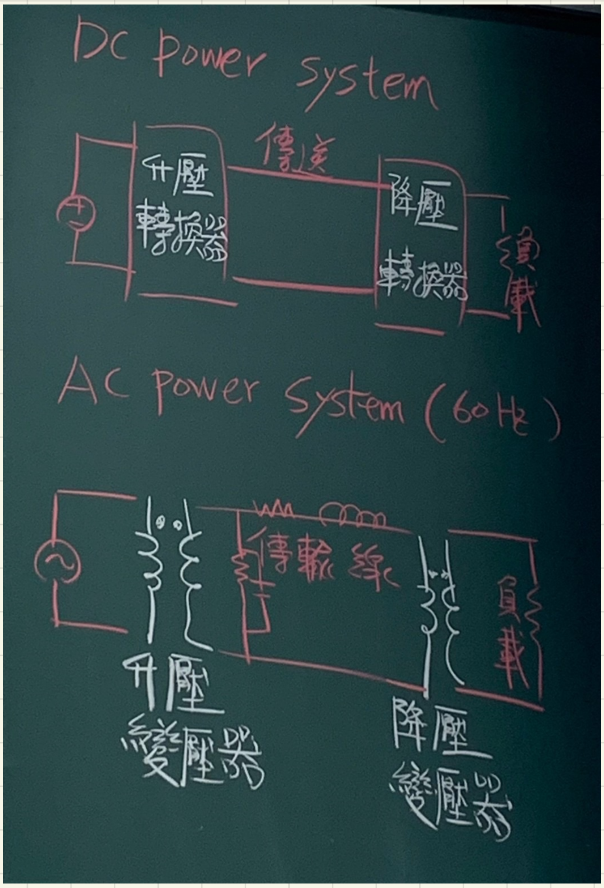
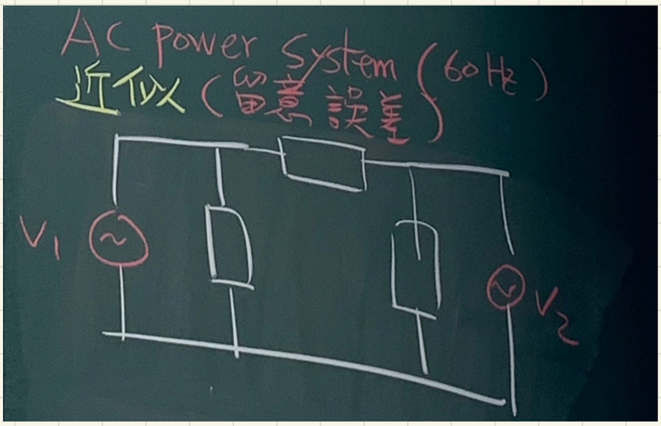

DC power system
升壓
轉換器
傳送
降壓
轉換器
負載
AC power system (60 Hz)
傳輸線
升壓
變壓器
降壓
變壓器
負載


AC power system (60 Hz)
近似 (留意誤差)
V1
V2

4.3傳輸矩陣(Transmission Matrix)

Steady-state terminal voltage and currents.

$V_1 = AV_2 + BI_2$; $I_1 = CV_2 + DI_2$,

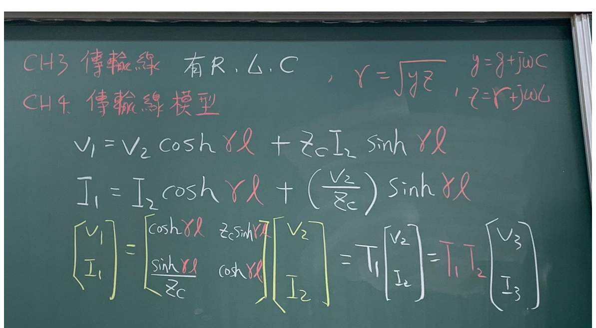
where $A= \cosh \gamma l$, $B= Z_c \sinh \gamma l$, $C= (1/Z_c) \sinh \gamma l$, $D= \cosh \gamma l$,

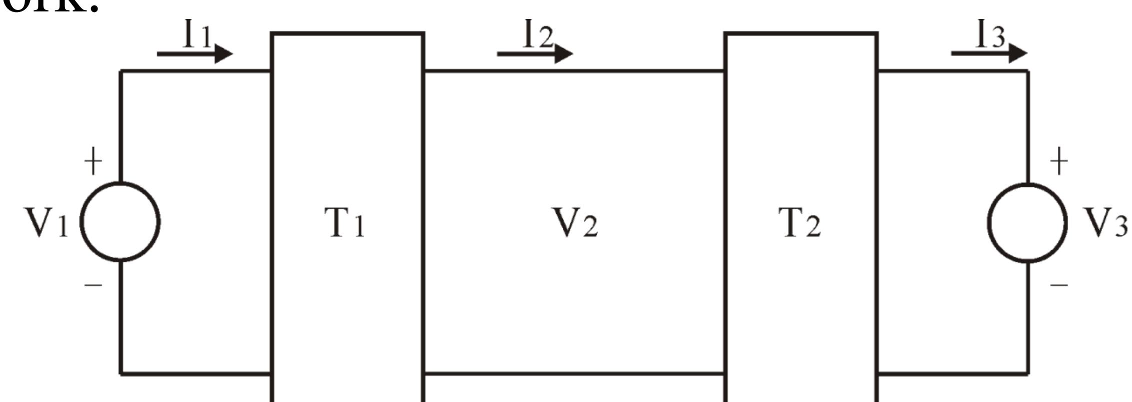
Transmission matrix (chain matrix) $T = [A\ B;C\ D]$, $T^{-1} =[D\ –B;-C\ A]$

$\det T = AD – BC = (\cosh \gamma l)^2 – (\sinh \gamma l)^2 = 1$

$[V_1\ I_1] = T_1\ [V_2\ I_2] = T_1T_2\ [V_3\ I_3] = T\ [V_3\ I_3]$

That det T = 1, holds in general for two-port networks composed of (linear time-invariant) resistors, capacitors, inductors, coupled inductors, and transformers. This provides a useful check of analytical or numerical work.





4.4等效集總電路(Lumped-Circuit Equivalent), $\gamma = (y\, z)^{0.5}$

$V_1 = AV_2 + BI_2$; $I_1 = CV_2 + DI_2$,

Find a Π equivalent circuit that has the same A, B, C, D parameters as the transmission line. We note that a T equivalent circuit may also be derived.

$V_1 = V_2 \cosh \gamma l + Z_c I_2 \sinh \gamma l$; $I_1 = I_2 \cosh \gamma l + (V_2 / Z_c) \sinh \gamma l$

$V_1 = V_2 + Z' [I_2 + (Y'/2)V_2] = (1 + Z'Y'/2)V_2 + Z'I_2$

$I_1 = (Y'/2)V_1 + (Y'/2)V_2 + I_2 = Y'(1 + Z'Y'/4)V_2 + (1 + Z'Y'/2)I_2$

A= $\cosh \gamma l = 1 + Z'Y'/2$, B= $Z_c \sinh \gamma l = Z'$,

C= $(1/Z_c) \sinh \gamma l = Y'(1 + Z'Y'/4)$, D= $\cosh \gamma l = 1 + Z'Y'/2$,

$Z' = Z_c \sinh \gamma l = (z/y)^{0.5} \sinh \gamma l = zl \sinh \gamma l / l(zy)^{0.5} = Z \sinh \gamma l / \gamma l = Z$

Assume $|\gamma l| << 1 \Rightarrow \sinh \gamma l / \gamma l = 1$; $Z = zl$ is the total series impedance of line

$1 + Z'Y'/2 = \cosh \gamma l \Rightarrow Y'/2 = (\cosh \gamma l - 1)/Z' = (\cosh \gamma l - 1)/(Z_c \sinh \gamma l)$

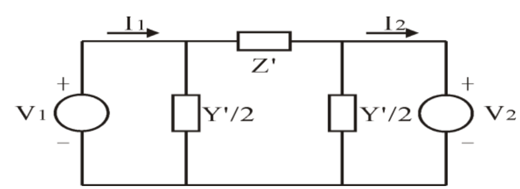
$=(1/Z_c)(e^{\gamma l} + e^{-\gamma l} - 2)/(e^{\gamma l} - e^{-\gamma l}) = (1/Z_c)(e^{\gamma l/2} - e^{-\gamma l/2})^2/(e^{\gamma l/2} + e^{-\gamma l/2})(e^{\gamma l/2} - e^{-\gamma l/2})$

$=(1/Zc)\tanh(\gamma l/2) = (y/z)^{0.5} \tanh(\gamma l/2) = (yl/\gamma l)\tanh(\gamma l/2) = (Y/2) \tanh(\gamma l/2)/(\gamma l/2)$

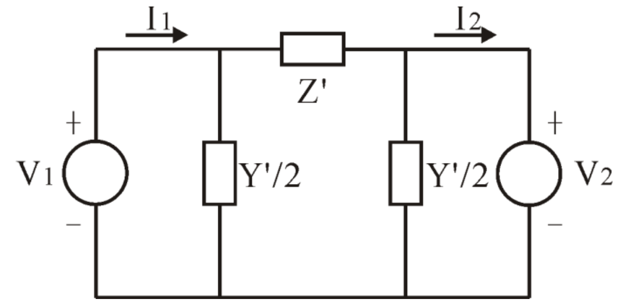
Assume $|\gamma l| << 1 \Rightarrow \tanh(\gamma l/2)/(\gamma l/2) = 1$; $Y = yl$ is the total line-neutral admittance of line

$Zc = (z/y)^{0.5} = (zl / yl)^{0.5} = (Z/Y)^{0.5}$

$\gamma l = (zy)^{0.5}\, l = (zl\, yl)^{0.5} = (Z\, Y)^{0.5}$



Ex4.4 Find the Π equivalent circuit in Ex4.1 A 60-Hz 138-kV 3Φ transmission line is 225mile long. The distributed line parameters are r =0.169 Ω/mile , l = 2.093 mH/mile , c = 0.01427 μF/mile , g = 0.



$z = r + j\omega l = 0.169 + j0.789 = 0.807 \angle 77.9^\circ$ Ω/mile

$y = g + j\omega c = j5.38\times10^{-6} = 5.38\times10^{-6} \angle 90^\circ$ mho/mile

$\Rightarrow Z_c = (z/y)^{0.5} = 387.3 \angle -6.05^\circ \ \Omega$

$\Rightarrow \gamma\, l = 225\,(y\, z)^{0.5} = 0.4688 \angle 83.95^\circ = 0.0494 + j0.466$

$2 \sinh \gamma l = e^{\gamma l} - e^{-\gamma l} = e^{0.0494} e^{j0.466} - e^{-0.0494} e^{-j0.466} = 1.051 \angle 0.466\text{rad} - 0.952 \angle -0.466\text{rad}$

$\sinh \gamma l = 0.452 \angle 84.4^\circ$

$Z' = Zc \sinh \gamma l = 387.3 \angle -6.05^\circ \ \Omega \times 0.452 \angle 84.4^\circ = 175.06 \angle 78.35^\circ$

$Z' = Z \sinh \gamma l / \gamma l = 225 \times 0.807 \angle 77.9 \times 0.452 \angle 84.4^\circ / (0.4688 \angle 83.95^\circ)$

$= 181.57 \angle 77.9 \times 0.9642 \angle 0.45^\circ = 175.07 \angle 78.35^\circ$

$2 \cosh \gamma l = e^{\gamma l} + e^{-\gamma l} = 1.051 \angle 0.466\text{rad} + 0.952 \angle -0.466\text{rad} = 1.790 \angle 1.42^\circ$

$\cosh \gamma l = 0.895 \angle 1.42^\circ$

$Y'/2 = (\cosh \gamma l - 1)/Z' = (0.895 \angle 1.42^\circ - 1) / 175.06 \angle 78.35^\circ = 614.57 \times 10^{-6} \angle 89.8^\circ$ mho

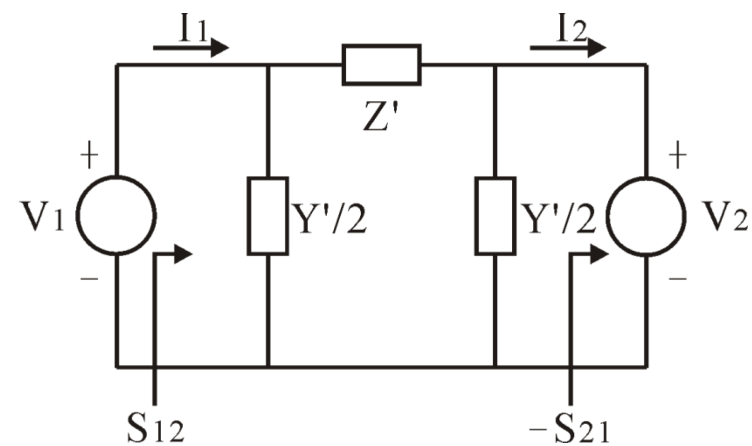
$Y/2 = (y l)/2 = (225 \times 5.38\times10^{-6} \angle 90^\circ)/2 = 605.25 \times 10^{-6} \angle 90^\circ$ mho

4.5 簡化模型(Simplified Models)

Long line (l > 150mile = 241.4 km): Use the Π equivalent circuit model with Z’ and Y’/2.

Medium length line (50mile < l < 150mile = 241.4 km): Use the Π equivalent circuit model with Z and Y/2 instead of Z’ and Y’/2.

Short line (l < 50mile = 80.5 km): Same as the medium length line except that we neglect Y/2.



$z = r + j\omega l \Rightarrow Z = zl$,

$y = g + j\omega c \Rightarrow Y = yl$,

$Z' = Z_c \sinh \gamma l$

$Y'/2 = (\cosh \gamma l - 1)/Z'$

$\gamma = (yz)^{0.5}$, $Z_c = (z/y)^{0.5}$

$\sinh \gamma l = (e^{\gamma l} - e^{-\gamma l})/2$, $\cosh \gamma l = (e^{\gamma l} + e^{-\gamma l})/2$

Ex 4.5 Consider the receiving-end voltage of a lossless open-circuited line and compare the results by use of the three models. V1 is fixed.

Open circuited => I2 =0 , lossless => $\alpha = 0$, $\gamma = j\,\beta$, assume β= 0.002 rad/mile

M1: Long line (l > 150mile):

$V_1 = V_2 \cosh \gamma l + Z_c I_2 \sinh \gamma l = V_2 \cosh \gamma l = V_2 (e^{\gamma l} + e^{-\gamma l})/2 = V_2 \cos \beta l$

$I_1 = I_2 \cosh \gamma l + (V_2 / Z_c) \sinh \gamma l = (V_2 / Z_c) \sinh \gamma l$

M2: Medium length line: Use the Π model with Z and Y/2 instead of Z' and Y'/2.

$V_1 = V_2 + Z' [I_2 + (Y'/2)V_2] = (1 + Z'Y'/2)V_2 + Z'I_2$

$= (1 + ZY/2)V_2 = [1 + (\gamma l)^2 /2]\, V_2 = [1 - (\beta l)^2 /2]\, V_2$

This is the first two terms in the Taylor series expansion of cos βl .

M3: Short line (l < 50mile = 80.5 km): Same as the medium length line (Y/2 = 0).

$V_1 = V_2 + Z' [I_2 + (Y'/2)V_2] = V_2$

This is the first term in the Taylor series expansion of cos βl .

(1) 50 miles => $\beta l = 0.1$ rad ,

M1: $V_1 = 0.995004\, V_2$, M2: $V_1 = 0.995000\, V_2$, M3: $V_1 = V_2$,

(2) 200 miles => $\beta l = 0.4$ rad ,

M1: $V_1 = 0.921\, V_2$, M2: $V_1 = 0.920\, V_2$, ~~M3: $V_1 = V_2$~~ ,

(1) 600 miles => $\beta l = 1.2$ rad ,

M1: $V_1 = 0.362\, V_2$, ~~M2: $V_1 = 0.280\, V_2$~~ (error ?), ~~M3: $V_1 = V_2$~~ (inaccurate),

4.6複數功率傳輸(長程或中程線路)(Complex Power Transmission: Long or Medium Lines)

Z between voltages V_1 and V_2

$$S_{12} = V_1 I_1^* = V_1[(V_1 - V_2)/Z]^* = |V_1|^2/Z^* - V_1 V_2^*/Z^*$$

$$= (|V_1|^2/|Z|)\, e^{j\angle Z} - (|V_1||V_2|/|Z|)\, e^{j\angle Z}\, e^{j\theta 12}$$

$$S_{21} = V_2 I_2^* = V_2((V_2 - V_1)/Z)^* = |V_2|^2/Z^* - V_2 V_1^*/Z^*$$

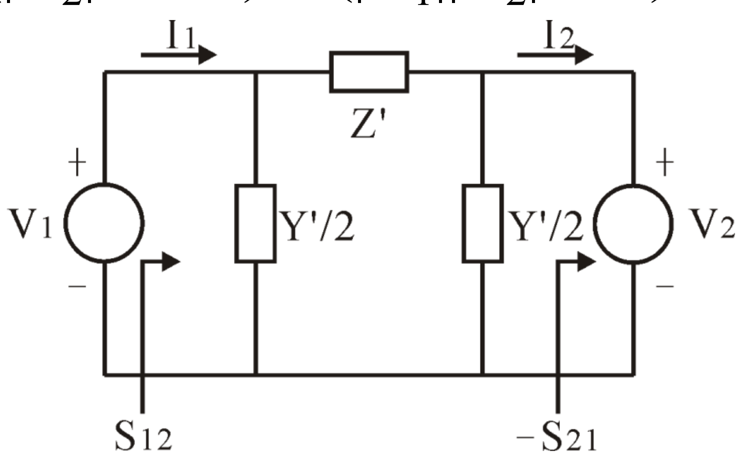
$$= (|V_2|^2/|Z|)\, e^{j\angle Z} - (|V_2||V_1|/|Z|)\, e^{j\angle Z}\, e^{-j\theta 12}$$

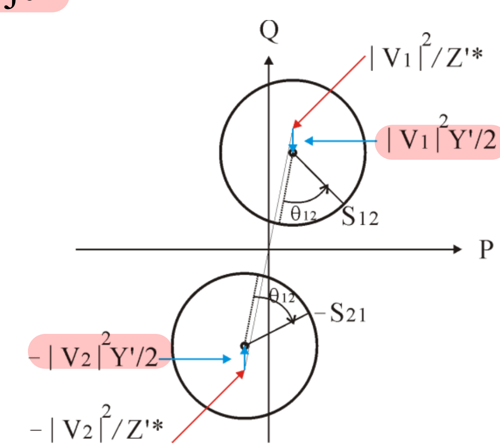
$$-S_{21} = -(|V_2|^2/|Z|)\, e^{j\angle Z} + (|V_2||V_1|/|Z|)\, e^{j\angle Z}\, e^{-j\theta 12}$$

Z’ and Y’/2 between voltages V_1 and V_2

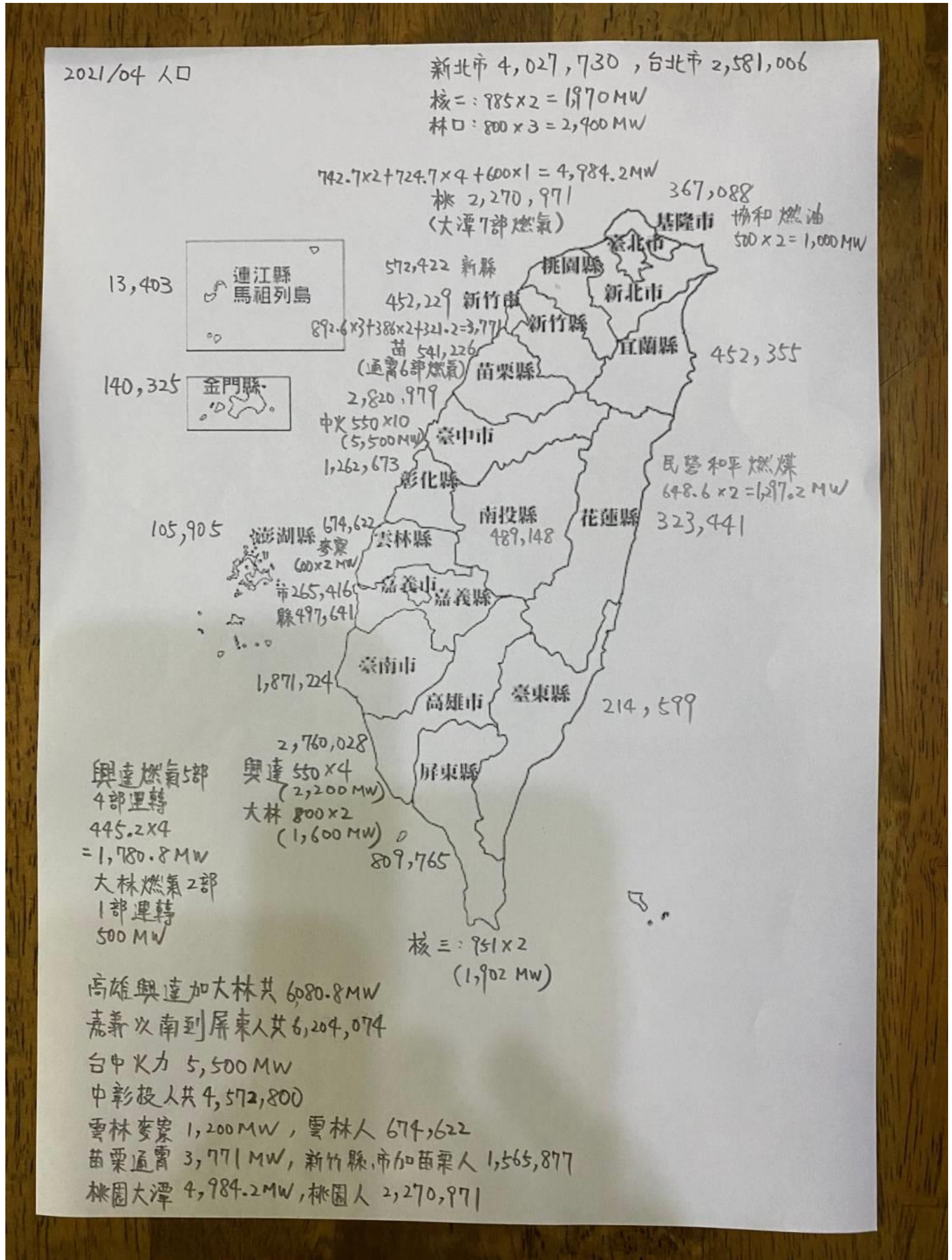
$$S_{12} = (Y'^*/2)|V_1|^2 + (|V_1|^2/Z'^*) - (|V_1||V_2|/Z'^*)\, e^{j\theta 12}$$

$$-S_{21} = -(Y'^*/2)|V_2|^2 - (|V_2|^2/Z'^*) + (|V_1||V_2|/Z'^*)\, e^{-j\theta 12}$$





台灣人口分布與發電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742.7x2+724.7x4+600x1 = 4,984.2MW
桃 2,270,971
(大潭7部燃氣)
367,088
基隆市
協和燃油
500x2 = 1,000MW
臺北市
桃園縣
新北市
13,403
連江縣
馬祖列島
572,422 新縣
452,229 新竹市
新竹縣
892.6x3+386x2+321.2=3,771
苗 541,226
(通霄6部燃氣)
苗栗縣
宜蘭縣
452,355
140,325
金門縣
2,820,979
中火 550x10
(5,500MW)
臺中市
1,262,673
彰化縣
民營和平燃煤
648.6x2=1,297.2MW
南投縣
489,148
花蓮縣
323,441
105,905
澎湖縣
674,622
麥寮
600x2MW
雲林縣
市265,416
縣497,641
嘉義市
嘉義縣
臺南市
1,871,224
高雄市
臺東縣
214,599
2,760,028
興達燃氣5部
4部運轉
445.2x4
=1,780.8MW
大林燃氣2部
1部運轉
500MW
興達 550x4
(2,200MW)
大林 800x2
(1,600MW)
屏東縣
809,765
核三：951x2
(1,902MW)
高雄興達加大林共6080.8MW
嘉義以南到屏東人共6,204,074
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雲林麥寮 1,200MW，雲林人 674,622
苗栗通霄 3,771MW，新竹縣.市加苗栗人 1,565,877
桃園大潭 4,984.2MW，桃園人 2,270,971

4.7線路的功率處理容量(Power-Handling Capability of Lines)

Power line are limited in their ability to deliver power. The two most important limits can be understood by considering thermal effects and stability.

When current flows in conductors, there are I^2R losses and heat is generated (T increased, T is limited 100°C). This loss of power reduces transmission efficiency.

If the cable gets too hot, the insulation will begin to deteriorate and may fail in time.

With limitations on maximum current and voltage there is a corresponding limitation on the MVA that can safely be transmitted.

The maximum angle θ_{12} is 90°, for stability, the maximum angle θ_{12} is 40°~50°, A lossless line with equal voltage magnitudes at each end as Ex 4.3.

$z = r + j\omega l = j\omega l$ series impedance per meter

$y = g + j\omega c = j\omega c$ shunt admittance per meter to neutral

$Z_c = (z/y)^{0.5} = (j\omega l / j\omega c)^{0.5} = (l / c)^{0.5} = (L/C)^{0.5}$,

$\gamma = (z\, y)^{0.5} = \alpha + j\beta = j\beta = (j\omega l\, j\omega c)^{0.5} = j\omega\, (l\, c)^{0.5}$

$\sinh \gamma l = (e^{\gamma l} - e^{-\gamma l})/2 = (e^{j\beta l} - e^{-j\beta l})/2 = j \sin \beta l$

$\cosh \gamma l = (e^{\gamma l} + e^{-\gamma l})/2 = (e^{j\beta l} + e^{-j\beta l})/2 = \cos \beta l$

$Z' = Z_c \sinh \gamma l = jZ_c \sin \beta l$

$Y'/2 = (\cosh \gamma l - 1)/Z' = (Y/2) \tanh(\gamma l/2)/(\gamma l/2) = (j\omega C/2) \tan(\beta l/2)/(\beta l/2)$

Assume $|V_1| = |V_2|$, $P_{SIL} = |V_1|^2 / Z_c$

$S_{12} = (Y'^*/2)|V_1|^2 + (|V_1|^2 / Z'^*) - (|V_1||V_2|/Z'^*)\, e^{j\theta 12}$

$P_{12} = -\,[|V_1||V_2| / (-\, jZ_c \sin \beta l)]\, (j\sin \theta_{12}) = (|V_1|^2 / Z_c)\, (\sin \theta_{12} / \sin \beta l)$

$P_{12} = P_{SIL}\, (\sin \theta_{12} / \sin \beta l)$

$-S_{21} = -(Y'^*/2)|V_2|^2 - (|V_2|^2 / Z'^*) + (|V_1||V_2|/Z'^*)\, e^{-j\theta 12}$

Ex 4.6 Assume that β =0.002 rad/mile and $\theta_{12} = 45\,^{\circ}$. Find P12/PSIL as a function of line length.

Assume $|V_1| = |V_2|$, $P_{SIL} = |V_1|^2 / Z_c$

$S_{12} = (Y'^*/2)|V_1|^2 + (|V_1|^2 / Z'^*) – (|V_1||V_2|/Z'^*)\, e^{j\theta 12}$

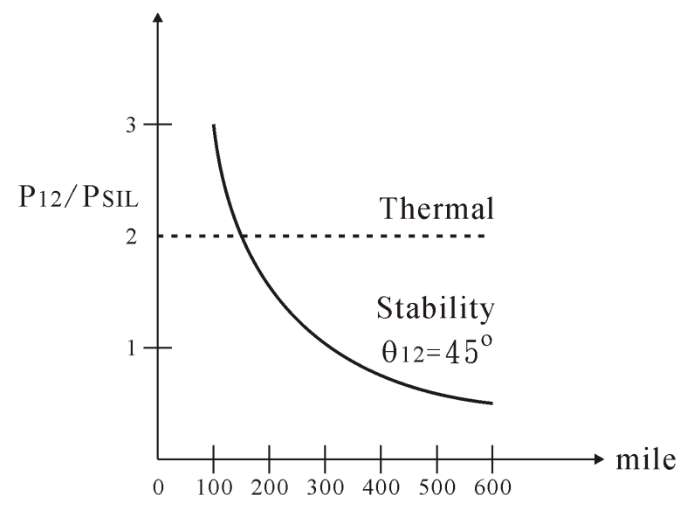
$P_{12} = – [|V_1||V_2| / (- jZ_c \sin \beta l)]\, (j\sin \theta_{12}) = (|V_1|^2 / Z_c)\, (\sin \theta_{12} / \sin \beta l)$

$P_{12} = P_{SIL}\, (\sin \theta_{12} / \sin \beta l) \Rightarrow P_{12} / P_{SIL} = (\sin \theta_{12} / \sin \beta l)$

$\theta_{12} = 45\,^{\circ}$, $\beta l = 0.002$ rad/mile $\times\, l = 0.1146\,^{\circ}$/mile $\times\, l$

$P_{12} / P_{SIL} = 0.707 / \sin (0.1146\,^{\circ}\text{/mile} \times l\,)$

We see that for short lines the thermal limit governs, where as for long lines the stability limit prevails.

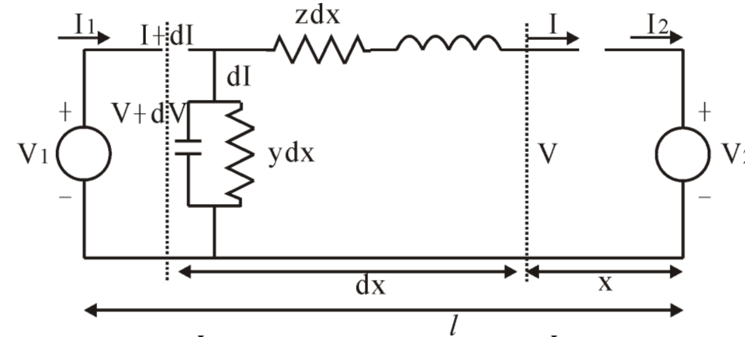


4.8結論與習題(Summary)

The long line equation is frequently used.

$$V_1 = V_2 \cosh \gamma l + Z_c I_2 \sinh \gamma l$$

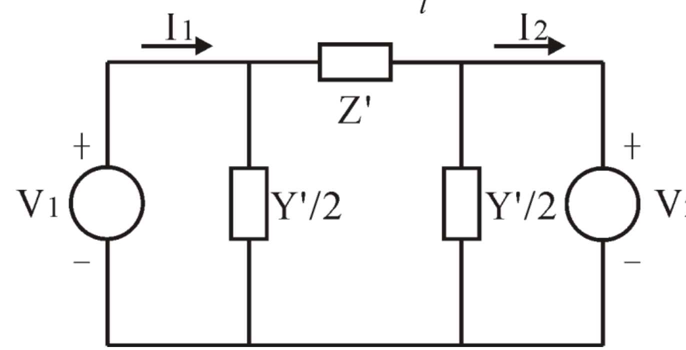
$$I_1 = I_2 \cosh \gamma l + (V_2 / Z_c) \sinh \gamma l$$



The Π equivalent circuit

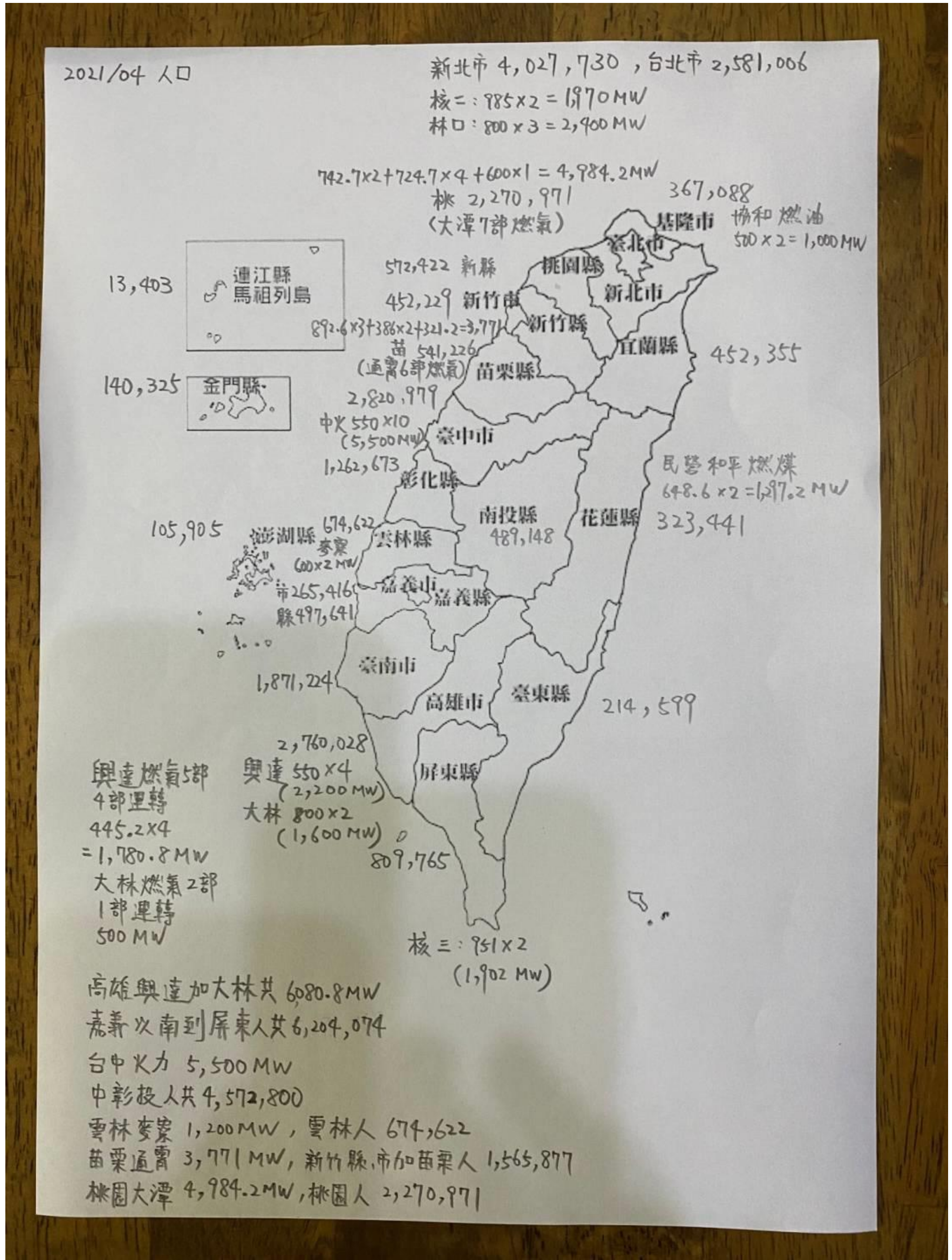
$$Z' = Zc \sinh \gamma l$$

$$Y'/2 = (\cosh \gamma l - 1)/Z'$$



Finally, we note that thermal effects limit the power handling capability of short and medium length lines, where as stability requirements impose the limitations on long lines.

台灣人口分布與發電



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