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Study of The Effective Electrical Resonance Frequency in series circuits

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ABSTRACT

In basic physics principles, the series LCR circuit is usually discussed in the context of the AC-driven circuit. A detailed investigation of the effect of resistance on the series LCR circuit has been given. The circuit provides a wide range of laboratory problems, demonstrations, theoretical and computational activities. In the present work, for fixed values of LC, the effect of resistance on the LCR series AC circuit is studied experimentally. At first it would be checked the effect of resistance on resonant frequency, and study the variation of the current I with frequency f. This work also focuses on measuring precise values of passive components such as resistors, inductors and capacitors through non-contact means through inductive or capacitive or resistive coupling for series. However, if one of the circuit components such as the resistance, inductance or capacitance is made to vary, it will cause a change in the output current with respect to change in frequency of signal generator (Patil et al., 2021).

This paper presents and reviews the Series Resonance Circuits starting from the concept of circuit impedance and how does resonance occur (Qabazard, 2015).

الملخص

في مبادئ الفيزياء الأساسية، عادةً ما يُناقش دائرة LCR على التوالي في سياق الدائرة التي تعمل بالتيار المتردد. تم تقديم دراسة تفصيلية لتأثير المقاومة على دائرة LCR التسلسلية. توفر

الدائرة مجموعة واسعة من القيم التجريبية. في هذا العمل الحالي، ولقيم ثابتة لكل من L وC،
يتم دراسة تأثير المقاومة على دائرة LCR التسلسلية التي تعمل بالتيار المتردد تجريبياً. في
البداية، سيتم التحقق من تأثير المقاومة على تردد الرنين ودراسة تغير التيار I مع التردد f .
ويركز هذا العمل أيضًا على قياس قيم دقيقة للمكونات الأساسية مثل المقاومات والمحاثات
والمكثفات من خلال وسائل غير تلامسية عبر الربط التحريضي أو السعوي أو المقاوم
للتسلسل. ومع ذلك، إذا تم تغيير أحد مكونات الدائرة مثل المقاومة أو الحث أو السعة،
فسيتسبب ذلك في تغير التيار الخارج بالنسبة لتغير تردد إشارة المولد.

Introduction:

In electronic field, the resistor, inductor and capacitor constitute the three fundamental elements of the electrical circuits. The electrical circuits consisting of these three elements exhibit chaotic instability behavior under a dynamic excitation. This undesirable type of behavior, which is also very useful in engineering and technology applications and in other fields of sciences, for discovering new phenomenon that linear systems cannot display, is due to inherent nonlinearities. These nonlinearities play an important role in electrical systems and can either arise from a resistive, an inductive or capacitive circuit components. Moreover, another important phenomenon like subharmonic and superharmonic reasonances which are very useful in electrical engineering applications and other branches of engineering and physical sciences, appear equally in forced nonlinear systems (Kpomahou et al., 2018).

Alternating current electrical circuits are those circuits supplied with alternating electromotive voltages, usually sinusoidal in time. These circuits are of particular importance in engineering because of their many advantages in the generation, transmission, distribution and use of electricity (Popescu et al., 2023).

LCR circuit is most useful and widely used circuit in electronics since they are simple as two or three components connected in series or parallel. For fixed values of L, C and R, magnitude and phase of the circuit current are controlled by the applied frequency. With the increase in frequency the impedance across the inductance increases and that of across the capacitance decreases. The circuit current increases with frequency and this enhancement of current continues until the impedance of inductance and the impedance of capacitance become equal in magnitude and opposite in phase, cancelling each other. Thus the circuit is completely resistive; no effect of inductance or capacitance remains present. At resonance the current flows through the circuit is the maximum and only depends on the total circuit resistance. At resonance condition the current and applied voltage are in the same phase (Patil et al., 2021). The frequency that causes this situation to occur is called the "resonant frequency" and its value depends on the size of the coil and capacitor in the circuit (Popescu et al., 2023).

In series LCR circuit, resonance occurs because energy is stored in two different ways. When capacitor is charged it stores electric field while magnetic field arises as current flows through the inductor. The stored energy can be transformed from one to other within circuit and the circuit becomes oscillatory (Patil et al., 2021). Theoretically in a series RLC circuit, resonance occurs when the inductive reactance (X_L) and capacitive reactance (X_C) are equal in magnitude but opposite in phase. The resonant frequency is the frequency at which X_L and X_C are equal, resulting in the cancellation of these two reactances, leaving only the resistance. In summary, the resonant frequency in a series RLC circuit is the frequency at which the inductive and capacitive reactances cancel each other out, leading to a minimum impedance and maximum current flow (Popescu et al., 2023).

Expressions of inductive and capacitive reactance in alternating current circuits;(Fr3)

$X_L = 2\pi f L$.. (1)

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

Series resonant circuits are some of the most important circuits used in electrical and electronic circuits. They can be found in various forms such as AC mains filters, noise filters and also in radio and television circuits producing a highly selective tuning circuit for the reception of different frequency channels. Resonance is a very valuable property of AC reactive circuits used in a variety of applications (Popescu et al., 2023).

THEORY

The case where inductive reactance equals capacitive reactance in a lossy circuit is called series resonance or voltage resonance. A Series resonant circuit is shown in Figure (1).

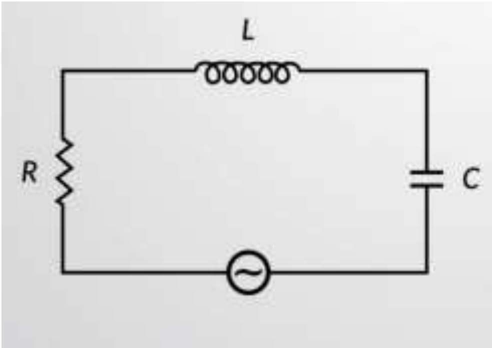

Figure (1): Circuit diagram of series RLC circuit

When an alternating voltage is applied to this circuit, the current passing through the circuit; It varies according to the circuit elements, the resistance, the inductive reactance of the coil and the capacitive reactance of the capacitor. The vectoral sum of the resistances and reactances here gives the Z impedance of the circuit (Zenk, 2022).

The fact that the inductive and capacitive reactance values are equal creates a very special situation in the circuit. A circuit consisting of equal reactances behaves like a circuit consisting of only one resistor this situation is called the resonance state of the circuit (Zenk, 2022).

Impedance (Z): Impedance is the total opposition to current flow in an AC circuit and is measured in ohms. There is no inductive or capacitive reactance in a DC circuit. However, in an AC circuit there is resistance, inductive and capacitive reactance. All of these oppose current flow and the combined opposition to current flow is called impedance. It is important to remember that any circuit can be reduced to a resistance and either a single inductive or capacitive reactance (Qabazard, 2015).

The impedance has an associated magnitude and phase given as (Qabazard, 2015):

$$|Z| = \sqrt{R^2 + (X_L - X_C)^2} \quad \text{.................................. (3)}$$

$$|Z| = \sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2} \quad \text{.................................. (4)}$$

When $X_L = X_C$, then the circuit contains exactly the same amount of inductive and capacitive reactance, the net reactance is zero and the circuit is resistive (Qabazard, 2015), (Zenk, 2022).

So:

$Z = R$.. (5)

$X_L = X_C$.. (6)

$2\pi f_r L = \frac{1}{2\pi f C}$................................... (7)

From equation (7), f_r is :

$f_r = \frac{1}{2\pi\sqrt{LC}}$....................................... (8)

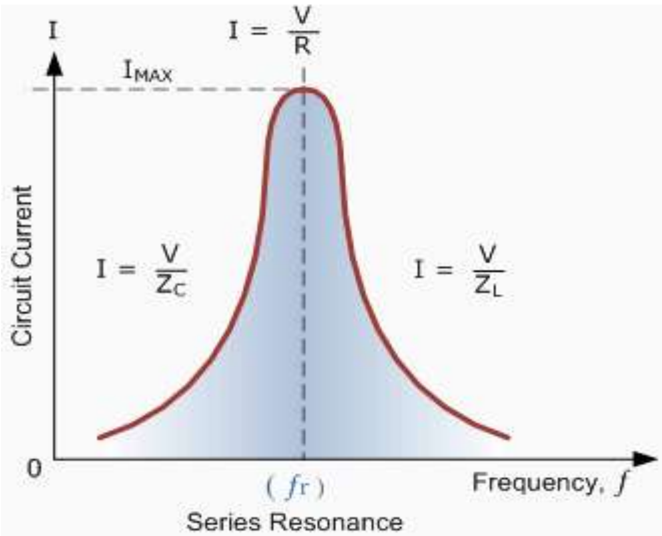

Figure (2): Series resonant circuit reactance-frequency graph

The graph in figure (2) shows the reactive and resistive responses of the series resonant circuit according to the to the frequency change. It is seen that as the frequency increases, X_C decreases exponentially, while X_L increases linearly, that is, the circuit is inductive. It is seen that X_C increases and X_L decreases as the resonance frequency is lowered, that is, the circuit is capacitive. At the resonant frequency, it is seen that $X_L = X_C$ and the circuit impedance is equal to R. In this case, the circuit is resistive. The current flowing through the circuit reaches its highest level (Zenk, 2022).

$I = \frac{I_m}{\sqrt{1+(\frac{X_L - X_C}{R})^2}}$.. (9)   (Qabazard, 2015).

Methods:

In this paper, the electric circuit was simulated using three basic components: resistor, capacitor and inductor connected in series with alternating electromotive voltages, and by fixed values of LC.

Results and Discussion:

Value of capacitance C= 5μF

Value of self-inductance L=561.976

Value of R=1KΩ

Table (1): Variation of X_L, X_C with frequency f

X_L (Ω)	X_C (Ω)	f (KHz)
3.531	31.831	1
5.297	21.221	1.5
7.062	15.915	2
8.828	12.732	2.5
10.593	10.61	3
12.359	9.095	3.5
14.125	7.958	4
15.89	7.074	4.5
17.656	6.366	5

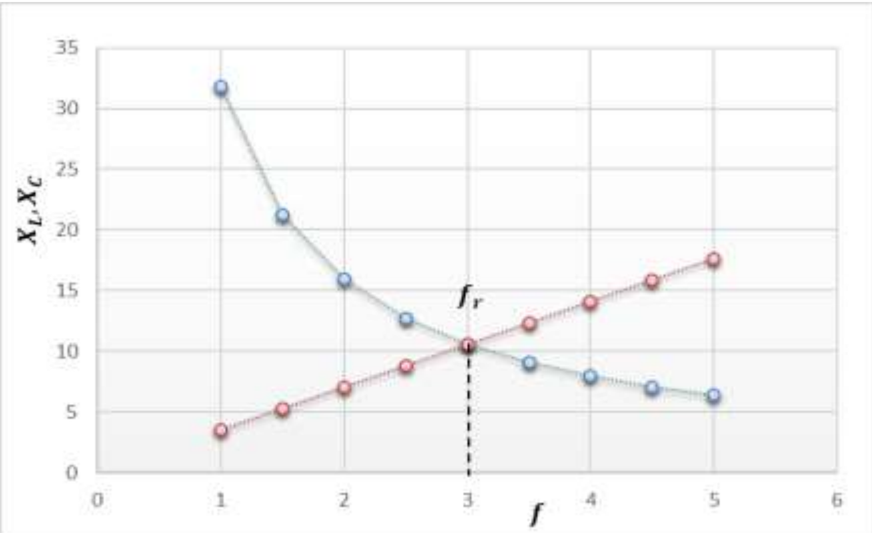

Figure (3): Series resonant circuit reactance frequency graph

Table (2): Variation of the current **I** with frequency **f**

$I_{R=0.5K\Omega}$ (A)	$I_{R=1K\Omega}$ (A)	f (KHz)
1.9326	1.914	0.5
4.1768	3.9988	1
7.1942	6.3846	1.5
11.8098	8.9881	2
18.94836	11.1844	2.5
24	12	3
20.06688	11.40056	3.5
15.0774	10.2023	4
11.80916	8.9881	4.5
9.70167	7.94717	5
8.24856	7.088	5.5
7.19338	6.3846	6

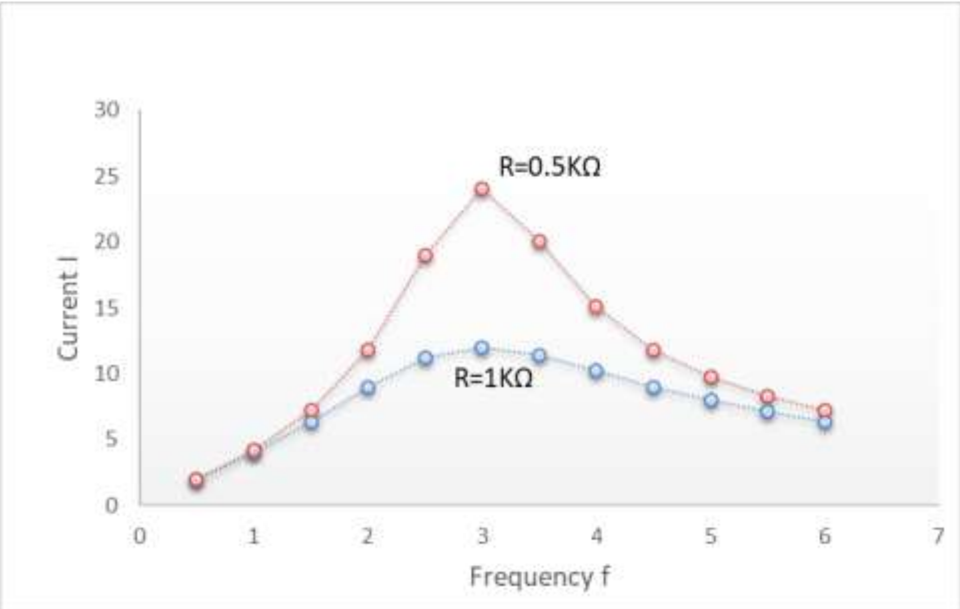

Figure (4): Shows that the magnitude of the current is a function of frequency with different resistors

Discussions & Conclusions

The paper has presented the series Resonance Circuits starting from the concept of circuit impedance and how did resonance occur then studied the circuit type and its characteristic, then finally some of important applications.

From table (1), Experimental results are obtained LCR series AC circuits. Measurements were recorded with varying applied frequency that results in a change of X_L and X_C. The output value was measured for every frequency increment of 500Hz. An AC signal is used to produce a change in X_L and X_C at the output.

Fig (3) illustrates the graph of variation of applied frequency with different values of capacitive and inductive reactances. At the cross point where X_C=X_L, f is equal to f_r (resonant frequency).

From table (2), we can see experimental results are obtained LCR series AC circuits. Measurements were recorded with varying applied frequency that results in a change in current at the output. The output value was measured for every frequency increment of 500Hz. An AC signal is used to produce a change in current at the output. Also the output value was measured for two times, one was measured with resistor $(R = 0.5KHz)$, and another value was measured with resistor $(R = 1KHz)$.

Fig (4) illustrates the graph of variation of applied frequency with different values of resistances (currents), it is also reveals that the sharpness of resonance gets decreases as the values of resistances is increased and vice versa.

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