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The Role of the Electrical Power System Practical Module in Improving Students' Understanding of Three-Phase Imbalance

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Abstract

Instruction on three-phase unbalance in the electric power systems course has not yet made optimal use of practicum modules. This study was conducted to assess improvements in learning outcomes and student responses to the implementation of a practical module on three-phase imbalance. A quantitative approach was employed using a quasi-experimental, one-group pretest-posttest design. The results indicate that the average pretest score—initially a low 52—rose to 86.4. The mean score increased from 52 to 86.4, representing a relative increase of 66.15%, with an N-gain score of 0.72, placing it in the high category. Student response was also highly positive, with 82% selecting the "strongly agree" option; this indicates that the module aids in conceptual understanding, aligns with learning needs, and enhances skills in the field of electric power systems. Based on these findings, the developed practical module proved effective in improving students' learning outcomes and understanding of electric power systems. Therefore, the module is suitable for use as a supporting tool for instruction in this subject.

Keywords*: Practicum Module, Electric Power Systems, Three-Phase Unbalance, Learning Outcomes*

Abstrak

Pembelajaran materi ketidakseimbangan tiga fasa pada mata kuliah Sistem Tenaga Listrik belum memanfaatkan modul praktikum secara optimal. Penelitian ini dilakukan untuk mengetahui peningkatan hasil belajar serta respon mereka terhadap penerapan modul praktikum pada materi ketidakseimbangan tiga fasa. Penelitian menggunakan pendekatan kuantitatif dengan metode *quasi-eksperimental one group pretest-posttest design.* Hasil penelitian menunjukkan bahwa rata-rata nilai pretest sebesar 52 tergolong rendah, meningkat menjadi 86,4. Persentase peningkatan hasil belajar mencapai 66,15% dengan nilai N-gain 0,72 pada kategori tinggi. Respons mahasiswa juga sangat positif; sebanyak 81,65% dari seluruh jawaban berada pada kategori “sangat setuju” yang menandakan modul ini membantu pemahaman konsep, relevan dengan kebutuhan pembelajaran, serta mampu meningkatkan keterampilan dalam bidang sistem tenaga listrik. Berdasarkan hasil penelitian, modul praktikum yang dikembangkan terbukti efektif dalam meningkatkan hasil belajar dan pemahaman mahasiswa pada bidang sistem tenaga listrik. Oleh karena itu, modul praktikum tersebut layak digunakan sebagai media pendukung pembelajaran sistem tenaga listrik.

Kata kunci: Modul Praktikum, Sistem Tenaga Listrik, Ketidakseimbangan Tiga Fasa, Hasil Belajar

Introduction

Learning in higher education not only emphasizes mastery of theory, but also provides opportunities for students to experience and apply the theory directly in the field or laboratory [1]. Instructional materials support students' learning by providing essential guidance throughout the learning process, particularly when the expected outcomes involve both mastery of technical concepts and the ability to apply them in practical contexts. Teaching materials can simplify the delivery of content, clarify concepts, and make learning more engaging. Teaching materials can also help visualize ideas, and accommodate learning styles [2]. With learning in the field or laboratory, learning becomes more meaningful [3] because students not only memorize concepts, but also understand how they work and the impact of their application in real contexts. The use of applicable teaching materials, such as practical modules, is one way to create a holistic and student-centered learning experience. Limitations in the provision of relevant and interactive teaching materials can hinder the learning process, and may hinder the integration of theory and practice [4]. A practical module is one form of instructional material that can serve as an effective learning tool for connecting students' theoretical understanding with the development of their technical skills. The practical module is teaching material that is compiled independently and systematically [5] and is designed to guide students in conducting experiments, observations, data analysis and evaluation of practical results independently or under guidance.

The Electrical Engineering Education Study Program plays a vital role in preparing qualified human resources with the knowledge and competencies required to understand, analyze, and address a wide range of issues related to electric power systems. One of the competencies that students must have is the ability to understand the characteristics of three-phase electric power systems, including the phenomenon of load imbalance that often occurs in electric power distribution systems. An ideal three-phase system should have a balanced load on each phase so as to produce high operating efficiency, low power losses, and good power quality. However, in practice, load imbalance often occurs due to uneven load distribution, variations in electrical energy use, and dynamic network operating conditions [6][7][8][9].

Three-phase imbalance is one of the problems that can affect the quality of electrical power, increase system losses, increase neutral currents, cause equipment temperature increases, and reduce the operational efficiency of the electric power distribution system [10][11][12][13]. In distribution transformers, unbalanced load conditions can cause additional losses and shorten the life of the equipment. In addition, voltage and current imbalances can also disrupt the performance of three-phase induction motors that are widely used in the industrial sector [14][15][16]. Therefore, a good understanding of the concept of three-phase imbalance is one of the important learning outcomes in the Electrical Power Systems course.

Although three-phase unbalance concepts are introduced in classroom lectures, previous studies indicate that students often struggle to connect theoretical principles and mathematical calculations with the actual conditions found in electric power systems [17][18]. Materials regarding symmetrical components, unbalanced load

analysis, neutral current, power losses, and the effect of unbalance on power quality are generally abstract, making them difficult to understand if only delivered through lecture methods or purely theory-based learning [19][20]. This condition causes students to tend to memorize concepts without understanding the physical phenomena that actually occur in the field.

A practical learning approach can be used to address these challenges by enabling students to apply classroom concepts in real or simulated settings. Through practicum activities, students gain direct experience in conducting measurements, making observations, analyzing data, and validating the theories they have learned [21][22]. In engineering education, laboratories play key role in developing cognitive, psychomotor, and problem-solving skills needed in the workplace [23][24]. Through practicum activities, students not only understand concepts theoretically but are also able to relate them to real-world conditions in electric power systems.

The effectiveness of practical activities is greatly influenced by the availability of structured teaching materials, such as a practical module. A practical module serves as a structured guide for laboratory activities, including learning objectives, relevant theoretical concepts, experimental steps, required measuring instruments, student worksheets, and procedures for evaluating experimental results [5][25]. A practical module can assist students in conducting experiments systematically and independently [26]. In addition, the practical module also plays a role in increasing student involvement during laboratory activities because each stage of the experiment has been designed to direct students to achieve certain competencies [27].

Various studies have shown that the use of practical modules can improve learning outcomes, conceptual understanding, learning motivation, and critical thinking skills of students and learners in the fields of engineering and science [28][29][30]. The development of practical modules in the field of electricity has also been shown to provide a positive contribution to students' analytical skills in understanding the phenomena of electric power systems and power electronics [31][32]. In the context of learning three-phase imbalance, practical modules that enable students to simulate and directly observe changes in current, voltage, power, and neutral current resulting from different load conditions across each phase, thereby making the concepts more tangible and easier to comprehend.

The development of higher education paradigms oriented toward Outcome-Based Education (OBE) and Merdeka Belajar–Kampus Merdeka (MBKM) requires a learning process that effectively integrates theory and practice [31], [32]. In the OBE approach, students are not only required to master knowledge, but also to be able to demonstrate analytical skills and problem-solving abilities based on authentic learning experiences [33]. Therefore, the use of practical modules in the Electrical Power Systems course is a relevant strategy to support the achievement of graduate learning outcomes, especially in the aspect of mastery of concepts and analytical skills of electrical power systems.

Students in the Electrical Engineering Education Study Program require stronger conceptual and practical understanding of three-phase imbalance, as the topic involves

mathematical analysis, circuit interpretation, and complex measurement data. Although practicum modules can provide direct laboratory experiences that connect theoretical knowledge with technical skills, their use in the Electric Power System practicum at the Faculty of Tarbiyah and Teacher Training, UIN Ar-Raniry Banda Aceh, remains limited. Consequently, students tend to acquire theoretical knowledge without sufficient opportunities to observe, measure, and analyze the effects of unbalanced loading in three-phase systems. Previous studies have mainly focused on module development and general learning outcomes, while empirical evidence regarding the effect of electric power system practicum modules on students' understanding of three-phase imbalance remains limited. Therefore, this study investigates whether the implementation of an electric power system practicum module can improve students' learning outcomes and technical skills related to three-phase imbalance.

This study examines the role of an electric power system practicum module in improving students' understanding of three-phase imbalance and contributes to the development of more effective laboratory-based learning in electrical engineering education.

Method

The method used in this study was quantitative research with a quasi-experimental one-group pretest-posttest design. This quasi-experimental one-group pretest-posttest design allows researchers to compare pre- and post-treatment results to determine the effectiveness of the intervention. Furthermore, the method employed provides a clearer picture of the changes in the subjects. *The one-group pretest-posttest design* was chosen because it aligns with the research objectives, which emphasize measuring improvement in abilities following treatment.

The research was conducted at the Electrical Power Engineering Laboratory of the Electrical Engineering Education Study Program, Faculty of Tarbiyah and Teacher Training, UIN Ar-Raniry Banda Aceh, in the odd semester of 2024/2025. The population in the study were all students of the Electrical Engineering Education Study Program, Faculty of Tarbiyah and Teacher Training, UIN Ar-Raniry Banda Aceh, totaling 273 people. This study employed purposive sampling to select 25 students from the Electrical Engineering Education Study Program, Faculty of Tarbiyah and Teacher Training, UIN Ar-Raniry Banda Aceh, who were enrolled in the Electrical Power Systems course.

Research data were collected using achievement tests and questionnaires. These instruments were used to measure changes in students' learning outcomes and to obtain their perceptions of the implementation of the electric power system practicum module for three-phase imbalance material. Data collection through test questions was carried out by providing *a pre-test* before the implementation of the practicum module to determine students' initial abilities. The instructional activities then proceeded with the use of the practicum module. At the end of the learning session, students completed a post-test containing the same items as the pre-test to assess improvements in their learning outcomes. Meanwhile, questionnaire data were obtained after the practicum was completed, using an instrument arranged with a five-level Likert scale, namely

strongly agree (5), agree (4), neither agree nor disagree (3), disagree (2), and strongly disagree (1). Data analysis was conducted in two stages: evaluating students' learning outcomes and analyzing their responses to the practicum module. Learning outcome data were obtained from *pre-test* and *post-test scores*, then analyzed using the n-gain test to determine the level of improvement, as well as *a paired sample t-test* to test the significance of differences before and after the implementation of the practical module. The analysis results were interpreted using improvement categories based on the normalized gain (N-gain) score. Students' response data were analyzed descriptively by calculating the percentage of responses obtained from a five-point Likert-scale questionnaire. The resulting percentages were then classified to identify students' overall attitudes toward the implementation of the electric power system practicum module on three-phase imbalance material.

Result

a. The Implementation of the Electrical Power System Practical Module

The data gathered in this study consisted of students' responses to the pre-test and post-test items. The data were obtained after implementing the electric power system practicum module. The data were subsequently analyzed to determine whether the implementation of the electric power system practicum module improved students' learning outcomes on three-phase imbalance material. The results of the study in the form of pre-test and post-test results obtained from the study can be seen in Table 1.

Table 1. Results of Pre-test and Post-test

No	Student Name	*Pre-test* results	*Post-test* Results	difference
1	A-Z	40	100	60
2	R	40	80	40
3	EM	40	80	40
4	AL	60	80	20
5	FJ	40	80	40
6	MA	60	80	20
7	MA	60	100	40
8	ALGK	80	100	20
9	HF	40	100	60
10	MF	40	80	40
11	TMR	40	80	40
12	GSP	60	80	20
13	KF	60	80	20
14	FI	60	80	20
15	MAJ	60	80	20
16	JA	60	80	20
17	RD	60	80	20
18	HT	60	100	40
19	TA	40	80	40
20	TIR	40	80	20
21	MI	40	80	40
22	S	40	80	40
23	MM	60	100	40
24	AN	60	100	40
25	LF	60	100	40
	Total number	1300	2120	860

No	Student Name	*Pre-test* results	*Post-test* Results	difference
Total Percentage (%)		52%	84.8%	66.15%
Average		52	86.4	34.4
Median		60	80	40
Minimum Value		40	80	20
Maximum Value		80	100	60

The results of the study showed a significant increase in student learning outcomes after the implementation of the electric power system practicum module on the three-phase imbalance material. The average pre-test score of students was 52, while the average post-test increased to 86.4, with an average difference of 34.4 points. Overall, the pre-test score reached 1300, then increased to 2120 in the post-test, meaning there was a total increase of 860 points. The median score also increased from 60 in the pre-test to 80 in the post-test, with the minimum score from 40 increasing to 80, and the maximum score from 80 increasing to 100. Individual score improvements ranged from 20 to 60 points, with an average percentage increase from 52% to 84.8%, resulting in a total increase of 66.2%.

The analysis of learning outcomes improvement through N-gain calculation yielded an average value of 0.72, which is considered high, confirming that the implementation of the module not only improved students' final scores but also strengthened their conceptual understanding. Statistical testing using *a paired sample t-test* showed a p-value <0.05, indicating a significant difference between the pre-test and post-test results. These findings indicate that the developed practicum module effectively improves students' learning outcomes. In addition, questionnaire data revealed highly positive student perceptions of the module, with a mean response percentage of 82.1%, categorized as very good. Students reported that the module helped them understand the concepts, increased their involvement in practical activities, and made learning more interesting and meaningful.

b. Student Responses

Following the implementation of the electric power system practicum module on December 10, 2024, in the Electrical Engineering Education Laboratory at UIN Ar-Raniry Banda Aceh, the researchers distributed questionnaires to 25 students participating in the practicum. The results of the respondents' responses can be seen in Table 2.

Table 2. Results of Respondents' Responses

Question	Number of Questions	Total Responses	Average	Percentage
Conceptual Understanding and Material Clarity	4	333	83	83%
The Relationship between Theory and Practice	3	232	77	77%
Skill Development and Critical Thinking	3	240	80	80%
Motivation and Learning Reflection	2	168	84	84%

Support, Implementation, and Satisfaction	5	408	82	82%
Total / Overall Average	17	1381	81	81%

Table 2 indicates that most respondents strongly supported the implementation of the electric power system practicum module, as reflected in the mean response percentage of 82%. Only a few respondents chose the concept of three-phase imbalance with a neutral answer, and no one expressed disagreement with the implementation of the electric power system module. The results of student responses show that most students gave very positive responses. A total of 347 out of 425 responses (81.65%) were rated as "strongly agree," while 68 responses (16.00%) were rated as "agree" and 10 responses (2.35%) were neutral. The findings suggest that the practicum module was associated with improved student learning outcomes. The average percentage reached around 82%. This indicates that the practicum module is considered very helpful in understanding the material, relevant to learning needs, and able to improve student learning outcomes and skills in the field of electric power systems.

The pre-test results showed that students' initial understanding of three-phase imbalance was generally low. Most students scored 40 (44%) or 60 (48%), while only 4% achieved a score of 80. Overall, these findings indicate limited prior mastery of the material before the implementation of the practicum module. In terms of score distribution, the *pre-test standard deviation* of 11.55 indicates that student scores varied considerably before the treatment. After the module was used, the *post-test standard deviation* decreased to 9.52, indicating that student scores were more evenly distributed in the high range. The average difference in student scores was 34.4 points, with the smallest increase being 20 points and the highest being 60 points. These findings indicate that every student demonstrated improved learning outcomes, although the extent of improvement varied among individuals. The relative increase was 66.15%, whereas the normalized gain was 0.72, classified as high. The improvement was further confirmed by the statistical analysis. The paired-samples t-test showed a statistically significant difference between the pretest and posttest scores, $t(24) = 14.01$, $p < .001$. Because the p-value was below 0.05, the null hypothesis was rejected, confirming a significant difference between the pre-test and post-test results. The electric power system practicum module effectively improved students' understanding of three-phase imbalance: 76% scored 80 and 24% scored 100 on the post-test, with no student scoring below 80.

The results of the study showed a higher increase in learning outcomes compared to Didi Trianda's study [30]. In this study, students' scores increased by 34.4 points (52 → 86.4) with a high n-gain category, while in Didi Trianda's study the increase was 26.25 points (50 → 76.25). The differences obtained indicate that the electric power system practicum module that focuses on three-phase unbalance has a stronger impact on students' conceptual understanding than the electric motor installation practicum module that emphasizes installation and operation skills. The results of Dewi Suriani's study [27] focused on module development and product feasibility, while Didi Trianda's study [28] focused on the effectiveness of module use

on learning outcomes. The results of the study [28] showed that the three-phase inverter module was feasible to use and helped students understand power electronics material, but did not report a quantitative increase in learning scores like the study conducted by the researcher. Thus, this study complements Putra's study [29] by providing empirical evidence of the increase in students' understanding after the module was implemented. Research [29] produced a practical module with a very high validation rate, namely 90.71% for the media aspect and 91.83% for the material aspect. The previous study focused on module validity, while this study proved that the feasible module improved learning outcomes, with an N-gain of 0.72.

The results complement the research [31] which focused on the development of the electric power system practicum module. The research showed that the developed module obtained media validation of 94%, material validation of 62%, and language validation of 86%, so it was declared suitable for application in the Electric Power System course. Thus, the research [31] proved that the module is of sufficient quality for use and effectively improves Electrical Engineering Education students' learning outcomes on three-phase imbalance material. Although the results were positive, the study was limited by the absence of a control group and its focus on only one class. Future research should assess the module on a broader scale to further support the development of electrical power system practicum learning media in higher education.

Conclusion

With respect to the implementation of the Electric Power System Practicum Module on three-phase unbalance, the findings indicate that the module had a substantial positive effect on students' learning outcomes. Students initially demonstrated relatively low levels of achievement; however, following the implementation of the module, the mean post-test score increased significantly to 86.4, representing an improvement of 66.15% compared with the pre-test results. All students experienced an increase in learning outcomes.

In addition, student responses to the use of the Electric Power System Practicum Module for Three-Phase Unbalance Material were also very good, the positive response indicates that the practical module is not only relevant to learning needs, but is also considered effective in improving students' skills in the field of electrical power systems. Accordingly, the module may serve as an alternative instructional resource for supporting the enhancement of practicum-based learning quality in higher education.

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