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The Effect of Capacitance on the Power Factor Value of Parallel RLC Circuits

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ABSTRACT

The power factor of the circuit is determined by the amount of pure resistance (R), self-inductance of the coil (L) and the capacitance of the capacitor (C). In this study, the measurement of the power factor value in a parallel RLC circuit was carried out through experimental testing and simulation with the value of C as the independent variable, while the values of R and L were fixed conditioned quantities. The purpose of this study was to determine the effect of capacitance on a parallel RLC circuit. One of the ways to improve the power factor value in a circuit is to install capacitive compensation using a capacitor. The relation between the power factor value and the capacitance and inductive reactance based on the experimental results and the simulation calculation results in the parallel RLC circuit both shows the same pattern with a relative uncertainty below 8%. The experimental results and simulation results both show that the power factor can be improved by using a right capacitance which is around the capacitance value when there is resonance in the circuit.

KEYWORDS
Capacitor
Power factor
Parallel RLC circuit
Resonance

INTRODUCTION

A parallel RLC circuit with an alternating current (AC) voltage source, has an impedance value (Z) which consists of a component that has a resistance value (R) and connected to a component that has an inductance reactance (XL) and / or capacitive reactance (XC) value. These components will produce a power factor which values range from 0.0 to 1.0. In accordance with its properties, a capacitor is a component specifically designed to store energy in the form of an electric field whose capacitance value is a parameter of the ability to store energy in the form of an electric field. The capacitor does not consume power, but stores power temporarily as field, which returns to the circuit. Reactive power is useless power so that it cannot be converted into power but is needed for the process of transmitting electrical energy at the load. So, what causes waste of electrical energy is the number of inductive loads. On the other hand, the capacitor can release energy in a short time, so the capacitor can be quickly charged and discharged repeatedly without being damaged. Parallel capacitor installation is very important to improve the reduction of

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reactive power of a power system (Yani, 2017). When the circuit is capacitive with the leading power factor, the load voltage increases linearly as the power factor increases to the maximum value (Fauzan et al, 2012). Because of these conditions, basically the capacitor can be used to increase the power that is installed in parallel with the load circuit (Noor et al, 2017). When the circuit is given a voltage, electrons will flow into the capacitor. When the capacitor is full of charged electrons, the voltage will change. Then the electrons will come out of the capacitor and flow into the circuit and at that time the capacitor generates reactive power. When the changed voltage returns to normal (constant), the capacitor will retain the electrons. When the capacitor releases electrons, it means that the capacitor supplies reactive power. In the RLC circuit the inductive load is a load that absorbs active power and will reduce the power factor of the circuit (Lisiani, 2020).

Based on the review of the properties of the inductor and capacitor in the RLC circuit, this research studies the effect of capacitor capacity and coil inductance on the power factor of the RLC parallel circuit through experimental and simulation results with the values of R and L as a fixed conditioned quantity and capacitor C capacity as the variable can be changed.

To get the most optimal power factor (close to 1), it is determined by the relationship between the power factor and capacitive reactance at several values of C.

LITERATURE REVIEW

A parallel RLC circuit with an AC voltage source is a circuit consisting of resistors, inductors and capacitors arranged in parallel and this circuit will form a harmonic oscillator.

Parallel RLC Circuit

In a parallel RLC circuit, the currents in each component of R, L and C have different values while the voltage is the same. The current characteristics of each component can be seen using a phasor diagram. The current in the resistor (IR) has the same phase as the source voltage V. The current in the inductor (IL) has a phase difference $\phi = 1 / 2\pi$ rad with the current, where the voltage precedes the current. The current in the capacitor (IC) has a phase difference $\phi = -1/2\,\pi$ rad with the voltage, where the current precedes the voltage (Ansari et al., 2017).

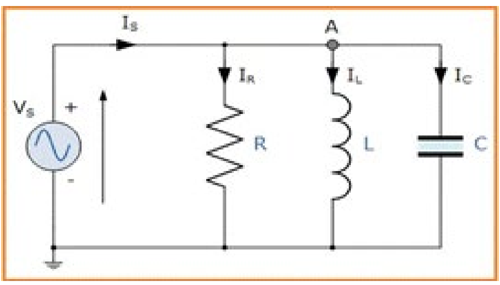

Figure 1a. Parallel RLC Circuit

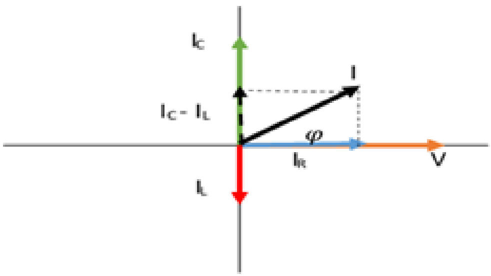

Figure 1b. Parallel RLC Circuit Phasor Diagram

The voltage relation in the circuit is:

$$V_R = V_L = V_C = V_S$$

$$I_S = \frac{V_S}{Z}, I_R = \frac{V_S}{R}, I_L = \frac{V_S}{X_L},$$

The impedance equation in parallel RLC is (Marin & Popa, 2019)

$$Z = \frac{1}{\sqrt{(\frac{1}{R})^2 + (\frac{1}{XC} - \frac{1}{XL})^2}} \tag{1}$$

Based on the phasor diagram, the power factor of a parallel RLC circuit meets the equation:

$$Cos\ \varphi = \frac{Z}{R} \tag{2}$$

$Cos\ \varphi$ will be a maximum value when $XC = XL$ (Resonance), in this state the current in the circuit will be minimum.

Load Properties R <L and C

AC or alternating current across the resistor, will cause a voltage of:

$$V_R = I\ R \tag{3}$$

Equation (1) shows the amount of current that passes through the resistor proportional to the resulting voltage, because the resistor is a limiter of the electric current that enters or decreases the electric potential in the circuit, as a result, the current and voltage do not change phase, or have the same phase.

Alternating Current in Inductors

When alternating current passes through an inductor, it will cause an electric motive force that is opposite to the source, that is, when the current in the inductor is zero, the voltage will be maximum, so that the voltage will reach the maximum value faster ¼ period than the current when it reaches the maximum value, this indicates that the current is not in phase with the current, the voltage will precede the current with a phase angle of 900.
The relation between induced currents and voltages is:

$$V_L = L\ \frac{di}{dt} \tag{4}$$

From equation (2), it shows that the more the change in current each time, the more the induced voltage. The induced voltage appears after a change in current at certain intervals.

Alternating Current in Capacitors

When the AC current passes through the capacitor, a voltage will arise and then the voltage on the capacitor will slowly increase, which satisfies the equation:

$$V_C = \frac{1}{C}\int I\,dt \tag{5}$$

Equation (3) shows that as the current passes through the capacitor, the voltage on the capacitor increases. And vice versa, when the current is lowered to point 0, the capacitor voltage will also decrease slowly.

Based on their physical properties, capacitors and inductors are passive components / elements in the RLC circuit, namely as energy storage elements. The capacitor is used to compensate for the inductance effect of the circuit, while the only power dissipating component is the resistor (R). In the RLC circuit, this energy storage and release process occurs continuously in capacitors and inductors. The more the current flowing in the circuit, the more the power loss, meaning that more energy is wasted in the form of heat. The inductor will store energy and send it back to the circuit continuously, this causes the power loss to the system will be even greater. On the other hand, the capacitor will minimize the effect of inductance so that the electrical system becomes more efficient. Capacitors and inductors have a different type of AC resistance known as inductive reactance (XL) and capacitive reactance (XC).

In an RLC circuit with an alternating voltage source with sinusoidal voltage and current, the multiplication of the two will produce visible power (S) which has two parts, the utilized power, namely active power (P) and the unused power present in the circuit is called reactive power (Q). Resistive loads only consume active power, inductive loads consume reactive power and capacitive loads only provide reactive power. The ratio of the amount of active power to the visible power generated by the source is called the power factor.

The relationship between active power, reactive power and power is shown in Figure 2

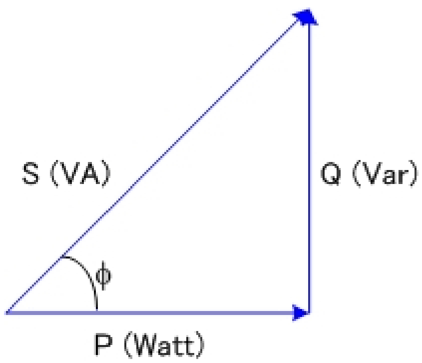

Figure 2. Power triangle

The ratio of the amount of active power to the visible power generated by the source is called the power factor, and based on the figure, the equation is as follows:

$$Cos\ \emptyset = \frac{P}{S} \tag{6}$$

From the figure, in order for the power factor (Cos $\emptyset$) to increase, it is necessary to install capacitive compensation using a capacitor in the RLC circuit, because capacitors are electrical components which produce reactive power. When a capacitor is installed, the reactive power that must be provided by the source is reduced by Q correction (which is the reactive power coming from the capacitor). Because the active power does not change while the reactive power decreases, as a result the angle $\emptyset$ decreases due to the installation of the capacitor so that the network power factor will increase.

Research Methodology

The method used in this research is descriptive analysis of laboratory experiments and computer assisted data processing. The research step was started by preparing a power factor experimental tool for the RLC parallel circuit adjusted to the required data collection, then testing it through data processing by calculating the theoretical power factor, plotting graphs and simulations.

The equipment used in data collection is shown in Figure 3.

Figure 3. RLC Parallel Circuit Equipment

RESULT AND DISCUSSION

In this study, the measurement of the power factor value of the parallel RLC circuit was carried out through experimental testing with the capacitance value C as the independent variable, while the resistance value R = 20 Ω as a fixed conditioned quantity. Power factor measurements were carried out at two different inductance values, namely L = 36 mH and L = 54 mH. The results of the experimental power factor measurement can be seen in Table 1.

Table 1. Experimental power factor measurement results for R = 20 Ω, L = 36 mH and L = 54 mH

C (μF)	XC (Ω)	Faktor Daya (L=36 mH)	Faktor Daya (L=54 mH)
25	127.4	0.49	0.64
50	63.7	0.58	0.70
100	31.8	0.65	0.87
200	15.9	0.88	0.99
250	12.7	0.90	0.86
300	10.6	0.96	0.85
333.3	9.5	0.89	0.80
500	6.4	0.65	0.59
1000	3.2	0.30	0.20
1400	2.3	0.14	0.13

The plot of power factor data against capacitance from the experimental measurement results and the simulation / theory calculation results can be seen in Figure 4.

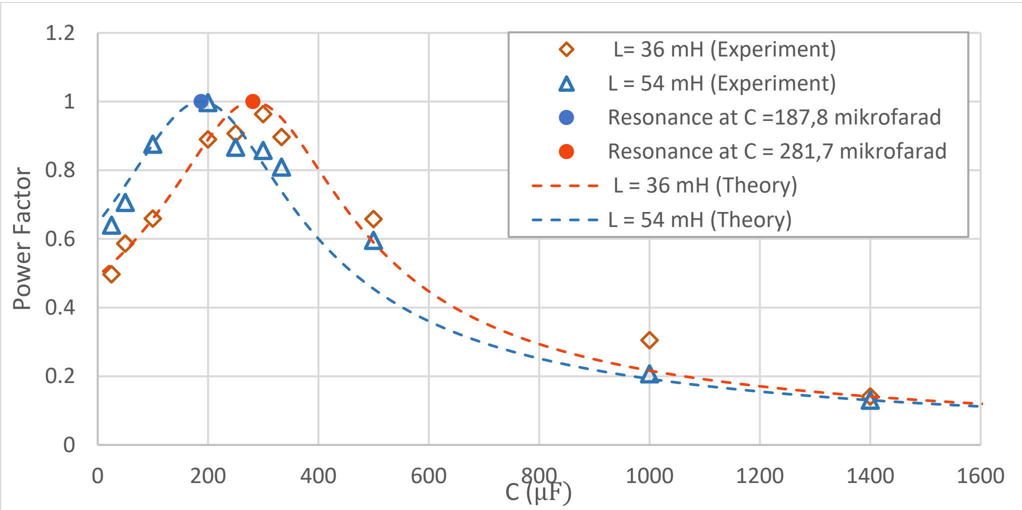

Figure 4. Graph of Power Factor Against Capacitance Results of Experiments and Simulated Calculations / Theory for Parallel RLC Circuits

The relation between the power factor value and the capacitance and the relation between the power factor value and the capacitive reactance from the experimental results and simulation / theory calculations both show the same pattern. The average relative uncertainty between the experimental results and the simulation / theory calculation results shows a value of 7.8% for L = 36 mH and 7.5% for L = 54 mH.

Figure 4 shows the relationship between the power factor value and capacitance, before resonance (at C = 281.7 µF for L = 36 mH and at C = 187.8 µF for L = 54 mH) the power factor value will increase with increasing capacitance value C. Meanwhile, after passing through resonance the power factor value at L = 36 mH and at L = 54 mH will decrease with increasing capacitance value.

The results of the power factor data plot against capacitive reactance based on experimental measurements and the results of simulation / theory calculations can be seen in Figure 5.

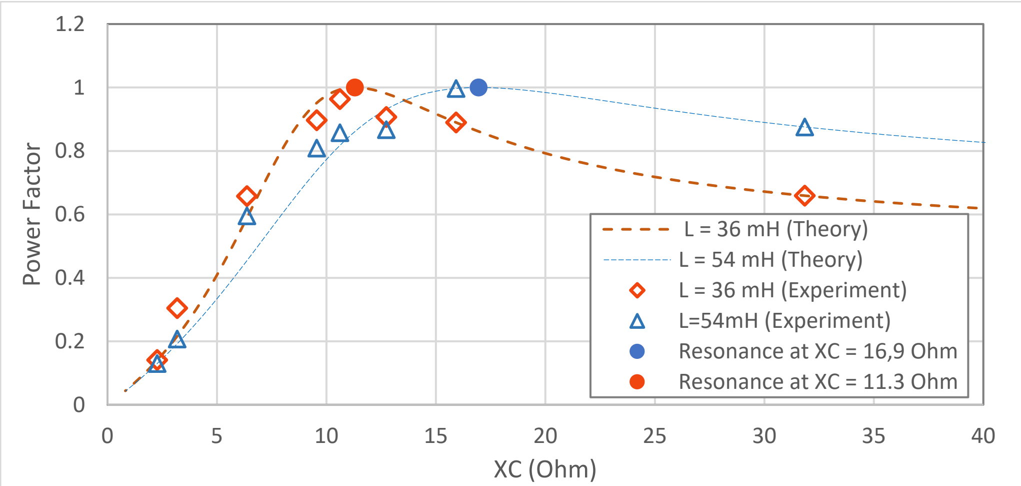

Figure 5. Graph of Power Factor against Inductive Reactance Experimental Results and Simulated / Theory Calculations for Parallel RLC Circuits

Figure 5 shows the relation between the power factor value and inductive reactance, before resonance (at XC = XL = 11.3 Ω for L = 36 mH and at XC = XL = 16.9 Ω for L = 54 mH) the power factor value will be increases with increasing capacitive reactance value XL (or decreasing capacitance value C). Meanwhile, after passing through the resonance the power factor value at L = 36 mH and at L = 54 mH will decrease with the increase in XL capacitive reactance. The more the inductive reactance (inductance), the more the capacitive reactance value is required to improve the power factor before the resonance point. However, the decrease in the power factor value to the capacitive reactance value for a parallel RLC circuit with a smaller inductive reactance (L = 36 mH) will experience a faster decrease compared to the larger inductive reactance (L = 54 mH) after past the resonance point.

The maximum power factor value from the experimental results for L = 36 mH is 0.96, namely at C = 300µF (XC = 10.6 Ω). Meanwhile, the maximum power factor value from the experimental results for L = 54 mH is 0.99, which is at C = 200 µF (XC = 15.9 Ω). This indicates that using the correct capacitance value for an inductive capacitor can improve the power factor. The capacitor value is around the capacitance value when there is resonance in the RLC circuit.

SUMMARY

The relation between the capacitance / reactance capacitance and the power factor in a parallel RLC circuit based on experimental results and the results of calculations through simulation both show the same pattern. The power factor value will increase with the increase in the capacitance value before passing through resonance. The power factor value will decrease as the capacitance increases after passing through resonance. The more the inductive reactance (inductance) in a parallel RLC circuit, the more the capacitive reactance value is required to increase the power factor value before resonance occurs. Based on the experimental and simulation results, both show that the maximum power factor value occurs around the capacitance value (inductive reactance) when resonance occurs, this shows that using the right capacitance value can improve the power factor value of the RLC circuit.

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