Pythagorean Theorem for Solving Simple RLC Circuit Problems

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Abstract. A simple solution to solving the problem of alternating current circuit materials. Alternating current circuit material is a material that has many mathematical equations and depends on the type of circuit combination. The combination of circuits on alternating current material is RC, RL, LC, and RLC circuits. This study will discuss the identification of the Pythagorean theorem and the impedance equations in simple series RL, RC, and RLC circuits. The steps in this research are to solving the impedance problem in alternating current circuit, then link the alternating current solutions using the Pythagorean theorem equation. The results of the relationship between the Pythagorean theorem and impedance equations in RC, RL, and RLC circuits have been tested in a limited way in student learning. Feedback has been obtained with positive values. In addition, its effectiveness has also been tested and has a high level of effectiveness which can be seen from the increase in post-test scores.

Keywords: Effectiveness · Pythagorean Theorem · Response · RLC circuit

1 Introduction

The paradigm shift from the 20th century to the 21st century has provided convenience in almost all fields, including education [1]. One of them is the implementation of learning evaluation which was previously carried out manually or Paper Based Test (PBT) which has now been changed to Computer Based Test (CBT) [2]. But on the other hand, the application of the CBT system also provides weaknesses, one of which is in computational subjects such as physics and mathematics. In these subjects students are required to be able to calculate more quickly and accurately by not using a lot of blank paper during the process. Even though in general students need a lot of blank paper in the process of solving physics [3].

The problems above indicate that there is a gaps in the process of implementing CBT-based exams. Therefore we need a method that is fast and precise in solving CBT-based exam questions, especially math subjects such as physics and mathematics so that students can answer correctly and can use processing time more efficiently. One fast way that can be used to solve physics problems is to use the Pythagorean theorem, because fast tricks are usually associated with mathematics and one of the links between physics and mathematics is the Pythagorean theorem [4].

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Based on data from the results of the 2019 UNBK assessment in physics subjects equivalent to SMA/MA, it shows that Indonesia ranks second lowest after mathematics with an average score of 46.47% [5]. Jember Regency with a total of 8,345 high school students, there are still 104 students whose scores are in the range of 85–100, while the other 5,113 students are still in the range of values 0–55 [6]. This shows the data that the results of studying physics at the high school level are still low.

The low physics learning outcomes are caused by several factors, including the short time to work on exam questions and subject matter that is too difficult to understand and the many mathematical equations in it [7]. One of the physics materials that students consider difficult and becomes the material for the National Examination as well as state university entrance exams, one of which is alternating current material. This is because the solution requires quite complicated mathematical calculations and approaches so that students experience difficulties [8]. Therefore, a simpler method is needed to solve the alternating current problem. A special, simpler way is to link the equations in the alternating current material, namely the RLC circuit, into an easier equation form, namely the Pythagorean theorem. This is because the equations in the RLC circuit are identical to the equations in the Pythagorean theorem.

Previous research on the Pythagorean theorem in solving physics problems has been carried out by Supriadi et al. in each sub-discussion of Einstein's special relativity, namely length contraction, time dilation, and relativistic mass [9]. This result has also been tested for its effectiveness by Khasanah et al. and the results obtained by the Pythagoras theorem are effective in solving problems [10]. In addition, students' responses to the Pythagorean theorem also have a strong average criterion [11].

Jati and Priyambodo in their book have explained about the transmission of Kirchhoff's Voltage Law (KVL) equations in AC circuits into the triangular shapes of cos and sin [12]. Research by Irvan et al. has also analyzed the ratio of active power, reactive power, and passive power in AC circuits using the help of a power triangle [13]. Furthermore, Iqrammullah et al. have also succeeded in linking the Pythagorean equation to the mathematical process of designing a three-phase distribution line power detector [14].

Based on the description of the problem and the success of previous research, the researcher wants to provide alternative solutions for students in solving Multi-plechoice questions on PBT and CBT based exams on alternating current circuit material using the Pythagorean theorem and will test its effectiveness and response to learning.

2 Equations in a Simple RLC Circuit

A. Series RL Circuit

The series RL circuit is a circuit that contains resistors and inductors arranged in series [15]. The value of resistance R can include other resistances in the circuit [16]. The RL circuit is as shown in Fig. 1.

So, to find the value of the voltage between points a and b, b and c, and a and c is to use the voltage equation between the two ends of the resistance, namely.

$$V_{ab} = V_R = I_m \ R \ \sin \ \omega t \tag{1}$$

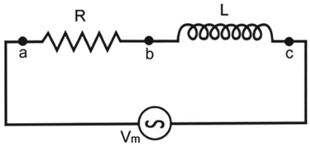


Fig. 1. Series RL Circuit

In the L circuit the voltage between the two ends of the inductor has a phase leading current of $\frac{\pi}{2} = 90°$ [17]. Then obtained.

$$V_{bc} = V_L = I_m X_L \ \sin(\omega t - 90°) \tag{2}$$

By substituting Eqs. (1) and (2), the voltage between the right end of the resistor and the left end of the inductor becomes

$$V_{ac} = V_{ab} + V_{bc}$$

$$= I_m R \ \sin \ \omega t + I_m X_L \ \sin(\omega t - 90°) \tag{3}$$

By using a flat axis having a phase angle ωt it can be used a solution

$$V_m = \sqrt{(I_m R)^2 + (I_m X_L)^2}$$

$$= \mathrm{I_m}\sqrt{\mathrm{R}^2 + \mathrm{X_L}^2} \tag{4}$$

$$\text{And} \qquad \tan \ \theta = \frac{I_m X_L}{I_m R} = \frac{X_L}{R} \tag{5}$$

Then the general form of the stress between points a and c is:

$$V_{ac} = V_m \ \sin(\omega t + 90°)$$

$$= \mathrm{I_m}\sqrt{\mathrm{R}^2 + \mathrm{X_L}^2} \ \sin(\omega t - 90°) \tag{6}$$

Or it can be written with

$$V_{ac} = I_m Z_{RL} \ \sin(\omega t - 90°) \tag{7}$$

With Z_{RL} is the impedance of the circuit RL

$$Z_{RL} = \sqrt{\mathrm{R}^2 + \mathrm{X_L}^2} \tag{8}$$

Because $V_{ab} = V_R$ and $V_{bc} = V_L$ then the equation $V_{ac} = V_{ab} + V_{bc}$ can be written with

$$V_{ac} = V_{RL} = \sqrt{V_R{}^2 + V_L{}^2} \tag{9}$$

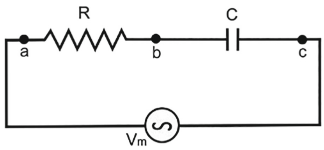


Fig. 2. Series RC Circuit

B. Series RC Circuit

The RC circuit is a circuit that contains resistors and capacitors arranged in series [15]. The RC circuit is one of the most frequently encountered circuits in everyday life. The RC circuit is as shown in Fig. 2.

So, to find the value of the voltage between points a and b, b and c, and a and c is to use the voltage equation between the two ends of the resistance. In circuit C the voltage at the two ends of the capacitor is left by $\frac{\pi}{2} = 90°$ against current [16]. Then it can be written as

$$V_{bc} = I_m X_C \ \sin(\omega t + 90°) \tag{10}$$

By substituting Eqs. (1) and (10) the equation becomes

$$V_{ac} = V_{ab} + V_{bc}$$

$$= I_m R \ \sin \ \omega t + I_m X_C \ \sin(\omega t + 90°) \tag{11}$$

Using a flat axis with a phase angle ωt then a solution can be used

$$V_m = \sqrt{(I_m R)^2 + (I_m X_C)^2}$$

$$= I_m \sqrt{R^2 + {X_C}^2} \tag{12}$$

$$\text{And} \qquad tan\theta = \frac{I_m X_C}{I_m R} = \frac{X_C}{R} \tag{13}$$

Then the general form of the stress between points a and c is:

$$V_{ac} = V_m \ \sin(\omega t - \varphi)$$

$$= I_m \sqrt{R^2 + {X_C}^2} \ \sin\left(\omega t + 90°\right) \tag{14}$$

Or it can be written with

$$V_{ac} = I_m Z_{RC} \ \sin(\omega t + 90°) \tag{15}$$

With Z_{RC} is the impedance of the RC circuit

$$Z_{RC} = \sqrt{R^2 + {X_C}^2} \tag{16}$$

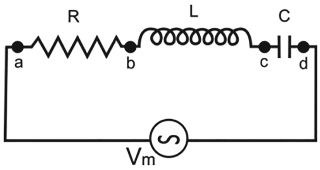


Fig. 3. Series RLC Circuit

Because $V_{ab} = V_R$ and $V_{bc} = V_C$ then the equation $V_{ac} = V_{ab} + V_{bc}$ can be written with

$$V_{ac} = V_{RC} = \sqrt{{V_R}^2 + {V_C}^2} \tag{17}$$

C. Series RLC Circuit

The RLC circuit is a circuit that contains resistors, capacitors and inductors and is connected to a generator with an EMF source. The arrangement of the RLC circuit is as shown in Fig. 3.

So, to find the value of Vad is to use the RL circuit equation for Vac as Eq. (3) and the LC circuit for Vbd. Between points b and d there are inductors and capacitors arranged in series, so that the voltage equation in the LC circuit is as follows:

$$V_{bd} = I_m X_L \sin\left(\omega t - 90^\circ\right) - I_m X_C \sin\left(\omega t + 90^\circ\right)$$

$$= I_m (X_L - X_C) \sin\left(\omega t + 90^\circ\right) \tag{18}$$

So, for the voltage value between points a and d there are three components arranged in series namely resistors, capacitors, and inductors so that the total voltage is

$$V_{ad} = V_{ab} + V_{bc} + V_{cd}$$

$$= V_R + V_L + V_C$$

$$= I_m R \sin \omega\mathrm{t} + I_m X_L \sin\left(\omega\mathrm{t} - 90^\circ\right)$$

$$+ I_m X_C \sin \sin\left(\omega\mathrm{t} + 90^\circ\right) \tag{19}$$

The sum of these three terms when depicted in a phasor diagram is as shown in Fig. 4.

So mathematically the equation for the RLC circuit is as follows.

$$X_L > X_C \qquad V_m = \sqrt{(I_m R)^2 + (I_m X_L - I_m X_C)^2}$$

$$= I_m \sqrt{R^2 + (X_L - X_C)^2}$$

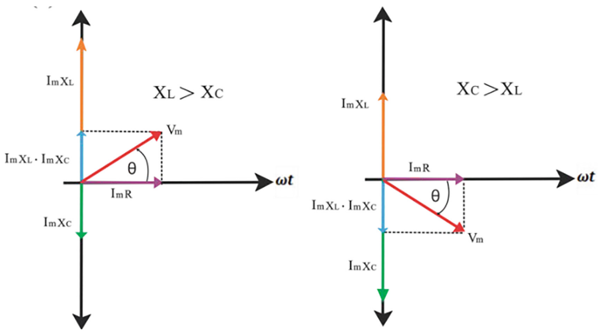


Fig. 4. Phasor diagram for addition in Eq. (19)

$$= I_m Z_{RLC} \tag{20}$$

Or $$V_m = V_{RLC} = V_R + V_L + V_C$$

$$V_{RLC} = \sqrt{{V_R}^2 + (V_L - V_C)^2} \tag{21}$$

$X_C > X_L$ $$V_m = \sqrt{(I_m R)^2 + (I_m X_C - I_m X_L)^2}$$

$$= I_m \sqrt{R^2 + (X_C - X_L)^2}$$

$$= I_m Z_{RLC} \tag{22}$$

Or $$V_m = V_{RLC} = V_R + V_C + V_L$$

$$V_{RLC} = \sqrt{{V_R}^2 + (V_C - V_L)^2} \tag{23}$$

where Z_{RLC} is the total impedance of the series RLC circuit

$$Z_{RLC} = \sqrt{R^2 + (X_L - X_C)^2}; X_L > X_C \tag{24}$$

$$Z_{RLC} = \sqrt{R^2 + (X_C - X_L)^2}; X_C > X_L \tag{25}$$

3 Method

In this study, the relationship between the Pythagorean theorem equations and the equations in a simple RLC circuit will be analyzed with the following steps, namely calculating in simple RLC circuits, calculating the equations of the Pythagorean theorem, analyzing how the relationship between the equations of simple RLC circuits and equations

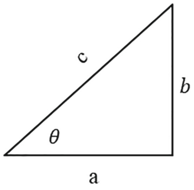


Fig. 5. Phtagoras Triangle

in the Pythagorean theorem, then test the effectiveness and response of these relationships in learning. The steps for calculating the RLC circuit equation and the Pythagorean theorem equation are as follows.

A. Phytagoras Theorem

In the book The Pythagorean Theorem it is explained that "In any right triangle, the square of the length of the longest side (hypotenuse) is equal to the sum of the squares of the lengths of each of the sides of the other triangles." The image of the Pythagorean triangle is as shown in Fig. 5.

From Fig. 5, the Pythagorean equation will be obtained:

$$c^2 = a^2 + b^2 \quad \text{or} \quad c = \sqrt{a^2 + b^2} \tag{26}$$

$$Sin\ \theta = \frac{b}{c} \tag{27}$$

$$Cos\ \theta = \frac{a}{c} \tag{28}$$

The Pythagorean theorem can also be obtained from the trigonometric relationship sin and cos with the following equation.

$$Sin^2\ \theta + Cos^2\ \theta = 1 \tag{29}$$

$$\text{So, it will be obtained : } \frac{b^2}{c^2} + \frac{a^2}{c^2} = 1 \tag{30}$$

Equation (30) is identical to the impedance and voltage equations in series RL, RC, and RLC circuits. Therefore, the impedance and voltage equations when associated with the Pythagorean theorem are as follows.

B. Series RL Circuits in the Phytagoras Theorem

By using Eq. (30) above, the impedance and voltage equation in the RL circuit can be written as follows:

$$\frac{R^2}{Z_{RL}{}^2} + \frac{X_L{}^2}{Z_{RL}{}^2} = 1 \tag{31}$$

$$\frac{V_R{}^2}{\mathrm{V}_{RL}{}^2} + \frac{V_L{}^2}{\mathrm{V}_{RL}{}^2} = 1 \tag{32}$$

C. Series RC Circuits in the Phytagoras Theorem

In the equation of a series RC circuit using the Pythagorean method, the impedance and voltage equations are obtained as follows:

$$\frac{\mathrm{R}^2}{\mathrm{Z_{RC}}^2} + \frac{\mathrm{X_C}^2}{\mathrm{Z_{RC}}^2} = 1 \tag{33}$$

$$\frac{V_R{}^2}{\mathrm{V}_{RC}{}^2} + \frac{V_C{}^2}{\mathrm{V}_{RC}{}^2} = 1 \tag{34}$$

D. Series RLC Circuits in the Phytagoras Theorem

In the series RLC circuit equation with the Pythagorean method, the impedance and voltage equations are obtained as follows:

$$\frac{R^2}{\mathrm{Z}_{RLC}{}^2} + \frac{(X_L - X_C)^2}{\mathrm{Z}_{RLC}{}^2} = 1 \tag{35}$$

$$\frac{R^2}{\mathrm{Z}_{RLC}{}^2} + \frac{(X_C - X_L)^2}{\mathrm{Z}_{RLC}{}^2} = 1 \tag{36}$$

$$\frac{V_R{}^2}{\mathrm{V}_{RLC}{}^2} + \frac{(V_L - V_C)^2}{\mathrm{V}_{RLC}{}^2} = 1 \tag{37}$$

$$\frac{V_R{}^2}{\mathrm{V}_{RLC}{}^2} + \frac{(V_C - V_L)^2}{\mathrm{V}_{RLC}{}^2} = 1 \tag{38}$$

so, Eqs. 31–38 are the impedance and voltage equations for series AC circuits that have been linked to the Pythagoras theorem. This equation is then described by the Pythagorean triangle.

E. The Effectiveness of the Phytagoras Theorem in Solving RLC Circuit Problems

The effectiveness of the Pythagorean Theorem in a simple RLC circuit can be seen from the increase in the pretest and posttest scores. In this study, researchers used the N-Gain Test to see an increase. The value of N-gain <g> can be calculated using the formula:

$$N - Gain = \frac{\boldsymbol{Post\ Test\ Score - Pretest\ Score}}{\textbf{Ideal Score} - \textbf{Pretest Score}}$$

With the N-gain Level Criteria [18] (Table 1).

Table 1. N-Gain Level Criteria

Limit	Criteria
$0,7 \leq \langle g \rangle$	High
$0,3 \leq \langle g \rangle < 0,7$	Currently
$\langle g \rangle < 0,3$	Low

Table 2. Student Response Criteria

Percentage Interval (%)	Criteria
$80\% < P \leq 100\%$	Very good
$60\% < P \leq 80\%$	Well
$40\% < P \leq 60\%$	Enough good
$20\% < P \leq 40\%$	Not good
$0\% \leq P \leq 20\%$	Very not good

F. Student Response

Analysis of student responses using a Likert scale for each indicator of student responses and analysis of student responses as a whole, which aims to measure a person's attitudes, opinions, and perceptions [19]. Analyze the results of the response using the following formula:

$$\boldsymbol{Presentase(P)} = \frac{\boldsymbol{Respondents'\ total\ answers}}{\boldsymbol{Maksimum\ Score}} \boldsymbol{x} 100\%$$

Results Percentage (P) can be classified according to the score criteria described in Table 2 [20].

4 Result and Discussion

Based on the results of the development of the theory, several equations have been obtained which are associated with the Pythagorean theorem. So that the data analysis table uses analytical methods to determine the relationship between the Pythagorean theorem and the alternating current equations as follows (Table 3).

The results of this study have been validated based on the results of research by Supriadi et al. [9]. After finding a simple equation which is the relationship between the Pythagorean Theorem and a simple RLC circuit. Furthermore, the effectiveness test was carried out in the learning process using Pretest and Posttest. The respondents of this study were students a high school in Jember Regency. The effectiveness of the Pythagorean Theorem in a Simple RLC Circuit was determined by calculating the N-Gain from the average of the Pretest and Posttest results. Data on the effectiveness of the Pythagorean Theorem in a Simple RLC Circuit can be seen in Table 4.

Table 3. Impedance and Voltage Equation Analysis With Phytagoras Theorem Equation

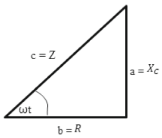
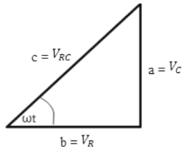
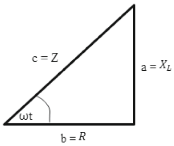
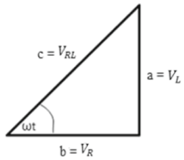
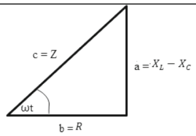
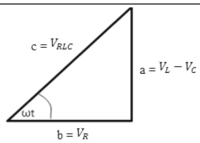
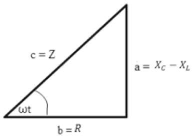
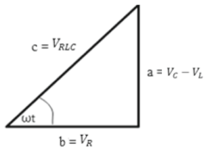
Pythagoras Theorem for Impedance	Impedance triangle Picture for Impedance	Pythagoras Theorem for Voltage	Impedance triangle Picture for Voltage
$\frac{R^2}{Z_{RC}{}^2}+\frac{X_C{}^2}{Z_{RC}{}^2}=1$	 $\frac{R^2}{Z_{RC}{}^2}+\frac{X_L{}^2}{Z_{RC}{}^2}=1$	$\frac{V_R{}^2}{V_{RC}{}^2}+\frac{V_C{}^2}{V_{RC}{}^2}=1$	 $\frac{V_R{}^2}{V_{RC}{}^2}+\frac{V_C{}^2}{V_{RC}{}^2}=1$
$\frac{R^2}{Z_{RL}{}^2}+\frac{X_L{}^2}{Z_{RL}{}^2}=1$	 $\frac{R^2}{Z_{RL}{}^2}+\frac{X_L{}^2}{Z_{RL}{}^2}=1$	$\frac{V_R{}^2}{V_{RL}{}^2}+\frac{V_L{}^2}{V_{RL}{}^2}=1$	 $\frac{V_R{}^2}{V_{RL}{}^2}+\frac{V_L{}^2}{V_{RL}{}^2}=1$
$\frac{R^2}{Z_{RLC}{}^2}+\frac{(X_L-X_C)^2}{Z_{RLC}{}^2}=1$	 $\frac{R^2}{Z_{RLC}{}^2}+\frac{(X_L-X_C)^2}{Z_{RLC}{}^2}=1$	$\frac{V_R{}^2}{V_{RLC}{}^2}+\frac{(V_L-V_C)^2}{V_{RLC}{}^2}=1$	 $\frac{V_R{}^2}{V_{RLC}{}^2}+\frac{(V_L-V_C)^2}{V_{RLC}{}^2}=1$
$\frac{R^2}{Z_{RLC}{}^2}+\frac{(X_C-X_L)^2}{Z_{RLC}{}^2}=1$	 $\frac{R^2}{Z_{RLC}{}^2}+\frac{(X_C-X_L)^2}{Z_{RLC}{}^2}=1$	$\frac{V_R{}^2}{V_{RLC}{}^2}+\frac{(V_C-V_L)^2}{V_{RLC}{}^2}=1$	 $\frac{V_R{}^2}{V_{RLC}{}^2}+\frac{(V_C-V_L)^2}{V_{RLC}{}^2}=1$

Table 4. Pythagorean Theorem Effectiveness Results Data in Simple RLC Circuit

Average *Pretest*	Average *Posttest*	*N-Gain*	Interpretation
44.64	83.93	0.71	Currently

Table 5. Student Response Questionnaire Data

Questionnaire Indicator	Presents	Category
Students Listen to Learning Explanations	77,2%	Good
Students Take an Active and Responsive Role in Learning	72%	Good
Students Dare to Ask	70%	Good

Table 4 shows that the effectiveness of the Pythagorean Theorem on a Simple RLC Circuit in a high school in Jember Regency with an average pretest result of 44.64 and an average posttest result of 83.93 obtained an N-Gain value of 0.71. According to the interpretation based on Hake and Richard in Husein the N-Gain results are in the range of 0.7 $\langle g \rangle$ so it can be categorized as High [20].

Student response data was obtained by providing response questionnaires to students after completing all learning activities. The student response data can be seen in Table 5.

Table 5 shows the aspect of students listening to learning explanations 77.2%, in the aspect of students playing an active and responsive role in learning 72%, and in the aspect of students having the courage to ask 70%, so that if according to the response criteria all aspects are in the range of $60\% < P \leq 80\%$ so that it can be categorized as good [20]. The average overall response result is 74% so that the Pythagorean Theorem on the Simple RLC Circuit gets a good response for students.

5 Conclusion

Based on the calculation of impedance and voltage equations in the RL, RC, and RLC circuits that have been obtained. The results of the analysis show that the RL, RC, and RLC circuits have the same equation form as the Pythagorean theorem. The similarity of these equations can make the Pythagorean theorem a simple solution for solving simple AC circuit problems. This is also supported by research data that the Pythagorean Theorem in Simple RLC Circuits has a high effectiveness value and gets a good response from students. So that future researchers can provide simple solutions for solving physics problems for students on other materials using the same theorem as this study, namely the Pythagorean theorem. So that students are more assisted with new, simpler completion steps in various materials.

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