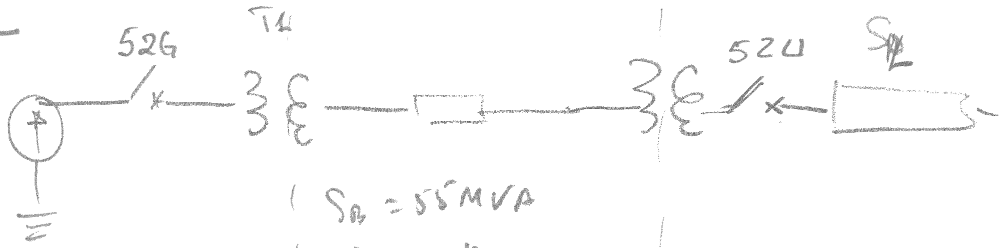
(1)

Exo 3

A



$U_B = 11 KV$

$Z_B =$

$S_B = 55 MVA = S_{generatrice}$

$S_B = 55 MVA$

$U_B = 70 KV$

$Z_{B(pu)} = \frac{6 + j12}{\frac{70^2}{S_B}}$

$U_B = 6,6 KV$

$S_B = 55 MVA$

2) Grandeur en pu.

Pour le generateur

$X_d = 160\% \Rightarrow X_d = 1,6 pu$

$X_q = 145\% \Rightarrow X_q = 1,45 pu$

$\Rightarrow X_S = \frac{X_d + X_q}{2} = 1,525 pu.$

$Z_{B_G} = \frac{U_G^2}{S_B} = \frac{11 KV^2}{55 MVA}$

$U_B = 11 KV$

$S_B = 55 MVA$

Pour le T1

$Z_{T1(pu)_{S_B}} = Z_{cc(60MVA)_3} \times \frac{S_B}{S_{T1}} = 0,1 \times \frac{55}{60}$

$Z_{T1(pu)_{S_B}} = 0,0916 pu.$

$U_B = 11 KV$

$S_B = 55 MVA$

$Z_B = \frac{U_B^2}{S_B}$

Pour Z_L

$$Z_{(pu)S_B} = \frac{Z_L(\Omega)}{Z_B} \quad \text{avec} \quad Z_B = \frac{70kV^2}{55\,MVA}$$

$$= \frac{6 + j\,12}{\frac{70kV^2}{55MVA} = 89,1}$$

$$Z_{L(pu)S_B} = 0,067 + j\,0,135$$

Pour T2

$$Z_{cc_{T2}(pu)_{S_B}} = Z_{cc_{T2}(pu)_{S_{T2}}} \times \frac{S_B}{S_{T2}} = 0,1 \times \frac{55}{25} = 0,22 \text{ pu}$$

S_{T2} ds la base $S_B \Rightarrow S_{T2(pu)_{S_B}} = 0,454$ pu.

$U_B = 70kV$

$S_B = 55MVA$

$$\Rightarrow Z_B = \frac{70^2}{55MVA}$$

Pour Z_L (charge)

$S = 20$ MVA $\quad \cos\varphi = 0,7 \Rightarrow \varphi = 45,5°$.

$P_L = 20 \times 0,7 = 14$ MW

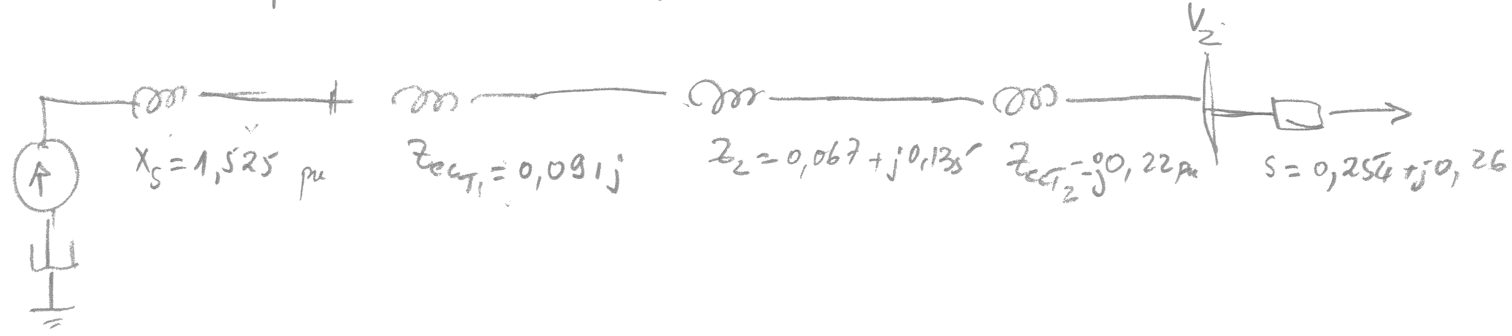
$Q = 20 \times \sin = 14,26$ MVAR.

$$P_{L(pu)S_B} = \frac{14}{55} = 0,254$$

$$Q_{L(pu)S_B} = \frac{14,26}{55} = 0,26$$

$$S_{L(pu)S_B} = \frac{20}{55} =$$

3/ Shema en pu de la Base S_G.



4) fem et V_S.

Sachant que la Tension de Base de l'usine est 6.6KV

a) $V_{L(pu)} = \dfrac{6}{6.6} = 0,91$ pu

→) $S = VI^* \Rightarrow I^* = \dfrac{0,254 + j0,26}{0,91}$

$I^* = 0,279 + j0,286$

$I_1 = 0,279 - j0,286$

<u>calcul de ΔV</u>

$V_S = \Delta V + V_L$ avec $V_L =$

avec $\Delta V = (Z_{ccT_1} + Z_L + Z_{ccT_2})\, I_1$

$= (0,067 + j0,446)(0,279 - j0,286)$

$\Delta V = \underline{0,146 + j0,105}$

d'où $V_S = (0,146 + j0,105) + (0,91) = 1,056 + j0,105 = 1,061\angle 5,70$

$V_{S_{11KV}} = 11,67KV$

$\underline{E} = \underline{V}_s + jX_s \underline{I}_1$

$= (1{,}05 + j0{,}105) + (j1{,}525) \times (0{,}279 - j0{,}286)$

$= 1{,}05 + j0{,}105 + j0{,}425 + 0{,}436$

$= 1{,}486 + j0{,}53$

$E = 1{,}577 \angle 19{,}62^\circ$

$\underline{E} = 17{,}347\ kV$

$\Rightarrow P_G = 0{,}896 \sin(19{,}62^\circ) + 0{,}0267 \sin(2 \times 19{,}62^\circ)$
$= 0{,}300 + 0{,}0168 = 0{,}3168$ pu.

5/ Puissance max à partir de l'expression

$$P_e = \underbrace{\frac{V_1 \times E}{X_d}}_{P_1} \sin\delta + \underbrace{\frac{V_1^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)}_{P_2} \sin 2\delta$$

$P_e = P_1 \sin\delta + P_2 \sin 2\delta$

Pour $P_{max} \Rightarrow \frac{dP_e}{d\delta} = P_1 \cos\delta + 2P_2 \cos 2\delta$ (1) or $\cos 2\delta = 2\cos^2\delta - 1$

(1) $\Rightarrow P_1 \cos\delta + 2P_2 [2\cos^2\delta - 1] = 0$

$P_1 \cos\delta + 4P_2 \cos^2\delta - 2P_2 = 0$ si $\cos\delta = x$.

$\Rightarrow 4P_2 x^2 + P_1 x - 2P_2 = 0$

$P_1 = \frac{0{,}91 \times 1{,}577}{1{,}6} = 0{,}896$

$P_2 = \frac{(0{,}91)^2}{2}\left(\frac{1}{1{,}45} - \frac{1}{1{,}6}\right) = 0{,}0267$

$\Rightarrow 0{,}1068\, x^2 + 0{,}897\, x - 0{,}0534 = 0$

$\Rightarrow x_1 = 0{,}0591 \Rightarrow \underline{\delta = 86{,}6^\circ}$

$x_2 = -8{,}458$ (NA). variation de $0 < \delta < 90^\circ$ dans le cas d'un fonctionnement alternateur

Pour

$\cos\delta = 0{,}0591 \Rightarrow \delta = 86{,}6°$ $\Rightarrow P_{G_{\delta_1}} = 0{,}896 \sin(86{,}6°) + (0{,}0267)\sin(2\times 86{,}6°)$

$= 0{,}897$ pu $\Rightarrow$ $P_{G\delta_1} = 49{,}32$ MW

~~$\cos\delta = -9{,}3955$~~ $\Rightarrow \delta_2 =$ $\Rightarrow P_{G_{\delta_2}} =$

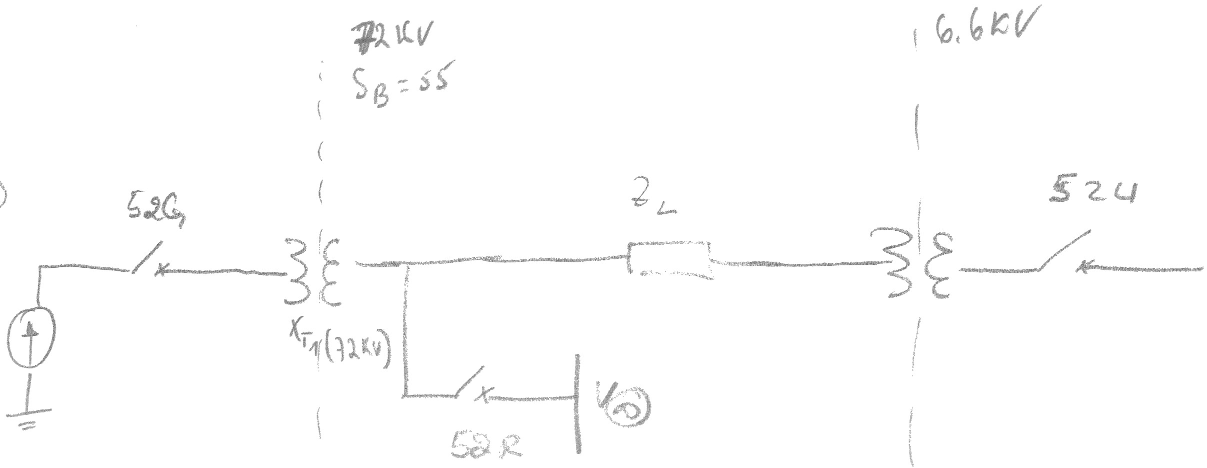
impossible

$\delta = 86{,}6°$ → utilisé pour calculer la $P_{gmax} = 49{,}36$ MW

et $S_\gamma = \dfrac{dP}{d\delta} = P_1 \cos\delta + 2 P_2 \cos 2\delta = 0{,}896 \cos(86{,}6°) + 2(0{,}0267)\cos(2\times 86{,}6°)$

$= 0{,}114 \cdot 10^{3}$ MW/rad.

B)



6) $\dfrac{\text{Tension Primaire}}{\text{Tension secondaire}} \Rightarrow T_1 \, (11\text{kV}) = \dfrac{72}{11} = 6{,}54$ ou $\dfrac{11}{72} = 0{,}1527$

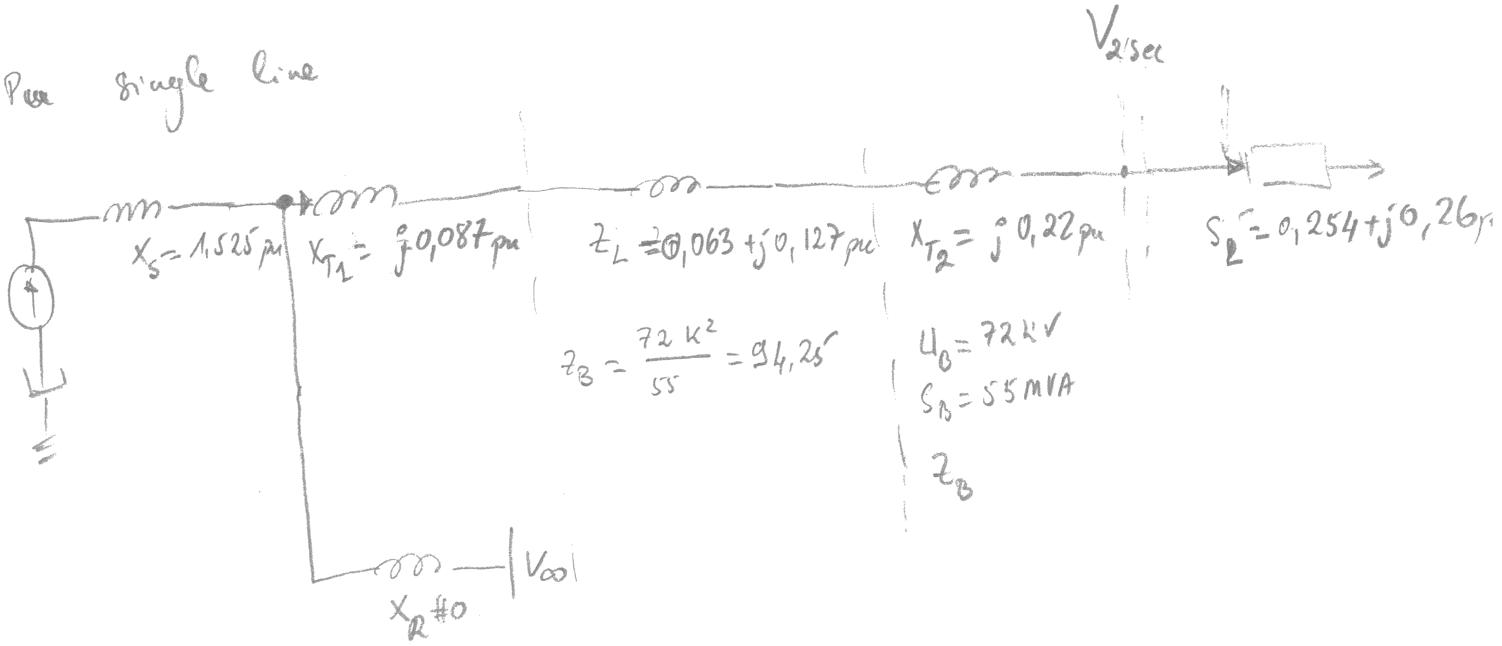
7/ la part de Puissance Transmise au réseau -

B/

7) Nouveau $Z_{eq\,T_1}$ car nous avons maintenant T_2 (72 kV/63MVA)

de l'exo 1 ⇒ $Z_{cc_{T_1(72kV)}} = 0,1 \times \left(\frac{63}{60}\right) \times \left(\frac{70\,kV}{72\,kV}\right)^2 = 0,099 \# 0,1.$

Par single line



$I_L^* = \frac{S_L}{V_L} = 0,254 + j0,26$

⇒ $I_L = 0,254 - j0,26$

0,016

$\Delta V = I_L \times (X_{T} + Z_L + X_{T_2}) = (0,254 - j0,26)(0,063 + j0,434) = 0,128 + j0,093$

$S_{Pertes} = \Delta V\, I_L^* = (0,128 + j0,093)(0,254 + j0,26) = 0,0083 + j0,0569$

$S_G = 1$ pu ⇒ $P_{GN} = 0,8$ pu et $Q_{GN} = 0,6$ pu. ⇒ $S_G = 0,8 + j0,6$

⇒

$S_G = 0,8 + j\,0,6$

$- S_L = -(0,254 + j\,0,26)$

$- S_{pertes} = -(0,0083 + j\,0,0569)$

$S_j = 0,5377 + 0,317$ pu ⇒ $P_R = 29,57$ MW

$Q_R = 17,435$ MVAR.

8) <u>f.e.m</u> au fonctionnement nominal.

$\Rightarrow V_{s_2} = \Delta V_2 + V_1 = 1,0083 + j\,0,0569$

$E = V_{s_2} + jX_s I_s + R_s I_s$ or $R_s = 0 \Rightarrow E = V_{s_2} + j I_s X_s$

$\Rightarrow E = (1,0083 + j\,0,0569) + j(1,525) \times (?)$

or $V_{s_2} I_s^* = P + jQ$

$$I_s^* = \frac{0,8 + j\,0,6}{V_{s_2}} = \frac{(0,8 + j\,0,6) \times (1,0083 - j\,0,057)}{(1,0083)^2 - (0,057)^2}$$

$$I_s^* = \frac{0,84 + j\,0,56}{1,0134} = 0,828 + j\,0,552$$

$I_s = (0,828 - j\,0,552)$ pu $\Rightarrow I_s = |1| \angle 33,7^\circ$ $\Rightarrow \cos\varphi = 0$
1 pu

$\Rightarrow E = (1,0083 + j\,0,057) + j\,(1,525)\,[0,828 - j\,0,552]$

$= (1,0083 + j\,0,057) + j\,1,2627 + 0,8418$

$= (1,85 + j\,1,32)$ pu

$\underline{\underline{E}} = |2,27| \angle 35,5^\circ$ pu $\rightarrow \underline{\underline{E = 24,97\text{ kV}}}$

c) Plan de Protection de T1

9) Choix des TI

Déterminer la grandeur à mesurer dans cette application.

$S_{NT_2} = \sqrt{3}\, U_{HV}\, I_n \Rightarrow I_n = \dfrac{S_{NT2}}{\sqrt{3}\, U_{HV}} = \dfrac{63\ MVA}{\sqrt{3} \cdot 72\ kV} = 505{,}2\ A = 1p$

1) une charge de 20% est autorisée par rapport à la grandeur caractéristique $\Rightarrow I_n \times 1{,}2 = 606\ A$ ou $I_n \times 1{,}3 = 656{,}5$

d'où le choix du TI **800/1 A** pour une $S_N = 63\ MVA$, $U_N = 72\ kV$

b) protection contre les court-circuits ph-ph.

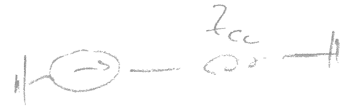
$\Rightarrow I_{cc} = \dfrac{1}{Z_{cc(pu)\,72kV}} \cong \dfrac{1}{0{,}1} = 10\ pu$ - avec $1\ pu = I_n$

Le choix du CT1 ne se base que sur la surcharge (51T) $\Rightarrow I_n \times 1{,}2$ ou $I_n \times 1{,}3$.

, d'où $\Rightarrow$ **CT1 = 800/1 A**

On assumera qu'en cas de court-circuit son coude de saturation est suffisamment grand pour cette application.

$I_{cc\ ph\text{-}ph} = 5050\ A$

c) Court circuit phase-Terre 

$I_{cc\ ph\text{-}T} = 5050\ A$

Seuil de déclenchement est 0,5 pu $\Rightarrow I_{Dph} = \dfrac{505}{2} = 203\ A \Rightarrow CT2 = 500/1\ A$

10) Seuil de Trip $51T > \dfrac{1{,}2 \times I_n}{\text{Ratio } CT1} = \dfrac{606}{800} = 0{,}7575\ A$

Trip 52R	$\Leftarrow 51T > = 0{,}7575\ A$	— Tempo < 60 sec
2R+52G	$\Leftarrow 50T = \dfrac{5050}{800} = 6{,}335$	— Tempo = 0 Sec
2R+52G	$\Leftarrow 51TN > \dfrac{505 \times 0{,}5}{500} = 0{,}505$	— Tempo < 2 sec

$\Rightarrow$ Trip 52R car le plus important est d'alimenter l'usine donc on fait action de délestage.

Exo1

Soit Z ds la base S_{pu} $\Rightarrow$ $Z = Z_{pu} \times Z_{B\in(S_{pu}, V_{pu})}$

$$= Z_{pu} \times \frac{V_{pu}^2}{S_{pu}} \quad (1)$$

Soit Z ds la S'_{pu} $\Rightarrow$ $Z = Z'_{pu} \times Z_{B\in(S'_{pu}, V'_{pu})}$

$$= Z'_{pu} \times \frac{V'^2_{pu}}{S'_{pu}} \quad (2)$$

(1) = (2)

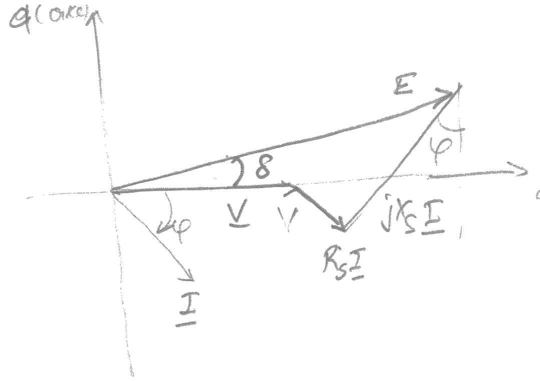
Comme $Z = Z$ $\Leftrightarrow$ $Z'_{pu} \times \frac{V'^2_{pu}}{S'_{pu}} = Z_{pu} \times \frac{V_{pu}^2}{S_{pu}}$

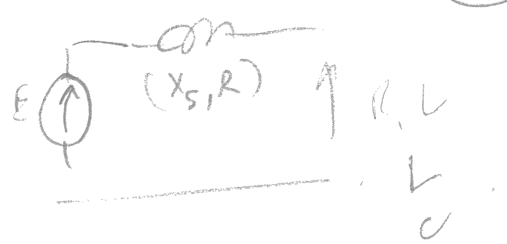
$$\Rightarrow \boxed{Z'_{pu} = Z_{pu} \times \frac{S'_{pu}}{S_{pu}} \times \frac{V_{pu}^2}{V'^2_{pu}}}$$

CQFD.

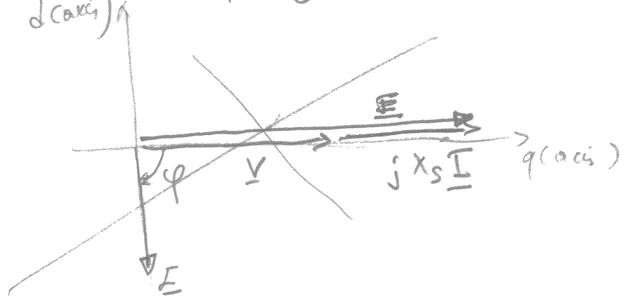
Exo 2

1) a)

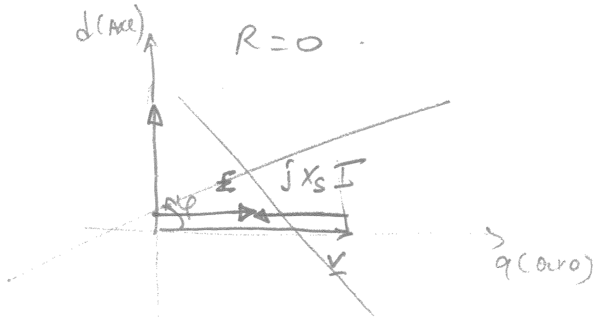




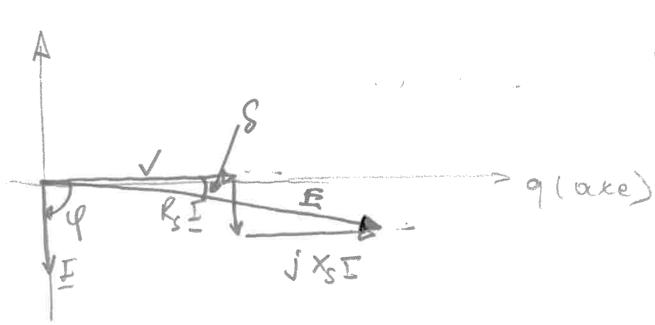
b) $R = 0$



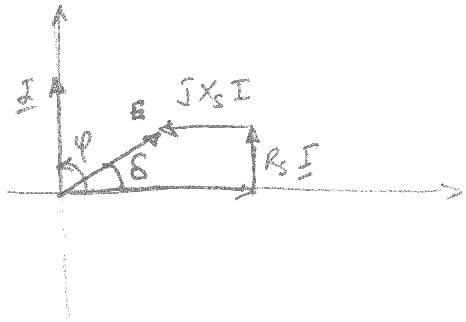
c) $R = 0$



b)

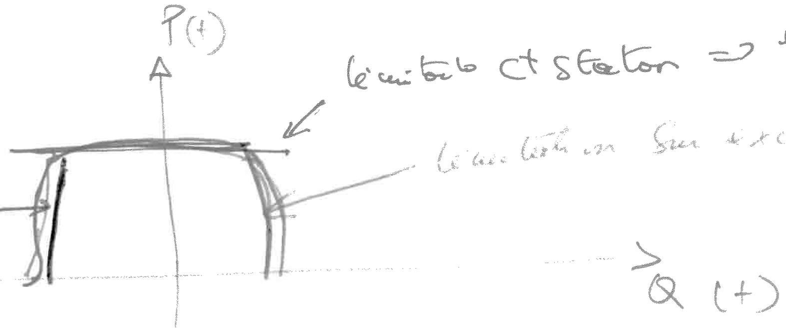


c)



d) $\underline{E} = \underline{V}_s + jX_s\underline{I} + R_s\underline{I}$

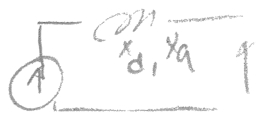
e)



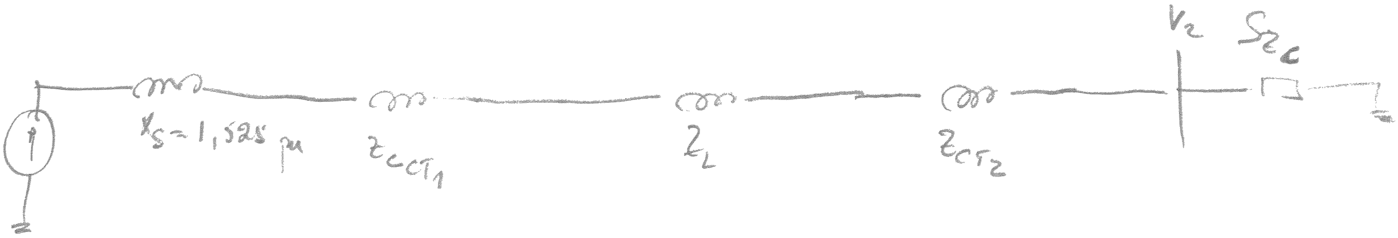
⇒ limite de fonction en Q (VAR) importation. risque perte d'excitation ou de champ au niveau synchronisme (rotor).

2)

$$P_G = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$



Géné 100MVA – 11,5 kV



$$Z_{ccT_1} = 0,1 \times \frac{100}{110} = 0,091j$$

$$Z_L = \frac{6 + j12}{\frac{70 kV^2}{100 MVA}} = 0,122 + j\,0,245$$

$$Z_{cT_2} = 0,1 \times \frac{100}{25} = 0,4j$$

$$S_{charge} = \frac{14 + j\,14,26}{100} = 0,14 + j\,0,1426$$

$S_{charge} = V \cdot I^*$ $\Rightarrow$ $I = 0,154 - j\,0,156$

$V_S = \Delta V + V_L$

$$\Delta V = (0,154 - j\,0,156) \times [0,122 + 0,736j]$$

$$= 0,1336 + j\,0,094$$

$$\Delta V = |0,163| \angle$$

$$\Rightarrow V_S = 1,0436 + j\,0,094$$

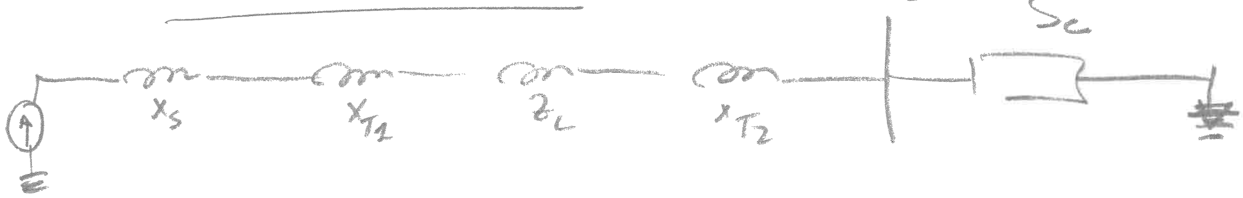
$$\Rightarrow E = V_S + j X_S I_1 = [1,0436 + j\,0,094] + (j\,1,525)\{0,154 - j\,0,156\}$$

$$= \quad + j\,0,235 + 0,238$$

$$E = 1,28 + j\,0,33$$

$$E = |1,32| \angle$$

Pour $S = 140MVA / 15KV$



$X_S = 1,525$ pu.

$X_{T1} = 0,1 \times \frac{140}{150} = j0,093$ pu

$Z_L = \frac{6+j12}{\frac{70kV^2}{140MV}} = 0,17 + j0,343.$ pu

$Z_{cT_2} = 0,1 \times \frac{140}{25} = j0,56$ pu

$S_{C(140MVA)} = \frac{14 + j14,26}{140} = 0,1 + j0,102$

$\Rightarrow I = 0,11 - j0,11$

$V_S = \Delta V + V_{Charge} =$

$\Delta V_S = (0,11 - j0,11) \times [0,17 + j0,996]$

$\Delta V = 0,128 + j0,091$

$\Rightarrow V_{Stator} = 1,038 + j0,091$

$\Rightarrow E = V_S + jX_S I_1 = (1,038 + j0,091) + (j1,525)[0,11 - j0,11]$

$= \qquad + j0,167 + 0,167$

$E = 1,205 + j0,258$

$E = |1,23| \angle$

S = 100 MVA − 11,5 kV

$$\Rightarrow \quad P_1 = \frac{0,91 \times 1,32}{1,6} = 0,7507$$

$$P_2 = \frac{(0,91)^2}{2}\left[\frac{1}{1,05} - \frac{1}{1,6}\right] = 0,0267$$

$$\Rightarrow \quad 4(0,0267)\,x^2 + 0,7507\,x - 2(0,0267) = 0$$

$$\Rightarrow \quad 0,1068\,x^2 + 0,7507\,x - 0,0534 = 0$$

$x_1 = -7,099 \Rightarrow$ solution non possible

$\cos\delta = x_2 = 0,0704 \Rightarrow \delta = 86°$

$$\Rightarrow S_y = P_1 \cos\delta + 2P_2 \cos 2\delta$$

$$= 0,7507 \cos\delta + 2(0,0267)\cos 2(86°)$$

$S_y = -0,0214 \cdot 10^{-3}$ MW/rad.

Partie c

$$Z'_{cc(113)} = 0,1 \times \frac{113}{110} \times \left(\frac{70}{72}\right)^2 = 0,097$$

$$I_n = \frac{113 \text{ MVA}}{\sqrt{3} \times 72 \text{ kV}} = 906 \text{ A} \xrightarrow{1,3} 1178 \rightarrow CT1 = 1400/1$$

$\Rightarrow 0,5\,I_n = 0,5 \times 906 = 453 \xrightarrow{\times 1,3} 588,9 \longrightarrow CT2 = 800/1$ ou $500/1$.

Seuil de ~~51EN~~ 51T $> \dfrac{I_n \times 1,2}{CT\ ratio} = \dfrac{906 \times 1,2}{1400} = 0,776$ A — tempo < 60 sec

Seuil de 50T $> \dfrac{I_n}{Z_{cc} \times CT\ ratio} = \dfrac{906}{0,097 \times 1400} = 6,67$ A — tempo instantané

Seuil de 51TN si CT2 = 800/1A $\Rightarrow$ 51TN $> \dfrac{I_n \times 0,5}{800} = 0,566$ A — tempo 2sec

si CT2 = 500/1A $\Rightarrow$ 51TN $> \dfrac{I_n \times 0,5}{500} = 0,906$ A tempo < 2sec

Pour $S_B = 140$ MVA - 15 kV

$$P_1 = \frac{E \cdot V}{X_d} = 0,7$$

$$P_2 = \frac{0,91^2}{2}\left[\frac{1}{1,45} - \frac{1}{1,6}\right] = 0,0267$$

$\Rightarrow 4P_2 X^2 + P_1 X - 2P_2 = 0$

$0,1068 x^2 + 0,7x - 0,0534 = 0.$

$x_1 = -6,629 \rightarrow$ Non possible

$x_2 = 0,0754 \Rightarrow \delta = 85,7°$ car $x_2 = \cos\delta$

$S_y = P_1 \cos\delta + 2P_2 \cos 2\delta$

$= 0,7 \cos(85,7) + 2(0,0267)\cos(2 \times 85,7°)$

$= -0,314 \cdot 10^{-3}$ MW/rad

Partie C

$$Z'_{cc\,(153\,MVA)} = 0,1 \times \left(\frac{153}{150}\right) \times \left(\frac{70^2}{72^2}\right) = 9,6\,\% = 0,096$$

$$I_n = \frac{153}{\sqrt{3}\,U} = 1227\,A \xrightarrow{1,3} 1594 \Rightarrow CT1 = 1600/1.$$

$$0,5\,I_n = 613\,A \xrightarrow{1,3} 797 \Rightarrow CT2 = 800\,A.$$

Seuil 51T $\Rightarrow I > I_n \times 1,2 = \frac{1472,4}{1600} = 0,92$ — tempo Max = 60 sec

Seuil 50T $\Rightarrow I > \frac{I_n}{Z_c \times CT_{ratio}} = \frac{1227}{0,096 \times 1600} = 7,98 \Rightarrow 8$ — tempo 0 sec

Seuil 51TN $\Rightarrow I > I_n \times 0,5 = \frac{1227 \times 0,5}{800} = 0,77$ — tempo 2 sec