第三章　变压器

3-1 解：（1）AA’-XX’，　aa’-xx’　图略

$$\mathrm{K}=\frac{1100}{110}=10$$

$$\begin{cases} I_1=\dfrac{5000}{1100}=4.545(A) \\ I_2=\dfrac{5000}{110}=45.45(A) \end{cases}$$

（2）A-X-A’-X，　a-x-a’-x’

$$\mathrm{K}=\frac{1100\times 2}{110\times 2}=10,\quad \begin{cases} I_1=\dfrac{5000}{1100\times 2}=2.27(A) \\ I_2=\dfrac{5000}{110\times 2}=22.7(A) \end{cases}$$

（3）AA’-XX’，　a-x-a’-x’

$$\mathrm{K}=\frac{1100}{110\times 2}=5,\quad \begin{cases} I_1=\dfrac{5000}{1100}=4.545(A) \\ I_2=\dfrac{5000}{110\times 2}=22.7(A) \end{cases}$$

（4）A-A’-X-X’，aa’-xx’

$$\mathrm{K}=\frac{1100\times 2}{110}=20,\begin{cases} \mathrm{I}_1=\dfrac{5000}{1100\times 2}=2.27(\mathrm{A}) \\ \mathrm{I}_2=\dfrac{5000}{110}=45.45(\mathrm{A}) \end{cases}$$

3-2 解:

$$I_{1N}=\frac{S_N}{\sqrt{3}U_{1N}}=\frac{1600}{\sqrt{3}\times 110}=84(\mathrm{A})\quad I_{1\emptyset}=I_{1N}=84(A)$$

$$I_{2N}=\frac{S_N}{\sqrt{3}U_{2N}}=\frac{1600}{\sqrt{3}\times 11}=8.4(\mathrm{A})\quad I_{2\emptyset}=\frac{I_{2N}}{\sqrt{3}}=4.85(A)$$

3-3 解：图略

3-4 解：

$$Z_1=0.1+j0.36=0.374\angle 74.5°（\Omega）$$

$$Z_m=5.5+j63.5=63.74\angle 85°（\Omega）$$

$$\dot{I}_0=\frac{U_{1N}}{Z_1+Z_m}=\frac{1000\angle 0°}{5.6+\mathrm{j}63.88}=\frac{1000\angle 0°}{64.1\angle 85°}=15.6\angle -85°(\mathrm{A})$$

$$\dot{I}_0 Z_1=15.6\angle -85°\times 0.374\angle 74.5°=5.83\angle -10.5°（\mathrm{V}）$$

$$\dot{I}_{1N} Z_1=\frac{200000}{1000}\angle -30°\times 0.374\angle 74.5°=74.8\angle -44.5°（\mathrm{V}）$$

$$-\dot{E}_{10}=\dot{I}_0 Z_m=15.6\angle -85°\times 63.74\angle 85°=994.3\angle 0°(\mathrm{V})$$

或$\dot{E}_{10}$=$994.3\angle -180°$

$$-\dot{E}_{1N}=\dot{U}_{1N}-\dot{I}_{1N} Z_1=1000\angle 0°-200\angle -30°\times 0.374\angle 74.5°$$

$$=1000\angle 0°-74.8\angle -44.5°=946.65-\mathrm{j}52.43=948.1\angle -3.17°$$

或$\dot{E}_{1N}$=$948.1\angle -176.83°$（V）

以上数据说明$\dot{E}_{10}$、$\dot{E}_{1N}$分别同U_{1N}相比，在大小相位上差别不大，故$U_{1N} \approx E_{10} = E_{1N} \propto \emptyset_m$ U_1不变，E_1、$\emptyset_m$基本不变。

3-5 解：（1）直接输入$P_1 = \left(\frac{E_s}{R_s+R}\right)^2 R = \left(\frac{8.5}{72+8}\right)^2 \times 8 = 0.09$（W）

经变压器$P_2 = Z_2^2 R = \left(\frac{E_s}{R_s+R}K\right)^2 R = \left(\frac{8.5}{72+8} \times 3\right)^2 \times 8 = 0.25$（W）

(2)经阻抗变换，令$K^2 R = R_3$输出功率最大

$$\mathrm{K} = \sqrt{\frac{72}{8}} = 3$$

（3）变压器作用：与阻抗匹配

3-6 解：$$\mathrm{K} = \frac{1000}{\sqrt{3}} / \frac{400}{\sqrt{3}} = 2.5$$

$$Z_l = 0.96 + j0.48 = 1.07 \angle 26.57°$$
$$Z_l' = K^2 Z_l = 6 + j3 = 6.71 \angle 26.57°$$
$$\dot{I}_1 = \frac{\frac{U_{1N}}{\sqrt{3}} \angle 0°}{Z_l + Z_l'} = \frac{\frac{1000}{\sqrt{3}} \angle 0°}{6.15 + j3.35} = \frac{\frac{1000}{\sqrt{3}} \angle 0°}{7 \angle 28.58°}$$
$$= 82.48 \angle -28.58°（\mathrm{A}）$$
$$\dot{I}_2 = K\dot{I}_2' = -K\dot{I}_1 = -206.2 \angle -28.58° = +206.2 \angle 151.4°（\mathrm{A}）$$
$$\dot{U}_2 = \sqrt{3}\dot{I}_2 Z_l = \sqrt{3}c206.2 \angle 151.4° \times 1.07 \angle 26.57° = 382 \angle 178°(\mathrm{V})$$
$$S_1 = \sqrt{3}U_{1N} I_1 = \sqrt{3}1000 \times 82.48 = 142.885(\mathrm{KVA})$$
$$S_2 = \sqrt{3}U_2 I_1 = \sqrt{3} \times 382 \times 206.2 = 136.427(\mathrm{KVA})$$
$$P_1 = \sqrt{3}U_{1N} I_1 \cos\varphi_1 = \sqrt{3}c1000 \times 82.48 \cos 28.58° = 125.448(\mathrm{KW})$$
$$Q_1 = \sqrt{3}U_{1N} I_1 \sin\varphi_1 = \sqrt{3} \times 1000 \times 82.48 \sin 28.58° = 68.34(\mathrm{K}\emptyset)$$
$$P_2 = \sqrt{3}U_2 I_2 \cos\varphi_2 = \sqrt{3} \times 382 \times 206.2 \cos 26.57° = 122(\mathrm{KW})$$
$$Q_2 = \sqrt{3}U_2 I_1 \sin\varphi_2 = \sqrt{3} \times 382 \times 206.2 \sin 26.57° = 61(\mathrm{K}\emptyset)$$

3-7 解:（1）原版电压是 35kv

$$r_K = \frac{P_{cu}}{I_{1N}^2} = \frac{9500}{(600/3.5)^2} = 32.33$$

$$X_K = \sqrt{Z_K^2 - r_K^2} = \sqrt{132.7^2 - 32.33^2} = 128.7$$

$$Z_K = 32.33 + j128.7 = 132.7 \angle 75.9°（\Omega）$$

$$r_1 = \frac{1}{2} r_K = 16.17 \ （\Omega）, \quad X_1 = \frac{1}{2} X_K = 64.35（\Omega）$$

$$Z_1 + Z_m = \frac{U_{1N}}{I_0} = \frac{3500}{(\frac{600}{35}) \times 0.055} = 37121.2$$

$$r_1 + r_m = (Z_1 + Z_m)\cos\varphi_2 = 37121.2 \times 0.1 = 3712$$
$$X_1 + X_m = (Z_1 + Z_m)\sin\varphi_2 = 37121.2 \times 0.995 = 36935$$
$$r_m = 3712 - 16.17 = 3695.8$$
$$X_m = 36935 - 64.35 = 36871$$
$$Z_m = 3695.8 + j36871 = 37056 \angle 84.28°（\Omega）$$

（2）

$$Z_l' = K^2 Z_l = \left(\frac{35}{6.3}\right)^2 \times 80\angle 40° = 2469\angle 40° = 1891.4 + \mathrm{j}1587$$

$$\dot{I}_1 = \frac{35000\angle 0°}{Z_K + Z_l'} = \frac{35000\angle 0°}{1923.7 + j1715.7} = \frac{35000\angle 0°}{2577.6\angle 41.7°} = 13.58\angle -41.7°(\mathrm{A})$$

$$\dot{I}_2 = K\dot{I}_2' = -K\dot{I}_l = -\left(\frac{35}{6.3}\right)^2 \times 13.58\angle -41.7° = 75.44\angle 138.3°（\mathrm{A}）$$

$$\dot{U}_2 = \dot{I}_2 Z_l = 75.44\angle -138.3° \times 80\angle 40° = 6035\angle 178.3°$$

3-8 解：“T” $Z_2' = (380/220)^2 \times (0.035 + j0.055) = 0.1044 + j0.1641 = 0.1945$

$$Z_l' = (380/220)^2 \times (4 + j3) = 11.934 + j8.9504 = 14.917\angle 36.87°$$

$$Z_m = 30 + j310 = 311.448\angle 84.47°$$

$$Z_{总} = Z_1 + \frac{Z_m(Z_2' + Z_l')}{Z_m + Z_2' + Z_l'}$$

图略

式中$Z_2' + Z_l'$ =0.1044+j0.1641+$11.934 + j8.9504 = 12.038 + j9.1145 = 15.1\angle 37.13°$

$$Z_m(Z_2' + Z_l') = 311.448\angle 84.47° \dot{I}_2' 15.1\angle 37.13° = 4702.86\angle 121.6°$$

$$Z_m + Z_2' + Z_l' = (30 + 0.1044 + 1.934) + j(310 + 0.1641 + 8.9504) = 42.038 + j319.115$$
$$= 321.87\angle 82.5°$$

$$\frac{Z_m(Z_2' + Z_l')}{Z_m + Z_2' + Z_l'} = \frac{4702.86\angle 121.6°}{321.87\angle 82.5°} = 14.61\angle 39.1°$$

$$Z_{总} = Z_1 + \frac{Z_m(Z_2' + Z_l')}{Z_m + Z_2' + Z_l'} = (0.14 + j0.22) + (11.338 + j9.214) = 11.478 + j9.434$$
$$= 14.89\angle 39.4°$$

$$\dot{I}_1 = \frac{\dot{U}_{1N}}{Z_{总}} = \frac{380\angle 0°}{14.87\angle 39.4°} = 25.55\angle -39.4° = 19.74 - \mathrm{j}16.22$$

$$\dot{I}_0 = \frac{U_{1N}}{Z_1 + Z_m} = \frac{380\angle 0°}{(0.14 + j0.22) + (30 + j310)} = \frac{380\angle 0°}{30.14 + j310.22} = \frac{380\angle 0°}{311.68\angle 84.45°}$$

$$= 1.219\angle -84.45° = 0.118 - \mathrm{j}1.213$$

$$\dot{I}_2' = \dot{I}_0 - \dot{I}_1 = (0.118 - \mathrm{j}1.213) - (19.74 - \mathrm{j}16.22) = -19.62 + j15.01 = -(19.62 - j15.01)$$
$$= -24.7\angle -37.4° = 24.7\angle 142.6°$$

$$\dot{I}_2 = \mathrm{K}\dot{I}_2' = \left(\frac{380}{220}\right) \times 24.7\angle 142.6° = 42.66\angle 142.6°$$

$$\dot{U}_2 = \dot{I}_2 I_l = 42.66\angle 142.6° \times 5\angle 36.87° = 213.3\angle 179.47°$$

$$\mathrm{P_1} = \mathrm{U_{1N}I_1}\cos\varphi_1 = 380 \times 25.55 \times \cos 39.4° = 7502.5\ (\mathrm{W})$$

$$P_2 = U_2 I_2 \cos\varphi_2 = 213.3 \times 42.66 \times \cos 36.87° = 7279.5\ (\mathrm{W})$$

$$\eta = \frac{P_2}{P_1} \times 100\% = \frac{7279.5}{7502.5} \times 100\% = 97\%$$

图略

$$P_{Fe} = I_0^2 r_m = 1.219^2 \times 30 = 44.58\ (W)$$

$$P_{cu} = 25.5^2 \times 0.14 + 42.66^2 \times 0.035 = 155.1\ (W)$$

解：“__”

$$\dot{I}_1 = -\dot{I}_2' = \frac{\dot{U}_{1N}}{Z_1 + Z_2' + Z_l'}$$

$$Z_1 + Z_2' + Z_l' = (0.14 + j0.22) + (0.1044 + j0.1641) + (11.934 + j8.9504)$$
$$= 12.18 + j9.3345 = 15.345\angle 37.466°$$

$$\dot{I}_1 = -\dot{I}_2' = \frac{380\angle 0°}{15.345\angle 37.466°} = 24.76\angle -37.466°$$

$$\dot{I}_2 = -\mathrm{K}\dot{I}_2' = \left(\frac{380}{220}\right) \times 24.76\angle -37.466° = 42.77\angle -37.466° = 42.77\angle 142.5°$$

$$\dot{I}_0 = 0$$

$$\dot{U}_2 = \dot{I}_2 I_l = 42.77\angle 142.5° \times 5\angle 36.87° = 213.87\angle 179.4°$$

$$P_1 = U_{1N} I_1 \cos\varphi_1 = 380 \times 24.76 \times \cos 37.466° = 7467.9 \ \text{(W)}$$

$$P_2 = U_2 I_2 \cos\varphi_2 = 213.87 \times 42.77 \times \cos 36.87° = 7317.8 \ \text{(W)}$$

$$\eta = \frac{P_2}{P_1} \times 100\% = \frac{7317.8}{7467.9} \times 100\% = 98\%$$

$$P_{Fe} = 0$$

$$P_{cu} = I_1^2 r_1 + I_2^2 r_2 = 24.76^2 \times 0.14 + 42.77^2 \times 0.035 = 149.85 \ (W)$$

比较: $I_{1T} > I_{1-}$ $(25.55 > 24.76)$ ∵忽略I_0

$I_{2T} > I_{2-}$ $(42.66 < 42.77)$ ∵$\begin{cases} \mathrm{I_{1T}}\text{大} \rightarrow \mathrm{I_1Z_1} \rightarrow \mathrm{E_2}\text{小} \rightarrow I_{2T}\text{小} \\ \mathrm{I_{1-}}\text{小} \rightarrow \mathrm{I_{2-}}\text{小} \end{cases}$ 故二相差无几者

$U_{2T} > U_{2-}$ $(213.3 < 213.87)$ ∵ $I_{2T} > I_{2-}$

$P_{1T} > P_{1-}$ $(7502.5 > 7467.9)$ ∵ P_{ce}存

$P_{2T} < P_{2-}$ $(7279.5 < 7317.8)$ ∵ $P_{Fe} = 0$ ∴P_{2-}大

$\eta_T < \eta_-$ $(97\% < 98\%)$ ∵ $P_{Fe} = 0$ ∴η_-大

3-9 解:

$$\mathrm{K} = \frac{10000}{\sqrt{3} \times 400} = 14.434$$

$$Z_0 = \frac{U_{20}}{I_{20}/\sqrt{3}} = \frac{400}{65\sqrt{3}} = 10.66\ (\Omega)$$

$$r_0 = \frac{P_0}{3\left(I_{20}/\sqrt{3}\right)^2} = \frac{3700}{65^2} = 0.876$$

$$\because Z_0 = Z_2 + Z_m \approx Z_m \quad r_0 = r_2 + r_m \approx r_m$$

$$\therefore X_m = \sqrt{Z_m^2 - r_m^2} = \sqrt{10.66^2 - 0.876^2} = 10.624 \quad (\Omega)$$

折回原边：

$$Z_m' = K^2 Z_m = 2221 \quad (\Omega)$$

$$X_m' = K^2 X_m = 2213.4 \quad (\Omega)$$

$$r_m' = K^2 r_m = 182.5\ (\Omega)$$

有图

$$Z_K = \frac{U_K}{\sqrt{3} I_K} = \frac{450}{\sqrt{3} \times 35} = 7.423$$

$$r_K = \frac{P_K}{3I_K^2} = \frac{3500}{3\times 35^2} = 2.041 \qquad r_1 \approx r_2' = 1.2\ (\Omega)$$

$$X_K = \sqrt{Z_K^2 - r_K^2} = \sqrt{7.423^2 - 2.041^2} = 7.137 \qquad X_1 \approx X_2' = 3.57\ (\Omega)$$

折标 75℃：

$$r_1 \approx r_2' = \frac{235+75}{235+30}\times 1.02 = 1.193 \quad (\Omega)$$

3-10 解：

$$I_{1N} = \frac{750000}{\sqrt{3}\times 10000} = 43.3\ (\mathrm{A}) \qquad \sin\varphi_2 = 0.6 \qquad \beta = 1$$

整理：

$$\Delta U_{\%} = \frac{I_{1N}(r_K\cos\varphi_2 + X_K\sin\varphi_2)}{U_{1N}/\sqrt{3}}\times 100\% = \frac{43.3\times(2.386\times 0.8 + 7.137\times 0.6)}{1000/\sqrt{3}} = 4.64\%$$

$$U_2 = (1-\Delta U)U_{2N} = (1-0.0464)\times 400 = 381.44\ (V)$$

$$\eta = \left(1 - \frac{P_{K75^\circ} + P_0}{S_N\cos\varphi_2 + P_{K75^\circ} + P_0}\right)\times 100\% = \left(1 - \frac{13.42+3.7}{750\times 0.8 + 13.42 + 3.7}\right)\times 100\% = 97.2\%$$

式中

$$P_{K75^\circ} = 3I_{1N}^2 r_{K75^\circ} = 3\times 43.3^2\times 2.386 = 13.42\ \ (KW)$$

容性：

$$\Delta U_{\%} = \frac{43.3\times(2.386\times 0.8 - 7.137\times 0.6)}{1000/\sqrt{3}} = -1.78\%$$

$$U_2 = (1+0.0178)\times 400 = 407.12\ \ (V)$$

$\eta = 91.72\%$（算的可能有误）

图略

3-11 解：

$$\mathrm{K} = \frac{6000}{\sqrt{3}\times 400} = 8.66 \qquad Z_l = 0.11662\ (\Omega)$$

$$I_{1N} = \frac{5600000}{\sqrt{3}\times 6000} = 538.88\ \ (A) \qquad \varphi_2 = t_g^{-1}\frac{0.06}{0.1} = 30.96^\circ$$

$$\cos\varphi_2 = 0.8575$$

（1）

$$Z_K = \frac{U_K}{\sqrt{3}I_{1N}^2} = \frac{280}{\sqrt{3}\times 538.85} = 0.3 \quad (\Omega)$$

$$r_K = \frac{p_{K75^\circ}}{3I_{1N}^2} = \frac{56000}{3\times 538.85^2} = 0.0643 \quad (\Omega)$$

$$X_K = \sqrt{Z_K^2 - r_K^2} = \sqrt{0.3^2 - 0.0643^2} = 0.293 \quad (\Omega)$$

$$Z_l' = K^2 Z_l = 8.66^2\times(0.1 + j0.06) = 7.5 + j4.5$$

$$I_1 = \frac{U_1}{Z_K + Z_l'} = \frac{6000/\sqrt{3}}{\sqrt{(0.0643+7.5)^2 + (0.293+4.5)^2}} = 386.85\ (A)$$

$$I_2 = \sqrt{3}KI_2' = \sqrt{3}\times 8.66\times 386.85 = 5802.75\ \ (A)$$

$$\beta = \frac{I_1}{I_{1N}} = \frac{386.85}{538.88} = 0.72$$

$$U_2 = \frac{I_2}{\sqrt{3}} Z_l = \frac{5602.75}{\sqrt{3}} \times 0.11662 = 390.7\ (V)$$

$$\eta = \left(1 - \frac{P_0 + \beta^2 P_{K75^\circ}}{\beta S_N \cos\varphi_2 + P_0 + \beta^2 P_{K75^\circ}}\right) \times 100\%$$

$$= \left(1 - \frac{18 + 0.72^2 \times 56}{0.72 \times 5600 \times 0.8575 + 18 + 0.72^2 \times 56}\right) \times 100\% = 98.66\%$$

（2）

$$\beta_m = \sqrt{\frac{P_0}{P_{K75^\circ}}} = \sqrt{\frac{18}{56}} = 0.567$$

3-12 解：据题意，

$$\Delta U_{\%} = \frac{U_{2N} - U_2}{U_{2N}} = \beta I_{1N} \left(\frac{r_K \cos\varphi_2 + X_K \sin\varphi_2}{U_{1N}}\right) \times 100\% = 0$$

$$\therefore\ r_K \cos\varphi_2 = -X_K \sin\varphi_2$$

$$\because -\sin\varphi_2 < 0 \quad \varphi_2 < 0 \quad \text{负载为容性}$$

式中：

$$Z_K = \frac{\frac{2610}{92.38}}{\sqrt{3}} = 16.23\ \ (\Omega)$$

$$r_K = \frac{53000}{3 \times 92.38} = 2.07\ \ (\Omega)$$

$$I_{1N} = \frac{5600}{\sqrt{3} \times 3600} = 92.38\ \ (A)$$

$$\varphi_2 = -t_g^{-1} \frac{2.07}{16.23} = -7.3^\circ$$

3-13 解：

$$\mathrm{K} = \frac{10/\sqrt{3}}{0.4/\sqrt{3}} = 25$$

$$I_{1N} = \frac{750}{\sqrt{3} \times 10} = 43.3\ (A) \qquad I_{2N} = \frac{750}{\sqrt{3} \times 0.4} = 1082.56\ (A)$$

$$Z_l' = 25^2 \times (0.2 + j0.07) = 125 + j43.75$$

(1)

$$I_1 = \frac{\frac{10000}{\sqrt{3}}}{\sqrt{(1.4 + 125)^2 + (6.48 + 43.75)^2}} = 42.45\ \ (A)$$

$$I_2 = KI_2' = KI_1 = 25 \times 42.45 = 1061.25\ \ (A)$$

(2)

$$U_2 = \sqrt{3} I_2 Z_l = \sqrt{3} \times 1061.25 \times \left(\sqrt{0.2^2 + 0.07^2}\right) = 389.5\ \ (V)$$

(3)

$$\varphi_2 = t_g^{-1}\frac{X_l}{r_l} = t_g^{-1}\frac{0.07}{0.2} = 19.29°$$

$$\cos\varphi_2 = 0.944 \quad \sin\varphi_2 = 0.33$$

$$\varphi_1 = t_g^{-1}\frac{X_K + X_l'}{r_K + r_l'} = t_g^{-1}\frac{6.48 + 43.75}{1.4 + 125} = 21.67°$$

$$\cos\varphi_1 = 0.929 \quad \sin\varphi_1 = 0.369$$

$$P_1 = \sqrt{3} \times 10 \times 42.45 \times 0.929 = 683.3 \ (KW)$$

$$Q_1 = \sqrt{3} \times 10 \times 42.45 \times 0.369 = 271.3 \ (K\emptyset)$$

$$P_2 = \sqrt{3} \times 389.5 \times 1061.25 \times 0.944 = 675.7 \ (KW)$$

$$Q_2 = \sqrt{3} \times 389.5 \times 1061.25 \times 0.33 = 236.3 \ (K\emptyset)$$

(4)

$$\eta = \frac{P_2}{P_1}100\% = \frac{675.7}{683.3} \times 100\% = 99\%$$

3-14 图略

3-15 图略

3-16 图略

3-17 解：

$$\mathrm{K} = \frac{220}{180} = 1.22$$

(1)

$$I_1 = \frac{I_2}{K} = \frac{180}{220} \times 400 = 327.27 \ (A)$$

$$\mathrm{I} = I_2 - I_1 = 400 - 327.27 = 72.73 \ (A)$$

(2)

$$S_1 = 220 \times 327.27 = 72 \ (KVA) \quad S_2 = 72 \ (KVA)$$

$$S_2' = U_2 I = 180 \times 72.73 = 13.09 \ (KVA)$$

$$S_2'' = U_2 I_1 = 180 \times 327.27 = 58.909 \ (KVA)$$