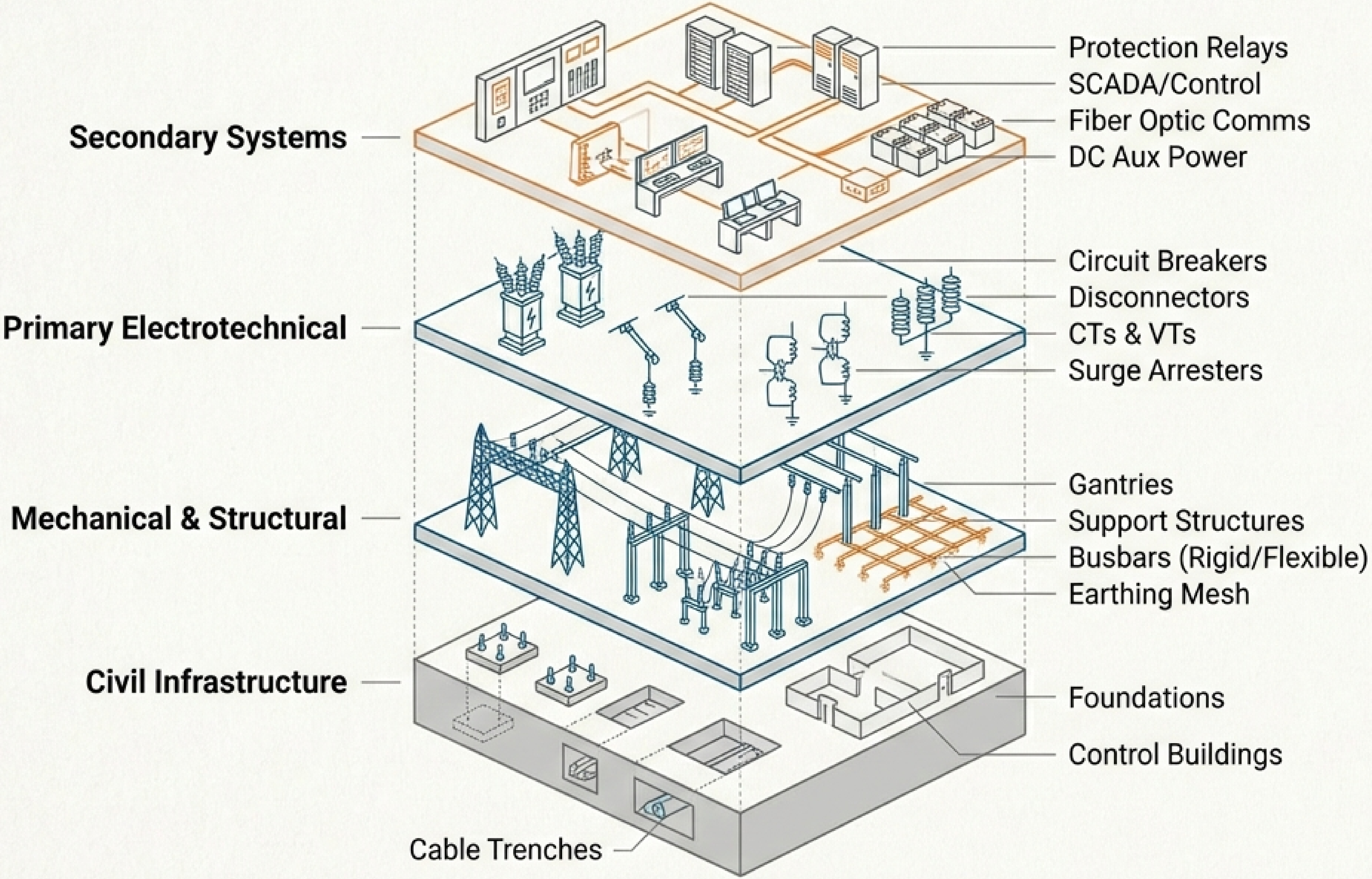
Safe breaking of fault currents & thermal withstand

Clearances, earthing, & mechanical interlocks

Handling normal continuous loads & emergency overloads

Topology for effective load flow & source transfer

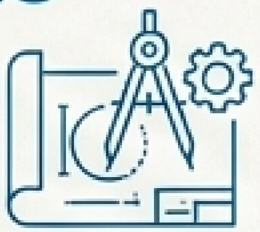
ANATOMY OF THE STATION: SYSTEM COMPOSITION



A substation is an assembly of four distinct ecosystems working in unison.

THE LANGUAGE OF COMPLIANCE: STANDARDS

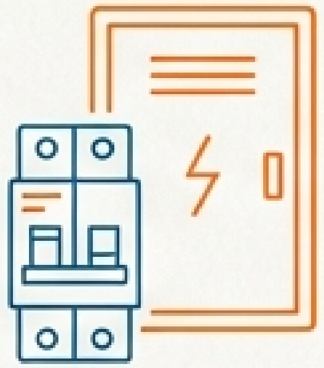
DOCUMENTATION & SYMBOLS



IEC 60617

Standardized symbols are mandatory. Detailed documentation is vital for maintenance and safety due to complex equipment interactions.

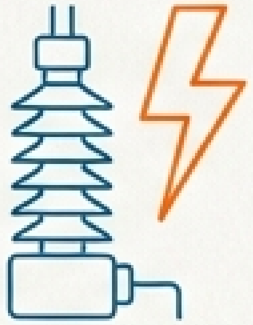
LOW VOLTAGE SPECS



IEC 60947 Series
IEC 60890

Governs switchgear and controlgear for low voltage applications.

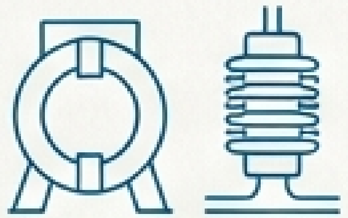
HIGH VOLTAGE SPECS



EN 50052
EN 50064

Design, performance, and testing requirements for gas-filled and other HV switchgear.

INSTRUMENT TRANSFORMERS



IEC 60044
IEC 61869 Series

Defines accuracy classes, transient behavior, and safety factors for CTs and VTs.

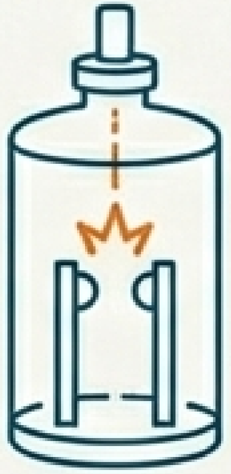
THE HIERARCHY OF SWITCHING DEVICES

Device Type	Load Breaking	Short-Circuit Breaking	Visual Isolation	Primary Function
Circuit Breaker (CB)	✓	✓	✗	Makes/Breaks all currents including faults.
Load Break Switch	✓	✗	✗	Breaks normal load. Cannot break faults.
Disconnector (Isolator)	✗	✗	✓	Safety isolation. Operates only under no-load.
Earthing Switch	✗	✗	N/A	Grounds equipment for personnel safety.
Fuse	✗	✓ - Once	N/A	Single-use protection. Melts under stress.

Safety Note: Critical Interlock: Disconnectors must be mechanically interlocked with the CB to prevent opening under load.

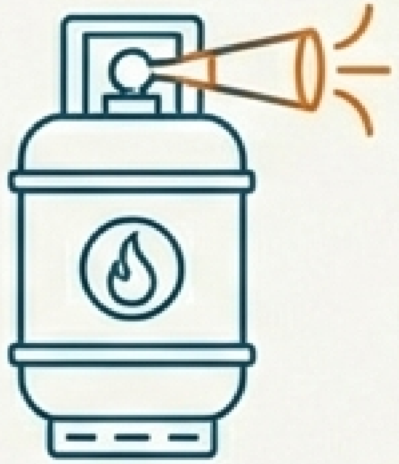
ARC EXTINCTION TECHNOLOGIES

MEDIUM VOLTAGE (MV)



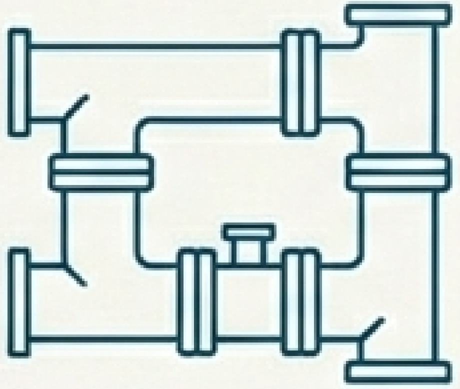
Vacuum Circuit Breakers (VCB). The predominant technology for MV applications.

HIGH VOLTAGE (HV/EHV)



Outdoor: SF6 (Sulfur Hexafluoride) or Air Blast (ACB). Designed for massive arc energy extinction.

GAS INSULATED SWITCHGEAR (GIS)



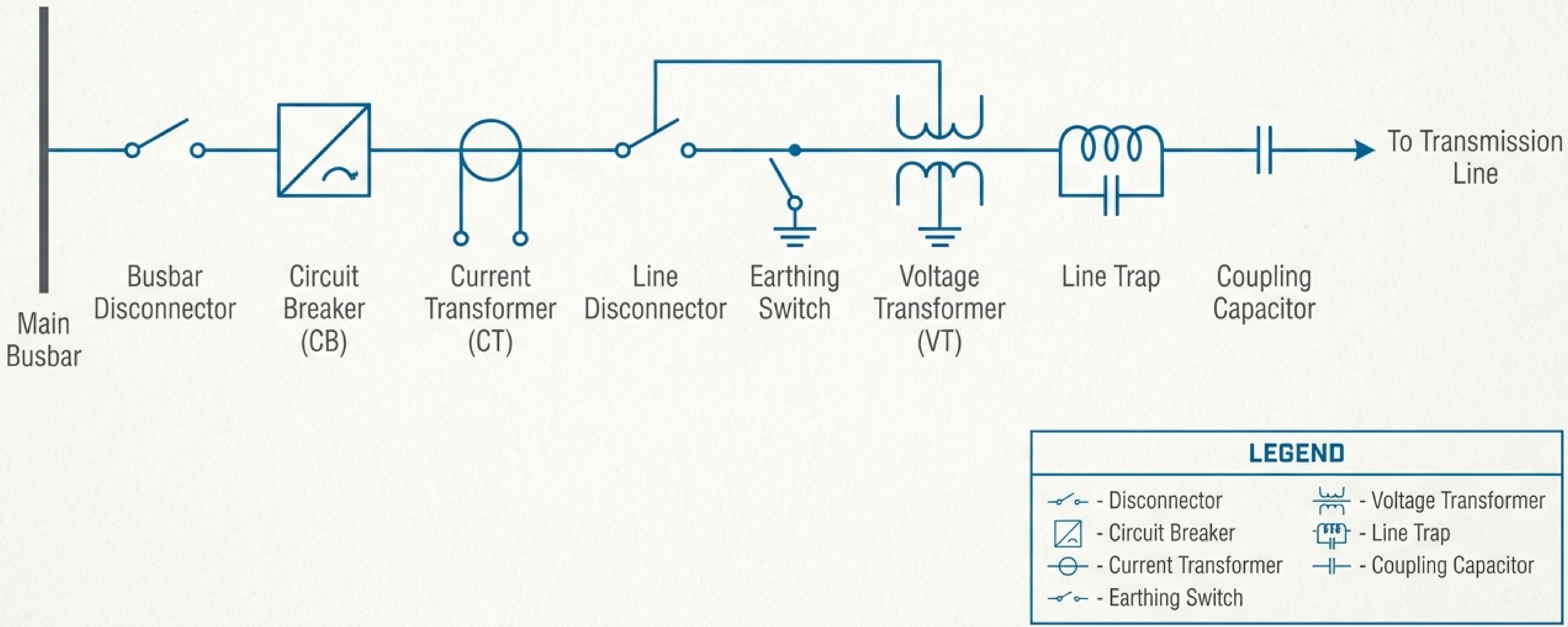
Compact Design. SF6 insulated and extinguished (SF6 CB).

RATING DEFINITIONS

Rated Short-time Withstand Current (Ith): RMS value for 1 second.

Rated Peak Withstand Current (Ipr): > 1.8 x sqrt(2) x Ith (Accounts for initial asymmetry).

STANDARD HV FEEDER TOPOLOGY



NotebookLM

CURRENT TRANSFORMERS (CT): THE GOLDEN RULES

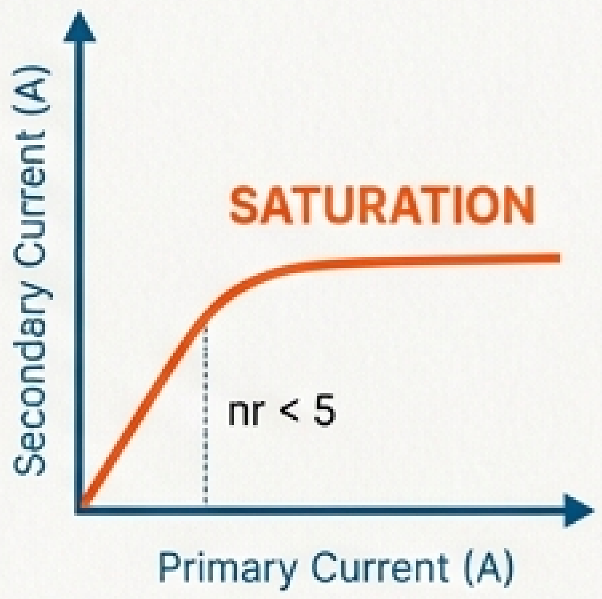
CRITICAL SAFETY RULE: NEVER open-circuit a CT secondary winding while under load. This causes **dangerous high voltage** and **catastrophic insulation failure**.

Defining the Objective

METERING CTs (Class 0.1, 0.2, 0.5)

Objective: Precision at normal load (100-120%).

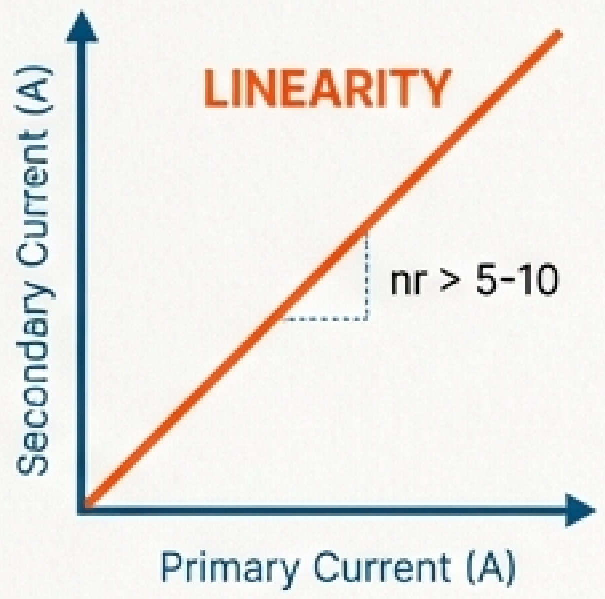
Safety Goal: Saturate EARLY (nr < 5) to protect connected instruments from massive fault currents.



PROTECTION CTs (Class 5P, 10P)

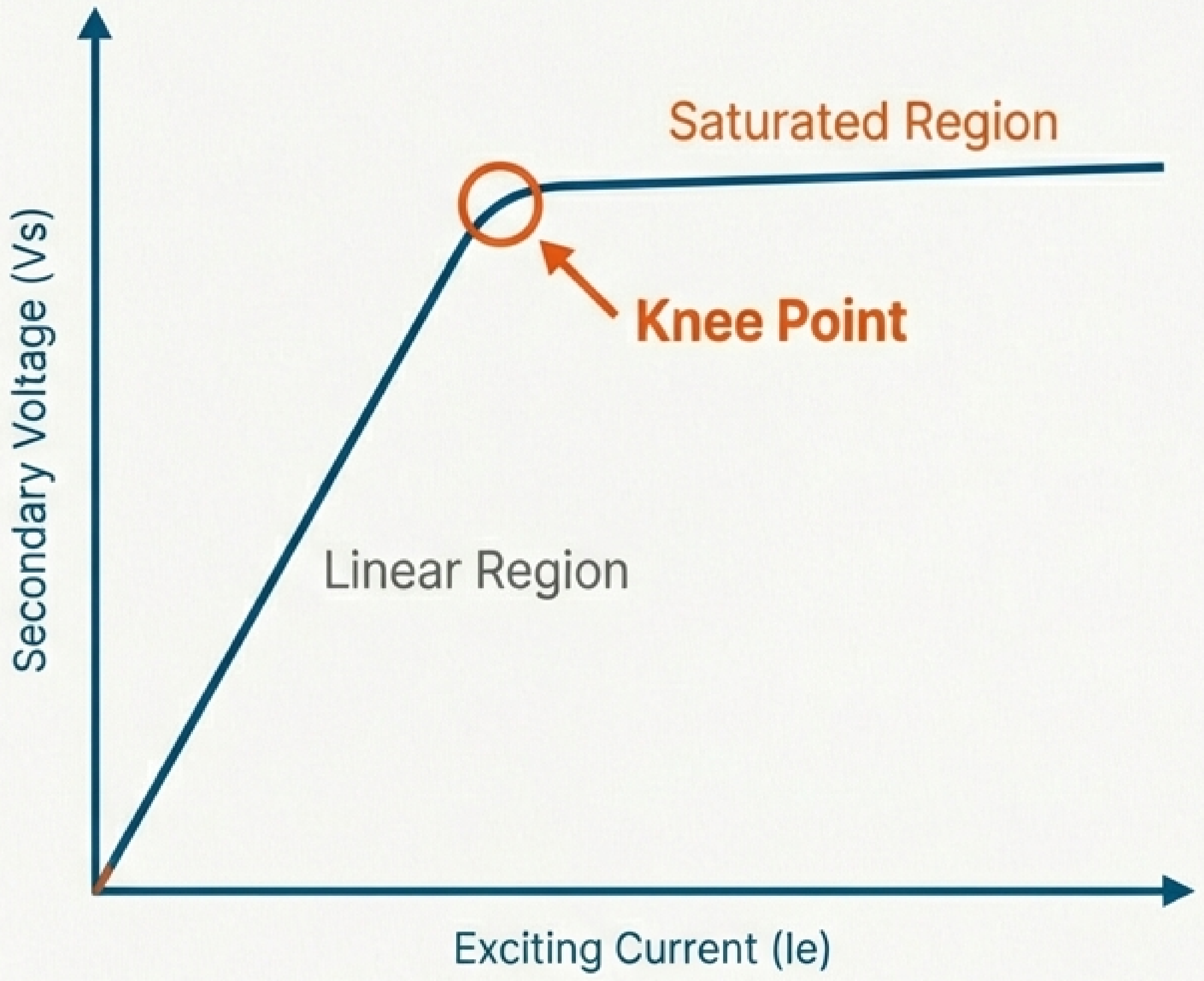
Objective: Linearity during chaos.

Safety Goal: Must NOT saturate during faults (nr > 5-10). Relays need to see the true magnitude of the fault to operate.



CT ENGINEERING: SATURATION & BURDEN

Excitation Curve



Calculating Limits

Accuracy Limit Factor (ALF) / Instrument Security Factor (ISF) determines when the CT stops being accurate.

The Burden Effect Formula

$$nr(SB) = nr * (Sr / SB)$$

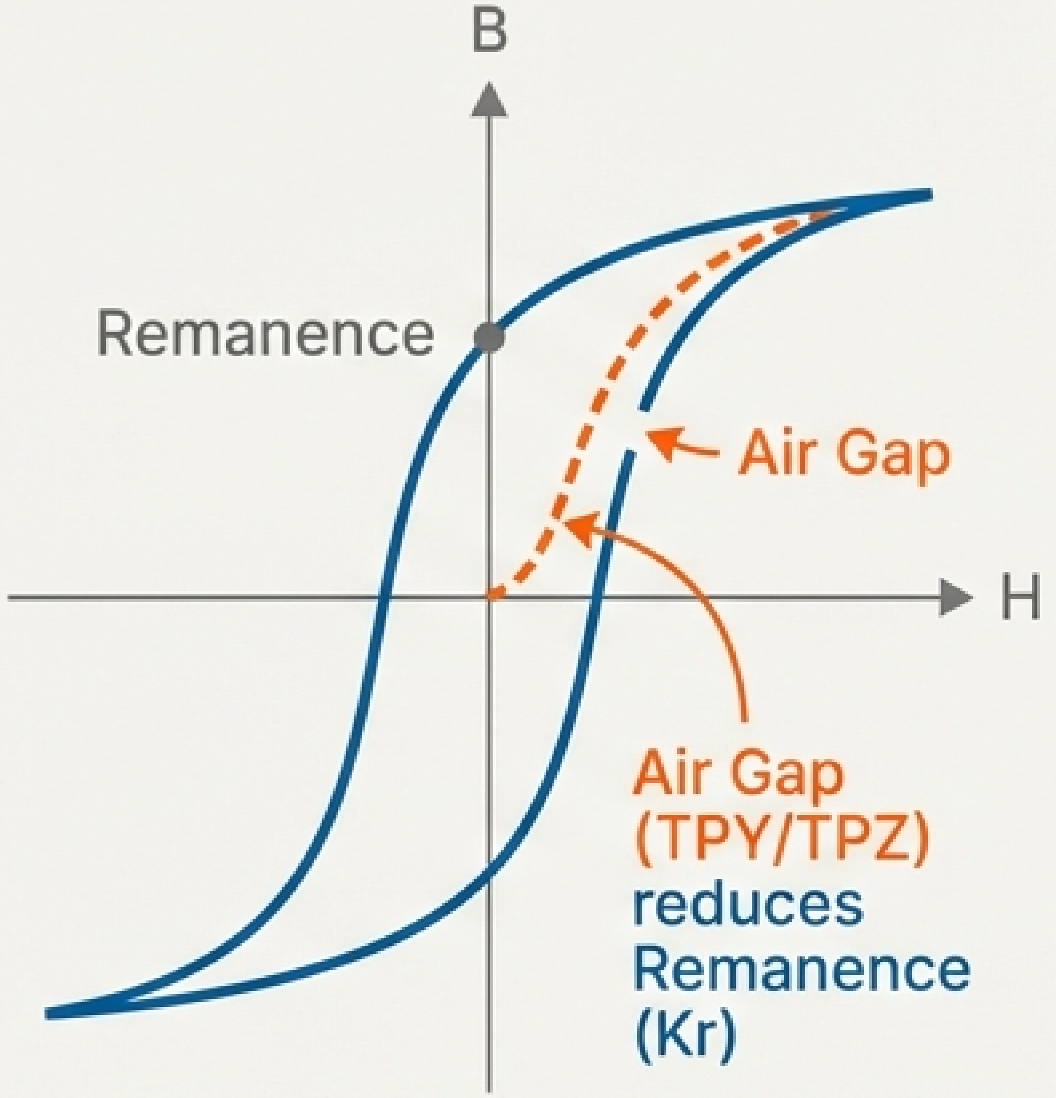
nr = Nominal Safety Factor
Sr = Nominal Burden (Rated)
SB = Actual Burden (Reduced)

Reducing the secondary burden (using lower impedance cables/devices) linearly **INCREASES the safety factor,** allowing the CT to handle higher fault currents without saturating.

TRANSIENT BEHAVIOR & REMANENCE (TP CLASSES)

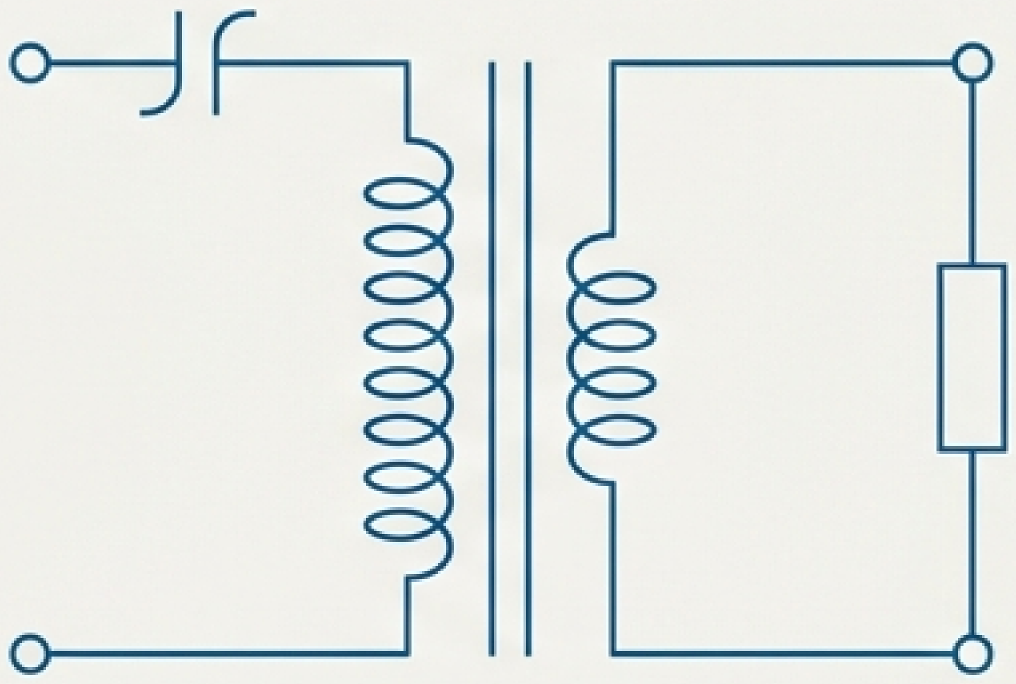
Managing magnetic memory during Auto-Reclosing cycles.

Class	Core Construction	Remanence Limit (Kr)	Application
Class P / TPS	Closed Iron Core	**No Limit (High Risk)**	Standard applications. Risk of saturation during reclosing.
Class TPX	Closed Core (No Air Gap)	No Limit	Specified cycles, but no remanence limit.
Class TPY	Small Air Gap	Limited (Kr <= 10%)	**IDEAL** for Auto-Reclosing (OTK). Gap helps demagnetize.
Class TPZ	Large Air Gap (Linear Core)	Negligible (Kr ~ 0)	DC offset tolerance required. Low remanence.



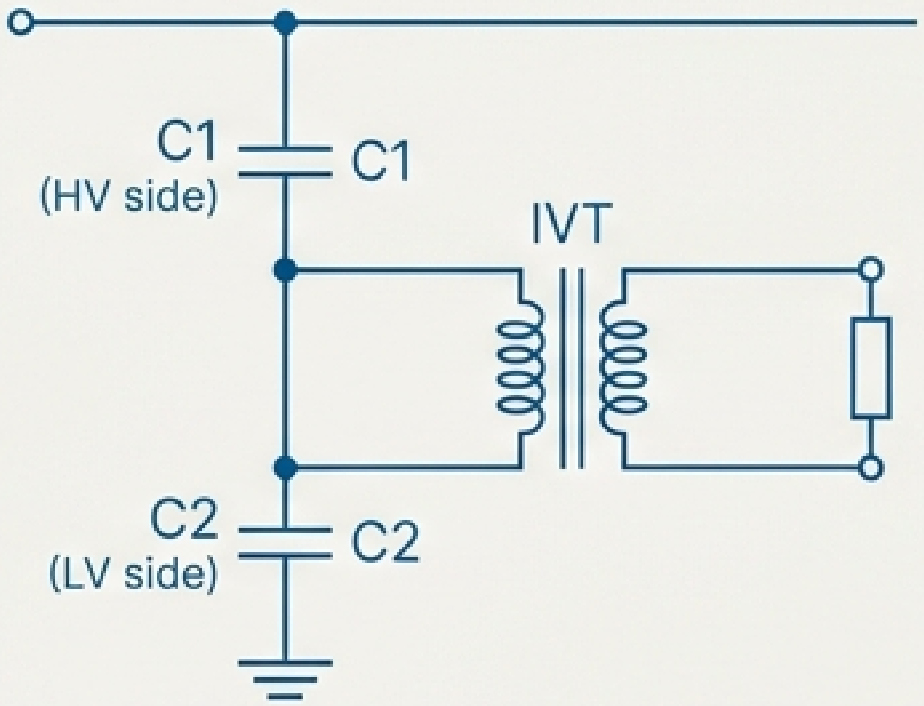
VOLTAGE TRANSFORMERS: MONITORING POTENTIAL

Inductive VT



Standard for 1kV – 765kV.

Capacitive VT (CVT)



Used at Un >= 60kV.

Dual Function: Acts as a Coupling Capacitor for Power Line Carrier (PLC) signals. Allows voice/data transmission over HV lines.

Accuracy Definition

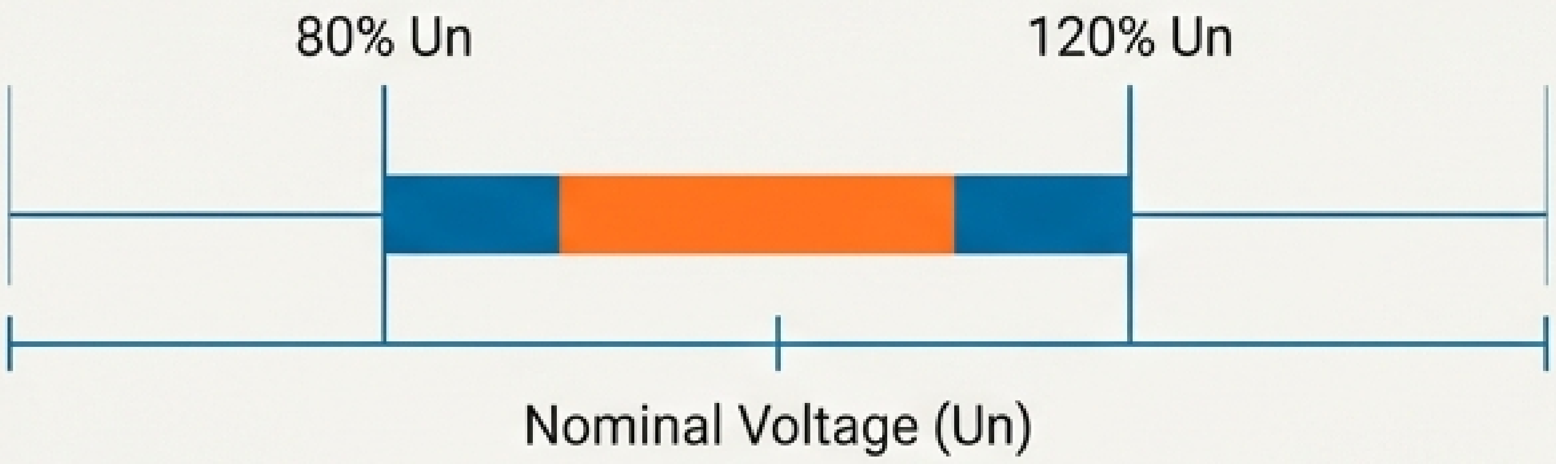
Performance = Magnitude Error (ε_u) + Phase Displacement (δ_u).

VT ACCURACY CLASSES

METERING (REVENUE)

Classes 0.1, 0.2, 0.5

Precision required for billing.

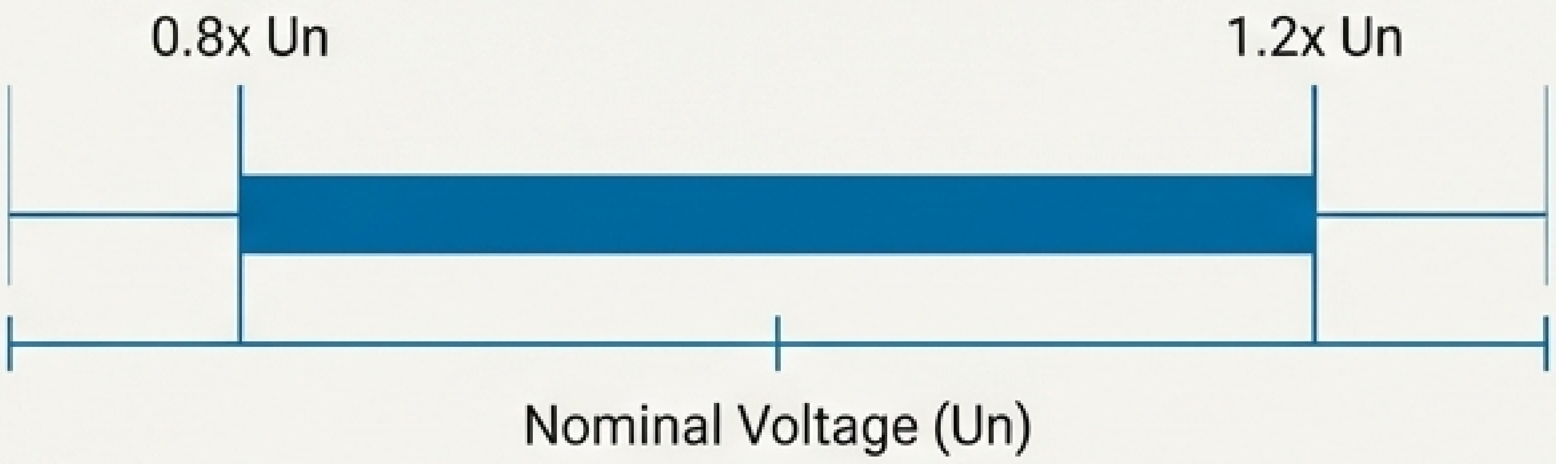


Accuracy valid between 80% – 120%
of Nominal Voltage (Un).

PROTECTION (RELIABILITY)

Classes 3P, 6P

Must maintain function during system collapse.



Must function from 0.8x Un (Voltage collapse)
up to 1.2x Un (Surge).

Phase Error Note:
3P = 120 min error limit.
6P = 240 min error limit.

VT OPERATIONAL CHALLENGES & RATINGS

Voltage Factor (Vf)

Determined by system grounding.

- **1.5 x Un (30s):** For effectively grounded systems (Earth fault factor <= 1.4).
- **1.9 x Un (30s/8h):** For isolated neutral systems. Must handle full line-to-line voltage on healthy phases during ground faults.

Ferroresonance

Risk in Inductive/Capacitive interactions. Requires **damping circuits** to prevent **thermal destruction**.

Transient Oscillation

CVT specific issue. Spurious **10Hz oscillations** (up to 10% amplitude) can occur during faults.

Impact: Can confuse **Distance Protection relays**, leading to **false tripping**.

CRITICAL ENGINEERING TAKEAWAYS

- **SAFETY FIRST:** Disconnectors must never break load. Mechanical interlocks with CBs are mandatory.
- **CT SIZING:** Protection CTs must have **nr > 10** to avoid saturation during maximum fault currents. Use **Class TPY** for Auto-Reclosing.
- **BURDEN MANAGEMENT:** Reducing secondary burden (SB) linearly improves the CT safety factor.
- **VT SELECTION:** Voltage factors (**1.5 vs 1.9**) must match the specific grounding scheme of the grid.
- **DOCUMENTATION:** Strict adherence to IEC 60617 symbols is essential for long-term maintenance and safety.

CONCLUSION

A substation is a balance of massive power flow and precise measurement. Its design dictates the reliability of the entire grid.”

REFERENCES & STANDARDS

Primary Author: Hüseyin GÜZEL

Reference Text: *Power System Engineering* by Jürgen Schlabbach & Karl-Heinz Rofalski

Key Standards List: IEC 60044, IEC 61869, IEC 60947, EN 50052