Tutorial 1: A Review of Power Supply Systems and Coupled Magnetic Circuits

Problem 1 Answer the following questions:

(A) The earth is generally not intended to be a return path for the current, but could have current flowing through it (unintentionally) under fault conditions, or due to leakage currents to ground.
State whether true or false?
Note:

(a) A fault is unintended connection between two points in a circuit.

(b) Leakage currents are usually very small (unavoidable) currents flowing through insulation resistance/capacitance.

(B) "All points on earth are always at the same potential." State whether true or false.

(C) Is the voltage drop along the earth when current flows through it only due to the resistance or is it due to loop inductance as well?

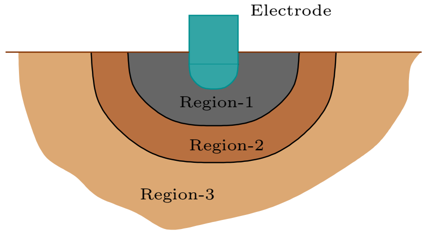
(D) Consider an earthing electrode as shown in the figure. Most of the resistance seen by the earth current is in

(a) Region-1

(b) Region-2

(c) Region-3

(d) Equally distributed over the regions.



Problem 2 State the differences between a "residual current circuit breaker" and a normal circuit breaker.

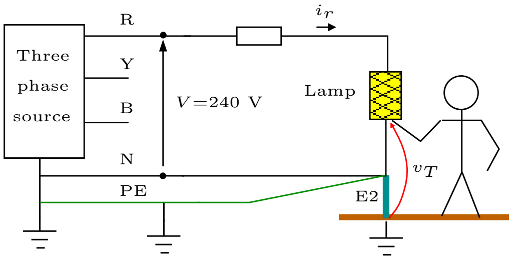
Problem 3 Consider a street lamp rated for 2×400 W which is supplied from a single phase voltage source of 240 V (rms), 50 Hz as shown in the figure. Assume the electrode E2 resistance to be 25 Ω.

(a) Under normal conditions (refer Figure (a)), what is the touch voltage v_T (i.e., the voltage between the touched point and the ground) ?

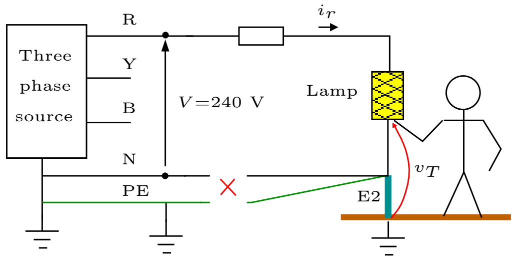
(b) If the metallic parts N and PE are disconnected (refer Figure (b)), then what is the touch voltage v_T?

Comment on the observations.

(Reference: K. Rajamani, *Application Guide for Power Engineers, Part-1 Earthing and Grounding of Electrical Systems*, Notion Press Publisher, (2018).)



(a) Circuit-1

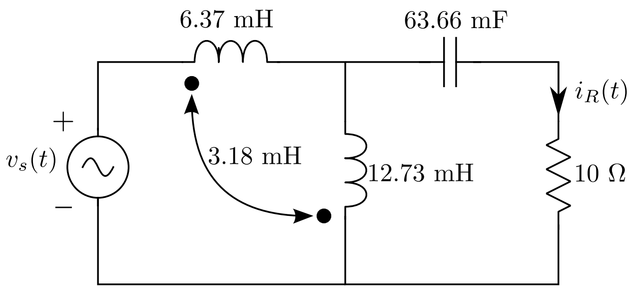


(b) Circuit-2

Problem 4 For the circuit shown in Figure, the voltage source $v_s(t)$ is given by

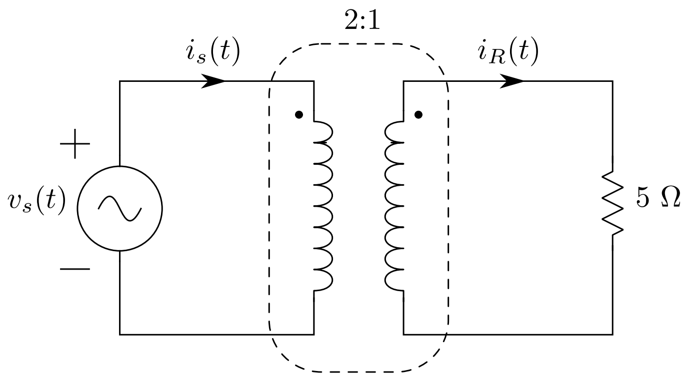
$$v_s(t) = 100\sqrt{2}\sin(2\pi \times 50t)\text{ V}$$

Find the steady state expression of the current $i_R(t)$ through the 10 Ω resistor.



Problem 5 For the circuit shown in Figure, the transformer has a rating of 100/50 V, 50 Hz, 700 VA. The expression of $v_s(t)$ is

$$v_s(t) = 100\sqrt{2}\sin\left(2\pi \times 50t + 45°\right)\text{ V}.$$



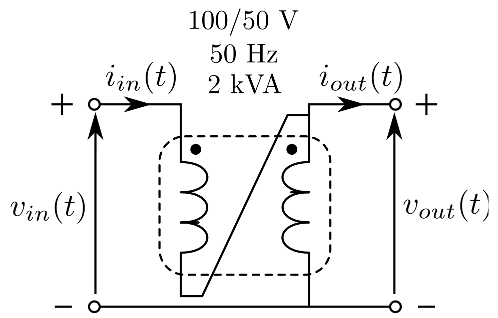
- Calculate the primary current $i_s(t)$, secondary current $i_R(t)$ of the transformer with
  (a) ideal transformer (with open-circuit current $i_{oc} \approx 0$), and
  (b) non-ideal transformer with leakage inductances L_{1l} = 3.18 mH, L_{2l} = 0.8 mH, winding resistances R_1 = 0.5 Ω, R_2 = 0.125 Ω and $i_{oc}(t)$ = $0.4\sqrt{2}\sin(2\pi \times 50t - 44.885°)$ A. **Note:** The open circuit current $i_{oc}(t)$ given here, is measured at the high voltage side (source side) with the low voltage side open circuited.

- Comment on the ratio of the terminal voltages $\bar{V}_1$ and $\bar{V}_2$ in each case.
- Comment on the ratio of the currents $\bar{I}_1$ and $\bar{I}_2$ in each case.
- Is $\Re(\bar{V}_1\bar{I}_1^*) = \Re(\bar{V}_2\bar{I}_2^*)$ for both the cases? Comment.

Problem 6 An ideal two-winding transformer of rating 100/50 V, 50 Hz, 2 kVA is connected as an auto-transformer with the dot polarities of the windings are as shown in Figure. Find the relation between

- input voltage $v_{in}(t)$ and output voltage $v_{out}(t)$,
- input current $i_{in}(t)$ and output current $i_{out}(t)$.

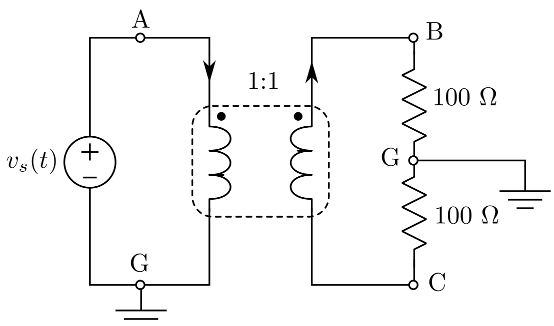
What is the equivalent rating of the transformer when connected as an auto-transformer? Comment on the results obtained.



Problem 7 For the circuit shown in Figure, the voltage source $v_s(t)$ is given as

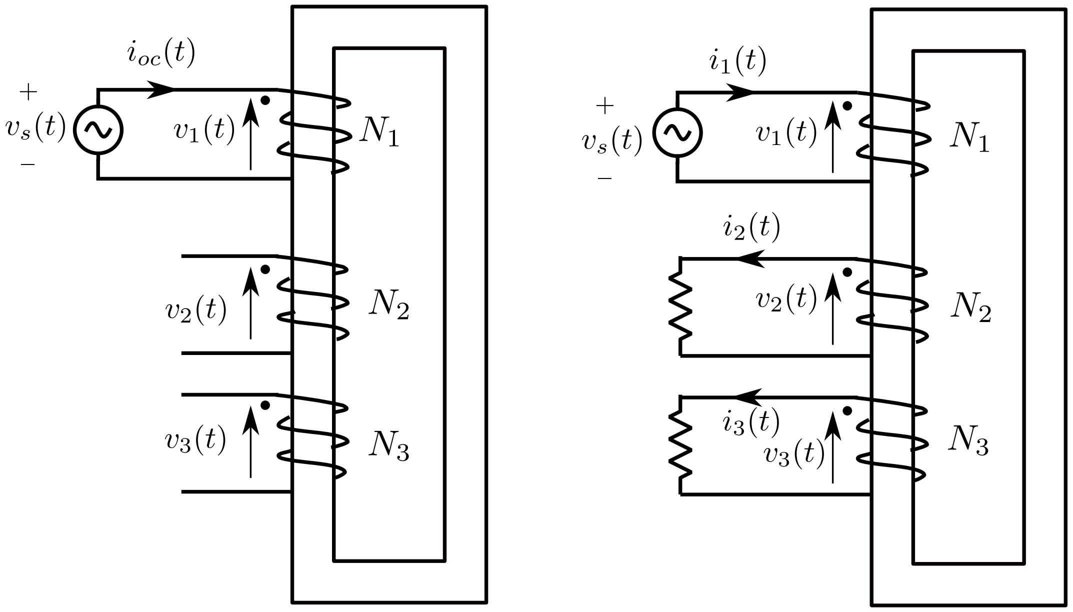
$$v_s(t) = \sqrt{2} \times 100 \sin(2\pi 50 \times t) \text{ V}.$$

Assuming the transformer is ideal, find the voltage $v_{AB}(t)$ between A and B.



Problem 8 A three-winding transformer is shown in Figure. The number of turns are N_1, N_2 and N_3, and the all windings are wound in the same way. The first winding is excited by a sinusoidal voltage source. In Case I (Figure(a)), the windings 2 and 3 are kept open, while in Case II (Figure(b)), the windings 2 and 3 are connected to a load. The magnitude of current in the Case I (i_{oc}) is negligible compared to that in Case II (i_1). If leakage flux, winding resistance and core loss/nonlinearities are neglected, then,

- find the relation between the voltages $v_1(t)$, $v_2(t)$, $v_3(t)$ in terms of the winding turns.
- find the relation between the currents $i_1(t)$, $i_2(t)$, $i_3(t)$ in terms of the winding turns.

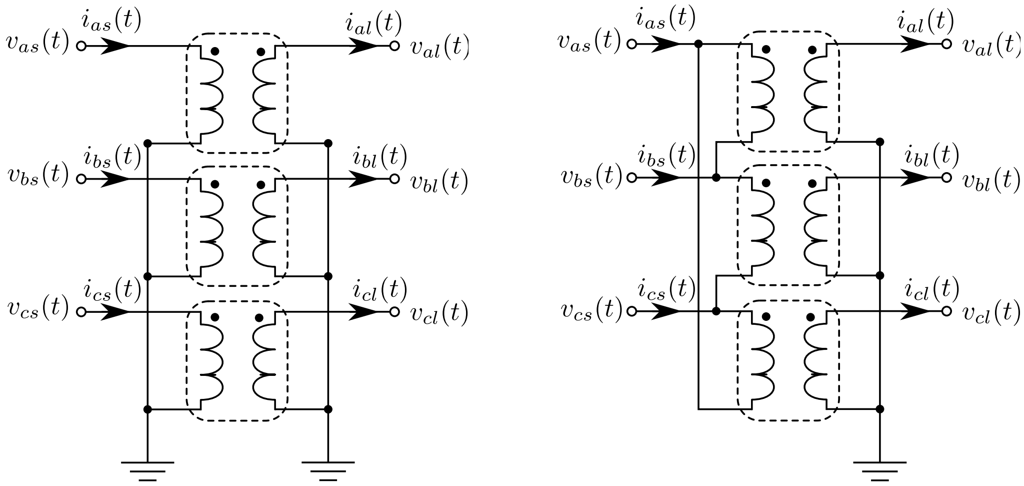


(a) Case I

(b) Case II

Problem 9 A star-connected neutral grounded three phase voltage source $v_s(t)$ is given as

$$v_a(t) = \sqrt{2} \times 50 \sin(2\pi \times 50t) \text{ V}$$
$$v_b(t) = \sqrt{2} \times 50 \sin\left(2\pi \times 50t - \frac{2\pi}{3}\right) \text{ V}$$
$$v_c(t) = \sqrt{2} \times 50 \sin\left(2\pi \times 50t + \frac{2\pi}{3}\right) \text{ V}.$$



(a) Configuration I

(b) Configuration II

A star-connected neutral grounded three phase load of resistance 10 Ω per phase is connected to this voltage source $v_s(t)$ by a three-phase transformer. The transformer is made of three single phase 2:1 ideal transformers connected appropriately. For the configurations of the transformer as shown in Figure(a) and Figure(b), calculate

- source side line current $i_{as}(t)$, $i_{bs}(t)$ and $i_{cs}(t)$ and load side line current $i_{al}(t)$, $i_{bl}(t)$ and $i_{cl}(t)$,
- load side line voltage $v_{al}(t)$, $v_{bl}(t)$ and $v_{cl}(t)$.

Problem 10 The transformers in Figure 3 and Figure 4 are ideal and

$$v_{AN}(t) = \sqrt{2} \times 110 \sin\left(2\pi 50 \times t\right) \text{ V},$$
$$v_{BN}(t) = \sqrt{2} \times 110 \sin\left(2\pi 50 \times t - \frac{2\pi}{3}\right) \text{ V},$$
$$v_{CN}(t) = \sqrt{2} \times 110 \sin\left(2\pi 50 \times t + \frac{2\pi}{3}\right) \text{ V}.$$

The three-phase transformer is constructed by appropriate connections of three single-phase ideal transformers of turns ratio 1:2. The transformer is connected to a balanced star-connected three-phase resistive load of resistance 5 Ω per phase. For both the circuits, calculate the rms value of the primary side line currents $i_A(t)$, $i_B(t)$ and $i_C(t)$ and that of the secondary side line currents $i_a(t)$, $i_b(t)$ and $i_c(t)$.
If the equivalent load seen at the source terminals A, B, C be a star-connected balanced load of impedance Z per phase, calculate the value of Z for both the cases.

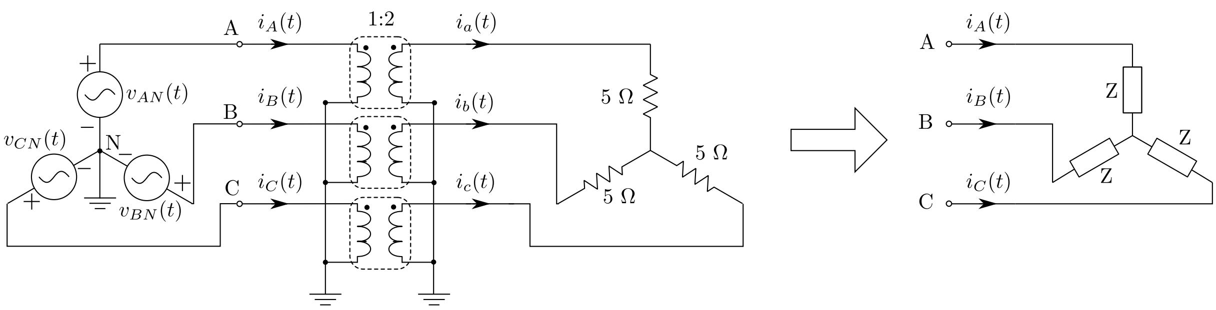


Figure 3: Figure for Problem 10

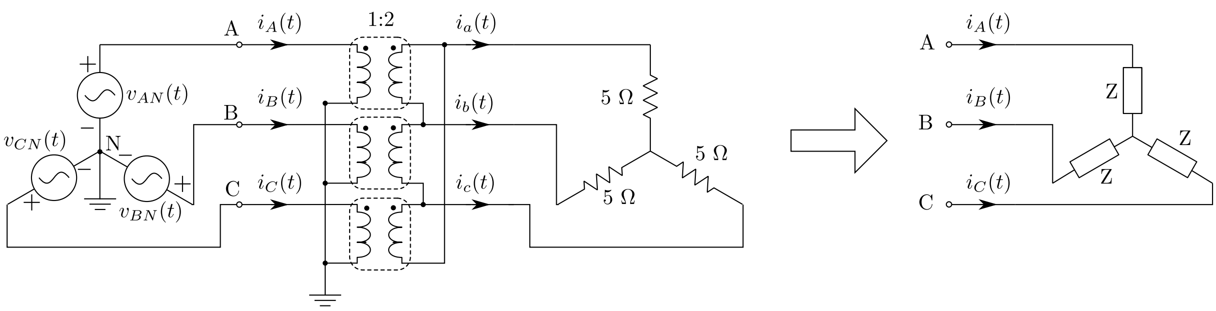
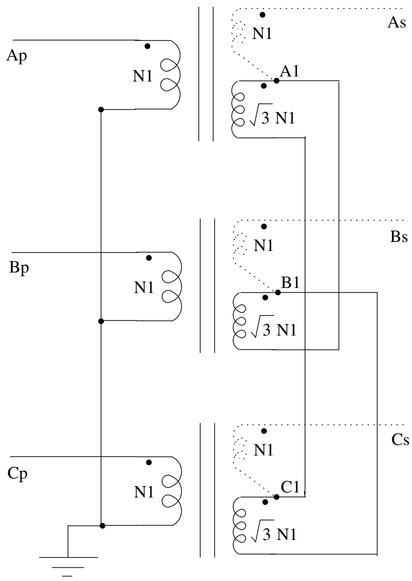
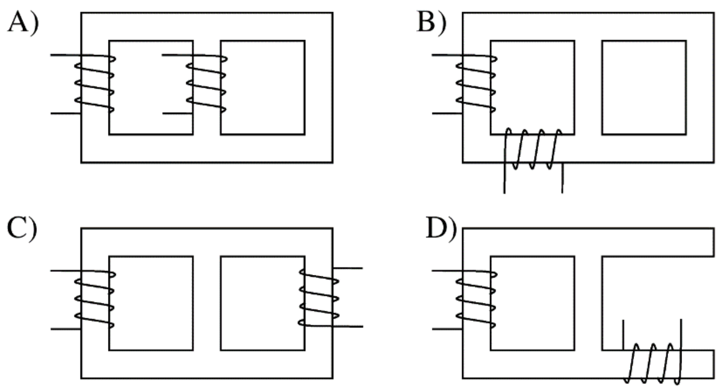


Figure 4: Figure for Problem 10

Problem 11 For the transformer connection shown in Figure, what is the phase shift between the line to line voltages on primary and secondary ? Consider phase sequence as A-B-C. Note that three winding transformers have been used.



Problem 12 The behavior of which of the following magnetically coupled circuits is closest to an ideal transformer?



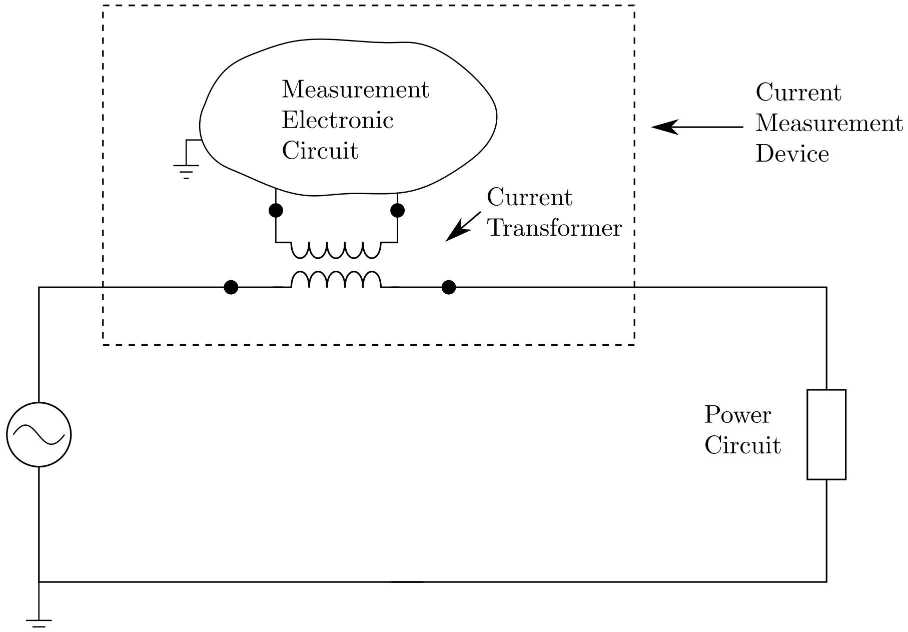
Problem 13 A current transformer is used as a part of a current measurement device. It is connected in series with an ac power circuit and can step down currents to measurable levels, besides providing isolation to the measurement circuits. Which of the following is TRUE?

A The load impedance offered by the measurement electronic circuit on the transformer should be very small

B The current transformer should practically be an open circuit on the measurement circuit side

C Short circuiting the winding on the measurement side will damage the power circuit and the current transformer

D The resistance and leakage reactance of the current transformer are designed to be very large as compared to a power transformer.



Problem 14 The inductance of each winding in Figure when excited individually (with the other winding open) is found to be 1 mH. If the leakage flux is negligible, the effective inductance as seen from the terminals HX as indicated in the circuit below is

(A) 0 mH

(B) 2 mH

(C) 3 mH

(D) 4 mH