

EE RLC assignment

by Rhys Jones

Submission date: 10-Jan-2025 04:13AM (UTC+0000)

Submission ID: 247890138

File name: 49553_Rhys_Jones_EE_RLC_assignment_632121_765746608.odt (273.54K)

Word count: 2192

Character count: 12206

ACDA 5001
Electrical Engineering
Course work
Student number: 2317422
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Abstract

This report is to develop power factor correction and analyse a parallel RLC circuit to understand its significance in AC systems. To represent real world components such as inductive loads and power factor correction capacitor, the circuit was simulated with Proteus. Plotting of voltage and current graphs, calculation of power parameters and determination of a capacitor value to improve power factor to ≥ 0.95 were included in key tasks. Phasor diagrams were also analysed for varying frequencies to determine the voltage-current relationship. The results also show enhanced energy efficiency, resonance effects and improved power transfer and thus the necessity of power factor correction in industrial applications.

Introduction

AC, known as alternating current, produces voltages varying in polarity, switching between negative and positive over time. The symbol for an AC voltage source is a circle with a sine wave, instead of the traditional battery symbol which consists of 2 lines one longer than the other. If a machine is designed to rotate a magnetic field around stationary coils, an AC voltage will be created across the coils as its being rotated, this happens as it complies with Faraday's law of electromagnetic induction. AC generators are also used in transformers as they often consist of less parts providing a simple and cheaper option to DC generators being used [1]. RLC circuits are circuits that consist of resistors, inductors and capacitors. They can be set up in either parallel or in series. This circuit gets its name from the abbreviation of each element represented in the circuit. When having an inductor and a capacitor, there are two components that can store energy, therefor requiring two initial conditions and as a result provide a second order differential equation. The characteristics of

the circuit change based on it being in series or parallel. When in series the voltage across the resistor is in phase with the current, leading by 90 degrees when across an inductor and lags when across a capacitor. When in parallel the voltage remains constant across the circuit while the current flowing through each component can change. To work out the current load through each component KCL, known as Kirchhoff's Current Law, would need to be applied [2]. The maximum power transfer principle is the idea that power is best delivered to a load when the load resistance is equal to the internal resistance of the source. This extends to matching the load impedance to the complex conjugate of the source impedance in alternating current systems. This principle is important in communication systems, including telecommunications, audio engineering, and power systems, for efficient transfer of energy or information. There are limitations, however; in power networks, maximum power transfer is not necessarily optimal, minimizing losses is usually better. Despite its limitations, this principle gives important ideas for improving the design of electrical and electronic circuits and enhancing the performance of systems [3]. The power factor is a measure of how much of the electrical power is really used to do work in a system. It is the ratio of effective power in watts (W) to apparent power in volt-amperes (VA). A power factor of 1 or 100% means that the system is very efficient. Other power factors are poor and occur when there are reactive components, such as inductors or capacitors, in the system that cause the voltage and current to be out of phase. Improving power factor increases system capacity, decreases energy losses, and lowers electricity prices. It is crucial in commercial and industrial electrical networks [4]. Resonance occurs in circuits containing inductors and capacitors when the inductive reactance equals the capacitive reactance, making the impedance purely resistive. At this frequency, the circuit has maximum energy transfer and current flow available. Resonance is key in applications like radio tuners, which are used to tune into specific frequencies for communication. It also has a vital job in resonant power converters and oscillators. However, uncontrolled resonance can cause excessive currents or voltages that can destroy components. Electrical resonance and how it is used is vital in optimizing circuit performance and avoiding the potential hazards of electrical and electronic systems [5].

Method

Figure 1 shows the circuit built in proteus. It is a parallel RLC circuit with values attained from my student number. The circuit contains 2 resistors, one being 2.3ohms and the other being 22ohms, the inductor is 174mH and was also derived from my student number. The capacitor was chosen later to attain better power factor.

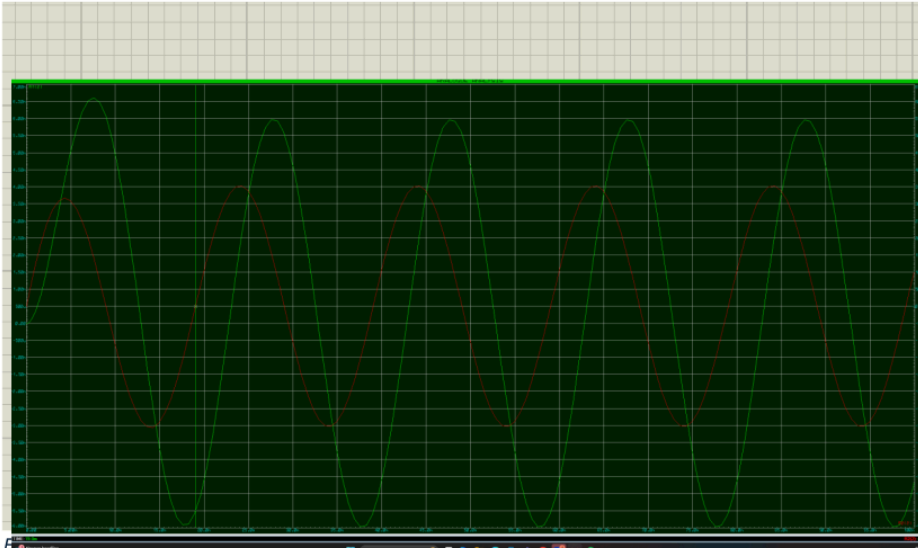


Figure 1
Figure 2

By using the formula $\phi = \tan^{-1}(XL/R)$ we can work out that the phase angle is 66.03 degrees. This shows how much the current lags the voltage before adding the correct value capacitor in. Figure 2 shows a picture of the graph before any power factor correction was applied and was used to work out the phase angle.

To work out active power the formula, $P = VI \cos\phi$ was used. This provided an output of 611.13W. The reactive power uses a similar equation, $Q = VI \sin\phi$. Using this formula gave the reactive power of 1374.76 VAR. To work out apparent power both active and reactive power was needed to be calculated first as the formula for apparent power is $|S| = \sqrt{P^2 + Q^2}$. Using this formula it gives an apparent power of 1504.48VA. to work out the power factor the formula, $PF = \text{active power}/\text{apparent power}$, was used. This gave a result of 0.48 which is far away from the desired outcome for this project, being 0.95. This is where the capacitor comes into play as changing the capacitance will change the power factor. A

reasonable capacitor value for this circuit is 45 μ F. This brings the power factor up to 0.97 which is ideal for this circuit as it is greater than 0.95.

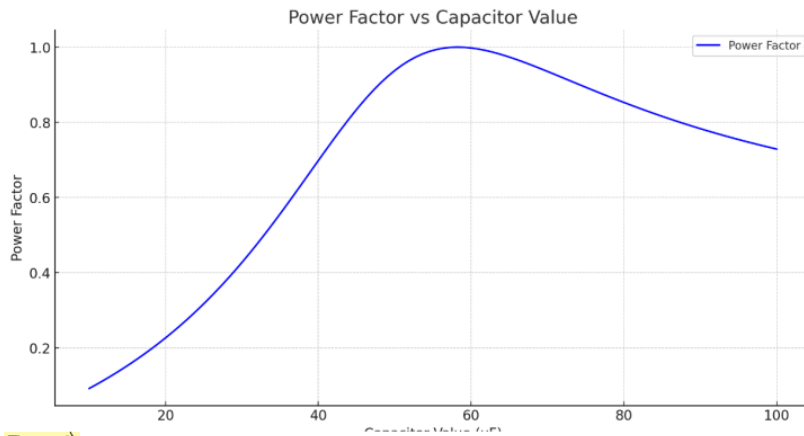


Figure 3

Figure 3 is a graph that shows how different value capacitors will affect the power factor.

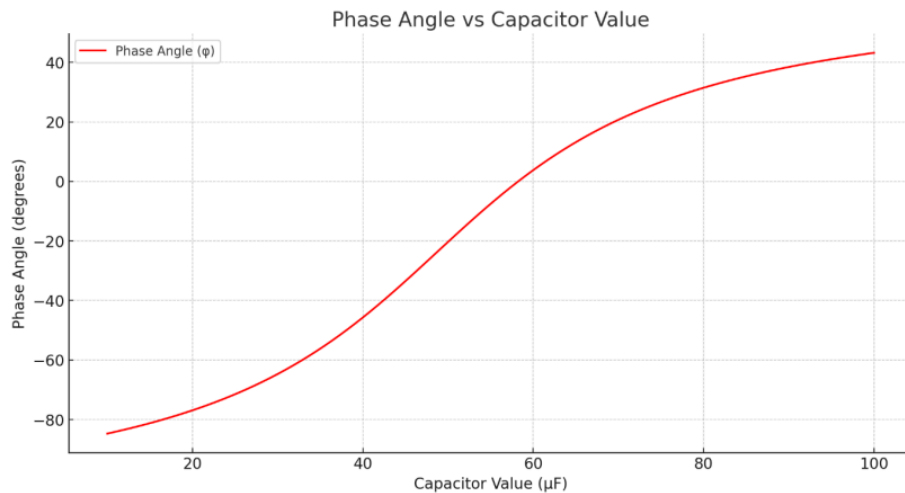


Figure 4

Figure 4 is a graph that shows the difference in phase angle as the capacitor value changes. When comparing fig 3 and 4 we can clearly see the similarity in the changes as the capacitor value changes. The power factor increases as the capacitance increases, approaching 1 (unity) as the circuit becomes more resistive (phase angle approaches 0degrees). The phase angle decreases with increasing capacitance, indicating reduced reactive effects as the capacitor compensates for the inductive reactance. As the power factor approaches 1, the capacitor and inductor internally balance reactive power, minimizing oscillations between the source and reactive components. The capacitor stores energy in its electric field during charging, while the inductor stores energy in its magnetic field as current flows. At unity

power factor, their reactance's cancel ($X_L = X_C$) reducing the net reactive power. The energy exchange becomes entirely internal, and the source supplies only real power, improving efficiency and minimizing transmission losses. This balance ensures that the circuit operates efficiently, with reduced strain on the source and better utilization of power.

Results

Figures 5,6,7 and 8 are all phasor diagrams at different frequencies, being 81.88hz which is 25hz above resonance, 6.88hz which is resonance, 50hz and 31.88hz which is 25hz below resonance.

At 31.88 Hz: The current lags the voltage significantly due to dominant inductive reactance ($X_L = \omega L$, $X_L = \omega L$) at lower frequencies. The phase angle (ϕ) is large, indicating poor power factor and high reactive power.

At 50 Hz: The phase angle decreases as the capacitive reactance ($X_C = 1/(\omega C)$, $X_C = 1/(\omega C)$) starts countering the inductive reactance. The power factor improves, and the current aligns more closely with the voltage.

At 56.88 Hz: This frequency is near resonance, where $X_L \approx X_C$, $X_L \approx X_C$. The phase angle is minimal, and the current is nearly in phase with the voltage. The power factor is close to 1, indicating efficient energy transfer with minimal reactive power.

At 81.88 Hz: The current leads the voltage as the capacitive reactance dominates at higher frequencies. The phase angle increases, but it shifts toward leading instead of lagging, reducing the power factor again.

Overall, these graphs show how the interplay between inductance and capacitance affects phase angle and power factor across frequencies, optimizing performance near resonance.

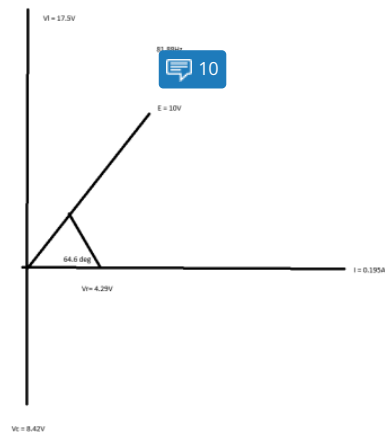


Figure 5 81.88hz

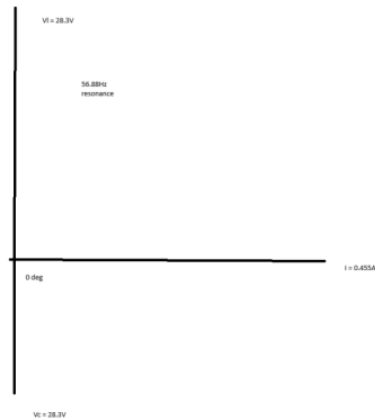


Figure 6 56.88hz resonance

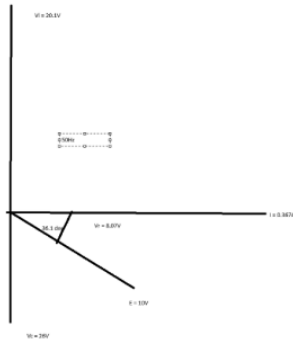


Figure 7 50hz

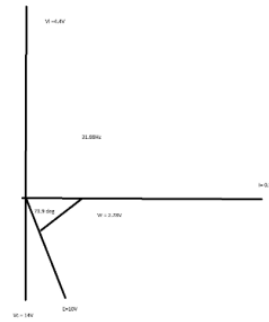


Figure 8 31.88Hz

Discussion

By providing the resonance and $\pm 25\text{Hz}$ from resonance, it gives a good understanding of how the resonance is working and how important it is in certain situations as stated earlier. At low frequencies the inductive reactance (X_L) is small whereas the capacitive reactance (X_C) is high. This results in the circuit to behave inductively. Alternatively at high frequencies the opposite happens. The inductive reactance now dominates the capacitive reactance providing the circuit to behave capacitively instead. At resonance the capacitive and inductive reactance equal each other and therefore cancelling each other out. Because of this there is only the resistive impedance. These behaviours have a direct impact on the phase angle, power factor and power distribution. The phase angle between voltage and current also changes with the frequency. At low frequencies, when the circuit is inductive, the current lags the voltage significantly. At resonance when the circuit is purely resistive, they are both in phase meaning that no lagging is occurring. At high frequencies the current will be leading the voltage providing an increase in the phase angle going the opposite direction. The power factor improvement shows more efficient energy transfer. The behaviour of real, reactive and apparent power reflects the circuit's efficiency at different frequencies. For power distribution low and high frequencies have the same affect on the circuit, where reactive power dominates which indicates a high amount of energy oscillations between the inductor and capacitor. This indicates that a high amount of power is getting wasted throughout the circuit and would not be ideal for real world circuits as you'd need to be producing much more energy than what is truly needed. The apparent power is high which also backs up this claim and is linked by the phase difference. Finding the resonance is crucial for ensuring minimal waste is occurring throughout the circuit. When the resonance frequency is being used, the current is maximized for the given voltage and the impedance is minimized and just resistive. The closer the power factor is to 1, the more of the supplied voltage is being used to turn into power. The resonance frequency represents the point of maximum power transfer to the load, aligning with the maximum power transfer theorem. The inductor and capacitor store energy in their respective magnetic and electric fields. At resonance, the energy oscillating between these components won't affect the source. This internal balance decreases the reactive power supplied from the source and therefore enhancing efficiency. Going further away from the resonance increases the balance between X_L and X_C and therefore increases the reactive power. Another benefit of keeping your circuit at resonance is the system stabilizes as the impedance becomes predictable and the phase angle minimizes. In return this reduces fluctuations in the current and voltage and therefore putting less stress on the components. This in return will allow the circuit to work for longer

and help save money. At low and high frequencies, the large phase angle results in significant reactive power, increasing the strain of the source and could lead to potential overloading or drops in voltage in practical applications.

Conclusion

The analysis of the RLC circuit has revealed how the behaviours of its resistive, inductive, and capacitive components vary with frequency. Some key observations are that impedance, power factor, and power distribution are frequency dependent. At the low end of the frequency range, the circuit is largely inductive with the current lags behind the voltage and there is a significant phase angle that results in a low power factor. At high frequencies, the circuit becomes capacitive, with the current leading the voltage and again, a poor power factor. There is a resonance at 56.88 Hz, this is the best frequency for operation. At this frequency the inductive and capacitive reactance's are equal and opposite, resulting in purely resistive impedance. This leads to maximum current flow and minimal reactive power consumption, and a power factor of 1. The power transfer is maximum at this frequency and the real power is maximum with the apparent power very close to real power. It was also found that reactive and apparent power are important to understand the energy efficiency. At the resonance energy is stored in the electrical and magnetic fields of the inductor and capacitor and hence there is minimal dependence on the source. Phasor diagrams were a useful tool to visualize the voltage-current relationships, and they are consistent with the numerical results. This session emphasizes the need for frequency control to enhance efficiency of power transmission and distribution, stability of energy supply and performance of circuits.

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

60/100

PAGE 1



Comment 1

It would
have been better if table of content in a fresh page



Comment 2

It is better to start from a fresh pages



Comment 3

Line
spacing between heading and para, between lines, between paragraphs should be
uniform.

PAGE 2



Comment 4

It is better to split them into number of paragraphs.

PAGE 3



Comment 5

caption
should be added for the figure, so the reader will get an idea about the figure



Comment 6

It would have been better the tabulation is included



Comment 7

It would have been better with more calculations.



Comment 8

caption
should be added for the figure, so the reader will get an idea about the figure



Comment 9

caption
should be added for the figure, so the reader will get an idea about the figure



Comment 10

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Comment 11

It is better to split into paragraph



Comment 12

stabilise



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Comment 14

It is
advisable to include more references from peer-reviewed journals.

PAGE 8

GRADING FORM: GRADING

RHYS JONES

60

ENGAGEMENT WITH LITERATURE

Marks will be awarded based on the extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions. You must include evidence of sources that you have discovered yourself during the course of your own student centred work.



Engagement with a wide range of literature.
Selection of relevant and credible sources. Good
use of referencing, Need improvement in
referencing and Citation. It is advisable to include
more references from peer-reviewed journals.

6

KNOWLEDGE AND UNDERSTANDING

Marks will be awarded for the depth and accuracy of understanding shown in explaining concepts, theories, and principles related to the topic. Work should reflect an understanding of the foundational principles as well as recent developments in the field. Explanations should show depth and clarity in conveying complex information.



Knowledge is reasonably extensive. Exhibits very competent critical understanding of the well-established concepts and principles of PFC in Electrical Engineering. It would have been better with more detailed explanation about PFC, maximum power transfer and energy efficiency.

19

COGNITIVE AND INTELLECTUAL

Marks will be awarded for evidence of critical thinking, logical reasoning, and analytical depth. Explaining why specific methods or approaches were chosen and how they address the problem. Evidence of synthesis and evaluation should be present, breaking down information and offering well-supported conclusions.



Sound critical evaluation and analysis of concepts. Is selective in the range of evidence used. Ability to devise arguments that show awareness of different stances. It would have been better if arguments were made with proper reference. The PF Vs capacitor value and Phase Vs PFC tables are missing. and also it would have been better with all the calculations and analysis.

17.2

PRACTICAL SKILLS

Apply relevant techniques and tools effectively, demonstrating how theoretical knowledge is translated into practice. Use simulation to address practical scenarios, with attention to how they apply in real-world contexts. Work should be well-organised, with awareness of limitations and considerations relevant to practical applications.



A very good application of a range of established methods, materials, tools and techniques. Consistent, accurate and logical application of theory to practice, making appropriate links between the two. Good use of software, however

12

it would have been better with the designed circuits and the output waveforms at different frequency.

TRANSFERABLE SKILLS FOR LIFE

Marks will be awarded for the overall quality and professionalism of the work, including organisation, coherence, and presentation. Effective communication of technical information, use of visuals, and a well-structured report, Fluency and clarity in language are essential for higher scores.



Can communicate effectively in a suitable medium for the audience, Mostly coherent, organised work, in a suitable structure and is for the most part clearly expressed. Document would have been better with proper referencing, alignment, appropriate subheading, table of content, title page and caption for figures. The ability to simulate the Electrical and Electronic circuit and the critical analysis of the collected data are evident from the report.

5.8