

sean upton course work

by Sean Upton

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Abstract



The task outlined is to improve the power factor of an AC inductor circuit by introducing a power factor correction capacitor and achieving a minimum power factor of 0.95. The report gives a brief overview of the principles of an AC RLC circuit function, it highlights the effects of different capacitor values and different frequencies has on the power factor. The goal was to minimize reactive power in the circuit and the report shows how this was achieved. The report touches on how the power factor correction capacitor affects the resonance of the circuit, max power transfer and energy efficacy. The power factor went from 0.75 to 0.99 at resonance frequency thus reducing reactive power.

Introduction

Alternating current (AC) is a form of electrical current which fluctuates periodically between – and + values. The rate of fluctuation is known as the frequency, the higher the frequency means a faster fluctuation, the unit measuring this is hertz (Hz). There are three types of power that can be measured in an electrical circuit. The first is apparent power, this is the amount of power perceived to be being used by the circuit, although not all of this will be useful. Useful power is known as active power, and useless power is known as reactive power. [1] [2]



In an AC circuit you will ideally have current and voltage alternating in phase which result in maximum efficiency. but this will never be the case. Due to factors which we will discuss you will suffer losses. When designing circuits, you must consider the components values, frequency, voltage and current to ensure that you have minimal reactive power and maximum reactive power.

In an AC circuit components can be split into three sections; a resistive load, an inductive load and a capacitive load. These loads will influence the phase of the current the current. If you have a circuit with only a resistive load the current and the voltage will remain in phase. A capacitive load will result in the current leading the voltage and an inductive load will result the current lagging the voltage, this will result in an increase in reactive power. Leading and lagging creates losses as [3]



The avoid these losses power factor correction needs to be complete. Power factor relates to the types of power that we mentioned earlier. Theoretically the maximum power factor value is 1 but this will never be achieved in practice. The power factor of a circuit needs to be as close to 1 as possible to ensure that there is minimal reactive power. If you have an inductive load in an AC circuit, you will need to have a capacitor to bring the current back in phase with the voltage. The power factor is equal to $\cos(\theta)$, with θ being the time difference in the two waveforms divided by the time period.



Method 6

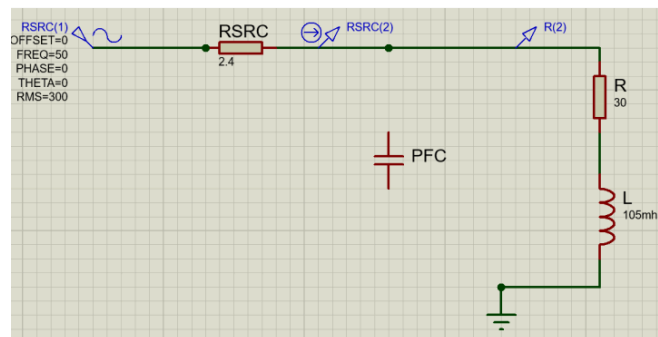


Image 1.0

Image 1.0 above shows an RLC circuit without a value for the power factor correction capacitor (PFC). The power factor will depend on the value of this capacitor, it is known that a power factor of ≥ 0.95 is required. Image 1.1 shows the current indicated by the red waveform, and voltage indicated by the green. The current is lagging the voltage which is what you will expect from an AC inductor circuit.

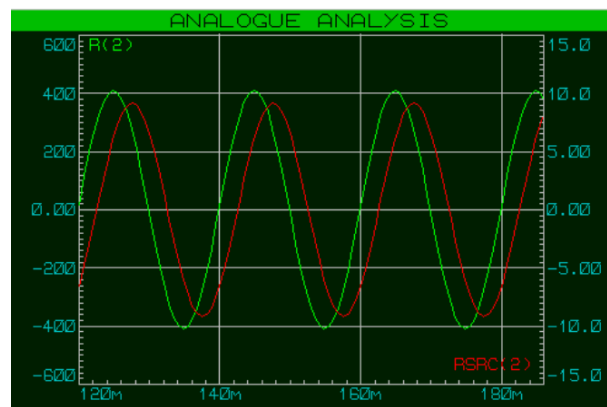


Image 1.1

Before calculating the PFC, the phase difference should be calculated, to find this you must find the time difference (t) and time period (T). Time difference can be found by looking at the time where both waves start at 0 volts and taking the difference.

$$62.54 - 59.87 = 2.67ms$$

And the time period if the time taken for a full wave to be complete, we are using a 50 Hz supply so this will be 20ms. To ensure that this was correct values were taken from the waveform.

$$79.87 - 59.88 = 20ms$$

Using the formula $\Phi = t / T \times 360$ it was determined that the phase angle is 48.06° .

$$(2.67/20) \times 360 = 48.06$$

The power factor could then be calculated using $PF = \cos(\Phi)$ to give a power factor of 0.75.

$$\cos(48.06) = 0.75$$

active power (P), reactive power (Q) and apparent power (S) are also required, these are given by the following formulas.

$$S = VI$$

$$Q = VI \sin(\Phi)$$

$$P = VI \cos(\Phi)$$

It's stated the VRMS is 300, and IRMS which can be found using $I_m / \sqrt{2} = I_{RMS}$. It is shown on the graph I_m is 9.15 and can be subbed into the equation to give IRMS.

$$9.15 / \sqrt{2} = 6.47 I_{RMS}$$

We can now find S, Q, P

$$S = 300 \times 6.47 = 1941VA \quad s = 300 \times 6.47 = 1941VA$$

$$Q = 1941 \times \sin(48.06) = 1443.8VAK$$

$$P = 1941 \times \cos(48.06) = 1297.3watts$$



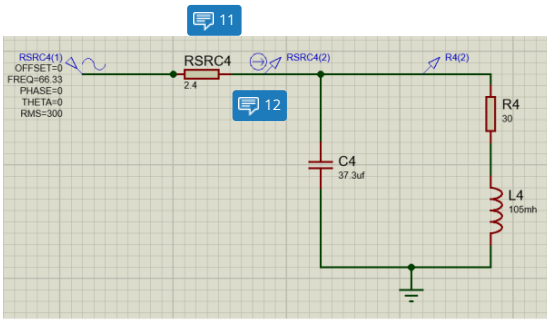
$$\begin{aligned} VL Rrms &= \frac{409}{\sqrt{2}} = 289.2 \\ IL Rrms &= 4.47 \\ \emptyset &= \cos^{-1}(0.95) = 18.2^\circ \end{aligned}$$

$$ILR_{rms} = 4.47$$

Diagram illustrating a 3D coordinate system with axes IC, IL, and 300RMS. A vector is shown in the IC-IL plane, with an angle of 18.2 degrees from the IC axis and 48.06 degrees from the IL axis. Another vector is shown in the 300RMS-IL plane, with an angle of ILR=6 degrees from the IL axis.

it balances out. $\frac{1}{2\pi} \times \sqrt{\frac{1}{37.7 \times 10^{-6} \times 105 \times 10^{-3}} - \frac{30^2}{(105 \times 10^{-3})^2}} = 66.33 \text{hz}$

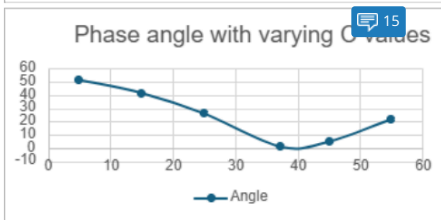
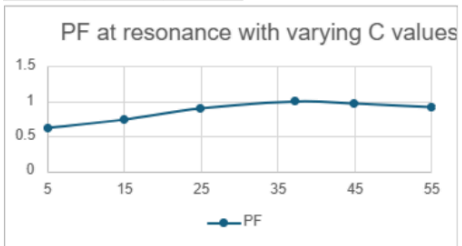
Using the resonance frequency and capacitor value we can build a complete circuit



To assess the new power factor simulations were undertaken.

at 66.33hz

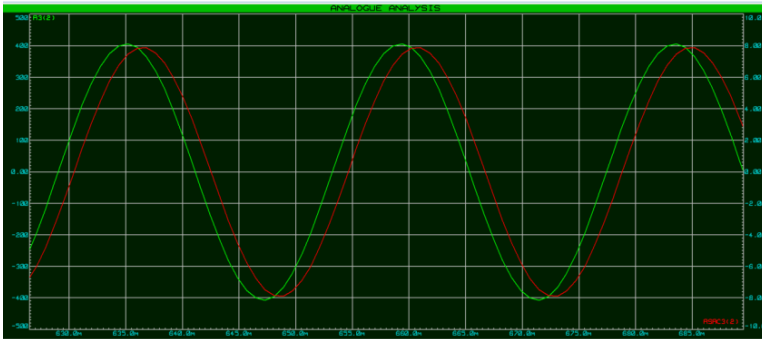
C(uf)	PF	angle
5	0.62	51.6
15	0.74	41.6
25	0.9	26.05
37.3	0.998	0.84
45	0.97	4.78
55	0.92	21.75



As the power factor approaches 1 both the capacitor and inductor reach points where they are having a minimal effect in the phase of the current. The reactance of both components is being minimized. The capacitor stores its energy in an electric field whereas the inductor stores a magnetic field. As the power factor approaches 1 it means that the energy stored is being better used as real power rather than reactive power.

Results (200 Words)

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$$I_C = 2.78A$$

17

$$I_{LR} = 7.1A$$

18

$$V = 300V$$

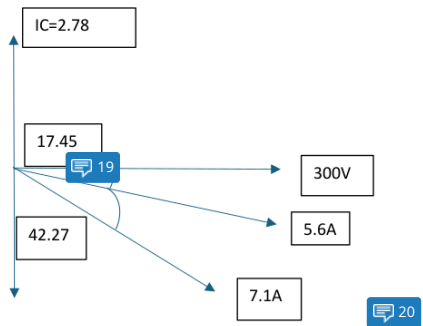
$$\phi_1 = 42.27^\circ$$

$$\phi = 21^\circ$$

$$I = 5.6A$$

$$IP = 7.9$$

$$I_{rms} = \frac{7.9}{\sqrt{2}} = 5.6$$



With the frequency at 41.33hz the current is lagging the voltage showing that it is an inductive circuit. The power factor in this case would be 0.96, this is above the required value and a good power factor.

Resonance



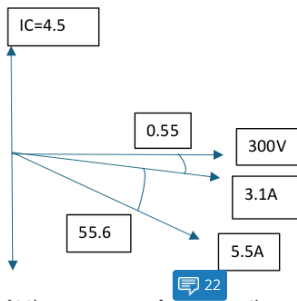
$$I_C = 4.5A$$

$$ILR = 5.5$$

$$V = 300V$$

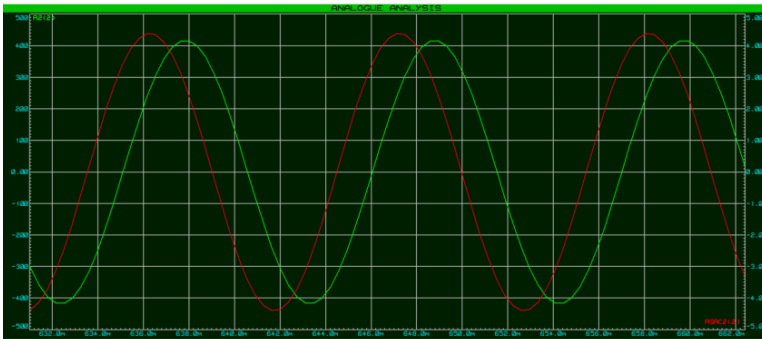
$$\phi = 0.55$$

$$I = 3.1A$$



At the resonance frequency the current marginally lags the voltage but as previously mentioned a power factor of 1 cannot be achieved.

25 above



$$IC = 6.3$$

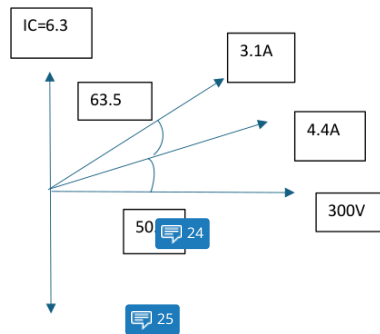
$$ILR = 4.4$$

$$V = 300V$$

$$\phi_1 = 63.5$$

$$\phi = 50.7$$

$$I = 3.1$$



When the frequency is 91.33 the current is now leading the voltage by 50.7 which is larger than acceptable and results in a power factor of 0.63. this is now a capacitive circuit

50hz



$$IC = 3.39$$

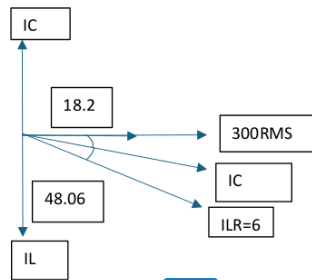
$$ILR = 6.47$$

$$V = 300V$$

$$\phi_1 = 48.06$$

$$\phi = 18.2$$

$$I = 4.32$$



At 50hz the current lags the voltage by 18.2 degrees which gives a 0.95 power factor which is an acceptable value.

Discussion

In task 1 it was calculated that to achieve a power factor of 0.95, the power factor correction capacitor needed to be 37.3uF.

The resonance of an electronic circuit relates to the frequency where the impedance of the capacitor and inductor have the same value. This results in the current and voltage being in phase. At lower frequencies the inductor has a low impedance, and the capacitor will have a high impedance resulting in the voltage lagging the current. As you increase the frequency the impedance in the inductor increases and, in the capacitor, it decreases. This would cause the voltage to lead the current. So, if the correct frequency is applied the impedance will be equal in both components and thus having voltage and current in phase. [5]

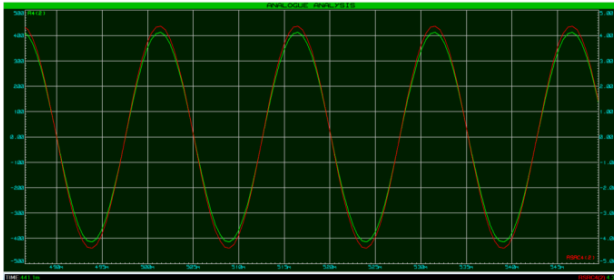
It was calculated for the circuit that the resonance frequency is 66.33hz to find this the formular

$$\frac{1}{2\pi\sqrt{\frac{1}{L^2} - \frac{1}{C^2}}} = f_r$$

the values from the circuit can then be subbed into the formular to give

$$\frac{1}{2\pi\sqrt{\frac{1}{(37.7 \times 10^{-6}) \times (105 \times 10^{-3})} - \frac{30^2}{(105 \times 10^{-3})^2}}} = 66.33$$

Simulating the circuit, the current and voltage look to be in phase at resonance



When looking closely at the waveform there is a marginal difference in the phases due to the power factor being 0.95. as shown in the image below the voltage is slightly leading the current.



As a result of the power factor being 0.95 there will not be maximum power transferred and there will be some reactive power which is wasted. It is impossible to avoid having any reactive power as a power factor of 1 can never be achieved. Max power transfer theorem states that for max power to be transferred to the load, the load resistance

must be the same as the internal resistance of the circuit. As you approach a power factor of 1 the current and voltage are approaching being in phase. This results in an increase in usable power and a decrease in reactive power. [6]

As previously mentioned, there are three types of power that should be assessed when analyzing energy efficiency, apparent, reactive and active power. Before any power factor correction is applied the power factor was 0.75, this is a low power factor and will result in poor efficiency. With the power factor being 0.75 the power was calculated to be as follows.

$$S = 300 \times 6.47 = 1941 \text{ VA} = 300 \times 6.47 = 1941 \text{ VA}$$

$$Q = 1941 \times \sin(48.06) = 1443.8 \text{ VAK}$$

$$P = 1941 \times \cos(48.06) = 1297.3 \text{ watts}$$

With the power factor correction capacitor, the power factor was brought up to 0.95 when at 50hz, this then improves the efficiency

$$I_{RMS} = \frac{6.45}{\sqrt{2}} = 4.56$$

$$S = 300 \times 4.56 = 1368 \text{ VA}$$

$$Q = 1368 \times \sin(18.2) = 427.27 \text{ VAK}$$

$$P = 1368 \times \cos(18.2) = 1299.56 \text{ Watts}$$

30

Comparing the reactive power from before power factor correction and after, it can be seen that after power factor correction is applied the reactive power decreases. This shows that the circuit has now become more energy efficient.

Conclusion

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The brief outlined that an appropriate capacitor value for the power factor correction capacitor must be calculated to achieve a minimum power factor of 0.95. The circuit was an RLC circuit with a known inductor and resistor value, using this alongside the voltage and an assumed frequency of 50hz it was calculated that the PFC would be 66.33hz. And this met the criteria of needed the PF to be 0.95. By changing the frequency the efficiency could be increased, this is the resonance frequency where the reactive power of both components is at its minimum. Finding this allowed the power factor to be 0.99. having a high power factor results in minimal losses in the form of

reactive power. The use of simulations gave a digital representation of how different capacitor values and different frequencies affect the PF furthering the readers understanding of the factors that play a role in how they affect the power factor.

33 32

[1]

E. Odunlade, "AC Circuit Theory: Introduction, AC Generation, AC vs DC & Transformers," *circuitdigest.com*, Jan. 24, 2018. <https://circuitdigest.com/tutorial/ac-circuit-theory> (accessed Dec. 13, 2024).

[2]

Matan, "What is the difference between real power, reactive power, and apparent power?," *Electricity - Magnetism*, Jun. 11, 2023. <https://www.electricity-magnetism.org/what-is-the-difference-between-real-power-reactive-power-and-apparent-power/> (accessed Dec. 13, 2024).

[3]

"Series RLC Circuit and RLC Series Circuit Analysis," *Basic Electronics Tutorials*, Jun. 25, 2013. <https://www.electronics-tutorials.ws/ac/circuits/series-circuit.html> (accessed Dec. 01, 2024).

[4]

"Power Factor Correction: What is it? (Formula, Circuit & Capacitor Banks) | Electrical4U," <https://www.electrical4u.com/>, Jun. 05, 2024. <https://www.electrical4u.com/power-factor-correction/> (accessed Dec. 14, 2024).

[5]

S. Bhuyan, "RLC Circuit: Definition, Equations, and Resonance," *Science Facts*, Oct. 2024. <https://www.sciencefacts.net/rlc-circuit.html> (accessed Dec. 15, 2024).

[6]

"Maximum Power Transfer Theorem - Statement, Proof & Solved Examples," *GeeksforGeeks*, Nov. 01, 2023. <https://www.geeksforgeeks.org/maximum-power-transfer-theorem/> (accessed Dec. 15, 2024).

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Line
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Comment 31

Good work



Comment 32

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



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Reference

GRADING FORM: GRADING

SEAN UPTON

70.70

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.



Excellent, detailed knowledge and highly critical
understanding of the well-established concepts
and principles of Electrical Engineering in Power
factor correction. It would have been better if
more information's were provided about theory
behind PFC with appropriate referencing.

22.2

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.



Excellent critical evaluation and analysis of concepts and principles of Electrical Engineering leading to logical, evidence-based, reasoned arguments and judgements. It would have been better with more detailed interpretation of obtained data.

22.5

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.



An advanced application of a range of established methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Consistent, accurate and logical application of theory to practice, making well-developed links between the two.

15

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