Development of Electric Motor Control Trainer Board: A Cost-Effective and Industrially Relevant Design

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ABSTRACT

This research presents the development of a cost-effective electric motor control trainer board designed for electrical engineering students. The board simulates various motor control circuits, providing hands-on experience for students. The trainer board can perform various motor control operations, including Start-Stop push button stations (Direct on Line), Jog Start, Forward-Reverse, Direct On Line Wye, Direct On Line Delta, Wye-delta, and Dynamic Braking. Key components used in the board include magnetic contactors, a circuit breaker, a digital phase converter, disconnecting means, an overload relay, a timer, a rectifier, a braking resistor, a ground port, terminal blocks, indicator lamps, and PVC Cable Wiring Duct. The overall fabrication cost of the trainer board was Php 28,067.00 (479.38 USD), making it significantly more cost-effective compared to commercially available trainer boards, which range from Php 29, 274.55 (500 USD) to Php 878, 235.05 (15,000 USD). This cost-effectiveness, coupled with its comprehensive functionality, makes the newly developed board a valuable tool for electrical engineering education, particularly in Eastern Visayas State University - Ormoc Campus.

Keywords: Electric Motor Control Trainer Board, Electrical Engineering

INTRODUCTION

The demand for skilled workers in the electrical industry is steadily increasing, both locally and globally [1]. However, many educational institutions struggle to provide students with adequate practical training due to limited resources, outdated equipment, and the difficulty in replicating real-world industrial environments within a classroom setting. This challenge is particularly evident in some universities across the world, where the insufficiency of instructional tools and equipment pose a significant obstacle to students' practical learning experiences [2].

Unfortunately, the Philippines faces a significant challenge in producing skilled electrical engineers, despite the high demand for qualified professionals in the field. The unemployment rate in the Philippines, while declining, remains high at 4.0% as of August 2024 and in terms of magnitude, the number of unemployed individuals in August 2024 was registered at 2.07 million, with a significant portion of the unemployed lacking the necessary technical skills for in- demand industries [3]. In line with this, the engineering students need a strong foundation in both theory and practical application before they graduate and enter the professional world, wherein, it is the responsibility of higher education institutions to provide this crucial combination of skills [4,5].

In electrical engineering, learning goes beyond just reading textbooks. Hands-on experience with real tools and equipment is essential for students to truly understand concepts and develop the skills they need for their future careers. Instructional tools are important because they bridge the gap between what students learn in the classroom and what they will encounter in the real world of electrical engineering. However, a lack of adequate laboratory resources, particularly for motor control activities, has been a recurring challenge in Electrical Engineering education, particularly at Eastern Visayas State University - Ormoc Campus (EVSU-OC). This shortage of instructional materials, devices, and equipment has been a significant concern for instructors, who often rely on theoretical explanations and diagrams rather than hands-on learning experiences. To address this

issue, this research proposes the development of a cost-effective and student-friendly, yet industrially relevant, motor control trainer. The trainer will simulate various motor control circuits, providing students with hands-on experience that is crucial for their future success in the field.

The need for such trainers is further amplified by the demand for skilled workers in the local market. According to the Department of Labor and Employment (DOLE), the Philippines faces a significant shortage of skilled workers in the engineering, architecture, and construction sectors, with an estimated one million vacancies. Wherein, this shortage is attributed to a lack of qualified applicants and a "brain drain," as skilled Filipino workers seek better opportunities abroad [6]. Thus, this situation highlights the need for improved training and education programs to equip Filipinos with the necessary skills to meet the growing demands of the local job market. While technological institutions aim to produce globally competitive graduates, the lack of adequate training facilities often leaves students unprepared for the demands of the industry. This gap between academic training and industry expectations is a major concern, as highlighted by the Commission on Higher Education's (CHED) CMO 88, Series of 2017, which emphasizes the importance of equipping electrical engineering graduates with practical skills in areas such as supervision of electrical equipment operation and maintenance, and the manufacture and repair of electrical equipment.

Previous researches have explored the effectiveness of various motor control trainers in different educational settings. Studies have been demonstrated the positive impact of such trainers on student learning [7-14]. However, some of the previous researches, while valuable, has a notable limitation of existing motor control trainer board designs found in previous studies is the absence of a single-phase to three-phase converter. This omission presents a significant practical challenge, particularly for commercialization, as not all universities or locations have access to a three-phase power supply. The inclusion of such a converter would enhance the trainer's versatility and broaden its applicability across a wider range of educational settings. This research aims to develop a motor control trainer board design and provide unique additional features that can enhance the trainer's usability and practicality across diverse educational settings.

MATERIALS AND METHODS

Materials

The trainer board was built using marine plywood measuring 122-cm by 90-cm by 2.54-cm, mounted on a steel frame. This design prioritized portability to facilitate easy movement, accessibility, and efficient use of space. Additionally, the construction made use of available owned materials that were still in good condition, including pilot lamps (2 red and 1 green), single phase circuit breaker (bolt-on type), two heavy-duty push-button switches (1 green NO switch and 1 red NC switch), electrical wires, screws, paint, and a portion of steel angle bars and plates, among other resources.

Moreover, the trainer board also includes essential components that were purchased such as three-phase induction motor, four magnetic contactors, three thermal overload relays, a three-phase circuit breaker, a digital phase converter, a changeover switch, two industrial timers, a bridge rectifier, a braking resistor, a grounding bus bar, terminal blocks, PVC cable wiring ducts and pipes and other complimentary materials indicated below. This setup allows students to learn and practice wiring magnetic controllers for various motor control operations, including Simple Start-Stop Push Button Stations (Direct on Line), Jog Start, Forward-Reverse, Direct On-Line Wye, Direct On-Line Delta, Wye-Delta connection, and Dynamic Braking. It also emphasizes troubleshooting existing wiring control networks, an essential skill in electrical engineering.

The trainer board is designed for practical learning, with all devices fully exposed to facilitate installation and familiarization.

Each component serves a specific purpose to enhance learning outcomes. The magnetic contactors function as magnetic switches, while the circuit breaker protects the circuitry from faults. The digital phase converter

transforms single-phase power into three-phase power, and the changeover switch provide a safe way to cut off electrical power and can redirect to other power supply. The overload relay prevents motor overheating, the timer

enables time-delay operations, and the rectifier that converts alternating current (AC) to direct current (DC). On the other hand, the braking resistor ensures controlled braking for operational safety, and the grounding bus bar safeguards users from electric shocks and equipment from damage. Additionally, terminal blocks serve as tapping points for connections, pilot lamps display run, stop, and fault indicators, and PVC cable wiring duct conceals and organizes wiring for a neat and professional appearance. By incorporating an industry-based training approach, this trainer board prepares students for professional competency, equipping them with practical skills and technical knowledge necessary for their future careers.

Table 1 provides a detailed list of materials and devices purchased in constructing the newly developed electric motor control trainer board, including their current market prices and the overall cost. Additionally, Table 2 features actual images of the electrical components and devices, offering a clear visual representation, and serving as a helpful reference for Figure 2 are the letters provided.

Table 1. List of Materials and Its Costs

Components/Devices	Brand/Manufacturer	Description	Unit Cost (₱)	Quantity	Amount (₱)
Three Phase Induction Motor	Meiji Electric Company	2 hp, 1750 RPM, 220/440V, 6.3/3.15A	₱ 7, 035.00	1	₱ 7, 035.00
Single Phase to Three Phase Converter (DPS)	Myung Youn Electronics Co., Ltd.	2-3 hp, 9A	₱ 7, 235.00	1	₱ 7, 235.00
Three Phase MCCB	Fuji Electric FA Components & Systems Co., Ltd.	30 AT, 3 Pole	₱ 1, 837.00	1	₱ 1, 837.00
Magnetic Contactor	Fuji Electric FA Components & Systems Co., Ltd.	19A, 1 NC, 1 NO	₱ 896.75	4	₱ 3, 587.00
Thermal Overload Relay	Fuji Electric FA Components & Systems Co., Ltd.	16-22A, 1 NC, 1 NO	₱ 562.33	3	₱1, 687.00
Control Manual Generator Dual Power Knife Changeover Switch	Shanghai Mezeen Electric Co., Ltd.	32A, 2 Pole	₱ 224.00	1	₱ 224.00
Industrial Timer On-Delay SPDT (Single-Pole Double Throw) and Instantaneous SPDT	CIKACHI Electric Co., Ltd.	Type AH3-3 60 seconds, 8 pins	₱ 259.00	2	₱ 518.00
Square Bridge Rectifier Diode	SEP Electronic Corp.	35A, 1000V	₱ 87.50	2	₱ 175.00
Braking Resistor	Changzhou Southern Electronic Element Factory Co., Ltd.	300 W, 100 Ω	₱ 1, 222.00	1	₱ 1, 222.00
Transformer Type Pilot Lamp	Gikoka Tong Chuan Electric Co., Ltd.	Orange, 220V/240V	₱ 102.00	1	₱ 102.00
Terminal Block Grounding Bus Bar	Jaxhand Electromech	400V, 12 Ways	₱ 265.00	1	₱ 265.00
Heavy-Duty Push-Button Switch (DPST)	Shanghai Liyou Electrification Co., Ltd.	Green, 1 NO, 1 NC, 10A, 380V	₱ 183.00	1	₱ 183.00

Banana Jacks/Sockets	Pomona Electronics	2 pin, 4 mm ⌀	₱ 8.20	40	₱ 328.00
Screw Terminal blocks	Altech Corp.	20A, 12 Ways	₱ 58.33	12	₱ 700.00
PVC Cable Wiring Duct (Gray)	McGill Electrical Product Group	5 x 5 x 200 cm	₱ 450.00	1	₱ 450.00
Aluminum Angle Bar	P.tech	2.5 m	₱ 153.00	3	₱ 459.00
Acrylic Fiberglass	SEA Olympus Marketing Inc.	Bronze, 25.4 x 45.72 mm	₱ 180.00	1	₱ 180.00
Hinge	-	2.54 x 3.81 mm	₱ 5.00	6	₱ 30.00
Marine Plywood	Santa Clara	1.22 x 2.44 m	₱ 1, 150.00	1	₱ 1, 150.00
Paint	Island Paints	Lemon Yellow, 1L	₱ 130.00	1	₱ 130.00
Rivets	-	-	₱ 2.00	30	₱ 60.00
Metal Steel Angle Bar	P.tech	3 m	₱ 420.00	1	₱ 420.00
PVC Pipe Elbow Conduit	Neltex Development Co., Ltd.	19.05 mm ⌀	₱ 15.00	3	₱ 45.00
Surface Utility Box	Royu Industrial Corp.	PVC	₱ 45.00	1	₱ 45.00
TOTAL EXPENSES					**₱ 28,067.00**

Table 2. Actual Images of Electrical Components/Devices

a  Three Phase Induction Motor 2 hp, 60 Hz, 1750 RPM, 220/440V, 6.3/3.15A	b  Single Phase to Three Phase Converter (DPS) 2-3 hp, 9A	c  Three Phase Molded Case Circuit Breaker (MCCB) 30AT, 3 Pole	d  Single Phase Circuit Breaker (15AT, 2 Pole) **Koten Enterprises Co., Inc.**
e  Magnetic Contactor 19A, 1 NC, 1 NO	f  Thermal Overload Relay 16-22A, 1 NC, 1 NO	g  Control Manual Generator Dual Power Knife Changeover Switch 32A, 2 Pole	h  Industrial Timer On-Delay SPDT and Instantaneous SPDT 60s, 8 pins

i  Square Bridge Rectifier Diode 35A, 1000V	j  Braking Resistor 300W, 100 Ω	k  Transformer Type Pilot Lamps 220V/240V **Gikoka Tong Chuan Electric Co., Ltd.**	l  Terminal Block Grounding Bus Bar 400V, 12 Ways
m  Green and Red Heavy-Duty Push-Button Switch (NO for Green and NC for Red) **Gikoka Tong Chuan Electric Co., Ltd.**	n  Heavy-Duty Push-Button Switch (DPST) Green, 1 NO, 1 NC, 10A, 380V	o  Black and Red Banana Jacks and Sockets 2 pin, 4 mm ⌀	p  Screw Terminal Strip 20A, 12 Ways
q  PVC Cable Wiring Duct Gray 2 x 2 x 78.74 in.	r  PVC Pipe Conduit and Elbow 3/4 in.		

Methods

This study utilized the research and development approach phase circuit breaker, digital phase converter, three phase circuit to design and build a motor control trainer board. Before its construction, a proposed layout was created using AutoCAD software to serve as a guide throughout the fabrication process. Careful consideration was given to the proper spacing of each component during the planning stage, which was meticulously implemented during the assembly phase.

The trainer was constructed using a 122-cm by 90-cm by 2.54-cm marine plywood board, and equipped with essential components, including four magnetic contactors, a 3-phase and single-phase circuit breaker, a digital phase converter, a changeover switch, three thermal overload relays, two timers, a rectifier, a braking resistor, a grounding bus bar, four pilot lamps, three heavy- duty push-button switches, terminal blocks, banana jacks and sockets, an acrylic fiberglass, and PVC cable wiring duct, pipe and elbow. The wiring connections between the electrical components/devices and terminal blocks are 3-cm apart (highlighted with red lines in Figure 1 for general classification) and designed for size 3.5-mm^2 stranded wires – standard wires intended for motor control which are connected to the terminal blocks. The components were integrated into a cohesive design where the

distance between major components in the board such as changeover switch, single breaker, between magnetic contactors together with thermal overload relays, timer delays, and between the rectifier and brake resistor (highlighted with blue broken lines in Figure 1 for general classification) to enhance learning and practical application in electrical wiring installations, as this will allow the students to make quick and precise connections.

The front view plan of the utility model, illustrating its design, components, and measurements is shown in Figure 1. Additional elements such as the schematic diagram and the researchers' profile has designated spaces shown in the figure. Moreover, an isometric view plan of the model, is presented in Figure 2 to provide a comprehensive visualization of the trainer, further important measurements of the trainer that can only be viewed in this angle, and referring to Table 2 for component classification and placement as designed. This research focused exclusively on designing and developing a trainer for electrical wiring installations and motor control to bridge the gap between theoretical knowledge and hands-on experience. Additionally, the total fabrication cost of the trainer board was calculated by summing up all the expenses incurred during its completion.

Motor Control Trainer Board Design

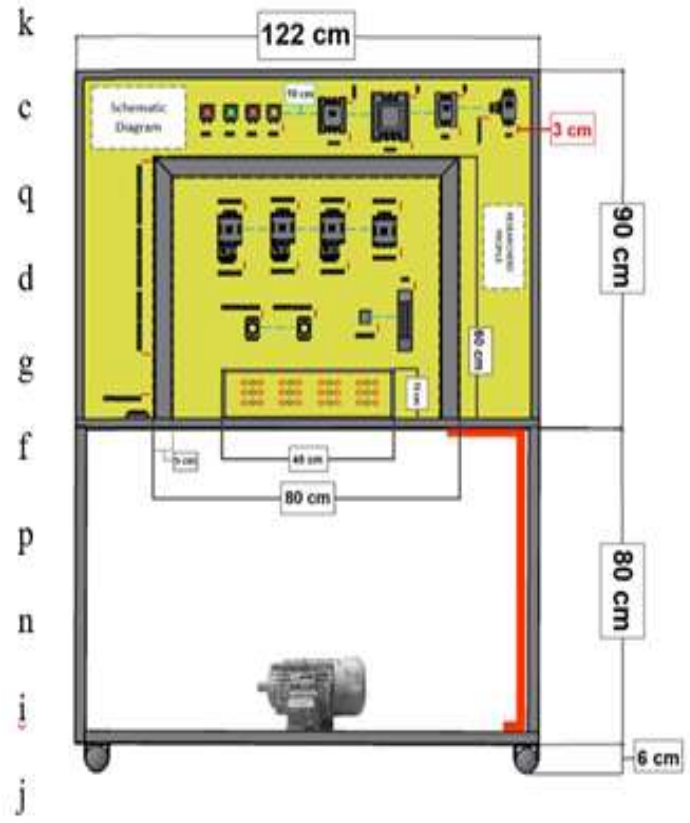

Figure 1: Front View Digital Design Plan

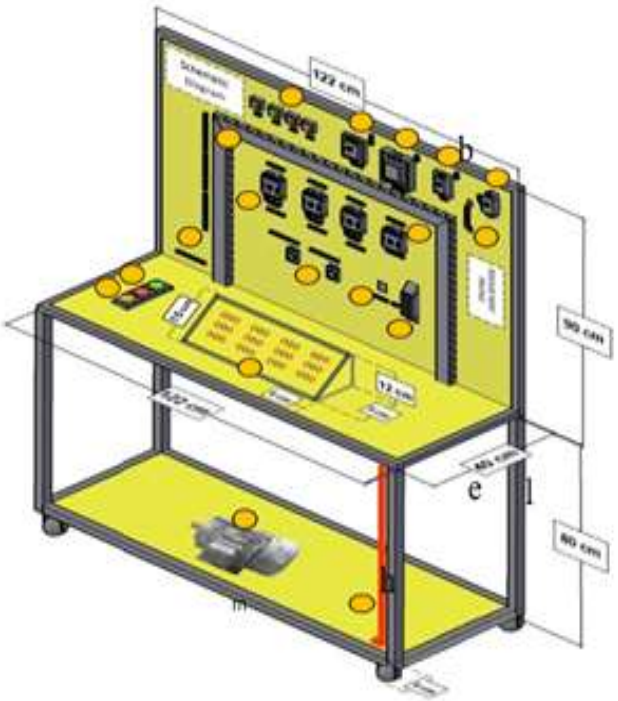

Figure 2: Isometric View Digital Design Plan

RESULTS AND DISCUSSION

Developed Motor Control Trainer Board

The trainer board was designed to enhance users' skills in motor control operations and wiring installations, focusing on maintenance, and troubleshooting for commercial and industrial applications. After practical demonstrations and consultations with the research adviser, the newly developed motor control trainer board successfully performed the following functions while operating at a standard voltage of 220 VAC: Simple Start-Stop Push Button Stations (Direct on Line), Jog Start, Forward-Reverse, Direct On-Line Wye, Direct On-Line Delta, Wye-Delta, and Dynamic Braking.

Figure 3 presents the actual image of the developed motor control trainer board, showcasing the final output of the project.

Figure 3: Developed Motor Control Trainer Board Front View

However, during the installation of the protection system and dynamic braking, electrical faults were observed due to the presence of multiple loop connections. This led the researchers to redesign a more streamlined version of the motor control system to address these issues. Additionally, during the inspection and repair of components, defective parts such as the thermal overload relay and magnetic contactor were identified but were promptly repaired, ensuring the system's operability.Overall, the trainer board demonstrated its capacity to fulfill its intended instructional purposes, despite the challenges encountered during the development and troubleshooting process.

Here is an additional isometric view of the newly developed motor control trainer board in Figure 4 where the trainer board was wired in switching for the Dynamic Braking System.

Figure 4. Developed Motor Control Trainer Board Isometric View

Fabrication Cost of The Motor Control Trainer Board

By summing up all the expenses, the fabrication cost of the motor control trainer board is Php 28,067.00 (479.38 USD). Hence, it has a greater markup selling price compared with the commercial ones from Php 29, 274.55 (500 USD) to Php 878, 235.05 (15,000 USD).

The cost is considered as commercially competitive considering the technical and economic advantages, safety features and varied teaching-learning activities with the use of this trainer.

CONCLUSION

The development of a cost-effective and industrially relevant electric motor control trainer board has proven to be a significant contribution to the field of electrical engineering education. This trainer board successfully bridges the gap between theoretical learning and practical application, addressing the lack of instructional tools in the Eastern Visayas State University - Ormoc Campus. It provides an affordable and comprehensive solution for training electrical engineering students in motor control operations, including Simple Start-Stop Push Button Stations, Jog Start, Forward- Reverse, Direct On Line Wye, Direct On Line Delta, Wye-Delta, and Dynamic Braking.

The fabrication cost of Php 28,067.00 makes the trainer board accessible, especially compared to commercially available alternatives, which are considerably more expensive. Despite encountering challenges during the development process, such as electrical faults and component defects, the researchers were able to resolve these issues, ensuring the trainer's functionality and reliability. The inclusion of a digital phase converter adds versatility, enabling use in educational institutions with single-phase power supply constraints.

This project demonstrates the potential of locally developed instructional tools to enhance practical learning experiences, preparing students to meet the demands of the electrical industry effectively. The trainer board not only serves as a cost-effective teaching device but also as a model for future innovations in educational tools for engineering.

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