

Thomas Seager 2100805

by Tom Seager

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Electronics Assignment – Thomas Seager - 2100805

Abstract



In this report, a circuit analysis of an RC circuit has been performed, with an addition of a power correcting capacitor, the value  which has been calculated and implemented into the circuit. Phasor diagrams have been drawn at resonance, and varying frequencies to further show the impact of the power correcting capacitor and how this effects the power factor, resonance, and maximum power transfer of the circuit as a whole. The capacitor was calculated to be most effective at a value of 127uF, to achieve maximum power transfer and a power factor of 1, this is further detailed throughout this report.

Introduction

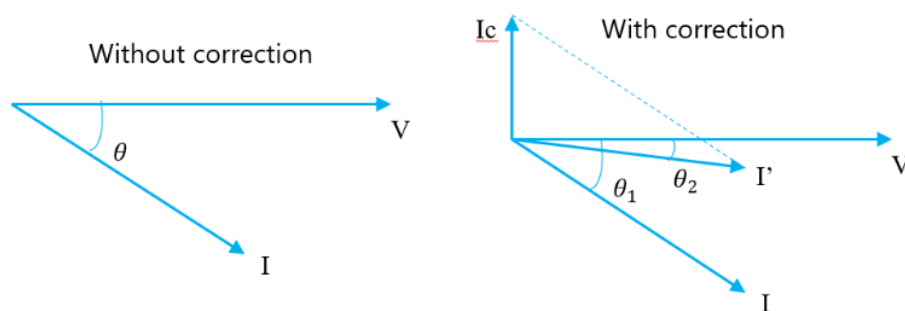
The major theme throughout this report is performance of critical analysis upon an AC RLC circuit, analysing the power factor, maximum power transfer, phase angles and optimum capacitor value to achieve this. Firstly, a capacitor stores electrical charge upon its plates and is able to charge and discharge depending on the circumstances. In this specific circuit, the role of the capacitor is to correct the power factor to 1 (or 0.95). Power factor is the ratio of active power to apparent power. Active power is the power that is useful and that can be used to power the circuit, it is also known as real power. Apparent power is the total power, this is made up of active and reactive power. Reactive power is useless power that is not wanted so this needs to be minimised to increase the power factor to as close to 1 as possible. [1]



The role of the capacitor is to increase the ratio of active power to apparent power, therefore increasing the power factor of the circuit. The capacitor does this by balancing the inductive load with the capacitive load which cancels out the extra power requirement from the supply. This essentially provides a leading current that will decrease the phase difference of the current as it pulls it closer to 0° and therefore a power factor of 1. [2]



This is best demonstrated using phasor diagrams as seen below; [3]



The phasor diagrams show the angle θ_1  significantly larger than angle θ_2 which is after the power correcting capacitor  has been added to the circuit. The leading current of the



capacitor will draw the lagging inductor current closer to V , ideally so that it is in phase but in a real life application this is incredibly difficult so above 0.95 is considered to be good.

In this report, the resonant frequency will be calculated. At resonance, X_L and X_C cancel each other out as they are equal, this leaves the circuit to act as if it has  11 short circuited with only the resistor value having any impact. As a pure resistor circuit does not have current lagging or leading voltage and is in phase, the phasor diagram will too be in phase with V and I in phase with one another.  12

The maximum power transfer is also a key aspect of this report. The maximum power transfer theorem states that "Maximum Power Transfer occurs when the resistive value of the load is equal in value to that of the voltage sources internal resistance allowing maximum power to be supplied" within the application of this specific circuit, this means that X_C and X_L again cancel out as this will be obtained at resonance. Maximum power will then be observed across the load, in this case the motor.  13

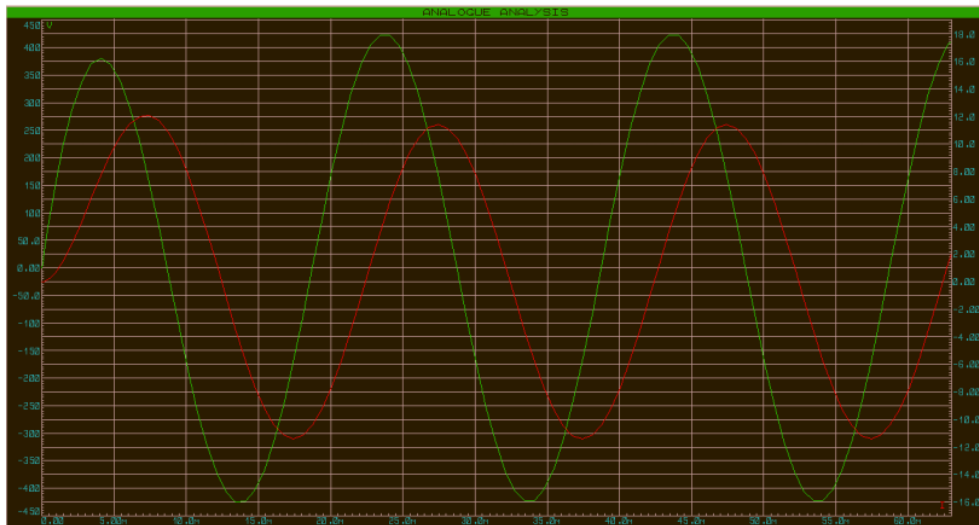
Method

Task 1

Task 1 was to plot the initial voltage and current graph for the circuit before the power correcting capacitor is added.

(1)

14



15

(2) Calculate apparent, active and reactive power.

Apparent Power;

$$S = VI$$

$$V = V_{rms} = V_m / \sqrt{2} \quad 565.7 / \sqrt{2} = 400V \quad V = 400V$$

$$I = V/R \text{ or } V/Z$$

$$Z = \sqrt{R^2 + X_L^2}$$

$$X_L = 2\pi fL$$

$$X_L = 2\pi * 50 * (108 * 10^{-6})$$

$$X_L = 33.93 \times 10^{-3}$$

$$Z = \sqrt{36^2 + 33.93^2}$$

$$Z = 49.47\Omega$$

$$I = 400 / 49.47 = 8.08A$$

$$S = VI$$

$$S = 400 \times 8.08$$

$$S = 3232\text{w}$$

$$\text{Active power} = VI \cos \phi$$

$$\phi = \tan^{-1} ((X_L - X_C) / R)$$

$$\phi = \tan^{-1} ((33.98) / 36)$$

$$\phi = 43.3^\circ$$

$$P = 400 \times 8.08 \times \cos(43.43)$$

$$P = 2352.16\text{w}$$

Reactive power

$$Q = VI \sin \phi$$

$$Q = 400 \times 8.08 \times \sin(43.3)$$

$$Q = 2216.54$$

$$\text{Check} = \text{Apparent power} = \sqrt{\text{Active}^2 + \text{Reactive}^2}$$

$$= 3232\text{w}$$

$$\text{Apparent power} = 3323\text{w}$$

$$\text{Active power} = 2352\text{w}$$

$$\text{Reactive power} = 2216.52\text{w}$$

(3)

$$\text{Power Factor} = \cos \phi$$

$$\text{Power factor} = 0.7278$$

(4) Calculate an appropriate capacitor value to obtain a power factor of >0.95

$$\phi = \tan^{-1} ((X_L - X_C) / R)$$

from testing, $X_C = 25\Omega$

$$\tan^{-1} (33.93 - 25) / 15$$

$$\cos \phi = 0.97$$

New power factor is 0.97

Capacitor value;

$$XC=25$$

$$25=1/2\pi FC$$

$$25=1/2\pi \times 50 \times C$$

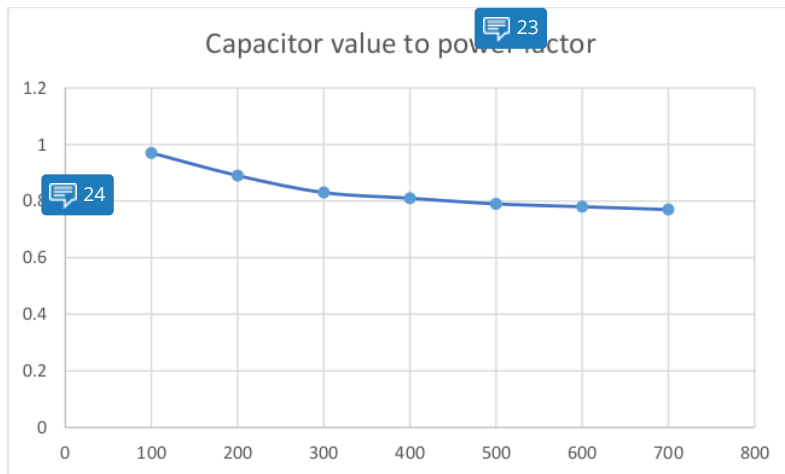
Rearrange so $C=1/2\pi \times 50 \times XC$

$$C = 1/2\pi \times 50 \times 25$$

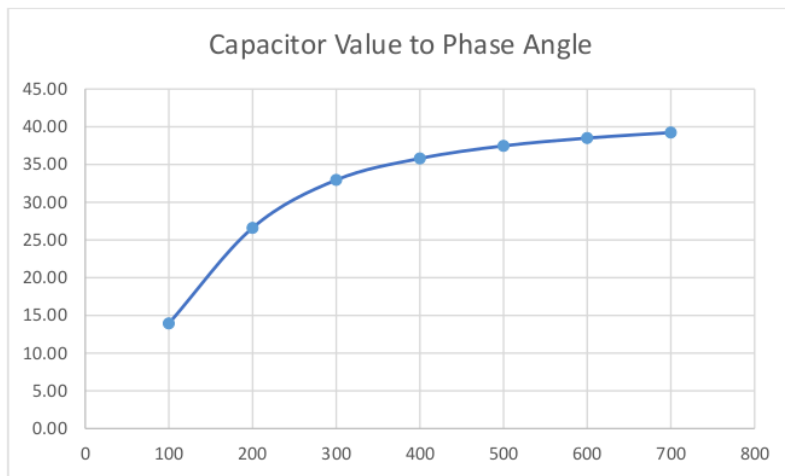
$$C=127\mu F$$

[6]

(5) plot a graph of power factor against capacitor value



(6) plot a graph of phase angle against capacitor value



Excel Spreadsheet Workings for Graphs included below.

Capacitor Value F	Capacitor Value uF	XC	Phase angle	Power Factor					
0.00010	100	31.78740583	13.93	0.97	100	XL	33.93		
0.00020	200	15.89370291	26.6	0.89	200	R	36		
0.00030	300	10.59580194	32.95	0.83	300	C	0.000127		
0.00040	400	7.946851457	35.8	0.81	400	pi	3.1459		
0.00050	500	6.357481166	37.47	0.79	500				
0.00060	600	5.297900972	38.5	0.78	600				
0.00070	700	4.541057976	39.23	0.77	700				
0.00080	800	3.973425729			800				
0.00090	900	3.531933981			900				
0.00100	1000	3.178740583			1000				

(7)

At power factors close to 1, the current and voltage waveforms are in phase with each other, which will cause the reactive power to be minimal and the active power to be maximum. In this case, the energy stored in the capacitor is relatively low because the capacitor's reactive power contribution is small. Most of the power is being used for useful work or dissipated as real or 'active' power.

In an inductor, when the power factor is close to 1, it implies that the current and voltage waveforms are again in phase. This indicates that the reactive power is minimal. However, in contrast to the capacitor, the energy stored in the inductor is relatively high. This is because the inductor's reactive power contribution is significant at power factors close to 1. The inductor stores and releases energy as the magnetic field expands and collapses, respectively, during each AC cycle.

In summary, at power factors close to 1, the energy stored in a capacitor is relatively low, while the energy stored in an inductor is relatively high. Reaching a power factor of 1 is very difficult and ear impossible to achieve in a real-life situation so power factors close to 1 are reached using the power correcting capacitor like in this example. The capacitor will decrease the phase difference between the voltage and current, decreasing the phase angle by as much as possible and as close to 0 as possible.



Results

After calculating the capacitor value, the next step was to plot phasor diagram for the current voltage at various frequencies so that they can be compared and analysed. The frequencies that have been used are 50hz, the resonant frequency which has been calculated as 36.85hz, and 25hz above and below resonant frequency.

Firstly 50hz;

For 29

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

$$X_C = \frac{1}{2 \times \pi \times 50 \times 12.7 \times 10^{-6}}$$

$$X_C = 25 \Omega$$

$$X_L = 2\pi f L$$

$$X_L = 2 \times \pi \times 50 \times 106 \times 10^{-3}$$

$$X_L = 33.93 \Omega$$

$$I_C = \frac{V}{X_C}$$

$$I_C = \frac{400}{25}$$

$$I_C = 16 A$$

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

$$I_L = \frac{400}{33.93}$$

$$I_L = 11.79 A$$

$$\sin \phi_1 = \frac{I_C}{I_L}$$

$$\sin \phi_1 = \frac{16}{11.79} = 1.357$$

$$\sin \phi_1 = 1.48 = 0.026^\circ$$

$$\cos \phi_1 = \frac{V}{I_L R}$$

$$\cos \phi_1 = \frac{400}{11.79 \times 10.78} = 3.710$$

$$\cos \phi_1 = 0.98^\circ$$

$$Z_{LR} = \sqrt{R^2 + X_L^2}$$

$$Z_{LR} = \sqrt{15^2 + 33.93^2}$$

$$Z_{LR} = 37.09 \Omega$$

$$I_{LR} = \frac{V}{Z_{LR}}$$

$$I_{LR} = \frac{400}{37.09}$$

$$I_{LR} = 10.78$$

$$I = \sqrt{(I_L \cos \phi_1)^2 + (I_L \sin \phi_1 - I_C)^2}$$

$$I = 17.92 A$$

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

$$Z = \frac{400}{17.92}$$

$$Z = 22.32 \Omega$$

$$\cos \phi = \frac{(I_L \cos \phi_1)}{I}$$

$$\cos \phi = \frac{10.78 \times \cos(37.1)}{17.92}$$

$$\cos \phi = 0.48$$

$$\phi = 0.99 \quad \cos^{-1}(0.99) = 0.81$$

Phasor Diagram

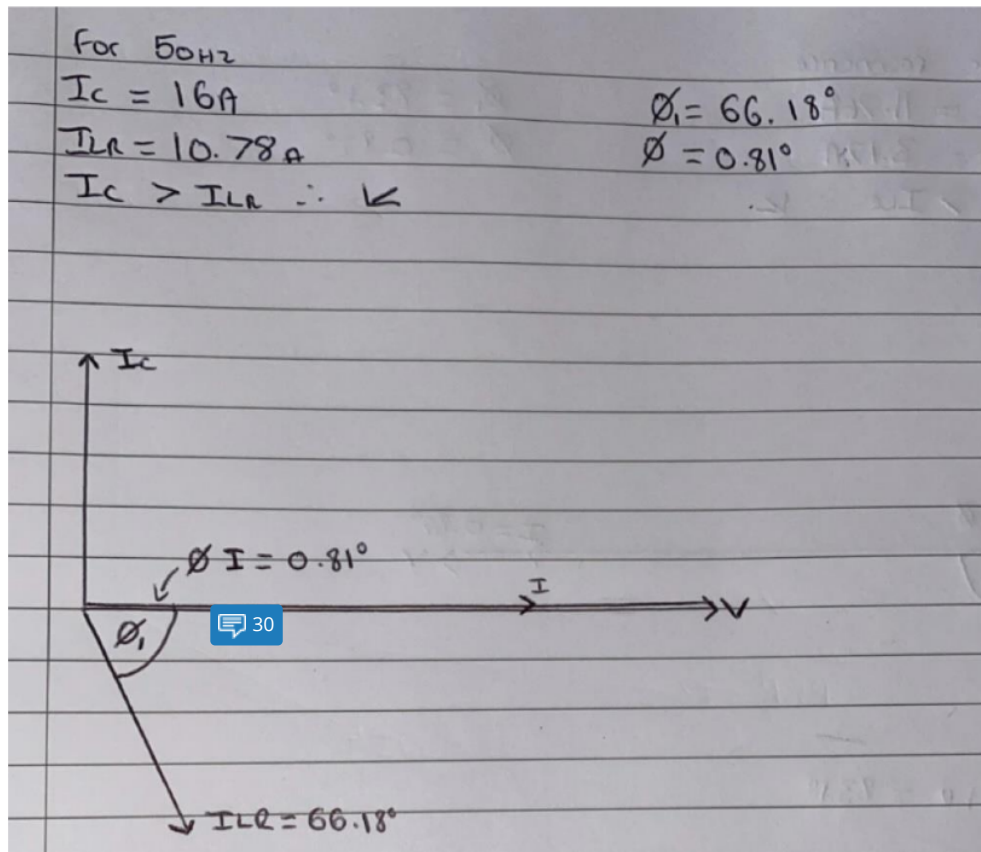
$$\phi_1 = \sin \phi_1 = \frac{X_L}{Z_{LR}}$$

$$\sin \phi_1 = 0.914$$

$$\phi_1 = \sin^{-1}(0.914)$$

$$\phi_1 = 66.18^\circ$$

Phasor Diagram



Resonant Frequency;

For Resonance

$$F_r = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

$$F_r = \frac{1}{2\pi} \sqrt{\frac{1}{63m \times 127\mu F} - \frac{15^2}{101^2 \times 10^{-3}}}$$

$$F_r = \cancel{42.355} \text{ Hz } 36.85 \text{ Hz}$$

$$X_c = \frac{1}{2\pi f c}$$

$$X_c = \frac{1}{2\pi \times 26.83 \times 127 \times 10^{-6}}$$

$$X_c = 34.00 \Omega$$

$$X_L = 2\pi f L$$

$$X_L = 2\pi \times \cancel{36.85} \times 101 \times 10^{-3}$$

$$X_L = 125.03 \Omega$$

$$I_c = \frac{V}{X_c}$$

$$I_c = \frac{400}{34}$$

$$I_c = 11.76 \text{ A}$$

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

$$I_L = \frac{400}{125.03}$$

$$I_L = 3.19 \text{ A}$$

$$\sin \phi_1 = \frac{I_c}{I_{LR}}$$

$$\sin \phi_1 = \frac{11.76}{3.17}$$

$$\sin \phi_1 = 3.71 = 0.06$$

$$\cos \phi_1 = \frac{V}{I_{LR}}$$

$$\cos \phi_1 = \frac{400}{3.17}$$

$$\cos \phi_1 = 126.18 = -0.59$$

$$Z_{LR} = \sqrt{R^2 + X_L^2}$$

$$Z_{LR} = \sqrt{15^2 + 125.03^2}$$

$$Z_{LR} = 125.93$$

$$I_{LR} = \frac{V}{Z_{LR}} = \frac{400}{125.93}$$

$$I_{LR} = 3.17 \text{ A}$$

$$I = \sqrt{I_{LR}^2 \cos^2 \phi_1 + (I_{LR} \sin \phi_1 - I_c)^2}$$

$$I = 11.49 \text{ A}$$

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

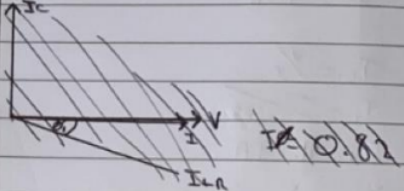
$$Z = \frac{400}{11.49}$$

$$Z = 34.81 \Omega$$

$$\cos \phi = \left(\frac{I_{LR} \times \cos \phi_1}{I} \right)$$

$$\cos \phi = \left(\frac{3.17 \times \cos \phi_1}{11.49} \right)$$

$$\cos \phi = 0.275$$

$$\phi = 0.99 \quad \cos^{-1}(0.99) = 0.82$$


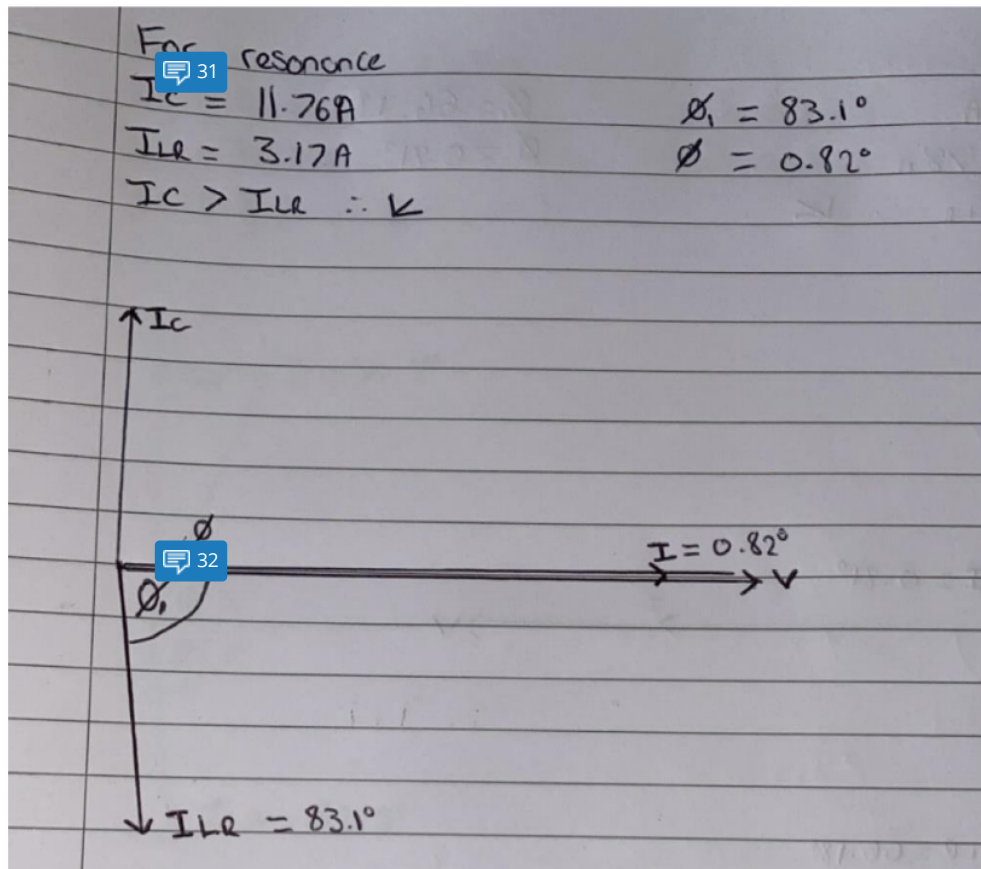
$$\phi_1 = \sin \phi_1 = \frac{X_L}{Z_{LR}}$$

$$\sin \phi_1 = 0.99$$

$$\phi = \sin^{-1}(0.99)$$

$$\phi = 83.1^\circ$$

Phasor Diagram;



Resonant Frequency -25Hz

For Resonance -25°

$$F = 36.85\text{Hz} - 25\text{Hz} = 11.85\text{Hz}$$

$$I = \sqrt{(I_{LR} \cos \phi_1)^2 + (I_{LR} \sin \phi_1 \sim I_C)^2}$$

$$I = 22.77\text{A}$$

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

$$Z = \frac{400}{22.77}$$

$$Z = 17.56\Omega$$

$$X_C = \frac{1}{2\pi FC}$$

$$X_C = \frac{1}{2\pi \times 11.85 \times 127 \times 10^{-6}}$$

$$X_C = 105.75\Omega$$

$$I_C = \frac{V}{X_C}$$

$$I_C = \frac{400}{105.75}$$

$$I_C = 3.78\text{A}$$

$$X_L = 2\pi FL$$

$$X_L = 2\pi \times 11.85 \times 108 \times 10^{-3}$$

$$X_L = 8.04\Omega$$

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

$$I_L = \frac{400}{8.04}$$

$$I_L = 3.19\text{A}$$

$$\sin \phi_1 = \frac{I_C}{I_{LR}}$$

$$\sin \phi_1 = \frac{3.78}{23.5}$$

$$\sin \phi_1 = 0.16$$

$$\cos \phi_1 = \frac{V}{I_{LR}}$$

$$\cos \phi_1 = \frac{400}{23.5}$$

$$\cos \phi_1 = 17.02$$

$$Z_{LR} = \sqrt{R^2 + X_L^2}$$

$$Z_{LR} = \sqrt{15^2 + 8.04^2}$$

$$Z_{LR} = 17.01\Omega$$

$$I_{LR} = \frac{V}{Z_{LR}}$$

$$I_{LR} = \frac{400}{17.01}$$

$$I_{LR} = 23.50\text{A}$$

$$\cos \phi = \frac{(I_{LR} \times \cos \phi_1)}{I}$$

$$\cos \phi = \frac{(23.5 \times \cos(17.01))}{22.77}$$

$$\cos \phi = 0.986$$

$$\phi = 9.29^\circ$$

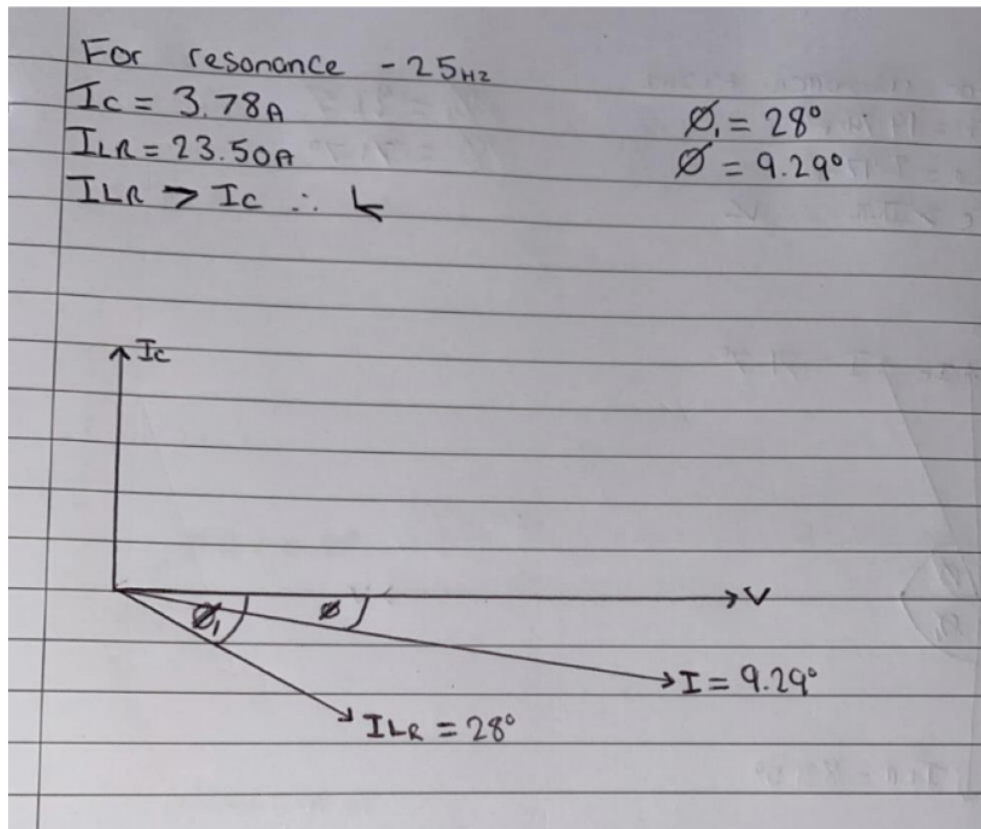
$$\phi_1 = \sin \phi_1 = \frac{X_L}{Z_{LR}}$$

$$\sin \phi_1 = 0.47$$

$$\phi = \sin^{-1}(0.47)$$

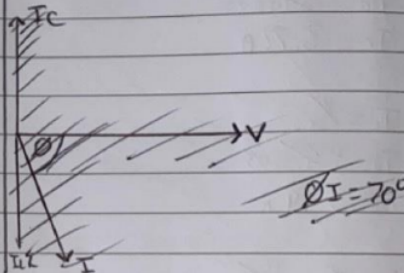
$$\phi = 28^\circ$$

Phasor Diagram;



Resonant Frequency +25Hz;

For resonance +25°	
$F = 36.85 + 25^\circ = 61.85^\circ$	$I = \sqrt{(I_{Lr} \cos \phi)^2 + (I_{Lr} \sin \phi + I_c)^2}$
	$I = 20.42$
$X_c = \frac{1}{2\pi FC}$	$Z = \frac{V}{I}$
$X_c = \frac{1}{2\pi \times 61.85 \times 12.7 \times 10^{-6}}$	$Z = \frac{400}{20.42}$
$X_c = 20.26 \Omega$	$Z = 19.59 \Omega$
$X_L = 2\pi FL$	$\cos \phi = \left(\frac{I_{Lr} \times \cos \phi}{I} \right)$
$X_L = 2\pi \times 61.85 \times 10.8 \times 10^{-3}$	$\cos \phi = \left(\frac{9.97 \times \cos \phi}{20.42} \right)$
$X_L = 41.97 \Omega$	$\cos \phi = 0.31$
$I_c = \frac{V}{X_c}$	$\phi = 71.7^\circ$
$I_c = \frac{400}{20.26}$	
$I_c = 19.74 A$	
$I_L = \frac{V}{X_L}$	
$I_L = \frac{400}{41.97}$	
$I_L = 9.53 A$	
$\sin \phi_1 = \frac{I_c}{I_{Lr}}$	
$\sin \phi_1 = \frac{19.74}{9.97}$	
$\sin \phi_1 = 2.2$	
$\cos \phi_1 = \frac{V}{I_{Lr}}$	
$\cos \phi_1 = \frac{400}{8.97}$	
$\cos \phi_1 = 44.59$	
$Z_{Lr} = \sqrt{R^2 + X_L^2}$	
$Z_{Lr} = \sqrt{15^2 + 41.97^2}$	
$Z_{Lr} = 44.57 \Omega$	
$I_{Lr} = \frac{V}{Z_{Lr}}$	
$I_{Lr} = \frac{400}{44.57}$	
$I_{Lr} = 8.97 A$	



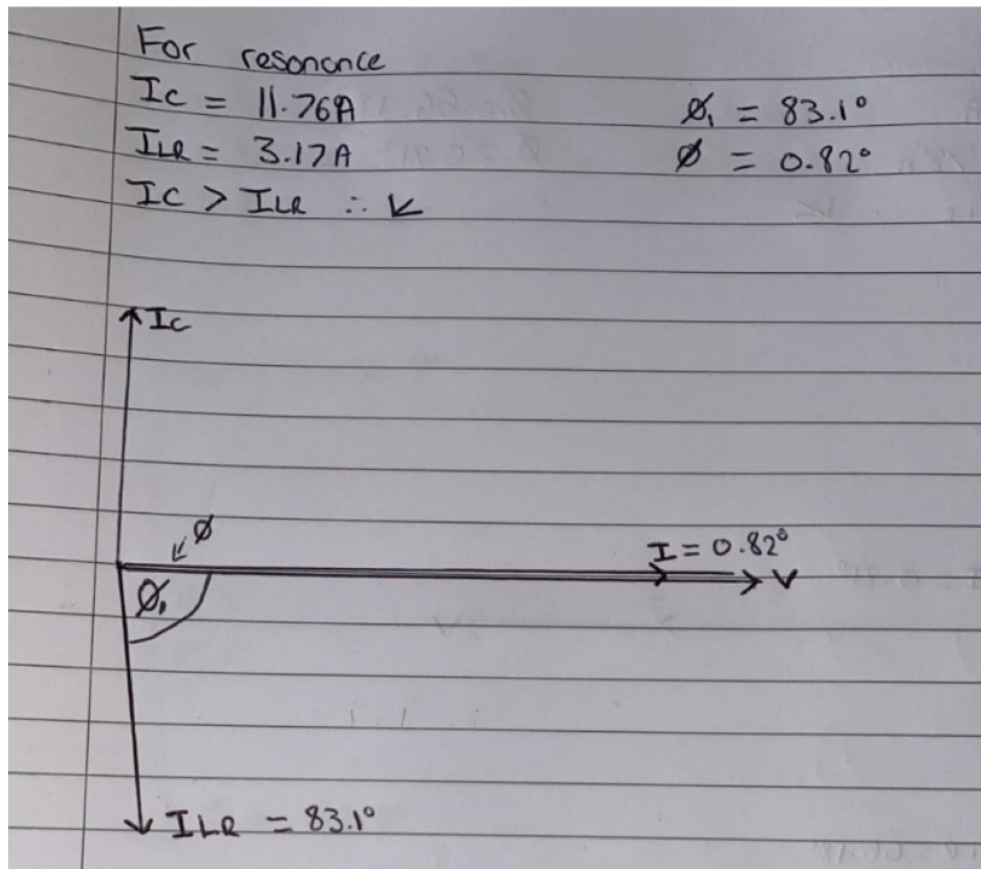
$$\phi_1 = \sin \phi_1 = \frac{X_L}{Z_{Lr}}$$

$$\sin \phi_1 = 0.99$$

$$\phi = \sin^{-1}(0.99)$$

$$\phi = 0.82$$

Phasor Diagram;



Discussion

From the calculations, phasor diagrams and analysis of the circuit and its functions, it is clear that the power correcting capacitor makes a significant difference to the power factor of the circuit. The phase angle of the circuit with the power correcting capacitor is less than 1° and gives a power factor above 0.95 as specified in the brief. This shows that the value of $127\mu\text{F}$ is accurate as it successfully corrects the power factor and makes the whole circuit more efficient as the ratio of active to reactive power is greatly increased.



The phasor diagrams contribute further to suggest that the power correcting capacitor significantly improves the circuit's efficiency as the phase angle is less than one, similarly at resonant frequency the angle is less than one, this is further proof that the calculated capacitor value is a success. The phasor diagrams at -25Hz and $+25\text{Hz}$ from the resonant frequency show that the current now leads the voltage, by a significant phase difference which is not a positive chance, leading to a higher percentage of reactive power from the apparent power total. A power factor close to 1 is not directly related to resonance in an AC circuit, the power factor is a measure of how effectively a circuit utilizes the real power and is defined as the ratio of real power to apparent power. A power factor close to 1 indicates efficient utilization of power, with minimal reactive power flow, which is again achieved with the use of the power correcting capacitor in this instance, achieving a power factor of 0.97.

With a power factor of 0.97, the circuit operates similarly to when it is at resonance, this is because the current and the voltage are almost in phase and have very little phase difference, represented by the phase angle. In this case less than 1 degree. Another factor to consider is the maximum power transfer of the circuit, which is also affected by the power factor as there is a higher ratio of active to reactive power the higher the power factor is, meaning that more power is transferred to the load.

When the circuit is operating at resonant frequency, $X_L = X_C$ therefore they essentially cancel each other out. This means that the circuit is now operating like a pure resistor circuit where the current and voltage are in phase with one another. When the current and voltage are in phase, the circuit is operating at maximum power as the apparent power is equal to the active power and therefore maximum power is transferred to the load.

Resonance, on the other hand, occurs in circuits containing inductors and capacitors when the natural frequency of the circuit matches the applied frequency. At resonance, the reactive components (inductor and capacitor) exchange energy back and forth, resulting in high currents and voltages across these elements.

When a circuit is operating at resonance, the power factor may not necessarily be close to 1. In fact, at resonance, the power factor tends to decrease significantly due to the high reactive power exchanged between the inductor and capacitor.

The relationship between power factor and resonance can be explained as follows: At resonance, the circuit draws a large amount of reactive power, leading to an increase in the

apparent power. Since power factor is the ratio of real power to apparent power, the power factor decreases when the reactive power component becomes significant.

It's worth noting that resonance can occur at any power factor, including a power factor close to 1. However, the focus of a power factor close to 1 is primarily on efficient utilization of power, while resonance relates to the behaviour of the circuit at specific frequencies.

In an AC circuit, the power factor is defined as the ratio of real power (which is the power that is actually used to do useful work) to apparent power (which is the product of voltage and current). A power factor close to 1 indicates that the current and voltage waveforms are in phase, meaning that the reactive power contribution is minimal.

Assuming the load is purely resistive, the power factor will be close to 1 when the resistance of the load matches the resistance of the circuit (including the source and the connecting wires). In this case, the circuit is said to be "matched," and the maximum power is transferred from the source to the load.

If the load resistance is lower or higher than the circuit resistance, the power factor will be less than 1, and the circuit will not be operating at its maximum power transfer capacity. This is because some of the apparent power will be dissipated as reactive power, which does not contribute to useful work.

In summary, a power factor close to 1 indicates that the circuit is operating at its maximum power transfer capacity, and the circuit is delivering maximum power to the load.

Conclusion



In conclusion to the calculations performed on the circuit, the analysis of results and graphs produced, some key points have been identified. The calculation performed on the circuit showed that the ideal power correcting capacitor value is 127 μ F, as this results in a power factor of 0.97, which is above the 0.95 specification.

The next calculation was the apparent, active and reactive power, this was done to then calculate the power factor before correction so that it could be improved to a rating of 0.95 or above. The findings were;

- Apparent power – 3232w
- Active power – 2352.16w
- Reactive power – 2216.56w

Following this, the power correcting capacitor value could be calculated, this resulted in a 127 μ F capacitor being used and connected in parallel with the RL branch of the circuit. This then allowed for graphs to be plotted, from which it can be concluded that the phase angle and capacitor had a positive correlation whereas the capacitor value to power factor had a negative correlation.

Finally, it can be concluded from this report that the power transfer to the load is at its maximum at resonance, when the voltage and current are in phase, as shown by the phasor diagrams, additionally that the energy stored in the capacitor and inductor at a power factor of one will be equal, therefore giving $X_L = X_C$ and causing the circuit to operating like a pure resistor circuit where V and I are in phase, and maximum power transfer is obtained.

References



- [1] P. Evans, "TheEngineeringMindset," 18 11 2018. [Online]. Available: <https://theengineeringmindset.com/power-factor-explained/>. [Accessed 10 05 2023].
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FINAL GRADE

50/100

GENERAL COMMENTS

Instructor

Engagement with Literature Skills: *Marks: 4/10*

Engagement with a limited range of mostly relevant and credible sources. Some omissions and minor errors. It is better to have reference from reputable academic publishers and articles from peer reviewed journals.

Knowledge and Understanding Skills: *Marks: 22/30*

Good knowledge and understanding of the main concepts and key theories of RLC circuit. It is evident that the author has the ability to design RLC circuits and determine a range of values using the basic theories.

Cognitive and Intellectual Skills: *Marks: 13/30*

Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. Some valid conclusions. The interpretation of key data's are missing in certain areas of the report.

Practical Application Skills: *Marks : 6/20*

Limited use of established methods, tools and/or techniques. Little appreciation of the context of the application. Limited understanding of the application of theory to practice or making appropriate links between the two. The simulation results are missing in the report.

Transferable Skills for Life and Professional Practice: *Marks : 5/10*

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.

Total: 50/100

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It is better to have a table of content



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Good abstract



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Is it RLC or RC



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The reference should be included before the full stop.



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The reference should be included before the full stop.



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PAGE 3



Comment 14

It is better to include a screenshot of the designed circuit,.



Comment 15

Pictures, should be named and numbered

PAGE 4



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Use appropriate font as mentioned in the university guideline.



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degree



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Unit is missing



Comment 19

Active power square



Comment 20

Use appropriate tool form MS word to type the equation.



Comment 21

Pictures and screenshots of the circuit design and the simulation result after power factor correction has no been included.

PAGE 5



Comment 22

It is better to differentiate X and Multiplication symbol. Make it clear for your reader and remove any ambiguity

PAGE 6



Comment 23

Although the graph is there, you should also explain the shape of the curve and any key points



Comment 24

The range of values of capacitor chosen for plotting graph is not enough. The graph should clearly show the capacitor value at which the power factor is maximum.



Comment 25

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.



Comment 26

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.



Comment 27

The tabulated values are not clear

PAGE 7



Comment 28

degree



Comment 29

The calculations should have been done in the word document.



Comment 30

Phasor diagram should have been drawn in word document



Comment 31

Phasor diagram should have been drawn in a word document



Comment 32

A brief description about the calculated results and the plotted graph should have been provided.



Comment 33

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



Comment 34

Good Work



Comment 35

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.