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The Practical Learning on Electric Bus Conversion to Support Carbon Neutrality Policy in Thailand's Transport Sector

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Abstract: Climate change is one of the problems that affects the climate, natural disasters, and lives, economies, and industries around the world. Since the main cause is the combustion of fossil fuels, the transportation sector is a significant factor in causing these problems. Therefore, many countries, including Thailand, have policies to promote the increased use of electric vehicles. However, past measures have focused mostly on promoting the use of personal electric vehicles. For public transportation, buses are a major part of creating pollution and the problems of particulate matter with a diameter of less than 2.5-micron (PM 2.5), which is another major problem in Thailand because Thailand has many old buses. However, pushing transport operators to switch from internal combustion engine (ICE) buses to electric buses requires a large budget. Therefore, the conversion of old ICE buses into electric buses is one approach that can help promote the use of electric buses to become more possible. Another issue that makes transport operators afraid to switch from ICE buses to electric buses is the shortage of maintenance personnel. Therefore, this action research focuses on creating knowledge and practical skills related to electric vehicle modification and maintenance in the education sector. From the results of this practical research, the researcher was able to modify the old ICE bus into an electric bus and passed the test according to the research objectives.

Keywords: transport policy; electric vehicles policy; carbon neutrality; electric bus conversion

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1. Introduction

The problem of climate change is one of the problems that affects the climate, natural disasters, and lives, economies, and industries around the world. Therefore, more than 190 countries around the world, including Thailand, which is a party to the agreement, endorsed the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) at the 21st Conference of the Parties (COP21) in Paris, France, 2015. The goal is to reduce greenhouse gas emissions to limit global warming below 1.5 degrees Celsius compared to the pre-industrial era. At the 2021 United Nations Conference on Climate Change (COP26) in Glasgow, Scotland, Thailand announced an increase in its operations, aiming to achieve carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065 [1]. The International Energy Agency (IEA) report shows that the share of fossil fuel consumption, including oil and natural gas, has increased significantly, and together, they account for 55.3% of global CO_2 emissions [2]. According to data from the Organization of the Petroleum Exporting Countries (OPEC), the demand for oil in the road

transport sector is at its highest, accounting for 43–46% over the past 10 years, or almost half of the world's oil consumption of global oil demand [3]. Therefore, these data show that the transport sector is a major user of fossil energy and a major source of greenhouse gas emissions. Reducing the use of fossil energy in the transport sector and reducing greenhouse gas emissions are essential to combat global warming and climate change, which requires improvements in technology, transport planning, and the promotion of alternative energy use.

Thailand uses 56.5% oil and 5.7% natural gas, with a proportion of CO_2 emissions from oil combustion at 40.4% and those from natural gas at 31.1% [2]. According to the Office of Energy Policy and Planning, Ministry of Energy, Thailand, CO_2 emissions from energy use in Thailand in 2023 were 243.6 million tons of CO_2, a decrease of 2.4% compared to the previous year, which is consistent with a slight decrease in energy use in Thailand. In the industrial sector and other economic sectors (household, agricultural, commercial, and other activities), CO_2 emissions decreased by 9.7% and 3.5%, respectively, compared to the previous year. Meanwhile, the electricity generation and transportation sectors slightly increased their CO_2 emissions by 0.8% and 0.1%, respectively. The transportation sector's CO_2 emissions from refined oil increased by 0.1%, while CO_2 emissions from natural gas decreased by 2.5% compared to the previous year. This is consistent with the decrease in NGV usage, partly due to the gradual increase in the retail price of NGV after the end of the measure to maintain the retail price of NGV. The proportion of CO_2 emissions from refined oil was 79 million tons or 97% and that from natural gas was 2.5 million tons or 3% of the total CO_2 emissions in the transport sector, which was 8.6 million tons [4]. However, at present, greenhouse gas emissions are still high, so many researchers are interested in studying the factors that affect the environment [5], greenhouse gas emissions [6], and the evaluation of the pressure of atmospheric pollutant emissions on the atmospheric environment [7]. The main objective is to study environmental factors and impacts or study the use of renewable energy to reduce greenhouse gas emissions [8] and improve the efficiency of home energy management [9]. From the above information, it shows that the development of the transportation sector using fossil fuels is a significant contributor to greenhouse gas emissions. Therefore, the research shows that if Thailand can switch to using 30% EVs, it will be able to reduce CO_2 emissions by 14,996.888 kTons in 2030 [10]. Considering the mentioned problems and the challenging goal of net-zero emissions, EV research is of more importance in engineering, technology, and policy.

In engineering, more materials researchers focus on improving battery performance, lifetime, and charging time, which provide higher energy density and better safety, which are significant areas to explore [11,12], using, for example, solid-state batteries [13], lithium-ion (Li-ion) batteries [14], or zinc-bromine flow batteries [15]. Many researchers are developing the batteries or energy storage systems for electric vehicles that can store more energy, reduce the charging time, and increase safety. In electrical engineering, traditional EV motors typically use three-phase systems, but research into multi-phase systems such as five-phase [16] or six-phase [17] systems is showing promise for enhancing efficiency and reliability. Multi-phase motors can provide higher power density, better fault tolerance, and more efficient operation across a wider range of speeds. This can lead to better performance and longer driving range or the design of innovative powertrains, including more efficient electric motors and regenerative braking systems, and is a significant area [18]. In the power systems area, more researchers are interested in the impact of EV on power systems [19]. Due to the problem of the rapid increase in the number of electric vehicles, which has an impact on the power transmission system [20], it is necessary to have a smart grid system to monitor and detect the breakdown of the electric transformer [21] and find the appropriate installation points of electric vehicle charging stations [22]. Another issue is effective heat

management, which is essential for maintaining battery performance and lifespan. Overheating can degrade batteries, reduce their efficiency, and pose safety risks. Recent research has focused on innovative cooling solutions, such as phase change materials (PCMs), liquid cooling systems, and even hybrid cooling systems that combine liquid and air cooling. These systems are designed to maintain optimal battery temperatures under a variety of operating conditions [23]. In the structural design of electric vehicles, reducing the weight of EVs is essential for improving range and efficiency. Research into lightweight materials such as carbon fiber, advanced composites, and aluminum alloys aims to reduce vehicle weight without compromising safety and structural integrity. Innovations in materials science are leading to the development of materials for EVs that are stronger, lighter, and more cost-effective [24] and other technologies such wireless charging systems [25]. Therefore, the engineering advancements in EVs are centered around improving battery technologies, optimizing powertrain efficiency, enhancing thermal management, and incorporating lightweight materials. These innovations are crucial for overcoming the current limitations and pushing the boundaries of what electric vehicles can achieve, ultimately leading to longer ranges, shorter charging times, better performance, and more sustainable designs.

Recently, EVs have had widespread use in various sectors, including personal transportation, public transit, and commercial logistics. The electric public transportation technologies offer modern urban mobility and cleaner, more efficient, and sustainable alternatives to traditional fossil fuel-powered vehicles. These technologies are increasingly being adopted worldwide to reduce greenhouse gas emissions, improve air quality, and support the transition to renewable energy sources. The main types of land electric transportation include battery electric buses (BEBs), buses that are powered entirely by batteries, which are charged through the electric grid. They produce zero tailpipe emissions and are quieter than traditional diesel buses. Advances in battery technology have improved their range, making them viable for a wide range of urban and intercity routes. BEBs are widely used in cities like Shenzhen, China, which has fully electrified its bus fleet, and in various cities across Europe and North America. They are especially popular in urban environments where reducing air pollution is a priority. Nowadays, in addition to using batteries like BEBs, there are also hydrogen buses (HBs) that have interested more researchers [26]. BEBs can be charged through fast-charging stations at bus terminals and other strategic points along their routes. The other type of electric bus is the trolleybus, a type of electric bus that draws power from overhead electric wires via spring-loaded trolley poles. They offer the benefits of electric propulsion without the need for large onboard batteries, as they are continuously connected to the power supply. They are common in cities with established overhead wire networks, such as San Francisco (USA), Zurich (Switzerland), Athens (Greece), and recently, Poland [27]. They are particularly effective in hilly areas where electric motors provide better performance than internal combustion engines [28]. Recently, the trolleybuses technologies that have interested many countries in Europe [29], Brazil [30], and even China, where the use of BEBs is popular [31]. In Thailand, researchers have studied the feasibility of using trolleybuses in Pattaya, Chonburi Province, but they have not yet been put into actual use [32]. Another technology of electric buses is hybrid electric buses (HEBs), combining an internal combustion engine (ICE) with an EV. While they still use fossil fuels, they can operate in electric-only mode for short distances, particularly in low-emission zones or during acceleration, reducing fuel consumption and emissions. HEBs are a transitional technology used in cities that are gradually moving towards fully electric public transport. Examples include London (UK) and New York City (USA), where hybrid buses have been deployed as part of broader efforts to reduce urban emissions.

According to the IEA's Global EV Outlook 2024 report, EV sales are set to continue to grow and reach 17 million units by 2024, accounting for more than one fifth of all cars sold worldwide. EVs continue to make progress as mass-market products in many countries. The market share of EVs could reach 45% in China, 25% in Europe, and 11% in the United States [2], driven by competition among manufacturers, falling battery and vehicle prices, and continued government policy support [33,34]. In Thailand, EV registrations have more than quadrupled year-on-year to nearly 90,000 units, with an impressive 10 percent market share. This may be due to government subsidies and tax breaks, coupled with the increasing presence of Chinese automakers, which have helped drive sales soaring. Chinese companies account for more than half of sales to date, and they could become even more prominent as BYD starts operating an EV plant in Thailand in 2024, with an annual capacity of 150,000 units, with an investment of almost USD 500 million. Thailand aims to become a major EV production hub for both domestic and export markets and is set to attract USD 28 billion in foreign investment over the next four years, supported by specific incentives to promote investment.

For the BEBs market, China will account for more than 50% of electric bus sales in 2023, and Canada, Chile, Finland, the Netherlands, Poland, Portugal, and Sweden will account for more than 25%. In 2023, almost 50,000 electric buses will be sold worldwide, accounting for 3% of total bus sales, bringing global bus sales to around 635,000 units. This relatively low share is largely due to limited sales in emerging and developing economies (EMDEs) and low market penetration of electric buses in some large markets, such as the United States and South Korea. China has been a significant early leader in the sales of electric buses, supported by early policies for the electrification of public transport systems and the availability of domestically produced electric buses, coupled with incentives. In 2020, China accounted for approximately 90% of global electric bus sales. However, using electric buses will also come with the problem of having to use a long charging time, which requires a super-fast-charging system, which may affect safety or require good management of charging and vehicle operation [35].

Thailand's transportation sector emits approximately 30% of the country's total CO_2 emissions. For Thailand's goal of carbon neutrality and net-zero policy, to achieve carbon neutrality by 2050 and net zero by 2065, Thailand must reduce CO_2 emissions through various measures, with the use of EVs being a significant measure to reduce these emissions. Therefore, the government has a policy to promote the use of EVs. The National Electric Vehicle Policy Committee has promoted the 30@30 project, meaning the National Electric Vehicle Policy Committee has set a target for the use of electric vehicles to be 30 percent of all car sales by 2030. In the production sector, by 2030, Thailand aims to produce 30 percent of all vehicle production using electric vehicles, 725,000 passenger cars and pickup trucks, 675,000 motorcycles, and 34,000 buses and trucks. In the usage sector, by 2030, Thailand aims to have 30 percent of all vehicle production using electric vehicles, with 440,000 passenger cars and pickup trucks, 650,000 motorcycles, and 33,000 buses and trucks.

Regarding the current commercial use of electric vehicles and future, Thailand has various plans and operations such as Bangkok's E-Buses Program, which aims to replace 3100 electric buses in Bangkok by 2024. The Bangkok Mass Transit Authority, a government company responsible for mass transit in Bangkok, has a policy of Electrification of Inter-City Buses to replace 3390 electric buses. The objectives of the operation are divided into three phases, which are in the process of being implemented, and The Transport Company Limited, a government company responsible for Bangkok and provincial mass transit buses, has a policy of Electrification of Inter-City Buses to replace 3390 electric buses, which is currently in the feasibility study stage. These projects aim to reduce CO_2 emissions

by 500,000 tons between 2021 and 2030 to promote sustainable energy use and reduce air pollution.

From the data on the number of buses compared to their age in Table 1, it can be seen that many buses have been in service for a long time. Out of a total of 126,602 buses, 45,411 buses have been in service for more than 20 years and 81,026 buses have been in service for more than 10 years. The transition from all internal combustion engine buses to electric buses is a challenge. Because buses in Thailand will be used for a long time, many buses have not yet reached the end of their service life and bus operators will still use them. Therefore, changing to electric buses cannot happen easily, unless there are promotional measures that encourage operators. Adding to the problem is that electric buses still lack personnel for both maintenance and repair, making it necessary to change spare parts, which results in high insurance prices.

Table 1. Number of buses and their age in Thailand.

Bus Types	Bus Age (Years)						
	0–5	6–10	11–15	16–20	>20	Not Specified	Total
Public Buses	7264	7448	9667	6902	23,414	17	54,712
Travel Buses	10,573	15,424	8291	6564	17,032	15	57,899
Private Buses	2436	2397	1955	2236	4965	2	13,991
Total	20,273	25,269	19,913	15,702	45,411	34	126,602

Recently, the House of Representatives, through the Industrial Committee, has appointed a working group to promote the electric vehicle industry in the passenger and truck categories to study measures to promote and solve these problems. The working group considered the study and presented it to the House of Representatives for consideration for the government to promote the education sector to study the conversion of old buses to electric buses, to study both technological knowledge and practical studies in order to be able to apply knowledge to create personnel for SME entrepreneurs in both the industrial sector to convert old buses to electric vehicles and personnel in maintenance, so that universities can be learning centers that will organize training and teaching to create personnel to support the transition to electric vehicles in the future.

From past studies, most policies mainly support the use of private cars. For public transportation, they support the replacement of internal combustion engine buses with new electric buses. Transport operators will have to invest heavily. Therefore, it is significant to encourage SMEs to convert old buses into electric buses and make enable internal combustion engine repair shops to be able to repair electric vehicles. Therefore, creating knowledge for the personnel of these SMEs is a key factor in making this change possible. Promoting education and research with an emphasis on knowledge creation and practical implementation is, therefore, significant for the education sector to act as a medium for education to provide education and training to personnel to support this change. This research article presents action research on the conversion of old ICE buses into electric buses. The objective is to create both theoretical and practical knowledge for educational personnel to use their knowledge and experience in research to develop personnel in electric vehicles in the manufacturing, electric vehicle modification, and maintenance industries, focusing on public buses to support the policy of promoting the electric vehicle industry in Thailand.

2. Research Methodology and Planning

2.1. Research Methodology

This research is action research, a research process that emphasizes actual practice, with the aim of causing changes or developments in what is being studied along with data collection, analysis, and continuous improvement of the implementation approach. Researchers will act as both learners and practitioners at the same time, focusing on solving problems in applying theoretical knowledge to actual practice. The goal is to be able to develop both theoretical and practical knowledge for use in teaching and promoting the development of personnel in the industrial sector at the production level, electric vehicle modification, and the creation of personnel to support electric vehicle maintenance in order to have knowledge and be able to practice actual work on electric vehicles, especially public buses that will occur according to Thailand's policy in the near future. This consists of four main steps:

1. Planning is the process of identifying the problem or issue to be solved, setting research objectives, and designing the operational guidelines and data collection methods.
2. An action is to put the plan into practice in real situations, recording the process and the results.
3. Observation and data collection includes observing the results of operations and collecting various data.
4. Reflection comprises analyzing the results obtained, comparing them with the set goals, and using the findings to improve the operational guidelines and implement new processes in the next round for continuous development.

2.2. Research Planning

This section identifies the problem or issue to be addressed, the research objectives, and the design of the implementation approach.

2.2.1. Problems or Issues That Need to Be Resolved

As mentioned above, the main problems in the transition from internal combustion vehicles to electric vehicles include the shortage of personnel to support them, the conversion of old vehicles to electric vehicles, and maintenance. However, the education sector itself still lacks people with sufficient knowledge, expertise, and experience to develop human resources for the country. Therefore, the main problems that this research aims to solve are as follows:

1. There is a lack of teachers or educational personnel with theoretical and practical knowledge in electric vehicles.
2. In the manufacturing industry, there is a shortage of personnel with theoretical and practical knowledge in electric vehicles.
3. There is a shortage of personnel for electric vehicle maintenance to support the use of electric vehicles in line with government policy.

2.2.2. Research Objectives

1. Develop the theoretical knowledge and practical practice of educational personnel through action research;
2. Design and analyze the size of the motor and battery to find the most suitable size;
3. Convert old internal combustion buses into electric buses and pass the required tests;
4. Create knowledge and experience in modifying old internal combustion buses into electric buses, which can be used to develop human resources in electric vehicles and promote government policies.

2.2.3. Design Research Guidelines

1. Electric bus conversion prototype design;
2. Construction design and prototype production;
3. Prototype testing;
4. Discussion and conclusion of the research results;
5. Preparing documents for publication as academic articles to serve as knowledge and guidelines for further research.

3. Research Actions

3.1. Electric Bus Conversion Prototype Design

Converting the old ICE bus into the e-bus in this research is based on architecture shown in Figure 1. The traction of wheels is delivered by a three-phase electric motor. The torque and speed of the electric motor are controlled by an inverter, which inverts the DC voltage to a three-phase AC voltage. For the electric motor and battery, the sizing design is based on force models [36].

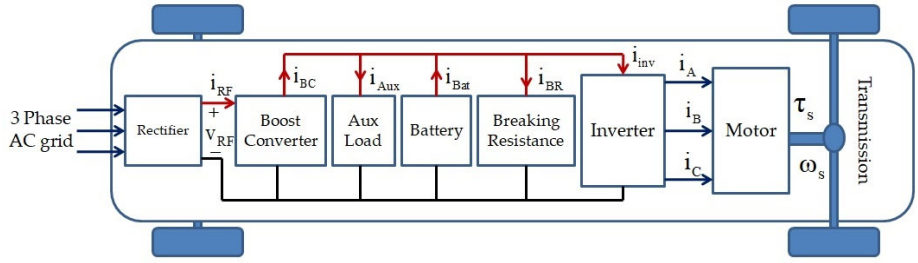


Figure 1. The electric bus architecture.

3.1.1. Subsection Dynamic Force Model

When designing electric vehicles (EVs), dynamic force models are essential for understanding the forces acting on the vehicle during motion. These forces influence the performance, energy consumption, and range of the EV. Below is a general outline of the dynamic force model equations that are commonly used in the design of electric vehicles. The main forces acting on an electric vehicle are as follows:

- Aerodynamic drag (F_{drag});
- Rolling resistance (F_{roll});
- Gravitational force on inclines ($F_{gravity}$);
- Inertial force ($F_{inertia}$).

The dynamic force model is shown in Figure 2. The details of force are as follows.

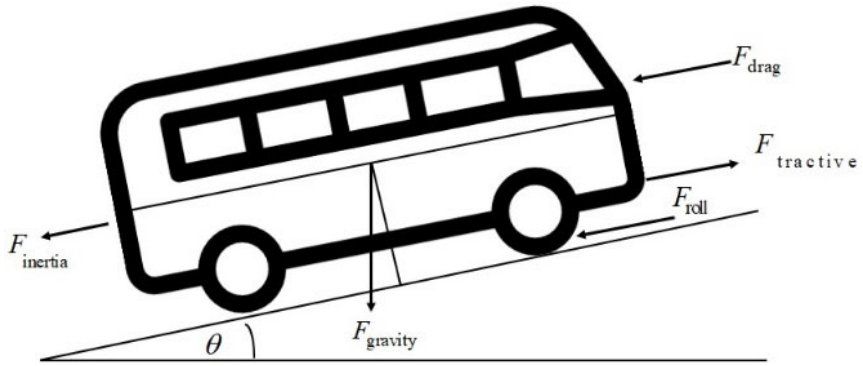


Figure 2. The dynamic force model.

Aerodynamic Drag Force: The aerodynamic drag force is given by Equation (1):

$$F_{\text{drag}} = \frac{1}{2} \times \rho \times C_d \times A_f \times v^2 \quad (1)$$

where ρ is the air density (kg/m^3), C_d is the drag coefficient (dimensionless), A_f is the frontal area of the vehicle (m^2), and v is the velocity of the vehicle (m/s).

Rolling Resistance Force: The rolling resistance force is given by Equation (2):

$$F_{\text{roll}} = C_r \times m \times g \times \cos(\theta) \quad (2)$$

where C_r is the rolling resistance coefficient (dimensionless), m is the mass of the vehicle (kg), g is the acceleration due to gravity (9.81 m/s^2), and θ is the road incline angle (radians).

Gravitational Force on Inclines: The gravitational force when the vehicle is on an incline is given by Equation (3):

$$F_{\text{gravity}} = m \times g \times \sin(\theta) \quad (3)$$

where θ is the road incline angle (radians).

Inertial Force: The inertial force, associated with the acceleration or deceleration of the vehicle, is given by Newton's second law and calculated by Equation (4):

$$F_{\text{inertia}} = m \times a \quad (4)$$

where a is the acceleration of the vehicle (m/s^2).

Total Tractive Force: The total tractive force F_{tractive} required to overcome all these forces is given by Equation (5):

$$F_{\text{tractive}} = F_{\text{drag}} + F_{\text{roll}} + F_{\text{gravity}} + F_{\text{inertia}} \quad (5)$$

Power Requirement: The power required by the electric motor to provide this tractive force is given by Equation (6):

$$P = F_{\text{tractive}} \times v \quad (6)$$

Energy Consumption: Energy consumption over a distance is given by Equation (7):

$$E = \int_0^d F_{\text{tractive}} \times v \, dt \quad (7)$$

Equations (1)–(7) are used to model the dynamic forces in the design of the prototype electric bus by analyzing these forces to design the efficiency and energy efficiency of the prototype electric bus. In the simulation using the MATLAB R2021 program that calculates the dynamic equations of electric vehicles, to calculate the force acting on the vehicle, total pulling force, power required, and energy consumption for a given distance, the following steps were performed.

1. Define constants and parameters:
   - Air density, drag coefficient, frontal area, vehicle mass, rolling resistance coefficient, and road incline angle are defined.
   - The maximum velocity and velocity profile over the specified distance are also defined.
2. Calculate forces: The aerodynamic drag force (F_{drag}), rolling resistance force (F_{roll}), gravitational force on inclines (F_{gravity}), and inertial force (F_{inertia}) are computed.

3. Total tractive force: The total tractive force is calculated by summing up the individual forces.
4. Power requirement: The power required by the electric motor to provide the tractive force is computed.
5. Energy consumption: The energy consumption over the specified distance is calculated using numerical integration.

3.1.2. Electric Motor and Battery Sizing Design

For an electric bus, the values for the air density, drag coefficient, frontal area, vehicle mass, and rolling resistance coefficient typically fall within certain ranges. Below are the typical values for these parameters.

Air Density (ρ): The typical value of air density is approximately 1.225 kg/m^3 at sea level under standard conditions (20 °C temperature and 1 atmosphere pressure). Drag Coefficient (C_d): The typical of drag coefficient is in the range of 0.50–0.80 for an approximate value for electric bus of $C_d \approx 0.6$. This value can vary depending on the design and aerodynamics of the bus. Frontal Area (A_f): The frontal area is the projected area of the vehicle facing the wind. The typical range 6–10 m^2, approximate value for the electric bus is $A_f \approx 8$ m^2. The bus mass (m) is the mass including the weight of the bus, batteries, and other components. The typical range between 10,000 and 20,000 kg (10–20 tons) or approximate value for the electric bus is about 15,000 kg. Rolling Resistance Coefficient (C_r): The rolling resistance coefficient depends on the tires and road surface. The typical range is between 0.005 and 0.01; for the electric bus, it is approximately about 0.007. The summary of values is simulated as below:

- Air density (ρ): 1.225 kg/m^3
- Drag coefficient (C_d): 0.6
- Frontal area (A_f): 8 m^2
- Vehicle mass (m): 15,000 kg
- Rolling resistance coefficient (C_r): 0.007

The simulation results of the total energy consumption and peak power requirement are shown in Figure 3a for, air density 1.225 kg/m^3, drag coefficient 0.6, frontal area 8 m^2, and rolling resistance coefficient 0.007. The simulation of the electric motor size in kW and battery size versus vehicle mass from 10,000 kg to 20,000 kg, for a bus distance from 100 to 400 km, is shown in Figure 3b.

For the electric motor and battery, sizing design is based on a force model. To convert an old ICE bus into an e-bus, the engine and structure of the old bus were removed and only the chassis was used, as old structures are damaged and heavy. The chassis is reassembled with the chassis number retained (according to the criteria of Thai law). The structure is designed to reduce weight while maintaining engineering safety. The selection of the traction motor size is based on the dynamic force model analysis from Figure 3b. The motor size must be not less than 72 kW to drive the electric bus. The selection of the traction motor size is based on the dynamic force model analysis from Figure 3b. The motor size must be no less than 72 kW to be able to drive the electric bus. The motor size must be selected to be no less than this. However, in practical design, other possible factors must be considered. In selecting the traction motor, the permanent magnet synchronous motor (PMSM) is selected as rated/maximum power 100/200 kW, rated/maximum torque 1000/2500 Nm, and maximum speed 2800 rpm. The selection of battery size depends on the sum of the electric power of the motor and the electric power supplied to other electrical devices in the bus, such as lighting, the control system, and entertainment equipment in the bus, which is related to the desired distance the bus can travel.

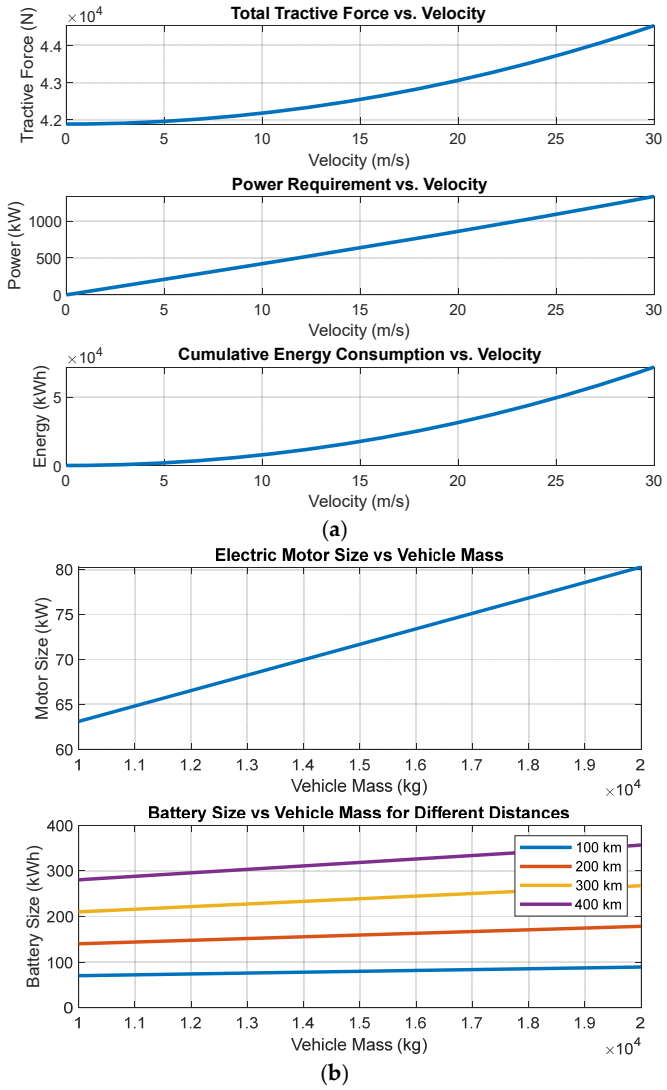


Figure 3. Simulation results. (**a**) The simulation results of total tractive force versus velocity, power requirement versus velocity, and cumulative energy versus velocity. (**b**) The simulation of electric motor size versus vehicle mass and battery size versus vehicle mass.

To calculate the energy required per distance, the energy consumption can be calculated by Equation (8):

$$E_{\text{per km}} = \frac{P_{\text{motor}}}{\eta} \times \frac{1}{v} \tag{8}$$

where

$E_{\text{per km}}$ is average motor power (kWh/km);
P_{motor} is average motor power (kW);
η is efficiency of the power transmission (e.g., 85% or 0.85);
v is average vehicle speed (km/h).

From the energy required per distance in Equation (8), the calculation of battery capacity can be calculated by Equation (9):

$$E_{\text{battery}} = E_{\text{per km}} \times D \tag{9}$$

where

E_{battery} is battery capacity required (kWh);
D is distance traveled per charge (km).

Lithium-ion batteries are rarely discharged to 100% capacity, but are typically discharged to 80–90% of their full capacity, so a safe depth of discharge (*DoD*) should be considered. The battery sizes that should be installed are as follows:

$$E_{\text{battry,install}} = \frac{E_{\text{battery}}}{DoD} \tag{10}$$

where

$E_{\text{battery,install}}$ is battery capacity that should be installed (kWh);
DoD is depth of discharge (%).

In selecting the battery capacity for the installation, the traction motor size with a maximum electric power of 100 kW and the required bus speed of 80 km/h with a system efficiency of 80% are selected from Equations (8)–(10). The results of the battery capacity used for the installation can be expressed in relation to the required distance traveled by the bus per charge, as shown in Figure 4. If *DoD* = 0.8 is selected for a bus travel of 100 km, the installed battery size will be 195.31 kWh.

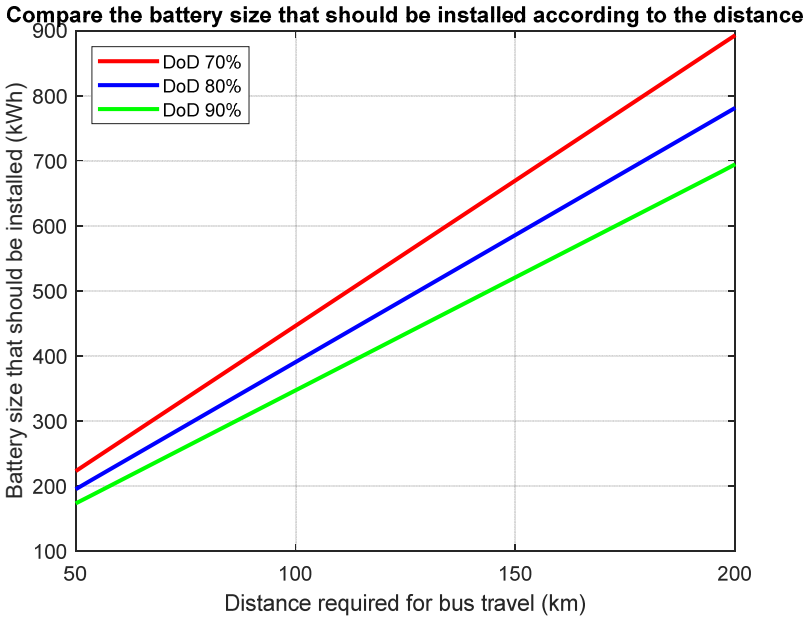


Figure 4. Simulation results of the distance required for bus travel versus battery capacity. The battery should be installed at different depths of discharge.

3.2. Construction Design and Prototype Production

Converting the old ICE bus into the e-bus in this research is based on the architecture shown in Figure 1. The traction of wheels is delivered by a three-phase PMSM motor. The torque and speed of the electric motor are controlled by inverter, which inverts the DC voltage to a three-phase AC voltage.

The other structures are assembled by hand. Electrical systems are installed such as the traction motor, battery, and battery management system (BMS). The details are shown in Figure 5. The complete prototype of an electric bus converted from an old ICE bus is shown in Figure 6.

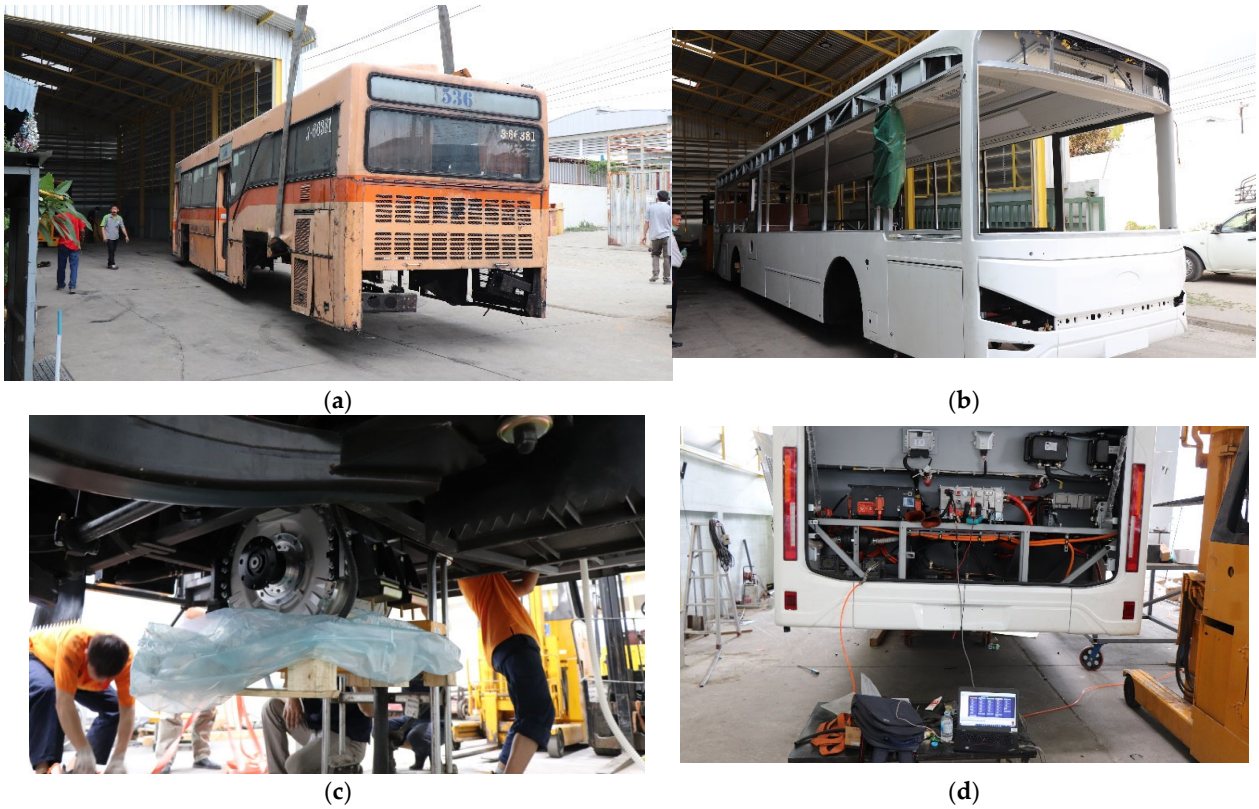


Figure 5. Production process. (**a**) Removing the ICE engines and old construction. (**b**) The new e- bus structure is assembled. (**c**) Electrical system installation. (**d**) BMS installation.



Figure 6. The final e-bus conversion prototype.

3.3. Prototype Testing

From the dynamic model, design, and simulation process as mentioned, the prototype is produced. The final e-bus conversion prototype is tested according to safety and performance tests. The details of the test topics are shown in Sections 3.3.1–3.3.7.

3.3.1. Center of Gravity Test

The center of gravity testing according to ISO 19380:2019 is a test of the force distribution of the bus body [37]. The force weight pressing on any wheel must not exceed 11 tons as required by Thai law. This test is performed both when the car is empty and when it is fully loaded. The test results are shown in Table 2. From the test results, the center of gravity is slightly offset to the front wheel, 40.7%: 59.3%. The left and right wheels are balanced. The maximum force that is pressed into each wheel is 8860 kg, lower than the legal limit of 11 tons.

Table 2. The center of gravity testing result.

Items	Empty Bus	Full Load Bus
Weight on front axle	4955 kg	6073 kg
Rear axle weight	7228 kg	8860 kg
Total weight	12,183 kg	14,933 kg
Wheelbase length	6 m	
Between wheel width	Front 2.1 m, Rear 1.97 m	
Tire statistical collapse radius	450 mm	
Weight distribution (F:R)	40.7:59.3	
Horizontal center of gravity	X = 3560 mm, Y = 6 mm	
Weight on rear axle (full load)	8860 kg < 11 tons	

3.3.2. Driving Performance and Energy Consumption Test

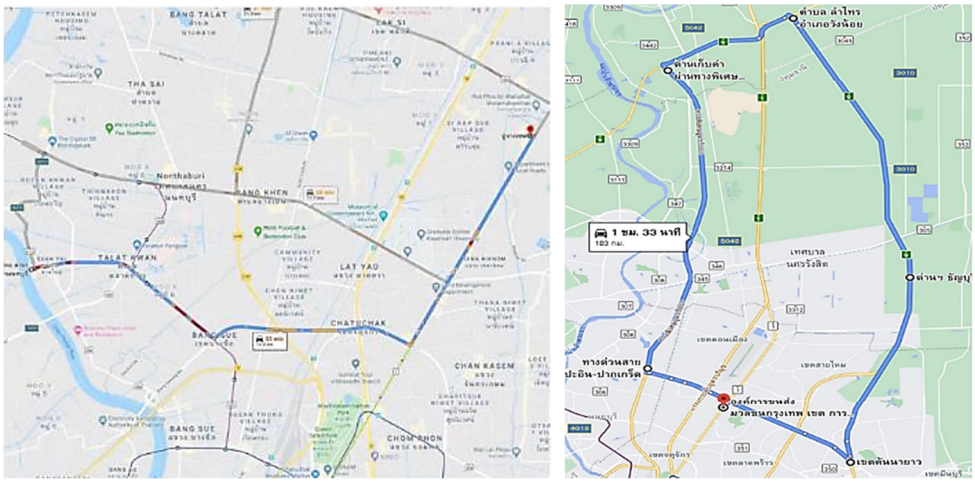
For this test, the prototype e-bus conversion is run continuously for 30 min at a speed of 80 km/h per test, provided that the electric bus does not overheat. The test has been performed using two routes that are shown in Figure 7a. The test results are shown in Figure 7b,c. The energy consumption testing result is an energy consumption of 96.87 kWh/100 km. Another energy consumption test is for driving in the city along the bus route, which cannot be limited or set to a constant speed, depending on the traffic conditions. The test results show that the energy consumption is 105.64 kWh/100 km.



Figure 7. Driving performance and energy consumption testing. (**a**) Testing routes. (**b**) First route testing results. (**c**) Second route testing results.

3.3.3. Charging/Discharge and Energy Consumption Test

The energy consumption test was tested on two routes in different environments. The first route test was one running along the BMTA bus route for three trips in different real traffic conditions, shown in Figure 8a. The second route is a test run on the expressway, running at a constant speed, shown in Figure 8b.



(**a**) (**b**)

Figure 8. Energy consumption testing. (**a**) Route 1, distance 117.38 km in city conditions. (**b**) Route 2, distance 108 km in expressway conditions.

For the first route, the charging time at 80% SoC with used average current of 29.3 A, or 21.15 kW by duration time, is 8:40 h. For driving testing at 117.38 km in real city traffic conditions, the duration of driving time is 7:30:42 h. The bus used the energy consumption of 57.21% or 105.64 kWh/100 km. Details are shown in Table 3.

Table 3. Energy consumption testing results for route 1.

Duration	**7:30:42 h**	**Avg. Charging**	**8:40 h**
Distance	117.38 km	Max charging current	29.3 A
SoC@start	100%		I_1 = 30.18 A
SoC@end	42.79%		I_2 = 28.86 A
Δ SoC	57.21%		I_3 = 29.23 A
Vmax	64.61 km/h	Avg. charging power	20.15 kW
Vavg	16.53 km/h	Max charging Power	20.42 kW
Range@80%SoC	164 km	Consumption	105.64 kWh/100 km

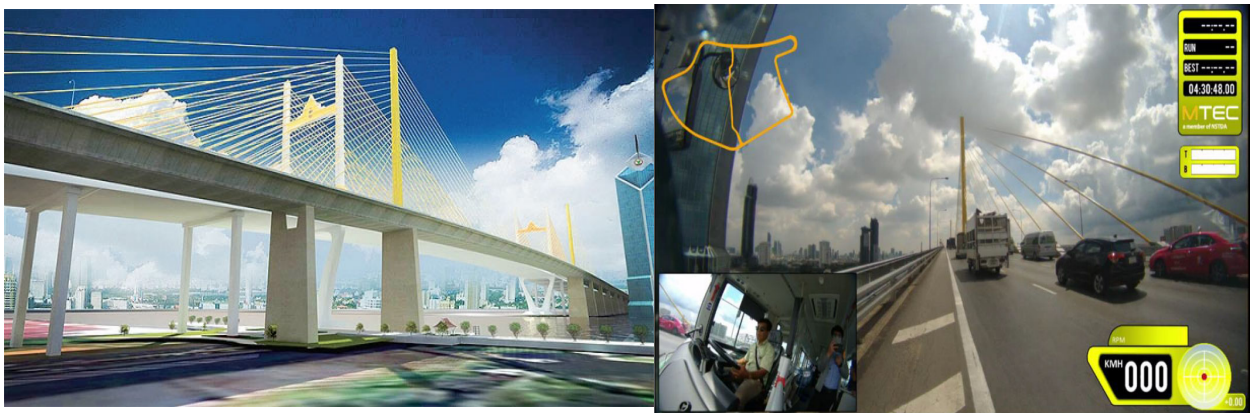
The second route testing results are shown in Table 4. The charging time at 80% SoC with used average current of 29.55 A, or 20.34 kW by duration time, is 8:51 h. For driving testing at 108 km in expressway conditions, the duration time is 2:05 h. The test results show that the bus used an energy consumption of 46% or 96.87 kWh/100 km.

Table 4. Energy consumption testing results for route 2.

Duration	**2:05 h**	**Avg. Charging**	**8:51 h**
Distance	108 km		29.55 A
SoC@start	94%	Max charging current	I_1 = 30.44 A
SoC@end	48%		I_2 = 29.28 A
Δ SoC	46%		I_3 = 29.50 A
Vmax	86.95 km/h	Avg. charging power	20.34 kW
Vavg	60.91 km/h	Max charging Power	20.47 kW
Range@80%SoC	187.18 km	Consumption	96.87 kWh/100 km

3.3.4. Slope-Driving Test

The test results for driving up the steep slope of the Rama IX Bridge, with a slope of about 5%, are shown in Figure 9 for two conditions: first, driving at a constant speed at 30 km/h; and second, driving at a constant speed, then stopping, then going. The test results passed all requirements.



(**a**) (**b**)

Figure 9. Slope driving test. (**a**) The Rama IX bridge. (**b**) The under-test condition.

3.3.5. Emergency Break Test

For the emergency braking test, these items are tested according to UN Regulation No. 13 [38] as shown in Figure 10. The performance of a braking system is determined by measuring the stopping distance in relation to the initial speed of the vehicle and by measuring the mean fully developed deceleration (MFDD) during the test. In the driving test, the three initial speeds are 30, 50, and 70 km/h. The stopping distances are 8.69, 26.15, and 39.69 m, and the MFDD is 0.61, 0.64, and 0.65, respectively, shown in Table 5. The test results that show the stop distance, MFDD, and center line deviation for all tests meet the requirements according to the standards.

Table 5. The emergency break test results.

Speed	**Distance (m)**	**MFDD (g)**	**Center Line Deviation**	**Max. Brake Force (N)**
30 km/h	8.69	0.61	−0.11	506.236
50 km/h	26.15	0.64	−0.54	740.570
70 km/h	39.69	0.65	−0.11	955.186



Figure 10. Emergency break testing.

3.3.6. Sudden Lane-Change Performance Testing

The sudden lane-change performance is tested according to the ISO 3888-2:2011 standard [39] as shown in Figure 11 and the onsite test are shown as Figure 12. The different driving speeds of 50, 60, 70, and 75 km/h are tested. All the test results meet the requirements outlined in the standards, as shown in Table 6.

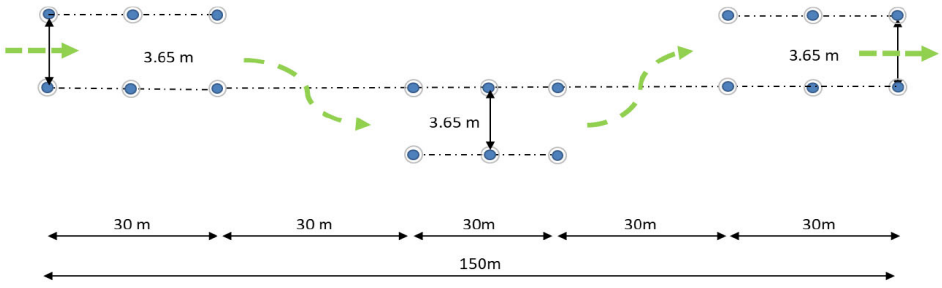


Figure 11. The sudden lane-change test according to ISO 3888-2 [39].

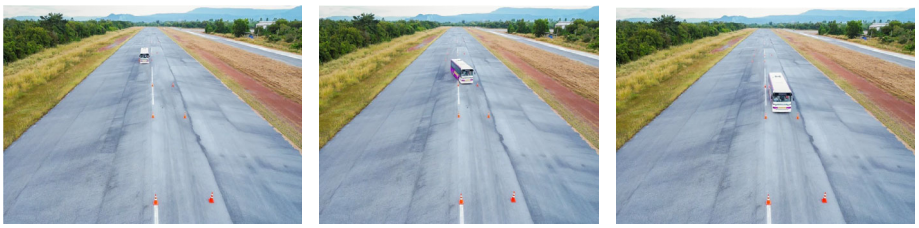


Figure 12. The sudden lane changes on-site test.

Table 6. Evaluation of driving performance in sudden lane changes.

Nominal Speed (km/h)	Speed at Start (km/h)	Speed at End (km/h)	Max. Lateral Acceleration (g)	Results
50	53.05	49.71	0.20	Pass
60	61.36	55.69	0.24	Pass
70	71.90	67.83	0.34	Pass
75	76.07	65.98	0.39	Pass

3.3.7. Flood Driving and Electrical Safety Testing

Driving tests in flood situations were performed by driving into a test bath 50 m long with a flood level of 50 cm. The test was carried out in two conditions, the first time

driving through flooded water at a constant speed of 30 km/h and the second time driving, stopping, and continuing, and the results are shown in Figure 13. The test results show that the car has no crashes and no water in the cabin. After that, the insulation testing was performed by applying a voltage of 1500 V between the live parts and the vehicle frame. The test results follow all the requirements as shown in Table 7.



Figure 13. Driving through the flood situation test.

Table 7. Driving through the flood situation test results.

	Results
Driving through	Pass
Stoping and going	Pass
Hi-voltage insulation test by applying 1500 Vac between live parts and EV ground part	Pass

4. Results and Discussion

From the objectives of the above action research, the researcher has studied the theory and actual practice of converting old unused ICE buses into electric buses by improving the structure to be lighter in weight in order to design the size of the traction motor, consuming less energy, which can reduce the battery size for driving at the same distance using the calculation principle of the dynamic mass model. The center of gravity test was performed according to ISO 19380 [37]. The test results of the prototype vehicle meet the specified standards, which shows that the prototype electric bus has rollover safety according to the standards. The driving performance and energy consumption test is a driving test and includes safety from overheating and energy consumption, with the test results being between 0.97 and 1.06 kWh per kilometer. The slope-driving test was performed to confirm the appropriate traction motor size design according to the dynamic model. The emergency braking test was conducted according to UN Regulation No. 13 [38]. In the driving test, the three initial speeds were 30, 50, and 70 km/h. The stopping distances were 8.69, 26.15, and 39.69 m, with the MFDD being 0.61, 0.64, and 0.65 respectively. The testing results that show the stop distance, MFDD, and center line deviation for all tests meet the requirements outlined in the standards. For the sudden lane-change test according to ISO 3888-2 [39] at different driving speeds of 50, 60, 70 and 75 km/h, the test results meet the specified standards, and the flood driving and electrical safety tests confirm the vehicle to be water-resistant, which will affect electrical safety according to the electrical safety standards.

From this research study, researchers were able to modify old internal combustion engine buses into electric buses to study both theories and actual use, as well as create knowledge for actual use to support Thailand's carbon reduction project. From the research results, the researchers were able to modify old buses into electric buses by performing appropriate calculations and designs to create knowledge for use in teaching in the education

sector and training SME entrepreneurs to support the future electric vehicle industry. In addition, the modified electric buses have also passed performance and safety tests from research support agencies, which is in line with the above research objectives.

This action research is a participatory process that emphasizes collaboration between researchers and practitioners to solve real-world problems while generating valuable knowledge in the field of EVs. Therefore, this action research serves as a bridge between theoretical frameworks and practical applications, ensuring that theoretical insights and practical experiences can be applied in academic, teaching, and training contexts to create a workforce to support the increase in EVs and lead to sustainable development.

In summary, the collaborative and participatory nature of action research makes it an effective way to generate high-level knowledge that is both theoretically sound and practically relevant. The effectiveness of action research is evident in its ability to bridge the gap between theory and practice, enhance the quality of research, empower participants, solve complex problems, and influence policy and practice.

5. Conclusions

The global warming problem has an impact on the economy, industry, and natural disasters that occur continuously. Many countries around the world, including Thailand, have policies to achieve carbon neutrality. The main factor in global warming is the burning of fossil fuels. Therefore, reducing the use of fossil fuels in the transportation sector is one way to achieve these goals. In the past, Thailand has had a policy to support electric vehicles, mainly passenger cars, by supporting tax measures and promoting investment. However, this can increase the use of electric vehicles. There are also problems for SMEs and garages that cannot repair electric vehicles. As a result, insurance operators lack confidence in maintenance, causing the price of insurance to be high.

This action research has received funding to convert old buses into electric buses to create knowledge, skills, and practical work in order to apply this knowledge to support the personnel of SME entrepreneurs in the electric vehicle conversion industry, enable auto repair shop operators to change from repairing internal combustion engine vehicles to repairing electric vehicles, and create personnel in the education sector to support the electric vehicle industry that will occur in the future. The design and construction of the electric prototype car were, therefore, created through the process of electrical engineering calculations and electric vehicle structure. The prototype modified electric bus has been tested for both performance and safety to confirm its practical usability by the responsible testing agency.

This research work has enabled the training of personnel in the EV industry in the modification and maintenance of electric buses. It has also/will be used to create a training program on electric bus modification and teaching, including promoting and supporting policies to promote the EV industry for the country to ensure that personnel can be created to support the change from internal combustion electric vehicles to EVs to achieve the government's carbon neutrality objectives.

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