Mesh and Supermesh Analysis Methods of Electrical Circuits Using The Electronics Workbench Virtual Laboratory

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ABSTRACT
Electrical circuit courses require students to think analytically in understanding the context of the problems contained in electrical circuits. The use of formulas with a fairly long calculation process and the many mathematical equations used to analyze electrical circuits make students find it difficult to learn electrical circuit courses. In addition, the COVID-19 pandemic condition also requires them to continue to study at home with all the limitations that exist. To help the analytical thinking process of students and the practicum learning process can continue, this study aims to apply Kirchhoff's law and Ohm's law to the mesh and supermesh analysis method of electrical circuits carried out using the Electronics Workbench virtual laboratory. The research method used is descriptive analysis study which consists of literature study, analysis, simulation, data collection, and evaluation. The results showed that the application of Kirchhoff's law and Ohm's law can be applied to facilitate the analysis of an electrical circuit. Mesh and supermesh analysis methods of electrical circuits can be simulated using a virtual Electronics Workbench laboratory which plays a role in proving the truth of the results of the analysis that have been carried out so that they can be implemented in practical learning activities. In general, students strongly agree that the Electronic Workbench virtual laboratory is used in electric circuit practicum learning during the COVID-19 pandemic with an average score of 3.32.

Keywords: *Mesh, Supermesh, Virtual Laboratory*

1. INTRODUCTION

Electrical circuits are one of the basic courses that must be taken in semester 1 by students of the Electro-medical Engineering Technology Study Program, Universitas PGRI Yogyakarta. This course has a weight of 3 credits consisting of 1 credit of theory and 2 credits of practice. Electrical circuit courses discuss a lot of conceptual learning material [1]. This course studies the basic concepts of electric circuits, basic laws of electric circuits, components of electric circuits, methods of electric circuit analysis, and electric circuit theorems. Electrical circuit courses require students to think analytically in understanding the context of the problems contained in electrical circuits. In addition, students are also required to be careful in analyzing electrical circuits because errors often occur in the calculation process [2]. The use of formulas with a fairly long calculation process and the many mathematical equations used to analyze electrical circuits make students find it difficult to learn electrical circuit courses.

During the Covid-19 pandemic, electric circuit lectures experienced difficulties because the learning process was carried out online so that practical activities were carried out virtually. Facilities and infrastructure that are not supportive are also an obstacle in electrical circuit lectures. In addition, the diverse educational backgrounds of students are also a big challenge for teaching students. This has an impact on the learning outcomes obtained by students. Based on the results of the learning evaluation for electrical circuit courses in the 2020/2021 academic year, it shows that of the 12 students, the most B- scores were obtained by students and not one student has yet received an A. The data on the value of the electric circuit can be seen in Figure 1.

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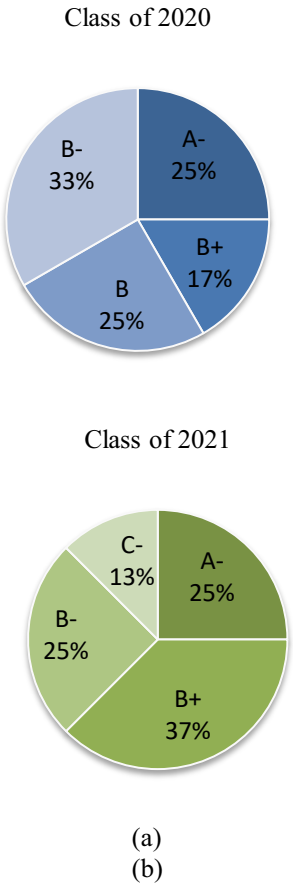

FIGURE 1. The score of the electrical circuit course for UPY's Electro-medical Engineering Technology students (a) Class of 2020 and (b) Class of 2021

The data in Figure 1 shows that students have difficulty in studying electrical circuit courses. This is evidenced by the absence of students who have obtained an A grade, even though all students have passed the electrical circuit course. This becomes an evaluation material to improve the quality of student learning outcomes which of course require special strategies in dealing with various kinds of problems that occur during the learning process, especially when learning is carried out online.

1.1. Electrical Circuit Analysis Method

The electrical circuit analysis method is one way to help solve a problem that arises in analyzing an electrical circuit. There are several methods that can be used to analyze electrical circuits, including mesh and supermesh analysis. Mesh and supermesh analysis are loop currents that are assumed to flow in a closed circuit. Mesh & supermesh analysis is based on Kirchhoff's 2nd Law which reads "The sum of the voltages in a closed circuit is equal to zero" [3].

There are several things that need to be considered in analyzing electrical circuits using the mesh analysis method, namely: 1) create a loop current in a closed circuit, the loop current can be clockwise or counterclockwise; 2) the number of loop currents indicates the number of equations generated; and 3) this method is easier to calculate if the supply source is a voltage source [3].

If there is a current source in the electric circuit, then the current source is treated as a supermesh. The selection of supermesh paths must avoid current sources because the current source is not known for its voltage value. There are several things that need to be considered in analyzing electric circuits using the supermesh analysis method, namely: 1) create a loop current in a closed circuit, the loop current can be clockwise or counterclockwise; 2) the number of loop currents indicates the number of equations generated; 3) this method is easier to calculate if the supply source is a voltage source; and 4) avoiding current sources because the current source is not known for its voltage value [3].

1.2. Kirchhoff's Law

Kirchhoff's law and Ohm's law as the basic laws of electric circuits can be used to analyze electrical circuits using mesh and supermesh analysis methods [2]. Kirchhoff's law was proposed by a German physicist named Gustav Robert Kirchhoff. Kirchhoff's law is divided into two, namely Kirchhoff's Law 1 on Kirchhoff's Current Law (KCL) and Kirchhoff's 2nd Law on Kirchhoff's Voltage Law (KVL) [4].

Kirchhoff's 1st law states that the number of currents entering through a branching point (node) is equal to the number of currents leaving the branching point (node), in other words the sum of all currents at a branching point (node) is equal to zero [5]. Mathematically Kirchhoff's Law 1 is written in equation 1:

$$\sum I = 0 \tag{1}$$

Kirchhoff's 2nd law states that the sum of the voltages in a closed circuit is equal to zero, or the sum of the voltages on each of its constituent components that make up a closed circuit will be equal to zero [5]. Mathematically Kirchhoff's 2nd Law is written in equation 2:

$$\sum V = 0 \tag{2}$$

In general, the material on Kirchhoff's Law has been understood by students, but most of them are still confused about applying the law in the context of electrical circuit problems. They already know the mathematical equations of Kirchhoff's Laws, but they have not been able to apply these laws to analyzing electric circuits.

1.3. Ohm's Law

Ohm's law was proposed by a German physicist named Georg Simon Ohm [4]. Ohm's law states that the voltage through the conducting material is directly proportional to the current flowing through the material [5]. Mathematically Ohm's Law is written in equation 3:

$$V = I.R \tag{3}$$

In general, the material on Ohm's Law has also been understood by students, but most of them are still confused about applying the law in the context of electrical circuit problems. They already know the mathematical equations of Ohm's Law, but they have not been able to apply the law to analyze electrical circuits.

1.4. Virtual Laboratory

The limitations of the practical learning process using a conventional laboratory can be overcome by applying practical learning using a virtual laboratory [6]. Virtual laboratories can assist students in overcoming the problem of incomplete facilities in conventional laboratories [7]. Simulation-based virtual laboratories assist educational institutions in expanding their academic reach and minimizing operational costs [8].

Virtual laboratories can help achieve practical skills and help in understanding laboratory content [9]. Virtual laboratories allow students to do practicals anywhere [10]. The virtual laboratory is easy to use and helps students to avoid mistakes that may occur during practicum [11]. Virtual laboratories can help students become independent learners because they can be used flexibly and are more economical than conventional laboratories [12], so virtual laboratories can overcome the high cost of practicum equipment [13]. In addition, virtual laboratories have advantages compared to conventional laboratories such as providing greater flexibility to carry out practicum [14]. By implementing a virtual laboratory, students can interact with the simulation method [15].

A study conducted in Slovenia showed that virtual laboratories can help in better understanding of learning materials [16]. Studies conducted in Saudi Arabia show that virtual laboratories play an important role in supporting the field of scientific learning and also for acquiring practical skills [17]. Studies conducted in India show that more than 90% of students are happy with virtual laboratories and their learning process is improved by implementing virtual laboratories in practical learning [7].

1.5. Electronics Workbench

Electronics Workbench is one of the electronics software that can be used to simulate electrical circuits [18]. By using this software, students can learn to assemble electrical circuits and perform virtual simulations with animations that look attractive and provide an overview of the performance of electrical circuits [19]. In addition, by using this software, students also do not need to buy the components needed to assemble electrical circuits and can reduce the occurrence of errors when assembling electrical circuits [20]. The use of this software is very easy and practical, all of its components are displayed on the workspace in the form of symbols and classified according to their type [21]. This software can be downloaded for free and can be used for learning activities [22]. This is very supportive of the online learning process during the Covid-19 pandemic.

Electronics Workbench is able to visualize the basic concepts of the electronics world. In this software there are several components that are presented virtually and can be assembled into an electrical circuit [19]. These components can be assembled into an electrical circuit on the Electronics Workbench software worksheet.

Research related to the use of Electronics Workbench software simulation has been carried out by several researchers. Research conducted by Islahudin states that there is a significant effect between the use of Electronics Workbench software as a virtual laboratory on understanding basic electronics concepts [19] and can improve student learning outcomes [23]. Another study conducted by Muhammad Zulfadhly stated that the Electronics Workbench can improve student learning outcomes in Basic Electrical and Electronics subjects [20]. Based on this background, this study aims to apply Kirchhoff's Law and Ohm's Law to the electrical circuit analysis method carried out using the Electronics Workbench software simulation.

2. METHODS

The method used in this research is a descriptive study related to the application of Kirchhoff's Law and Ohm's Law on the mesh and supermesh analysis method of electrical circuits using the Electronics Workbench virtual laboratory. This research was conducted at the Electro-medical Engineering Technology Study Program, Faculty of Science and Technology, Universitas PGRI Yogyakarta. The process of carrying out the research is shown in Figure 2.

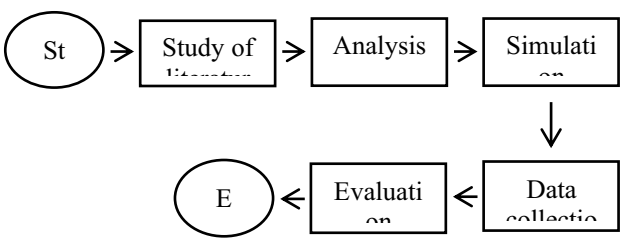

FIGURE 2. Research implementation process

This research was started by conducting a literature study to obtain information related to the application of Kirchhoff's Law and Ohm's Law to the mesh and supermesh analysis method of electric circuits. After the information was obtained, the research continued by analyzing the electrical circuit using mathematical equations. The results of the analysis are simulated using an Electronics Workbench virtual laboratory. Data collection was carried out to students by distributing questionnaires using a Likert scale with a score range of 1 to 4 as shown in Table 1. This study ended with an evaluation

.

TABLE 1. Student assessment uses a Likert scale [24]

Student Assessment	Score
Strongly disagree	1
Disagree	2
Agree	3
Strongly agree	4

3. RESULTS

The electrical circuit analysis method that will be discussed in this research is the mesh and supermesh analysis methods. These two methods were chosen because they are often used to analyse electrical circuits.

3.1. Mesh Analysis Method

The mesh analysis method can be performed when the electrical circuit has a voltage source in its circuit as shown in Figure 3.

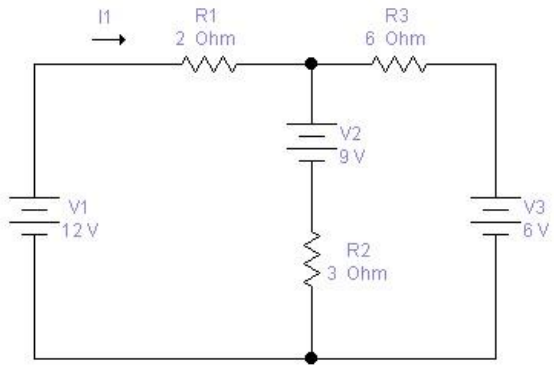

FIGURE 3. Electrical circuit with a voltage source

To get the value of I1 in Figure 3, it can be done by making loop current a (Ia) and loop current b (Ib) in a closed circuit as shown in Figure 4. For example, the direction of loop current a (Ia) and loop current b (Ib) is made clockwise. Since there are two loop currents in a closed circuit (Ia and Ib), we get two equations.

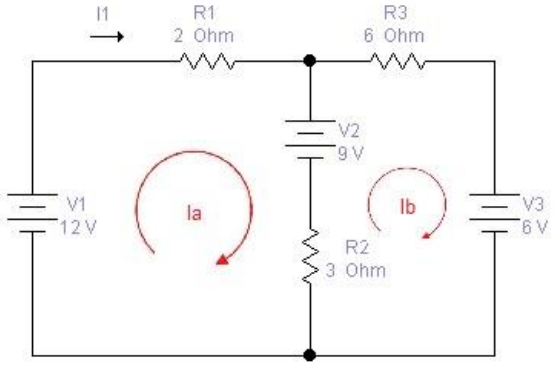

FIGURE 4. Mesh analysis method in electric circuit

Kirchhoff's Law and Ohm's Law can be applied to analyze electrical circuits.

Review loop current a (Ia):

$$R_1.I_a + V_2 + R_2(I_a - I_b) - V_1 = 0$$
$$2I_a + 9 + 3(I_a - I_b) - 12 = 0$$
$$2I_a + 9 + 3I_a - 3I_b = 12$$
$$5I_a - 3I_b = 3 \quad (4)$$

Review loop current b (Ib):

$$R_3.I_b + V_3 + R_2(I_b - I_a) - V_2 = 0$$
$$6I_b + 6 + 3(I_b - I_a) - 9 = 0$$
$$6I_b + 6 + 3I_b - 3I_a = 9$$
$$-3I_a + 9I_b = 3 \quad (5)$$

Elimination of equation (4) with equation (5):

$$5I_a - 3I_b = 3 \quad |x3| \text{ menjadi } 15I_a - 9I_b = 9$$
$$-3I_a + 9I_b = 3 \quad |x1| \text{ menjadi } \underline{-3I_a + 9I_b = 3} +$$
$$12I_a = 12$$

$$I_a = \frac{12}{12}$$
$$I_a = 1A$$

The value of I1 is the same as the value of Ia, then I1 = Ia = 1A

The results of the electrical circuit mesh analysis simulation using the Electronics Workbench virtual laboratory are shown in Figure 5.

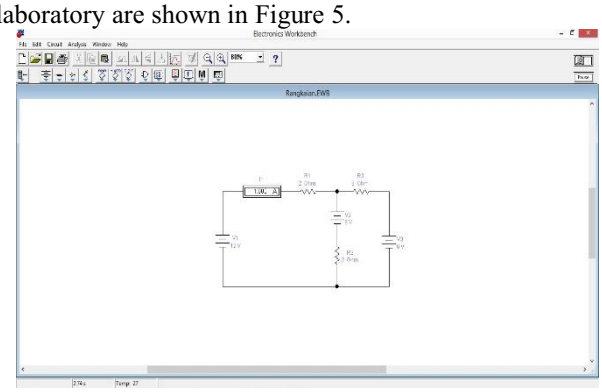

FIGURE 5. Electrical circuit mesh analysis simulation results using the Electronics Workbench virtual laboratory

3.2. Supermesh Analysis Method

The supermesh analysis method can be carried out when the electric circuit has a current source in its circuit as shown in Figure 6.

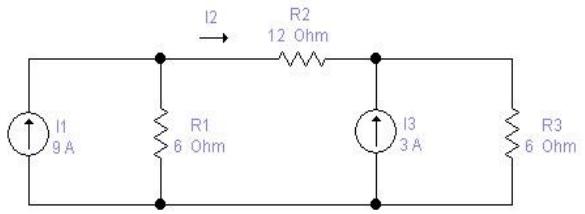

FIGURE 6. Electric circuit with current source

To get the value of I2 in Figure 6, it can be done by making loop current a (Ia), loop current b (Ib), and loop current c (Ic) in a closed circuit as shown in Figure 7. For example, the direction of loop current a (Ia), loop current b (Ib), and loop current c (Ic) are made clockwise. Since there are three loop currents in a closed circuit (Ia, Ib, and Ic), this results in three equations.

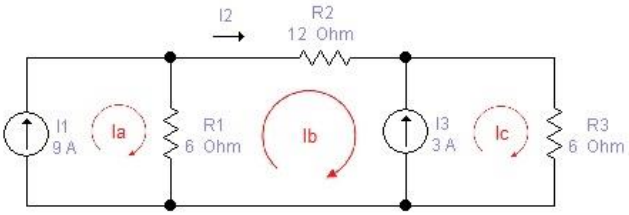

FIGURE 7. Supermesh analysis method in electric circuit

Kirchhoff's Law and Ohm's Law can be applied to analyze electrical circuits.

Review loop current a (Ia):

$$I_a = I_1 = 9A \tag{6}$$

Review loop current b (Ib) and loop current c (Ic):

$$I_c - I_b = 3A$$
$$I_c = 3 + I_b \tag{7}$$

Supermesh track review

$$R_1(I_b - I_a) + R_2.I_b + R_3.I_c = 0$$
$$6(I_b - I_a) + 12I_b + 6I_c = 0 \tag{8}$$

Substitute equation (6) and equation (7) in equation (8):

$$6(I_b - 9) + 12I_b + 6(3 + I_b) = 0$$
$$6I_b - 54 + 12I_b + 18 + 6I_b = 0$$
$$24I_b - 36 = 0$$
$$24I_b = 36$$
$$I_b = \frac{36}{24}$$
$$I_b = 1{,}5A$$

The value of I2 is the same as the value of Ib, then I2 = Ib = 1.5A

The simulation results of the electrical circuit supermesh analysis using the Electronics Workbench virtual laboratory are shown in Figure 8.

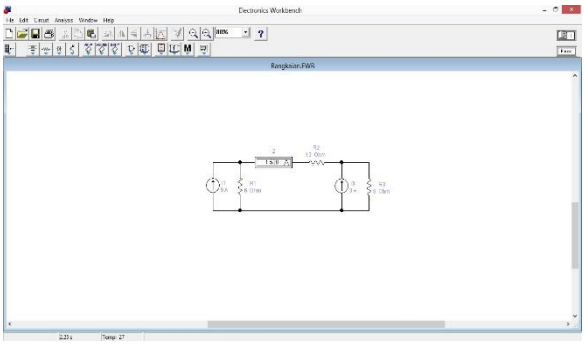

FIGURE 8. The simulation results of the electric circuit supermesh analysis using the Electronics Workbench virtual laboratory

The application of Kirchhoff's Law and Ohm's Law is the basis for analyzing an electrical circuit. Electrical circuits can be analyzed using mesh and supermesh analysis methods. Two-variable linear equation system with elimination and substitution method is also used to solve electric circuit equations. The elimination method can solve the electric circuit equation by eliminating one of the existing variables, while the substitution method can solve the electric circuit equation by inserting one equation into the other equation [25]. The application of Kirchhoff's Law and Ohm's Law as well as the use of a two-variable system of linear equations in analyzing electrical circuits is adapted to the context of the circuit. The Electronics Workbench virtual laboratory plays a role in conducting simulations and proving the truth of the results of the electrical circuit analysis that has been carried out [20].

In general, students highly agree that the Electronics Workbench virtual laboratory is used in electric circuit practicum learning during the COVID-19 pandemic with an average score of 3.32 as shown in Figure 9.

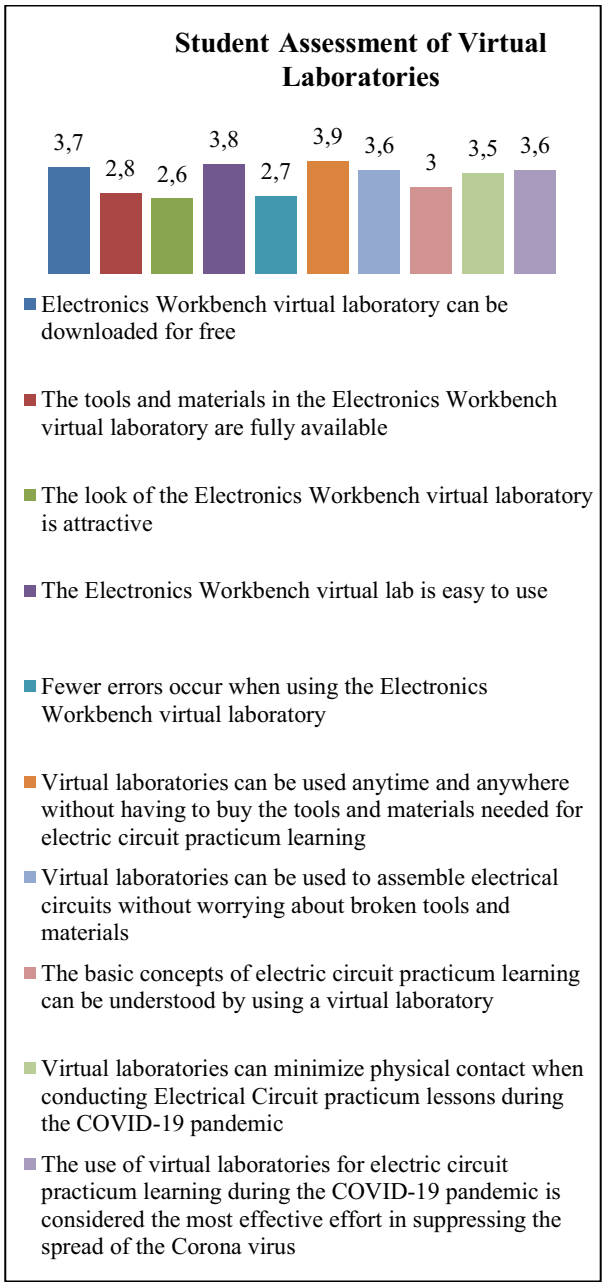

FIGURE 9. Student assessment of virtual laboratories

The evaluation results show that the application of Kirchhoff's Law and Ohm's Law on the electrical circuit analysis method using the Electronics Workbench virtual laboratory can be implemented in practical learning activities.

4. CONCLUSION

The application of Kirchhoff's Law and Ohm's Law can be applied to make it easier to analyze an electrical circuit. Electrical circuits that can be analyzed by applying Kirchhoff's Law and Ohm's Law are mesh and supermesh

analysis methods. The mesh analysis method can be performed when an electrical circuit has a voltage source in its circuit. The supermesh analysis method can be performed when the electric circuit has a current source in its circuit. The electrical circuit analysis method can be simulated using an Electronics Workbench virtual laboratory which can also prove the truth of the results of the analysis that has been carried out so that it can be implemented in practical learning activities. In general, students strongly agree that the Electronic Workbench virtual laboratory is used in electric circuit practicum learning during the COVID-19 pandemic with an average score of 3.32.

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