Comparative Analysis of Experimental Testing and Simulation of the Inductance Effect in the RLC Circuit toward the Power Factor Value

Ratu Fenny Muldiani[1,*] Kunlestiowati Hadiningrum[2] Defrianto Pratama[3]

[1]*Energy Conversion Engineering, Politeknik Negeri Bandung, Indonesia*
[2]*Chemical Engineering, Politeknik Negeri Bandung, Indonesia*
[3]*Electrical Engineering, Politeknik Negeri Bandung, Indonesia*
[*]*Corresponding author, email: ratu.fenny@Polban.ac.id*

ABSTRACT
The power factor value in RLC circuits 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 series and parallel RLC circuits is conducted through experimental and simulation testing with the values of L and R as independent variables, while the value of C as a fixed. The purpose of this research is to determine the effect of inductance on the power factor in RLC circuit and to prove whether the experimental results are close to the simulation results. The experiment and simulation results are presented in graphical form. The relationship between the power factor and the inductive reactance of the experimental results for the values of R = 10 Ω and R = 20 Ω shows a pattern closed to the simulation results. In the series RLC circuit the power factor will decrease with the addition of the inductive reactance value, at R = 10 Ω and R = 20 Ω. Experimental calculation results show an average relative uncertainty below 10% of the theoretical calculation results. In the parallel RLC circuit, the experimental and simulation results both show a decrease in the power factor with the increase in the value of inductive reactance, at R = 10 Ω and R = 20 Ω. Experimental calculation results show an average relative uncertainty below 13% of the theoretical calculation results.
Keywords: *Experiment, Simulation, RLC circuit power factor, Series Circuit, Parallel Circuit*

1. INTRODUCTION

The quality of electrical power in industry is very important, because is greatly affects the process and the final product. More sensitive equipment in industry, the quality of electrics power becomes thing important to note. The quality of electrical power is expressed by the power factor. The greater the power factor value, the better the electric power quality. In the case of low power factor, there will be considerable voltage drop and loss electrical energy along the conductor, and will cause the system or equipment to have low efficiency values [1].
In AC electrical circuits, there are three type electrical loads, namely resistive, inductive, and capacitive loads. The R component dissipates power, while the inductor and capacitor do not consume power, but store the power temporarily in the form of a field, which will return to the system. This energy storage-discharge process occurs continuously in capacitors and inductors. The most important part of this circuit is the power factor.
The more the resistance to the inductor or inductive reactance (X_L) or the resistance to the capacitor or capacitive reactance (X_C), the more the impedance of the circuit. The more resistive, the more balanced X_L and X_C are, consequently to the more efficient they are in utilizing energy, this is happening due to the higher power factor. So, the inductance effect (X_L) is countered by the capacitance effect (X_C) so that the power factor gets closer to one. In the AC circuit the inductor can reduce unwanted current fluctuations, the main use of the inductor is to increase and decrease the alternating voltage and the electric current flowing in the inductor does not change rapidly and the change in current passing through the inductor depends with the inductor voltage [2].
The faster the current in the inductor changes, the faster the magnetic field in the inductor changes. The faster the magnetic field or flux changes, the greater the voltage generated. If the inductor is connected to an AC voltage source, the current and voltage are different in phase by 90°, as a result, on average, no energy is transformed in the inductor and no energy is wasted as heat. The bigger the effect of the inductance in the circuit, the smaller the power factor value so that the efficiency of the electric power generated will be reduced [3].

The main cause of the low power factor is inductive load, so understanding of the effect on inductive load on power factor values is important. The purpose of this research is to study the effect of inductance on the power factor of the circuit through experimental and simulation results by determining the self-inductance of inductors L and R as independent variables, while the value of C is a fixed conditioned quantity. To get the power factor that is closest to the maximum, the relationship between power factor and inductive reactance is determined at several values of L. The purpose of this research is to determine the effect of inductance on the power factor in RLC circuit and to prove whether the experimental result is close to the simulation result.

2. BACKGROUND

2.1. Power Factor

In the distribution of electrical energy, the term power factor (Cos φ) is known. The power factor can also be said to be the ratio of real power or active power to apparent power [4]. In AC power supply devices, this power factor value is very important, because the power factor states the level of efficiency of the electric power produced. The higher the power factor value of the voltage generating device, the better device quality is.
The quality of electric power is greatly influenced by the use of certain types of loads which result in reduced efficiency; the types of loads that affect the quality of electric power are inductive loads. [5,6]

2.2. Series RLC Circuit

In a series RLC circuit, the current in each component of R, L and C have the same value while the voltage is different. The voltage characteristics of each component can be seen using a phasor diagram. The voltage across the resistor (VR) has the same phase as the current. The voltage on the inductor (VL) has a phase difference ϕ = 2π rad with the current, where the voltage precedes the current. The voltage on the capacitor (VC) has a phase difference ϕ = -2π rad with the current, where the current precedes the voltage [3.4].

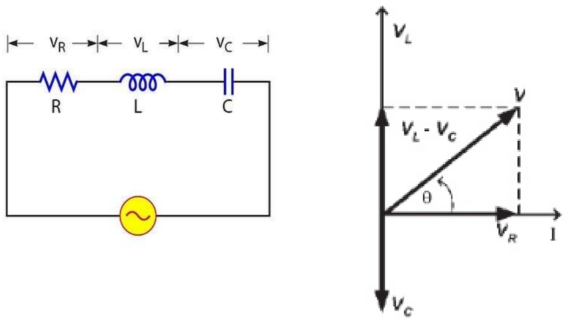

Figure 1. a. Series RLC Circuits, 1.b. Phasor diagram of Series RLC Circuits

The currents in each load or component are the same, so that IR = IL = IC = IS and the impedance of the RLC series circuit is

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \quad (1)$$

and X where $X_L = \omega L$, is the inductive reactance $X_C = 1 / \omega C$, the capacitive reactance.
Based on phasor diagram the power factor in the series RLC circuit are:

$$Cos\ \varphi = \frac{R}{Z} \quad (2)$$

Cos φ will be at maximum value. When $X_C = X_L$ (called Resonance), in this state the current in the circuit will be maximum. [7]

2.3. Parallel RLC Circuit

In a parallel RLC circuit, the current 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 ϕ = 2π rad with the current, where the voltage precedes the current. The current in the capacitor (IC) has a phase difference ϕ = -2π rad with the voltage, where the current precedes the voltage [8].

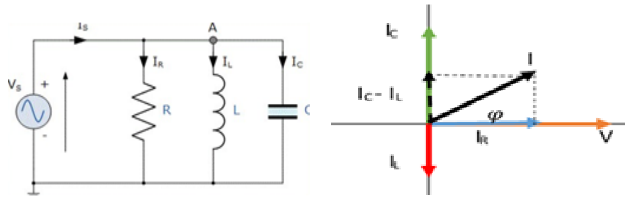

Figure 2. a. Parallel RLC Circuit, b. Phasor Diagram of Parallel RLC

The voltage relationship in the circuit is:

$V_R = V_L = V_C = V_S$

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

The impedance equation in parallel RLC is [8]

$$Z = \frac{1}{\sqrt{(\frac{1}{R})^2 + (\frac{1}{XC} - \frac{1}{XL})^2}} \quad (3)$$

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

$$Cos\ \varphi = \frac{Z}{R} \quad (4)$$

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

3. METHODOLOGY

The method used in this research is descriptive analysis of laboratory experiments and computer assisted data processing. The research procedure consists of several steps.

Experiment method: Series RLC circuit and Parallel RLC circuit setting with R=10 Ω and 20 Ω, C=1000 μF and variations L=9 mH, 18 mH, 36mH, 45 mH, and 54 mH. Collecting experimental data (P, Ieff and Veff) and calculate power factor from the experimental data cos ϕ = P/ (Ieff Veff).[9] The equipment used in experimental data collection is shown in Figure 3.

Figure 3. The RLC Circuit Tools

Simulation method base on theory: Calculate the Impedance of Series RLC circuit and Parallel RLC circuit analytically, Calculate the Impedance with variations of L (0-60 mH) and R (10 Ω and 20 Ω) using Microsoft Excel program, Calculate the power factor with variations of L and R. Research flowchart is shown in figure 4.

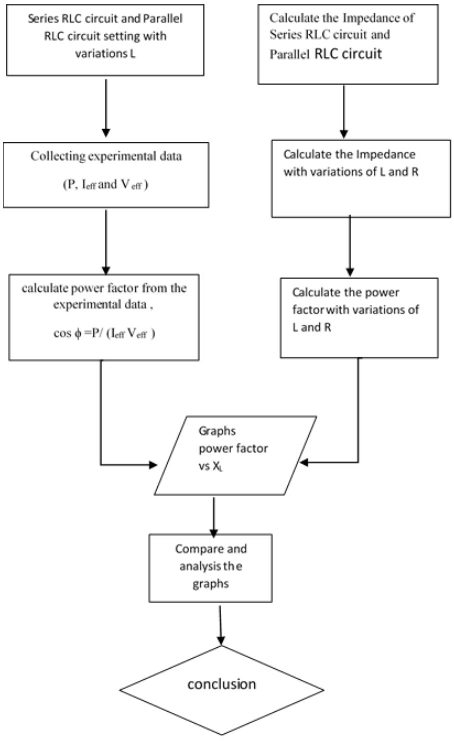

Figure 4. Research Flowchart

4. RESULT AND DISCUSSION

In this research, the power factor value (Cos φ) was measured in series and parallel RLC series through experimental test and simulation or theory with the values of L and R as independent variables, while the value of C = 1000 μF as a fixed conditioned quantity.

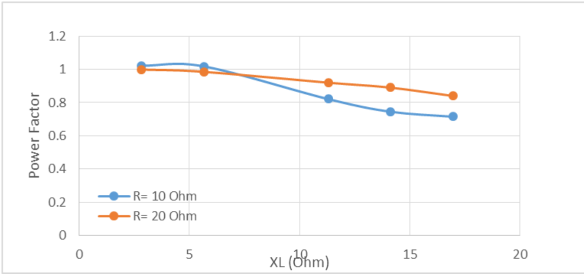

Figure 5. Relationship of power factor (Cos φ) to X_L for the value of R = 10Ω and 20Ω on the RLC series based on experimental data

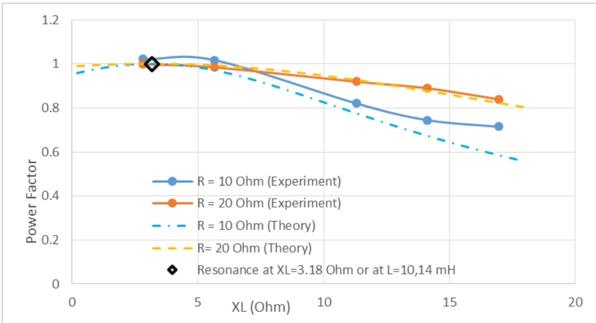

Figure 6. Graph of the relationship between power factor (Cos φ) and XL in the RLC series experimentally and in simulation

In the graph of the relation between power factor and inductive reactance, for R = 10 Ω and 20 Ω, it shows the same pattern, this proves that the inductor has an effect on the power factor value, even though the R value is different. The experimental calculation results for R = 10 Ω and 20 Ω the maximum power factor values are reached when L = 9 mH. This result is confirmed based on simulation calculations that the resonance (power factor = 1) occurs when $X_L = X_C = 3.18$ Ω or at L = 10.14 mH. Figure 4 shows a graph of the relationship between the power factor and inductive reactance (X_L) of the experimental and simulation results for a Series RLC circuit.

The simulation or theory of series RLC calculation results show that the power factor value before resonance increases with the increase in XL, then decreases sharply after passing resonance. In the series RLC circuit for R = 10 Ω and R = 20 Ω the experimental results show a similar pattern to the simulation or theory results and both show that the power factor value decreases with the increase in the inductive reactance value. For a series RLC circuit with a value of R

= 10 Ω, it shows a faster reduction in the power factor to the increase in the value of the inductive reactance than in the RLC circuit with a value of R = 20 Ω. The average relative uncertainty between the experimental results and the simulation results shows a value of 9.0% for R = 10 Ω and 0.99% for R = 20 Ω.

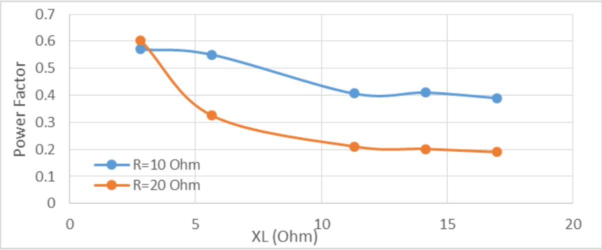

Figure 7. The relation of Power Factor (Cos φ) to XL for R = 10Ω and 20Ω in the RLC parallel circuit based on experimental data

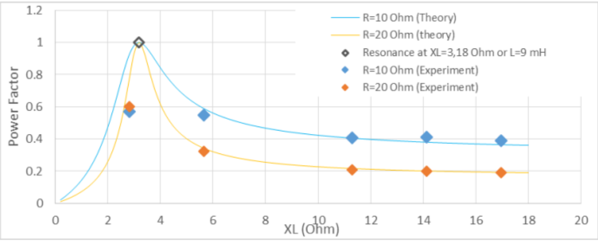

Figure 8. Graph of cos φ against XL in a parallel RLC circuit experimentally and in simulation

In Figure 7, R = 10 Ω and R = 20 Ω shows the same pattern, namely the reduction in the power factor value to the increase in the value of inductive reactance. The decrease in the power factor value for R = 20 Ω is faster than the decrease in the power factor for R = 10 Ω.

The maximum power factor value for both R values is obtained at XL = 3.18 Ω or L = 9 mH. Meanwhile, based on the results of simulation calculations, resonance occurs at XL = XC = 3.18 Ω or at L = 10.14 mH. Figure 6 shows a graph of the relationship between the power factor and inductive reactance of the experimental and simulation calculations for a parallel RLC circuit.

The simulation parallel RLC circuit calculation results show that the power factor value increases sharply before resonance and decreases after resonance with the increase in the value of inductive reactance. In the parallel RLC circuit, the experimental and simulation results both show that the power factor value decreases with the increase in the value of the inductive reactance. For a parallel RLC circuit with a value of R = 20 Ω, it shows a faster reduction in the power factor to the increase in the value of the inductive reactance compared to the value of R = 10 Ω. The average relative uncertainty between the experimental results and the simulation results shows a value of 12.0% for R 10 Ω and 10.1% for R = 20 Ω. [10]

5. CONCLUSION

The relation between the inductance value and the power factor based on the experimental results and the simulation calculation results both show the same behaviour or pattern for both series RLC circuits and parallel RLC circuits. In the series RLC circuit and the parallel RLC circuit, both show that the power factor value will decrease with the increase in the value of the inductance after passing resonance. The rate at which the power factor value declines against the inductance value will be different for different resistance values. For series RLC circuits with R = 10 Ω, the power factor decreases faster than series RLC circuits with R = 20 Ω, while parallel RLC circuits with R = 20 Ω will experience a decrease in power factor faster than parallel RLC circuits with R = 10 Ω.

ACKNOWLEDGMENT

This work was supported by Polban Research and Community Service Unit with the Laboratory Capacity Enhancement research scheme and the implementation contract number was B/186.24/PL1.R7/PG.00.03/2020.

REFERENCES

[1] Sameron, P., and Litran, S.P.: ' Improvement of the Electrical Power Quality Using Series Active and Shut Passive Filter', IIEE Transactions on Power Delivery, 2010, 25,(2), pp. 1058–1067.

[2] Jose, M.L.V., et.al.: 'Toridal versus Spiral Inductors in Multilayered Tecnologies', IIEE Radio Frequency Integrated Circuits Symposium, 2016, pp. 55–58.

[3] Ghanim, T.H., et.al. : 'Study the Effect of Serial Inductance on Reducing the Current Harmonic Distrotion of Three-Phase Bridge Rectifier', Tikrit Journal of Engineering Sciences, 2018, 25(3) pp. 1–4.

[4] Ansari, S., et.al.: ' Dynamic Performance Analysis of AC Voltage Regulator Feeding RLC Load', Engineering Science and Technology International Research Journal, 2017, 1,(4), pp. 21–26.

[5] Nuraini, Badriana.: ' Perancangan Perbaikan Faktor Daya Lampu TL dengan Kapasitor', Jurnal Energi Elektrik, 2018, 7, (2), pp 11-15.

[6] Faroda.: 'Analisis Inverter Pada Pembangkit Listrik Kapagen dengan menggunakan Grounding', Jurnal Surya Energy, 2018, 3, (1), pp 228-233

[7] McHutchon, Andrew.: 'RLC Resonant Circuits', Cambridge Machine Learning Group, 2013, pp 1-7.

[8] Marin, C., Popa, I.F.: 'Direct/Reverse Analogy Between Mechanical System and RLC Series/Paralel

Alternative Current Circuits-AC', The Scientific Bulletin of Valaha University, 2019, 17, (16), pp 56-67.

[9] Jovanović, B., Damnjanović, M., Petković, P. "Digital Signal Processing for an Integrated Power Meter ", Conference Proceedings of 49. Internationales Wissenschaftliches Kolloquium Technische Universirtat Ilmenau 27-30 September 2004, Vol. 2, pp. 190-195

[10] Muldiani, R. F. and Hadiningrum K. 'Optimasi Alat Praktikum Termodinamika Hukum Charles Gay-Lussac untuk Mahasiswa Rekayasa Politeknik Negeri Bandung' *Pros. Seminar Nas. Fis. dan Apl.* **3,** 2018, pp 237-245.