100 年特種考試地方政府公務人員考試試題　　代號：33980　全一頁

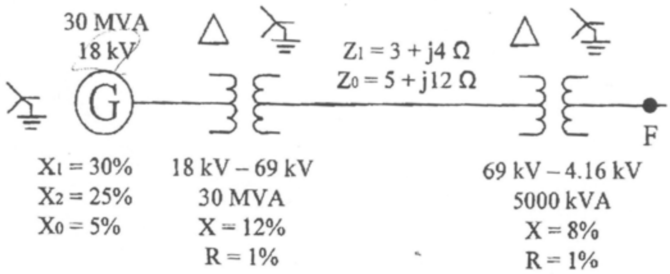
等　別：三等考試
類　科：電力工程
科　目：電力系統
考試時間：2 小時　　座號：____________

※注意：(一)可以使用電子計算器。
(二)不必抄題，作答時請將試題題號及答案依照順序寫在試卷上，於本試題上作答者，不予計分。

一、有一條三相傳輸線，每相線路阻抗均為 Z = 5+j60 Ω，當送電端線電壓為 220 kV、實功率與虛功率為 200 MW 與 25 Mvar 時，請計算接收端之線電壓與功率因數、傳輸線之實功率損失與虛功率損失。(20 分)

二、請說明求解電力潮流 (power flow) 的目的，當使用牛頓-拉普森法 (Newton-Raphson method) 解電力潮流時，請說明匯流排的分類、電力潮流方程式 (power flow equation)、賈克比亞 (Jacobian) 矩陣、疊代方式、收斂條件。(20 分)

三、針對下圖之電力系統，其正序、負序、零序參數值均標示於圖形中，其中發電機與變壓器之阻抗百分比值使用自身之額定值。如選用 100 MVA 為功率基底值及發電機端 18 kV 為線電壓基底值，請畫出以 pu 值標示之正序、負序、零序相序網路圖。當發電機端線電壓為 18.5 kV，且在 F 點發生 B 相與 C 相間之線對線故障時，請計算故障電流之 A、B、C 相 pu 值與真實值。(20 分)



四、有一部圓軸型同步發電機，經由電抗值 $X_L = 0.4$ 之傳輸線接至無限匯流排 (infinite bus)，已知發電機電動勢 (emf) $E = 1.8$、單位慣量常數 (per unit inertia constant) $H = 5$ 秒、直軸與交軸同步電抗 $X_d = X_q = 1$、無限匯流排電壓 $V_\infty = 1$，故障前發電機輸出之實功率 $P = 0.55$。請寫出擺動方程式、功率角方程式、穩態時之功率角與振動頻率。當傳輸線之無限匯流排端發生一個持續 4 電力週期之三相短路故障，之後再清除故障，請用等面積 (equal area) 圖描述發電機功率角之變動情形與穩定性的要求。(20 分)

五、請分別畫出利用差動電驛 (differential relay) 保護匯流排與變壓器之單線圖，說明保護原理與動作條件。(20 分)

100 地特三等「電力系統」申論題解答

一、

$Z = 5+j60$

$220\,kV$

$P = 200\,MW$

$Q = 25\,Mvar$

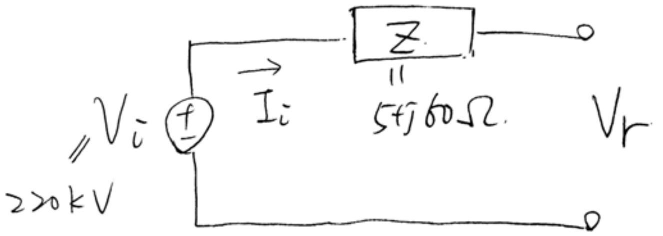
$|S| = \sqrt{P^2+Q^2} = \sqrt{(200M)^2+(25M)^2} = 201.55\,MW$

$P = \sqrt{3}\,V_L I_L \cos\theta_p = 3 V_p I_p \cos\theta_p$

$Q = \sqrt{3}\,V_L I_L \sin\theta_p$

$|S| = \sqrt{3}\,V_L I_L = \sqrt{3}\cdot 220\,kV\cdot I_L = 201.556\,MW$

$I_L = 528.948\,A$



$\dfrac{Q}{P} = \dfrac{\sqrt{3}\,V_L I_L \sin\theta_p}{\sqrt{3}\,V_L I_L \cos\theta_p}$

$= \tan\theta_p = \dfrac{25}{200} = \dfrac{1}{8}$

$\theta_p = 7.125^\circ$

$\cos\theta_p = 0.99227$

$I_i = 528.948\angle -7.125^\circ$

$V_r = 220\,kV - 528.9\angle -7.125^\circ \cdot Z$

$= 220k - 528.9\angle -7.125^\circ \cdot (5+j60)$

$= 220k - 528.9\left[\cos(-7.125^\circ) + j\sin(-7.125^\circ)\right](5+j60)$

$= 220k - 528.9\left[0.99228 - j0.124\right](5+j60)$

$= 220k - 528.9\left[4.9614 + j59.5368 - j0.62 + 7.44\right]$

$= 220k - \left[6571.5 + j31220.0\right]$

$= 213428.5 - j31220$

$\therefore$ 傳輸線實功率損失 $P = 6571.5\,W$

虛功率損失 $Q = 31220\,Var$

接收端的線電壓 $= \sqrt{213428.5^2 + 31220^2} = 215699.8\,V$

$= 215.7\,kV$

$V_r = 213428.5 - j31220$

$I_r = 528.9(0.99228 - j0.124)$

$\angle V_r = -8.322^\circ$

$\angle I_r = -7.125^\circ$

$\angle V_r - \angle I_r = -1.197^\circ$

接收端的功因 $= \cos(-1.197^\circ) = 0.99978$

二、

求解电力潮流目的

(1) 模擬供电系統正常及非正常的運轉狀態

(2) 計算供电系統內各匯流排的电压大小，相角及电压降

(3) 計算系統內各变压器及电纜饋線的負載电流或电力潮流，決定各供电設備的额定容量

(4) 驗證確認供电系統於正常及非正常運轉狀態時，供电模式及系統架构可提供高可靠度的电力，能安全無虞的滿足[redacted]營運的最大电力負載需求

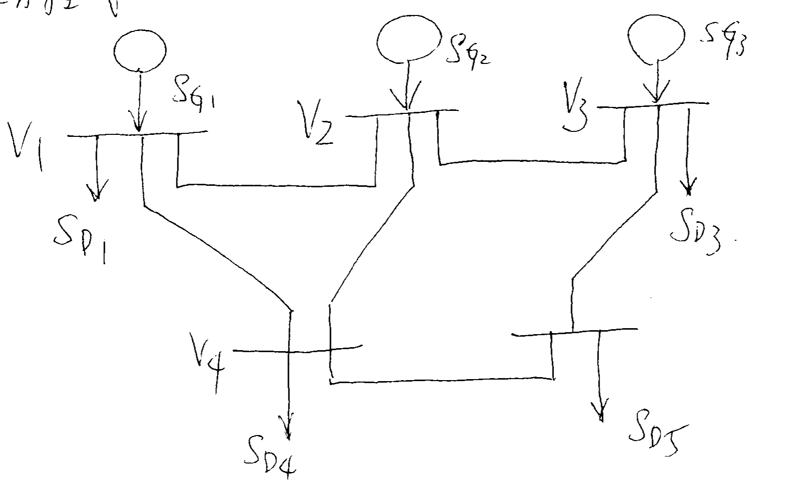
簡單来說，是适時，視需要，在容許的电压或频率範圍內，以可靠且經济的方式，將电力輸送至用戶。

匯流排分類 1、电压源。稱為弛放匯流排 (slack bus) 或搖擺匯流排或电压參考匯流排

2、P, |V| 电源电压控制匯流排 (voltage control bus)

3、P, Q 电源負載匯流排 (load bus)

电力潮流方程式：



S_{Gi}：發电功率

S_{Di}：負載功率

V_i：匯流排电压

$I_i = \sum_{k=1}^{n} y_{ik} V_k \qquad \underset{\sim}{I} = \underset{\approx}{Y_{bus}} \underline{V} \quad , i=1,2,\cdots,n$

第i個匯流排的功率：

$S_i = V_i I_i^* = V_i \left(\sum_{k=1}^{n} y_{ik} V_k \right)^* = V_i \sum_{k=1}^{n} y_{ik}^* V_k^*$

$V_i = |V_i| e^{j\angle V_i} = |V_i| e^{j\theta_i} \quad , \quad \theta_i = \angle V_i$

$\theta_{ik} = \theta_i - \theta_k$

$y_{ik} = g_{ik} + j b_{ik}$

電導 電納

$S_i = \sum_{k=1}^{n} |V_i||V_k| e^{j\theta_{ik}} (g_{ik} - j b_{ik})$

$= \sum_{k=1}^{n} |V_i||V_k| (\cos\theta_{ik} + j\sin\theta_{ik})(g_{ik} - j b_{ik})$

複數電力潮流方程式

$$\Rightarrow \begin{cases} P_i = \sum_{k=1}^{n} |V_i||V_k| [g_{ik}\cos(\theta_i - \theta_k) + b_{ik}\sin(\theta_i - \theta_k)] \\ Q_i = \sum_{k=1}^{n} |V_i||V_k| [g_{ik}\sin(\theta_i - \theta_k) - b_{ik}\cos(\theta_i - \theta_k)] \end{cases}$$

$\underline{\theta} = \begin{bmatrix} \theta_2 \\ \vdots \\ \theta_n \end{bmatrix}, \quad |\underline{V}| = \begin{bmatrix} |V_2| \\ \vdots \\ |V_n| \end{bmatrix}, \quad \vec{X} = \begin{bmatrix} \underline{\theta} \\ |\underline{V}| \end{bmatrix}$

$$\begin{cases} P_i(\vec{X}) - P_i = 0 \\ Q_i(\vec{X}) - Q_i = 0 \end{cases} \Rightarrow \underline{f}(\vec{X}) = \begin{bmatrix} P_2(\vec{X}) - P_2 \\ \vdots \\ P_n(\vec{X}) - P_n \\ \hline Q_2(\vec{X}) - Q_2 \\ \vdots \\ Q_n(\vec{X}) - Q_n \end{bmatrix} = 0$$

f 的 Jacobian $\vec{J} = \begin{bmatrix} \vec{J}_{11} & \vec{J}_{12} \\ \vec{J}_{21} & \vec{J}_{22} \end{bmatrix}$

(4)

$$\underset{\sim}{J}_{11} \sim \frac{\partial P_i(\vec{x})}{\partial \theta_K}, \quad \underset{\sim}{J}_{12} = \frac{\partial P_i(\vec{x})}{\partial |V_K|}$$

$$\underset{\sim}{J}_{21} \sim \frac{\partial Q_i(\vec{x})}{\partial \theta_K}, \quad \underset{\sim}{J}_{22} = \frac{\partial Q_i(\vec{x})}{\partial |V_K|}$$

$$\underset{\sim}{J}^{\nu} \Delta \underline{x}^{\nu} = -f(\underline{x}^{\nu}) \text{ — 疊代}$$

$$\Delta \underline{P}(\vec{x}) = \begin{bmatrix} P_2 - P_2(\vec{x}) \\ \vdots \\ P_n - P_n(\vec{x}) \end{bmatrix} \qquad \Delta \underline{Q}(\vec{x}) = \begin{bmatrix} Q_2 - Q_2(\vec{x}) \\ \vdots \\ Q_n - Q_n(\vec{x}) \end{bmatrix}$$

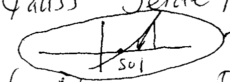
$$\underline{f}(\vec{x}) = -\begin{bmatrix} \Delta \underline{P}(\vec{x}) \\ \Delta \underline{Q}(\vec{x}) \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} \underset{\sim}{J}_{11}^{\nu} & \underset{\sim}{J}_{12}^{\nu} \\ \underset{\sim}{J}_{21}^{\nu} & \underset{\sim}{J}_{22}^{\nu} \end{bmatrix} \begin{bmatrix} \Delta \underline{\theta}^{\nu} \\ \Delta |\underline{V}|^{\nu} \end{bmatrix} = \begin{bmatrix} \Delta \underline{P}(\vec{x}^{\nu}) \\ \Delta \underline{Q}(\vec{x}^{\nu}) \end{bmatrix}$$

⇒ Jacobian 特定：每一个子矩陣中非对角線的項包含了傳輸線 Π 形等效电路的橋接元件。如果兩个兩匯流排之間沒有直接的連接，則对应的橋接导纳为零。則矩陣中就会有一个 0。

如图的 $\underset{\sim}{Y}_{bus}$ 中 $y_{15} = 0$.

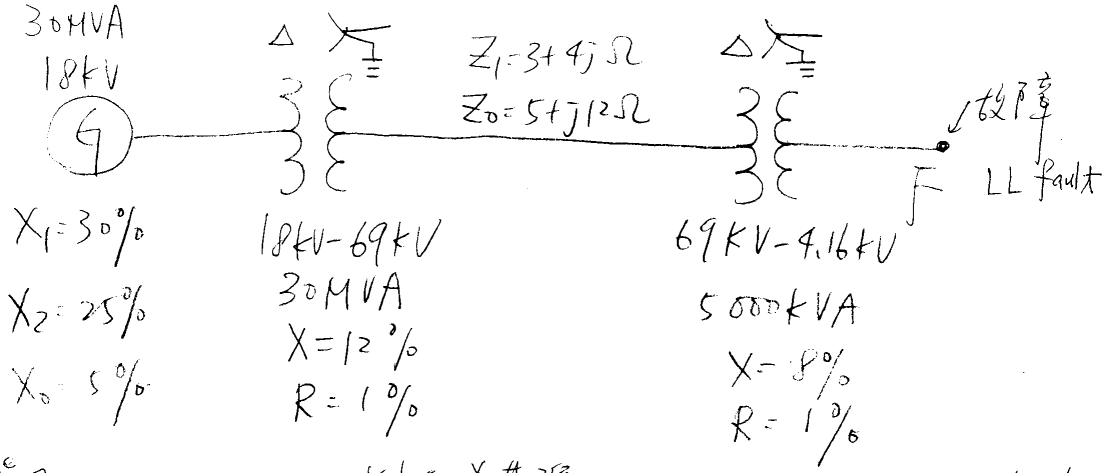
疊代方式：
- 高斯塞德爾法（Gauss-Seidel method）— ①
- 牛頓-拉夫生疊代法（Newton-Raphson (N-R) method）— ②



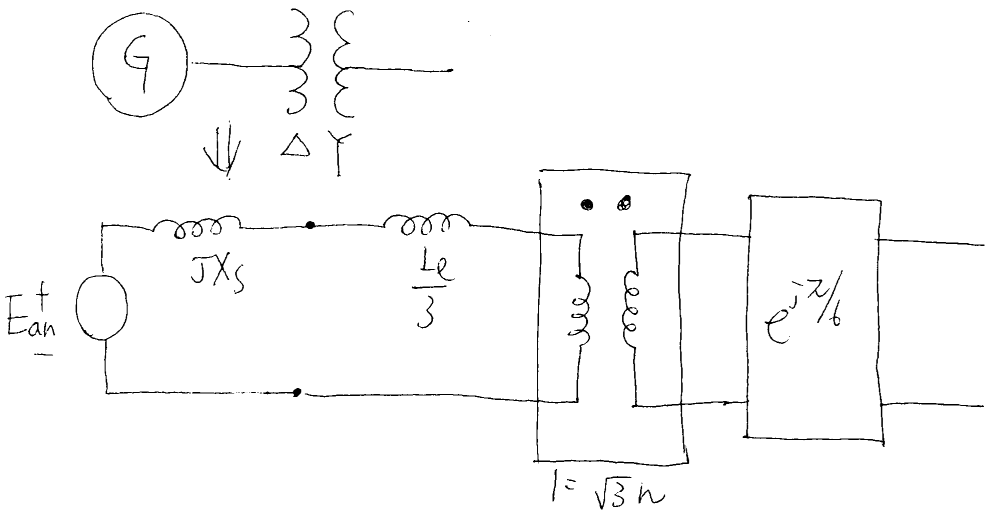
法 1 的收斂條件為矩陣為正定对稱（symmetric positive-definite）或是嚴格且对角為主的矩陣（strictly or irreducibly diagonally dominant）

法 2 的收斂是猜的解在实際解的附近

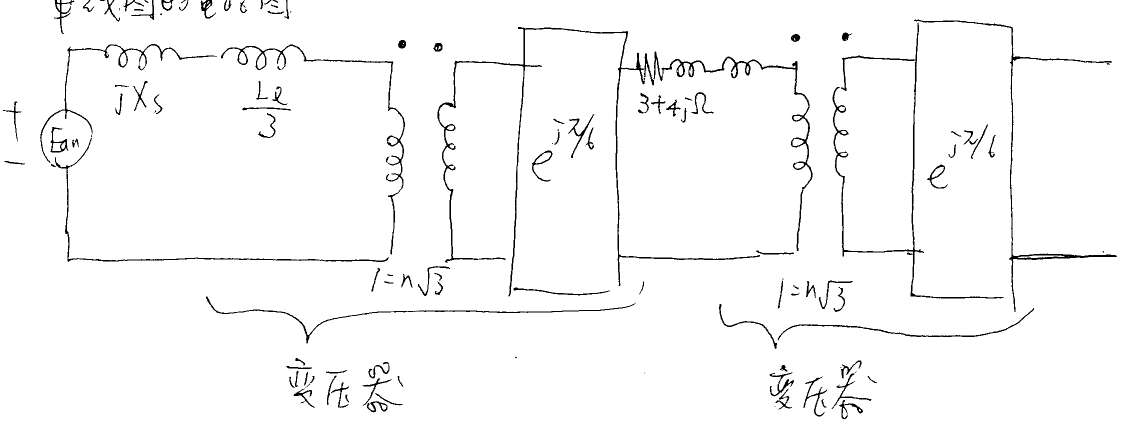
三、



選用 100MVA，18kV 線電壓為基準，發電機端線電壓 18.5kV



單線圖的電路圖



以 100MVA, 18kV 為準

$$Z_{base} = \frac{(18\times10^3)^2}{100\times10^6} = \frac{18^2\times10^6}{100\times10^6} = 3.24$$

$$I_{base} = \frac{100\times10^6}{3}\times\frac{\sqrt{3}}{18\times10^3} = 3207.5$$

$$Z_{1線路} = \frac{3+4j}{3.24} = 0.926 + j1.23456$$

$$Z_{0線路} = \frac{5+12j}{3.24} = 1.5432 + j3.7037$$

$$Z_{T1}^{new} = (0.01+j0.12)\left(\frac{18k}{18k}\right)^2\left(\frac{100}{30}\right) = 0.0333+j0.4$$

$$Z_{T2}^{new} = (0.01+j0.08)\left(\frac{4.16k}{18k}\right)\left(\frac{100}{5}\right) = (0.01+j0.08)4.6222$$

$$= 0.0462 + j0.36978$$

$$|E_s| = \frac{18.5}{18} = 1.0278$$

$$X_{+}^{new} = \frac{0.3j}{3.24} = 0.0926j$$

$$X_{-}^{new} = \frac{0.25j}{3.24} = 0.0772j$$

$$X_{0}^{new} = \frac{0.05j}{3.24} = 0.015432j$$

用pu表示相序圖，忽略相位移器

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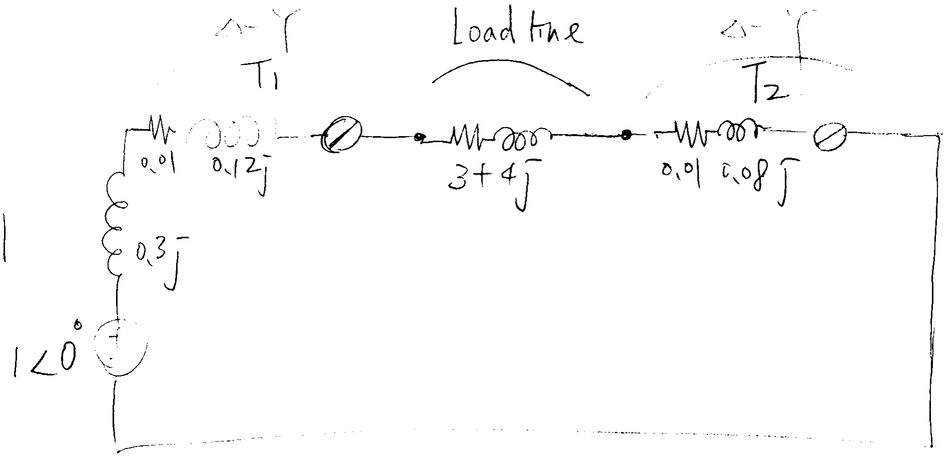
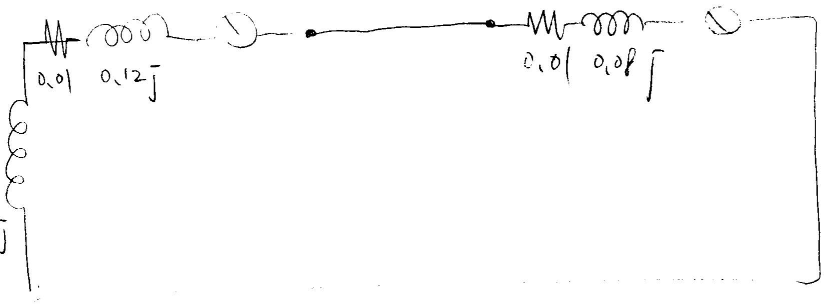
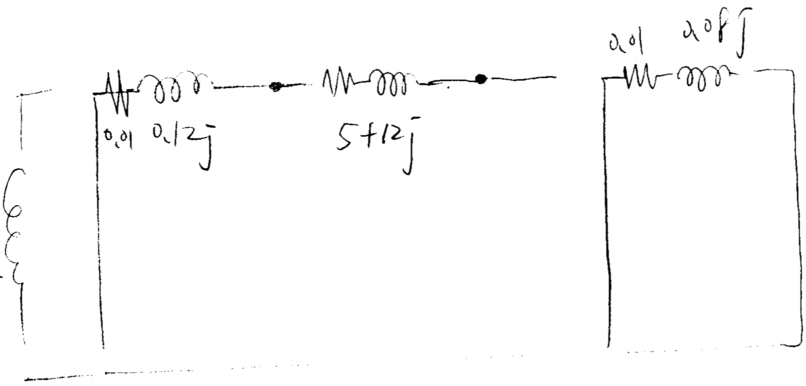
正序 1


T1
Load line
T2
0.01
0.12j
3+4j
0.01
0.08j
0.3j
1∠0°

負序 2

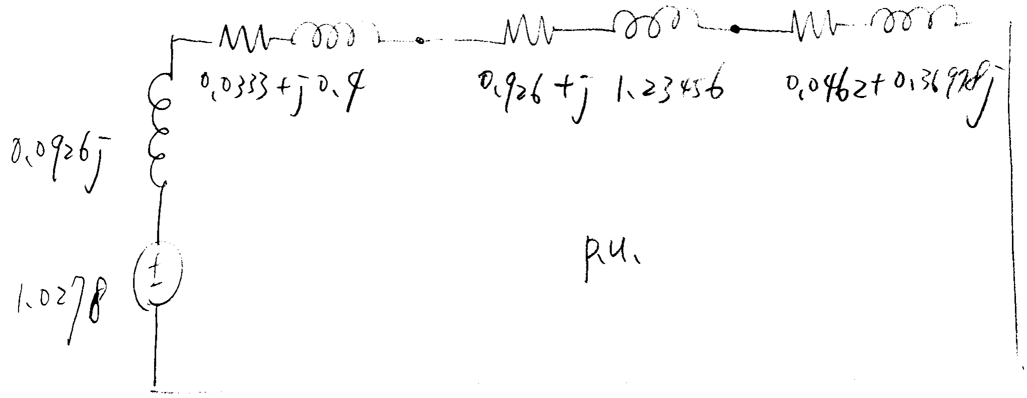

0.01
0.12j
0.01
0.08j
0.25j

零序 0

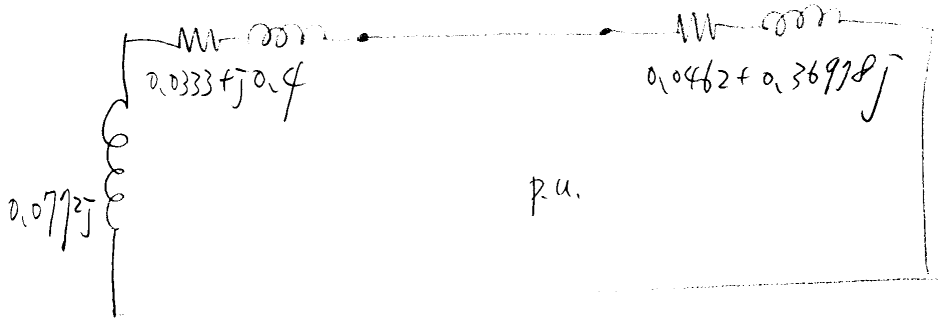

0.01
0.12j
5+12j
0.01
0.08j
0.05j

8

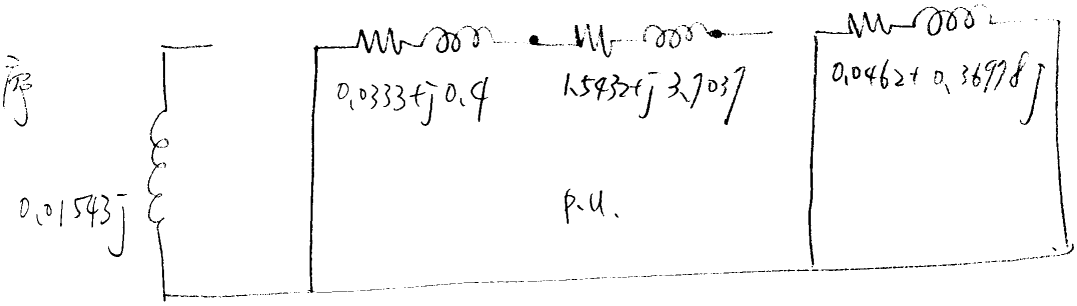
正序



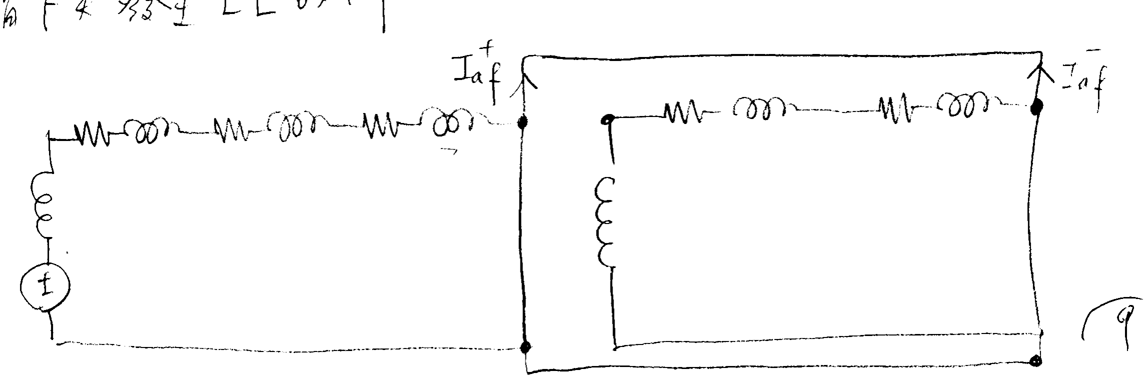
負序

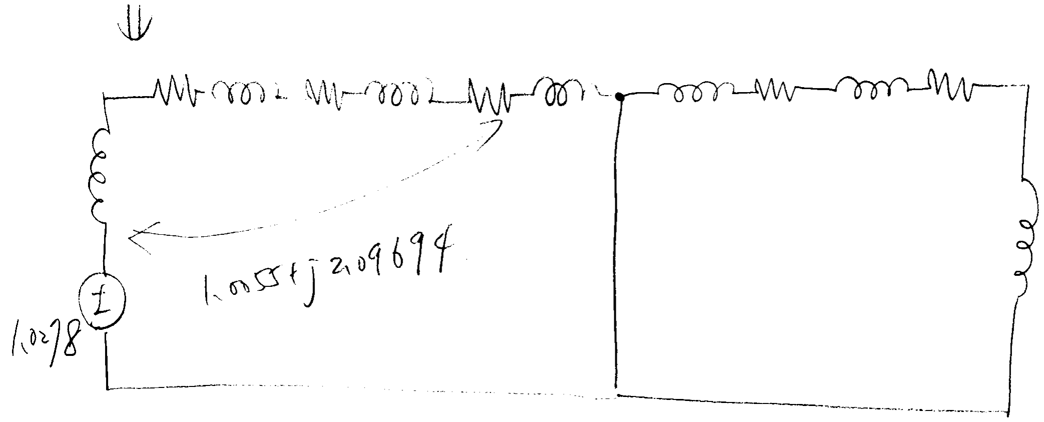


零序



當F點發生LL故障：





$$Z_{ag}^{+} = \underline{0.0926j} + 0.0333 + \underline{j0.4} + 0.926 + \underline{j1.23456} + 0.0462 + \underline{0.36918j}$$

$$= 1.0055 + j2.09694$$

$$Z_{ag}^{-} = \underline{0.0772j} + 0.0333 + \underline{j0.4} + 0.0462 + \underline{0.36918j}$$

$$= 0.0795 + j0.84698$$

$$I_{af}^{+} = -I_{af}^{-} = \frac{1.0278}{1.0055+j2.09694+0.0795+j0.84698}$$

$$= \frac{1.0278}{1.085+j2.94392} = 0.1133-0.3074j$$

$$I_{af}^{0} = 0$$

$$I_{af} = I_{af}^{+} + I_{af}^{-} + I_{af}^{0} = 0$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}_{pu} \cdot 3207.5 = \text{實際值} = \begin{bmatrix} \\ -1707-335j \\ 1707+335j \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}_{pu} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ 0.1133-0.3074j \\ -0.1133+0.3074j \end{bmatrix} = \begin{bmatrix} 0 \\ -0.5324-0.1962i \\ 0.5324+0.1962i \end{bmatrix}$$

(1). 轉子角 $= \theta(t) = \omega_0 t + \theta_0 + \Delta\theta(t) \Rightarrow \dot{\theta}(t) = \omega_0 + \Delta\dot{\theta}(t) \approx \omega_0$

$\phi = \phi_{max}\cos\theta \Rightarrow$ a相：$\lambda_{aa'}(t) = N\phi_{max}\cos[\omega_0 t + \theta_0 + \Delta\theta(t)]$

$$e_{aa'}(t) = -\frac{d\lambda_{aa'}}{dt} = (\omega_0 + \Delta\dot{\theta})N\phi_{max}\sin[\omega_0 t + \theta_0 + \Delta\theta(t)]$$

$$\approx \underbrace{\omega_0 N\phi_{max}}_{E_{max}}\cos\left[\omega t + \theta_0 + \Delta\theta(t) - \frac{\pi}{2}\right]$$

$\delta = \underbrace{\theta_0 + \Delta\theta}_{\text{轉子角(在同步旋轉參考架構下)}} - \frac{\pi}{2}$；內部電壓相角(電工角)

系統瞬間發電机功率(p.u.) $= p_{3\phi}(t) = P_G(\delta) = \frac{|E_a||V_\infty|}{\tilde{X}_d}\sin\delta + \frac{|V_\infty|^2}{2}\left(\frac{1}{\hat{X}_q} - \frac{1}{\tilde{X}_d}\right)\sin 2\delta$

$= a\sin\delta(t) + b\sin 2\delta(t)$

故障前：$P_M^0 = 3P_G(\delta^0)$ → 單相功率

渦輪机供給的机械功率

$\Rightarrow$ 故障後：$P_M^0 = 3P_G(\delta) + \frac{d}{dt}W_{kinetic} + P_{friction}$

$$W_{kinetic} = \frac{1}{2}J\dot{\theta}^2 \Rightarrow \frac{dW_{kinetic}}{dt} = J\dot{\theta}\ddot{\theta} \approx J\omega_0\ddot{\theta} \cong J\omega_0[\Delta\ddot{\theta}(t)]$$

$(\ddot{\theta} = \Delta\ddot{\theta}(t),\ \dot{\theta}(t) = \omega_0 + \Delta\dot{\theta}(t))\ (\dot{\delta} = \Delta\dot{\theta},\ \ddot{\delta} = \Delta\ddot{\theta})$

$\therefore \begin{cases} \frac{dW_{kinetic}}{dt} = J\omega_0\ddot{\delta} \\ f_0 = 60\,Hz \end{cases}$，又正規化 $\boxed{\frac{J\omega_0}{S_B^{3\phi}} = \frac{\frac{1}{2}J\omega_0^2}{S_B^{3\phi}}\frac{2}{\omega_0} = \frac{1}{\pi f_0}\frac{W_{kinetic}^0}{S_B^{3\phi}} = \frac{H}{\pi f_0}}$

$H = \frac{W_{kinetic}^0}{S_B^{3\phi}}$ (百万焦耳/百万伏安 = S; H ~ 1~10 S)

$$P_{friction} = k\dot{\theta}^2 = k(\omega_0 + \Delta\dot{\theta})^2 = k\omega_0^2 + 2k\omega_0\Delta\dot{\theta} + k(\Delta\dot{\theta})^2$$

$$\approx k\omega_0^2 + 2k\omega_0\Delta\dot{\theta} = k\omega_0^2 + 2k\omega_0\dot{\delta}$$

$\therefore P_M^0 = 3P_G(\delta) + \frac{d}{dt}W_{kinetic} + P_{friction} \Rightarrow \frac{P_M^0}{S_B^{3\phi}} = \frac{3P_G(\delta)}{S_B^{3\phi}} + \frac{J\omega_0\ddot{\delta}}{S_B^{3\phi}} + \frac{2k\omega_0\dot{\delta}}{S_B^{3\phi}}$

$$\Rightarrow \frac{P_M^0}{S_B^{3\phi}} = \frac{H}{\pi f_0}\ddot{\delta} + \frac{2k\omega_0}{S_B^{3\phi}}\dot{\delta} + \frac{3P_G(\delta)}{S_B^{3\phi}}$$

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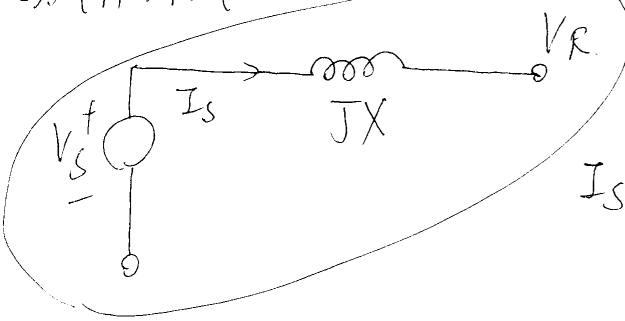
∴所以此標么物理的方程式

$$\Rightarrow M\ddot{\delta}+D\dot{\delta}+P_G(\delta)=P_M^0 \longrightarrow$$ 為 swing equation 搖擺方程式

功率角方程式：



$$\begin{cases} V_S=V_1\angle\delta \\ V_R=V_2\angle 0^\circ \end{cases}$$

$$\dot{I}_S=\frac{V_1\angle\delta-V_2}{jX}=\frac{V_1\cos\delta-V_2+jV_1\sin\delta}{jX}$$

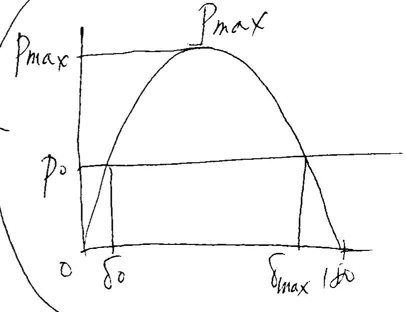
$$P_S+jQ_S=V_S I_S^*=V_1(\cos\delta+j\sin\delta)\left(\frac{V_1\cos\delta-V_2-jV_1\sin\delta}{-jX}\right)$$

$$=\frac{V_1\left(\cos\delta V_1\cos\delta-\cos\delta V_2-\cancel{jV_1\sin\delta\cos\delta}+\cancel{j\sin\delta V_1\cos\delta}-j\sin\delta V_2+\sin\delta V_1\sin\delta\right)}{-jX}$$

$$=\frac{V_1(V_1-\cos\delta V_2-j\sin\delta V_2)}{-jX}=\frac{(V_1^2-\cos\delta V_1V_2)-j\sin\delta V_1V_2}{-jX}$$

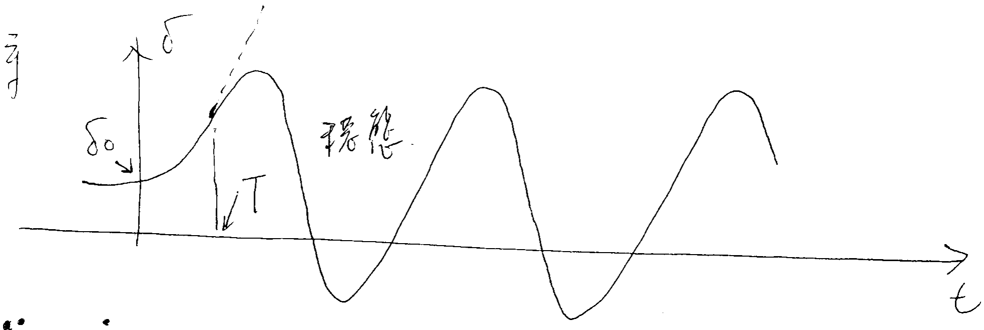
$$=\frac{\sin\delta V_1V_2+j(V_1^2-V_1V_2\cos\delta)}{X}$$

$$P_e=P_S=P_R=\frac{V_1V_2}{X}\sin\delta=P_{max}\sin\delta$$



∴在純電抗網路中的方程式 $P_e=P_{max}\sin\delta$ 即為功率角方程式

穩態時



$M\ddot{\delta}+D\dot{\delta}+P_G(\delta)=P_M^0$ ，令 $\delta=\delta^0+\Delta\delta$

$$P_G(\delta)=P_G(\delta^0+\Delta\delta)=P_G(\delta^0)+\frac{dP_G(\delta^0)}{d\delta}$$

$$\Rightarrow M\Delta\ddot{\delta}+D\Delta\dot{\delta}+J=0 \overset{解}{\Rightarrow} Ms^2+Ds+J=0$$

$$\Rightarrow s_{1,2}=\frac{-D\pm\sqrt{D^2-4MJ}}{2M}=\alpha\pm j\omega$$

$$=\frac{-D\pm j\sqrt{4MJ-D^2}}{2M}, \quad MJ\gg D^2$$

$$\therefore \omega=\sqrt{\frac{4MJ-D^2}{4M^2}}\approx\sqrt{\frac{4MJ}{4M^2}}=\sqrt{\frac{J}{M}}$$

$X_L=0.4$, $E=1.8$, $H=5s$, $X_d=X_q=1$, $V_\infty=1$, $P=0.55$

$$P_G(\delta^0)=\frac{|E_a||V_\infty|}{\tilde{X}_d}\sin\delta^0=\frac{1.8\cdot 1}{1+0.4}\sin\delta^0=1.286\sin\delta^0$$

$$\tilde{X}_d=X_L+X_d=0.4+1$$

$$0.55=1.286\sin\delta^0\Rightarrow\delta^0=25.32^\circ=0.442\text{ rad}$$

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$$J=\frac{dP_G(\delta^0)}{d\delta}=1.286\cos\delta^0=1.1624$$

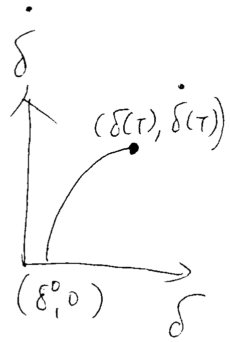
$$\omega=\left(\frac{J}{M}\right)^{1/2}=\left(\frac{J}{H/\pi f_0}\right)^{1/2}=\left(\frac{J\pi f_0}{H}\right)^{1/2}=\sqrt{\frac{1.1624\cdot\pi\cdot 60}{5}}\simeq 6.6197$$

$\Rightarrow f \fallingdotseq 1.053\text{Hz}$

$\delta=\delta^0,\ \dot\delta=0,\ P_G(\delta^0)=P_M^0$

CB open = $D=0 \Rightarrow M\ddot\delta=P_M^0,\quad 0<t<T$

$\Rightarrow \begin{cases} \dot\delta(t)=\dfrac{P_M^0}{M}t+\dot\delta(0)=\dfrac{2\pi f_0 P_M^0}{H}t \\ \delta(t)=\dfrac{P_M^0}{2M}t^2+\delta^0=\dfrac{2\pi f_0 P_M^0}{2H}t^2+\delta^0 \end{cases}$



$\delta-\delta^0=\dfrac{P_M^0}{2M}t^2=\dfrac{M}{2P_M^0}\left(\dfrac{P_M^0}{M}t\right)^2=\dfrac{M}{2P_M^0}\dot\delta^2$

$t=T \Rightarrow M\ddot\delta+P_G(\delta)=P_M^0$ 令 $p(\delta)=P_G(\delta)-P_M^0$

$\Rightarrow M\ddot\delta+p(\delta)=0$，令 $W(\delta)=\int_{\delta^0}^{\delta}p(u)du$

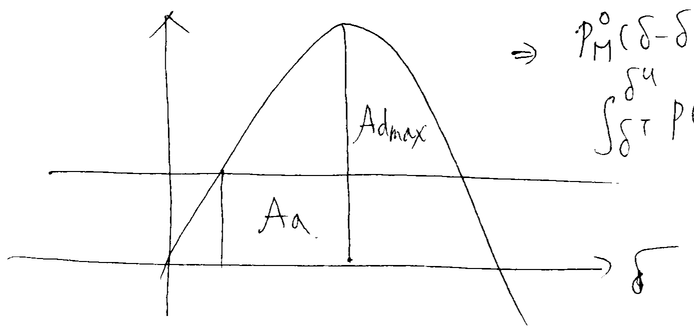
$V(\delta)=\frac{1}{2}M\dot\delta^2+\int_{\delta^0}^{\delta}p(u)du \Rightarrow V(\delta_T)<W_{max}$ 穩定

$\Rightarrow \frac{1}{2}M\dot\delta_T^2+\int_{\delta^0}^{\delta_T}p(u)du<\int_{\delta^0}^{\delta^u}p(u)du$

$\Rightarrow \frac{1}{2}M\dot\delta_T^2<\int_{\delta_T}^{\delta^u}p(\delta)d\delta$

又 $\frac{1}{2}M\cdot\dot\delta_T^2=P_M^0(\delta-\delta^0)$

$\therefore P_M^0(\delta-\delta^0)<\int_{\delta_T}^{\delta^u}p(\delta)d\delta$



$\Rightarrow P_M^0(\delta-\delta^0)=A_a$

$\int_{\delta_T}^{\delta^u}p(\delta)d\delta=A_{dmax}$

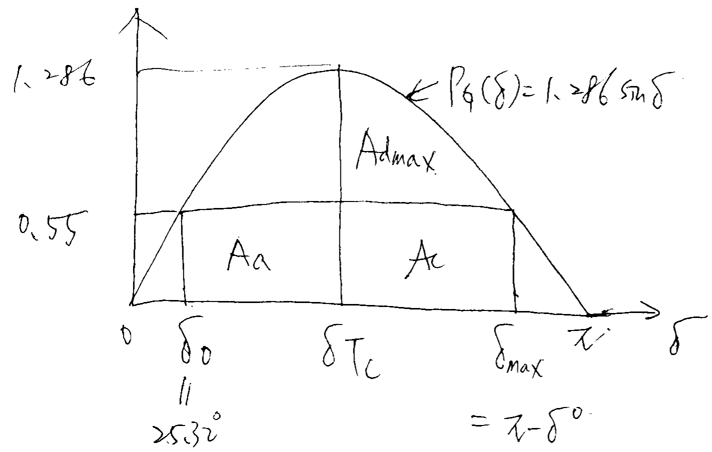
$\Rightarrow A_d<A_{dmax}$

穩定

4个週期，$4T = 4\frac{1}{f} = 4\cdot\frac{1}{60} = \frac{1}{15} = 0.0666\,S$

~~[illegible]~~

∵ $P_e(\delta^0) = 0.55 = 1.286\sin\delta^0 \Rightarrow A_d + A_c = A_{dmax} + A_c$



$0.55(\pi - 2\delta^0)$

$= \int_{\delta_{T_c}}^{\pi-\delta^0} (1.286\sin\delta)\,d\delta$

$= 0.55(\pi - 2\cdot 0.442)$

$= 1.24176$

$= 1.286(\cos\delta_{T_c} + 0.9039)$

$\Rightarrow 0.0616 = \cos\delta_{T_c}$

$\delta_{T_c} = 86.462^\circ$

$= 1.50905\,rad$

$\delta_{T_c} = \frac{P_M^0}{2M} T_{critical}^2 + \delta_0$

$= 1.50905 = \frac{\pi f_0 P_M^0}{2H} T_{critical}^2 + 0.442$

$= \frac{\pi\cdot 60\cdot 0.55}{2\cdot 5} T_{critical}^2 + 0.442$

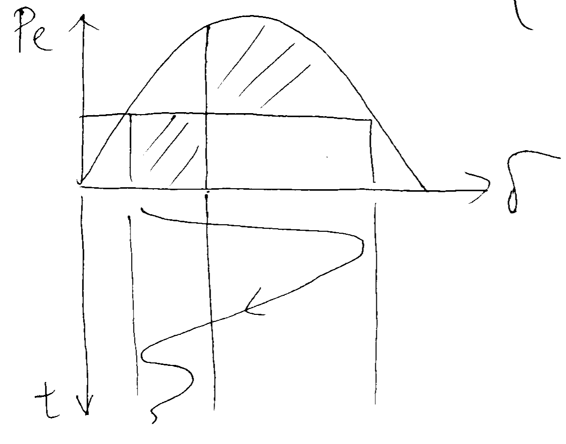
$T_{critical} = 0.3208\,S$

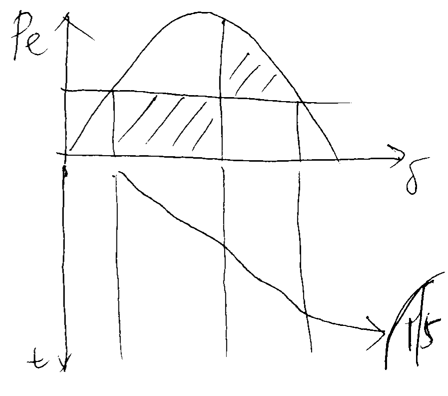
∵ $\boxed{4T < T_{critical}} \Rightarrow 0.067S < 0.32S$ 此系統穩定

$T < T_{critical}$ 为穩定

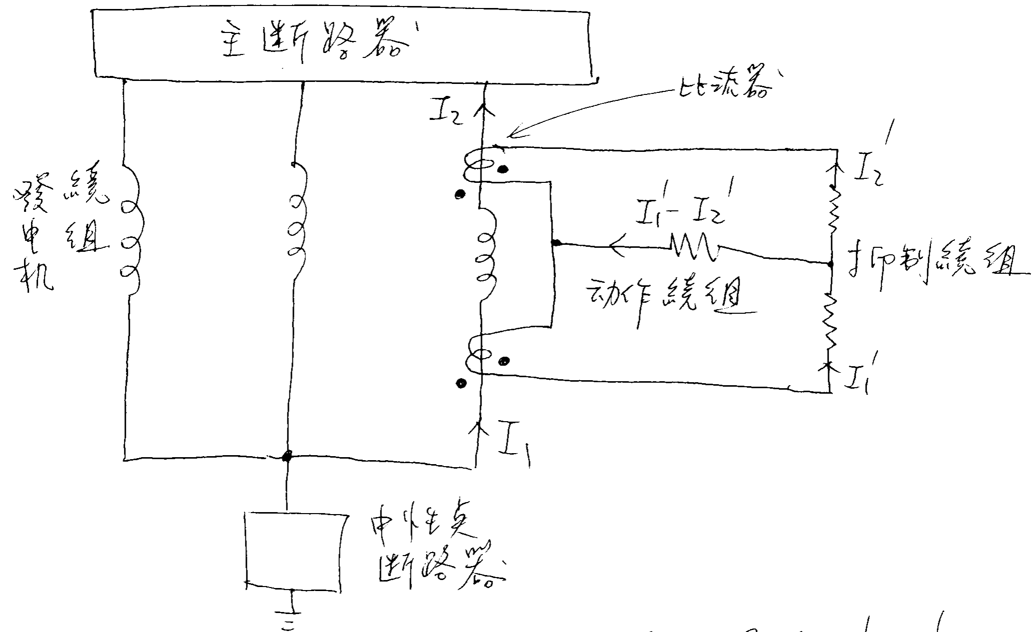
$T > T_{critical}$ 为發散不穩定

∴





五、~~依~~ Kirchhoff's first law ~~電壓~~ 電流定律及流進及流出的電流相等，但一旦發生事故，有大量故障電流流入而流出的電流微乎其微，即為差動保護。如下圖只考慮a相



如果沒有內部故障，$I_2=I_1$，比流器相同時 $I_1'=I_2'$，因為比流器串聯，電流從一個二次側流到另一個二次側，電驛的動作線組中沒有電流。現在假設線組中有接地或三相短路。則 $I_2 \neq I_1$，因此 $I_2' \neq I_1'$，動作線組中有差動電流 $I_1'-I_2'$ 流動。故稱為差動電驛(differential relay)