Q: Complete the following sentences by suitable words :

1- Draw the vector (phasor) diagram of an ideal transformer.

2- Draw the exact equivalent circuit of a single phase transformer.

3- Draw the approximate equivalent circuit of a single phase transformer.

4- Draw the equivalent circuit of a single phase transformer at short circuit.

5- Draw the equivalent circuit of two single phase transformers connected in parallel with same voltage ratio.

6- Define leakage flux, how can its effect be representing in the equivalent circuit?

7-How the transformer core represents in the equivalent circuit?

8-What is the iron loss? How can be minimized?

9-At what condition the transformer can be operate at its maximum efficiency; write the equation for maximum efficiency.

10-Write down the equation of induced voltage E1.

11-What are the conditions of parallel operation of transformers.

12- Why the iron losses in transformers are considered constant?

13- The active power output of a transformer of 1KVA at p.f 0.8 at no load is ------.

14- The total equivalent reactance of transformer referred to the secondary is equal to ------------.

15- Define the voltage regulation.

16- The information obtained from open circuit test are ---------, ------- and ---------.

17- The cooling methods of transformers greater than 50kVA are ------- - and -------.

18- Electric Machine can be defined as --------------------------.

19- The electromagnetic system is a necessary element of -----------------.

20-The role of electromagnetic system is to ------------ and ------------ electromagnetic fields for carrying out conversion of energy.

21- The strength of a coil's magnetic field is proportional to ------------- and ----------- .

22-The direction of magnetic field can be determined by ------------- and ---------------- rules .

23-The opposition that a magnetic circuit presents to the passage of magnetic lines through it is called -----------.

24-. Faraday`s First Law states ---------------------------------.

25- Mutually induced e.m.f. can be defined as ------------------------.

26- The equation of inductance L can be written with the relation of permeability as ------------.

27-The equation of induced voltage produced by conductor rotating in a magnetic field is ---------------------.

28- Draw the vector diagram of an ideal transformer.

29- Draw the vector diagram for single phase transformer supplying a lagging power factor for (K=1).

30- Draw the exact equivalent circuit of a single phase transformer.

31- Draw the equivalent circuit of single phase transformer at no load.

Example *A d.c. motor takes an armature current of 110 A at 480 V. The armature circuit resistance is 0.2 Ω. The machine has 6-poles and the armature is lap-connected with 864 conductors. The flux per pole is 0.05 Wb. Calculate (i), the speed and (ii) the gross torque developed by the armature.*

Solution. $E_b = 480 - 110 \times 0.2 = 458$ V, $\Phi = 0.05$ W, $Z = 864$

Now, $E_b = \frac{\Phi ZN}{60}\left(\frac{P}{A}\right)$ or $458 = \frac{0.05 \times 864 \times N}{60} \times \left(\frac{6}{6}\right)$

$\therefore \quad N = 636$ r.p.m.

$T_a = 0.159 \times 0.05 \times 864 \times 110\ (6/6) = 756.3$ N-m

Example 1 *A 4 pole, long-shunt, compound gatorator supplys 100 A at a terminal voltage of 500 V. If armature resistance is 0.02Ω, series field resistance it 0.04 Ω and shunt field resistance 100Ω, find the generated EMF. Take drop per brush as 1 V, Neglect armature reaction.*

Solution:

Generator circuit is shown in Fig. 1

$$I_{sh} = \frac{500}{100} = 5\,A$$

Current through armature and series field winding is:

=100+5=105 A

Voltage drop on series field windings=105*0.04=4.2V

Armature voltage drop= 105 * 0.02=3.1 volt

Drop at brushes= 2 * 1= 2 V

Now,

$$EMF = V + I_a R_a + series\ drop + brush\ drop$$

$$= 500 + 4.2 + 2.1 \quad + 2 \quad = 508.3\ Volt$$

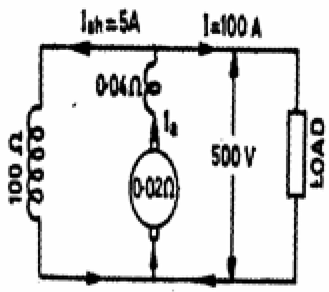


Fig. 1

Example *Determine developed torque and shaft torque of 220-V, 4-pole series motor with 800 conductors wave-connected supplying a load of 8.2 kW by taking 45 A from the mains. The flux per pole is 25 mWb and its armature circuit resistance is 0.6 Ω.*

Solution. Developed torque or gross torque is the same thing as armature torque.

$\therefore \quad T_a = 0.159\ \Phi\ ZA\ (P/A)$

$= 0.159 \times 25 \times 10^{-3} \times 800 \times 45\ (4/2) = 286.2$ N-m

$E_b = V - I_a R_a = 220 - 45 \times 0.6 = 193$ V

Now, $\quad E_b = \Phi\ ZN\ (P/A)$ or $193 = 25 \times 10^{-3} \times 800 \times N \pi \times (4/2)$

$\therefore \quad N = 4.825$ r.p.s.

Also, $\quad 2\pi N T_{sh}$ = output or $2\pi \times 4.825\ T_{sh} = 8200 \qquad \therefore T_{sh} = 270.5$ N-m

Example : *A 220-V d.c. shunt motor runs at 500 r.p.m. when the armature current is 50 A. Calculate the speed if the torque is doubled. Given that R_a = 0.2 Ω.*

Solution. As seen from Art 27.7, $T_a \propto \Phi I_a$. Since Φ is constant, $T_a \propto I_a$

$\therefore \quad T_{a1} \propto I_{a1}$ and $T_{a2} \propto I_{a2} \quad \therefore \quad T_{a2}/T_{a1} = I_{a2}/I_{a1}$

$\therefore \quad 2 = I_{a2}/50$ or $I_{a2} = 100$ A

Now, $N_2/N_1 = E_{b2}/E_{b1}$ — since Φ remains constant.

$F_{b1} = 220 - (50 \times 0.2) = 210$ V $\qquad E_{b2} = 220 - (100 \times 0.2) = 200$ V

$\therefore \quad N_2/500 = 200/210 \qquad \therefore N_2 =$ **476 r.p.m.**

Example *A d.c. shunt machine develops an a.c. e.m.f. of 250 V at 1500 r.p.m. Find its torque and mechanical power developed for an armature current of 50 A. State the simplifying assumptions.*

Solution. A given d.c. machine develops the same e.m.f. in its armature conductors whether running as a generator or as a motor. Only difference is that this armature e.m.f. is known as back e.m.f. when the machine is running as a motor.

Mechanical power developed in the arm $= E_b I_a = 250 \times 50 = 12{,}500$ W

$T_a = 9.55\ E_b\ I_a/N = 9.55 \times 250 \times 50/1500 =$ **79.6 N-m.**

Example: A three phase transformer has 420 turns on the primary and 36 turns on the secondary winding. The supply voltage is 3300V . Find The secondary line voltage on no-load when the windings are connected 1- star- star 2-delta–delta 3- star-delta 4- delta-star Solution: 1- star-star Primary phase voltage = V_{ph} = 3300/√3 Volt Secondary phase voltage $V_2=KV_1=V_{p1}*N_2/N_1$=3300/√3*36/420=163.3 Volt Secondary line voltage =163.3 * √3= 282.853 Volt 2- delta-delta Primary phase voltage V_1= V_{ph} = 3300 Secondary phase voltage V_2 = kV_1 , Secondary line voltage V_2 = 3300 *36/420 = 489.9 Volt H.W. 3-Star-delta 4-delta-star

Example *A single-phase transformer has 400 primary and 1000 secondary turns. net cross-sectional area of the core is 60 cm². If the primary winding be connected to a 50-Hz sup at 520 V, calculate (i) the peak value of flux density in the core (ii) the voltage induced in secondary winding.*

Solution. $K = N_2/N_1 = 1000/400 = 2.5$

(*i*) $E_2/E_1 = K \quad \therefore \quad E_2 = KE_1 = 2.5 \times 520 = 1300$ V

(*ii*) $E_1 = 4.44 f N_1 B_m A$

or $520 = 4.44 \times 50 \times 400 \times B_m \times (60 \times 10^{-4}) \therefore B_m = 0.976\ Wb/m^2$

Example *A 25-kVA transformer has 500 turns on the primary and 50 turns on the secondary winding. The primary is connected to 3000-V, 50-Hz supply. Find the full-load primary and secondary currents, the secondary e.m.f. and the maximum flux in the core. Neglect leakage drops and no-load primary current.*

Solution. $K = N_2/N_1 = 50/500 = 1/10$

Now, full-load $I_1 = 25{,}000/3000 = \mathbf{8.33\ A}$. F.L. $I_2 = I_1/K = 10 \times 8.33 = \mathbf{83.3\ A}$

e.m.f. per turn on primary side $= 3000/500 = 6\ V$

$\therefore$ secondary e.m.f. $= 6 \times 50 = \mathbf{300\ V}$ (or $E_2 = KE_1 = 3000 \times 1/10 = 300\ V$)

Also, $E_1 = 4.44\, f\, N_1 \Phi_m$; $3000 = 4.44 \times 50 \times 500 \times \Phi_m \therefore \Phi_m = \mathbf{27\ mWb}$

Example *The full-load copper loss on the h.v. side of a 100-kVA, 11000/317-V, 1-phase transformer is 0.62 kW and on the L.V. side is 0.48 kW.*

(i) Calculate R_1, R_2 and R_3 in ohms (ii) the total reactance is 4 per cent, find X_1, X_2 and X_3 in ohms if the reactance is divided in the same proportion as resistance.

Solution. *(i)* F.L. $I_1 = 100 \times 10^3/11000 = 9.1$ A. F.L. $I_2 = 100 \times 10^3/317 = 315.5$ A

Now, $I_1^2 R_1 = 0.62$ kW or $R_1 = 620/9.1^2 = 7.5\ \Omega$

$I_2^2 R_2 = 0.48$ kW, $R_2 = 480/315.5^2 = 0.00482\ \Omega$

$R_2' = R_2/K^2 = 0.00482 \times (11{,}000/317)^2 = 5.8\ \Omega$

$$\%\ \text{reactance} = \frac{I_1 \times X_{01}}{V_1} \times 100 \text{ or } 4 = \frac{9.1 \times X_{01}}{11000} \times 100,\ X_{01} = 48.4\ \Omega$$

$X_1 + X_2' = 48.4\ \Omega$. Given $R_1/R_2' = X_1/X_2'$

or $(R_1 + R_2')/R_2' = (X_1 + X_2')/X_2'$ $(7.5 + 5.8)/5.8 = 48.4/X_2'$ $\therefore$ $X_2' = 21.1\ \Omega$

$\therefore$ $X_1 = 48.4 - 21.1 = 27.3\ \Omega$, $X_2 = 21.1 \times (317/11000)^2 = \mathbf{0.175\ \Omega}$

Example *(a) A 2,200/200-V transformer draws a no-load primary current of 0.6 A and absorbs 400 watts. Find the magnetising and iron loss currents.*

(b) A 2,200/250-V transformer takes 0.5 A at a p.f. of 0.3 on open circuit. Find magnetising and working components of no-load primary current.

Solution. *(a)* Iron-loss current

$$= \frac{\text{no-load input in watts}}{\text{primary voltage}} = \frac{400}{2,200} = \mathbf{0.182\ A}$$

Now $I_0^2 = I_w^2 + I_\mu^2$

Magnetising component $I_\mu = \sqrt{(0.6^2 - 0.182)^2} = \mathbf{0.572\ A}$

(b) $I_0 = 0.5$ A, $\cos \phi_0 = 0.3 \therefore I_w = I_0 \cos \phi_0 = 0.5 \times 0.3 = 0.15$ A

$I_\mu = \sqrt{0.5^2 - 0.15^2} = 0.476$ A

Example *A single-phase transformer has 1000 turns on the primary and 200 turns on the secondary. The no load current is 3 amp. at a p.f. of 0.2 lagging. Calculate the primary current and power-factor when the secondary current is 280 Amp at a p.f. of 0.80 lagging.*

Solution. V_2 is taken as reference. $\cos^{-1} 0.80 = 36.87°$

$$I_2 = 280 \angle -36.87° \text{ amp}$$

$$I'_2 = (280/5) \angle -36.87° \text{ amp}$$

$$\phi = \cos^{-1} 0.20 = 78.5°, \sin\phi = 0.98$$

$$I_1 = I_0 + I'_2 = 3(0.20 - j\,0.98) + 56\,(0.80 - j\,0.60)$$

$$= 0.6 - j\,2.94 + 44.8 - j\,33.6$$

$$= 45.4 - j\,2.94 + 44.8 - j\,33.6$$

$$= 45.4 - j\,36.54 = 58.3 \angle 38.86°$$

Thus I lags behind the supply voltage by an angle of 38.86°.

Example *A transformer with a 10 : 1 ratio and rated at 50-kVA, 2400/240-V, 50-Hz is used to step down the voltage of a distribution system. The low tension voltage is to be kept constant at 240 V.*

(*a*) *What load impedance connected to low-tension size will be loading the transformer fully at 0.8 power factor (lag) ?*

(*b*) *What is the value of this impedance referred to high tension side ?*

(*c*) *What is the value of the current referred to the high tension side ?*

Solution. (*a*) F. L. $I_2 = 50{,}000/240 = 625/3$ A; $Z_2 = \dfrac{240}{(625/3)} = \mathbf{1.142\ \Omega}$

(*b*) $K = 240/2400 = 1/10$

The secondary impedance referred to primary side is

$$Z_2' = Z_2/K^2 = 1.142/(1/10)^2 = \mathbf{114.2\ \Omega}$$

(*c*) Secondary current referred to primary side is $I_2' = KI_2 = (1/10) \times 625/3 = \mathbf{20.83\ A}$

Example *A 230/460-V transformer has a primary resistance of 0.2 Ω and reactance of 0.5 Ω and the corresponding values for the secondary are 0.75 Ω and 1.8 Ω respectively. Find the secondary terminal voltage when supplying 10 A at 0.8 p.f. lagging.*

Solution. $K = 460/230 = 2;\ R_{02} = R_2 + K^2 R_1 = 0.75 + 2^2 \times 0.2 = 1.55\ \Omega$

$$X_{02} = X_2 + K^2 X_1 = 1.8 + 2^2 \times 0.5 = 3.8\ \Omega$$

$$\text{Voltage drop} = I_2\,(R_{02} \cos\phi + X_{02} \sin\phi) = 10\,(1.55 \times 0.8 + 3.8 \times 0.6) = 35.2\text{V}$$

$\therefore$ Secondary terminal voltage $= 460 - 35.2 = \mathbf{424.8\ V}$

Example *A 30 kVA, 2400/120-V, 50-Hz transformer has a high voltage winding resistance of 0.1 Ω and a leakage reactance of 0.22Ω. The low voltage winding resistance is 0.035 Ω and the leakage reactance is 0.012 Ω. Find the equivalent winding resistance, reactance and impedance referred to the (i) high voltage side and (ii) the low-voltage side.*

Solution.
$$K = 120/2400 = 1/20;\ R_1 = 0.1\ \Omega,\ X_1 = 0.22\ \Omega$$
$$R_2 = 0.035\ \Omega \quad \text{and} \quad X_2 = 0.012\ \Omega$$

(*i*) Here, high-voltage side is, obviously, the primary side. Hence, values as referred to primary side are

$$R_{01} = R_1 + R_2' = R_1 + R_2/K^2 = 0.1 + 0.035/(1/20)^2 = \mathbf{14.1\ \Omega}$$
$$X_{01} = X_1 + X_2' = X_1 + X_2/K^2 = 0.22 + 0.12/(1/20)^2 = \mathbf{5.02\ \Omega}$$
$$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2} = \sqrt{14.1^2 + 5.02^2} = \mathbf{15\ \Omega}$$

(*ii*)
$$R_{02} = R_2 + R_1' = R_2 + K^2R_1 = 0.035 + (1/20)^2 \times 0.1 = \mathbf{0.03525\ \Omega}$$
$$X_{02} = X_2 + X_1' = X_2 + K^2X_1 = 0.012 + (1/20)^2 \times 0.22 = \mathbf{0.01255\ \Omega}$$
$$Z_{02} = \sqrt{R_{02}^2 + X_{02}^2} = \sqrt{0.0325^2 + 0.01255^2} = \mathbf{0.0374\ \Omega}$$
$$(\text{or } Z_{02} = K^2Z_{01} = (1/20)^2 \times 15 = 0.0375\ \Omega)$$

Example *A 50-kVA, 4,400/220-V transformer has $R_1 = 3.45\ \Omega$, $R_2 = 0.009\ \Omega$. The values of reactances are $X_1 = 5.2\ \Omega$ and $X_2 = 0.015\ \Omega$. Calculate for the transformer (i) equivalent resistance as referred to primary (ii) equivalent resistance as referred to secondary (iii) equivalent reactance as referred to both primary and secondary (iv) equivalent impedance as referred to both primary and secondary (v) total Cu loss, first using individual resistances of the two windings and secondly, using equivalent resistances as referred to each side.*

Solution. Full-load $I_1 = 50{,}000/4{,}400 = 11.36$ A (assuming 100% efficiency)

Full-load $I_2 = 50{,}000/2220 = 227$ A; $K = 220/4{,}400 = 1/20$

(*i*)
$$R_{01} = R_1 + \frac{R_2}{K^2} = 3.45 + \frac{0.009}{(1/20)^2} = 3.45 + 3.6 = \mathbf{7.05\ \Omega}$$

(*ii*)
$$R_{02} = R_2 + K^2R_1 = 0.009 + (1/20)^2 \times 3.45 = 0.009 + 0.0086 = \mathbf{0.0176\ \Omega}$$

Also,
$$R_{02} = K^2 R_{01} = (1/20)^2 \times 7.05 = 0.0176\ \Omega \text{ (check)}$$

(*iii*)
$$X_{01} = X_1 + X_2' = X_1 + X_2/K^2 = 5.2 + 0.015/(1/20)^2 = \mathbf{11.2\ \Omega}$$
$$X_{02} = X_2 + X_1' = X_2 + K^2 X_1 = 0.015 + 5.2/20^2 = \mathbf{0.028\ \Omega}$$

Also X_{02}
$$= K^2 X_{01} = 11.2/400 = 0.028\ \Omega \text{ (check)}$$

(*iv*)
$$Z_{01} = \sqrt{(R_{01}^2 + X_{01}^2)} = \sqrt{(7.05^2 + 11.2)^2} = \mathbf{13.23\ \Omega}$$
$$Z_{02} = \sqrt{(R_{02}^2 + X_{02}^2)} = \sqrt{(0.0176^2 + 0.028)^2} = \mathbf{0.03311\ \Omega}$$

Also Z_{02}
$$= K^2Z_{01} = 13.23/400 = 0.0331\ \Omega \text{ (check)}$$

(*v*) Cu loss
$$= I_1^2 R_2 + I_2^2 R_2 = 11.36^2 \times 3.45 + 227^2 \times 0.009 = \mathbf{910\ W}$$

Also Cu loss
$$= I_1^2R_{01} = 11.36^2 \times 7.05 = \mathbf{910\ W}$$
$$= I_2^2R_{02} = 227^2 \times 0.0176 = \mathbf{910\ W}$$

Example *A single-phase transformer with a ratio of 440/110-V takes a no-load current of 5A at 0.2 power factor lagging. If the secondary supplies a current of 120 A at a p.f. of 0.8 lagging, estimate the current taken by the primary.*

Solution. $\cos\phi_2 = 0.8, \phi_2 = \cos^{-1}(0.8) = 36°54'$

$\cos\phi_0 = 0.2 \quad \therefore \quad \phi_0 = \cos^{-1}(0.2) = 78°\,30'$

Now $K = V_2/V_1 = 110/440 = 1/4$

$\therefore \quad I_2' = KI_2 = 120 \times 1/4 = 30\text{ A}$

$I_0 = 5\text{ A.}$

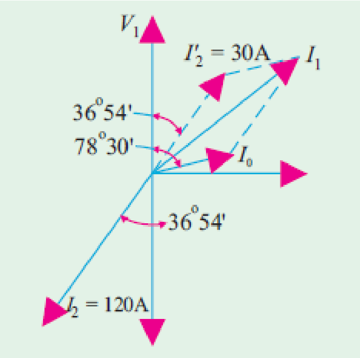
Angle between I_0 and I_2'

$= 78°\,30' - 36°\,54' = 41°\,36'$

Using parallelogram law of vectors (Fig. 32.19) we get

$$I_1 = \sqrt{(5^2 + 30^2 + 2 \times 5 \times 30 \times \cos 41°\,36')}$$

$= \mathbf{34.45\ A}$



The resultant current could also have been found by resolving I_2' and I_0 into their X and Y-components.

Q: Complete the following sentences by suitable words :

1- Electric Machine can be defined as --------------------------.

2- Energy conversion process is the process of ………………..

3-When current flows through a conductor, it produces a ---------- around the conductor. The strength of the magnetic field is proportional to -------------.

4- An electromagnet can be made by ----------------.

5- Permeability (μ) can be defined as ---------------------

6- Ferromagnetic materials have ---------of relative permeability?

7- The ability of a ferromagnetic material to retain residual magnetism is called ----------------.

8- Self Induced e.m.f. can be defined as …………………………… .

9- Faraday`s Second Law states ----------------------------------.

10-The equation of force produced by conductor carries current in a magnetic field is ---------.

Example *The following data refer to a 1-phase transformer :*

Turn ratio 19.5 : 1 ; R_1 = 25 Ω ; X_1 = 100 Ω ; R_2 = 0.06 Ω ; X_2 = 0.25 Ω. No-load current = 1.25 A leading the flux by 30°.

The secondary delivers 200 A at a terminal voltage of 500 V and p.f. of 0.8 lagging. Determine by the aid of a vector diagram, the primary applied voltage, the primary p.f. and the efficiency.

Solution. The vector diagram is similar to Fig. 30.28 which has been redrawn as Fig. 32.31. Let us take V_2 as the reference vector.

$$\therefore \quad \mathbf{V_2} = 500\angle 0° = 500 + j0$$

$$\mathbf{I_2} = 200\,(0.8 - j\,0.6) = 160 - j\,120$$

$$\mathbf{Z_2} = (0.06 + j\,0.25)$$

$$\mathbf{E_2} = V_2 + \mathbf{I_2}\,\mathbf{Z_2}$$

$$= (500 + j\,0) + (160 - j\,120)\,(0.06 + j\,0.25)$$

$$= 500 + (39.6 + j\,32.8) = 539.6 + j\,32.8 = 541\angle 3.5°$$

Obviously, $\beta = 3.5°$

$$\mathbf{E_1} = \mathbf{E_2}/K = 19.5\,\mathbf{E_2} = 19.5\,(539.6 + j\,32.8)$$

$$= 10{,}520 + j\,640$$

$$\therefore -\mathbf{E_1} = -10{,}520 - j\,640 = 10{,}540\angle 183.5°$$

$$\mathbf{I_2}' = -\mathbf{I_2}K = (-160 + j\,120)/19.5$$

$$= -8.21 + j\,6.16$$

As seen from Fig. 32.31, $\mathbf{I_0}$ leads $\mathbf{V_2}$ by an angle

$$= 3.5° + 90° + 30° = 123.5°$$

$$\therefore \quad \mathbf{I_0} = 1.25\angle 123.5°$$

$$= 1.25\,(\cos 123.5° + j \sin 123.5°)$$

$$= 1.25\,(-\cos 56.5° + j \sin 56.5°)$$

$$= -0.69 + j\,1.04$$

$$\mathbf{I_1} = \mathbf{I_2}' + \mathbf{I_0} = (-8.21 + j\,6.16) + (-0.69 + j\,1.04)$$

$$= -8.9 + j\,7.2 = 11.45\angle 141°$$

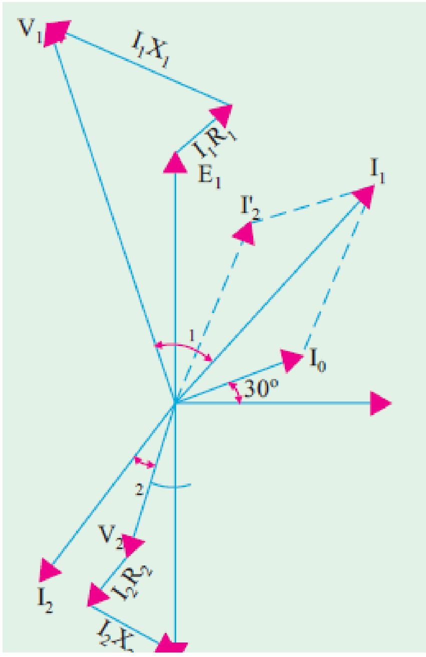
$$\mathbf{V_2} = -\mathbf{E_1} + \mathbf{I_1}\mathbf{Z_1}$$

$$= -10{,}520 - j\,640 + (-8.9 + j\,7.5)\,(25 + j\,100)$$

$$= -10{,}520 - j\,640 - 942 - j\,710$$

$$= -11{,}462 - j\,1350$$

$$= 11.540\angle 186.7°$$



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