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Design and Construction of a Variable Speed Drive Trainer as a Learning Medium for Electric Motor Installation at SMKS Sinar Husni 2 TR Labuhan Deli

Ricky Nelson Tampubolon[a], Muhammad Aulia Rahman Sembiring[a],, Felix Hizkia Simanjuntak[a]

[a]Universitas Negeri Medan

E-mail: rickyntampubolon@gmail.com

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Abstract

A persistent mismatch between vocational education outcomes and industry requirements presents a global challenge, often stemming from limited student exposure to modern industrial technologies. This study addresses the gap by designing, developing, and validating a cost-effective Variable Speed Drive (VSD) trainer as a practical and pedagogically appropriate learning medium. The research employed the waterfall development model, encompassing a structured process of needs analysis, system design, hardware implementation, and comprehensive evaluation to ensure the trainer's feasibility and instructional effectiveness. The evaluation phase included expert validation and practicality testing with end-users. Validation results showed the VSD trainer and accompanying job sheet were rated "Highly Suitable," with average scores of 3.67 from media experts and 3.63 from subject matter experts on a four-point Likert scale. Practicality scores were 3.61 from teachers and 3.38 from students, indicating strong usability and instructional relevance in real classroom settings. The findings suggest that the VSD trainer is a validated, scalable, and effective instructional solution that improves students' conceptual understanding, practical skills, and motivation. These outcomes align vocational training more closely with industry demands. Further development integrating IoT-based remote monitoring is recommended to enhance the trainer's functionality and relevance in digitally supported learning environments.

Keywords*: electric motor installation, trainer, variable speed drive*

Abstrak

Ketidaksesuaian yang terus-menerus antara hasil pendidikan vokasi dan kebutuhan industri menjadi tantangan global, yang sering kali disebabkan oleh keterbatasan paparan siswa terhadap teknologi industri modern. Studi ini bertujuan untuk mengatasi kesenjangan tersebut dengan merancang, mengembangkan, dan memvalidasi trainer Variable Speed Drive (VSD) yang hemat biaya sebagai media pembelajaran yang praktis dan sesuai secara pedagogis. Penelitian ini menggunakan model pengembangan waterfall, yang mencakup tahapan terstruktur berupa analisis kebutuhan, perancangan sistem, implementasi perangkat keras, dan evaluasi menyeluruh untuk memastikan kelayakan dan efektivitas instruksional trainer. Tahap evaluasi mencakup validasi oleh para ahli serta uji kepraktisan oleh pengguna akhir. Hasil validasi menunjukkan bahwa trainer VSD dan lembar kerja pendukungnya dikategorikan "Sangat Layak", dengan skor rata-rata 3,67 dari ahli media dan 3,63 dari ahli materi pada skala Likert empat poin. Uji kepraktisan menghasilkan skor 3,61 dari guru dan 3,38 dari siswa, yang menunjukkan tingkat kegunaan dan relevansi instruksional yang tinggi dalam lingkungan kelas nyata. Temuan ini menunjukkan bahwa trainer VSD merupakan solusi pembelajaran yang tervalidasi, skalabel, dan efektif dalam meningkatkan pemahaman konseptual, keterampilan praktis, dan motivasi belajar siswa. Pengembangan lebih lanjut dengan mengintegrasikan fitur pemantauan jarak jauh berbasis IoT direkomendasikan untuk memperluas fungsionalitas dan relevansi trainer dalam lingkungan pembelajaran digital.

Kata kunci: Instalasi motor listrik, Trainer, Pengendali Kecepatan Variabel

Introduction

The rapid evolution of industrial automation has placed new demands on technical and vocational education and training (TVET) systems worldwide. The importance of hands-on laboratories in electrical engineering education cannot be overstated, as they provide crucial practical experience [1]. A fundamental component of modern industry is the electric motor, whose efficiency and control are paramount. Electric motors are widely used in industry and households because they can efficiently convert electrical energy into mechanical motion. One of the key technologies utilized to control the speed and direction of electric motors is the Variable Speed Drive (VSD). The use of VSD not only facilitates a more dynamic operation of electric motors but also allows for significant energy savings and precise process control [2]. Consequently, the readiness of vocational school graduates to face the challenges of modern industry is largely determined by their acquisition of relevant, industry-aligned practical skills. This alignment is crucial, as contemporary research identifies a complex blend of professional expertise, personal capital gained through direct experience, and critical soft skills as the foundation for graduate employability in technical fields [3]. Students are expected not only to understand theory but also to master the application of this knowledge in authentic workplace scenarios. The use of training kits is an internationally proven method for enhancing technical skills, teamwork, and problem-solving [4]. Therefore, strengthening practical learning by providing tools and media that mirror industry standards is essential to ensure graduates are truly work-ready, a point underscored by similar research on developing electric machine training kits in Indonesia [5].

Despite this need, many vocational institutions face challenges in providing adequate training facilities, a problem that has spurred various "Rancang Bangun" (Design and Build) research projects in Indonesia [6][7]. This study focuses on a common problem observed at SMKS Sinar Husni 2 TR Labuhan Deli, which is representative of many vocational schools in the region. At SMKS Sinar Husni 2 TR Labuhan Deli, students are expected to understand the installation and operation of electric motors using VSD. However, in practice, learning still encounters several obstacles, primarily the limited availability of suitable training equipment and the absence of a dedicated VSD trainer. This is compounded by the lack of jobsheets or practical modules that can systematically guide students [8]. This scarcity of adequate resources means learning remains primarily theoretical, leaving students with limited real-world practical experience. This challenge is a recurring theme in Indonesian vocational schools, where research consistently shows that the development of validated hands-on learning media, such as assembly trainers, is an effective strategy for improving students' technical competencies and bridging the theory-practice gap [9]. Existing practical tools are often not equipped with clear instructions and fail to simulate actual industrial conditions, leading to suboptimal practical abilities, especially in operating and maintaining VSD-based systems [10].

International studies have confirmed that industry-based VSD trainers can significantly improve the technical skills of vocational students [11], and the development of such trainers serves as a major international precedent in vocational schools [2]. The pedagogical approach is also critical; a systematic review has identified Project-Based Learning (PBL) as a highly effective approach [4], which has been shown to be effective when integrated with hands-on modules like job sheets [8]. Previous studies have also confirmed that industry-based VSD trainers can significantly improve the technical skills of vocational students [11]. However, while many studies report on the creation of such trainers, a systematic validation process that combines expert review with user-based practicality testing within an authentic vocational school context is less common. Furthermore, few studies have explicitly documented the use of a structured development model like the waterfall method for such a project.

This highlights a clear research gap: while the need for VSD trainers is acknowledged, there is a lack of documented, systematically developed, and rigorously validated low-cost trainers that can be easily replicated in under-resourced vocational institutions. To address these problems, this study details the development of a VSD trainer that is ergonomic, safe, easy to use, and equipped with an integrated job sheet. This study aims to design and construct a Variable Speed Drive trainer as a practical learning medium and evaluate its feasibility, ease of use, and effectiveness in enhancing students' skills using the waterfall model to ensure a structured and systematic approach.

Method

This study utilized the waterfall model for the trainer's development, comprising four sequential stages: (1) needs analysis, (2) system design, (3) implementation, and (4) evaluation. Although modern agile methodologies are commonly used, the waterfall model was deliberately chosen because of its structured and sequential approach, which remains highly effective and is often represented in research literature for projects with well-defined requirements and a focus on physical hardware development [12]. The use of structured development is a common practice in Indonesian educational research [5] and is internationally recognized for developing and validating such trainers [2]. This structured approach ensures the final product aligns with the pedagogical and technical requirements of practical learning in vocational schools.

a. Needs Analysis

A needs analysis was conducted at SMKS Sinar Husni 2 TR Labuhan Deli to identify specific learning requirements. The analysis, involving lab observations, interviews with teachers, and curriculum review, revealed a critical lack of equipment for VSD technology, leading to no direct student experience with VSD installation, operation, or testing. Teachers expressed an urgent need for a safe, user-friendly VSD trainer suitable for various motor control simulations, accompanied by structured job sheets to enable independent, industry-relevant learning. Based on this analysis, the trainer's core specifications were defined (Table 1).

Table.1 Specifications of the VSD Trainer

No	Component	Specification / Description
1	LS Starvert iC5 VSD	0.75 kW capacity
2	Three-phase Induction Motor	0.75 kW power
3	AC Input	200-230V, 10A, equipped with Switch and Fuse
4	Digital Multimeter	1 unit, for measuring Voltage, Current, Frequency
5	Toggle Switch	5 units, for various control functions
6	Potentiometer	For adjusting motor speed
7	Tachometer	For measuring motor (rpm)

b. System Design

The system design stage was carried out after the needs for the Variable Speed Drive trainer were fully identified. This stage included designing the trainer and the integrated practical job sheet to support learning activities for electric motor installation at SMKS Sinar Husni 2 TR Labuhan Deli. The approach of developing the trainer and job sheet as integrated yet separately developed components has been validated as an effective practice [13].

The design began with creating circuit diagrams, panel layouts, and determining the position of each main component on the trainer panel. The main components integrated into a single trainer unit include LS Starvert iC5 VSD (0.75 kW), three-phase induction motor (0.75 kW), AC input (200–230V, 10A) with switch and fuse, two digital multimeters for measuring voltage, current, and frequency, five toggle switches for control, a potentiometer for speed adjustment, and a tachometer for measuring motor rotation.

The trainer panel was designed to be 45 cm x 34 cm, using acrylic or sheet metal. All components were arranged ergonomically for ease of operation and safety. The panel also featured clear labels for each switch, measuring instrument, input, and output terminal to facilitate identification and troubleshooting. The design layout of the Variable Speed Drive trainer panel is shown in Figure 1.

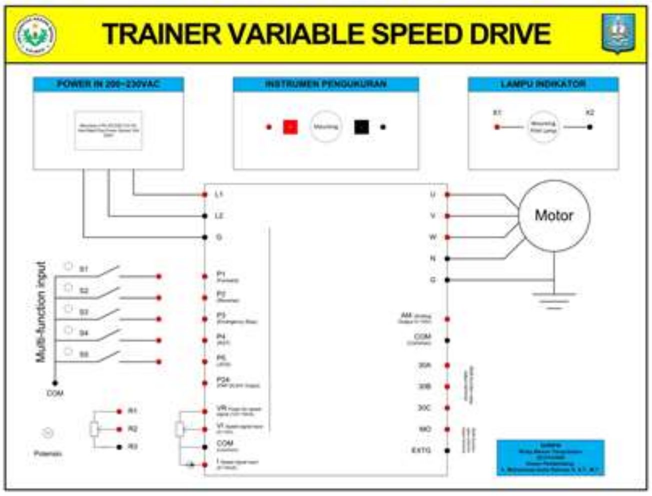

Figure 1. VSD Trainer Panel Layout

In addition to the trainer panel design, a practical job sheet was also developed as a guide for students to carry out installation, operation, and troubleshooting of the VSD and electric motor system. The job sheet is designed with systematic main material, structured practical steps, safety instructions, and an evaluation sheet to enable students to conduct practical activities independently and in a structured manner. The cover design of the practical job sheet used in this study is shown in Figure 2.

Figure 2. VSD Practical Job sheet Cover

All system design results, including circuit diagrams, panel layouts, and job sheets, were documented in detail and used as the main reference in the trainer manufacturing process in the subsequent stage.

c. Implementation

The implementation stage involved the physical construction of the trainer based on the design specifications. All components were assembled and installed on the acrylic panel according to the layout. Wiring was performed meticulously as per the circuit diagram, with safety features like switches and fuses installed on the AC input. Staged functional testing was conducted to verify the power supply, VSD operation, speed and direction controls, and the accuracy of measurement instruments. The parallel-compiled job sheet was also tested internally for clarity and effectiveness.

Figure 3. VSD Trainer Assembly Process

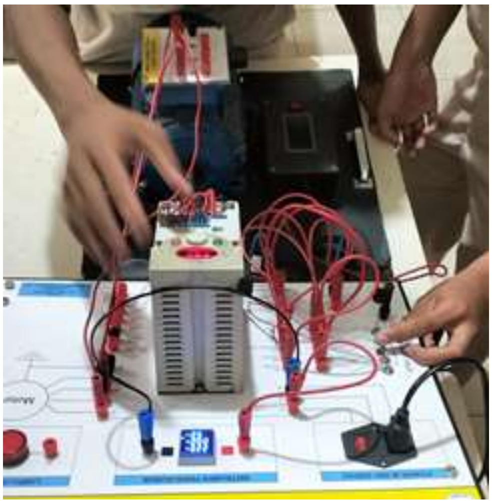

Figure 4. Initial Trial Use of the Trainer

In parallel with the trainer assembly, the practical job sheet was also compiled and printed. The job sheet was tested internally to ensure the sequence of work steps was easy to understand, safety instructions were clear, and the observation table could be effectively used by students during practice.

d. Evaluation

The evaluation stage aimed to ensure that the Variable Speed Drive trainer and its accompanying job sheet functioned as intended and were feasible as practical learning media. Evaluation was conducted through two main stages: validation by experts and field testing by users (teachers and students). Expert validation involved two categories: media experts and subject matter experts. The importance of a rigorous instrument validation process within the Indonesian vocational education context has been previously highlighted [14]. Media experts assessed aspects such as trainer visual design, panel neatness, label clarity, installation safety, and completeness of instructions on the panel and job sheet. Subject matter experts evaluated the job sheet's content alignment with core competencies, the sequence of practical steps, clarity of technical instructions, and material relevance to practical learning in VSD-based electric motor installation. Each validator provided input and suggestions for improvement if deficiencies were found in the trainer or job sheet.

Table 2. Media Expert Validation Instrument Grid

No	Aspect	Indicator	Items
1	Appearance	- Component layout	1
		- Placement of writing	2
		- Accuracy of component selection	3
		- Clarity of indicator components	4
		- Overall neatness	5
		- Overall appeal	6
2	Operating Techniques	- Security level	7
		- Ease of understanding components	8
		- Overall ease of operation	9
		- Work method	10
		- Job stability	11
		- Facilitate the teaching and learning process	12
3	Benefits	- Cultivating learning motivation	13

		- Attracting students' attention	14
		- Stimulate student learning activities	15
		- Make it easier for teachers	16
		- Relation to other materials	17
		- Making effective use of practical materials	18

Table 3. Expert Validation Instrument Grid

No	Aspects	Indicator	Items
1	Relevance of Material	- Knowing the suitability of the material with CP	1
		- Knowing the level of competence	2
		- Know the completeness of the material contained in the learning media	3
		- Knowing the level of understanding of the material contained in the media	4
		- Knowing the scope of material contained in the media	5
		- Knowing the level of suitability between the conditions of students and the learning media needed	6
2	Learning Media Techniques	- Knowing the completeness of the components	7
		- Knowing the quality of design	8
		- Knowing the ease of operation and maintenance	9

Field testing was conducted by teachers and students at SMKS Sinar Husni 2 TR Labuhan Deli, as the primary users of the trainer and job sheet. Teachers and students performed practical activities on the installation, operation, and testing of VSD-based electric motors using the developed job sheet. Aspects observed included the ease of use, clarity of job steps, safety during practice, and achievement of learning objectives. Practicality was measured using questionnaires and observation sheets with indicators such as: 1) ease of understanding instructions, 2) clarity of job steps, 3) safety during practice, 4) achievement of intended outcomes, and 5) students' motivation and interest during practice.

Table 4. User Trial Test Instrument Grid

No	Aspect	Indicator	Items
1	Media	- Knowing the level of usefulness and ease of use of trainer media	1
		- The influence of media trainers on student learning processes	2,3,4
2	Content	- Suitability of material to students' competency needs	5
		- Suitability of student evaluation with the material presented	6
		- Ease of delivering material	7,8

A four-point Likert scale was used for scoring, with interpretation guidelines as follows: 4 = Strongly Agree/Very Good, 3 = Agree/Good, 2 = Disagree/Sufficient, 1 = Strongly Disagree/Poor. The percentage results determined eligibility categories: 81–100% (Very Suitable), 61–80% (Suitable), 41–60% (Moderately Suitable), ≤ 40% (Not Suitable).

Table 5. Assessment Scoring Guidelines

Score	Assessment Categories
4	Strongly Agree/Very Good
3	Agree/Good
2	Disagree/Quite
1	Strongly Disagree/Less Agree

Once the data has been obtained, the total assessment score is converted into a percentage to determine the suitability category of the media and job sheet using the following criteria.

Table 6. Eligibility Category Criteria

Percentage (%)	Eligibility Category
81% – 100%	Very Worthy
61% – 80%	Worthy
41% – 60%	Quite Decent
≤ 40%	Not feasible

Result and Discussion

a. Trainer and Job sheet Development Process

The design and construction process for the Variable Speed Drive (VSD) trainer began with a needs analysis, followed by system design, implementation, and evaluation. The trainer was built using an LS Starvert iC5 VSD (0.75 kW), a three-phase induction motor, and supporting components such as multimeters, toggle switches, a potentiometer, and a tachometer. The trainer panel was assembled with an ergonomic layout, while the job sheet was structured to systematically guide students through installation, operation, measurement, and troubleshooting activities. All steps were aligned with the core competencies of electric motor installation in vocational school curricula.

b. Expert Validation

The validation process was conducted by three media experts and three subject matter experts. The media expert validation yielded an average score of 3.67, falling into the "Very Suitable" category. The content validation by subject matter experts resulted in an average score of 3.63, also categorized as "Very Suitable".

Table 7. Media Expert Validation Results

Validator	Score
Validator 1	3,39
Validator 2	3,83
Validator 3	3,78
Average	3,67

Table 8. Subject Matter Expert Validation Results

Validator	Score
Validator 1	3,78
Validator 2	3,56
Validator 3	3,56
Average	3,63

c. Practicality Test Results

Practicality testing involved three vocational teachers and eleven students. The average practicality score from teachers was 3.61 ("Very Suitable"), and the average score from students was 3.38 ("Very Suitable"). Teachers noted the trainer was easy to use and greatly facilitated practical instruction, while students reported increased understanding and confidence.

Table 9. Practicality Test Results by Teachers

Teacher	Score
Teacher 1	3,60
Teacher 2	3,80
Teacher 3	3,43
Average	3,61

Table 10. Practicality Test Results by Students

Student	Score
Student 1	3,20
Student 2	3,20
Student 3	3,43
Student 4	3,57
Student 5	3,37
Student 6	3,17
Student 7	3,27
Student 8	3,47
Student 9	3,33
Student 10	3,70
Student 11	3,47
Average	3,38

Teachers stated that the trainer and job sheet were easy to use and greatly facilitated practical teaching, while students reported increased understanding and confidence in conducting laboratory work. Users' suggestions were adopted for further improvement, especially regarding job sheet sequence and troubleshooting instructions.

The results of this study demonstrate that the developed VSD trainer and its accompanying job sheet are highly suitable and practical learning media for vocational education. The high validation scores from both media (3.67) and subject matter (3.63) experts suggest that the trainer successfully balances pedagogical clarity with technical accuracy. These scores are comparable to and even slightly exceed the findings of similar 'Rancang Bangun' research in Indonesia, such as the average feasibility score of 3.50 reported by [6]. Similarly, a study on the development of power electronics trainers reported high feasibility scores from media experts (93%) and material experts (97%), further validating the 'Design Build' approach as a reliable method for producing highly feasible learning media in the field of electrical engineering education [15]. The strong validation results are also consistent with findings from Hamid et al. (2024), who stress the importance of expert validation frameworks for vocational trainers. This indicates that the design is not only visually appealing and easy to use but also robust and relevant in its technical content, a crucial combination for effective educational tools.

The practicality scores from teachers (3.61) and students (3.38) further reinforces these findings. The strong positive reception from teachers indicates the trainer integrates well into existing teaching workflows, while the high score from students confirms its effectiveness from a learner's perspective. These findings align with Suganob et al. (2022), who also found that well-designed trainers significantly enhance competency assessment. Our results also resonate with the work of Setyawan et al. (2023), whose project-based job sheet approach was shown to be effective; the high practicality score of our integrated job sheet supports this conclusion. Conceptually, this trainer's design shares a pedagogical purpose with more complex multi-functional test benches described by Anuchin et al. (2025), which is to provide a hands-on platform for electrical engineering experimentation. In the broader "physical vs. virtual" lab debate, a meta-analysis by Wu & Hu (2024) argues that physical trainers provide an essential hands-on experience that cannot be fully replaced by virtual alternatives. Our trainer supports this by offering tactile interaction. This tactile engagement is at the heart of constructivist learning theory, which states that students actively construct knowledge through experience; this trainer serves as a platform for that process, enabling the simulation of real-world scenarios in a controlled and interactive environment [17]. However, this does not exclude the value of simulation. As a meta-analysis by Chernikova, et al., (2020) shows, simulations are highly effective for complex problem-solving skills. Therefore, this physical trainer is best positioned as a fundamental, foundational step that allows students to master the basics before progressing to more abstract, simulation-based scenarios.

This study offers several key implications. Practically, it presents a validated, low-cost model for a VSD trainer that can be replicated by other vocational institutions, particularly those with limited resources. It provides a direct solution to the common problem of outdated or non-existent equipment. Theoretically, this research validates the waterfall model as a systematic and effective framework for developing educational hardware in a vocational context. The sequential nature of the model proved beneficial in ensuring that pedagogical needs identified early on were systematically addressed through design and implementation, leading to a highly-rated final product.

Despite the positive results, this study has several limitations. First, the research was conducted at a single vocational school, which may limit the generalizability of the findings. The user testing sample, while providing valuable qualitative insights, was relatively small (3 teachers, 11 students). Second, the evaluation focused on perceived feasibility and practicality rather than measuring quantitative changes in student competency through pre-test/post-test assessments. Future research should address these limitations. Specifically, conducting a longitudinal study to track the career outcomes of graduates would be a valuable next step, as such research has shown that structured learning experiences in the workplace positively influence long-term professional commitment and career development [19]. We recommend expanding the effectiveness testing to multiple vocational schools to ensure broader validity. A longitudinal study could track students' skill development over time. Finally, as initially suggested, the integration of IoT-based monitoring for remote data collection and diagnostics represents a promising avenue for enhancing the trainer's capabilities and aligning it with Industry 4.0 trends. However, successful implementation will require careful consideration of institutional readiness, as studies in Indonesian vocational schools highlight that factors such as technological infrastructure and teacher readiness are critical to the successful adoption of IoT in education [20].

Conclusion

The design and development of the Variable Speed Drive (VSD) trainer and its accompanying practical worksheet were successfully implemented as an effective instructional medium for electric motor installation at SMKS Sinar Husni 2 TR Labuhan Deli. A rigorous evaluation process involving expert validation and user-based practicality testing indicated that the media were categorized as "Highly Suitable," demonstrating significant contributions to students' conceptual understanding, hands-on skills, and learning motivation. The waterfall development model proved to be a systematic and adaptive framework for producing instructional tools aligned with modern industrial needs. This study offers a validated and replicable framework that can be adopted by other educational institutions seeking to bridge the gap between vocational education and industry requirements. Future efforts should focus on broader implementation and the integration of Internet of Things (IoT)-based features to further enrich the interactivity and digital relevance of the learning experience.

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