

HIGH VOLTAGE ENGINEERING

THEORY, SYSTEMS, AND PRACTICE

FILIFE AZEVEDO

AUTHOR

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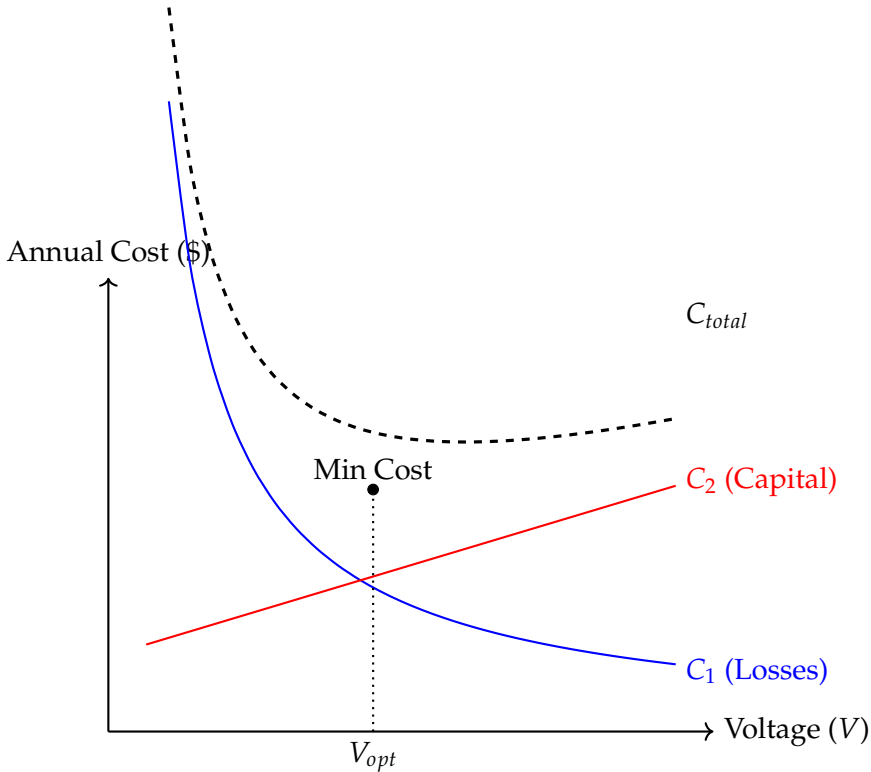


Figure 1.1: Kelvin's Law: The economic voltage is a trade-off between the cost of losses (decreasing with V) and the cost of insulation/structures (increasing with V).

1.3 Standardization of Voltage Levels (IEC 60038)

Interconnection between countries requires rigid standardization. The International Electrotechnical Commission (IEC) standard 60038 defines the voltage ranges. In Portugal, the following levels are standard:

- **Medium Voltage (MV):** 1 kV to 52 kV.
 - Common values: 10 kV, 15 kV, 30 kV.
 - Usage: Distribution networks (E-Redes) and industrial feeders.

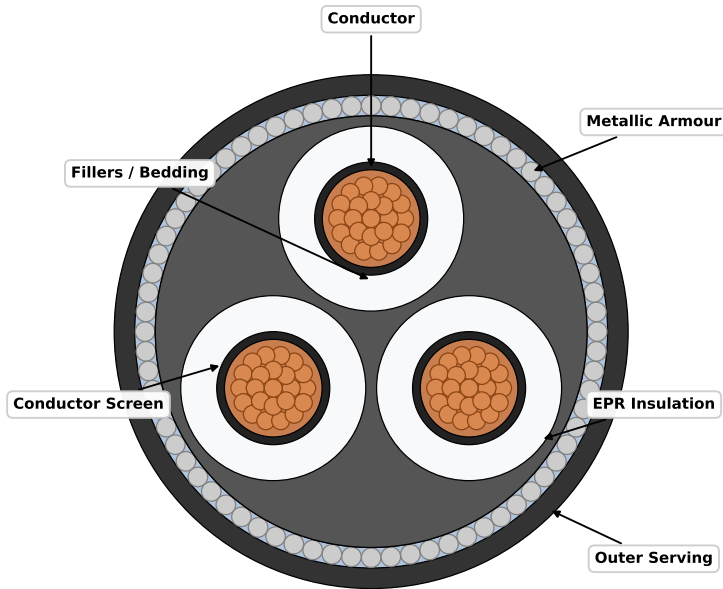


Figure 7.1: Typical internal construction of a three-core High Voltage (HV) cable cross-section, showing the main functional layers: conductor, conductor screen, EPR insulation, fillers/bedding, metallic armour, and outer serving. Source: Original work by the author.

7.1.1 1. The Conductor

For high currents ($> 1,000$ A), the Skin Effect and Proximity Effect significantly increase AC resistance. To mitigate this, large copper or aluminum conductors (typically cross-sections $\geq 1,000$ mm²) are not solid.

- **Milliken Construction:** The conductor is divided into 4, 5, or 6 segment shapes, each insulated from the others (using varnish or paper). This effectively reduces the skin effect factor (y_s) closer to unity.
- **Water Blocking:** The strands are filled with swelling powder/yarns to pre-

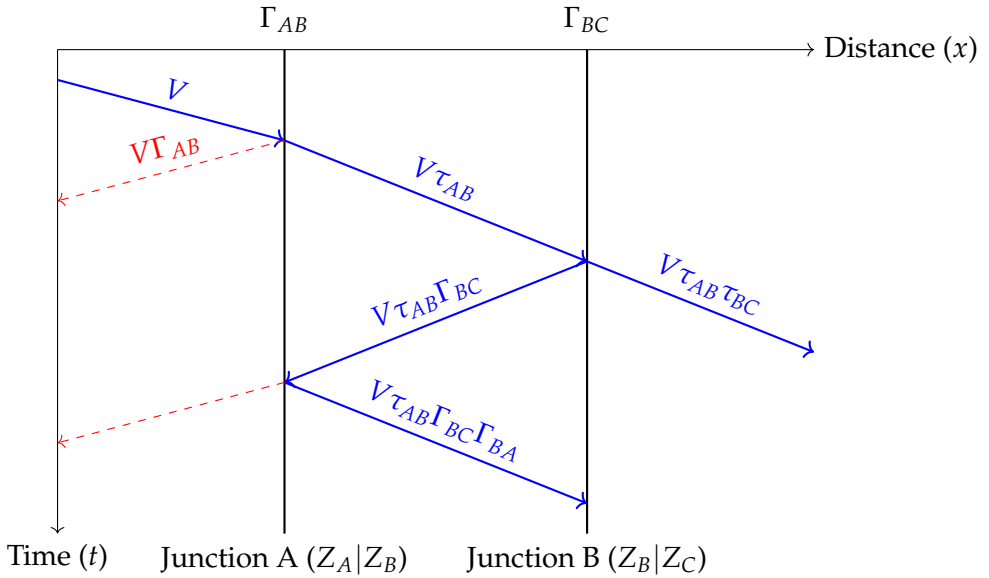


Figure 12.2: Bewley Lattice Diagram representing multiple reflections on a line segment bounded by Junctions A and B.

2. A transformer modeled as a capacitance $C = 2,000 \text{ pF}$. Calculate the maximum voltage at the line end for both cases.

Solution: *Case 1: Open Circuit* Ideally, $Z_2 = \infty$.

$$\Gamma = \frac{\infty - 400}{\infty + 400} = 1$$

$$V_{total} = V_{inc} + \Gamma V_{inc} = 1000 + 1000 = 2,000 \text{ kV}$$

This confirms that voltage **doubles** at an open end, which is the most dangerous scenario for substation insulation.

Case 2: Capacitive Termination The capacitor acts as a dynamic impedance $Z_C = 1/(sC)$ in the Laplace domain. The voltage at the

- **Front Time (T_1):** $1.2\mu\text{s} \pm 30\%$. Represents the steepness of the strike.
- **Tail Time (T_2):** $50\mu\text{s} \pm 20\%$. Represents the energy content.

The voltage $v(t)$ is mathematically described by the double-exponential function:

$$v(t) = V_0k(e^{-\alpha t} - e^{-\beta t}) \quad (16.1)$$

Where $\alpha \approx 14,600\text{ s}^{-1}$ controls the tail, and $\beta \approx 2,460,000\text{ s}^{-1}$ controls the front.

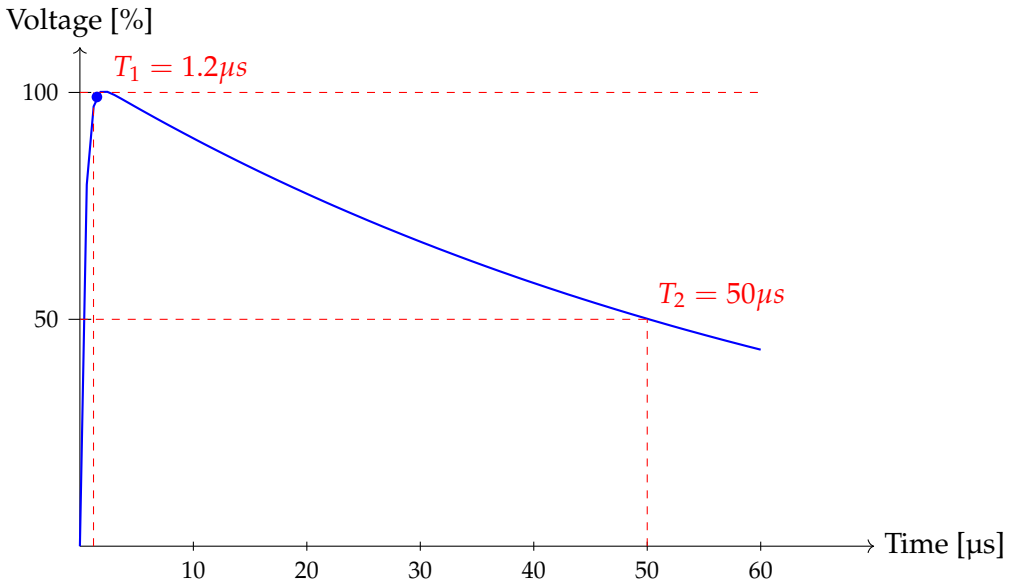


Figure 16.1: Standard Lightning Impulse waveform 1.2/50μs.

16.1.2 Switching Impulse Voltage (SI)

For EHV systems ($> 300\text{ kV}$), switching surges often dictate the insulation clearance. The standard wave is 250/2500μs. Because the wavefront is slower, the electric field distribution is more uniform than in LI, but the longer duration allows space charge to develop in large air gaps, leading to the **U-Curve**

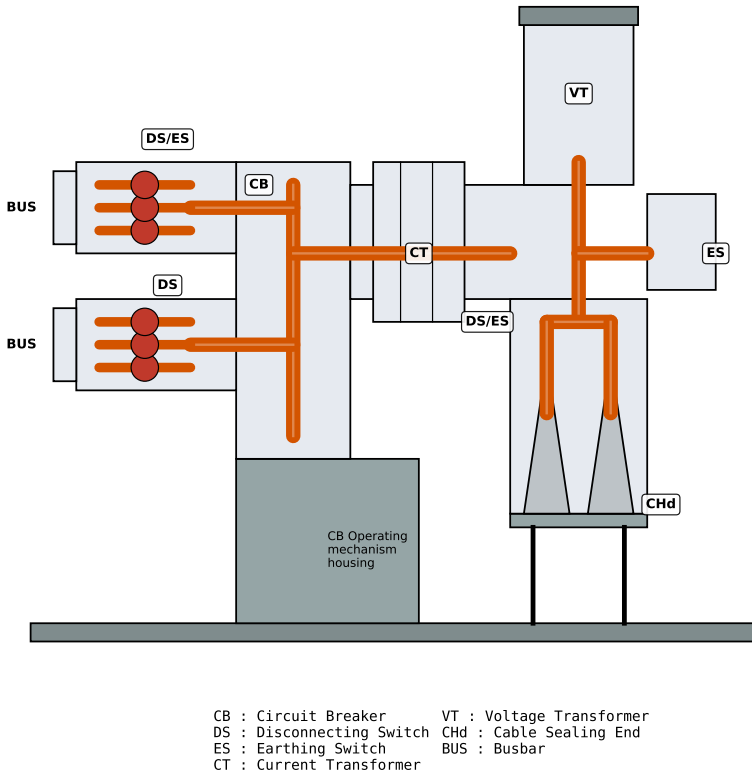


Figure 19.1: Schematic cross-section of a typical Gas Insulated Substation (GIS) bay, showing the internal arrangement of the circuit breaker (CB), disconnectors (DS), earthing switches (ES), instrument transformers (CT/VT), and cable sealing ends (CHd). Source: Original work by the author.

19.2 Topology and Reliability Analysis

Given the strategic importance of this node, a **Double Busbar (DBB)** topology with a transverse Bus Coupler was selected for both voltage levels.

HIGH VOLTAGE ENGINEERING

THEORY, SYSTEMS, AND PRACTICE

FILIPE AZEVEDO

About the book

High Voltage Engineering: Theory, Systems, and Practice is a comprehensive guide to the principles and technologies that make modern power transmission possible. It brings together the physical foundations of high-voltage phenomena and the engineering methods used to design, test, protect, and maintain real power systems. The result is a book that speaks equally to theory and practice, offering a rigorous treatment of a field where electromagnetic fields, dielectric materials, environmental stress, mechanical forces, and operational safety must all be understood together.

The book begins with the fundamentals of electric fields, dielectrics, breakdown mechanisms, and atmospheric effects, then develops the core technologies of high-voltage engineering: overhead lines, insulators, cables, transformers, switchgear, grounding systems, protection relays, overvoltage phenomena, surge arresters, and insulation coordination. Throughout, the emphasis is on clear physical interpretation, analytical rigor, and practical engineering relevance. A distinctive feature of the work is its strong connection to actual transmission and substation practice. The discussion is grounded in the structure of the Portuguese power system and aligned with IEC and IEEE standards, giving the book both local applicability and international relevance. Worked examples, solved problems, and design-oriented discussions help the reader move from concepts to engineering decisions with confidence. The final chapters address testing, diagnostics, reliability, asset management, safety, and an integrated substation design case study, completing a broad view of the discipline from first principles to field application. Written for senior students, researchers, and practicing engineers, this book is intended to be both a teaching text and a lasting professional reference.

About the author

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