# Sizing of d.c. traction circuit

Goals and constraints

Calculation of voltage drops

Thermal calculation

Selectivity of the protections

Electrical standards

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# Goals

- **Number and Positioning of TPSSs;**
- **Number and Size of Transformer Rectifier Groups;**
- **Wire Section of traction line;**
- **Number and pk of parallel points.**

# Design constraints and verifications

**Design constraints**

1. **Maximum voltage drops,**
2. **Maximum current density**
3. **Transformer overload limit.**

**Other Verifications**

- **Selectivity of protections**
- constraints 1), 2) and 3) also in case of out of order of a single TPSS.

# Design Constraints: Voltage Drop Limits

- IEC 850: measured voltage on pantograph

| Type of traction | $V_{min}$ | $V_n$ | $V_{max}$ |
|---|---|---|---|
| D.C. | 500 | 750 | 900 |
| D.C. | 1000 | 1500 | 1800 |
| **D.C.** | **2000** | **3000** | **3600** |
| A.C. 16 2/3 HZ | 12000 | 15000 | 17250 |
| A.C. 50 HZ | 19000 | 25000 | 27500 |

Total Voltage Drop: Grid + TPSS + contact line + return circuit line

# Design Contraints: Current Density

- **Current Density: $J < 4\ A/mm^2$**
- Electrical limit for copper wire: **T max = 85° C**

**T max = 45° C** (environmental conditions) + **40° C** (maximum increase of temperature because of electric load)

# Design Contraints: TPSS Power

**Transformer Overload**:

- **Overload for 2 hours**
- **Overload for 5 minutes**

# Other verifications: selectivity of protections

$\mathbf{I_{SC}^{\ MIN} > I_{LOAD}^{\ MAX}}$

- $I_{SC}^{\ MIN}$ minimum short circuit current
- $I_{LOAD}^{\ MAX}$ maximum load current

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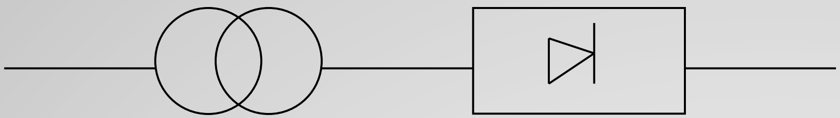
# Calculation of TPSS Voltage Drops



**Open-Circuit**: $V_u$ = 3.400 V

**On load**: total voltage drops = transformer voltage drops (>) + rectifier voltage drops (<)

- Silicon rectifiers 3.600 kW:

  $V_{sc}^{trasf}$ = 0.07 pu → Voltage drop $_{tot}$ < 8%

# Calculation of voltage drops on contact line – simplified hypotheses

- Constant voltage at the exit of the TPSS
- Absorbed current from train: costant and indipendent from the voltage value

Contact line resistance

$$R_l = \frac{18{,}8}{s} \times l(Ohm)$$

18,8 Ω mm² / km (copper resistivity)

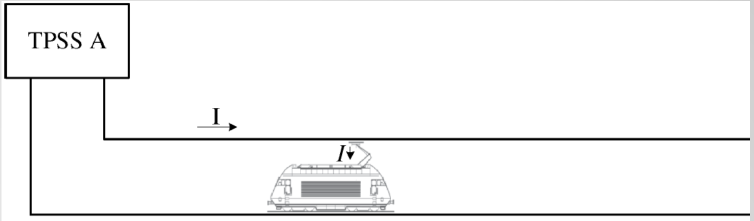
Rail resistance

$$R_b = \frac{1}{2p} \times L(Ohm)$$

p = mass per linear meter of rail

# Calculation of voltage drops on contact line – case study

- UNILATERAL POWER SUPPLY
  - 1 TRAIN
  - 2 TRAINS
  - Uniformly Distributed Load

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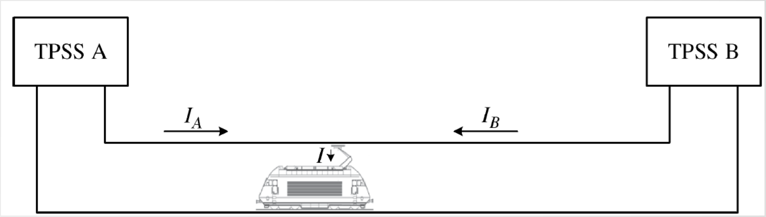
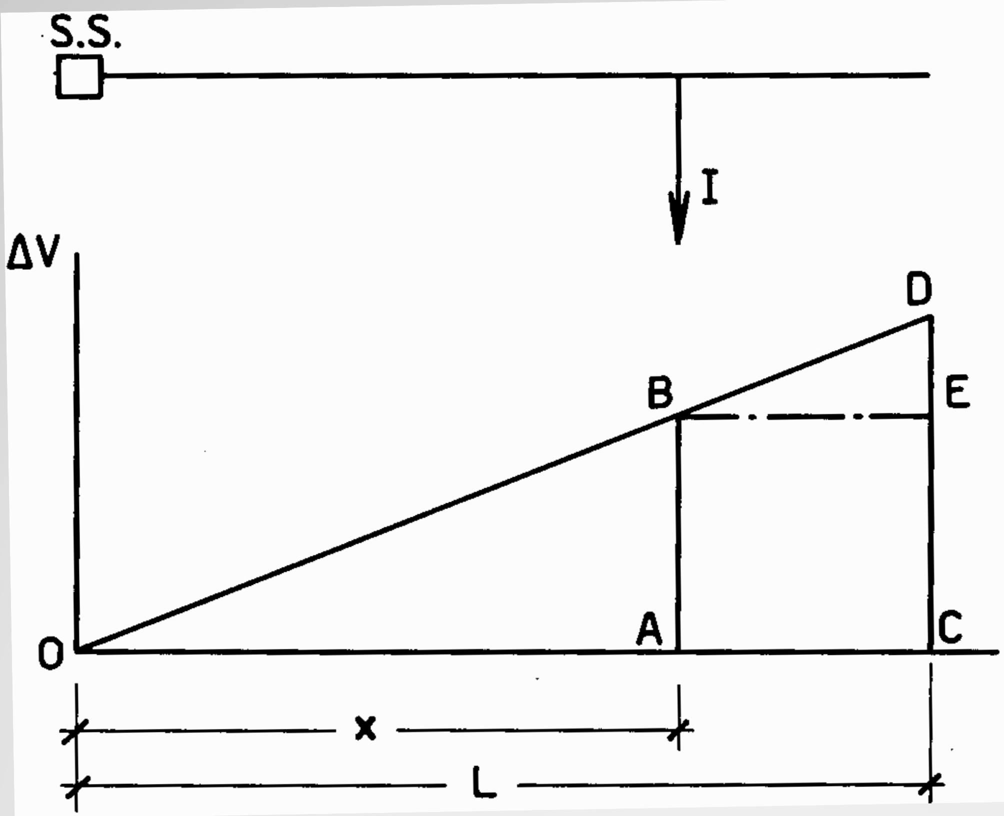


# Calculation of voltage drops on contact line : unilateral power supply

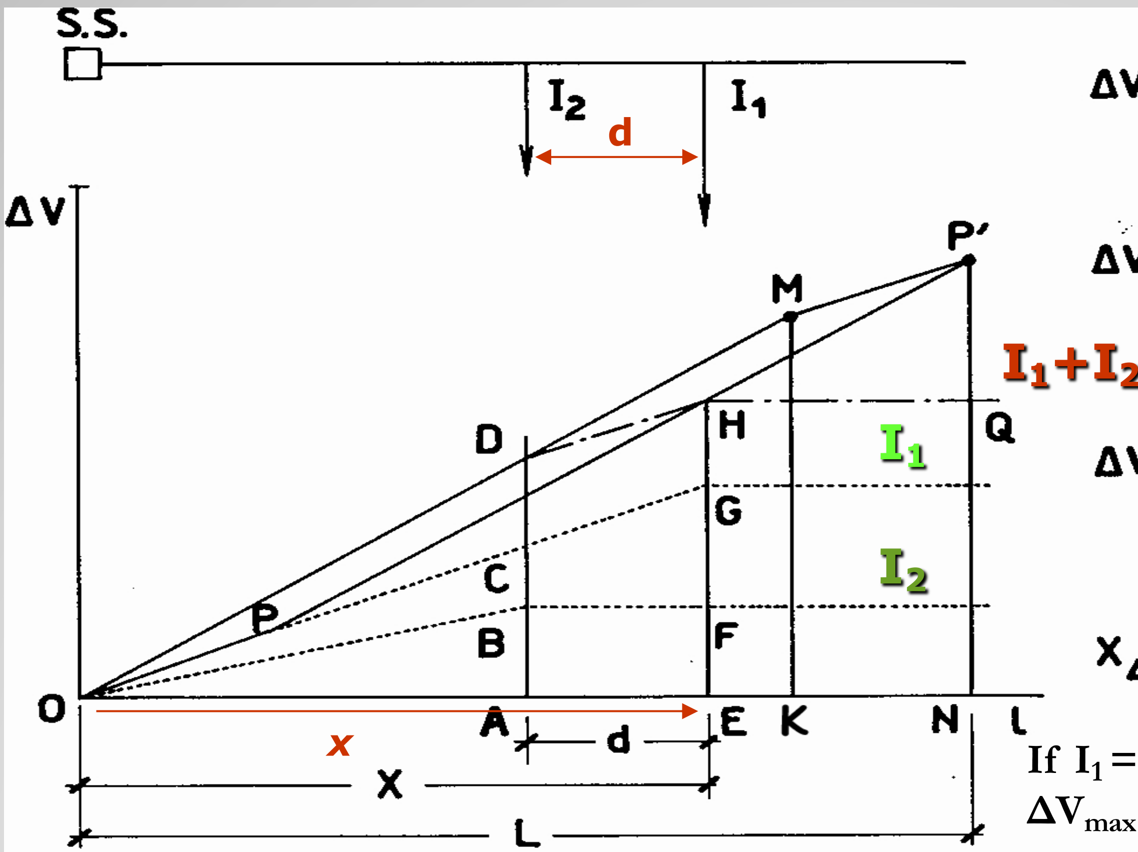



$\Delta V_x = \overline{AB} = r x I$

$\Delta V_{max} = \overline{CD} = r L I$

$X_{\Delta v max} = L$

# Calculation of voltage drops on contact line : unilateral power supply




$$\Delta V_x = EH = \overline{EF} - \overline{EG} =$$

$$= r(x-d)I_2 + r\,x\,I_1$$

$$\Delta V|_{x-d} = \overline{AD} = \overline{AB} + \overline{AC} =$$

$$= r(x-d)(I_2 + I_1)$$

$$\Delta V_{max} = \overline{NP'} =$$

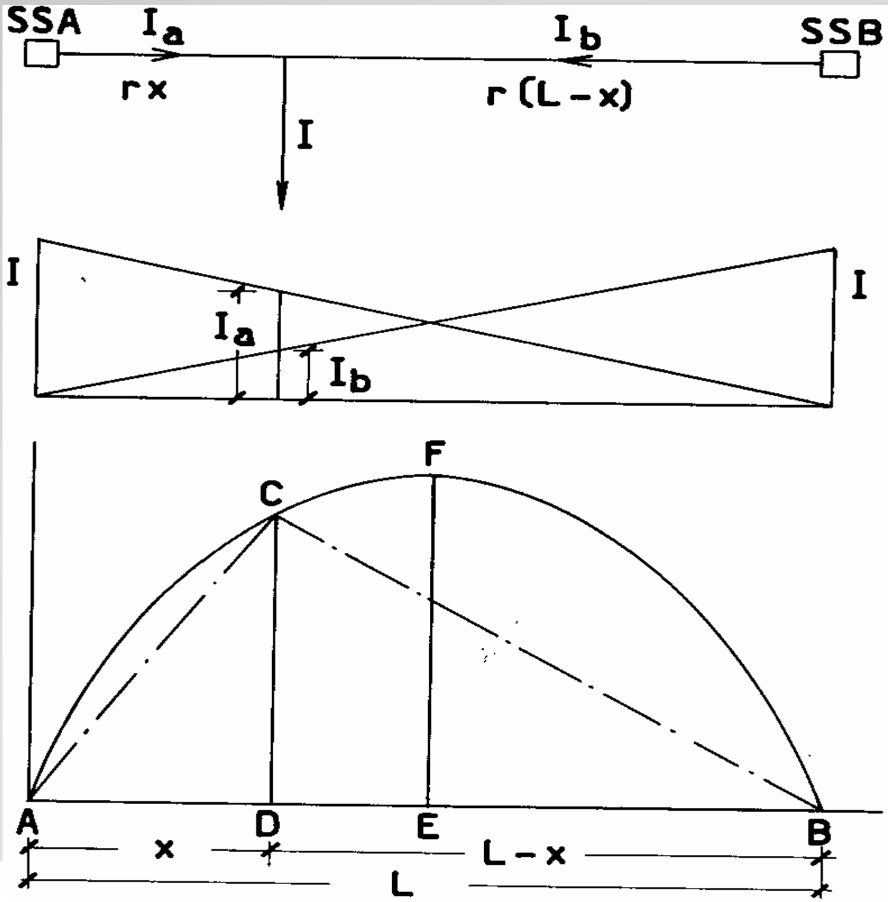
$$= r(L-d)\,I_2 + r\,L\,I_1$$

$$X_{\Delta v max} = L$$

If $I_1 = I_2$

$$\Delta V_{max} = rLI + rI(L\text{-}d) = rI(2L\text{-}d)$$

# Calculation of voltage drops on contact line : bilateral power supply




$$I_a + I_b = I$$

$$r x I_a = r(L-x) I_b$$

$$I_a = \frac{L-x}{L} I$$

$$I_b = \frac{x}{L} I$$

$$\Delta V_x = \overline{CD} = r x I_a = r(L-x) I_b =$$

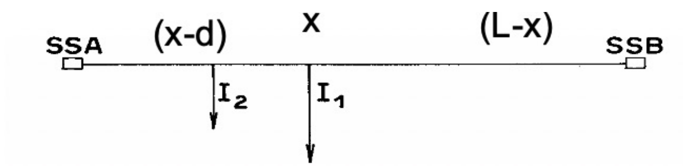
$$= r \frac{x(L-x)}{L} I$$

$$\Delta V_{max} = \overline{EF} = \frac{r L I}{4}$$

$$X_{\Delta v max} = \frac{1}{2} L$$

Maximum voltage drop of 25% of bilateral power supply

# Calculation of voltage drops on contact line : bilateral power supply




$I_1 = I_{1a} + I_{1b}$ ; $\quad r x\, I_{1a} = r(L-x)\, I_{1b}$

$I_{1a} = [(L-x) / L]\, I_1 \quad \rightarrow I_{1a} = I_1$ se $x = 0$

$= 0$ se $x = L$

$I_{1b} = (x / L)\, I_1 \quad \rightarrow I_{1b} = I_1$ se $x = L$

$= 0$ se $x = 0$

$\Delta V_x = r\, x\, I_{1a} = r\, x\, (L-x) / L]\, I_1$

$\Delta V_{x-d} = r(x-d)\, I_{1a} = r\,(x-d)\, [(L-x)/L]\, I_1$

$I_2 = I_{2a} + I_{2b}$ ; $\quad r(x-d)\, I_{2a} = r(L-x+d)\, I_{2b}$

$I_{2a} = [(L-x+d) / L]\, I_2$

$I_{2b} = (x-d) / L\, I_2$

$\Delta V_{x-d} = r(x-d)\, I_{2a} = r\,(x-d)\, (L-x+d)/L]\, I_2$

$\Delta V_x = r(L-x)\, I_{2b} = r\,(L-x)\, [(x-d)] /L]\, I_2$

$$\Delta V_x = r\, x\, (L-x) / L]\, I_1 + r\,(L-x)\, [(x-d)] /L]\, I_2 = \frac{r\,(L-x)}{L}\,[x\, I_1 + (x-d) I_2]$$

$$\Delta V_{x-d} = r\,(x-d)\, [(L-x)/L]\, I_1 + r\,(x-d)\, (L-x+d)/L]\, I_2 = \frac{r\,(x-d)}{L}\,[(L-x) I_1 + (L-x+d)\, I_2]$$

# Calculation of voltage drops : parameters

- **Voltage level**: 3 kV o 1.5 kV (in Italy)
- **Wire section**: equivalent section= (contact line number* contact line section*0,7) + (messenger wire number * messenger wire section) + (reinforcement feeder number * reinforcement feeder section)
- **Distance between TPSSs**

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# Thermal Calculation - limits

**Current density: $J < 4\ A/mm^2$**

$\Downarrow$

**For copper wire: $T_{max} = 85^\circ\ C$**

# Thermal Calculation - limits

- **Time constant of about 10′ with a density current of 4 A/mm$^2$ , increase of temperature of 40° C in 30 ‘**
- **Time constant of about 7′ with interruption of current, temperature lowering of 40° C in 20 ‘**

# Sizing of d.c. traction circuit

# Selectivity of the protections

The following condition needs to be verified on each feeder:

$$\mathbf{I_{SC}^{\ MIN} > I_{LOAD}^{\ MAX}}$$

$$\mathbf{I_{SC}^{\ MIN} = Vdo_{min} / R_{PTSS} + (r * L) + R_g}$$

$Vdo_{min}$ open-circuit minimum voltage;

r kilometric resistance of the line at maximum temperture;

L distance between PTSSs;

$R_{sse}$ maximum internal resistance of TPSSs;

$R_g$ fault resistance;

# Selectivity of the protections

**Other protections:** **relays conditioned to the gradient, Minimum Voltage relays or Maximum Nondirectional Line Current relays, pilot wire**

If distance between PTSSs is 40 km:

R = 40 x 0.08 Ω/km = 3,2 Ω/km ⇒ I = V/R = 3400/3,2 ≈ 1000 A ≈ operating current

$$\frac{\Delta V'}{V} = \frac{r'L'I'_{max}}{4V} = 0{,}2 \qquad I'_{sc} = \frac{V}{r'L'}$$

$$\frac{\Delta V''}{V} = \frac{r''L''I''}{4V} = 0{,}1 \qquad I''_{sc} = \frac{V}{r''L''}$$

$$\frac{I'_{max}}{I'_{sc}} = 0{,}8 \qquad \frac{I''_{max}}{I''_{sc}} = 0{,}4$$

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# RFI Electrical standard– contact line

**Traction Circuit**

**Catenary of 540mm$^2$ per direction**

- 2 Messenger wires of 120 mm$^2$
- 2 Contact lines of 150 mm$^2$

- **Reinforcement feeder (1 conductor or 2): 100 mm$^2$**
  **150 mm$^2$**

# RFI Electrical standard– TPSS

**5.4 MVA Group:**

- Nominal Power 5,4 MVA
- Open-circuit Voltage 3,6 kV
- Internal resistance 0,13 Ω
- Overload 100% for 2h -  133% for 5 min

# RFI Electrical standard

- **Standard**:

- L = 16 km
- S = 540 $mm^2$ (2x150 $mm^2$ + 2 x 120 $mm^2$)
- $P_{TPSS}$ = 2 x 5.400 kW (overload: 100 % for 2h – 133 % for 5' )