



L5 - Electrical Engineering (ACDA5001)

Assignment 1: Analysis of an RLC Network

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Abstract

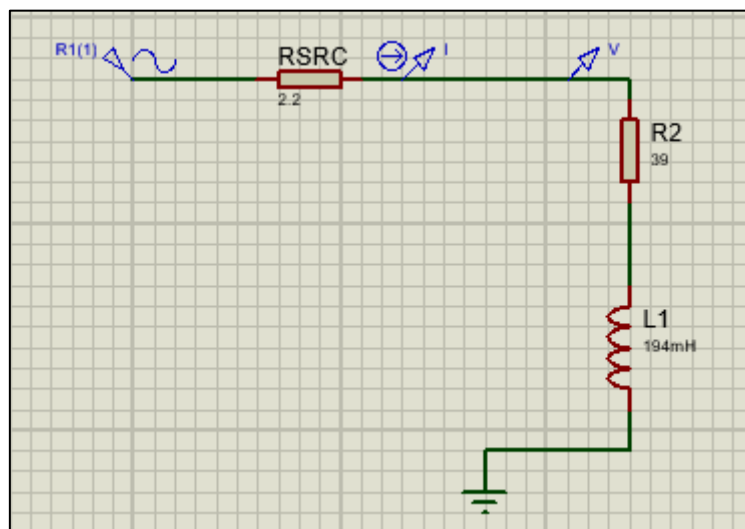
This study explores the dynamics of a parallel RLC circuit with a focus on power factor correction. Using Proteus and Excel, simulations and calculations were performed to analyse the behaviour of the circuit before and after the application of power factor correction. The tasks involved plotting current and voltage against time, calculating active, reactive, and apparent power, determining an optimal capacitor value for power factor correction, and creating graphs illustrating the relationship between power factor, capacitor value, and phase angle. Phasor diagrams were also drawn at different frequencies. The results offer insights into the impact of power factor correction on resonance and maximum power transfer in the circuit.

Introduction

Parallel RLC circuits play a crucial role in alternating current (AC) systems. This study delves into the interplay of resistive (R), inductive (L), and capacitive (C) elements within a parallel RLC circuit. Specifically, the circuit components are analogous of an AC system, where R_{src} represents the resistance of the source, including cabling and transformer windings, L corresponds to the inductance of devices like motors, and the power factor correction capacitor (PFC) addresses efficiency concerns. The investigation aims to analyse the circuit's performance by employing simulation tools like Proteus and computational methods in Excel.

Task 1

i) Before Power Factor Correction is Added



Using the information given in the assignment, the values to be used in my simulation will be:

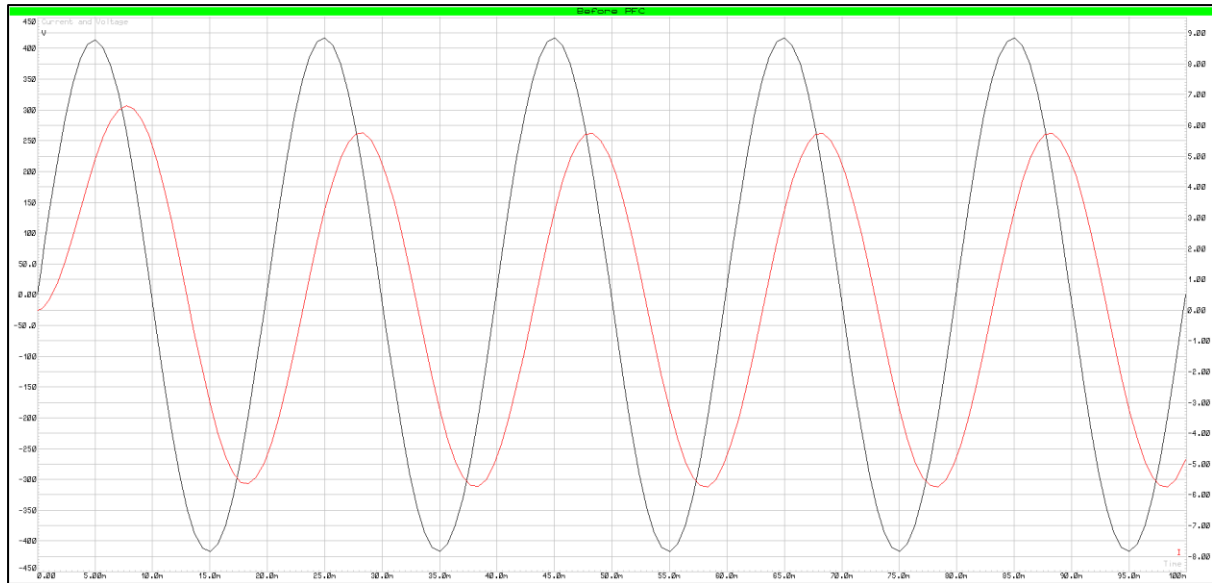
My student number – 2219439

$R1(1)$ – 300Vrms, 50Hz sinusoidal source

$R_{src} = 2.2 \Omega$

Load inductor value - 194 mH

Load resistor value - 39 Ω



- Voltage is the black trace
- Current is the red trace



From the graph above, you can see that the current lags the voltage by 3ms and 90 degrees.

ii) Active, Reactive and Apparent Power

Prior to calculating active, reactive and apparent power – a few calculations are required first:

Inductive Reactance

$$X_L = 2\pi fL$$

$$X_L = 2\pi \times 50 \times 0.194$$

$$X_L = 60.95$$

Circuit Current

$$I = \frac{V}{X_L}$$

$$I = \frac{300}{60.95}$$

$$I = 4.92A$$

Current RMS

$$I_{rms} = \frac{I}{\sqrt{2}}$$

$$I_{rms} = \frac{4.92}{\sqrt{2}}$$

$$I_{rms} = 3.48A$$

Phase Angle

$$\phi = \tan^{-1} \left(\frac{X_L}{R} \right)$$

$$\phi = \tan^{-1} \left(\frac{60.95}{39} \right)$$

$$\phi = 57.39^\circ$$

Active Power

$$P = V \times I_{rms} \times \cos\phi$$

$$P = 300 \times 3.48 \times \cos(57.39)$$

$$P = 562.63 \text{ kW}$$

Reactive Power

$$\text{Reactive Power (Q)} = V \times I_{rms} \times \sin\phi$$

$$Q = 300 \times 3.48 \times \sin(57.39)$$

$$Q = 879.42 \text{ VAR}$$

Apparent Power

$$\text{Apparent Power (S)} = V \times I$$

$$S = 300 \times 4.92$$

$$S = 1476 \text{ VA}$$

iii) Power Factor

$$PF = \frac{\text{Active Power (kW)}}{\text{Apparent Power (VA)}}$$

$$PF = \frac{562.63}{1044}$$

$$PF = 0.54$$

iv) Capacitor Calculation

Firstly we need to work out IC before calculating the capacitor value:

$$IC = I \times \sin\phi$$

$$IC = 4.92 \times \sin(57.38)$$

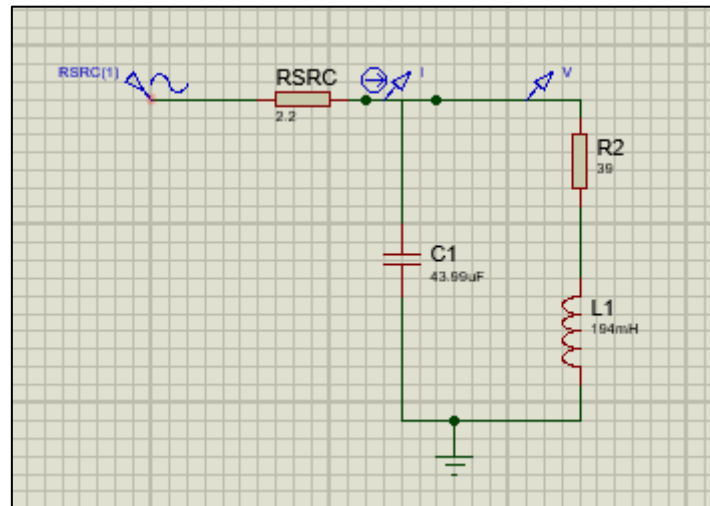
$$IC = 4.14A$$

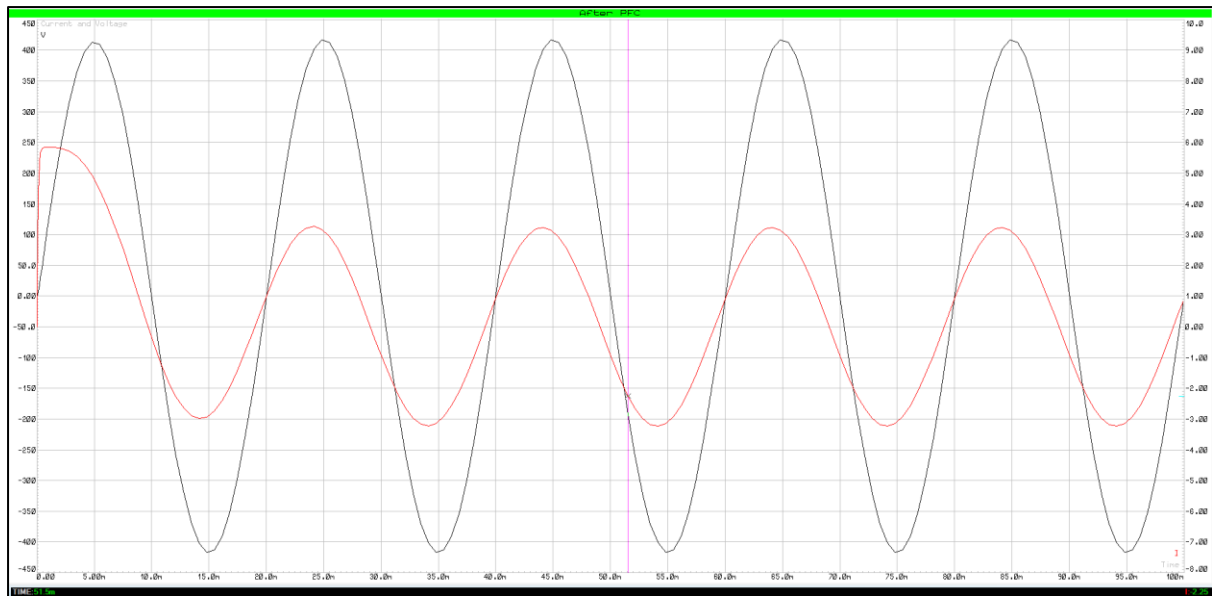
Now to calculate the capacitor value:

$$C = \frac{IC}{2\pi f V}$$

$$C = \frac{4.14}{2\pi \times 50 \times 300}$$

$$C = 43.93\mu F$$

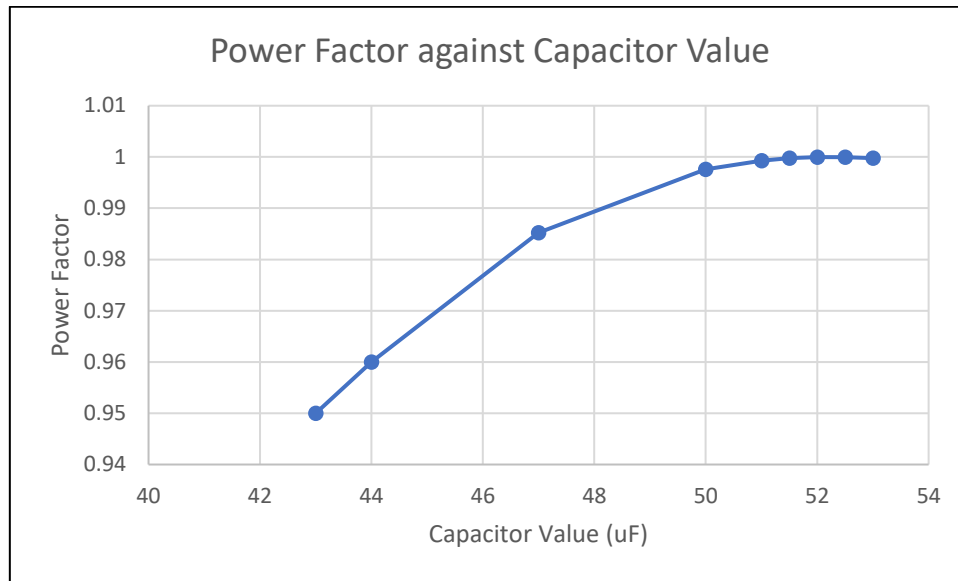




After the power factor correction capacitor has been added, you can see that the current and voltage are now close to being in phase. Looking closely at the graph:



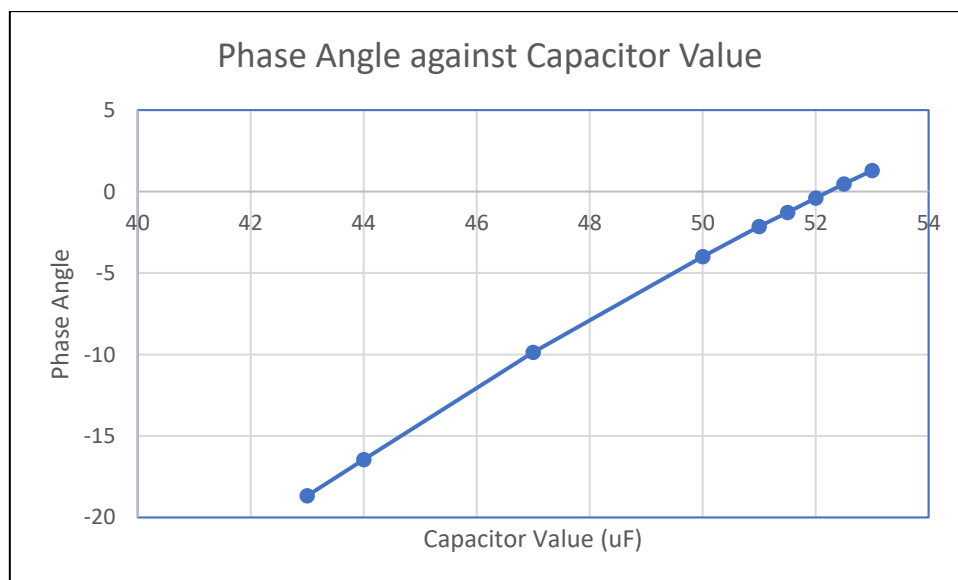
v) A Graph of Power Factor against Capacitor Value



When analysing the chart above, you can notice that a 52uF capacitor would give us an ideal power factor of 1. Although this isn't really possible, this would be a perfect value.

Also, our calculated value of a 43.93uF capacitor would give us a power factor of 0.96, which satisfies our assignment task.

vi) A Graph of Phase Angle against Capacitor Value



When analysing the phase angle chart above, a capacitor value of 52uF would give a phase angle of -0.4°. This is in keeping with an ideal power factor of 1. As capacitive reactance (X_C) is near enough equal to capacitive inductance (X_L) the circuit will be at resonance.

vii) What happens to the Energy Stores in the Capacitor and Inductor at Power Factors Close to 1

When the power factor of a circuit is close to 1, it means that the relationship between voltage and current is nearly in phase. In such conditions, the energy dynamics in capacitors and inductors are notable:

Capacitors store energy as an electric field builds up across them. At a power factor close to 1, the capacitive reactance is low, making the capacitor more effective in compensating for inductive effects in the circuit.

The energy stored in the capacitor continually oscillates with the circuit voltage. Since the power factor is close to 1, most of this energy is used to contribute to real power, with minimal reactive power.

Inductors store energy in a magnetic field as current flows through them. A power factor close to 1 indicates low inductive reactance, reducing the inductor's impact on reactive power.

Energy stored in the inductor fluctuates with the magnetic field changes, synchronized with the voltage waveform. With a power factor close to 1, the exchange of energy is more efficient, contributing primarily to real power.[1]

Task 2

i) 25 Hz Below Resonance

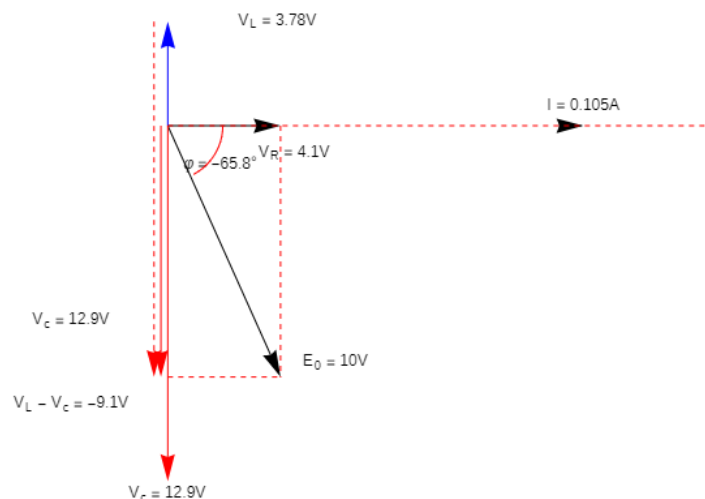
Prior to beginning this task, we first need to find out what our resonant frequency is.

$$F_{res} = \frac{1}{2\pi\sqrt{LC}}$$

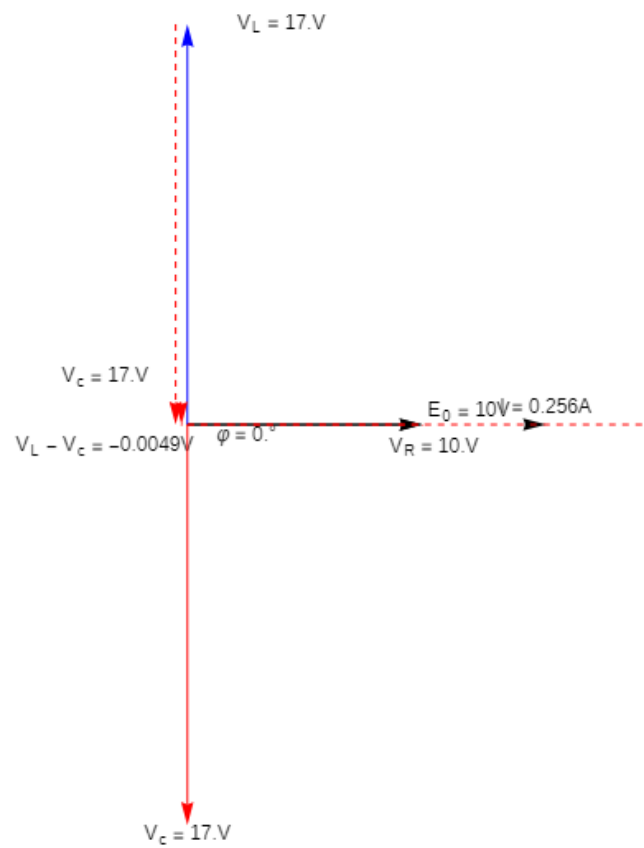
$$F_{res} = \frac{1}{2\pi\sqrt{0.194 \times (43.93 \times 10^{-6})}}$$

$$F_{res} = 54.51\text{Hz}$$

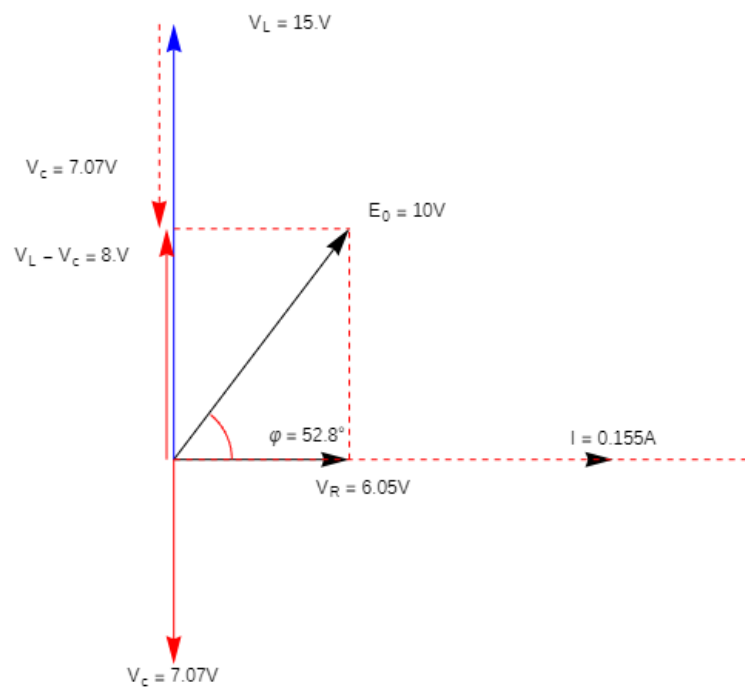
So 25Hz below resonance would be $54.51 - 25 = 29.51\text{Hz}$.



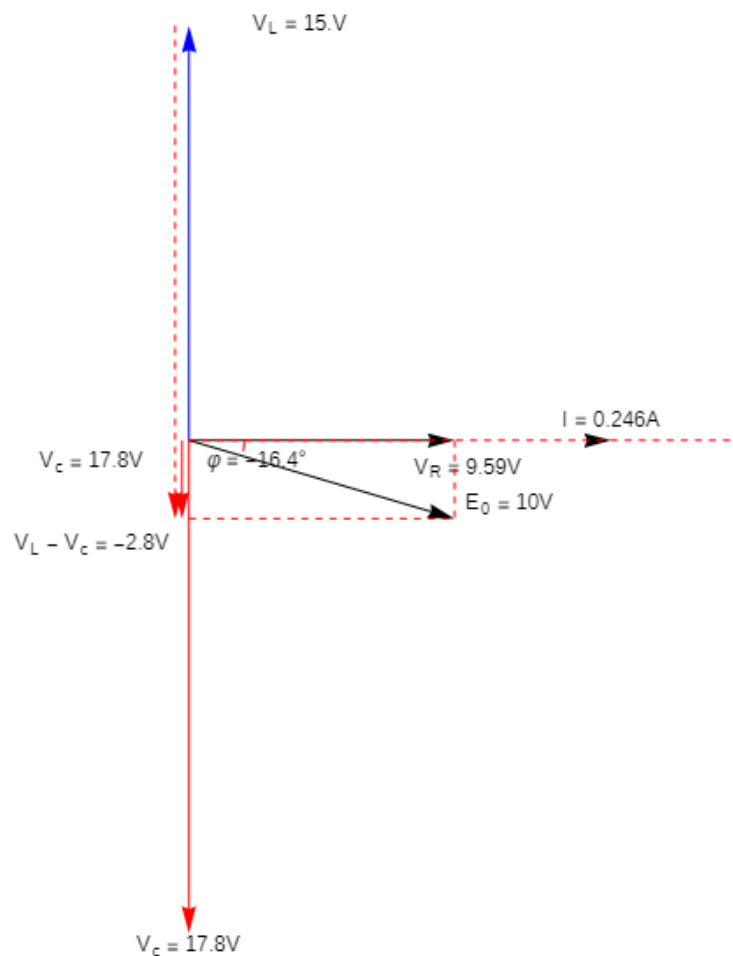
ii) Resonance



iii) 25Hz Above Resonance



iv) 50Hz



[2]

Task 3

i) Resonance

Resonance in an AC circuit occurs when the capacitive reactance and the inductive reactance become equal in magnitude but opposite in phase.

In the context of power factor correction, the calculated capacitor value is chosen to offset the inductive reactance in the circuit. The goal is not to reach resonance, but to minimize the overall reactive power in the system. By introducing a capacitor, which has a negative reactance that opposes the inductive reactance, the power factor is improved without causing resonance.[3]

ii) Maximum Power Transfer

Maximum power transfer occurs in a circuit when the impedance of the load matches the complex conjugate of the source impedance. For a purely resistive load, maximum power transfer occurs when the load resistance equals the source resistance.

In power factor correction, the addition of a capacitor is aimed at reducing the reactive power and improving the power factor. While it does influence the impedance seen by the source, the primary

goal is not to achieve maximum power transfer. Instead, it is to minimize the reactive power, which helps in reducing losses and improving the efficiency of the system.

In summary, the choice of the capacitor value for power factor correction is made to minimize reactive power and improve the power factor without necessarily causing resonance or aiming for maximum power transfer. The focus is on improving the overall efficiency of the system by reducing the impact of reactive elements.[4]

Conclusion

In conclusion, this study has provided valuable insights into the behavior of a parallel RLC circuit, emphasizing the significance of power factor correction in optimizing AC system performance. Through simulations in Proteus and calculations in Excel, we explored the circuit's dynamics, analysing the interplay of resistive, inductive, and capacitive elements. The investigation highlighted the crucial role of power factor correction capacitors in minimizing reactive power, enhancing the power factor, and consequently improving system efficiency.

As the capacitor value increased, the power factor approached and exceeded 0.95, underscoring the effectiveness of power factor correction in mitigating inefficiencies associated with reactive power.

Phasor diagrams further illuminated the circuit's behaviour at various frequencies, illustrating the impact on component voltages and currents below resonance, at resonance, above resonance, and at 50 Hz.

Considering the resonance and maximum power transfer aspects, our findings suggest that the calculated capacitor value for power factor correction does not induce resonance but significantly influences power factor without aiming for maximum power transfer. The emphasis lies in mitigating losses associated with reactive power rather than seeking an optimal match for power transfer.

In summary, this study contributes to the broader comprehension of AC system dynamics, emphasizing the role of power factor correction in enhancing efficiency. The insights gained can inform practical applications, guiding the design and optimization of AC circuits for improved performance and reduced energy losses.

References

- [1] R. T. Paynter and B. B. J. Toby, Electronics Technology Fundamentals. Upper Saddle River, NJ: Prentice Hall, 2002.
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- [3] [1] A. C. Gilli, Electrical Principles of Electronics. New York: McGraw-Hill, 1968.
- [4] E. Hughes, J. Hiley, K. Brown, and I. M. Smith, Hughes Electrical and Electronic Technology. Harlow, England: Pearson, 2012.