A Development of Electric Tuk Tuk Conversion in Thailand

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***Abstract*— Electric Vehicle Association of Thailand (EVAT) consisting of various members in both the industrial and educational sectors related to electric vehicle, made a prototype of an electric Tuk Tuk conversion to be a guideline for SME to understand the electric Tuk Tuk (Thailand) conversion from Internal Combustion Engine (ICE) vehicle to the electric power vehicle. This research purposed an e-Tuk Tuk conversion procedure in details to demonstrate the electric vehicles production in Thailand and its experiment. The study started on February 21st, 2017 to December 25th, 2017. This project aims to: 1) provide the local-made electric vehicle conversion procedure ; 2) establish basic requirements (specifications) for modification of electric Tuk Tuk such as power, speed, size, dimensions; and 3) provide a guideline for product development and new business model of electric Tuk Tuk and other local-made vehicles. The specification of the prototype is following; motor 5kw 72V, battery LiFePo4 72V150Ah, maximum speed 71km./hr, maximum distant 110 km. maximum power 13kw on Dynamometer.**

Keywords—Electric Vehicle Conversion, Internal Combustion Engine (ICE), Tuk Tuk, Vehicle restoratin

I. Introduction

Tuk Tuk has been a public transport vehicle in Thailand for more than 60 years. The name of Tuk Tuk came from sound of exhaust pipe of two stroke and one piston engine running. In 1960, Tuk Tuk was imported from Japan for public transportation with the purpose of human ride tricycle replacement. When Tuk Tuk was used more than ten years, they were needed for repair, reconstruction, and renew. At that time, most Tuk Tuks were maintenance by small SME garages and most spare parts were made by SME's factories, from small parts, up to assembling a whole body of Tuk Tuk. In 1970, Tuk Tuk was discontinued in Japan and no spare parts services from Japan was available, SMEs starts to do their own design and improves quality by themselves until it has become a unique Tuk Tuk of Thailand at present time. Until now, most Tuk Tuks are made by local Thai SMEs both for local use in public transportation and export. Only engine parts, gears, and axial rear gear are used parts from Japan, especially Daihatsu and Suzuki but, chassis and other steel, plastic, leather parts are produced in Thailand.

The previous engine of Tuk Tuk was a two-stroke gasoline engine, 350 cc two-stroke two pistons and currently developed into a gasoline engine, 650 cc three pistons four-stroke engine with injection system. Most of them uses LPG and some uses NGV. All of them using of second-hand engines from Japan, they lack environmental control standards. In the Tuk Tuk industry, it often lacks standard design. Each SME designs and produces their own design, so they lack industry standard and vehicle standard. Hence, the chassis is always changed according to the engine dimension, gear box dimension and differential gear dimension, leading to different designs.

Electric Tuk Tuk conversion is alternative ways in lower production costs. It is created jobs for Thai people. It is valued added from making new jobs. Conversion electric Tuk Tuk is inexpensive cost but depended on condition of Tuk Tuk and battery selection. The highest cost of electric Tuk Tuk both new one or conversion one is battery. The structure of Tuk Tuk is simple and economical but it's categorize to be low speed vehicle.

The objectives of the research are to 1) provide the electric Tuk Tuk conversion procedure. 2) establish basic requirements (specifications) for modification of ICE Tuk Tuk to electric Tuk Tuk such as power, speed, size, and dimensions. 3) provide a guideline for product development and new business of electric Tuk Tuk Thailand and for other locally national vehicles.

II. Litterature review

A. History of electric vehicle

Battery-powered electric vehicle [1] is an electric vehicle that has only an electric motor. The power driven a motor vehicle is used from the electricity from only battery without other engine driven motor vehicle. Therefore, the running distance of the vehicles depends on the design, size, type of battery, including payload. The advantages of electric vehicles are more economical cost, cheaper maintenance, no emissions to the atmosphere, and not noisy. Westbroke [2] discusses the general basics of important electric vehicles, including various automotive electrical technology, which is the basis for the development of electric vehicles from the past to the present.

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B. Electricification vehicle

Gottlieb [3] discusses the theory of electric motors and electric motor control with a sample circuit of various motor control units. Husain [4] discusses various computational theories both mechanical and electrical used in the design of motor vehicles, both electrics and hybrid vehicles. Almeida et.al. [5] discuss an increase of the technical efficiency of the motor and control unit with minimum loss of power, such as the selection of metals, and narrowing the air inlet design. Hackleman [6] discusses the design and construction of an electric train, by focusing on mechanical and electrical design and using lead-acid batteries. Watkins [7] shows an example of how to modify a typical car into an electric vehicle, and explains details of the modification, such as motor, battery and gear installation.

III. Electric Tuk Tuk conversion procedures

In making the electric Tuk Tuk conversion, there are 9 steps of the procedure from the beginning to the end of the project as follows. This is only a guideline but it can be adapt properly by technicians, engineers.

A. Studying relevant information and requirements

It starts by studying relevant laws and interviewing Tuk Tuk drivers and Tuk Tuk stake holders in Bangkok and vicinity. Related laws included e.g. the announcement of the Department of Land Transport regarding the determination of the power of the electric motor used to drive the car in accordance with the automobile law, 2017, with following details; "Public tricycle and personal tricycle, which use an electric motor, must have rated power of electric motor not less than 4 kilowatts and the motor can drive the vehicle to the maximum speed of not less than 45 kilometres per hour."

B. Provide donated Tuk Tuk

Tuk Tuk 1999 Co.LTD (Thailand) donated a used Tuk Tuk to EVAT to use in conversing it to an electric Tuk Tuk. This Tuk Tuk was ICE with LPG system as in figure 1.

Figure 1. The donated Tuk Tuk before restoration

C. Checking condition of the donated Tuk Tuk

From checking the overall condition of the donated Tuk Tuk, its condition was very old e.g. stained steel parts, front grille, and truck so they lost strength. Many parts were needed replacements for safety issue. The example of the donated one is shown in figure 2.

Figure 2. Checking an overall condition of the donated Tuk Tuk

D. Recondition of donated Tuk Tuk

The body was removed from the damaged parts. The chassis was cleaned and rust was removed then painting the surface was prepared. Then pickup truck and front grille of Tuk Tuk was installed and painting the surface was prepared. Painted chassis and truck is shown in figure 3.

Figure 3. Preparing painting surface and replacement part

E. Motor, motor controller and battery selection

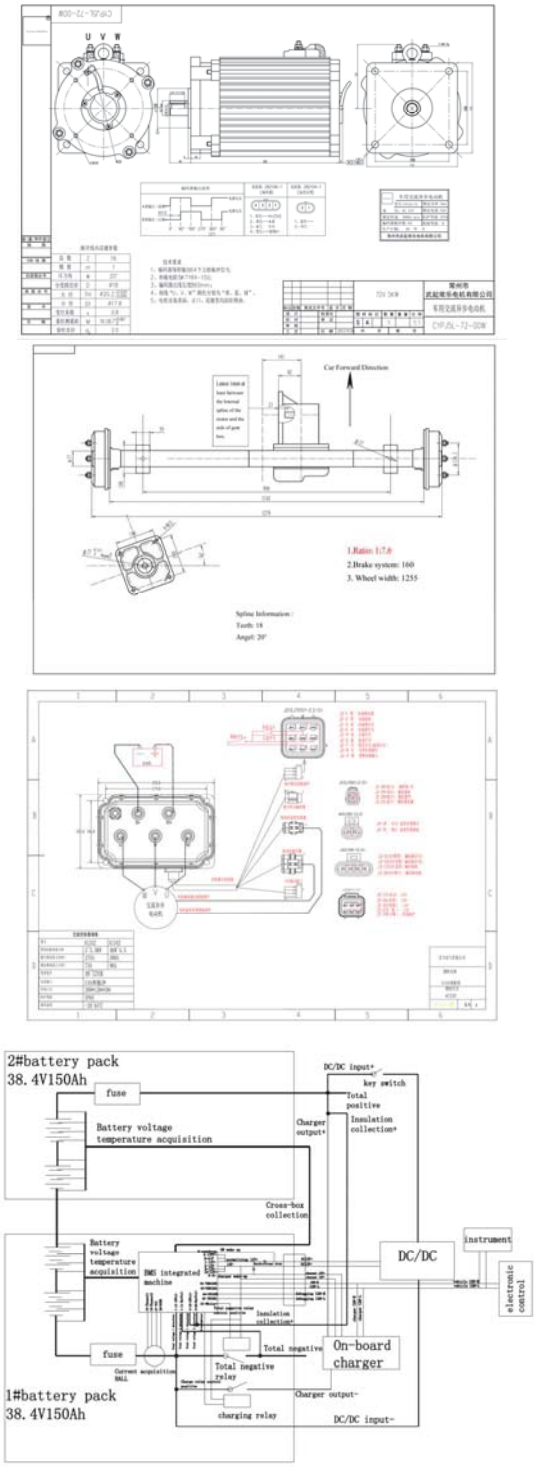

Figure 4. AC motor, AC motor controller, battery, and axial gear specification

There are several designs for power train selection, e.g. axial motor, motor with propeller shaft and differential gear. In this research, AC motor 5kW 72V was selected based on design in section IV. Speed and torque of motor were designed and selected following the requirements. Selecting motor specification; motor speed is 3000-6000 rpm, motor's power is 5kW (Continuous)/16.3kW (Peak) maximum torque 15.9 Nm, rear axial gear ratio 1: 6.4, wheel radius 25 cm. The no load speed is about 44-73 km./hr.. If the transmission efficiency is 95%, the driving force (6.4x15.9x.9/0.25) is 366 N. Battery, controller, and motor with rear axial gear are shown in figure 4.

F. Design, and installation of motor, motor controller, and battery unit including electric system

In this stage, the wiring diagram was designed and tested including motors, control units and LiFePo4 battery. There are two batteries. The first battery was installed in the middle of Tuk Tuk chassis under a pick up box. The second battery was installed under the driver seat position. Because foot area was limited, the battery was installed on the floor pan. Therefore, the battery was raised and put in the steel frame under the driver's seat area. The motor control unit was installed at the battery area under the driver's seat for ease of maintenance.

Figure 5. Battery and axial gear installation

G. Installation and testing motor, controller, battery and overall system

Electric voltage of electric Tuk Tuk conversion is 72V system as its driving system. But for the electric equipment is 12 V DC, so it was converted by using DC-DC converter. After completed checking, then the overall system was tested

including vehicle motors, motor controller, wheels, brakes, electrical systems, etc.

Figure 6. Testing and Installation of motor, battery, and motor controller unit

Figure 7. cable arrangement and testing

H. Cable arrangement

During installing the electrical system, it needs to check the overall electrical system, both the main power for driving motor and the low voltage for usage. The cable may need to adjust properly, if the cable is too long or too shot to match the body structure of Tuk Tuk, including the installation of a switch, and various signal bulbs. The cable wiring may need to arrange a new power cord along with testing the operation of the drive system.

I. Painting and assembling structural details

Removing metal parts for painting piece by piece by starting from rusting, polishing the surface, preparing the surface, preparing painting. After the paint was dried the parts were assembled to the proper position, the electric drive system and low-voltage electrical system were tested whether it worked according to the design or not, and the operation of the brake system during use.

Figure 8. Painting and part assembly

J. Testing and data collection

The electric Tuk Tuk was tested for real running, and the data was collected by the Power Analyzer HIOKI PW3390 to determine the efficiency of the motor control unit. Testing on Dynamometer is made by using the Dynotech 2WD Chassis Dynamometer to keep information without road condition effect and wind-resistant effect.

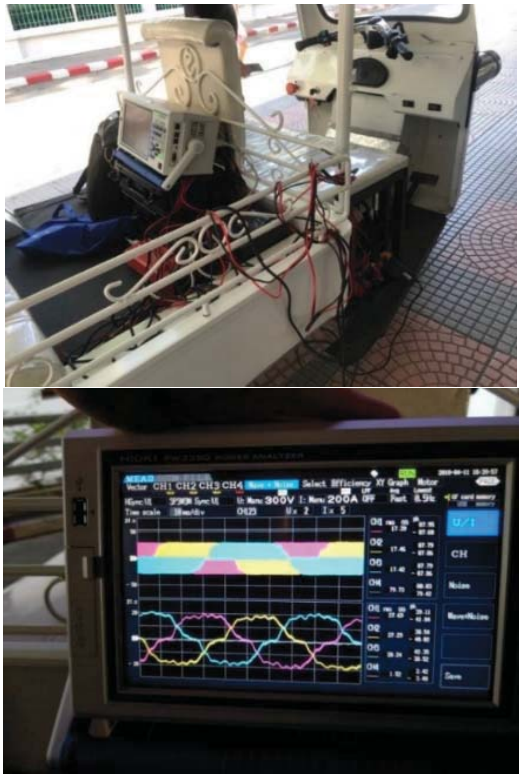

Figure 9. Information was collected by Power Analyser PW3390

Figure 10 Testing on Dynamometer Dynatech

K. Register with the Department of Land Transport and costs calculation before delivering to customers.

After the test period of approximately 1 year, the electric Tuk Tuk conversion is in the process of registration with the Department of Land Transport. Characteristics of a prototype electric Tuk Tuk conversion has the maximum speed of 71 km/h. The maximum distance is 130 km. The charging time is 6-8 hours. Summarize total cost before delivering to customers.

IV. Power Train Design

In this section, Basic requirements come from users' interview. size of motor is calculated to meet basic need specification. Now aday maximum speed of ICE Tuk Tuk is 80-100 km/hr or more because they are used 660 CC engine and light weight.

Basic requirements	
Dry weight	665 kg
Gross Vehicle Weight (G.V.W.)	875 kg
Passenger	3 people
Length	3.1 m
Width	1.4 m
Height	1.8 m
Wheel span	2.15 m
Front span	0.25 m
Rear span	0.67 m
Ground clearance	30 cm
Chassis width	0.75 m
Distance between centres of rear tires	1.23 m
Minimum turn radius	3.5 m
Climbing incline angle	10 degree
Maximum speed	70 km/hr
Maximum torque	20 km/hr
Acceleration time to max speed	40 sec

*Remark Dimension is only guideline from average local Tuk Tuk.

Total force calculation

$$F_{TT} = F_{RR}+F_{GR}+F_{AC}+F_{AD} \quad (1)$$

In which,

F_{TT} Total force

F_{RR} Force required to rolling resistance

F_{GR} Force required to climb a grade resistance

F_{AC} Force required to acceleration to final speed

F_{AD} Force required to air drag

1 Force required to rolling resistance (F_{RR})

1.1 In case of flat plane road, constant velocity

$F_{RR} = GVW \times C_{rr} = 875 \times 9.81 \times 0.012 = 103.005$ N

GVW gross vehicle weight

C_{rr} Rolling Resistance Coefficient (0.012 asphalt road)

$G = 9.81\ m/s^2$

1.2 In case of inclined road, constant velocity

$F_{RR} = GVW \cos\theta\ C_{rr} = 875 \times \cos(10°)$

$F_{RR} = 875x9.81x0.985x0.012 = 101.44\ N$

2 Force required to climb a grade resistance (F_{GR})

$F_{GR} = GVW \sin\theta = 875x9.81 \times \sin(10°)$

$F_{GR} = 875x9.81x.173 = 1{,}490.6\ N$

3 Force required to acceleration to final speed (F_{AC})

$F_{AC} = GVW \times (V2-V1)/(9.81 \times t_A)$

$F_{AC} = (875 \times 9.81 \times 19.44)/(9.81 \times 40) = 425.25\ N$

V_2 Final top speed 70km/hr (19.44 m/sec)

V_1 Starting speed 0 m/sec

t_A Acceleration time (40 sec)

4 Force required to air drag (F_{AD})

$F_{AD} = ½\ \rho C_d A_f V^2 = ½x1.2x0.5x1.5x(19.44)^2 = 170\ N$

ρ Air density ($1.2kg/m^3$)

C_d Coefficient of air friction (0.5)

A_f Frontal area of vehicle ($1.5m^2$)

$F_{TT} = 101.4+1{,}490.6+425.7+170 = 2{,}187.35\ N$

Torque at one axial shaft

$$\tau_M = F_{TT} x R_w x R_f \quad (2)$$

Choose tire diameter 0.5 m., radius .25 m. and circumference 1.57 m.

τ_M Motor Torque

R_f Mechanical friction is 1.1.

$\tau_M = 2{,}187.35x0.25x1.1 = 601.5\ N$

Hence, torque at one axial shaft is 601.5/2 = 300.8 N

Motor selection

$P_m = \tau_W \times \omega =$

In case of wheel circumference 1.57 m, maximum torque of motor at 20km/hr (5.5m/sec)

$$\omega = 2\pi\ V_{mt}/d \quad (3)$$

d wheel circumference

V_{mt} Velocity at maximum torque

$\omega = 2\pi\ 5.5/1.57 = 22$ rad/sec

P_m 601.5 x 22 =13.2 kW

Hence, motor, which nominal power 5kW and peak power 15 kW, is selected.

V. EXPERIMENT AND RESULTS

The results of the experiment of electric Tuk Tuk conversion are separated in 2 section; which are the result from the Dynamometer and the result from the actual running.

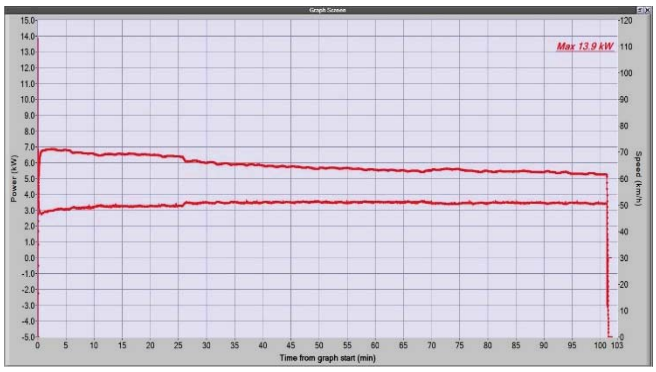

Figure 11. Relationship among power, speed, and time

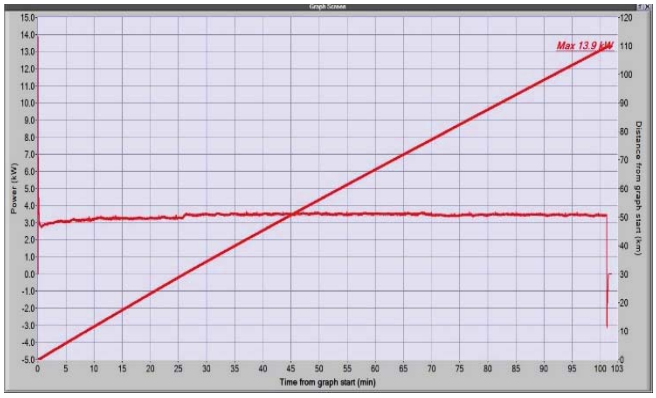

Figure 12. Relationship among power, distant, and time

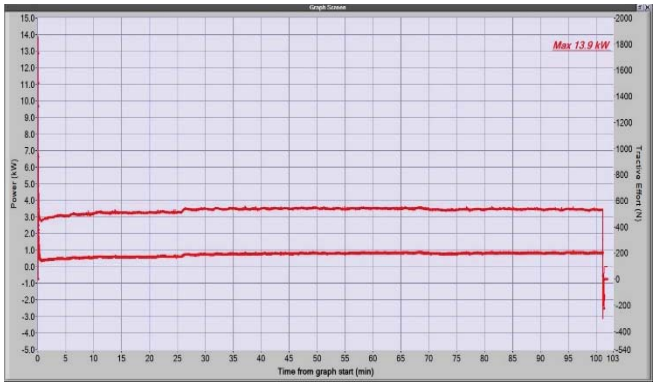

Figure 13. Relationship among power, tractive effort and time

The results from Dynotech 2WD Chassis Dynamometer is shown in figure 11-13. In this experiment, a throttle is locked for highest speed during testing all the time until battery cut-off. Software of the dynamometer records since the roller starts running until the rotor stop running. Figure 11 shows the relationship among power, speed and time. At the beginning, the motor is high starting torque, so the maximum power of the dynamometer is 13.9 kW comparing to the motor power is 5kW (Continuous)/16.3kW (Peak). The power of motor is 3.5kw at maximum speed. The power slightly decreases due to voltage of battery decrease and heat loss of the motor and battery. Total running time of batter is 110 min until battery cut-off for constant speed test. Relationship among power,

distant, and time shows in figure 12. the total distant increase related to running time. The maximum distant is 110 km. until battery cut-off. In practice, motor and battery can be operate again after waiting to temperature cool down. However, it's not considered this experiment. The relationship among power, tractive effort and time is shown in figure 13. Tractive force refers to total traction a Tuk Tuk exerts on surface or total traction that is parallel to direction of motion. The motor power is 3.5kw approximately along the running time and tractive force is about 180N along the running time.

The result from actual running was made in made during 24th June 2018 to 6th July 2018 as shown in figure 14. The starting point is Bangkok to Ayutthaya province in total distant 100km. Maximum speed is 65km by using GPS measurement because road resistance and wind resistance.

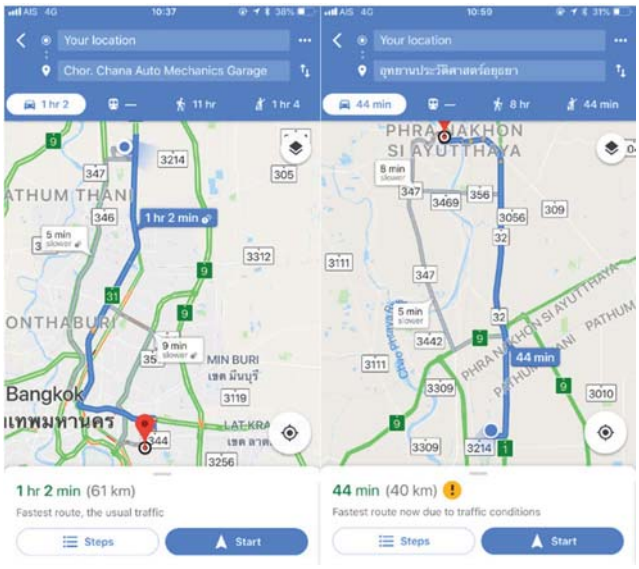

Figure 14. Actual run testing

The applications of electric Tuk Tuk from users and passengers' interviews are following;

• Agriculture truck. it can be used by farmers in coconut farm, sugar cane field etc.

• Hotel transportation. It can be used for tourist transportation.

• Social services. It can be used for garbage keepers, plant watering etc.

• Factory's truck. It can be used in building or factory.

• Business diversification. It can be used for moving shop such as coffee shop, burger shop etc.

VI. CONCLUSION

When testing on the Dynamometer at the maximum speed by twisting the maximum throttle at 71 km / h, the distance of 110 km, the energy consumption is only 0.1 kWh / km. Before conversion process, it is necessary to check the condition of the donated Tuk Tuk before making decision for choosing the donor. If the condition of the donor is poor, the total budget is more increase. The cost of electric Tuk Tuk conversion is $ 10,000 - $11,500. For this research, it is a relatively high budget it consists of almost all new parts. The main cost of a modified electric Tuk Tuk is in the battery and control unit which is worth $5700. In this research, we designed the Tuk Tuk should be pass water flood test, Tuk Tuk should be running smoothly in water depth 30 cm. and length 25 m, to make sure that it should be fine while driving in water flood. However, if it is manufactured in mass production line, the cost is more economical.

Figure 15. Before conversion and restoration

Figure 16. After conversion and restoration

The features of the electric Tuk Tuk conversion are as follows:

- Total weight 680 kg.,
- Maximum speed 71 km./h,
- Distance at maximum speed 110 km, (fix throttle)
- Maximum distance> 130 km., (on road)
- Battery charging time 3-8 hours,

- 3.4 meters turn radius,
- Battery 72V208Ah LiFePo4, AC motor 5kW

Electric Tuk Tuk is safer than motorcycle but as safe as car. But it's also easy for manufacture and low maintenance. From the stake holders' interview, Electric Tuk Tuk industry can generate many careers both indudtry and services business, such as part manufacturers, food truck, sightseeing vehicle for tourist, small truck. Many People all around the world remember the basic Tuk Tuk style.

As mention above, this research purposes the electric Tuk Tuk conversion procedure, basic requirements for electric Tuk Tuk conversion e.g. dimension, power, speed, size, width, length, height and weight. This research is also a guideline for product development and new business development of electric Tuk Tuk in Thailand and for other local-made vehicles.

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