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Current Magnification using Parallel RLC Circuit

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Abstract: In this project, you study current amplification and parallel resonance in an RLC circuit. It consists of a resistor, inductor(L) and capacitor (C) all of three elements are connected in parallel to an ac power source, when the circuit is at resonance, X_L and X_C cancel each other out and the circuit becomes a resistive circuit, allowing delivering maximum current. This phenomenon allows for dramatic current gain in the device circuit, so it is important for high-frequency applications that require little power loss and significant current gain. The Quality factor (Q) which reflects the sharpness of resonance, can quantitate the capability of energy storage and release. For example, a radio receiver may selectively amplify particular frequencies to serve as both amplification and tuning. We emphasize on parallel resonance to achieve optimal performance and explain why desired characteristics such as bandwidth and amplification depend on component selection.

Keywords: RLC Circuit, Parallel Resonance, Capacitive Reactance, Inductive Reactance, Quality Factor, Current Magnification.

INTRODUCTION

A parallel arrangement has been formed by a resistor, inductor, and capacitor, known as the parallel RLC circuit. Its characteristics such as current amplification and parallel resonance tones come into play in such fields as signal filtering and power electronics systems. For example, essential design techniques in active filter applications will often cause the part of parallel circuits to effectively shape the signal distribution [1]. Additionally, it was explained in depth how RLC circuit behavior focuses on resonance in these configurations for electronic design use. parallel resonance can characterize how circuits such as those described above operate by focusing completely on the problem at hand [2]. These circuits were analyzed and optimized with computer simulation to improve performance in signal processing systems. This Research was about electric circuits in a wider scenery, detailing the theoretical basis behind resonance and current behavior in parallel arrangements [3]. Finally, it was elaborated on how RLC circuits contribute to advanced electronic functionalities, especially in resonance-based systems [4].

Current Magnification

This feature of current amplification, particular to the parallel RLC circuit means that the magnitude of the current flowing through the circuit can be orders of magnitudes greater than that supplied at its input [5]. When the parallel LC circuit is excited at this resonant frequency, the impedance of this parallel combination is minimized, producing a dramatic increase in current flowing through the circuit due to resonance occurring with the capacitive and inductive reactance canceling each other out [6].

Parallel Resonance

Moreover, the parallel RLC circuit behaves such that when reactance of capacitance and inductive are canceled at a certain frequency called resonant frequency the reaction is known as "parallel resonance". The impedance resonates at this frequency, rejecting other frequencies and enabling a sharp current increase for a very selective response around the resonance [2]. He explains how parallel RLC circuits can achieve this level of selectivity and form of resonance control—especially important for electronic design applications, while provides an assessment of the theoretical principles associated with reactance balance and some impedance characteristics in parallel formats [7]. Such practical implications are further elaborated at. in a form of resonance which promotes the efficient through put of current — making it desirable for certain power electronics middleware and applications [8].

Principles of Parallel Resonance in RLC Circuit Theory

Like series RLC circuits, parallel RLC circuits are also resonators with a similar behavior but featuring different characteristics compared to energy dissipation through the resistor as heat and the magnetic and electric potential energies of the inductor and capacitor respectively [2]. This recaptured energy stems from the fact that when inductive and capacitive reactance are related in just such a way, they can annihilate one another at a given frequency and leave the circuit with very high impedance. Johnson, "The Balance of Reactive Components for Efficient Current Recovery in RLC Designs," [9]. It explains the balance of resistance and reactance in the circuit, and how this interplay creates ideal current crests. Last, explaining the theory behind resonance and frequency-dependent impedance behaviors occurring in RLC circuits and how this relates.

Circuit Design

Fig.1 presents the schematic diagram of resistor (R), Inductor(L) and capacitor(C) connected in parallel across 3.53 V AC using 50 Hz. The response to the AC signal is different for each element which causes a different current through each branch. Ohm's law determines the current in resistor branches (R1 = 0.9 Ω and R3 = 5 Ω). The current in R1 is 0.65 A and in R3, it is 0.59 A both of which are low compared to the reactive components (the capacitor and inductor) indicating that resistive branches dissipates energy as heat and in a constant value like DC not affected by the frequency of AC source. The capacitor ($C_1 = 0.01$ F) shows a much higher current around 9.44 A, according to the capacitor impedance inverse relationship with frequency on AC circuits which allows large amount of charge carriers moving through it [10] .

This results in the current to be 90° out of phase with the voltage, i.e. the peak value for a given cycle is reached without having get there yet. This large current through the capacitor at 50Hz is further proof of how well it reacts to an AC signal [11].

The inductor (L1 = 1 mH) is not far behind with a current equal to 9.30 A, almost the same as the capacitor! But the inductor rather than 90 ° lags its current behind the voltage, thus due to its captive nature it resists changes of either stored or passing by. It is the interplay of resistive, capacitive and inductive elements that shapes the overall behavior of this circuit. These individual currents add together in a complex way that creates a phase shift between branches, but the total current is such balanced according to vectors related with AC frequency and impedance of each component.

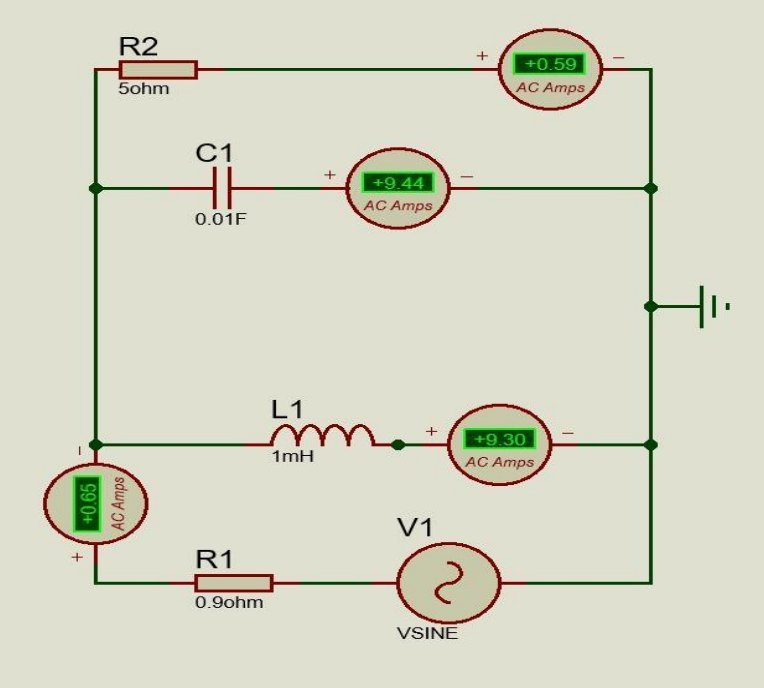

Fig. 1. Circuit Diagram of Parallel RLC

Calculations

The dual of a series resonant circuit is often considered as a parallel resonant circuit and it is as shown in Fig. 2.

The phasor diagram for resonance is shown in Fig-3.

The admittance as seen by the current source is

$$Y(j\omega) = Y_R + Y_L + Y_C$$

$$= \frac{1}{R} + j\left(\omega C - \frac{1}{\omega L}\right)$$

$$= G + jB$$

If the resonance occurs at ω_0, then the susceptance B is zero [12] .

That

$$\omega_0 C = \frac{1}{\omega_0 L} \quad \text{or}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \text{ rad/sec}$$

At resonance, $I_{C0} = -I_{L0} = j\omega_0 CRI$

And $I_{LC} = I_{C0} + I_{L0} = 0$

The quality factor, as in the case of series resonant circuit is defined as

$$Q = 2\pi \frac{Maximum\ energy\ stored}{Energy\ dissipated\ in\ a\ period}$$

$$Q = 2\pi \frac{\frac{1}{2}CV_m^2}{\frac{1}{2}\frac{V_m^2 T}{R}}$$

Since $\omega_0 C = \frac{1}{\omega_0 L}$

$$Q = \frac{R}{\omega_0 L}$$

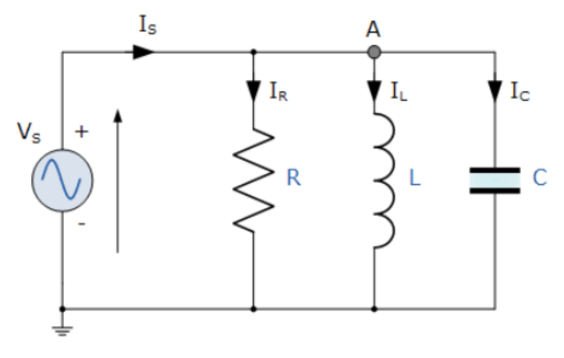

Fig.2 Circuit Diagram of Parallel RLC

Calculation of theoretical values:

Amplitude of Input Voltage = 3.53 Volts

Capacitance(C) = 0.01 Farad

Inductance (L) = 10^{-3} Henry

Resistance (R) = 5 Ω

Resonant frequency (F_0) =50 Hz

Voltage drop across resistor, capacitor, inductor is $V_L = V_R = V_C = 2.96$ V. As it is connected in parallel [13].

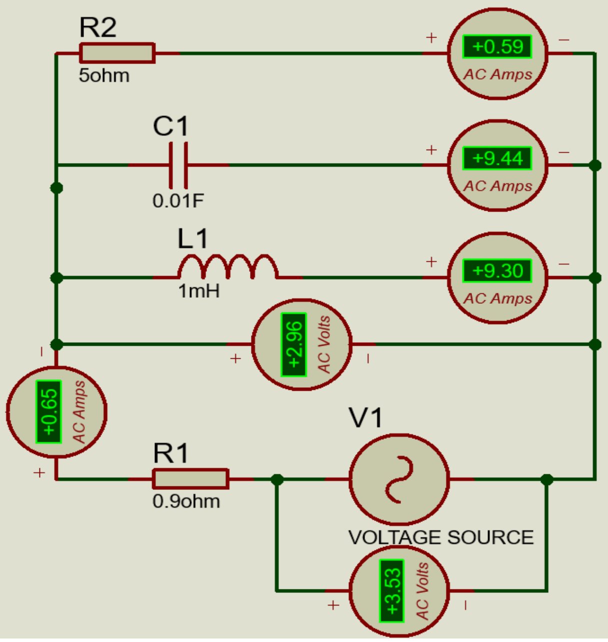

Fig. 3 Circuit for Calculation of theoretical values

Now,

Inductive reactance (X_L)= ωL, ($\omega = 2\pi F_0 L$)

$$= 2 \times \pi \times 50 \times 1 \times 10^{-3}$$

$$= 0.314159265359\ \Omega$$

Inductive reactance (X_C)= $\frac{1}{\omega C}$ ($\omega = 2\pi F_0 C$)

$$= \frac{1}{2 \times \pi \times 50 \times 0.01}$$

$$= 0.3183098862\ \Omega$$

Current through Inductor (I_L)= $I_L = \frac{v_L}{x_L}$

$I_L = 9.42$ A

Current through Capacitor (I_C)= $I_C = \frac{v_C}{x_C}$

$I_C = 9.29$ A

Current through Resistor (I_R)= $I_R = \frac{v_R}{R}$

$I_R = 0.592$ A

The supply current

$(I_S) = \sqrt{(I_R)^2 + (I_L - I_C)^2}$ = 0.6061 A

So,

Current through Inductor (I_R)=9.42 A

Current through Capacitor (I_C)=9.29 A

Current through Resistor (I_R)=0.592 A

Quality factor(Q) = $\frac{R}{\omega_0 L}$ ($\omega_0 = 2\pi F_0$)

Q =15.91

Table 1: Current Flowing Through the Total Circuit and Each Component of the RLC Circuit

S.L No	Frequency (Input) (in Hz)	Total Input Current (in Amperes)	Current through Capacitor (in Amperes)	Current through Inductor (in Amperes)	Current through Resistor (in Amperes)
1.	30	3.68	2.12	5.79	0.22
2.	35	3.47	3.34	6.75	0.30
3.	40	2.89	5.29	8.14	0.41
4.	45	1.73	7.65	9.25	0.53
5.	50	0.65	9.44	9.30	0.59
6.	55	1.83	9.26	7.64	0.54
7.	60	2.67	8.32	5.09	0.44
8.	65	3.12	7.43	4.38	0.36
9.	100	3.78	5.01	1.23	0.16

Result and Analysis

1. AC Circuit Behavior:

If the input is an AC signal, then the behaviour of RLC circuit (Resistor, Inductor, Capacitor) changes with frequency. Key points of observation. If in the next part the inductive reactance equals the capacitive reactance, then this circuit will reach resonance. The impedance in the circuit reaches its lowest value at resonance, so the current through the circuit is largest [14] . Inductive Reactance (X_L)**:** Non-linear with frequency increases. Capacitive Reactance (X_C): It decreases as frequency increases. This reactance's affect the current through each of the components. The capacitor will have a high reactance at low frequencies and the inductor will have a low one. The opposite is true at very high frequencies.

From the table 1 you can see the total current and current from capacitor, Inductor and resistant subparts under different frequencies. Here is a brief analysis: At 30 Hz, the current through the inductor is relatively high at 5.79 A; that for the capacitor is small (2.12 A). This means that the circuit is far from resonance at this low frequency. At 50 Hz, the current through the inductor and the capacitor are almost equal, indicating this may be near a resonance frequency. (9.44 A through the capacitor, 9.30 A through the inductor). The total input current (0.65 A) is at a minimum, consistent with our concept of resonance.

The current flowing through the inductor is significantly low (1.23 A) but current passing through the capacitor is still intermediate (5.01 A), indicating that at 100 Hz, the frequency is well above resonance and very high allowing inductor to dominate circuit behavior (since L has same properties as resistance moving away from resonance) [15] .

2. Graphical Analysis:

The current vs frequency graph for parallel RLC circuit is plotted in Fig. 4 and is used to calculate the percentage error from different frequencies on measured and theoretical currents. Key observations include: Low Frequency High Deviation: Below 50 Hz (30-40 Hz), the deviation is large (> 200%). That's because, at these low frequencies, the impedance is mainly defined by its capacitive reactance and the measured currents can be more affected by parasitic effects or measurement errors. Near Resonance Minimal Deviation: At 50 Hz, the deviation is minimized and occurs at the resonance frequency.

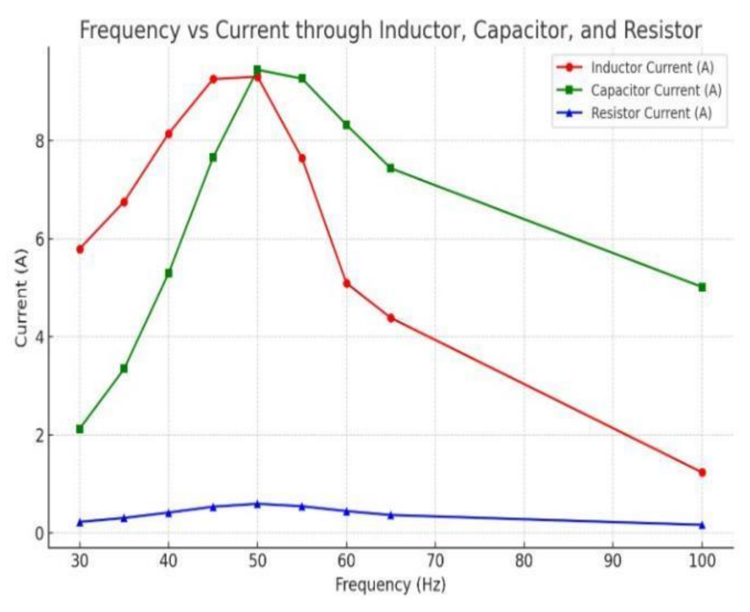

Fig. 4 Graph for Frequency vs Current for RLC Parallel

The theoretical and measured currents are very close, as expected for an RLC circuit at resonance. Higher frequencies show an increase in the deviation. After 50 Hz, the inductive reactance is prevailing and therefore the deviation goes again up: reflecting those larger measured currents compared to theoretical predictions.

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3. Conclusion

Theoretically, we expect the RLC circuit to be resonant at this frequency of about 50 Hz, and that is indeed borne out by the data. The difference between the theoretical values and the simulated ones are due to non-ideal circuit components, parasitic aspects or measure inaccuracies in low or high frequencies. The circuit behaviour versus frequency is starkly evident in the analysis and graph, with almost no discrepancies at resonance and making bigger ever larger deviations away from resonance.

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