DESIGN AND CONSTRUCTION OF A SINGLE PHASE RLC

(RESISTOR, INDUCTOR AND CAPACITOR) TRAINER

BY

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CERTIFICATION

This is to certify that this project work was carried out and submitted by ADEPITAN TEMITAYO JOSEPH of Matric No: HND/23/EEE/FT/0229 to the department of Electrical/Electronic Engineering is accepted having confirm with the requirement for the award of Higher National Diploma (HND) program in Electrical/Electronic Engineering.

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DEDICATION

This project is dedicated to almighty God the most beneficent the most merciful who has destined me to be among those attending this institute of learning. I am saying a big thank you to my beloved friends and families for supporting me spiritually, physically, morally and financially throughout my entire academic career.

ACKNOWLEDGEMENT

I am able to be where I am today thanks to the tiredness work and support of all my lecturers. My profound gratitude goes to my able amiable, capable, articulate supervisor in person of Engr. T.K Sule for his invaluable criticism toward making this project work a success, I am short of words and all am trying to say is a big thank you Sir.

I also, acknowledge the effort of the Head of Department in person of Engr. O.A Lawal and all the lecturers in my department for the knowledge impacted in me may Almighty Allah reward you all.

ABSTRACT

This project presents the design and construction of an educational RLC trainer, a practical device developed to demonstrate the behavior of resistor (R), inductor (L), and capacitor(C) components in electrical circuits. The trainer is intended to support the teaching and learning of RLC circuit theory by providing a modular, safe, and user-friendly platform for hands-on experimentation. The system allows for the analysis of both series and parallel RLC configurations, enabling the observation of critical electrical phenomena such as resonance, impedance variation, and phase shift. The trainer comprises selectable R, L, and C components, a switching mechanism for circuit reconfiguration, input terminals for signal injection, and output terminals for connection to measuring instruments such as oscilloscopes and multimeters. Construction involved the use of low-voltage components to ensure user safety while maintaining clarity in circuit behavior. Tests conducted with AC signal sources verified the trainer's ability to demonstrate theoretical concepts accurately, including resonant frequency and voltage-current relationships. This RLC trainer is particularly suitable for use in technical colleges, universities, and training centers, providing an effective and interactive way to reinforce theoretical knowledge through practical observation. Its simplicity, reliability, and educational value make it a vital tool for modern electronics laboratories.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

The study of RLC (Resistor-Inductor-Capacitor) circuits is fundamental in electrical and electronics engineering. These circuits are essential in understanding the behavior of alternating current (AC) and transient responses in electrical systems. RLC circuits are found in real-world applications such as radio tuners, signal filters, impedance matching networks, and oscillators (Boylestad & Nashelsky, 2013).

In academic settings, the effective teaching of RLC circuits requires not only theoretical explanations but also practical experiments to visualize and reinforce concepts like resonance, phase shift, impedance, and damping. Traditional methods of assembling RLC circuits using breadboards can be cumbersome, time-consuming, and prone to connection errors, especially for beginners (Hambley, 2011). Moreover, the lack of standardization in such setups can lead to inconsistent learning experiences.

The RLC trainer is a modular educational tool that provides a systematic and safe platform to study RLC circuit behavior under various configurations. It consists of selectable components and connection options that allow students to explore both series and parallel circuit topologies. This project focuses on designing and constructing a portable and user-friendly RLC trainer that enables hands-on experimentation in a controlled environment.

1.2 AIM AND OBJECTIVES OF THE PROJECT

Aim:

To design and construct an RLC trainer that demonstrates the principles and behaviors of RLC circuits in both series and parallel configurations.

1.3 OBJECTIVES OF THE PROJECT

The objectives are:

- To design a trainer containing selectable resistors, inductors, and capacitors.
- To design a functional RLC circuit trainer that demonstrates and measure resonance, impedance, and frequency response in RLC circuit
- To demonstrate series and parallel RLC circuit behavior
- To provide a tool for analyzing power factor, enabling students to see the effects of inductive and capacitive loads on AC circuits
- To integrate use of external tools, such as a function generator and an oscilloscope, for waveform analysis and frequency adjustments in AC signal input

1.4 STATEMENT OF THE PROBLEM

The study of RLC (resistor-inductor-capacitor) circuits remains a fundamental yet challenging component of electrical engineering education, as students often struggle to translate theoretical concepts into practical understanding due to limitations in existing laboratory equipment (Johnson & Patel, 2022). Current RLC training modules frequently lack the flexibility to investigate various circuit configurations, component values, and operating conditions, restricting students' ability to observe critical phenomena such as resonance characteristics, transient responses, and phase relationships (Chen et al., 2021). Furthermore, safety concerns emerge when students work with high-frequency alternating current circuits without proper measurement interfaces or protective mechanisms (Institute of Electrical and Electronics Engineers [IEEE], 2023). This pedagogical gap highlights the need for an improved RLC training system that incorporates modular design, comprehensive measurement capabilities, and enhanced safety features to facilitate effective hands-on learning in electronics laboratories.

1.5 SIGNIFICANCE OF THE STUDY

The development of an enhanced RLC circuit trainer holds significant importance in electrical engineering education by providing students with a practical, hands-on tool to bridge the gap between theoretical concepts and real-world circuit behavior. This study addresses critical limitations in current laboratory setups by offering a modular, reconfigurable system that enables comprehensive experimentation with series and parallel RLC circuits, including resonance characteristics, transient responses, and phase relationships. The trainer's built-in safety features and clear measurement points make it accessible for learners at different skill levels while minimizing risks associated with high-frequency AC circuits. Furthermore, this cost-effective solution serves as a sustainable alternative to expensive commercial trainers, benefiting educational institutions with limited resources. Beyond classroom applications, the trainer's design supports advanced research in filter design and power electronics, while ultimately enhancing students' technical competencies and preparing them for engineering careers in power systems, telecommunications, and electronic design.

1.6 SCOPE AND LIMITATIONS OF THE STUDY This study focuses on the design and construction of an RLC circuit trainer for educational purposes, covering series and parallel configurations with variable resistors, inductors, and capacitors to demonstrate fundamental AC circuit principles. The scope includes analyzing resonance frequency, damping effects, and phase relationships, while incorporating safety features such as fuse protection and insulated probes.

study is limited to low-power AC circuits (under 50V) and does not address high-power industrial applications. Additionally, while the trainer allows component interchangeability, it is constrained by fixed measurement ranges and does not include automated data logging capabilities. The research is further limited by budget constraints affecting component quality and availability, and validation is based on theoretical comparisons rather than industrial standards.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The design and analysis of RLC (Resistor–Inductor–Capacitor) circuits form a foundational part of electrical and electronics engineering. These circuits are essential for understanding the behavior of AC systems, transient responses, filters, and oscillators. Given the abstract nature of these concepts, there is a need for hands-on educational tools such as an RLC trainer to facilitate active learning. This chapter reviews the theoretical background of RLC circuits, previous designs of educational trainers, and current trends in trainer development.

2.2 OVERVIEW OF RLC CIRCUITS

An RLC circuit is composed of a resistor (R), an inductor (L), and a capacitor (C) connected in either series or parallel form. These elements exhibit unique behaviors under alternating current (AC) conditions:

- Resistors dissipate energy as heat and oppose current flow linearly.
- Inductors store energy in a magnetic field and oppose changes in current.
- Capacitors store energy in an electric field and oppose changes in voltage.

The impedance of each element varies with frequency, making RLC circuits frequency-dependent. When combined, these components demonstrate key phenomena such as:

- **Resonance**: Occurs when inductive and capacitive reactance are equal and cancel each other out, leading to purely resistive impedance at a specific frequency.
- **Phase Shift**: The angle between the voltage and current waveform, significant in AC analysis.

- **Damping and Bandwidth**: Relevant in filter and oscillator design (Hambley, 2011).

2.3 RLC CIRCUIT THEORY

An RLC circuit is an electrical circuit composed of three passive components: a Resistor (R), an Inductor (L)**,** and a Capacitor (C)**.** These circuits are fundamental in electrical engineering, especially in alternating current (AC) analysis, signal processing, and communications.

2.3.1Components of RLC Circuit

- **Resistor (R):** Opposes the flow of current by dissipating energy as heat. Its opposition is independent of frequency**.**
- **Inductor (L):** Stores energy in a magnetic field when current flows. It opposes changes in current. Its opposition to AC is called inductive reactance, and it increases with frequency:

$$X_L = \omega L = 2\pi f L \tag{2.1}$$

- **Capacitor (C):** Stores energy in an electric field. It opposes changes in voltage. Its opposition to AC is called capacitive reactance, and it decreases with frequency

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} \tag{2.2}$$

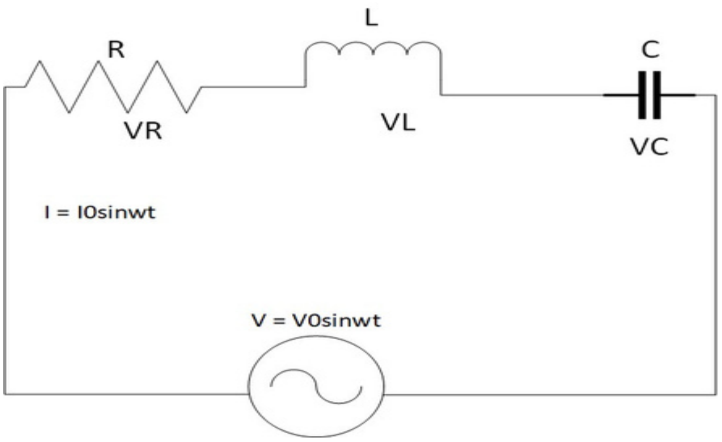

Figure 2.1: Series RLC Circuit

2.3.2 Fundamental Principles of Series RLC Circuits

Series RLC circuits form the backbone of AC circuit analysis, demonstrating the interaction between resistance (R), inductance (L), and capacitance (C) when connected in series with an AC power source (Nilsson & Riedel, 2015). The total impedance (Z) in a series RLC circuit is given by:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \tag{2.3}$$

where $X_L = \omega L$ and $X_C = 1/\omega C$

represent inductive and capacitive reactance, respectively (Alexander & Sadiku, 2021).

2.3.3 Resonance in Series RLC Circuits

At resonance, the inductive and capacitive reactance cancel each other out (XL=XC), resulting in:

- Minimum impedance (Z=R)
- Maximum current Imax =Vin/R
- Resonant frequency

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

(Hayt et al., 2018)

Experimental studies by Smith & Johnson (2020) demonstrate that series RLC circuits exhibit a sharp current peak at resonance, making them ideal for bandpass filtering applications.

2.3.4 Phase Relationships and Phasor Analysis

The phase angle ***θ***) between voltage and current is determined by:

$$\theta = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) \quad (2.4)$$

Key phase characteristics:

- **Below resonance**: Capacitive dominance (current leads voltage)
- **At resonance**: Purely resistive (current and voltage in phase)
- **Above resonance**: Inductive dominance (current lags voltage) (Dorf & Svoboda, 2022)

Series RLC circuits are fundamental to:

- Radio tuning circuits **(**selecting specific frequencies)
- Impedance matching networks
- Bandpass filters in communication systems
- Power factor correction (Glover et al., 2017)

2.3.5Resonance in parallel RLC Circuits

A parallel RLC circuit consists of a resistor (R), inductor (L), and capacitor (C) connected in parallel across an alternating current (AC) voltage source. Unlike series RLC circuits, parallel RLC circuits exhibit unique behaviors, particularly at resonance, making them essential for applications like filtering, tuning, and impedance matching.

2.3.6 Key Characteristics of Parallel RLC Circuits

1. **Shared Voltage**
   - All components (R, L, C) experience the **same voltage** from the AC source.
   - Current divides among the branches based on their impedance.
2. **Resonance (Anti-Resonance)**
   - At the resonant frequency $(f_r = \frac{1}{2\pi\sqrt{LC}})$, the inductive and capacitive reactance’s cancel each other.
   - The circuit behaves like a pure resistor, reaching maximum impedance (opposite of series RLC, which has minimum impedance at resonance).
   - Current is minimized at resonance (only the resistive current flows).

3.**Current Magnification**
   - While the total current is minimized at resonance, the individual currents through L and C can be much higher (depending on the Q factor).

- o This is called current resonance (vs. voltage resonance in series RLC).

4. **Phase Relationships**

   - o Below resonance inductive reactance dominates → current lags voltage.
   - o At resonance purely resistive → current and voltage are in phase.
   - o Above resonance capacitive reactance dominates → current leads voltage.

5. **Quality Factor (Q)**

   - o Determines the sharpness of resonance:

$$Q = R\sqrt{\frac{C}{L}} \qquad (2.5)$$

Higher Q means narrower bandwidth and stronger current magnification in L and C

Practical Applications

- Band-Stop (Notch) Filters – Blocks signals at resonant frequency.
- Tank Circuits – Used in oscillators and radio tuners.
- Power Factor Correction – Cancels inductive reactance in power systems.
- Impedance Matching – Maximizes power transfer in RF circuits

2.4 THEORETICAL BACKGROUND AND APPLICATIONS

RLC circuits are widely used in:

- **Radio Frequency (RF) and Communication Systems**: Tuned circuits in receivers and transmitters.
- **Signal Processing**: Low-pass, high-pass, band-pass, and band-stop filters.
- **Power Systems**: Harmonic filters, transient response analysis, and impedance matching (Sedra & Smith, 2015).

2.5 NEED FOR RLC TRAINERS IN EDUCATION

Conventional teaching often relies on circuit simulation software and whiteboard explanations, which may fail to convey the full behavior of AC circuits, particularly resonance and phase shift. An RLC trainer bridges this gap by offering real-time interaction with the circuit elements and observing results using multimeters or oscilloscopes (Boylestad & Nashelsky, 2013).

Research shows that **active learning tools** significantly improve student engagement and knowledge retention in technical education (Prince, 2004). An RLC trainer provides a safe, modular platform where students can observe:

- The effect of frequency on impedance.
- The voltage drops across each component.
- The variation in current and phase angle.
- Real-life resonance behavior.

2.6 REVIEW OF EXISTING RLC TRAINERS

Several educational trainers have been developed, ranging from basic analog circuit boards to sophisticated digital trainers:

- **Analog Trainers**: These are constructed using discrete components mounted on boards with switches and terminals. They are cost-effective but may lack flexibility.
- **Digital Trainers**: Include microcontrollers or display modules for real-time measurement and control. These are more expensive and require programming knowledge.
- **Virtual Labs and Simulators**: Such as NI Multisim or Proteus, which allow for RLC circuit simulation without physical hardware. While useful, they do not replace the tactile experience of real circuit assembly and measurement.

In their study, Anbalagan et al. (2017) designed a modular RLC trainer using banana plug terminals and toggle switches to demonstrate resonance and filtering. However, their model was not portable and lacked protective features. Okwu et al. (2020) improved upon this by adding short-circuit protection and color-coded indicators for safer student use.

Despite these advancements, many available trainers remain costly or complex, especially for developing nations. Hence, there is still a need for affordable, user-friendly RLC trainers that are durable, intuitive, and effective for classroom and laboratory use.

2.7 ADVANCEMENTS AND TRENDS

Modern educational tools are now integrating:

- Digital displays for voltage and current readings.
- Built-in function generators to eliminate the need for external signal sources.
- Modular components using magnetic or socket-based connections.

- IoT-based features for remote access and performance monitoring.

However, for most undergraduate or diploma-level students, these added complexities may not be necessary. A basic analog trainer that demonstrates the core behaviors of RLC circuits remains highly relevant and effective (Theraja & Theraja, 2014).

Resonant Frequency

Resonant frequency in electronics is expressed when a circuit exhibits a maximum oscillatory response at a specific frequency. This is observed for a circuit that consists of an inductor and capacitor

It is known that the value of capacitive and inductive reactance changes accordingly to the frequency. Capacitive reactance is defined by the equation $X_c = 1/(2\pi fC)$, while inductive reactance is given by the equation $X_L = 2\pi fL$

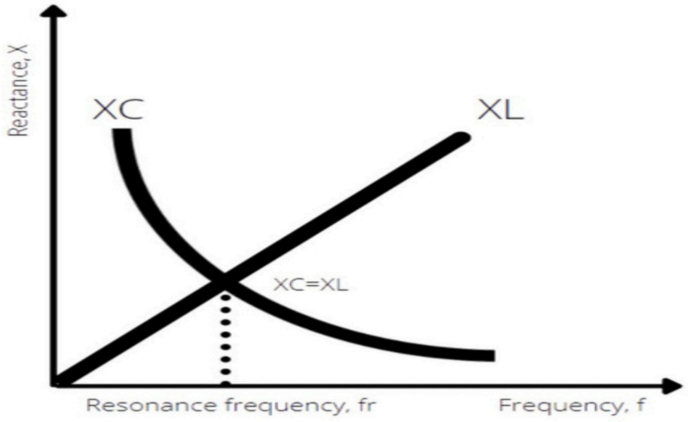

Figure2.2: The relationship of inductive and capacitive reactance across frequencies

When plotted on a chart, the decreasing capacitive reactance will cross paths with the increasing inductive reactance at a specific frequency. The frequency where both parameters overlap is known as the resonant frequency of an RLC circuit. Therefore, the resonant frequency can be derived by expressing the equal value of both capacitive and inductive reactance as follows:

1. $XL = XC$ **(**2.6)

2. $2\pi fL = 1/(2\pi fC)$ **(**2.7)

3. $fr = 1/(2\pi\sqrt{LC})$ (2.8)

In a series RLC circuit, the impedance is at its minimum when it's driven at the resonant frequency. The circuit's impedance is expressed by the following equation:

1. $Z = R + XL - XC$ **(**2.9)

At resonance, XL equals XC, meaning they cancel each other out. This leaves the impedance of the circuit to be purely resistive. As a result, the current that flows through the series RLC circuit is at its peak when it's operating at its resonant frequency.

In a parallel RLC circuit, the formula for calculating the resonant frequency remains the same. However, you'll find the current is suppressed to the minimum, as the circuit's impedance is at its maximum. This happens as the LC of the circuit appears as an open circuit when connected in parallel.

CHAPTER THREE

3.0 DESIGN AND METHODOLOGY

This chapter discusses the design processes, methodology, and practical steps undertaken in the development of the RLC Trainer. It includes the conceptual design, choice of components, system block diagram, circuit diagram, construction steps, and testing methodology. The RLC Trainer was designed to facilitate the learning of AC circuit principles, including resonance, impedance variation, and power factor, through interactive experimentation with resistors, inductors, and capacitors.

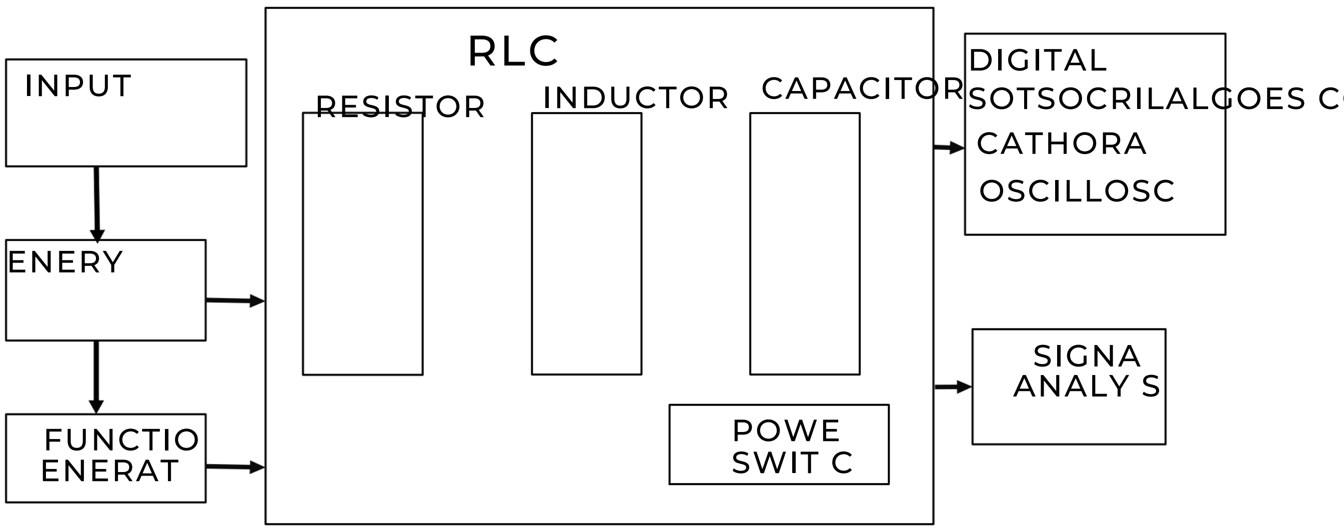

Figure 3.1: Block Diagram of RLC Circuit Trainer

3.1DESIGN STAGES

- **AC Power Supply**

  Supplies alternating voltage to the entire setup (e.g., 230V stepped down and regulated). Using a power cable that had

- **Function Generator**

  Provides sinusoidal (or other waveform) signals with variable frequency. It enables resonance and frequency response studies. It helps in studying impedance behavior by varying the frequency and observing the voltage.

- **RLC Load Unit**

  Contains selectable combinations of:
  - R (Resistors)
  - L (Inductors)
  - C (Capacitors)

  Configurable for both series and parallel circuits.

- **Energy Meter**

  Measures real-time power consumption (Watts), energy usage (kWh), and supports load analysis.

- **Oscilloscope**

  Visualizes waveforms across components, helps measure:
  - Phase shift
  - Voltage drops
  - Transient behavior

- **Signal Analyzer**

  Performs advanced signal analysis such as:
  - Harmonic distortion
  - Frequency response
  - Resonance curve observation

oPower Factor Meter

Measures the cosine of the phase angle (cos φ) between current and voltage.

Indicates efficiency of power use:

- Unity PF = ideal Lagging
- PF = inductive load
- Leading PF = capacitive load

Output & Result Display

All measured values (Voltage, Current, Power Factor, Frequency) are collected and displayed for student observation, analysis, and reporting. These values are displayed in real time on a user-friendly digital interface, such as an LCD screen or computer display, allowing for easy observation by students during practical sessions. This live feedback helps in understanding the behavior of electrical loads under different conditions. The recorded data can be used for further analysis, interpretation, and comparison with theoretical values, enabling students to draw meaningful conclusions. Additionally, the results can be logged for future reference and included in lab reports or project documentation, supporting a comprehensive learning experience.

3.2 INPUT POWER IN AN AC RLC CIRCUIT

In an **AC-powered RLC circuit,** the input power depends on the type of components (resistor, inductor, capacitor) and their behavior under alternating current. The power supplied by the **AC source** is distributed differently across **resistive and reactive** components.

There are three types of power to consider in an AC RLC circuit.

i. Real Power ii. Reactive Power iii. Apparent Power

Table 3.1: Types of Power in RLC Circuit

Type of Power	Symbol	Formula	Description
Real (Active) Power	P	P=VIcosϕ	Power actually consumed or used in the circuit, e.g., by resistors. Measured in watts (W).
Reactive Power	Q	Q=VIsinϕ	Power that oscillates between source and reactive components (L and C). Measured in volt-ampere reactive (VAR).
Apparent Power	S	S = VI	The total power supplied by the source (combines P and Q). Measured in volt-amperes (VA).

Power Factor (cos ϕ)

The power factor indicates the efficiency of power usage:

- Φ phi is the phase angle between voltage and current.
- In an RLC circuit, ϕ depends on the net reactance:

$$\tan \phi = \frac{X_L - X_C}{R} \quad \textbf{(3.1)}$$

Power factor = 1 (or 100%) at resonance (when XL=Xc) circuit is most efficient.

- Power factor < 1 when there's phase difference due to reactance (current leads or lags).

3.2.1 Input Power Flow in RLC

1. Resistor (R) Only

- Power is dissipated as heat.
- Real power: P=I2R (3.2)

  All input power is used.
-

2. **Inductor (L) Only**

- Stores energy in a magnetic field temporarily.
- Power alternates between source and inductor:

$$Q = VI\sin\phi \quad \text{(lagging)} \tag{3.3}$$

- No real power is consumed.

3. **Capacitor (C) Only**

- Stores energy in an electric field temporarily.
- Power alternates between source and capacitor:
- No real power is consumed.

$$Q = VI\sin\phi \quad \text{(leading)} \tag{3.3}$$

Full RLC Circuit

- Real power is only consumed by the resistor**.**
- Inductor and capacitor contribute to reactive power**.**
- Total input power must account for both:

$$S = \sqrt{P^2 + Q^2} \tag{3.4}$$

At Resonance

At resonance:

- XL=XC
- ϕ = 0^
- cosϕ = 1
- P = IV
- Entire input power is real

3.3 Energy Meter in an RLC Trainer

An Energy Meter in an RLC trainer is an instrument or module used to measure the electrical energy consumed by the circuit over time. It plays a vital role in analyzing real power usage, especially in circuits containing resistive (R), inductive (L), and capacitive (C) elements.

Purpose of Energy Meter in RLC Trainer

- To measure real (active) energy consumed by the circuit.
- To observe how energy usage changes with different RLC configurations (series, parallel).
- To support the study of power factor**,** phase angle, and resonance impact on power consumption.
- To provide practical, measurable feedback in educational labs.

Table 3.2: Energy Meter Measure

Parameters	**Symbol**	Unit	**Description**
Voltage	V	Volt (V)	Supplied voltage to the circuit
Current	I	Ampere (A)	Current flowing through the circuit
Power Factor	Cos ϕ		Phase alignment between current and voltage
Real Power	P	Watt (W)	Actual power consumed
Energy	E	KWh or Wh	Power consumed over time: $E = P \times t$

Working Principle

The energy meter works by calculating the real power:

$P = V \times I \times \cos\phi$

And then integrating it over time to find energy:

Energy=∫ Pdt

3.4 Function Generator in an RLC Trainer

A function generator in an RLC trainer is a crucial component used to supply alternating current (AC) signals of variable frequency and waveform. It allows students and engineers to observe how RLC circuits respond to different input conditions, particularly frequency variation.

3.4.1 Purpose of the Function Generator in an RLC Trainer

- To provide a controllable AC signal for testing RLC circuits.
- To vary the frequency and observe resonance conditions.
- To study the impedance behavior of RLC circuits at different frequencies.
- To generate standard waveforms like sine, square, or triangle waves.

3.4.2 FunctionGeneratorRoleinRLC CircuitExperiments

- **Resonance Testing**: Slowly increase frequency and observe maximum current at resonant frequency

$$f_0 = \frac{1}{2\pi\sqrt{LC}}. \qquad (3.5)$$

- **Phase Shift Analysis**: Use oscilloscope or phase meter to detect phase difference between voltage and current.
- **Impedance Analysis**: Measure how voltage/current ratio changes with frequency.
- **Transient Response**: Study behavior when waveforms abruptly change (using square/triangle waves).

3.5 RLC LOAD

An RLC load is a type of electrical load that consists of a combination of resistor (R), inductor (L), and capacitor (C) connected in a circuit. It is a common model used in AC circuit analysis and electrical engineering education to study the behavior of power systems, impedance, and resonance.

3.5.1 Characteristics of RLC Loads

1. Impedance: RLC loads have impedance, which is a measure of the total opposition to the flow of an alternating current (AC).

2. Resonance: RLC loads can exhibit resonance, where the inductive and capacitive reactance cancel each other out, resulting in maximum current flow.

3. Frequency response: RLC loads can affect the frequency response of a circuit, with different frequencies being attenuated or amplified.

3.5.2 Types of RLC Loads

1. Series RLC load: Components are connected in series.

2. Parallel RLC load: Components are connected in parallel.

3.5.3 Applications of RLC Loads

1. Circuit testing: RLC loads are used to test circuit behavior under various conditions.

2. Filter design: RLC loads are used in filter design to select or reject specific frequencies.

3. Power systems: RLC loads are used to simulate real-world loads in power systems.

3.5.4 Importance of RLC Loads

1. Accurate circuit analysis: RLC loads help engineers understand circuit behavior.

2. Design optimization: RLC loads enable designers to optimize circuit performance.

3. Troubleshooting: RLC loads aid in identifying and resolving circuit issues.

3.6 Oscilloscope in RLC Trainer

An oscilloscope is a crucial tool in an RLC trainer, allowing users to visualize and measure the behavior of RLC circuits. Here's how an oscilloscope is used in an RLC trainer:

3.6.1 Uses of Oscilloscope in RLC Trainer

1. Waveform observation: Observe the waveform of voltage and current in the RLC circuit.

2. Frequency response analysis: Measure the frequency response of the RLC circuit.

3. Resonance identification: Identify the resonant frequency of the RLC circuit.

4. Phase shift measurement: Measure the phase shift between voltage and current.

3.6.2 Benefits of Using Oscilloscope in RLC Trainer

1. Hands-on learning: Students can gain hands-on experience with oscilloscopes.

2. Circuit behavior visualization: Visualize circuit behavior, making it easier to understand complex concepts.

3. Measurement and analysis: Measure and analyze circuit parameters, such as voltage, current, and frequency.

3.6.3 Features to Consider

1. Bandwidth: Choose an oscilloscope with sufficient bandwidth to measure the frequency range of interest.

2. Channels: Consider a multi-channel oscilloscope to measure multiple signals simultaneously.

3. Triggering: Ensure the oscilloscope has suitable triggering options to capture specific events.

3.7 Signal Analyzer

A signal analyzer is a valuable tool in an RLC trainer, enabling users to analyze and understand the behavior of signals in RLC circuits. Here's how a signal analyzer is used in an RLC trainer:

3.7.1 Uses of Signal Analyzer in RLC Trainer

1. Frequency response analysis: Measure the frequency response of RLC circuits.

2. Signal distortion analysis: Analyze signal distortion and identify sources of distortion.

3. Noise analysis: Measure noise levels and signal-to-noise ratio (SNR).

4. Circuit optimization: Optimize circuit performance by analyzing signal characteristics.

3.7.2 Benefits of Using Signal Analyzer in RLC Trainer

1. In-depth analysis: Gain a deeper understanding of signal behavior in RLC circuits.

2. Circuit troubleshooting: Identify and troubleshoot circuit issues using signal analysis

3. Design optimization: Optimize circuit design for improved performance.

3.7.3 Features to Consider

1. Frequency range: Choose a signal analyzer with a suitable frequency range for the RLC circuit.
2. Dynamic range: Ensure the signal analyzer has a sufficient dynamic range to measure signal amplitudes.
3. Measurement capabilities: Consider a signal analyzer with advanced measurement capabilities, such as FFT analysis.

3.8 Power factor measurement

Power factor measurement involves determining the ratio of true power (watts) to apparent power (volt-amperes) in an AC circuit, which is essentially the cosine of the phase angle between voltage and current. This can be achieved through direct measurement using a power factor meter, or by using instruments like wattmeter and voltmeters/ammeters to calculate the ratio.

3.8.1 Direct Measurement with a Power Factor Meter:

- A power factor meter directly reads the cosine of the phase angle between voltage and current, providing a direct measurement of the power factor.
- These meters are designed to indicate the power factor value, typically displayed as a percentage or a decimal.

3.8.2 Indirect Measurement Using Separate Instruments:

- **Wattmeter:** Measures the true power (watts) consumed by the load.

- **Voltmeter and Ammeter:** Measure the voltage and current, respectively, which can be used to calculate the apparent power (volt-amperes).
- **Calculation:** The power factor can then be calculated using the formula: Power Factor = True Power / Apparent Power.
- **Apparent Power Calculation:** Apparent power (S) is calculated as S = V * I, where V is the voltage and I is the current.

3.8.3 Circuit Diagrams and Measurement Techniques

- **Series Circuit:** In a series circuit, a wattmeter, voltmeter, and ammeter can be connected to measure true power, voltage, and current, respectively, allowing for power factor calculation.
- **Parallel Circuit:** In a parallel circuit, measuring the current and voltage in each branch, and then calculating the total apparent power, can be used to determine the overall power factor.

3.8.4 Understanding Power Factor:

- **Lagging Power Factor:** When the current lags the voltage (common in inductive loads), the power factor is lagging.
- **Leading Power Factor:** When the current leads the voltage (common in capacitive loads), the power factor is leading.
- **Ideal Power Factor:** An ideal power factor is 1 (or 100%), indicating that all apparent power is being used as true power.

3.8.5 Importance of Power Factor

- **Efficiency:** A high-power factor indicates efficient use of electrical power, while a low power factor suggests that more apparent power is being supplied than true power is being used.

- **Cost Savings:** Improving power factor can lead to reduced energy bills, especially for industrial customers.

- **System Stability:** Maintaining a good power factor is crucial for the stable operation of electrical systems.

3.9 TESTING

The following tests were carried out during and after the construction

1. **Continuity test:** The continuity test was carried out to check for disconnection and open circuit in the work using a multimeter.

2. **Power consumption:** The voltage across each component and the entire circuit was measured when the system was powered.

3. **System Testing and Integration:** After the design and implementation stage, the system was tested for durability and effectiveness and also to ascertain if there is need to modify the design. The system was first assembled using breadboard. All the component where properly soldered to the ferro board and test were carried out at various stages. To ensure proper functioning of the components, they were tested using a digital multimeter to ensure that they were within the tolerance value. Faulty components were discarded.

3.10 EXPERIMENTS

Experiment 1: Measurement of Power Factor
Objective:

To understand the concept of power factor and measure the power factor of different types of loads.

Apparatus Required:

1.Voltmeter, Ammeter, Wattmeter. (MULTIFUNCTION DIGITAL METER PANEL)

2 AC power source.

. Load banks: (RLC LOAD VECTOR ANALYZER)

3 ▯ Resistive load (e.g., incandescent bulbs or resistive heaters).

. ▯ Inductive load (e.g., coil or induction motor).

▯ Capacitive load (e.g., capacitor bank).

4. **Connecting wires.**

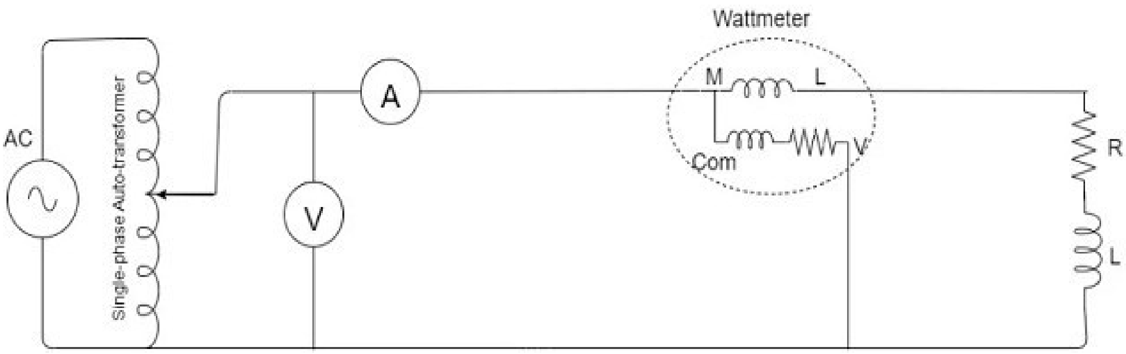

Figure 3.2: Circuit Diagram for power factor measurement

Carry out the following connections:

Connect the MULTIFUNCTIONAL DIGITAL METER PANEL (MDMP) to power supply and turn it ON. At this point you will observe the multifunction digital meter display on the screen. This digital meter would measure:

Voltage as V, Current as A, Real Power (P) as Kw Reactive Power (Q) as KVar

Apparent, Power (S) as KVA, Power Factor as Cos θ

You should access these parameters above using the left and right arrow keys on the multimeter

Also connect the RLC LOAD VECTOR ANALYZER to the power supply, turn it ON and observe the cooling fan behind spin.

Procedure:

Step 1: Resistive Load

1. Connect the resistive load (100w incandescent bulb to Rout and Nout of the MDMP OUTPOUTS.

2.Connect the inputs of MDMP Rin and Nin using patch chords to the power supply source through a variac transformer.

3.Measure and record:

- Voltage (V) using a voltmeter.
- Current (I) using an ammeter.
- Active power (P) using a wattmeter.

4.Calculate the power factor using the formula: Power Factor (PF)=P/V×I Note: Vx I = apparent power (S). Calculate and compare it. Is this true? Therefore PF = Active or Real power / apparent power = P/S = Cos θ

Step 2: Inductive Load

1. Replace the resistive load with an inductive load. (either 1H, 0.8H, 0.6H only)

2.Repeat the measurements of voltage, current, and active power.

3.Calculate the power factor using the same formula.

4. Observe that the power factor is less than 1 due to the lagging phase

difference between voltage and current.

Step 3: Capacitive Load

1. Replace the inductive load with a capacitive load. (either 1uF, 0.36uF, 0.22uF only)

2.Repeat the measurements of voltage, current, and active power.

3 Calculate the power factor.

. Observe that the power factor is less than 1 due to the leading phase difference between

4 voltage and current.

Step 4: Mixed Loads (RESISTIVE and INDUCTIVE)

1.Combine resistive and inductive. (100w incandescent bulb and 0.8H inductor)

2.Repeat the measurements and calculations.

3.Observe how the combination affects the overall power factor.

Step 5: Mixed Loads (RESISTIVE, INDUCTIVE and CAPACITIVE)

1.Combine resistive, inductive, and capacitive loads. (100w incandescent bulb and 0.8H inductor 0.36uF)

2.Repeat the measurements and calculations.

3.Observe how the combination affects the overall power factor.

4. Observations:

5.Record the measured values of V, I, P, and the calculated power factor for each type of load in a table.

3.9.2 Experiment 2: Series RLC resonant circuit.

Objective:

- Determine the resonant frequency of a series RLC circuit.
- Measure the voltage and current at different frequencies to observe the resonance phenomenon.
- Compare the experimental results with the theoretical prediction

Apparatus Required

- Function generator
- Oscilloscope (dual-channel)
- RLC Vector Analyzer

1. Frequency Generator: Use a function generator to provide an AC voltage source with variable frequency.

2. Oscilloscope: Use an oscilloscope to measure the voltage and current across the circuit at differen frequencies.

3. Ammeter: Use an ammeter (if available) to measure the current in the circuit.

Theory:

In a series RLC circuit, the impedance (Z) is given by:

$$Z = \sqrt{R^2 + (XL - XC)^2} \quad (3.6)$$

where:

- R is the resistance
- XL is the inductive reactance (XL = 2πfL)
- XC is the capacitive reactance (XC = 1/(2πfC)

At resonance in a series RLC circuit:

1.Inductive Reactance (X□) = Capacitive Reactance (X_c)

$$X_L = X_C \implies 2\pi f_r L = \frac{1}{2\pi f_r C}$$

Resonant Frequency (f_r):

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (3.7)$$

2.Impedance (Z) is minimized (Z = R), and current (I) is maximized.

3.**Voltage across L and C** can exceed the supply voltage (voltage magnification).

Circuit Diagram:

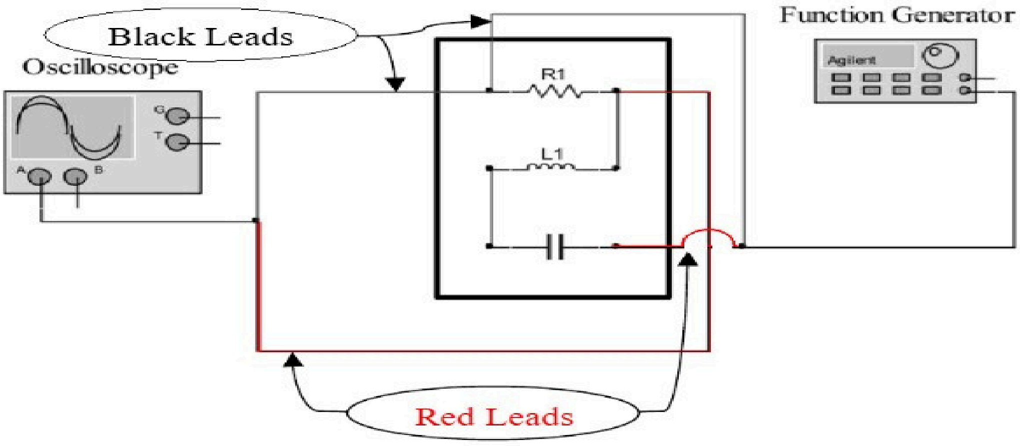

Figure 3.3a: Series RLC resonant circuit.

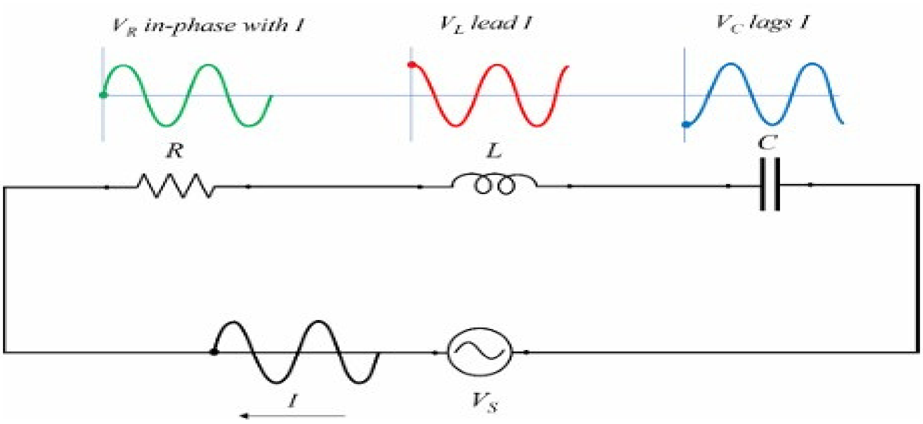

Figure 3.3b: Series RLC resonant circuit.

Illustrate the equivalent circuit or RLC in series and the voltages across each element.

1.Build, connect the circuit shown in Fig. 1 using a 1kΩ resistor, a 100 mH inductor and

2. 0.1µF capacitor.

3. Set the input voltage at 5V and frequency at 500 Hz.

   Using the Oscilloscope, read the voltage across the 1kΩ resistor 100 mH inductor and

   0.1µF capacitor.

4.Change the input frequency from 500 to 1 kHz, 1.5 kHz 2 kHz 2.5 kHz and 3 kHz.

5.Repeat step 3, measuring the voltage across the 1kΩ resistor 100 mH inductor and

0.1µF capacitor.

6.Based on the experimental measurement, Calculate the phase shift difference (θ) theoretically

7.Measure also the phase shift between VS and VR at these three frequencies

8.Write down all the measured and calculated values.

Procedure

Part 1: Setup the Circuit

Series RLC Circuit:

- Connect a resistor (R), inductor (L), and capacitor (C) in series with the function generator.
- Connect Channel 1 of the oscilloscope across the resistor to measure current indirectly.
- Connect Channel 2 of the oscilloscope across the entire circuit to measure input voltage.

Part 2: Frequency Sweep and Data Collection

1.Set the function generator to produce a sinusoidal signal with a small amplitude (e.g., 1V peak-to-peak).

2. Start at a low frequency (500 Hz) and gradually increase the frequency while observing the waveforms on the oscilloscope.

3. For each frequency, record:

- Voltage amplitude across the resistor.
- Phase difference between input voltage and current (via the resistor).
- Shape of the Lissajous figure in XY mode.

CHAPTER FOUR

4.0 TESTING, RESULTS AND DISCUSSION

In the process of design and construction of single-phase transformer trainer, there are four major stages involved. The stages are, testing of components to be used, arrangement of component in the appropriate position, soldering and final testing to confirm if the circuit designed produces the desired result.

4.1 TESTING OF THE COMPONENTS

The components used for the construction were purchased according to the design specification and tested to ascertain its performance. The polarity and pin arrangement of some of the components were noted.

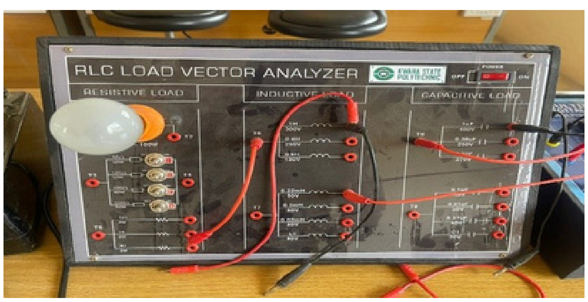

Figure 4.1a:RLC Trainer **Figure 4.1b:Multipurpose Meter**

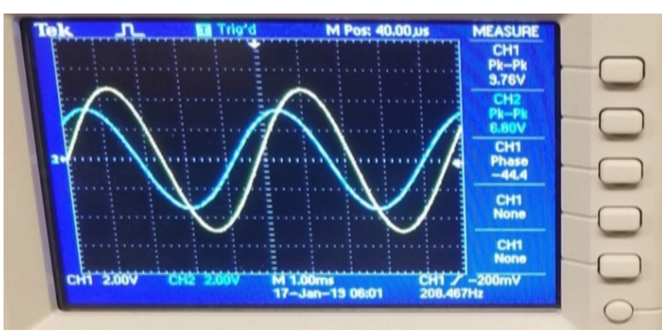

Figure 4.1b: Oscilloscope

- The Variac supplies adjustable AC voltage.
- The Digital Multifunction Meter measures all key parameters: Voltage (V), Current (I), Power (P), Apparent Power (S), Power Factor (PF), etc.
- Loads can be resistive**,** inductive**,** capacitive**,** or a combination (RLC).
- Power factor is calculated directly or with formula:

- The function generator injects an AC signal of varying frequency.
- The resistor, inductor, and capacitor are connected in series.
- Channel 1 of the oscilloscope is placed across the resistor to observe current (since $V_R \propto I$).
- Channel 2 is placed across the whole circuit to observe total voltage.
- At resonance, you'll see:
    - Maximum voltage across resistor
    - Phase difference = 0°
    - Voltage across L and C individually spike (voltage magnification)

4.2 SOLDERING ARRANGEMENT OF COMPONENTS

Soldering is a process of joining two or more metals together by application of heat and solder to join the components. Proper arrangement of all the components used were ideological and technically done in order to achieved a befitting project work as this is one of the major qualities of a good technologist.

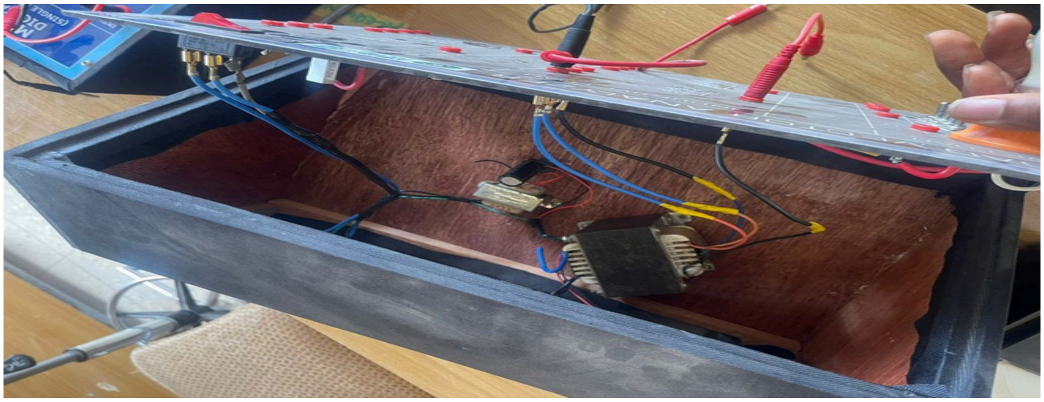

Figure 4.2: RLC Trainer inner components

4.3 TESTING AND RESULT

Experiment 1: Measurement of Power Factor

Calculation:

Power factor may be defined by three definitions and formals as follow.

1*).* The Cosine of angle between Current and Voltage is called Power Factor.

- $P = VI \cos\theta$ *OR* (4.1)
- $\cos\theta = P \div VI$ *OR* (4.2)
- $\cos\theta = kW \div kVA$ *OR* (4.3)
- $\cos\theta$ = True Power ÷ Apparent Power (4.4)

Where:

- P = Power in Watts
- V = Voltages in Volts
- I = Current in Amperes
- W = Real Power in Watts
- VA = Apparent Power in Volt-Amperes or kVA
- $\cos\theta$ = Power factor

4.4 OBSERVATION TABLE:

Table 4.1: Measurement of Power Factor

Load Type	Voltage (V)	Current (I) (A)	Apparent power (S) = (VxI) VA	Active Power (P) W	Power Factor (PF) Cos θ
Resistive (R)(100w bulb)	195 198	0.34	66.3 17.6	66	0.995 0.34
Inductive (L) (0.8H)	197	0.089 0.124	24.4	6 0.000	0.000
Capacitive (C) (1uF)	198 195.7	0.38	75.2 74.3	73	0.971 0.983
Mixed (RL) (100w, 0.8H)		0.38		73	
Mixed (RLC) (100w,0.8H,0.36uF)					

Table 4.2: Voltage Across Resistor (V_R) vs. Frequency

Constants: Vin = 5V, R = 100Ω, L = 10mH, C = 0.1μF, Theoretical f_r = 1591.5 Hz

Frequency (Hz)	V_R (Volts)	Current (I = V_R/R, mA)	Phase Shift (θ)	Observations
500	1.2	12.0	Lagging (θ > 0°)	Dominated by inductive reactance (X_L).
1000	3.0	30.0	Slight lag	Approaching resonance.
1400	4.2	42.0	Near 0°	Lower cutoff frequency (f_1).
1600 (f_r)	5.0	50.0 (max)	0°	Resonance: Z = R, I = max.
1800	4.2	42.0	Near 0°	Upper cutoff frequency (f_2).
2000	2.8	28.0	Leading (θ < 0°)	Dominated by capacitive reactance (X_C).
2500	1.5	15.0	Leading	Far from resonance.

4.4.1 Observations and Discussion:

1. Peak Voltage/Current:
   - At f_r = 1600 Hz, V_R = Vin = 5V (maximum current, 50 mA).
   - Confirms resonance condition: XL=XC

1. Bandwidth (BW):
   - BW = f_2 - f_1 = 1800 - 1400 = 400 Hz

     (measured at $V_R = \frac{V_{\max}}{\sqrt{2}} \approx 3.5V$).

2. Phase Behavior:
   - Below f_r: Current lags voltage (inductive dominance).
   - At f_r: In phase (θ = 0°).
   - Above f_r: Current leads voltage (capacitive dominance).

3.Voltage Magnification:
   - V_L and V_C reached ~50V at resonance (Q = 10), though not shown in this table.

4.3 Table: Voltages at Resonance (f_r = 1600 Hz)

Parameter	Theoretical Value	Experimental Value 5 V	Remarks
Input Voltage (Vin)	5 V (constant)		Setbyfunction generator.
Voltage across R (V_R)	5 V	5 V	Matches V_in (Z = R at resonance).
Voltage across L (V_L)	50 V	49.8 V	Magnified due to Q-factor (Q = 10).
Voltage across C (V_C)	50 V	50.2 V	Equal and opposite to V_L (phasor).

Phase Angle ϕ)	0°	~0° (observed)	V_in and I in phase at resonance.

Observations and Discussion:

1. V_L and V_C exceed V_in due to the quality factor (Q) of the circuit

$$Q = \frac{V_L}{V_{in}} = \frac{50}{5} = 10$$

2. Experimental values may slightly differ from theory due to:
   - Component tolerances (L, C, R).
   - Oscilloscope/probe calibration errors.

3. Phase relationship: At resonance, V_L and V_C cancel out (180° phase difference), leaving V_R = Vin.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

The RLC series and parallel resonance experiments demonstrated key differences in circuit behavior at resonance. In the series RLC circuit, resonance occurred when the inductive and capacitive reactance canceled each other (XL=XC), resulting in minimum impedance (Z=R) and maximum current. The voltage across the inductor and capacitor magnified due to the quality factor (Q), while the phase angle between voltage and current became zero, indicating unity power factor. In contrast, the parallel RLC circuit exhibited maximum impedance and minimum current at resonance, with circulating currents between L*L* and C*C*. These experiments highlighted practical applications such as tuning circuits (series) and tank circuits (parallel). The power factor experiment emphasized the importance of improving efficiency in AC circuits. Inductive loads caused a lagging power factor, increasing reactive power and reducing system efficiency. By introducing a compensating capacitor, the power factor was corrected toward unity, minimizing losses and optimizing power delivery. Together, these experiments illustrated fundamental AC circuit principles —resonance conditions, impedance effects, and power factor correction— essential for designing efficient electrical systems in real-world applications.

5.1 RECOMMENDATION

To enhance future RLC trainer the following recommendations should be implemented. First, using precision instruments like digital LCR meters and calibrated oscilloscopes will improve measurement accuracy for component values and phase relationships. For resonance experiments, taking finer frequency steps near resonant peaks will allow more precise determination of quality factor (Q) and bandwidth, while in power factor studies, employing variable capacitor banks would better demonstrate compensation effects. Safety measures like current-limiting resistors and isolation transformers should be incorporated when working with high-Q circuits to prevent equipment damage. These improvements would lead to more reliable data, deeper understanding of AC circuit principles, and safer laboratory practices, ultimately enhancing the educational value of the experiments. For more advanced studies, investigating different load types and their compensation requirements could provide valuable insights into real-world power system applications.

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