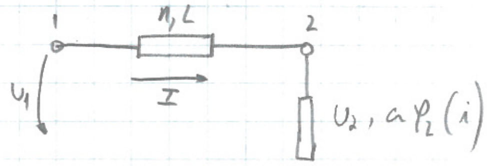
REE (2ª PARTE)

Diagrama Vectorial de Tensões e correntes de uma linha:

B.T. → o único parâmetro que intervém é a resistência

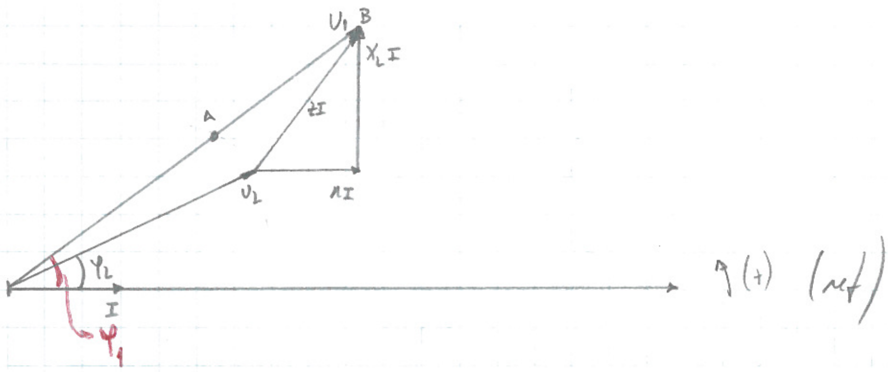
A.T. →
- até 30KV → Intervêm r e L
- até 60KV → " r, L e C
- >60KV → " r, l, g e C

4.1. Expressões do cálculo da queda de Tensão em linhas monoalimentadas.



$$\bar{U}_1 = \bar{U}_2 + (r + jX_L)\cdot\bar{I} = \bar{U}_2 + Z\bar{I} \Rightarrow \bar{U}_1 - \bar{U}_2 = \underbrace{Z\bar{I}}_{\Delta\bar{U}_s}$$

↳ Vector queda de Tensão



$$\Delta\bar{U}_a = |\bar{U}_1| - |\bar{U}_2| \rightarrow \text{Valor exacto}$$

$$Z\bar{I} = \Delta\bar{U}_s \simeq \overline{AB} = |\bar{U}_1| - |\bar{U}_2| = \Delta\bar{U}_a$$

Normalmente a q.d.t é expressa em % da tensão à chegada, da tensão à partida ou ainda da Tensão nominal da linha.

$$m\% = \frac{|\bar{U}_1| - |\bar{U}_2|}{|\bar{U}_1|} \times 100\% \rightarrow \text{Valor da q.d.t em \% da Tensão à partida}$$

$$m\% = \frac{|\bar{U}_1| - |\bar{U}_2|}{|\bar{U}_2|} \times 100\% \rightarrow \text{" " " " " " à chegada}$$

$$\bar{U}_1 = \bar{U}_2 + (r + jX_L)\,\bar{I}$$

$$U_1 \angle \varphi_1 = U_2 \angle \varphi_2 + rI \angle 0^\circ + X_L I \angle 90^\circ$$

$$U_1 \cos\varphi_1 = U_2 \cos\varphi_2 + rI\cos 0^\circ + \overbrace{X_L I \cos 90^\circ}^{0} \longrightarrow \text{Parte real}$$

$$U_1 \sin\varphi_1 = U_2 \sin\varphi_2 + \underbrace{rI\sin 0^\circ}_{0} + X_L I \sin 90^\circ \longrightarrow \text{" Imag.}$$

$$U_1 = \sqrt{(U_2\cos\varphi_2 + rI)^2 + (U_2\sin\varphi_2 + X_L I)^2}$$

$$(U_1\cos\varphi_1)^2 + (U_1\sin\varphi_1)^2 = (U_2\cos\varphi_2 + rI)^2 + (U_2\sin\varphi_2 + X_L I)^2$$

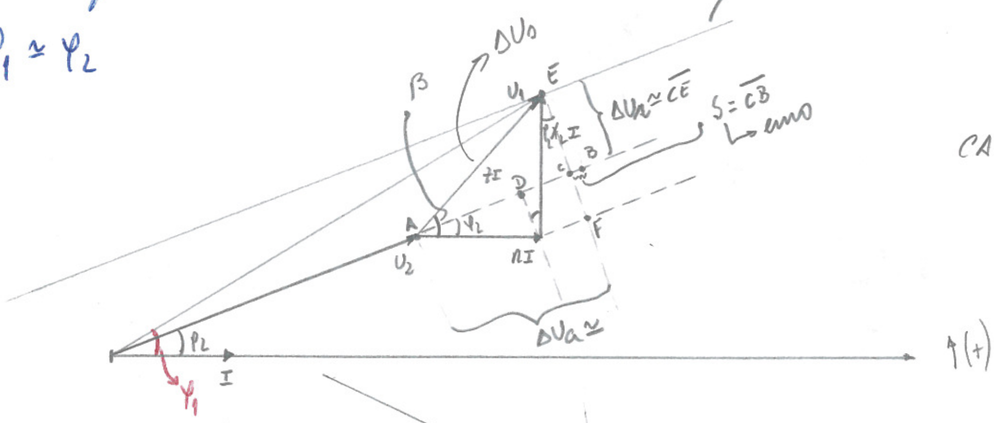
$$\bar{S}_1 = 3\,\bar{U}_1 \cdot \bar{I}_1^{*} =$$

$$=$$

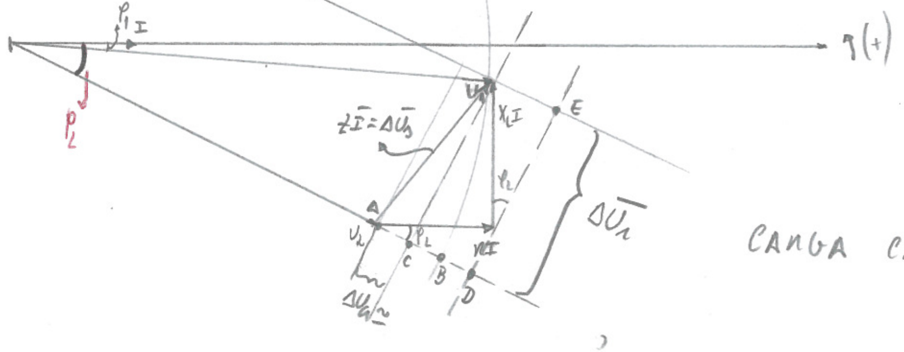
$$\varphi_1 = \text{arc tg}\,\frac{U_2\sin\varphi_2 + X_L I}{U_2\cos\varphi_2 + rI} \quad \text{ou} \quad \text{tg}\,\varphi_1 = \frac{U_1\sin\varphi_1}{U_2\cos\varphi_1}$$

Cálculo aproximado:

$\varphi_1 \simeq \varphi_2$



CARGA INDUTIVA



CARGA CAPACITIVA

FOLHA PARA ESBOÇO

PARA CARGA INDUTIVA:

→ relaciona a diferença dos módulos das tensões à partida e à chegada

$\overline{AB} = \Delta \overline{U}_a = |\overline{U}_1| - |\overline{U}_2|$ → Valor exacto

$\overline{AC} = \Delta \overline{U}_a \simeq \longrightarrow \Delta \overline{U}_a = \overline{AD} + \overline{DC}$ → Valor Aproximado

$\Delta \overline{U}_a \simeq \overbrace{r I \cos\varphi_2}^{\overline{AD}} + \overbrace{X_L I \sin\varphi_2}^{\overline{DC}} \simeq (r I \cos\varphi_2 + X_L I \sin\varphi_2) \cdot \frac{3U_2}{3U_2} \simeq$ multiplico e divido por $3U_2$

$\simeq \dfrac{r \overbrace{3 I U_2 \cos\varphi_2}^{P_2} + X_L \overbrace{3 I U_2 \sin\varphi_2}^{Q_2}}{3U_2} \simeq \dfrac{r P_2 + X_L Q_2}{3U_2}$

$\Delta U_t \simeq \overline{CE} \simeq (\overbrace{X_L I \cos\varphi_2}^{\overline{EF}} - \overbrace{r I \sin\varphi_2}^{\overline{CF}}) \simeq (X_L I \cos\varphi_2 - r I \sin\varphi_2) \cdot \frac{3U_2}{3U_2} \simeq$

↳ permite relacionar o desfasamento entre essas tensões.

$\simeq \dfrac{X_L\, 3 U_2 I \cos\varphi_2 - r\, 3 U_2 I \sin\varphi_2}{3U_2} = \dfrac{X_L P_2 - r Q_2}{3U_2}$

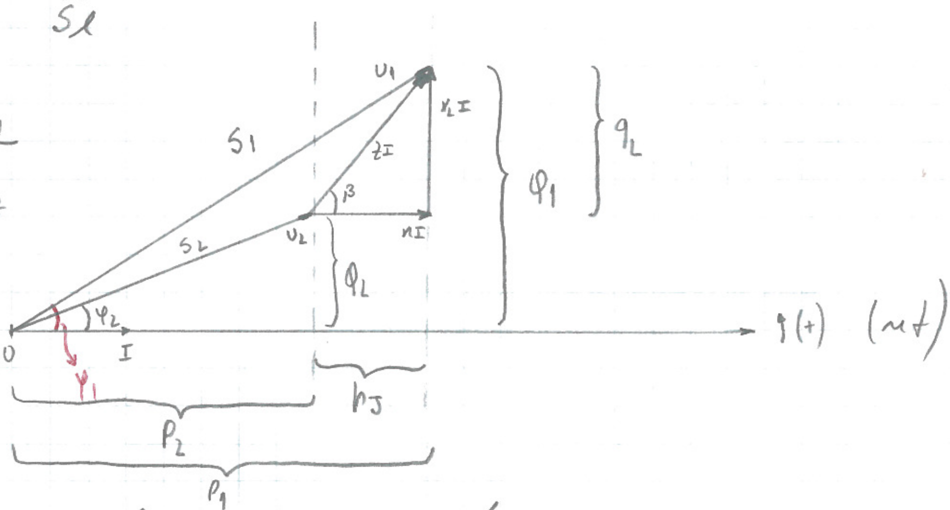
então $\Delta \overline{U}_1 = Z\overline{I} = \Delta \overline{U}_a + j \Delta \overline{U}_t$

Potencias na linha:

$\underbrace{3\overline{U}_1\overline{I}^*}_{\overline{S}_1} = \underbrace{3\overline{U}_2\overline{I}^*}_{\overline{S}_2} + \underbrace{3(r + jX_L)\overline{I}\,\overline{I}^*}_{\overline{S}_l}$ ⇒ ①

$\overline{U}_1 = U_{1ef} \angle \varphi_1$

$\overline{U}_2 = U_{2ef} \angle \varphi_2$



① ⇒ $3 \cdot U_{1ef} \cdot I_{ef} \angle{+\varphi_1} = 3 U_{2ef} \cdot I_{ef} \angle{+\varphi_2} + 3 \cdot \overline{Z} I^2$

↳ $3 \cdot Z \angle \beta \cdot I^2$

$$\underbrace{3 \cdot U_{1ef} \cdot I_{ef} \cos\varphi_1}_{P_1} = \underbrace{3 \cdot U_{2ef} \cdot I_{ef} \cos\varphi_2}_{P_2} + \underbrace{3 \cdot r I^2}_{P_J}$$

$$\underbrace{+3 \cdot U_{1ef} \cdot I_{ef} \cdot \sin\varphi_1}_{Q_1} = \underbrace{+3 U_{2ef} \cdot I_{ef} \cdot \sin\varphi_1}_{Q_2} + \underbrace{3 X_L I^2}_{q_L}$$

$$\bar{S}_1 = P_1 \pm j Q_1 \quad ; \quad \bar{S}_2 = P_2 \pm j Q_2 \quad ; \quad \bar{S}_\ell = P_J + q_L$$

PARA CARGA CAPACITIVA:

$\overline{AB} = \Delta \bar{U}_a = |\bar{U}_1| - |\bar{U}_2| \rightarrow$ Valor exacto

$\overline{AC} = \Delta \bar{U}_a \simeq \longrightarrow \Delta \bar{U}_a = \overline{AD} - \overline{CE} \simeq r I \cos\varphi_2 - X_L I \sin\varphi_2 \simeq$

$$\simeq \left(r I \cos\varphi_2 - X_L I \sin\varphi_2 \right) \cdot \frac{3U_2}{3U_2} \simeq \frac{r \overbrace{3 I U_2 \cos\varphi_2}^{P_2} - X_L \overbrace{3 I U_2 \sin\varphi_2}^{Q_2}}{3U_2} = \frac{r P_2 - X_L Q_2}{3U_2}$$

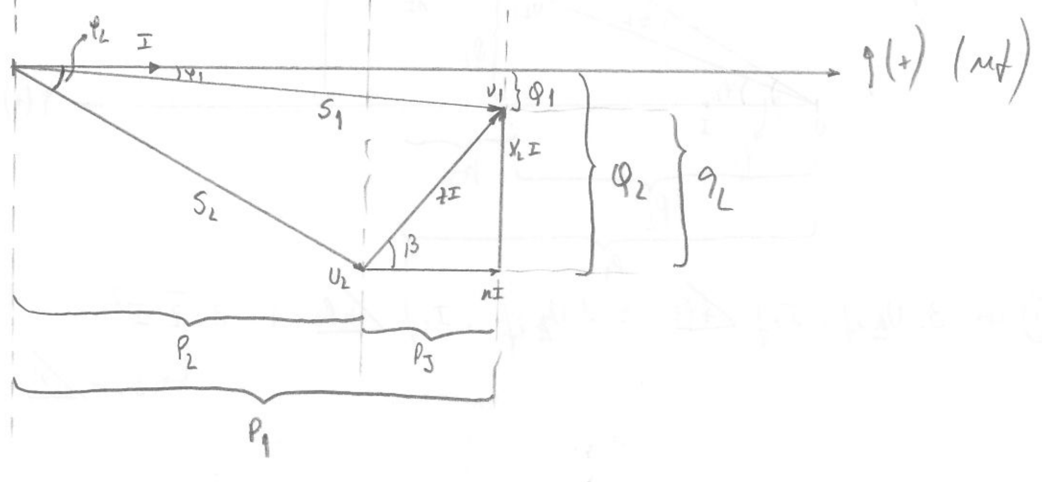
$$\Delta \bar{U}_r \simeq \overline{ED} \simeq \left(X_L I \cos\varphi_2 + r I \sin\varphi_2 \right) \simeq \left(X_L I \cos\varphi_2 + r I \sin\varphi_2 \right) \cdot \frac{3U_2}{3U_2} \simeq$$

$$\simeq \frac{X_L \overbrace{3 I U_2 \cos\varphi_2}^{P_2} + r \overbrace{3 I U_2 \sin\varphi_2}^{Q_2}}{3U_2} = \frac{X_L P_2 + r Q_2}{3U_2}$$

então $\Delta \bar{U}_1 = \Delta \bar{U}_a + j \Delta \bar{U}_r$

Potencias na linha:

$3 \bar{U}_1 \bar{I}^* = 3 \bar{U}_2 \bar{I}^* + 3 (r + j X_L) \bar{I} \bar{I}^* \Rightarrow$ (2)



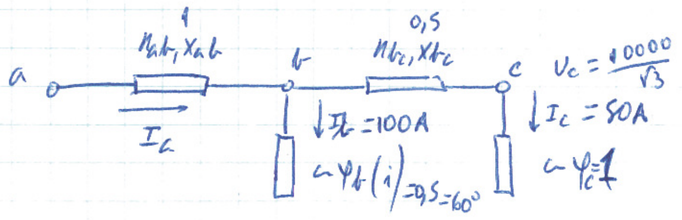
$\cos(-\varphi_1) = \cos\varphi_1$
$\sin(-\varphi_1) = -\sin\varphi_1$

(2) $$3 \cdot U_{1ef} \cdot I_{ef} \angle{-\varphi_1} = 3\, U_{2ef}\, I_{ef} \angle{-\varphi_2} + 3\, \bar{Z} I^2$$
$\hookrightarrow 3 Z \angle\beta\, I^2$

$$\underbrace{3\, U_{1ef} \cdot I_{ef} \cdot \cos\varphi_1}_{P_1} = \underbrace{3\, U_{2ef}\, I_{ef} \cos\varphi_2}_{P_2} + \underbrace{3\, r I^2}_{P_3} \longrightarrow \text{real}$$

$$\underbrace{-3\, U_{1ef} \cdot I_{ef} \cdot \sin\varphi_1}_{Q_1} = \underbrace{-3\, U_{2ef} \cdot I_{ef} \cdot \sin\varphi_2}_{Q_2} + \underbrace{3\, X_L I^2}_{q_L} \longrightarrow \text{Imag.}$$

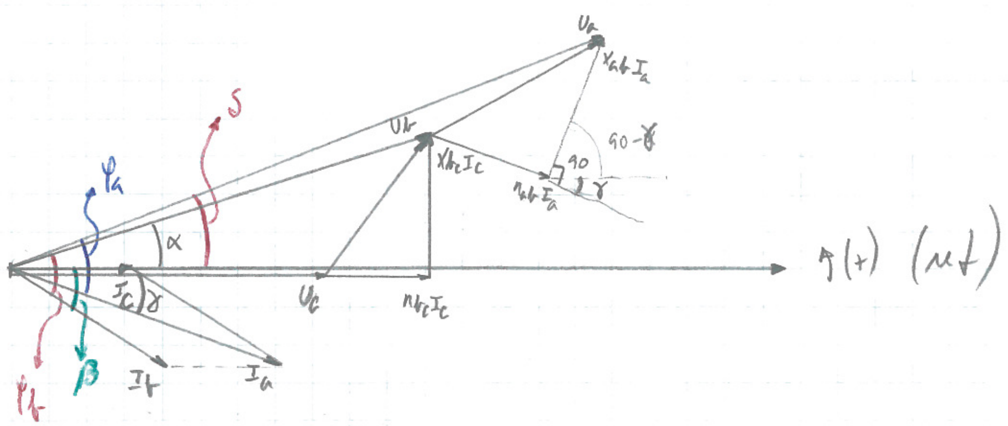
Cálculo das quedas de Tensão em linhas monoalimentadas e c/ cargas distribuidas:



$$\left.\begin{aligned} \Delta U_{bc} &= |\bar{U}_b| - |\bar{U}_c| \\ \Delta U_{ab} &= |\bar{U}_a| - |\bar{U}_b| \\ \Delta U_{ac} = \Delta U_{máx} &= |\bar{U}_a| - |\bar{U}_c| \end{aligned}\right\} \text{Valores Exactos}$$

↳ queda de Tensão máxima

Cálculo do Valor Exacto:



$$\bar{U}_b = \bar{U}_c + (r_{bc} + j\, x_{bc})\, \bar{I}_c$$

$$U_b \angle\alpha = U_c \angle 0° + r_{bc} I_c \angle 0° + x_{bc} I_c \angle 90°$$

$$U_b \angle \alpha = \frac{10000}{\sqrt{3}} \angle 0^\circ + 0{,}5 \cdot 50 \angle 0^\circ + 0{,}5 \cdot 50 \angle 90^\circ =$$
$$= 5773{,}5 + 25 + j25 = 5798{,}5 + j25 = 5798{,}56 \angle 0{,}247^\circ$$

$$\boxed{\begin{array}{l} U_b = 5798{,}56 \\ \alpha = 0{,}247^\circ \end{array}}$$

ou

$$\begin{cases} U_b \cos\alpha = U_c \cos 0^\circ + r_{bc} I_c \cos 0^\circ + X_{bc} I_c \overbrace{\cos 90^\circ}^{0} \\ U_c \sin\alpha = \underbrace{U_c \sin 0^\circ}_{0} + \underbrace{r_{bc} I_c \sin 0^\circ}_{0} + X_{bc} I_c \cdot \sin 90^\circ \end{cases}$$

$$U_b = \sqrt{\left(U_c \cos 0^\circ + r_{bc} I_c \cos 0^\circ\right)^2 + \left(X_{bc} I_c \sin 90^\circ\right)^2} =$$
$$= \sqrt{\underbrace{\left(\frac{10000}{\sqrt{3}} + 0{,}5 \cdot 50\right)^2}_{5798{,}5} + \underbrace{\left(0{,}5 \cdot 50\right)^2}_{25}} = 5798{,}56$$

$$\alpha = \operatorname{arctg} \frac{25}{5798{,}5} = 0{,}247^\circ$$

$$\bar{I}_a = \bar{I}_b + \bar{I}_c$$

$$\beta = \varphi_b - \alpha = 60 - 0{,}247 = +59{,}75$$

$$I_a \angle -\gamma = I_b \angle -\beta + I_c \angle 0^\circ = 100 \angle -59{,}75 + 50 \angle 0^\circ =$$
$$= 50{,}37 - j\,86{,}38 + 50 = 100{,}37 - j\,86{,}38 =$$
$$= 132{,}42 \angle -40{,}71$$

$$\boxed{\begin{array}{l} I_a = 132{,}42 \\ \gamma = +40{,}71 \end{array}}$$

$$\bar{U}_a = \bar{U}_b + (r_{ab} + j x_{ab}) \cdot \bar{I}_a$$

$$U_a \angle \delta = U_b \angle \alpha + r_{ab} I_a \angle -\gamma + x_{ab} I_a \angle 90-\gamma$$
$$= 5798{,}56 \angle 0{,}247 + 1 \cdot 132{,}42 \angle -40{,}71 + 1 \cdot 132{,}42 \angle 49{,}29 =$$
$$= 5798{,}5 + j25 + 100{,}38 - j\,86{,}36 + 86{,}37 + j\,100{,}38 =$$
$$= 5985{,}25 + j\,39{,}02 = 5985{,}38 \angle 0{,}373^\circ$$

$$\boxed{\begin{array}{l} U_a = 5985{,}38 \\ \delta = 0{,}373^\circ \end{array}}$$

Cálculo das Potências

$$\bar{S}_C = 3 \cdot \bar{U}_C \cdot \bar{I}_C^{*} = 3 \cdot \frac{10000}{\sqrt{3}} \angle 0° \cdot 50 \angle -0° =$$
$$= 866025,4 \angle 0°$$

$$\bar{S}_t = \bar{S}_{tc} + \bar{S}_c + \bar{S}_{tcarga}$$

$$\bar{S}_{tc} = 3\, \bar{Z}_{tc} \cdot I_C^2 = 3 \cdot 0,707 \angle 45° \cdot 50^2 = 5302,5 \angle 45°$$

$$Z_{tc} = \sqrt{0,5^2 + 0,5^2} = 0,707 \angle 45°$$

$$\bar{S}_{tcarga} = 3\, \bar{U}_t \cdot \bar{I}_t^{*} = 3 \cdot 5798,56 \angle 0,247° \cdot 100 \angle 59,75 =$$
$$= 1739568 \angle 60°$$

$$\bar{S}_t = 5302,5 \angle 45° + 866025,4 \angle 0° + 1739568 \angle 60° =$$
$$= 3749,43 + j\,3749,43 + 866025,4 + 869784 + j\,1506510,08 =$$
$$= 1739558,83 + j\,1510259,5 = 2303681,55 \angle 40,96° \quad (2)$$

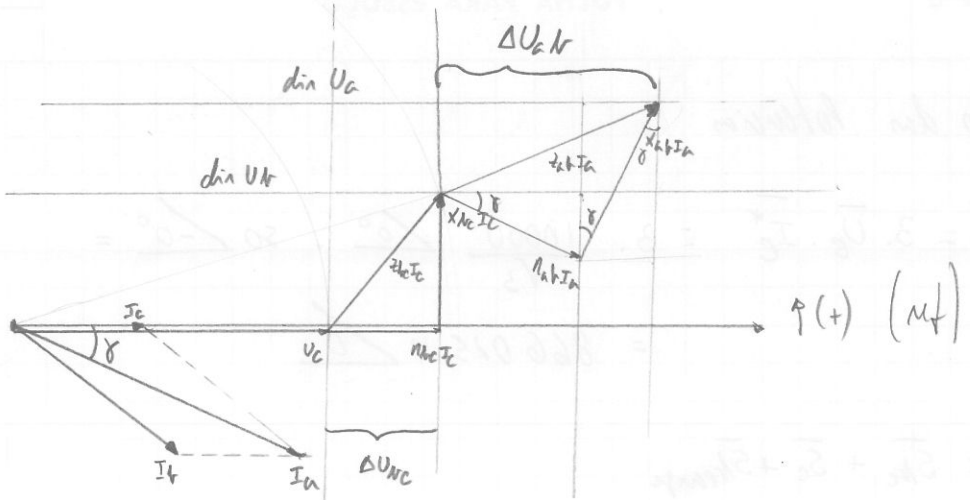
$$\bar{S}_a = 3\, \bar{U}_a \cdot \bar{I}_a^{*} = 3 \cdot 5985,38 \angle 0,373 \cdot 132,42 \angle +40,71 =$$
$$= 2377752,06 \angle +41,083$$

$$\bar{S}_t = \bar{S}_a - \bar{S}_{at} = 2377752,06 \angle 41,083 - 74394,94 \angle 45° =$$
$$= 1792250,6 + j\,1562543,6 - (52605,16 + j\,52605,16) = (1)$$

$$\bar{S}_{at} = 3\, \bar{Z}_{at} \cdot I_a^2 = 3 \cdot \sqrt{2} \angle 45° \cdot 132,42^2 = 74394,94 \angle 45°$$

(1) $= 1739645,44 + j\,1509938,44 = 2303536,5 \angle 40,96$ é igual a (2)

Cálculo aproximado:



$$\Delta U_{bc} \simeq r_{bc} I_c \cos\varphi_c \simeq 0{,}5 \cdot 50\,(1) = 25\,[V]$$

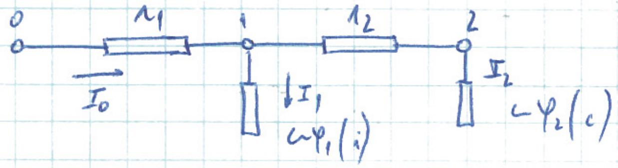
$$\Delta U_{ab} \simeq r_{ab} I_a \cos\gamma + x_{ab} I_a \,\text{sen}(\gamma) = 1.132{,}42\,(0{,}758 + 0{,}652) =$$

então $\Delta U_{máx} \simeq 25 + \quad = \quad [V]$

Cálculo do valor exacto:

$$\Delta U_{máx} = |\bar{U}_a| - |\bar{U}_c| = 5985{,}38 - \frac{10000}{\sqrt{3}} = 211{,}87\,[V]$$

Expressão do cálculo aproximado das quedas de tensão, em linhas monoalimentadas, c/ cargas distribuídas em B.T.

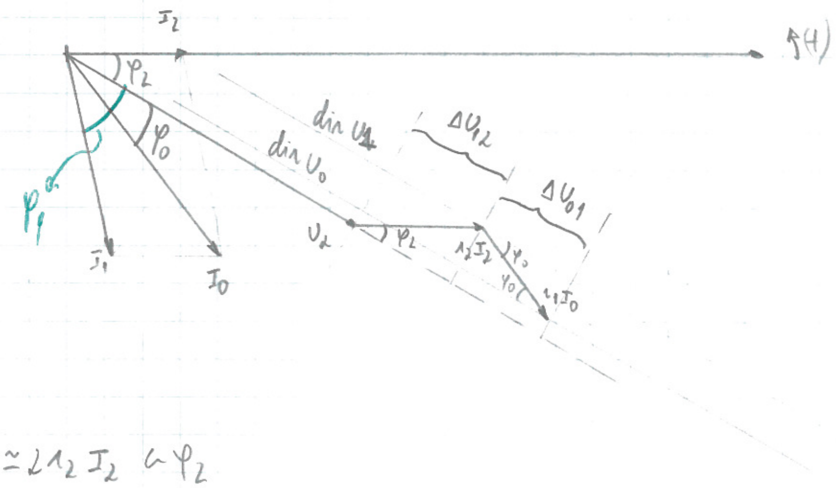


$\overline{U_1} = \overline{U_2} + 2\, r_2\, \overline{I_2}$

$\overline{U_0} = \overline{U_1} + 2\, r_1\, \overline{I_0}$

$\overline{I_0} = \overline{I_1} + \overline{I_2}$

Cálculo aproximado:



$\Delta U_{12} \simeq 2 r_2 I_2 \cos\varphi_2$

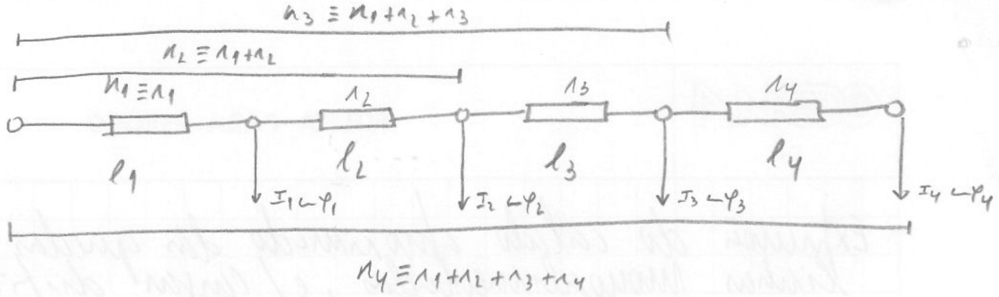
$\Delta U_{01} \simeq 2\, r_1 I_0 \cos\varphi_0$, $I_0 \cos\varphi_0 \simeq I_1 \cos\varphi_1 + I_2 \cos\varphi_2$

então $\Delta U_{01} \simeq 2 r_1 \left(I_1 \cos\varphi_1 + I_2 \cos\varphi_2 \right)$

$\Delta U_{máx} \simeq \Delta U_{12} + \Delta U_{01} \simeq 2 r_2 I_2 \cos\varphi_2 + 2 r_1 \left(I_1 \cos\varphi_1 + I_2 \cos\varphi_2 \right) \simeq$

$\simeq 2 \underbrace{r_1}_{R_1} I_1 \cos\varphi_1 + 2\, I_2 \cos\varphi_2 \underbrace{(r_1 + r_2)}_{R_2}$

Para n cargas :



$$\Delta U_{máx} \simeq 2 r_1 I_1 \cos\varphi_1 + 2 r_2 I_2 \cos\varphi_2 + 2 r_3 I_3 \cos\varphi_3 + 2 r_4 I_4 \cos\varphi_4$$

$$\simeq 2 r_1 (I_1\cos\varphi_1 + I_2\cos\varphi_2 + I_3\cos\varphi_3 + I_4\cos\varphi_4) + 2 r_2 (I_2\cos\varphi_2 + I_3\cos\varphi_3 + \ldots) +$$

$$\Delta U_{máx} \simeq 2 \sum_{i=1}^{n} R_i I_i \cos\varphi_i$$

↳ resistência equivalente

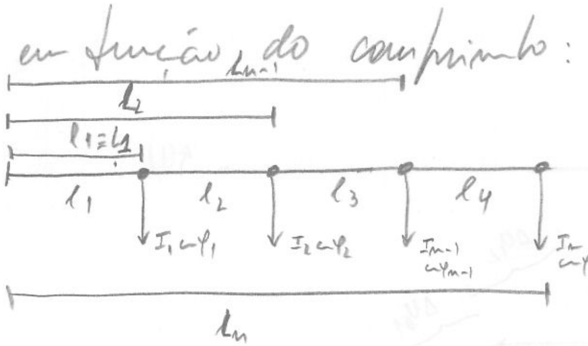
$$\Delta U_{máx} \simeq \frac{2\rho}{S} \left[l_1 (I_1\cos\varphi_1 + I_2\cos\varphi_2 + I_3\cos\varphi_3 + I_4\cos\varphi_4) + l_2 (I_2\cos\varphi_2 + I_3\cos\varphi_3 + I_4\cos\varphi_4) + l_3 (I_3\cos\varphi_3 + I_4\cos\varphi_4) + l_4 (I_4\cos\varphi_4) \right]$$

$$\text{ou} \simeq \frac{2\rho}{S} \left[I_1\cos\varphi_1 \overbrace{l_1}^{L_1} + I_2\cos\varphi_2 \overbrace{(l_1+l_2)}^{L_2} + I_3\cos\varphi_3 \overbrace{(l_1+l_2+l_3)}^{L_3} + I_4\cos\varphi_4 \overbrace{(l_1+l_2+l_3+l_4)}^{L_4} \right]$$

ou $\Delta U_{máx} \simeq \frac{2\rho}{S} \sum L_i I_i \cos\varphi_i$

↳ comprimento equivalente

Se for em função do comprimento:



$$\Delta U_{máx} \simeq \frac{2\rho}{S} \left[l_1 (I_1\cos\varphi_1 + I_2\cos\varphi_2 + I_{n-1}\cos\varphi_{n-1} + I_n\cos\varphi_n) + l_2 (I_2\cos\varphi_2 + I_{n-1}\cos\varphi_{n-1} + I_n\cos\varphi_n) + l_{n-1} (I_{n-1}\cos\varphi_{n-1} + I_n\cos\varphi_n) + l_n (I_n\cos\varphi_n) \right]$$

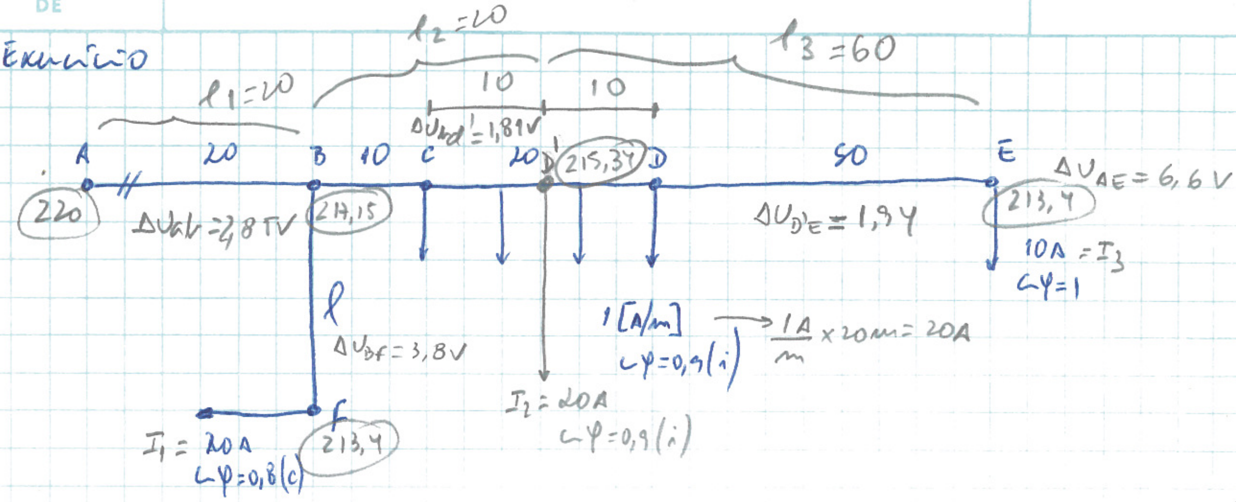
$$\text{ou } \Delta U_{máx} \simeq \frac{2\rho}{S} \left[I_1\cos\varphi_1 \overbrace{l_1}^{L_1} + I_2\cos\varphi_2 \overbrace{(l_1+l_2)}^{L_2} + I_{n-1}\cos\varphi_{n-1} \overbrace{(l_1+l_2+l_3)}^{L_3} + I_n\cos\varphi_n \overbrace{(l_1+l_2+l_3+l_4)}^{L_4} \right]$$

Monofásico	Trifásico
$\Delta U_{máx} \simeq 2 \sum_{i=1}^{n} r_i I_i \cos\varphi_i$	$\Delta U_{máx} \simeq \sum_{i=1}^{n} r_i I_i \cos\varphi_i$
$\simeq \frac{2\rho}{S} \sum_{i=1}^{n} L_i I_i \cos\varphi_i$	$\simeq \frac{\rho}{S} \sum_{i=1}^{n} L_i I_i \cos\varphi_i$
$\simeq \frac{2\rho}{S U_s} \sum_{i=1}^{n} \overbrace{L_i}^{l_n} S_i \cos\varphi_i$	$\simeq \frac{\rho}{S\sqrt{3} U_c} \sum L_i S_i \cos\varphi_i$

OGMA DE

FOLHA PARA ESBOÇO

Exercício



$$\Delta U_{BD'} = 2 \cdot \frac{1}{56} \cdot \frac{1}{11{,}04} \cdot \left[20 \times \underbrace{\left(20 \times 0{,}9 + 10 \times 1\right)}_{l_2\left(I_2 \cos\varphi_2 + I_3 \cos\varphi_3\right)} \right]$$

$$= 1{,}81\,V$$

$U_A = 220\,V$

$\rho = \frac{1}{56}\ [\Omega\, mm^2/m]$

s

$m = 3\%$ entre A e E e A e F

a) Secção s; b) Comprimento l; c) o Valor das Tensões nos pontos F e E.

a) $$m = \frac{\Delta U_{máx}}{U} \times 100\% \quad \Delta U_{máx} = \frac{3 \times 220}{100} = 6{,}6$$

$$\Delta U_{máx} \simeq \frac{2\rho}{s}\left[l_1\left(I_1 \cos\varphi_1 + I_2 \cos\varphi_2 + I_3 \cos\varphi_3\right) + l_2\left(I_2 \cos\varphi_2 + I_3 \cos\varphi_3\right) + l_3\left(I_3 \cos\varphi_3\right)\right]$$

$$= \frac{2\rho}{s}\left[I_1 \cos\varphi_1\, l_1 + I_2 \cos\varphi_2 \left(l_1 + l_2\right) + I_3 \cos\varphi_3 \left(l_1 + l_2 + l_3\right)\right]$$

$$6{,}6 \simeq 2 \cdot \frac{1}{56} \cdot \frac{1}{s}\left[\overbrace{20 \cdot 0{,}8 \cdot 20}^{320} + \overbrace{20 \cdot 0{,}9(40)}^{720} + \overbrace{10 \cdot 1 \cdot 100}^{1000}\right] \Leftrightarrow$$

$$6{,}6 \simeq 2 \cdot \frac{1}{56} \cdot \frac{1}{s}\left[2040\right] \Leftrightarrow s \simeq 11{,}04\ mm^2$$

b)

$$\Delta U_{ab} = 2{,}85\ V$$
$$\Delta U_{bf} = 3{,}80\ V$$
$$6{,}6\ V$$

$$\Delta U_{AF} \simeq \Delta U_{máx} \simeq 6{,}6$$

$$\Delta U_{AF} \simeq \underbrace{2 \cdot \frac{1}{56} \cdot \frac{1}{11{,}04} \left[l_1 \left(I_1 \cos\varphi_1 + I_2 \cos\varphi_2 + I_3 \cos\varphi_3 \right) \right.}_{\Delta U_{ab}} \left. + \, l\, I_1 \cos\varphi_1 \right]$$

ΔU_{bF}

$$6{,}6 \simeq 2 \cdot \frac{1}{56} \cdot \frac{1}{11{,}04} \left[\underbrace{20 \left(20 \times 0{,}8 + 20 \times 0{,}9 + 10 \times 1 \right)}_{880} + l \left(20 \times 0{,}8 \right) \right] \Rightarrow$$

$$6{,}6 \simeq \overbrace{2{,}85}^{\Delta U_{ab}} + 0{,}051\, l \Rightarrow l = 73{,}53\,[m]$$

$$\Delta U_{AF} = \Delta U_{AB} + \Delta U_{BF} \Rightarrow \Delta U_{BF} = \Delta U_{AF} - \Delta U_{AB} = 6{,}6 - 2{,}85 = 3{,}75\ [V]$$

ou $\Delta U_{BF} \simeq 2 \cdot \frac{1}{56} \cdot \frac{1}{11{,}04} \left[l\, I_1 \cos\varphi_1 \right] \simeq 2 \cdot \frac{1}{56} \cdot \frac{1}{11{,}04} \cdot 73{,}53 \cdot 20 \cdot 0{,}8 \simeq 3{,}75\,[V]$

c) $\Delta U_{AE} = U_A - U_E \Rightarrow U_E = U_A - \Delta U_{AE} = 220 - \underbrace{2 \cdot \frac{1}{56} \cdot \frac{1}{11{,}04} \left[l_1 \left(I_1 \cos\varphi_1 + I_2 \cos\varphi_2 + I_3 \cos\varphi_3 \right) + l_2 \left(I_2 \cos\varphi_2 + I_3 \cos\varphi_3 \right) + l_3 \left(I_3 \cos\varphi_3 \right) \right]}_{\Delta U_{AE} \simeq 6{,}6}$

$$U_F \simeq U_E \simeq 220 - 6{,}6 = 213{,}4\ [V]$$

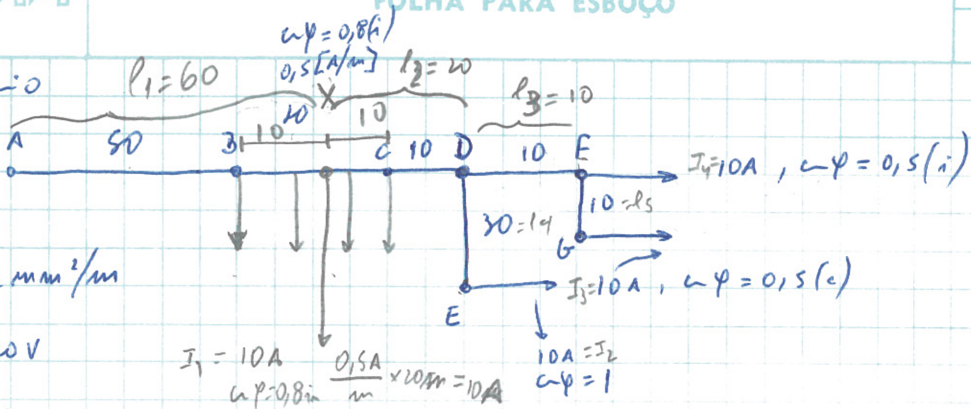
$$\Delta U_{AB} = U_A - U_B \Rightarrow U_B = U_A - \Delta U_{AB} = 220 - 2{,}85 = 217{,}15\ [V]$$

ou

$$\Delta U_{BF} = U_B - U_F \Rightarrow U_B = \Delta U_{BF} + U_F = 3{,}75 + 213{,}4 = 217{,}15\ [V]$$

$$\Delta U_{AF} = U_A - U_F \Rightarrow U_F = U_A - \Delta U_{AF} = 220 - 6{,}6 = 213{,}4$$

Exercício



$\rho = \frac{1}{56}\ \Omega\, mm^2/m$

$U_A = 220\ V$

$m = 5\%$

$s_{DE} = s_{DF} = s_{FG} = 2,5\ [mm^2]$

a) A secção no troço s_{AD}

b) U_G (Tensão no ponto G)

a)

$$m\% = \frac{\Delta U_{máx}}{U} \times 100\% \Rightarrow \Delta U_{máx} = \frac{5 \times 220}{100} = 11\ [V]$$

$$\Delta U_{DG} \simeq 2 \cdot \frac{\rho}{s}\left[l_3\left(I_3\cos\varphi_3 + I_4\cos\varphi_4\right) + l_5\left(I_3\cos\varphi_3\right)\right]$$

$$\Delta U_{DG} \simeq 2 \cdot \frac{1}{56} \cdot \frac{1}{2,5}\left[10\left(10 \cdot 0,5 + 10 \cdot 0,5\right) + 10\left(10 \times 0,5\right)\right] =$$

$$\Delta U_{DG} \simeq 2,14\ [V]$$

Troço c/ maior queda de tensão

$$\Delta U_{DE} \simeq 2 \cdot \frac{\rho}{s}\left[l_4\left(I_2\cos\varphi_2\right)\right] = 2 \cdot \frac{1}{56} \cdot \frac{1}{2,5}\left[30 \cdot \left(10 \times 1\right)\right] = 4,28\ [V]$$

$$\Delta U_{DF} \simeq 2\ \frac{\rho}{s}\left[l_3\left(I_4\cos\varphi_4 + I_3\cos\varphi_3\right)\right] = 2 \cdot \frac{1}{56} \cdot \frac{1}{2,5}\left[10\left(10 \times 0,5 + 10 \times 0,5\right)\right] =$$
$$= 1,428\ [V]$$

$$\Delta U_{AE} \simeq \Delta U_{máx} \simeq \Delta U_{AD} + \Delta U_{DE} \Leftrightarrow \Delta U_{AD} = 11 - 4,28 = 6,72\ [V]$$

$$\Delta U_{AD} \simeq 2\ \frac{\rho}{s_{AD}}\left[l_1\left(I_1\cos\varphi_1 + I_2\cos\varphi_2 + I_3\cos\varphi_3 + I_4\cos\varphi_4\right) + l_2\left(I_2\cos\varphi_2 + I_3\cos\varphi_3 + I_4\cos\varphi_4\right)\right]$$

$$6,72 \simeq 2\ \frac{1}{56} \cdot \frac{1}{s_{AD}}\left[\overbrace{60\left(10 \times 0,8 + 10 \times 1 + 10 \times 0,5 + 10 \times 0,5\right)}^{1680} + \overbrace{20\left(10 \times 1 + 10 \times 0,5 + 10 \times 0,5\right)}^{400}\right]$$

$$s_{AD} = 11,05\ [mm]^2$$

$s_{AD} = 11{,}05\ mm^2$

b) $U_G = ?$

$$\Delta U_{AG} = U_A - U_G \Rightarrow U_G = U_A - \Delta U_{AG} = 220 - 8{,}86 = 211{,}14\ [V]$$

$$\Delta U_{AG} = \Delta U_{AD} + \Delta U_{DG} = 6{,}72 + 2{,}14 = 8{,}86\ [V]$$

$$\Delta U_{AE} = U_A - U_E \Rightarrow U_E = U_A - \Delta U_{AE} = 220 - 11 = 209\ [V]$$

$$\Delta U_{AE} = \Delta U_{AD} + \Delta U_{DE} = 6{,}72 + 4{,}28 = 11\ [V]$$