Experiment 2
Open circuit(OC) and Short circuit(SC) tests on Single Phase Transformer

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1 Aim of the experiment

To obtain the equivalent circuit parameters from OC and SC tests, and to estimate efficiency & regulation at various loads.

2 Circuit Diagrams

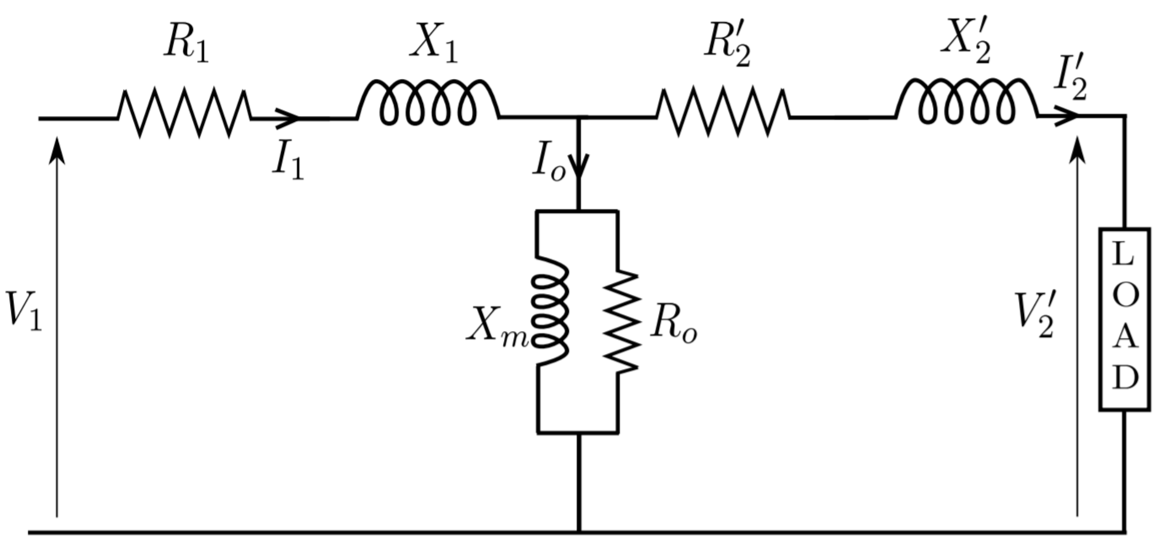


Figure 1: Equivalent Circuit of a transformer

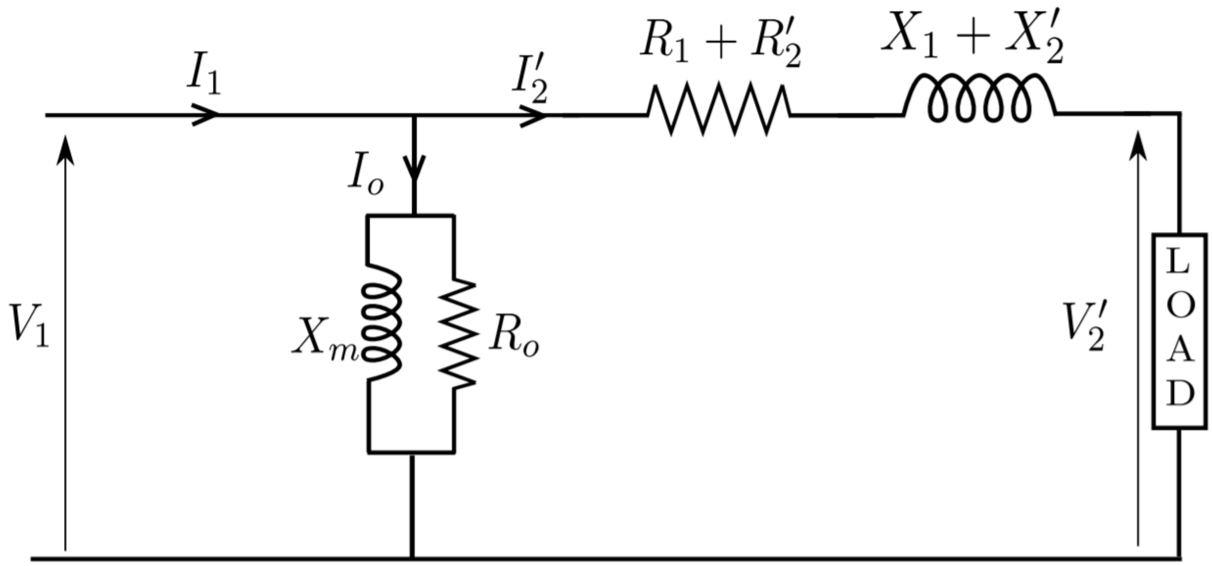


Figure 2: Simplified Equivalent Circuit of a transformer

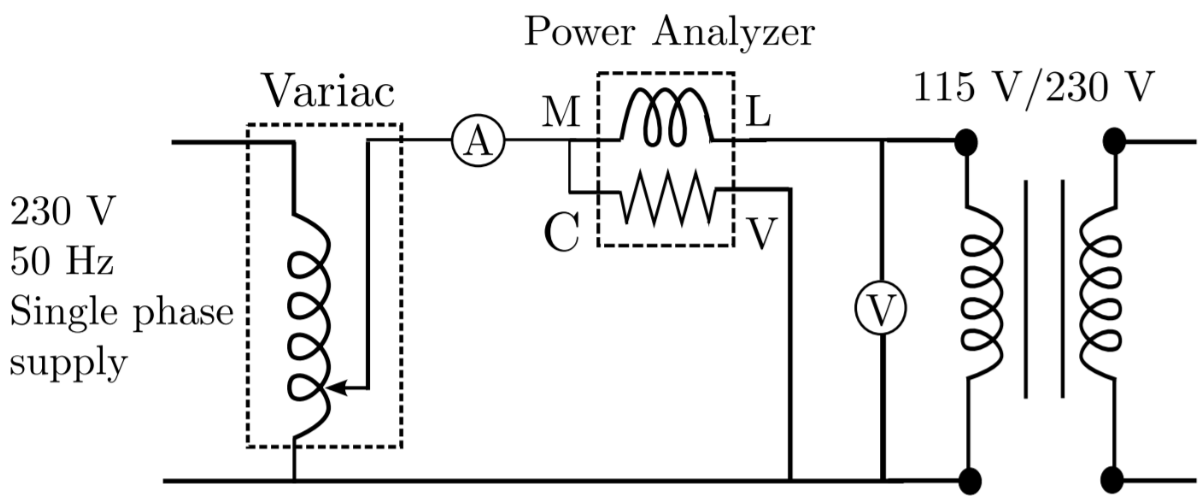
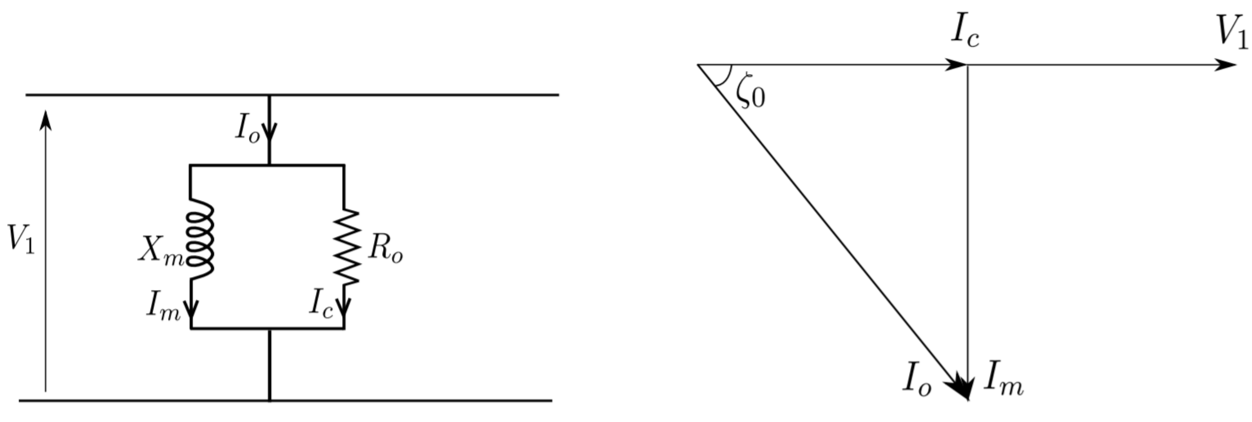


Figure 3: Connection diagram for OC test of a transformer



(a) Equivalent circuit for no load

(b) Phasor diagram on no-load

Figure 4: Equivalent circuit and phasor diagram for OC test

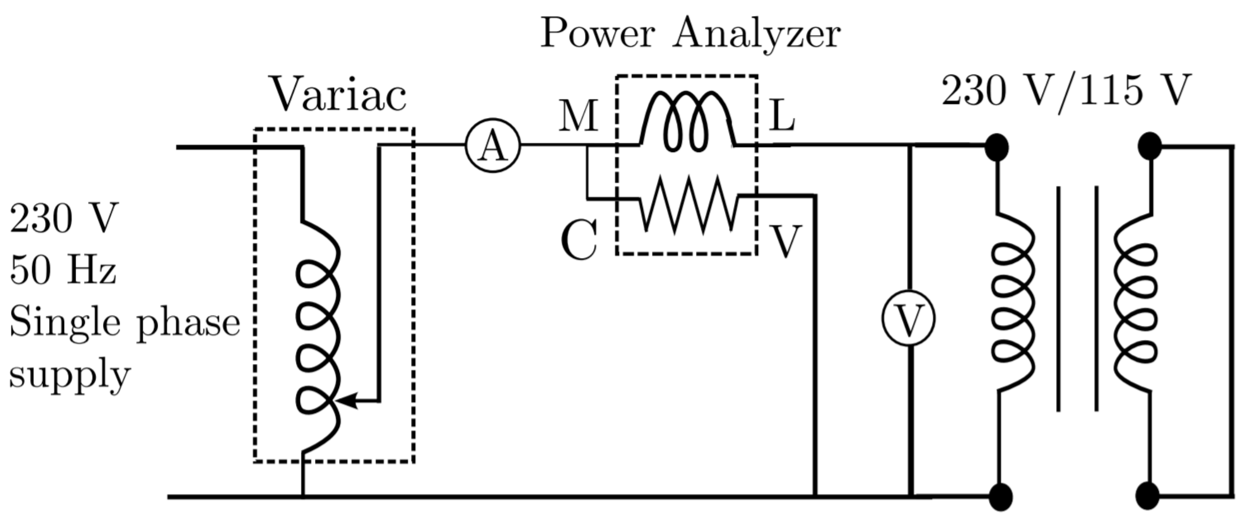


Figure 5: Connection diagram for short circuit test

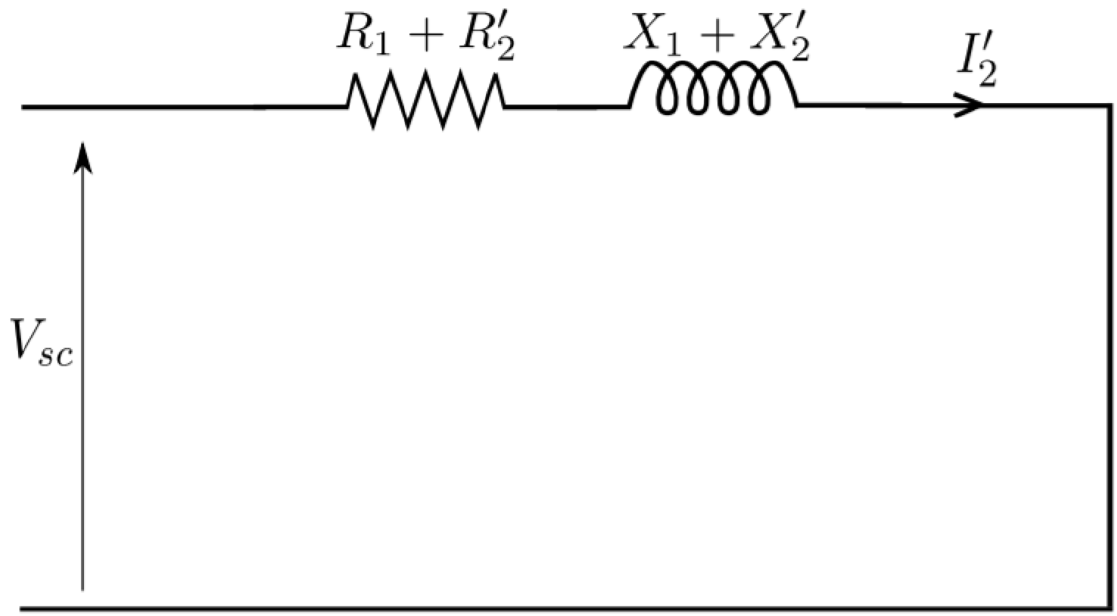


Figure 6: Equivalent circuit on SC test

3 Observations

Transformer Nameplate:1-ϕ, 2kVA, 230V/115V, 50Hz

3.1 Open Circuit/No Load Test

Current(LV)	Current(HV)	Voltage(LV)	Resistive Power
0.281 A	0A	114.68V	13.571 W

Table 1: Open Circuit Test Readings

$$PowerFactor = \frac{ResistivePower}{NoLoadCurrent \times OpenCircuitVoltage(LV)}$$

$$PowerFactor = 0.4211$$

$$R_O = \frac{V_{LV}}{I \times PowerFactor} = \mathbf{969.16}\ \Omega$$

$$X_m = \frac{V_{LV}}{I \times \sqrt{1 - (PowerFactor)^2}} = \frac{V_{LV}}{I \times sin\theta} = \mathbf{449.96}\ \Omega$$

3.2 Short Circuit Test

Current(HV)	Voltage(LV)	Voltage(HV)	Resistive Power
9.18A	0V	12.46V	107.87W

Table 2: Short Circuit Test Readings

$$PowerFactor = \frac{W}{V_{sc}I_2'} \approx 0.943(\text{lag})$$

$$R_1 + R_2^{'} = \frac{V_{HV} \times Cos\theta}{I_{HV}} = \mathbf{1.279}\Omega$$

$$X_1 + X_2^{'} = \frac{V_{HV} \times \sqrt{1 - (PowerFactor)^2}}{I_{HV}} = \frac{V_{HV} \times Sin\theta}{I_{HV}} = \mathbf{0.4516}\Omega$$

4 Calculations

Transformer Nameplate : 1-ϕ, 2000VA, 230V:115V, 50Hz

4.1 Voltage Regulation

According to the nameplate of the transformer: $V_{rated} = 115V$ and 2kVA, hence $I_{rated} = 17.39$
Using the calculated circuit parameters,
$R_{eq} = \mathbf{1.279}\Omega$
$X_{eq} = \mathbf{0.4516}\Omega$

These values of the winding resistance and leakage are computed referring to the HV side, since we performed the SC test on the HV side. Referring these values to the LV side, we get

$$R_{eq'} = \frac{R_{eq}}{(\frac{N_2}{N_1})^2} = \frac{R_{eq}}{4} = 0.31975\Omega$$

$$X_{eq'} = \frac{X_{eq}}{(\frac{N_2}{N_1})^2} = \frac{X_{eq}}{4} = 0.1129\Omega$$

The expression for regulation is given by,

$$Regulation = \frac{V_{no\ load} - V_{load}}{V_{load}}$$

This can be simplified to:

$$\%Regulation = \frac{I_2^{'}.R_{eq'}.cos\theta \pm I_2^{'}.X_{eq'}.sin\theta}{V_2^{'}} \times 100$$

where $I_2^{'}$ = Load Current, $R_{eq} = R_1 + R_2^{'}$, $X_{eq} = X_1 + X_2^{'}$
'+' sign for lagging pf and '-' for leading pf.

Load/Powerfactor	1	0.6 lag	0.6 lead
25%	1.20575	1.21875	0.38475
75%	3.61725	3.65625	1.15425
Full-load	4.823	4.875	1.539

Table 3: Regulation values in % .

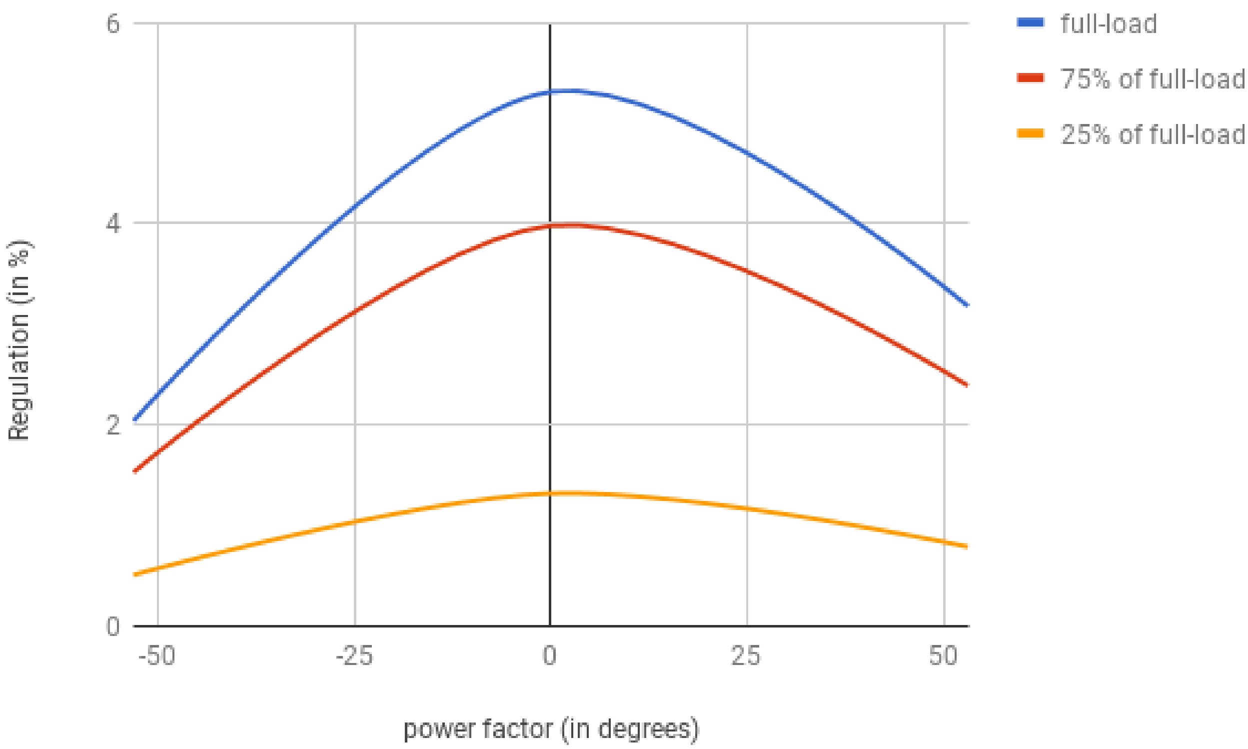


Figure 7: Regulation with power factor for each load

4.2 Efficiency

The efficiency of a transformer is given by

$$\eta = \frac{xScos\phi}{xScos\phi + P_c + P_I}$$

Efficiency is given by the ratio of output power to input power. Here the output power is expressed as x percentage of full load output power. The input power is the sum of output power and copper and iron losses.
The calculated efficiency using the above formula is given in the table below.

Load (VA)	Efficiency (%)		
	pf = 1	pf = 0.8 lag	pf = 0.6 lead
500	0.9622	0.9532	0.9386
1000	0.9636	0.9550	0.94089
1500	0.9567	0.9464	0.9299
2000	0.9478	0.9356	0.9160

Table 4: Efficiency vs Load for various Power Factors

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Figure 8: Efficiency vs Load for various Power Factors

5 Conclusions

We observe that the transformer has very high efficiency(around 90%) and very low regulation(1% to 6%). We also note that the core resistance R_c and magnetizing inductance X_m are very large compared to the coil resistance $R_1 + R_2^{'}$ and inductance $X_1 + X_2^{'}$ and core losses of the transformer are constant and load independent while the copper losses are load dependant and increase with greater load.
We also observe that for the same fraction of full-load, efficiency increases with increasing power factor.

6 Question and Answer

1. **Which winding (LV or HV) should be kept open while conducting OC test? Justify your answer.**
   Answer: While conducting OC test on a transformer, we keep the HV side open. This is because to conduct OC test, we have to apply rated voltage to one of the terminals and it is easier and safer to apply low voltage at LV side rather than applying a high voltage at HV side.

2. **Assume that the given transformer has the following name plate ratings: 40 kVA, 440 V/11 kV, 50 Hz.**
   What do these numbers imply?
   Answer: In this case 40 kVA is the secondary kVA rating. 440V/11kV represents that if we apply 11kV to the primary winding then the output voltage = 440V at the secondary when rated current is being drawn. 50Hz represents the frequency of operation.

3. **Comment on the nature of the current waveform drawn from the source during OC test for (i) 50%, (ii) 100% and (iii) 110% of the rated voltage.**
   Answer: The waveform of current drawn from the source during OC test at:
   (a) 50% rated voltage will be sinusoidal as core does not saturate
   (b) 100% rated voltage will be distorted. It will have spikes at the extremas of the current waveform as the core is being operated at knee point of B-H loop
   (c) 110% rated voltage will be even more distorted and the current will spike near the extremas of the current waveform as the core is going in to saturation and hence required more current to increase flux by equal amount.

4. **Can the regulation be negative? What does it signify?**
   Answer: Voltage regulation is given by:
   $$regulation = \frac{V_{no\ load} - V_{load}}{V_{no\ load}} \tag{1}$$
   If regulation is -ve, that implies that $V_{load} > V_{no\ load}$. This can happen only when the load power factor is leading.

5. **Assume that you have been given a transformer manufactured in the US (The supply voltage and frequency are 110 V and 60 Hz respectively). What voltage will you apply if this transformer is to be used in this country? Justify your answer.**
   Answer:We know that,
   $$V = 4.4f\Phi_{max}n \tag{2}$$
   It is fair to assume that the flux and number of turns will remain same in both countries. Let V_1 and V_2 will be the voltages in US and India respectively.Using the above relation we get-
   $$\frac{V_1}{V_2} = \frac{f_1}{f_2} \tag{3}$$
   From here we can calculate value of $V2 = \frac{550}{6} = 91.667V$.

6. **What is the reason for high no load current at lower-than-rated voltage for the no load test on high frequency transformer which was demonstrated to you by the TAs ?**
Answer We know that,

$$I_m = \frac{V}{Z_L} = \frac{V}{\omega L} \implies I_m \ \alpha \ \frac{1}{f}$$

The high frequency transformer is designed to to draw small no-load current at rated frequency.At lower than rated frequency, the transformer draws greater magnetizing current (I_m). This justifes the observation of high no load current at even lower-than-rated voltage.

7. **Assume that you have been given two transformers of identical VA, and voltage ratings. But one of them is a 10 kHz transformer and another is a 100 Hz transformer. Just by inspection, how would you identify which one is the high frequency transformer? Justify your answer.**
Answer We use equation 2, voltage and flux in both cases are equal. We are given f_1= 10kHz and f_2= 100Hz .Let n_1 and n_2 be the number of turns in two sides of transformer. Now we get,

$$f \alpha \frac{1}{n}$$

So, the 10kHz transformer would be smaller and will be the high frequency one.

8. **What is an 'impedance matching' transformer? Name one instrument of everyday use, in which this transformer being used.**
Answer Impedance matching is a practice to design input or output impedance of a circuit in order to either maximize power transfer or minimize signal reflection from the load. It is used in a television balun transformer,audio speakers and many more devices.

6.1 Short Summary of Demo experiment

The demo experiment was about observing the effect DC current at secondary causes in primary side. We initially observe the current in primary winding when a resistive load is applied to the secondary. The result was as expected from the theory i.e the primary and secondary currents both are AC in nature. We also observed that the primary current was distorted which can be explained by the fact that we operate the transformer at knee point.
To observe the effect of DC current in the secondary, a diode was connected in series with the load resistance. This rectified the secondary current which has a finite DC component. Hence we can write the secondary current $I_2 = I_{2,DC} + I_{2,AC}$. According to the equation $N_1 I_1 = N_2 I_2$, we should get a similar equation for I_1 i.e I_1 should also have a finite DC component.
We observe that this is not true and that the current in the secondary is purely AC. This can be seen using Faraday's law which more fundamental.

$$V = \frac{d\phi}{dt}$$

As the voltage applied to the primary winding (V_1) is AC, this will induce flux ϕ_m in the core. Since the flux is also alternating, this induces V_2 in the secondary and hence there is a current I_2. The flux due to this current, say ϕ_2 would oppose the flux in the core. This would result in a current I_1 and hence a flux ϕ_1 in the primary which would be such that $V_1 = \frac{d}{dt}(\phi_m + \phi_1 - \phi_2)$. As derivative of constant is zero, hence ϕ_1 and I_1 won't have a DC component.