



GANDHI SCHOOL OF ENGINEERING

Brahmapur, Odisha

Laboratory Manual

Basic Electrical Engineering Laboratory

Complete Laboratory Manual

B.Tech 1st Year · Semester 1 · Circuit Branch

Academic Year 2026-27



About this lab manual

This manual covers the **Basic Electrical Engineering Laboratory** (0-0-2) of the first semester. Each experiment contains the aim, apparatus with ratings, a neat circuit diagram, **theory with a clear explanation**, step-by-step procedure, **observation tables with a full set of sample readings**, fully worked calculations and graphs, result, precautions and viva-voce questions with answers.

No.	Experiment	Topic
1	Familiarisation with instruments and components; verification of Ohm's law	Basics
2	Verification of Kirchhoff's current and voltage laws	DC circuits
3	Verification of the superposition theorem	Network theorems
4	Verification of Thevenin's and Norton's theorems	Network theorems
5	Verification of the maximum power transfer theorem	Network theorems
6	Resonance in a series RLC circuit	AC circuits
7	Power and power factor of a fluorescent lamp; power factor improvement	AC circuits
8	Measurement of three-phase power by the two-wattmeter method	Three-phase circuits
9	Open-circuit and short-circuit tests on a single-phase transformer	Transformers
10	Speed control of a DC shunt motor	DC machines
11	Staircase wiring and study of fuse, MCB and earthing	Electrical installations

Electrical safety rules (read before every class)

- Never work on a live circuit. Make all connections with the **supply switched off**, and get them checked by the teacher before switching on.
- Use wires of proper current rating and tighten all terminals; loose connections cause sparking and heating.
- Keep the **variac at zero** and rheostats at the safe position (maximum resistance in series, minimum across) before switching on.
- Check the **range and type (AC/DC)** of every meter before connecting it. An ammeter is always in series and a voltmeter in parallel.
- Do not touch metal parts of machines while they are running; keep hands, loose clothes and hair away from rotating parts.



- In case of electric shock, switch off the supply immediately; do not touch the victim with bare hands; use a dry wooden stick to separate the victim; give first aid (CPR) and call for medical help.
- In case of an electrical fire, switch off the supply and use a CO₂ or dry-powder extinguisher — **never water**.

Common instruments

Instrument	Use	Type
Ammeter	Measures current (in series, very low resistance)	PMMC for DC; moving-iron (MI) for AC and DC
Voltmeter	Measures voltage (in parallel, very high resistance)	PMMC for DC; MI for AC
Wattmeter	Measures power; current coil (CC) in series, pressure coil (PC) in parallel	Electrodynamometer type
Multimeter	Measures V, I, R, continuity; digital (DMM) or analogue	—
Energy meter	Measures energy in kWh	Induction type or electronic
Tachometer	Measures speed of rotating machines (rpm)	Contact or non-contact (optical)
Variac (autotransformer)	Gives variable AC voltage from 0 to 230/270 V	—
Rheostat	Variable resistance for controlling current	Wire-wound, sliding contact



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Basic Electrical Engineering Laboratory

Eleven experiments · Theory with explanation · Sample readings · Calculations · Viva

Experiment 1: Instruments, Components and Ohm's Law

Aim

(a) To become familiar with common electrical instruments, components and the resistor colour code. (b) To verify Ohm's law and find the value of an unknown resistance by the voltmeter-ammeter method.

Apparatus

Regulated DC power supply (0–30 V), resistor 100 Ω /2 W, DC milliammeter (0–200 mA), DC voltmeter (0–15 V), digital multimeter, breadboard, connecting wires.

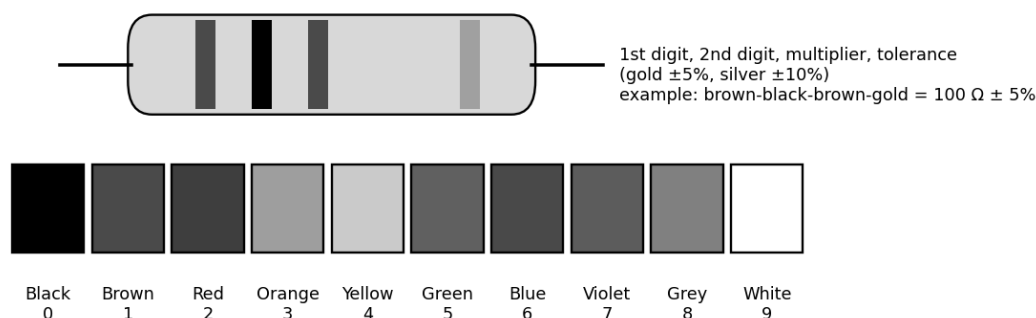


Figure 1.1: Resistor colour code. The first two bands give the digits, the third the multiplier and the fourth the tolerance.

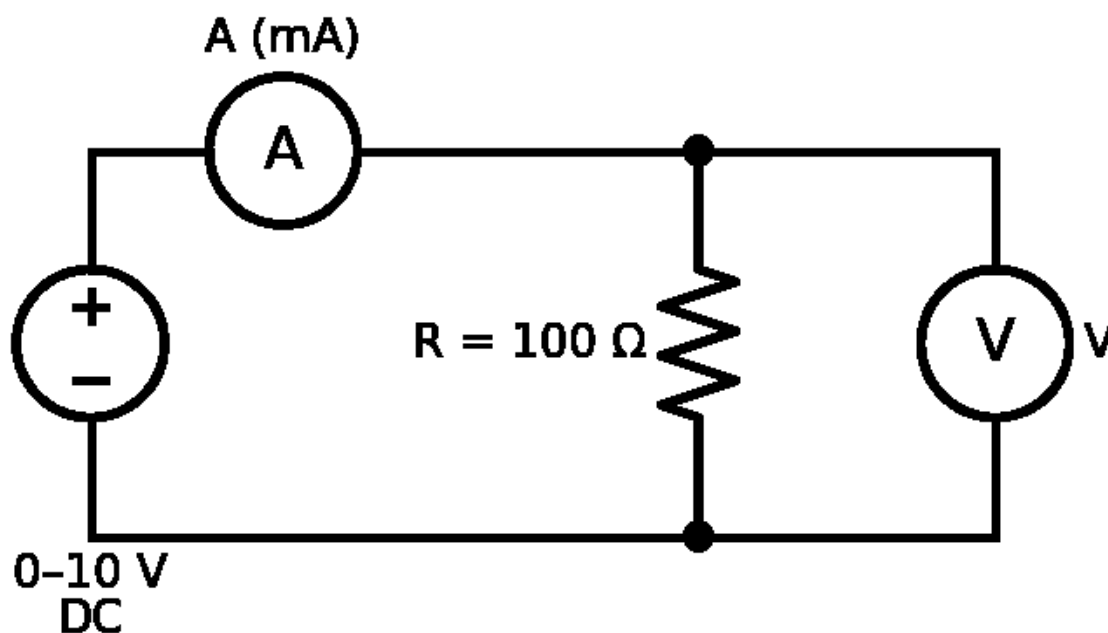


Figure 1.2: Circuit for verifying Ohm's law.

Theory (with explanation)

Ohm's law: at constant temperature (and other physical conditions), the current through a conductor is directly proportional to the potential difference across it:

$$V \propto I \Rightarrow V = IR$$

The constant R is the **resistance** of the conductor, measured in ohms (Ω). It depends on the material (resistivity ρ), length l and area of cross-section A: $R = \rho l/A$.

Why the graph is a straight line: in a metallic conductor, free electrons drift under the electric field; their drift velocity (and hence current) is proportional to the field (and hence the applied voltage), as long as the temperature does not change. So the V-I graph is a straight line through the origin and its **slope equals R**. Devices that obey this (resistors) are **linear**; diodes, lamps and thermistors are **non-linear**.

Colour code: e.g. brown (1), black (0), brown ($\times 10^1$), gold ($\pm 5\%$) gives $10 \times 10 = 100 \Omega \pm 5\%$. A mnemonic for the colours 0–9 is "BB ROY of Great Britain has a Very Good Wife" (black, brown, red, orange, yellow, green, blue, violet, grey, white).

Power rating: a resistor must dissipate $P = I^2R = V^2/R$ without overheating; its wattage rating must be greater than this.

Procedure

- Read the colour bands of the given resistor and find its nominal value; check it with the multimeter (Ω range).
- Connect the circuit of Figure 1.2 with the supply at zero. Check the polarity of the meters.
- Increase the voltage in steps of 1 V up to 10 V and note the current each time.
- Calculate $R = V/I$ for each reading and plot V against I.

Observations and calculation (sample readings)

S. No.	Voltage V (V)	Current I (mA)	R = V/I (Ω)
1	1.0	10.00	100.0
2	2.0	20.22	98.9
3	3.0	30.29	99.0
4	4.0	39.84	100.4
5	5.0	49.88	100.2
6	6.0	59.75	100.4
7	7.0	70.32	99.5
8	8.0	79.96	100.0
9	9.0	90.54	99.4
10	10.0	98.52	101.5

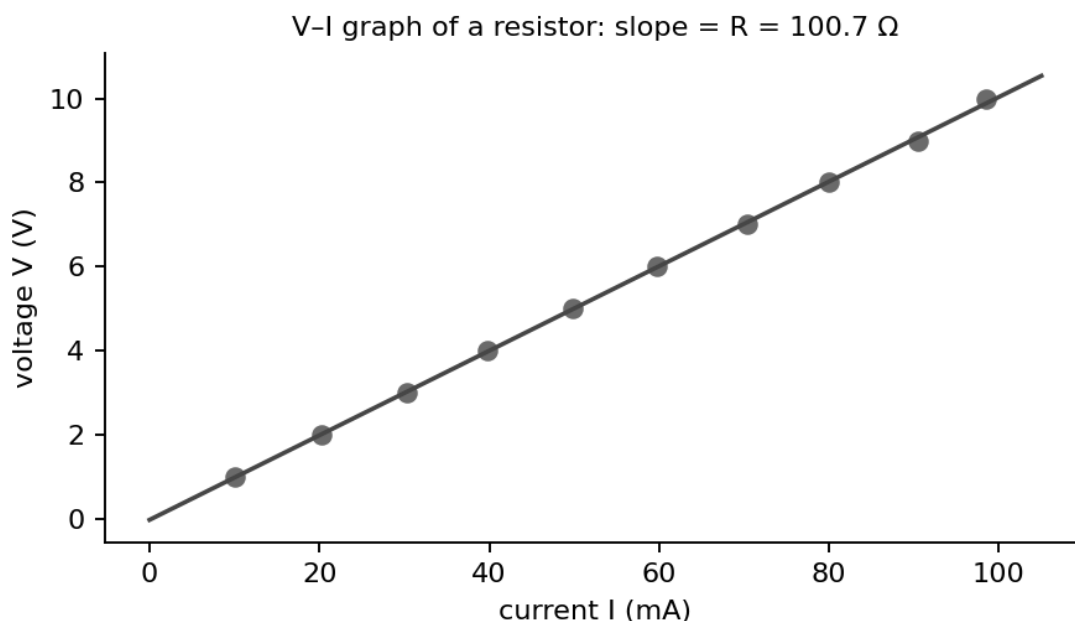


Figure 1.3: The V-I graph is a straight line through the origin, so the resistor obeys Ohm's law.

Calculation:

- Mean of $V/I = 99.9 \, \Omega$; slope of the V-I graph = $100.7 \, \Omega$.
- Colour-code value: brown-black-brown-gold = $10 \times 10^1 = 100 \, \Omega \pm 5\%$ (95-105 Ω). The measured value lies within the tolerance.
- Power dissipated at 10 V: $P = V^2/R = 100/99.9 = 1.00 \, \text{W}$, so a resistor of at least 2 W rating is needed.

Result

The resistance found from the V-I graph is $100.7 \, \Omega$ (colour-code value $100 \, \Omega \pm 5\%$); the linear graph verifies Ohm's law.

Precautions

- Do not exceed the power rating of the resistor; the resistor should not become hot (heating changes R).
- Connect the ammeter in series and the voltmeter in parallel with correct polarity.
- Avoid parallax when reading analogue meters.

Viva-voce questions**Q1. State Ohm's law and its limitations.**

$V = IR$ at constant temperature. It does not apply to non-linear devices (diodes, transistors, arc lamps), electrolytes and gases, or when the temperature changes.

Q2. Why is an ammeter connected in series and a voltmeter in parallel?

An ammeter must carry the circuit current, so it has very low resistance and is in series. A voltmeter measures the potential difference between two points, so it has very high resistance and is connected across them.

Q3. What happens if an ammeter is connected in parallel?



Its low resistance short-circuits the element; a very large current flows and may damage the ammeter.

Q4. What is the effect of temperature on the resistance of metals?

It increases: $R_t = R_0(1 + \alpha t)$, where α is the temperature coefficient of resistance.

Q5. Find the value of a resistor with bands red, violet, orange, silver.

$27 \times 10^3 = 27 \text{ k}\Omega \pm 10\%$.

Experiment 2: Verification of Kirchhoff's Laws

Aim

To verify Kirchhoff's current law (KCL) and voltage law (KVL) in a DC circuit with two sources.

Apparatus

Two regulated DC supplies (0–30 V), resistors 1 k Ω , 2.2 k Ω and 3.3 k Ω , DC milliammeters (0–20 mA) three, DC voltmeter or multimeter, breadboard, wires.

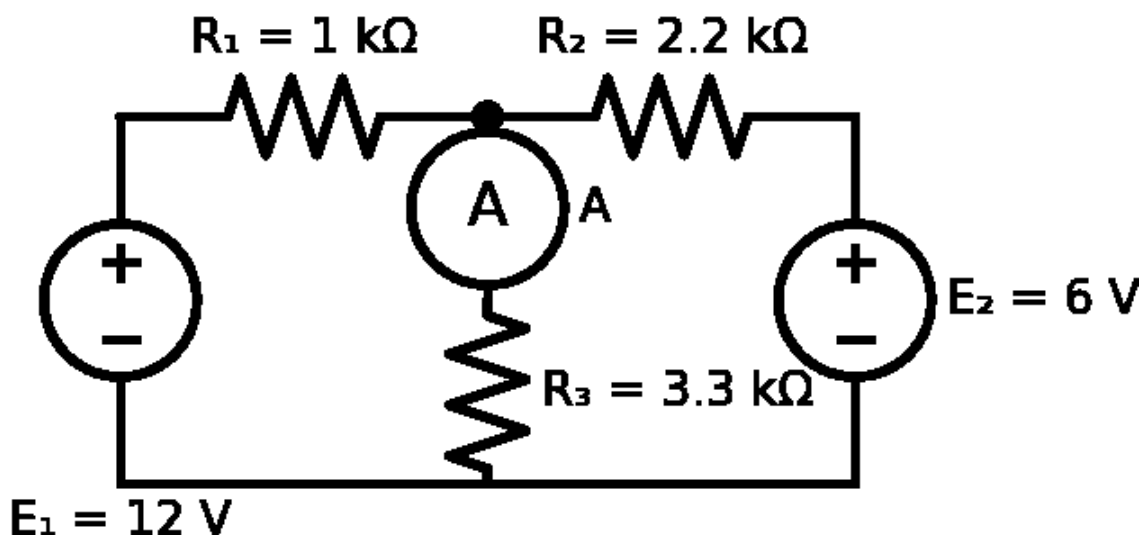


Figure 2.1: Two-source circuit for verifying KCL and KVL (ammeters are placed in each branch; the figure shows the meter in the R_3 branch).

Theory (with explanation)

Kirchhoff's current law (KCL): the algebraic sum of the currents meeting at a node (junction) is zero; that is, the total current entering a node equals the total current leaving it.

$$\sum I = 0 \text{ (at every node)}$$

Why it is true: charge is conserved. A node cannot store charge, so whatever charge flows in per second must flow out per second.

Kirchhoff's voltage law (KVL): in any closed loop, the algebraic sum of the EMFs and voltage drops is zero.

$$\sum V = 0 \text{ (around every closed loop)}$$

Why it is true: energy is conserved. A unit charge taken round a closed path returns to the same potential, so the energy gained from sources equals the energy lost in resistors.

Sign convention: moving round the loop, a rise in potential (– to + of a source, or across a resistor against the current) is positive and a drop is negative.

Applying the laws to Figure 2.1: with the node voltage V (bottom as reference), the three branch currents are $I_1 = (E_1 - V)/R_1$ (towards the node), $I_2 = (V - E_2)/R_2$ (away from the node, into E_2), and $I_3 = V/R_3$ (down through R_3). KCL at the node gives $I_1 = I_2 + I_3$, which is solved for V (nodal analysis).

Procedure

- Connect the circuit with $E_1 = 12\text{ V}$ and $E_2 = 6\text{ V}$ (supplies set before connecting) and one milliammeter in each branch.
- Switch on and note the three branch currents and the voltage across each resistor.
- Check KCL at the node and KVL for both loops, and compare with the theoretical values.
- Repeat with other supply voltages if time permits.

Observations and calculation (sample readings)

Theoretical values (nodal analysis): node voltage $V = (E_1/R_1 + E_2/R_2)/(1/R_1 + 1/R_2 + 1/R_3) = (12/1 + 6/2.2)/(1/1 + 1/2.2 + 1/3.3) = 8.379\text{ V}$.

- $I_1 = (12 - 8.379)/1\text{ k}\Omega = 3.621\text{ mA}$; $I_3 = 8.379/3.3\text{ k}\Omega = 2.539\text{ mA}$; $I_2 = (8.379 - 6)/2.2\text{ k}\Omega = 1.082\text{ mA}$.

Verification of KCL at the node:

Quantity	$I_1\text{ (mA)}$	$I_2\text{ (mA)}$	$I_3\text{ (mA)}$	$I_2 + I_3\text{ (mA)}$
Theoretical	3.621	1.082	2.539	3.621
Measured	3.618	1.079	2.546	3.625

Verification of KVL:

Loop	Equation	Measured values (V)	Sum
Loop 1 (E_1, R_1, R_3)	$E_1 - V_{R1} - V_{R3} = 0$	$12 - 3.655 - 8.414$	$-0.068 \approx 0$
Loop 2 (E_2, R_2, R_3)	$V_{R3} - V_{R2} - E_2 = 0$	$8.414 - 2.378 - 6$	$0.036 \approx 0$

- Error in KCL = $|3.618 - 3.625| = 0.008\text{ mA}$, which is within meter accuracy.

Result

In the given circuit, the algebraic sum of currents at the node and of voltages around each loop is zero within experimental error, so KCL and KVL are verified.

Precautions

- Note the direction of current in each branch from the ammeter polarity; a reversed deflection means the current flows the other way.
- Keep the supply voltages constant while taking readings.
- Use meters of suitable range for better accuracy.

Viva-voce questions**Q1. On which conservation laws are KCL and KVL based?**

KCL on conservation of charge; KVL on conservation of energy.

Q2. What is a node, a branch and a loop?

A node is a junction of two or more elements; a branch is an element (or series elements) between two nodes; a loop is any closed path.

Q3. Are Kirchhoff's laws valid for AC circuits?

Yes, with instantaneous values or phasors (complex values) of voltages and currents.



Q4. Why is there a small error in verification?

Meter tolerance and resistance, tolerance of resistors, contact resistance and loading effect of the voltmeter.

Experiment 3: Verification of the Superposition Theorem

Aim

To verify the superposition theorem for a linear bilateral DC network with two sources.

Apparatus

Same as Experiment 2.

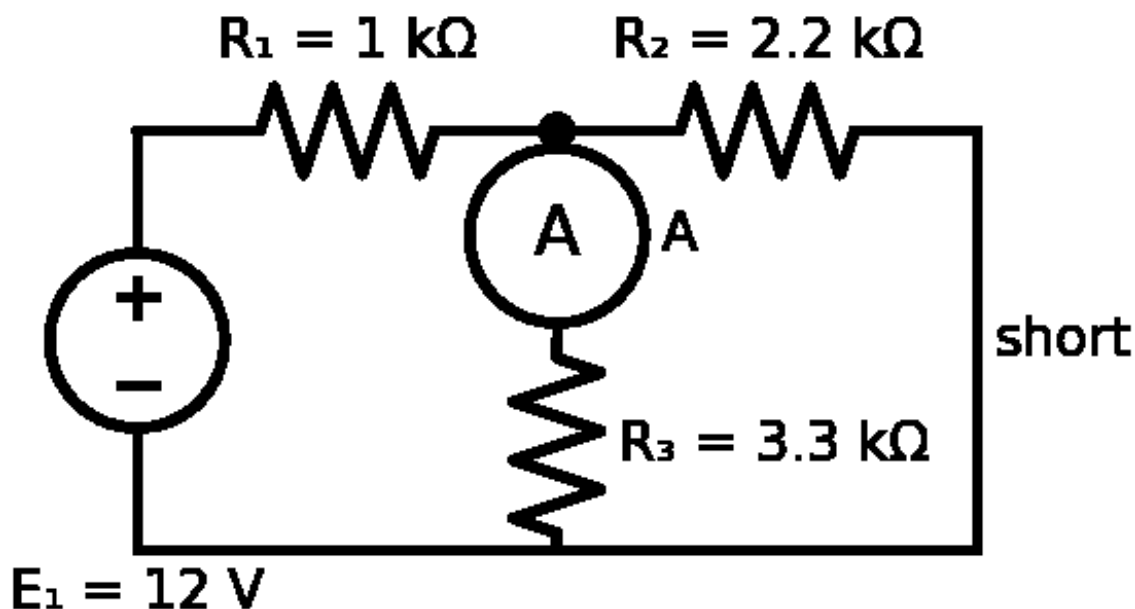


Figure 3.1: E_1 acting alone (E_2 replaced by a short circuit).

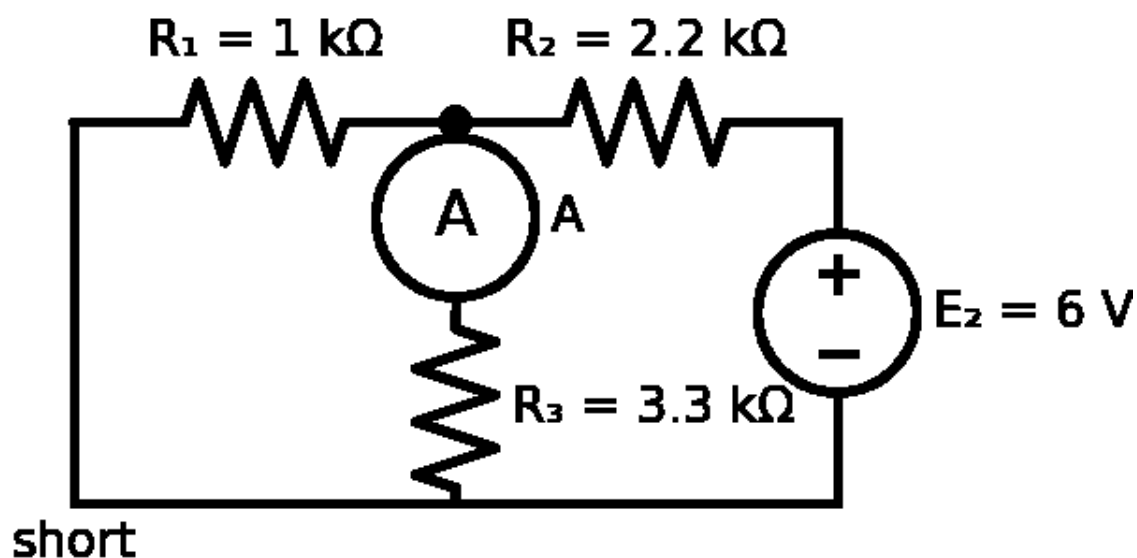


Figure 3.2: E_2 acting alone (E_1 replaced by a short circuit).

Theory (with explanation)

Statement: in a linear, bilateral network containing more than one independent source, the current through (or voltage across) any element is the **algebraic sum** of the currents (or voltages) produced by each source acting alone, with all other independent sources replaced by their internal resistances.

- An ideal **voltage source** is replaced by a **short circuit** (zero internal resistance).

- An ideal **current source** is replaced by an **open circuit** (infinite internal resistance).

Why it works: in a linear network every current is a linear combination of the source values (the network equations are linear). So the response to E_1 and E_2 together equals the response to E_1 alone plus the response to E_2 alone.

Limitations: it applies only to linear networks and only to currents and voltages — **not to power**, because power is proportional to the square of current: $(I' + I'')^2 R \neq I'^2 R + I''^2 R$.

Procedure

- Connect the circuit of Figure 2.1 and measure the current I_3 in R_3 with both sources acting.
- Remove E_2 and replace it by a short (connect the two points together); measure I_3' with E_1 alone (Figure 3.1).
- Restore E_2 , remove E_1 and short its terminals; measure I_3'' with E_2 alone (Figure 3.2).
- Check that $I_3 = I_3' + I_3''$ (taking directions into account) and compare with theoretical values.

Observations and calculation (sample readings)

Theoretical calculation of the current in R_3 (3.3 k Ω):

- **E_1 alone (E_2 replaced by a short):** $R = R_1 + R_2 \parallel R_3 = 1 + (2.2 \times 3.3)/5.5 = 2.320$ k Ω ;
 $I = 12/2.320 = 5.172$ mA; $I_3' = 5.172 \times 2.2/5.5 = \mathbf{2.069$ mA.
- **E_2 alone (E_1 replaced by a short):** $R = R_2 + R_1 \parallel R_3 = 2.2 + (1 \times 3.3)/4.3 = 2.967$ k Ω ;
 $I = 6/2.967 = 2.022$ mA; $I_3'' = 2.022 \times 1/4.3 = \mathbf{0.470$ mA.
- **Both sources:** $I_3 = I_3' + I_3'' = 2.069 + 0.470 = \mathbf{2.539$ mA (agrees with nodal analysis, 2.539 mA).

Observation table:

Condition	I_3 theoretical (mA)	I_3 measured (mA)
E_1 acting alone	2.069	2.079
E_2 acting alone	0.470	0.470
Sum $I_3' + I_3''$	2.539	2.549
Both E_1 and E_2 acting	2.539	2.537

- Difference between the measured total and the sum of individual currents = 0.012 mA ($\approx 0.5\%$).
- Power check (why power cannot be superposed): P with both sources = 21.28 mW, but $P' + P'' = 14.13 + 0.73 = 14.86$ mW $\neq 21.28$ mW.

Result

The current in R_3 with both sources (2.537 mA) equals the sum of the currents due to each source acting alone (2.549 mA) within experimental error, so the superposition theorem is verified.

Precautions

- Never short-circuit a power supply by mistake: disconnect the source first, then join the two points where it was connected.
- Note the direction of each current carefully.



Viva-voce questions

Q1. State the superposition theorem.

In a linear bilateral network with several sources, the response in any element equals the algebraic sum of the responses due to each source acting alone, others being replaced by their internal resistances.

Q2. How are sources "removed" in superposition?

Ideal voltage sources are short-circuited and ideal current sources are open-circuited; practical sources are replaced by their internal resistances.

Q3. Why can power not be found by superposition?

Power is a non-linear (square) function of current or voltage.

Q4. Can superposition be applied to a circuit containing a diode?

No, a diode is non-linear (and unilateral).

Experiment 4: Verification of Thevenin's and Norton's Theorems

Aim

To find the Thevenin and Norton equivalent circuits of a given network and verify the theorems by comparing the load current with the directly measured value.

Apparatus

Regulated DC supply, resistors 1 k Ω , 2.2 k Ω , 470 Ω , load resistors (470 Ω , 1 k Ω , 2.2 k Ω , 3.3 k Ω), milliammeter, voltmeter, digital multimeter, breadboard, wires.

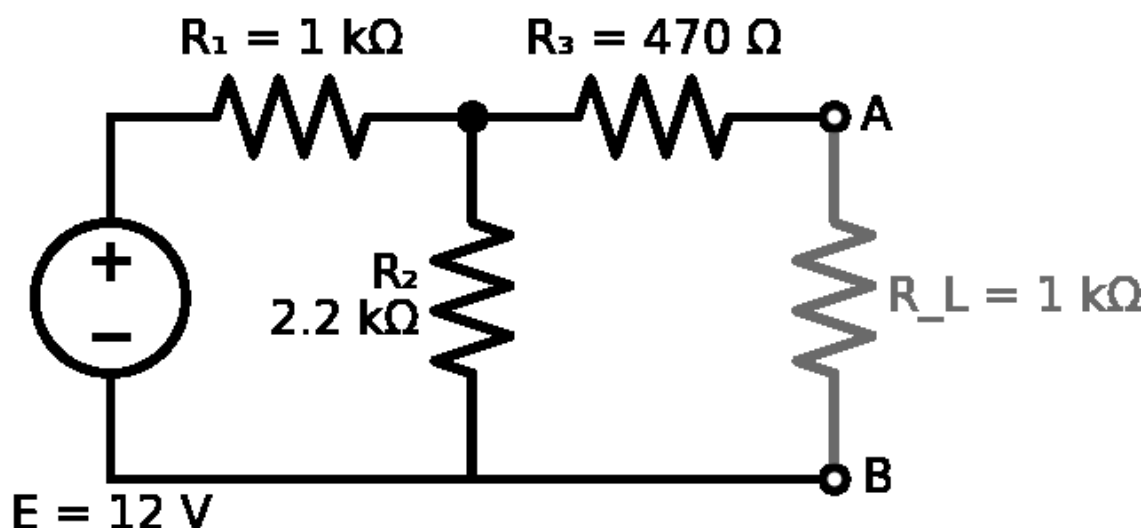


Figure 4.1: Network for verification. The load R_L is connected between terminals A and B.

Theory (with explanation)

Thevenin's theorem: any linear, bilateral two-terminal network can be replaced by a single voltage source V_{th} in series with a resistance R_{th} .

- V_{th} is the **open-circuit voltage** across the terminals A-B (load removed).
- R_{th} is the resistance seen from A-B when all independent sources are replaced by their internal resistances.

$$I_L = V_{th} / (R_{th} + R_L)$$

Norton's theorem: the same network can be replaced by a current source I_N in parallel with $R_N = R_{th}$, where I_N is the **short-circuit current** through A-B.

$$I_N = V_{th} / R_{th}; I_L = I_N R_{th} / (R_{th} + R_L)$$

Why it is useful: when the load changes (as in a power supply feeding different loads), we do not have to solve the whole network again; the load current follows from the two-element equivalent. The two equivalents are source transformations of each other.

Explanation for Figure 4.1: with A-B open, no current flows in R_3 , so V_{th} is the voltage across R_2 from the divider R_1 - R_2 . With the source shorted, R_1 and R_2 are in parallel and in series with R_3 .

Procedure

- Connect the network with $R_L = 1\text{ k}\Omega$ and measure the load current directly.
- Remove R_L and measure the open-circuit voltage across A-B: this is V_{th} .

- Remove the supply, short its terminals, and measure the resistance across A-B with a multimeter: this is R_{th} .
- Short A-B through a milliammeter (with the supply restored) and measure the short-circuit current: this is I_N .
- Build the Thevenin equivalent (supply set to V_{th} in series with a resistance R_{th}) and connect R_L ; measure I_L . Compare with the original.
- Repeat for other load resistances.

Observations and calculation (sample readings)

Theoretical values:

- V_{th} (open-circuit voltage at A-B, no current in R_3): $V_{th} = 12 \times 2.2/(1 + 2.2) = \mathbf{8.250\ V}$.
- R_{th} (source shorted): $R_{th} = (1 \parallel 2.2) + 0.47 = 0.6875 + 0.47 = \mathbf{1.1575\ k\Omega}$.
- Load current for $R_L = 1\ k\Omega$: $I_L = 8.250/(1.1575 + 1) = \mathbf{3.824\ mA}$.
- Norton current $I_N = V_{th}/R_{th} = 8.250/1.1575 = \mathbf{7.127\ mA}$; $I_L = I_N R_{th}/(R_{th} + R_L) = 3.824\ mA$.

Observation table:

Quantity	Theoretical	Measured
V_{th} (V)	8.250	8.278
R_{th} (k Ω) (with multimeter)	1.1575	1.1494
I_N (short-circuit current, mA)	7.127	7.144
I_L for $R_L = 1\ k\Omega$ (mA)	3.824	3.789

Load current for different loads (from the Thevenin equivalent and by direct measurement):

R_L (k Ω)	$I_L = V_{th}/(R_{th} + R_L)$ (mA)	I_L measured directly (mA)
0.47	5.069	5.049
1.0	3.824	3.780
2.2	2.457	2.445
3.3	1.851	1.846

Result

For the given network, $V_{th} = 8.28\ V$, $R_{th} = 1.149\ k\Omega$ and $I_N = 7.14\ mA$; the load currents from the equivalent circuits agree with the measured currents, so Thevenin's and Norton's theorems are verified.

Precautions

- Measure R_{th} only after disconnecting the supply; an ohmmeter must never be used in a live circuit.
- Set the equivalent source exactly to V_{th} with a multimeter.

Viva-voce questions

Q1. State Thevenin's theorem.



Any linear bilateral two-terminal network can be replaced by an equivalent voltage source V_{th} (open-circuit voltage) in series with R_{th} (resistance seen from the terminals with sources removed).

Q2. What is the relation between Thevenin and Norton equivalents?

$$R_N = R_{th} \text{ and } I_N = V_{th}/R_{th}.$$

Q3. How is R_{th} found when the network contains dependent sources?

By $R_{th} = V_{oc}/I_{sc}$, or by applying a test source at the terminals with the independent sources removed.

Q4. Give one practical application of Thevenin's theorem.

Analysing the load current of a power supply or an amplifier stage for different loads; finding the load for maximum power.

Experiment 5: Verification of the Maximum Power Transfer Theorem

Aim

To verify that maximum power is transferred from a DC source to a load when the load resistance equals the internal (Thevenin) resistance of the source, and to find the efficiency at that condition.

Apparatus

Regulated DC supply (10 V), resistor 100 Ω (representing the source resistance), decade resistance box (0–1 k Ω) as load, milliammeter (0–100 mA), voltmeter (0–10 V), wires.

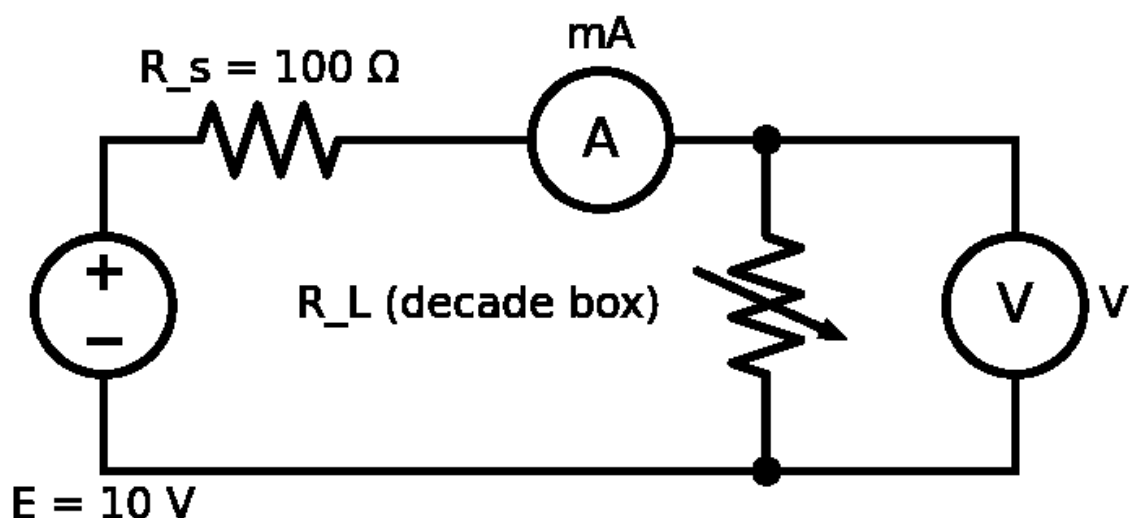


Figure 5.1: Circuit for the maximum power transfer theorem.

Theory (with explanation)

Statement: a linear network delivers maximum power to a load resistance R_L when R_L equals the Thevenin resistance R_{th} of the network as seen from the load terminals.

Proof: with the network replaced by its Thevenin equivalent (V_{th} , R_{th}), the load current is $I = V_{th}/(R_{th} + R_L)$, so the load power is

$$P_L = I^2 R_L = V_{th}^2 R_L / (R_{th} + R_L)^2$$

For maximum P_L , $dP_L/dR_L = 0$: $(R_{th} + R_L)^2 - 2R_L(R_{th} + R_L) = 0$, which gives $R_L = R_{th}$. Then

$$P_{max} = V_{th}^2 / (4R_{th}); \text{ efficiency } \eta = R_L / (R_{th} + R_L) = 50\%$$

Explanation of the curve: when R_L is very small, the current is large but the voltage across the load is nearly zero; when R_L is very large, the voltage is large but the current is nearly zero. In both cases the power is small, so there is a maximum in between.

Where it is used: in communication and electronic circuits (antenna to receiver, amplifier to loudspeaker) where the power is small and getting the maximum signal matters more than efficiency. In power systems it is not used, because 50% efficiency would waste half the energy.

Procedure

- Connect the circuit with the 10 V supply, the 100 Ω source resistance and the decade box as the load.
- Vary R_L from 20 Ω to 500 Ω ; for each value note the current and the load voltage.
- Calculate the load power $P = V_L I$ and the efficiency.
- Plot P against R_L and find the value of R_L at the peak.

Observations and calculation (sample readings)

Source: $E = 10\text{ V}$ with a series (internal) resistance $R_s = 100\ \Omega$.

$R_L\ (\Omega)$	$I\ (\text{mA})$	$V_L\ (\text{V})$	$P_L = V_L I\ (\text{mW})$	Efficiency $\eta = \frac{R_L}{(R_s + R_L)}\ (\%)$
20	82.8	1.65	137.0	16.7
40	71.4	2.87	205.0	28.6
60	62.4	3.74	233.2	37.5
80	55.7	4.46	248.3	44.4
100	49.9	5.01	250.3	50.0
120	45.7	5.45	249.0	54.5
150	39.8	6.01	239.4	60.0
200	33.4	6.70	223.7	66.7
300	24.8	7.48	185.7	75.0
500	16.6	8.26	137.1	83.3

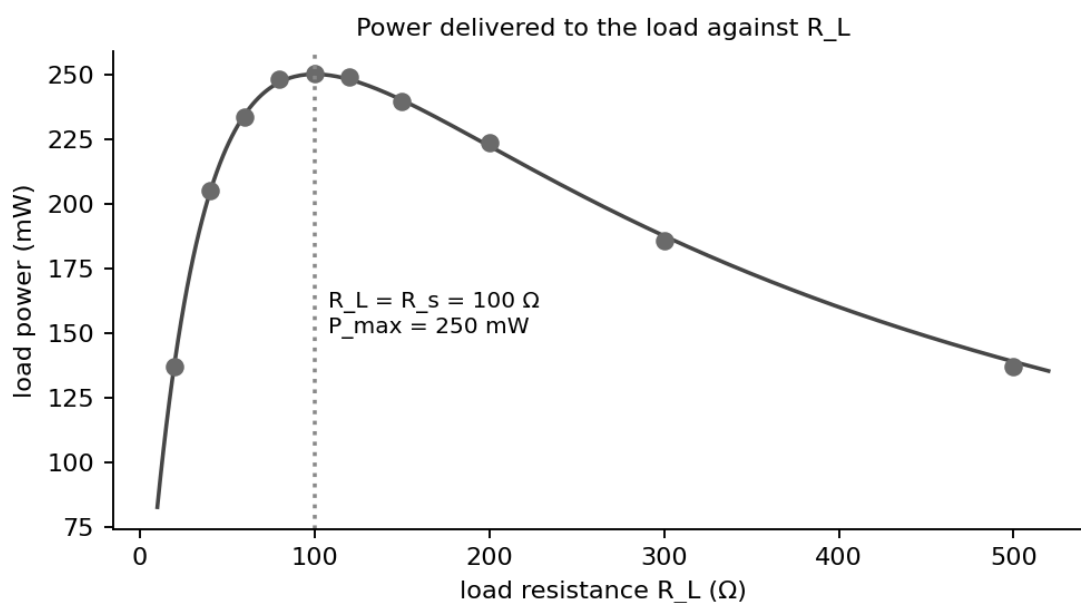


Figure 5.2: The load power is maximum when R_L equals the source resistance.

Calculation:

- Theoretical maximum power $P_{\text{max}} = \frac{E^2}{4R_s} = \frac{100}{400} = 0.25\ \text{W} = \mathbf{250\ mW}$ at $R_L = 100\ \Omega$.
- Measured maximum power = 250.3 mW at $R_L = 100\ \Omega$.
- Efficiency at maximum power = $100/(100 + 100) = \mathbf{50\%}$.



Result

Maximum power (250 mW, theoretical 250 mW) is delivered when the load resistance equals the source resistance (100 Ω), and the efficiency at that point is 50%; the maximum power transfer theorem is verified.

Precautions

- The source resistance must be able to carry the maximum current (100 mA at $R_L = 0$: $P = 1$ W; use a 2 W resistor).
- Keep the supply voltage constant throughout.
- Take more readings near $R_L = R_s$ to locate the peak accurately.

Viva-voce questions

Q1. State the maximum power transfer theorem.

Maximum power is transferred to the load when the load resistance equals the Thevenin resistance of the source network.

Q2. What is the efficiency at maximum power transfer?

50%, because equal power is dissipated in R_{th} and R_L .

Q3. For AC circuits, what is the condition for maximum power transfer?

The load impedance must be the complex conjugate of the source impedance: $Z_L = Z_{th}^*$ ($R_L = R_{th}$, $X_L = -X_{th}$).

Q4. Why is the theorem not used in power systems?

Because the efficiency would be only 50%; power systems are designed for high efficiency with $R_L \gg R_{th}$.

Experiment 6: Resonance in a Series RLC Circuit

Aim

To study the frequency response of a series RLC circuit and to find the resonant frequency, bandwidth and quality factor.

Apparatus

Function generator (sine wave, 20 Hz–20 kHz), resistor 100 Ω , inductor 100 mH, capacitor 0.1 μF , AC milliammeter (or measure the voltage across R with a multimeter/CRO), connecting wires.

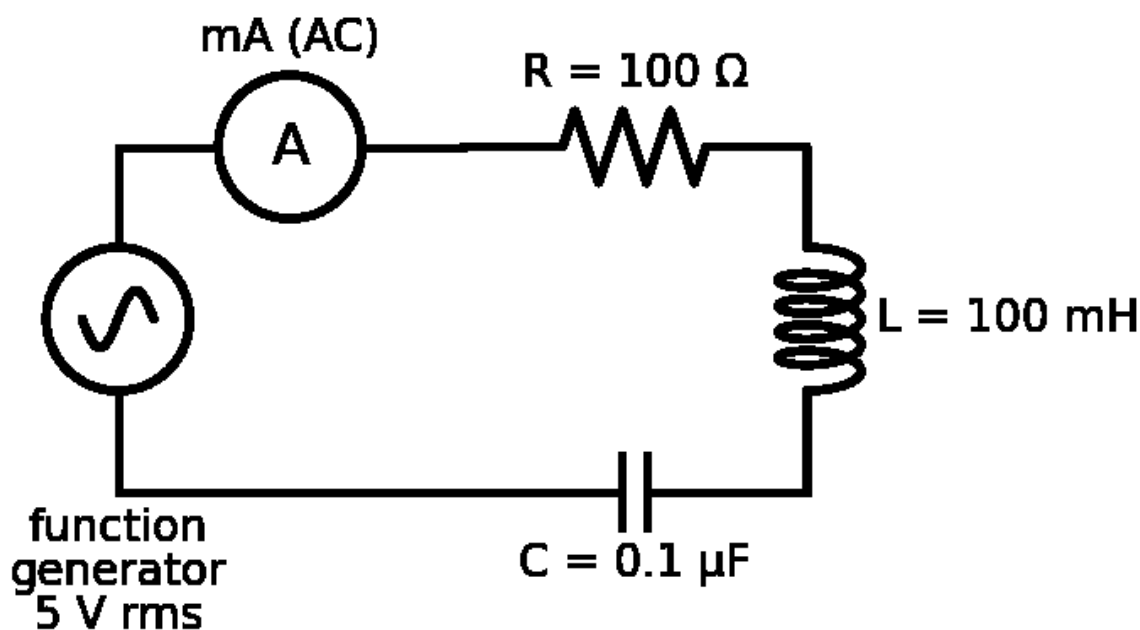


Figure 6.1: Series RLC circuit driven by a variable-frequency source.

Theory (with explanation)

In a series RLC circuit the same current flows through all elements. The inductive reactance $X_L = 2\pi fL$ rises with frequency, while the capacitive reactance $X_C = 1/(2\pi fC)$ falls. The impedance is

$$Z = \sqrt{R^2 + (X_L - X_C)^2}, I = V/Z$$

At resonance $X_L = X_C$, so the reactances cancel, $Z = R$ (minimum) and the current is maximum, $I_{\max} = V/R$, in phase with the voltage (unity power factor). The resonant frequency is

$$f_0 = 1/(2\pi\sqrt{LC})$$

- **Below f_0** the circuit is capacitive (current leads the voltage); **above f_0** it is inductive (current lags).
- **Half-power frequencies** f_1 and f_2 are where $I = I_{\max}/\sqrt{2}$ (power is half the maximum).
Bandwidth $BW = f_2 - f_1$.
- **Quality factor** $Q = \omega_0 L/R = (1/R)\sqrt{L/C} = f_0/BW$. A high Q gives a sharp, selective resonance curve.

- **Voltage magnification:** at resonance the voltage across L or C is Q times the supply voltage, which can be dangerous in power circuits.

The series RLC circuit is called an **acceptor circuit** because it accepts (passes) the resonant frequency with minimum impedance; it is used in radio tuning.

Procedure

- Connect the circuit and set the generator output to 5 V rms.
- Vary the frequency from 500 Hz to 3 kHz in steps (small steps near the expected $f_0 = 1.59$ kHz), keeping the input voltage constant at 5 V; note the current at each frequency.
- Plot current against frequency; find f_0 , the half-power frequencies, the bandwidth and Q.

Observations and calculation (sample readings)

Circuit values: $R = 100\ \Omega$ (including the coil resistance), $L = 100\text{ mH}$, $C = 0.1\ \mu\text{F}$; input voltage kept at 5 V (rms) at all frequencies.

Frequency f (Hz)	$X_L = 2\pi fL$ (Ω)	$X_C = 1/2\pi fC$ (Ω)	Current I (mA)
500	314	3183	1.74
800	503	1989	3.37
1000	628	1592	5.12
1200	754	1326	8.73
1400	880	1137	18.27
1500	942	1061	32.44
1550	974	1027	44.37
1600	1005	995	50.20
1650	1037	965	40.01
1700	1068	936	30.39
1800	1131	884	18.89
2000	1257	796	10.42
2500	1571	637	5.34
3000	1885	531	3.67

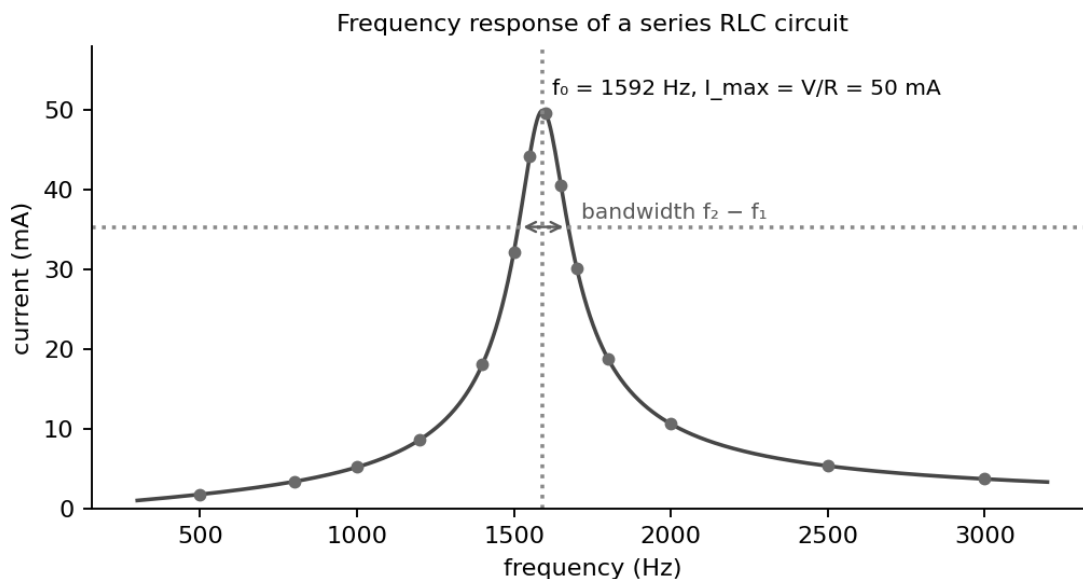


Figure 6.2: Current against frequency. The peak occurs at the resonant frequency; the half-power points define the bandwidth.

Calculation:

- $f_0 = 1/(2\pi\sqrt{LC}) = 1/(2\pi\sqrt{0.1 \times 0.1 \times 10^{-6}}) = \mathbf{1591.5 \text{ Hz}}$.
- At resonance $X_L = X_C = 2\pi \times 1591.5 \times 0.1 = 1000 \Omega$, $Z = R$ and $I_{\text{max}} = 5/100 = 50 \text{ mA}$.
- Quality factor $Q = \omega_0 L/R = 1000/100 = \mathbf{10.0}$.
- Half-power frequencies ($I = 50/\sqrt{2} = 35.4 \text{ mA}$): $f_1 \approx 1514 \text{ Hz}$, $f_2 \approx 1673 \text{ Hz}$; bandwidth $= 159 \text{ Hz} = f_0/Q$.
- Voltage across L or C at resonance $= I X_L = 0.05 \times 1000 = 50 \text{ V} = Q \times V$ (voltage magnification).

Result

The series RLC circuit resonates at $f_0 \approx 1592 \text{ Hz}$ (theoretical 1591.5 Hz) with a maximum current of 50 mA , quality factor 10 and bandwidth 159 Hz .

Precautions

- Keep the input voltage constant at every frequency (the generator output changes with load).
- Take closely spaced readings near resonance.
- The resistance of the inductor coil adds to R ; measure it and include it.

Viva-voce questions

Q1. What is resonance in a series RLC circuit?

The condition when $X_L = X_C$, the impedance is purely resistive and minimum, and the current is maximum and in phase with the voltage.

Q2. What is the power factor at resonance?

Unity.



Q3. Define bandwidth and quality factor.

Bandwidth is the frequency range between the half-power points ($f_2 - f_1$). $Q = f_0/BW$
 $= \omega_0 L/R$ measures the sharpness of resonance.

Q4. Why is a series resonant circuit called an acceptor circuit?

It offers minimum impedance and passes maximum current at the resonant frequency.

Q5. What is the effect of increasing R on the resonance curve?

The peak current falls and the curve becomes broader (lower Q, larger bandwidth); f_0 is unchanged.

Experiment 7: Power and Power Factor of a Fluorescent Lamp

Aim

To measure the voltage, current, power and power factor of a fluorescent lamp (tube light) circuit and to improve its power factor by connecting a capacitor.

Apparatus

Fluorescent tube 40 W with choke and starter, single-phase variac, AC voltmeter (0–300 V), AC ammeter (0–1 A), low-power-factor wattmeter (300 V, 1 A), capacitor 4 μF /400 V, fuse, wires.

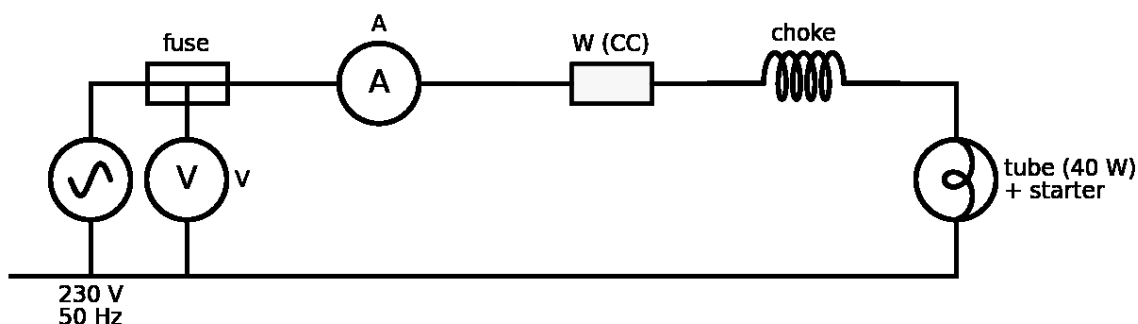


Figure 7.1: Circuit for measuring the power and power factor of a fluorescent lamp.

Theory (with explanation)

Working of a fluorescent lamp: when switched on, the **starter** (a small neon glow switch with a bimetallic strip) closes and current flows through the choke and the tube filaments, heating them. The strip then opens; the sudden break in current makes the **choke** (an iron-cored inductor) produce a high voltage surge ($L \, di/dt$), which strikes an arc through the mercury vapour in the tube. The arc emits ultraviolet light, which the **phosphor coating** converts into visible light. After starting, the choke limits the current (ballast).

Why the power factor is low: the choke is highly inductive, so the current lags the voltage by a large angle. In an AC circuit,

$$P = VI \cos \phi; \text{ power factor } \cos \phi = P/(VI) = \text{true power/apparent power}$$

Power factor improvement: a capacitor across the supply draws a leading reactive current that cancels part of the lagging reactive current of the choke. The active power stays the same, but the line current and apparent power fall. The required capacitor is

$$Q_C = P(\tan \phi_1 - \tan \phi_2); C = Q_C/(2\pi fV^2)$$

Why a low power factor is bad: for the same power it draws more current, causing larger copper losses, bigger cable and equipment ratings and larger voltage drops; supply companies charge a penalty for low power factor.

Procedure

- Connect the circuit with the variac at zero. Switch on and raise the voltage slowly until the tube lights.
- Note V, I and W at different voltages from 180 V to 230 V.
- Calculate the power factor at each voltage.

- Connect the 4 μF capacitor across the supply and note the new current and power at 230 V.

Observations and calculation (sample readings)

Supply voltage V (V)	Current I (A)	Power P (W)	Apparent power VI (VA)	Power factor $\cos \phi = P/VI$	ϕ (°)
180	0.30	33	54.0	0.611	52.3
200	0.34	40	68.0	0.588	54.0
220	0.38	46	83.6	0.550	56.6
230	0.40	50	92.0	0.543	57.1

Calculation at rated voltage (230 V):

- Apparent power $S = VI = 230 \times 0.40 = 92 \text{ VA}$; power factor = $50/92 = \mathbf{0.543}$ (**lagging**), $\phi = 57.1^\circ$.
- Reactive power $Q = \sqrt{(S^2 - P^2)} = \sqrt{(92^2 - 50^2)} = 77.2 \text{ VAR}$ (taken by the choke).
- The tube is rated 40 W; the remaining 10 W is lost in the choke (copper and iron losses).

Power factor improvement to 0.95 lagging:

- Capacitor kVAR: $Q_C = P(\tan \phi_1 - \tan \phi_2) = 50(1.545 - 0.329) = 60.8 \text{ VAR}$.
- $C = Q_C / (2\pi f V^2) = 60.8 / (2\pi \times 50 \times 230^2) = \mathbf{3.66 \mu\text{F}}$ (a standard 4 μF , 400 V capacitor is fitted across the supply).
- With the capacitor, current = $P / (V \times 0.95) = 50 / (230 \times 0.95) = 0.229 \text{ A}$ (reduced from 0.40 A).

Result

The power factor of the fluorescent lamp circuit is 0.54 lagging at 230 V; a capacitor of about 3.7 μF (4 μF standard) across the supply raises it to 0.95.

Precautions

- Use a low-power-factor wattmeter; an ordinary wattmeter gives very small deflection at low power factor.
- Do not exceed the current rating of the wattmeter's current coil.
- Discharge the capacitor after switching off before touching it.

Viva-voce questions

Q1. What are the functions of the choke in a tube light?

It produces a high voltage surge to start the discharge and then limits the current through the tube (ballast).

Q2. What is the function of the starter?

It closes to heat the filaments and then opens automatically, causing the choke to produce the starting voltage surge.

Q3. Define power factor. Why is it low in a fluorescent lamp circuit?



The cosine of the angle between voltage and current (P/VI). It is low because the choke is highly inductive.

Q4. How is the power factor improved?

By connecting capacitors in parallel with the load (or synchronous condensers in large systems), which supply leading reactive power.

Q5. Why is an electronic ballast preferred today?

It works at high frequency, gives higher efficiency, near-unity power factor, flicker-free light and instant start.

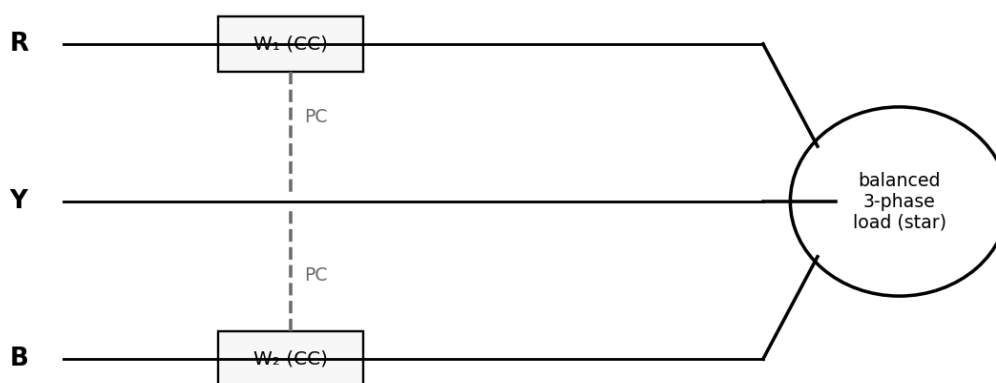
Experiment 8: Measurement of Three-Phase Power by the Two-Wattmeter Method

Aim

To measure the power and power factor of a balanced three-phase load using two wattmeters.

Apparatus

Three-phase 400 V, 50 Hz supply with TPIC switch, three-phase variac, two wattmeters (600 V, 10 A), AC ammeter (0–10 A), AC voltmeter (0–600 V), balanced three-phase load (resistive-inductive), wires.



Current coils in lines R and B; pressure coils from R to Y and from B to Y (Y is the common line).

Figure 8.1: Two-wattmeter connection: current coils in two lines, pressure coils between those lines and the third line.

Theory (with explanation)

Blondel's theorem: in an n-wire system, the total power can be measured with $(n - 1)$ wattmeters. For a three-phase three-wire system, **two wattmeters** are enough, whether the load is balanced or not, and whether it is star- or delta-connected.

Why the sum gives the total power: the current coils carry the line currents I_R and I_B , and the pressure coils see the line voltages V_{RY} and V_{BY} . The sum of their instantaneous readings is $v_{RY}i_R + v_{BY}i_B = (v_R - v_Y)i_R + (v_B - v_Y)i_B = v_Ri_R + v_Bi_B - v_Y(i_R + i_B)$. Since $i_R + i_Y + i_B = 0$, this equals $v_Ri_R + v_Yi_Y + v_Bi_B$, the total instantaneous power.

Readings for a balanced load of power factor $\cos \phi$ (lagging):

$$W_1 = V_L I_L \cos(30^\circ - \phi); W_2 = V_L I_L \cos(30^\circ + \phi); P = W_1 + W_2 = \sqrt{3} V_L I_L \cos \phi$$

$$\tan \phi = \sqrt{3}(W_1 - W_2)/(W_1 + W_2); \text{ reactive power } Q = \sqrt{3}(W_1 - W_2)$$

Effect of power factor on readings:

Power factor	ϕ	Readings
1.0	0°	$W_1 = W_2$
0.5	60°	$W_2 = 0$; $W_1 = \text{total power}$
Less than 0.5	$> 60^\circ$	W_2 negative (reverse the pressure-coil connection and take the reading as negative)

Power factor	ϕ	Readings
0 (pure inductive)	90°	$W_1 = -W_2$; total power zero

Procedure

- Connect the circuit with the variac at zero and the load switched off.
- Switch on the supply, raise the voltage to 400 V and switch on the load in steps.
- For each load note the line voltage, line current, W_1 and W_2 . If a wattmeter reads backwards, switch off, reverse its pressure-coil (or current-coil) terminals and record the reading as negative.
- Calculate the total power and power factor.

Observations and calculation (sample readings)

Line voltage $V_L = 400$ V (balanced star-connected load).

I_L (A)	W_1 (W)	W_2 (W)	$P = W_1 + W_2$ (W)	$\tan \phi = \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$	$\cos \phi$
3.0	1042	1035	2077	0.006	1.000
4.0	1596	901	2497	0.482	0.901
5.0	1979	790	2769	0.744	0.802
5.5	2022	264	2286	1.332	0.600
6.0	2074	0	2074	1.732	0.500
6.0	1940	-270	1670	2.292	0.400

Worked calculation (row 3): $I_L = 5$ A, $\cos \phi = 0.8$ lagging ($\phi = 36.87^\circ$).

- $W_1 = V_L I_L \cos(30^\circ - \phi) = 400 \times 5 \times \cos(-6.87^\circ) = 1985.6$ W; $W_2 = V_L I_L \cos(30^\circ + \phi) = 400 \times 5 \times \cos 66.87^\circ = 785.6$ W.
- Total power $P = W_1 + W_2 = 2771$ W; check: $\sqrt{3} V_L I_L \cos \phi = 1.732 \times 400 \times 5 \times 0.8 = 2771$ W.
- Reactive power $= \sqrt{3}(W_1 - W_2) = 1.732 \times 1200 = 2078$ VAR.

Observations about the readings:

- At unity power factor the two wattmeters read equal values.
- At 0.5 power factor one wattmeter reads zero ($W_2 = 0$) and all the power is shown by W_1 .
- Below 0.5 power factor W_2 becomes **negative**; its pressure-coil (or current-coil) connection is reversed to get a reading, which is then taken as negative.

Result

The total power of a balanced three-phase load is the sum of the two wattmeter readings, and the power factor calculated from $\tan \phi = \sqrt{3}(W_1 - W_2)/(W_1 + W_2)$ agrees with the load power factor.

Precautions

- The current coils must be in series with the lines and the pressure coils across the correct lines.
- Check the ranges of the wattmeters; use current transformers for large currents.



- Note negative readings carefully.

Viva-voce questions

Q1. How many wattmeters are needed to measure power in a three-phase four-wire system?

Three ($n - 1$ with $n = 4$).

Q2. At what power factor does one wattmeter read zero?

At 0.5 power factor ($\varphi = 60^\circ$).

Q3. Can the two-wattmeter method be used for unbalanced loads?

Yes, it measures total power for any three-wire load; but the power factor formula $\tan \varphi = \sqrt{3}(W_1 - W_2)/(W_1 + W_2)$ is valid only for balanced loads.

Q4. What is the relation between line and phase quantities in star and delta?

Star: $V_L = \sqrt{3} V_{ph}$, $I_L = I_{ph}$. Delta: $V_L = V_{ph}$, $I_L = \sqrt{3} I_{ph}$.

Experiment 9: Open-Circuit and Short-Circuit Tests on a Single-Phase Transformer

Aim

To perform the open-circuit (OC) and short-circuit (SC) tests on a single-phase transformer, determine its equivalent circuit parameters, and predict its efficiency and voltage regulation.

Apparatus

Single-phase transformer 2 kVA, 230/115 V; single-phase variac; AC voltmeters (0–150 V, 0–30 V); AC ammeters (0–1 A, 0–10 A); wattmeters (low power factor 150 V/1 A for OC; 75 V/10 A for SC); wires.

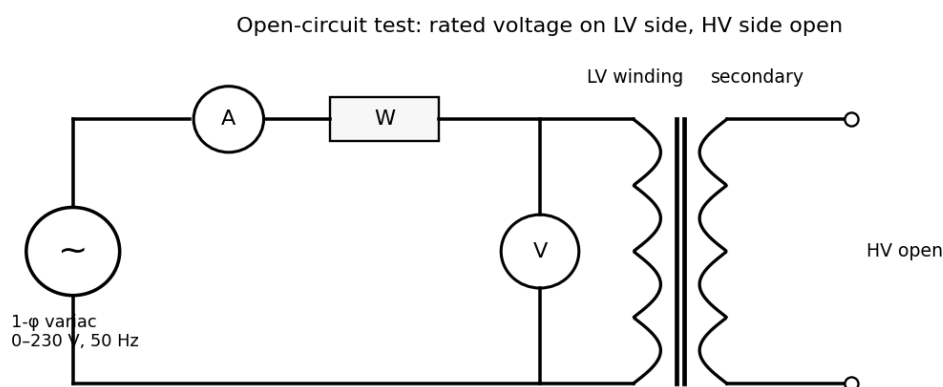


Figure 9.1: Open-circuit test connections.

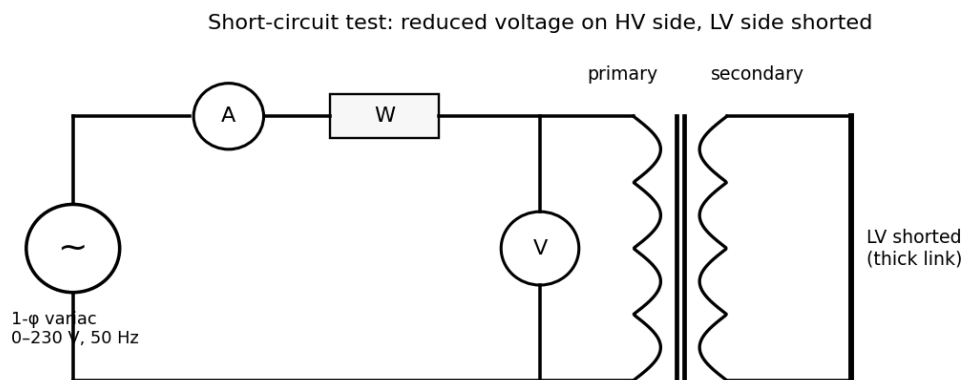


Figure 9.2: Short-circuit test connections.

Theory (with explanation)

A transformer has two kinds of losses:

- **Iron (core) loss** — hysteresis and eddy-current loss in the core. It depends on the voltage and frequency, so it is almost **constant** at all loads.
- **Copper loss** — I^2R loss in the windings. It depends on the load current, so it **varies as the square of the load**.

Testing a large transformer at full load would waste energy and need a large load. These two tests find the losses with very little power.

Open-circuit (no-load) test: rated voltage is applied to the LV winding with the HV winding open. The current drawn (2-5% of rated) is the no-load current I_o . Since this current is small, copper loss is negligible, and the **wattmeter reads the iron loss** W_o . I_o has two components: the working (core-loss) component $I_w = I_o \cos \phi_o$ and the magnetising component $I_\mu = I_o \sin \phi_o$; they give the shunt branch $R_o = V_o/I_w$ and $X_o = V_o/I_\mu$.

Short-circuit test: the LV winding is shorted and a small voltage (5-10% of rated) is applied to the HV side until **rated current** flows. Since the voltage is low, the flux and iron loss are negligible, and the **wattmeter reads the full-load copper loss** W_{sc} . From it: $Z_{eq} = V_{sc}/I_{sc}$, $R_{eq} = W_{sc}/I_{sc}^2$ and $X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$.

Efficiency at any load (fraction x of full load, power factor $\cos \phi$):

$$\eta = \frac{x S \cos \phi}{(x S \cos \phi + W_o + x^2 W_{sc})} \times 100\%$$

Efficiency is maximum when copper loss = iron loss, i.e. at $x = \sqrt{W_o/W_{sc}}$.

Voltage regulation is the change in secondary voltage from no load to full load, as a percentage of the full-load voltage:

$$\% \text{ regulation} = \frac{I(R_{eq} \cos \phi \pm X_{eq} \sin \phi)}{V} \times 100 \text{ (+ for lagging, - for leading power factor)}$$

Procedure

- **OC test:** connect the circuit of Figure 9.1 with the variac at zero. Increase the voltage to rated LV voltage (115 V) and note V_o , I_o and W_o .
- **SC test:** connect the circuit of Figure 9.2 (HV side supplied, LV shorted by a thick wire). Starting from zero, raise the voltage very carefully until the ammeter reads the rated HV current (8.7 A). Note V_{sc} , I_{sc} and W_{sc} .
- Calculate the parameters, efficiency at various loads and regulation.

Observations and calculation (sample readings)

Transformer rating: 2 kVA, 230/115 V, 50 Hz, single phase.

Open-circuit test (on the LV side, HV open):

V_o (V)	I_o (A)	W_o (W)
115	0.40	30

Short-circuit test (on the HV side, LV shorted, rated current):

V_{sc} (V)	I_{sc} (A)	W_{sc} (W)
12	8.70	60

Calculation from the OC test (iron loss and shunt branch, referred to LV):

- No-load power factor $\cos \phi_o = W_o/V_o I_o = 30/(115 \times 0.40) = 0.652$.
- Working component $I_w = I_o \cos \phi_o = 0.261$ A; magnetising component $I_\mu = I_o \sin \phi_o = 0.303$ A.
- $R_o = V_o/I_w = 441 \Omega$; $X_o = V_o/I_\mu = 379 \Omega$. Iron (core) loss = $W_o = 30$ W.

Calculation from the SC test (series parameters, referred to HV):

- $Z_{eq} = V_{sc}/I_{sc} = 12/8.70 = 1.380 \Omega$; $R_{eq} = W_{sc}/I_{sc}^2 = 60/75.61 = 0.793 \Omega$; $X_{eq} = \sqrt{(Z^2 - R^2)} = 1.129 \Omega$.
- Full-load copper loss = $W_{sc} = 60 \text{ W}$.

Efficiency at different loads: $\eta = xS \cos \phi / (xS \cos \phi + W_0 + x^2W_{sc}) \times 100$

Load (fraction of full load)	Output at pf 1 (W)	Copper loss x^2W_{sc} (W)	Total loss (W)	η at pf 1 (%)	η at pf 0.8 (%)
0.25	500	3.8	33.8	93.68	92.22
0.5	1000	15.0	45.0	95.69	94.67
0.75	1500	33.8	63.8	95.92	94.96
1.0	2000	60.0	90.0	95.69	94.67
1.25	2500	93.8	123.8	95.28	94.17

- Maximum efficiency occurs when copper loss = iron loss: $x = \sqrt{(W_0/W_{sc})} = \sqrt{(30/60)} = 0.707$, i.e. at 70.7% of full load (1414 VA).

Voltage regulation at full load (HV side):

- At 0.8 pf lagging: % reg = $I(R_{eq} \cos \phi + X_{eq} \sin \phi)/V \times 100 = 8.70(0.793 \times 0.8 + 1.129 \times 0.6)/230 \times 100 = \mathbf{4.96\%}$.
- At unity pf: % reg = $I R_{eq}/V \times 100 = \mathbf{3.00\%}$.

Result

For the 2 kVA transformer, the iron loss is 30 W and the full-load copper loss is 60 W; the full-load efficiency is 94.67% at 0.8 pf and 95.69% at unity pf, maximum efficiency occurs at 71% load, and the full-load regulation is 4.96% at 0.8 pf lagging.

Precautions

- In the SC test, start from zero voltage and increase slowly; even 10-15% of rated voltage can drive very large currents.
- Use low-power-factor wattmeters for the OC test.
- Make the short circuit with a thick wire of low resistance.

Viva-voce questions

Q1. Why is the OC test done on the LV side and the SC test on the HV side?

The OC test needs rated voltage, which is lower (easier) on the LV side; the SC test needs rated current, which is smaller on the HV side.

Q2. Why does the wattmeter read iron loss in the OC test?

The no-load current is very small, so copper loss is negligible, while rated voltage gives full flux and full iron loss.

Q3. Why is iron loss negligible in the SC test?

The applied voltage is only a few per cent of rated, so the flux (and hence iron loss, roughly $\propto V^2$) is very small.



Q4. When is the efficiency of a transformer maximum?

When copper loss equals iron loss.

Q5. Can regulation be negative?

Yes, at a leading power factor the secondary voltage may rise on load.

Experiment 10: Speed Control of a DC Shunt Motor

Aim

To control the speed of a DC shunt motor by (a) the armature voltage (rheostatic) control method and (b) the field (flux) control method, and to plot the speed characteristics.

Apparatus

DC shunt motor 220 V, 1.5 kW, 1500 rpm with three-point starter; rheostats for the armature circuit (50 Ω , 10 A) and field circuit (500 Ω , 1 A); DC voltmeter (0–300 V); DC ammeters (0–10 A, 0–1 A); tachometer; DPST switch; wires.

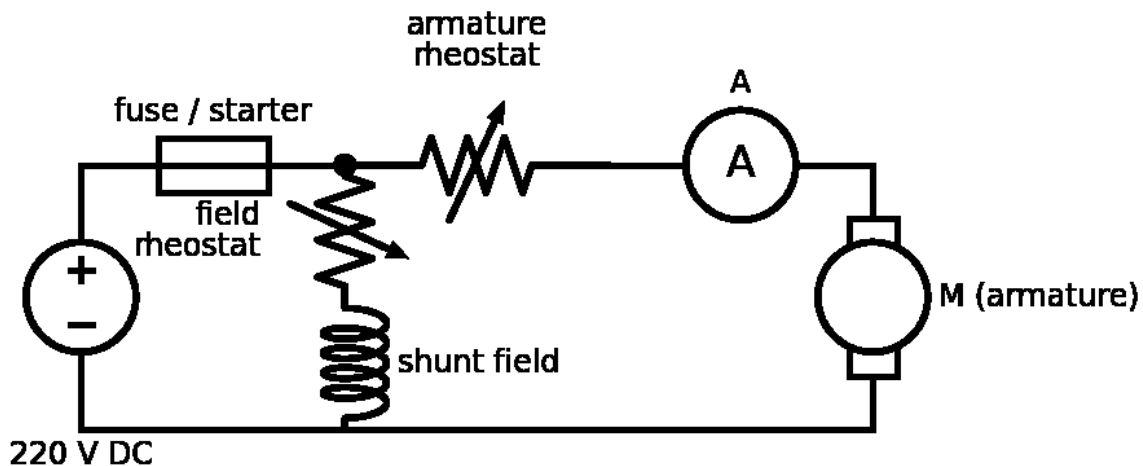


Figure 10.1: Circuit for speed control of a DC shunt motor.

Theory (with explanation)

When the armature of a DC motor rotates in the magnetic field, it generates a **back EMF** E_b that opposes the applied voltage:

$$E_b = V - I_a R_a = P\phi ZN/(60A) \Rightarrow N \propto E_b/\phi = (V - I_a R_a)/\phi$$

So the speed can be changed by changing either the voltage across the armature or the flux ϕ .

(a) Armature voltage (rheostatic) control: a variable resistance in series with the armature reduces the voltage reaching it, so E_b and hence speed fall. It gives speeds **below the rated speed**. The rheostat carries the full armature current, so it wastes power (poor efficiency), but the method is simple. (Modern drives vary the armature voltage electronically without this loss.)

(b) Field (flux) control: a rheostat in series with the shunt field reduces the field current and flux; since $N \propto 1/\phi$, the speed **rises above the rated speed**. The field current is small, so the loss in the rheostat is small and the method is efficient.

Warning: the field circuit must never be opened while the motor is running. As $\phi \rightarrow 0$, the speed rises dangerously (the motor "runs away") and the armature current becomes very large.

Why a starter is needed: at the moment of starting, $E_b = 0$ and the armature current V/R_a would be very large ($220/2 = 110$ A). The starter puts resistance in series and cuts it out as the speed rises; it also has a no-volt release and overload release for protection.

Procedure

- Connect the circuit. Keep the armature rheostat at maximum and the field rheostat at minimum resistance.
- Start the motor with the three-point starter, moving the handle slowly to the ON position.
- **Armature control:** keep the field current constant (0.6 A). Vary the armature rheostat to change the armature voltage from 140 V to 220 V; note the speed at each step.
- **Field control:** cut out the armature rheostat (armature at 220 V). Increase the field rheostat to reduce the field current from 0.6 A to 0.5 A in steps; note the speed. Do not exceed 1.2 times the rated speed.
- Bring the rheostats back to their starting positions and switch off.

Observations and calculation (sample readings)

Motor: 220 V, 1.5 kW DC shunt motor; armature resistance $R_a = 2 \Omega$; no-load armature current $I_a \approx 2$ A.

(a) Armature voltage control (field current constant at 0.6 A):

Armature voltage V_a (V)	Back emf $E_b = V_a - I_a R_a$ (V)	Speed N (rpm)	N/E_b
140	136	944	6.94
160	156	1086	6.94
180	176	1228	6.94
200	196	1371	6.94
220	216	1491	6.94

(b) Field flux control (armature voltage constant at 220 V):

Field current I_f (A)	Speed N (rpm)	$N \times I_f$
0.600	1505	900
0.575	1568	900
0.550	1636	900
0.525	1707	900
0.500	1809	900

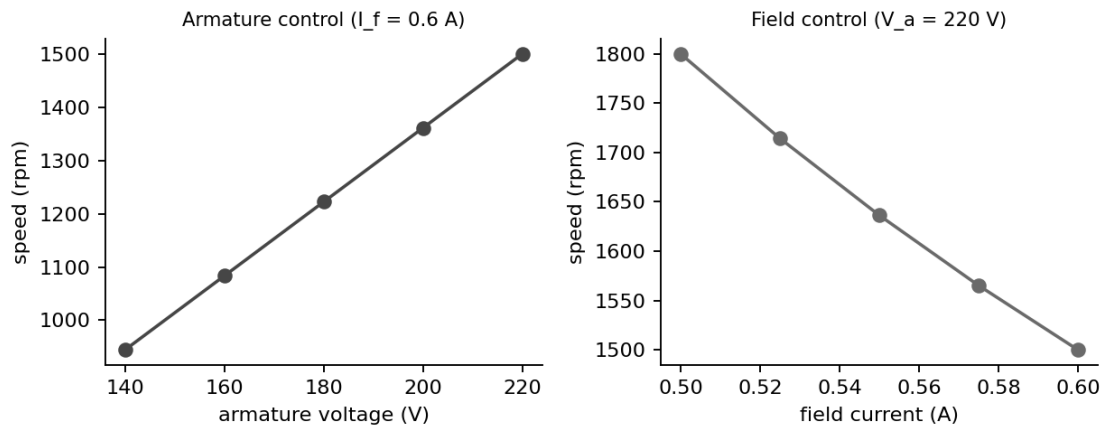


Figure 10.2: Speed rises linearly with armature voltage (below rated speed) and rises as the field current is reduced (above rated speed).

Calculation:

- $N \propto E_b / \phi$. With ϕ constant, N/E_b is constant (6.94 rpm per volt), confirming $N \propto E_b$.
- With V_a constant, $N \times I_f \approx 900$ is constant, confirming $N \propto 1/\phi$ ($\phi \propto I_f$ in the linear region).
- Example: reducing I_f from 0.60 A to 0.50 A raises the speed from 1500 to $1500 \times 0.60/0.50 = 1800$ rpm.

Result

For the DC shunt motor, armature voltage control gives speeds below rated speed ($N \propto V_a - I_a R_a$) and field control gives speeds above rated speed ($N \propto 1/I_f$).

Precautions

- Never start the motor without the starter, and never open the field circuit while running.
- Keep the field rheostat at minimum resistance at starting so that the starting torque is high (maximum flux).
- Do not exceed the rated speed by more than 20%.

Viva-voce questions

Q1. What is back EMF? Why is it important?

The EMF induced in the rotating armature that opposes the supply voltage. It regulates the armature current automatically according to the load.

Q2. Why does the speed increase when the field current is decreased?

The flux decreases; to produce the back EMF needed to balance the supply voltage, the armature must rotate faster ($N \propto E_b / \phi$).

Q3. Why is a starter necessary for a DC motor?

At starting the back EMF is zero, so without extra resistance the armature current would be many times the rated value and damage the motor.

Q4. Which method gives speed below rated speed and which above?



Armature control gives speeds below rated speed; field control gives speeds above rated speed.

Q5. What happens if the field of a shunt motor opens while running?

The flux falls to the residual value and the speed rises to a dangerous level; the armature current also rises sharply.

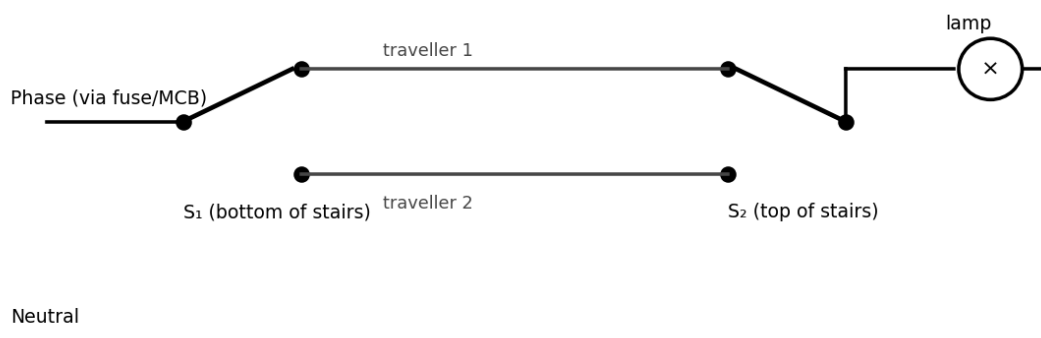
Experiment 11: Staircase Wiring and Study of Fuse, MCB and Earthing

Aim

To wire a staircase lighting circuit (one lamp controlled from two places with two-way switches) and to study the fuse, miniature circuit breaker (MCB) and earthing.

Apparatus

Wiring board, two two-way switches, lamp holder with 15 W lamp, MCB (6 A), kit-kat fuse, PVC wires (1.5 mm²), screwdriver, cutting plier, wire stripper, tester, multimeter.



Lamp glows when both switches are on the same traveller; either switch changes its state.

Figure 11.1: Staircase wiring with two two-way switches S_1 and S_2 .

Theory (with explanation)

Staircase (two-way) wiring: a lamp on a staircase must be switched on from the bottom and switched off from the top (and vice versa). Each two-way switch has one common terminal and two outgoing terminals. The phase is connected to the common terminal of S_1 ; the two outgoing terminals of S_1 are joined to those of S_2 by two wires called **travellers**; the common terminal of S_2 goes to the lamp; the other lamp terminal goes to neutral.

Position of S_1	Position of S_2	Lamp
Upper (traveller 1)	Upper (traveller 1)	ON
Upper	Lower (traveller 2)	OFF
Lower	Upper	OFF
Lower	Lower	ON

The truth table is that of an **XNOR** function: changing either switch changes the state of the lamp. The same idea is used in long corridors and bedrooms (with an intermediate switch for three places).

Protective devices:

- **Fuse:** a short piece of wire of low melting point (tinned copper or alloy) connected in series with the phase. Excess current heats and melts it, opening the circuit. It must be replaced after operation. Fuse rating is chosen slightly above the normal current.



- **MCB (miniature circuit breaker):** an automatic switch that trips on overload (by a bimetallic strip, with time delay) and on short circuit (by an electromagnetic coil, instantly). It can be reset and is more reliable than a fuse. Ratings: 6, 10, 16, 20, 32 A.
- **ELCB/RCCB (residual current device):** trips when the current in phase and neutral differ by more than 30 mA (leakage to earth), protecting people from shock.

Earthing: connecting the metal body of equipment to the general mass of the earth through a low-resistance path (pipe or plate earthing, resistance below 1–5 Ω). If insulation fails and the live wire touches the body, a large fault current flows to earth and blows the fuse or trips the MCB, so the body never stays at a dangerous voltage.

Procedure

- Fix the switches and lamp holder on the board as shown. Connect the phase through the MCB to the common terminal of S_1 .
- Connect the two outgoing terminals of S_1 to the corresponding terminals of S_2 (travellers).
- Connect the common terminal of S_2 to one terminal of the lamp holder and the other terminal to neutral.
- Check the circuit with a multimeter (continuity test) before switching on.
- Switch on and verify the truth table by operating S_1 and S_2 .

Observations

S_1	S_2	Lamp (observed)
Up	Up	ON
Up	Down	OFF
Down	Up	OFF
Down	Down	ON

Result

The staircase wiring was completed and the lamp could be controlled independently from two places; the working of the fuse, MCB and earthing was studied.

Precautions

- Switches must always be connected in the **phase** wire, never in the neutral.
- Use wires of proper colour code: red/brown for phase, black/blue for neutral, green (or green-yellow) for earth.
- Tighten all terminals and insulate joints properly.

Viva-voce questions

Q1. Why is the switch always placed in the phase wire?

So that when the switch is off, the lamp holder and appliance are not live, making replacement and repair safe.

Q2. What is the difference between a fuse and an MCB?

A fuse melts and must be replaced; an MCB trips and can be reset. The MCB is faster, more accurate and safer.



Q3. What is the purpose of earthing?

To give a low-resistance path for fault current to earth so that the protective device operates and the metal body does not reach a dangerous voltage.

Q4. What is the function of an RCCB?

It detects leakage current (difference between phase and neutral currents, typically 30 mA) and trips to protect people from electric shock.

Q5. What logic function does staircase wiring represent?

XNOR (the lamp is on when both switches are in the same position).



Appendix: Model Viva Questions

Q1. What is the difference between AC and DC?

DC flows in one direction with constant magnitude; AC reverses direction periodically (50 Hz in India) and its magnitude varies sinusoidally.

Q2. What is the RMS value of an alternating current?

The value of steady DC that produces the same heat in a resistor in the same time; for a sine wave $I_{\text{rms}} = I_{\text{m}}/\sqrt{2} = 0.707 I_{\text{m}}$.

Q3. What is the supply voltage and frequency in India?

230 V single-phase (400 V three-phase line voltage), 50 Hz.

Q4. What is a variac?

A single-winding autotransformer with a sliding contact that gives a smoothly variable AC output voltage.

Q5. Why are transformer cores laminated?

To reduce eddy-current loss by breaking the paths of eddy currents.

Q6. Why is the transformer rated in kVA and not in kW?

Its losses depend on voltage (iron loss) and current (copper loss), not on the power factor of the load.

Q7. What is the unit of electrical energy used for billing?

The kilowatt-hour (kWh), called one "unit" = 3.6×10^6 J.