

Electrical_A1_By_KM_ID1804424 _Final

by Krzysztof Sylwester Matela

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15/05/2021



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2020/2021

Electrical Engineering
Assignment
HND Electrical & Electronic Engineering Course
UWTSD

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15/05/2021

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1. Abstract

This paper contains investigation of complications of having a reactive circuit on power consumption. Starts from clearing basic terminology such as reactance and impedance, as properties of linear devices. Next sections display the concept of complex numbers and their usefulness in theory of an AC circuit.

Next sections involve exemplar application of theory by performing an analysis on a parallel RLC circuit with the values for it coming from my student number. The analysis included current and voltage drops across components; and power factor against frequency. Each graph was done in frequency domain on a logarithmic scale. Additionally, 3 phasor diagrams will show the angle of voltage to current in that circuit.

Last task will show the required impedance to achieve maximum power transfer for a described inductive power source and its visualization behind a 3D graph.

2. Introduction

2.1. Impedance and reactance

Capacitors and inductors are known as linear devices which means that this device has the ability to output a signal proportional to that of an input waveform. The output often has a change in amplitude and phase but never the frequency [1].

A typical resistor, has the property called *resistivity* and it generally defines that the voltages and currents are always in phase however, the linear devices have similar property called *reactance* and it behaves like a frequency depended resistance. The combination of both resistivity and reactance is called *impedance* [1].

The capacitors on their own have the ability to store a charge within internal electric field and it does it by applying positive voltage to one side which cannot go through because of an isolation. The positive voltage building up on one conductive plate will result in negative charge building up on opposite plate [2]. The charging property of a capacitor in purely capacitive circuit with an AC power source circuit results in current leading the voltage by 90° [3].

The linear property is best visualized using frequency domain graph which shows voltage drop in a circuit:

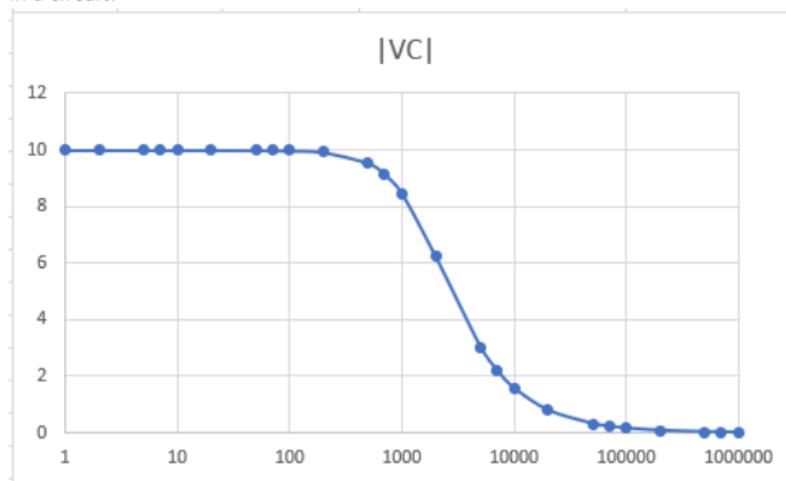


Figure 1. Voltage across capacitor against frequency in RC circuit

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This graph shows that the voltage across capacitor decreases as the frequency rises and maintain linear attenuation for a range of about 1kHz to about 10kHz

The principle of operation for an inductor is very similar to a capacitor but opposite. In capacitors, the rate of voltage change is proportional to the current through it and, for inductors, the rate of current change is proportional to the voltage across it. So, applying voltage to an inductor will cause a current to rise, unlike in capacitors where applying current will cause voltage to rise [4].

Using same form of frequency analysis for a RL circuit a following graph was produced:

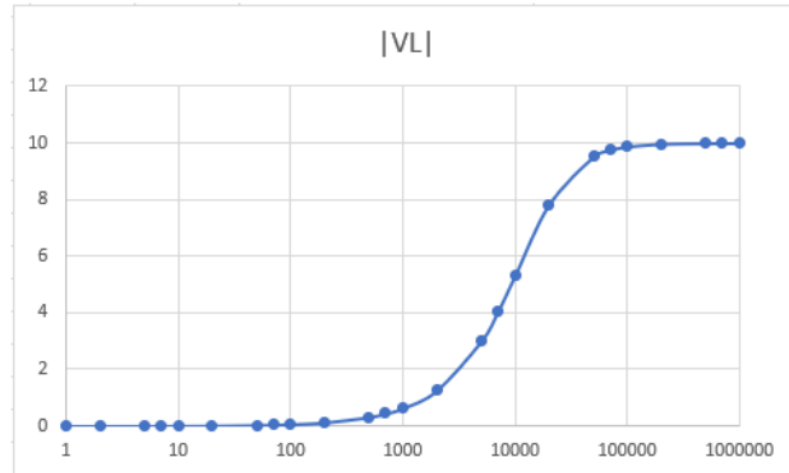


Figure 2. Voltage across inductor against frequency in RL circuit

This graph shows how the voltage across inductor rises up with the frequency applied.

The inductive and capacitive properties together produce in RLC circuit produce:

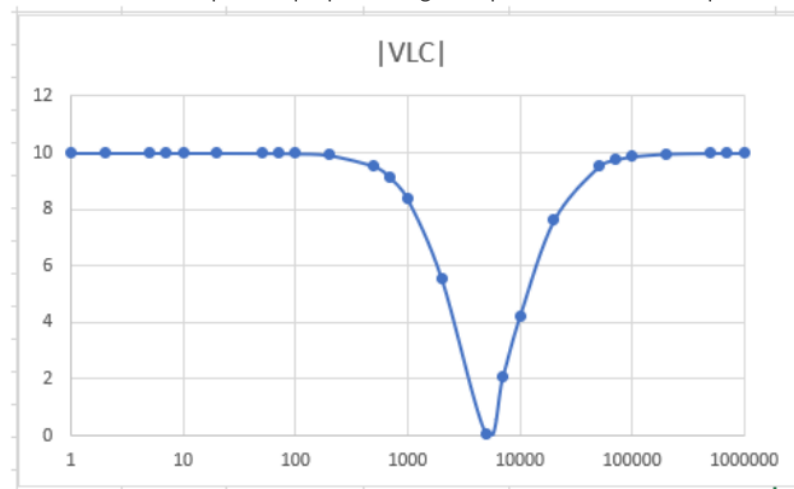


Figure 3. Voltage across LC network in series against frequency in RLC circuit

This graph shows how the two slopes meet creating a slope for bandwidth of frequencies.

2.2. Power Factor

The power factor is important in industrial sectors where inductive loads are common and heavy. The electrical distribution companies actually bill industrial users with the poor power factor as it costs them in heating resistance of transformers generators and wirings [5].

The power delivered to the circuit is generally defined by a product of voltage and current but for reactive circuits V and I is not proportional and are generally defined as complex RMS amplitudes (see 2.4. Formulas) [5].

2.3. Complex numbers

The complex numbers are made out of two parts, the *real* part and *imaginary*. The imaginary number contains algebraic component $\sqrt{-1}$ which can't exactly be solved and it is denoted in engineering as " j ". The individual parts of a complex number can be used as a vector points to plot them on a graph:

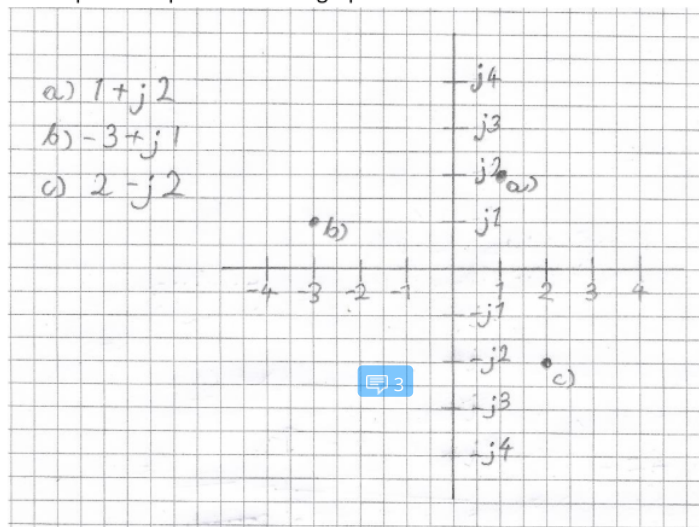


Figure 4. Complex numbers on a vector graph

This figure shows an example of how complex numbers can be visualized on a graph. In the theory of an AC circuit, the total impedance takes the form of a complex number where resistance is *real* and reactance is *imaginary* and this gives an ability to take into account the phase of a signal in theory using θ :

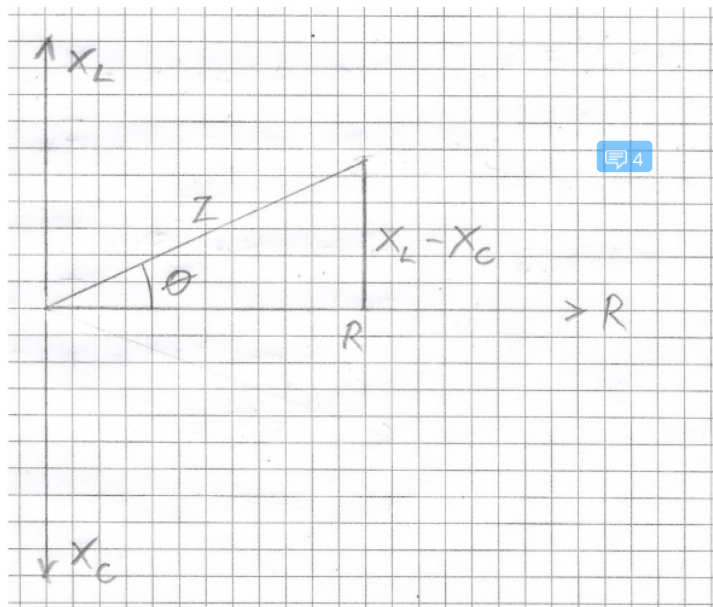


Figure 5. Total impedance triangle

Figure 5 shows how a combined reactance and resistance form a triangle and therefore a complex number can be a subject to a number of trigonometric functions such as Pythagoras theorem $c = \sqrt{a^2 + b^2}$.

The similar operations relate to the power consumption by a circuit where the imaginary number is the amount of power used up by reactive components and real part is the actual power delivered to the circuit.

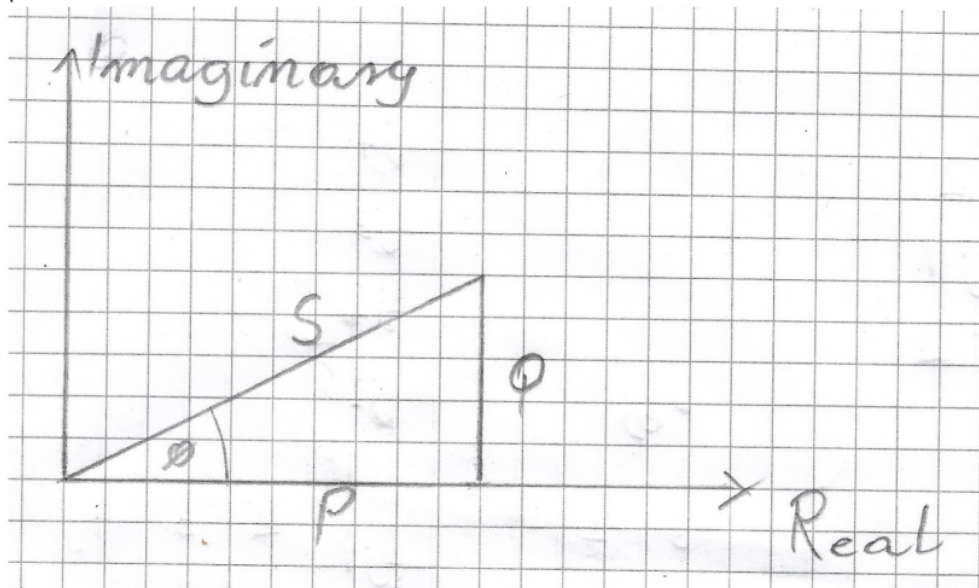


Figure 6. Power triangle

Figure 6 shows the power triangle where P is the Real power, S is the apparent power, and Q is the reactive power.

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2.4. Formulas

The next tasks will require formulas:

The Ohms' Law

$$I = \frac{V}{R} = \frac{V}{Z} \quad \text{Caption required}$$

V - Voltage

I - Current

R - Resistance

Z - Total impedance

Angular Frequency (omega)

$$\omega = 2\pi f$$

f - Frequency

π - PI

Caption required

Inductive Reactance

$$X_L = j\omega L$$

Capacitive Reactance

$$X_C = -\frac{1}{j\omega C}$$

Total Reactance for in series LC

$$X_T = X_L - X_C$$

Total Reactance for parallel LC circuit

$$X_T = \frac{X_L X_C}{X_L + X_C}$$

Total Impedance

$$Z = R + jX_T \quad |Z| = \sqrt{R^2 + X_T^2}$$

Phase Angle

$$\varphi = \tan^{-1} \frac{X_T}{R}$$

Power with proportional voltage to current

$$P = VI$$

Power with phase component

$$P = \operatorname{Re}(VI^*) = \operatorname{Re}(V^*I)$$

I^* & V^* - complex conjugate

Resonant frequency

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

Real power

$$P = |I|^2 R$$

Reactive power

$$Q = |I|^2 X$$

Apparent power

$$S = P + jQ$$

Power factor

$$pf = \cos \varphi$$

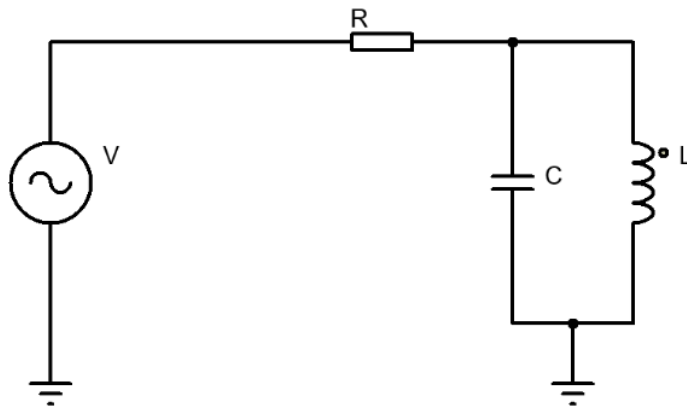
Caption required

φ - Phi

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3. Task 1

3.1. Circuit diagram



Component Values:

R - 44Ω

L - 180mH

C - $24\mu\text{F}$

3.2. Current against frequency graph

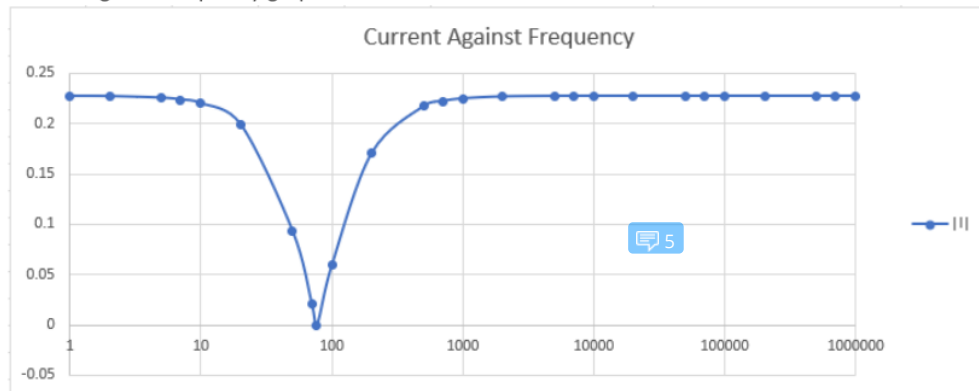


Figure 4. Circuit current drop against frequency

This frequency domain graph was made using ohms law for current $|I| = \frac{V}{Z}$ and it shows gradual decrease of current as the frequency approach resonance and then gradual increase of current as the frequency leaves resonance.

3.3. Component voltage drop

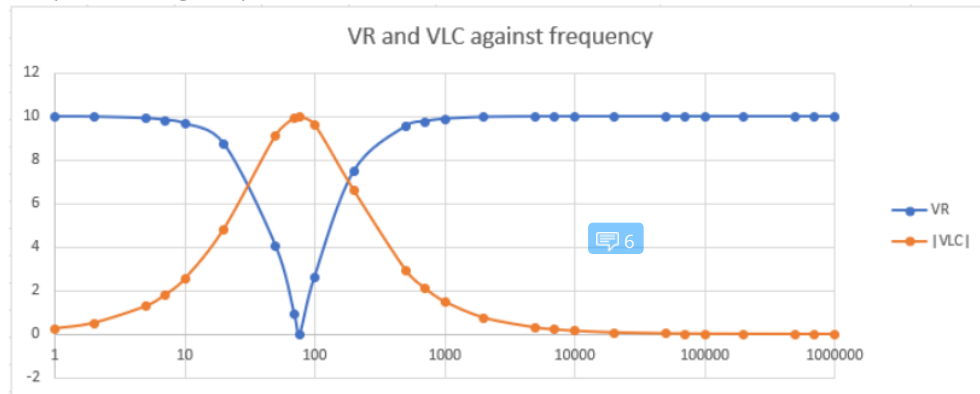


Figure 5. Circuit component voltage drop against frequency

Using ohms law $V_R = |I|R$ and $|V_{LC}| = IX_{LC}$ produced a graph that shows a clear correlation between voltage drop at resistor and voltage spike at reactive components when at the resonant frequency.

3.4. Active, reactive and apparent power

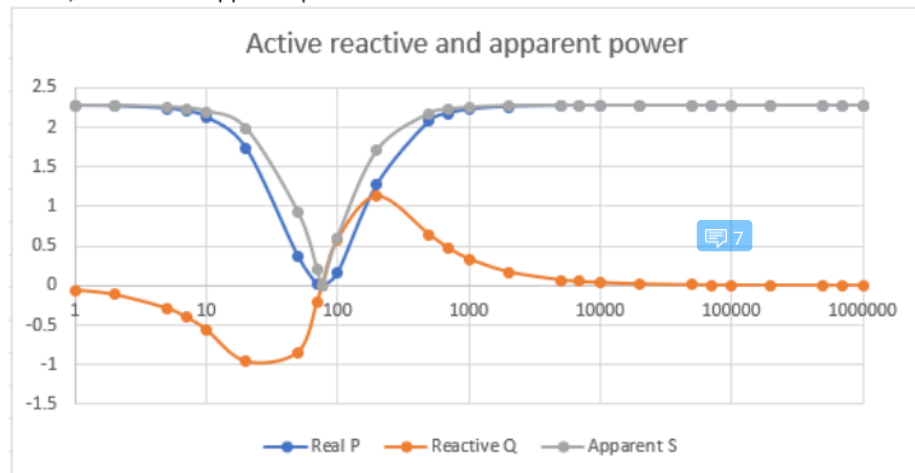


Figure 6. Active, reactive and apparent power against frequency

Using formulas $P = |I|^2 R$, $Q = |I|^2 X$, and $|S| = \sqrt{P^2 + Q^2}$ produced a graph which firstly, the reactive power took a sinusoidal shape, which for a brief moment, passes through apparent power slope. Secondly, the shapes of apparent power and reactive power are shaped exactly as V_R and $|V_{LC}|$ in Figure 5, suggesting correlation between resonant frequency and power consumption.

3.5. Power factor

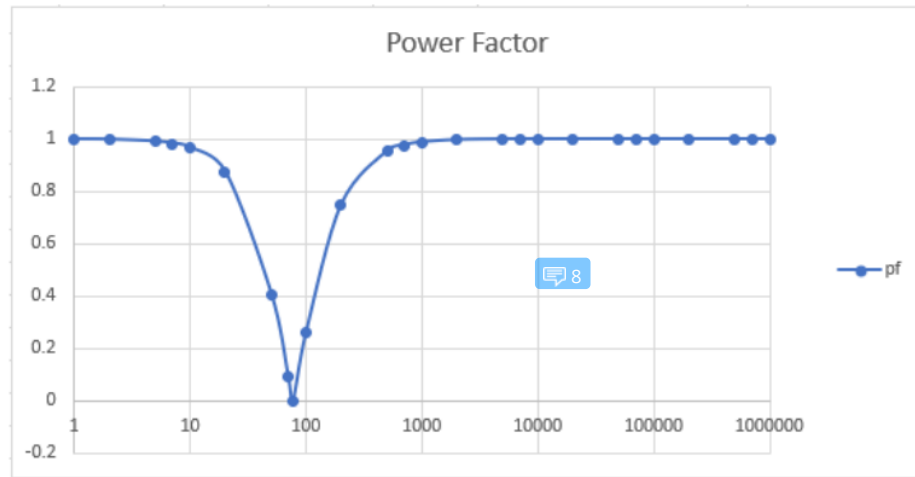


Figure 7. Power Factor against frequency

Using formula $pf = \cos \phi$ made a graph which again shows an exact same shape of V_R in Figure 5. *apparent power* in Figure 6. along with $|I|$ in Figure 4. while each time vector is matching at frequency.

3.6. What happens at the resonance?

Reactive power in Figure 6. shows how the reactance goes from being purely capacitive to being purely inductive. The resonance must be a result of combined reactance of inductor and capacitor which as described in section 2.1, both have opposite results to the phase of voltage to current which then impacts the power consumption.

4. Task 2

Task 2 is to produce three phasor diagrams to visualize what happens:

4.1. 25Hz before resonance



Figure 8. VLC to VR phasor diagram

4.2. At resonance

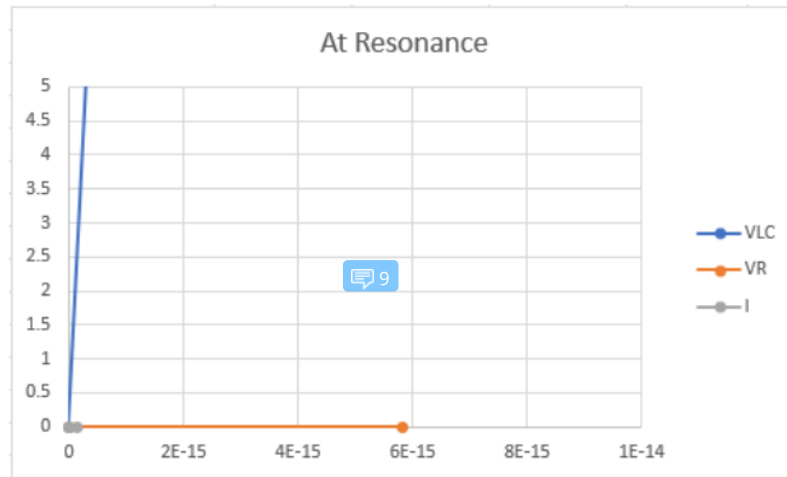


Figure 9. VLC to VR phasor diagram

4.3. 25Hz after resonance



Figure 10. VLC to VR phasor diagram

4.4. Summary

Figures 9-11. Show hows the phase difference between voltages at resistor and LC network.

At first, the voltages are 90° apart then move to 45° 25Hz after resonance.

5. Task 3

For a voltage source with 5Ω resistance and 150μH inductance the maximum power transfer is calculated by equalizing source and load impedances. Using formula for $P = R[|I|^2|Z_{load}|]$ and $X_{src} = 2\pi L$ the following graph was produced.

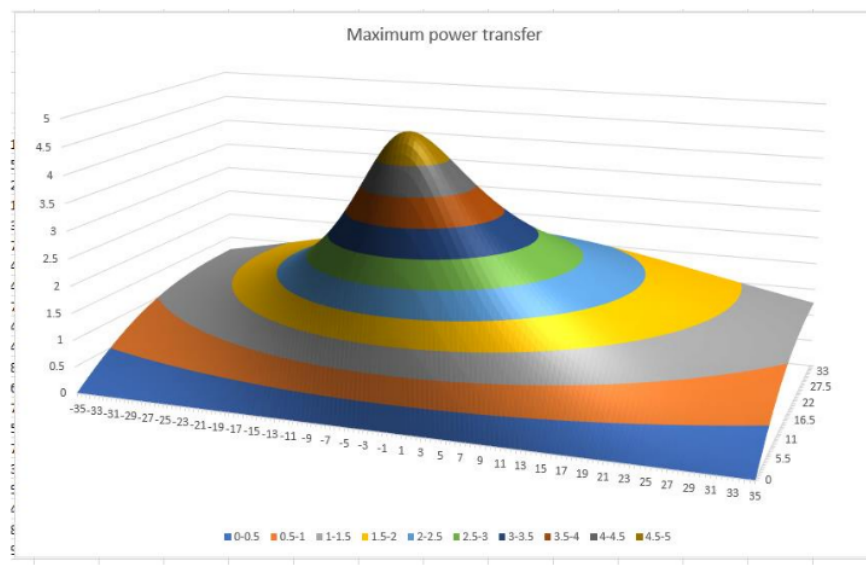


Figure 12. Maximum power transfer

This graph differs from others by having both reactive and real elements to it. The maximum power transfer occurs at the peak of the shape at around 16.5Ω and -3 inductance.

6. Conclusion

The linear properties of capacitors and inductors appear to have both applications and implications. The application is that an RLC circuit can be used to filter out frequencies and therefore can be used for things such as noise filter. The problem is in large inductive loads, the resonance causes by having certain loads with poor power factor cause a lot of power consumption.

Application of complex numbers in AC theory gives an ability to estimate the results of various frequencies on the load. Interesting are the shapes in Figures 5-7, which have identical components for voltage drop across V_R and power factor showing how at resonance, the impedance, being a product of resistance and reactance, is at its maximum. This causes complications for power because of $P = I^2 R$.

Lastly the 3D graph shows how the source impedance can affect the power consumption.

In future it would be best to investigate further the magnetism in devices such transformers and inductors.

7. References

- [1] P. Horowitz, W. H. (2015). "The Art of Electronics", Third Edition. Cambridge University Press. Chapter 1.7 Impedance and reactance. Page 40
- [2] P. Horowitz, W. H. (2015). "The Art of Electronics", Third Edition. Cambridge University Press. Chapter 1.4.1 Capacitors. Page 18
- [3] P. Horowitz, W. H. (2015). "The Art of Electronics", Third Edition. Cambridge University Press. Chapter 1.7.1 Frequency analysis of reactive circuits. Page 41
- [4] P. Horowitz, W. H. (2015). "The Art of Electronics", Third Edition. Cambridge University Press. Chapter 1.7.2 Reactance of inductors. Page 44
- [5] P. Horowitz, W. H. (2015). "The Art of Electronics", Third Edition. Cambridge University Press. Chapter 1.7.6 Power in reactive circuits. Page 47

Vary sources

FINAL GRADE

GENERAL COMMENTS

Instructor

54/100

PAGE 1

PAGE 2

PAGE 3



Comment 1

This just seems to be a list of things in your report rather than an abstract. In an abstract you should say what you are doing, why you are doing it, what you achieved, what result you had and what conclusions you made.

PAGE 4

PAGE 5



Comment 2

This should fall under assumed knowledge - You do not need to include this as it should be assumed the reader is aware of complex numbers.



Tone

Inappropriate Tone:

The way you say something can be just as meaningful as the content of what you say. In an academic essay, there is a danger of being too informal. As you write, you must have a clear sense of the kind of reader (audience) you are writing for, and adjust the formality, complexity, sincerity, and depth of your writing accordingly. In short, your tone is your overall attitude toward your reader. Your tone should in all circumstances be consistent and respectful. Problems with tone arise most often from the use of slang expressions, which you must avoid in academic writing.



Comment 3

Consider using computer drawn diagrams instead of scanned hand drawn diagrams.

PAGE 6



Comment 4

You should consider drawing your diagrams on a computer instead of paper and scanning. It will look more professional.

PAGE 7

QM

Caption required

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

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

QM

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e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

PAGE 8



Comment 5

Graph missing:

- Axis labels
- Units

Could also benefit from minor vertical gridlines to allow the reader to immediately identify it as a log graph.

PAGE 9



Comment 6

See fig 4 comment



Comment 7

See fig 4 comment

PAGE 10



Comment 8

See fig 4 comment

PAGE 11



Comment 9

The end of the VLC line seems to have been cut off



Comment 10

The end of the VLC line seems to have been cut off



Comment 11

I would generally expect the voltage phase of the reactive components to switch between leading and lagging either side of resonance.

PAGE 12



Comment 12

I think you may have this idea the wrong way around.

Large inductive loads will draw large reactive powers which is wasteful. Reactive power can be minimised by moving the system closer to resonance, allowing maximum power transfer to occur.



Comment 13

...3D graph shown in figure 12 illustrates how...

If you mention something in an image, tell the reader which on it is by using the caption number.

QM

Vary sources

There are several ideas from this particular source throughout the writing. Strengthen your writing by including evidence or quotes from other sources as well as your own original ideas.

GRADING FORM: SMU GENERIC_SMOSEY

KRZYSZTOF SYLWESTER MATELA

53.50

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



"References to a limited range of mostly relevant sources. Some omissions and minor errors. Referencing conventions evident though not always applied consistently.

4.2

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Knowledge is accurate with a good understanding of the field of study.

16.8

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance.

17.4

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An adequate awareness and mostly appropriate application of well-established methods, materials, tools and/or techniques. Basic appreciation of the context of the application.

9

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate well, confidently and consistently in a suitable format. Work is coherent and fluent and is well structured and organised.

6.1